VAAL UNIVERSITY OF TECHNOLOGY

Inspiring thought. Shaping talent.

APPLICATION OF NONWOVEN MICROFILTRATION MEMBRANE ON ACTIVATED SLUDGE FINAL EFFLUENT: IMPROVING WASTEWATER QUALITY FOR RE-USE

Dissertation submitted in partial fulfilment of the requirements for the degree
Master of Engineering in Chemical Engineering
In the Faculty of Engineering and Technology

Murendeni Shonisani Masala

B-Tech in Chemical Engineering

Student number: 210080841

Supervisor: Prof J Kabuba Tshilenge

Co-Supervisor: Mr James Topkin

April 2022

Declaration

I, Murendeni Shonisani Masala, declare that the dissertation, which I hereby submit for the degree Master of Engineering in Chemical Engineering at the Vaal University of Technology, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

……………………………………. ………………………………

Signature Date

Murendeni Shonisani Masala

Acknowledgement

I would like to express my sincere gratitude to my supervisor, Prof John Kabuba, for his utmost guidance and patience throughout the journey of completing this dissertation.

To my co-supervisor, Mr James Topkin, who is also my colleague, my sincerest thanks for giving me an opportunity to work together on this project. I really appreciate the lessons, support, and guidance that you offered throughout this dissertation.

To my mother, Mrs Noriah Mashau-Masala, thank you for your unconditional love, prayers, and support. Thank you for always reminding me that quitting is never an option. As you always say, “no child of mine is a quitter, unless if you are not my child, then you can quit.”

To my brother, Tony Masala, thank you for always supporting and motivating me to be the best version of myself. Moreover, to my sister, Faith Masala, thank you for your continuous support and prayers.

To my beloved cousin and colleague, Tendani Mphaga, thank you for your guidance, continuous help, and support throughout this dissertation. I am really grateful ‘cuzzy’.

To my best friend, Mukondeleli Manuga, thank you for always being there and supporting me throughout this dissertation.

To the Ekurhuleni Water Care Company (ERWAT) Waterval Wastewater Care Works manager, Mr Livhuwani Mathomu, thank you for granting me permission to do this study at your plant.

To my ERWAT colleagues who supported and encouraged me throughout this dissertation, sincere thanks to you all.

Above all, I want to thank the almighty God who gives me strength and wisdom in everything that I do and who is always there in every situation.

Proverbs 3:5-6 - “Trust in the Lord with all your heart and lean not on your own understanding. In all your ways submit to Him and He will make your paths straight.

Dedication

I dedicate this dissertation to my mother Mrs Noriah Mashau-Masala.

Abstract

Water scarcity is one of the biggest problems that South Africa is facing currently, as a results it limits economic and social development. The application of membrane technology in wastewater treatment for re-use is one of the alternatives to reduce the demand of water in domestic, agricultural and industrial sectors. The primary aim of this study was to improve effluent wastewater quality prior to disinfection for re-use. This was done by diverting biological nutrient removal (BNR) clarifier effluent to a pilot nonwoven membrane filtration unit. The physical barrier provided by this unit, together with the effect of aeration within this system, provided particulate, physicochemical, and microbial removal. Monitoring of water quality was attained from the BNR clarifier effluent, and the nonwoven membrane permeate. Water quality trends against the standards were analysed for compliance with a water use license (WUL), and the removal efficiency for the permeate was also determined.

The Single Factor Pollution Index (P_i) was used to determine the extent of pollution in the BNR clarifier effluent and the permeate, while the Water Quality Index (WQI) was utilised to determine the suitability of water derived from the BNR clarifier effluent and the permeate for re-use. Water Use Licence standards were utilised to determine the Water Quality Index of the BNR clarifier effluent and the permeate. Results for the BNR clarifier effluent showed that the physicochemical water quality parameters comply with the limits however, electrical conductivity (EC) and microbial water quality *Escherichia coli (E. coli)* were exceeded. Permeate results indicated that physicochemical and microbial parameters were compliant with the limits of the WUL. *E. coli* reduction was the highest with a removal efficiency of 90%, followed by chemical oxygen demand (COD) at 25%, NH_4N at 22%, NO_3 at 12.6%, PO_4 at 7.8%, suspended solids (SS) at 6.3%, and the lowest was EC at 5.2%.

The Single Factor Pollution Index has revealed that the BNR clarifier effluent water quality is medium polluted and the permeate water quality is slightly polluted. The WQI results for the BNR clarifier effluent showed good water quality and the water can be re-used for domestic, irrigation, and industrial purposes, while permeate WQI results indicated excellent water quality and the water can be re-used for drinking, domestic, irrigation, and industrial purposes. Outstanding permeate water quality improvement was observed on *E. coli* counts improving from 4974.48 counts/L to 294.33 counts/L. The standard of *E. coli* according to the WUL at Waterval WCW is 500 counts/L. The results indicate that nonwoven membrane filtration can improve microbial contamination and decrease the demand of chlorine for disinfection of wastewater final effluent. The nonwoven membrane filtration can decrease the water scarcity gap in South Africa for direct water reclamation by improving effluent wastewater.

Keywords: *E. coli*; Nonwoven membrane filtration; Water Quality Index; Water re-use; Water Use License; Single Factor Pollution Index

Table of contents

List of Tables **Page**

List of Figures **Page**

Acronyms & Abbreviations

BOD	Biochemical oxygen demand
CAS	Conventional activated sludge
CASP	Conventional activated sludge processes
COD	Chemical oxygen demand
DBP	Disinfection byproduct
DWS	Department of Water and Sanitation
EC	Electrical conductivity
E. coli	Escherichia coli
HRT	Hydraulic retention time
GSM	Geo textile fabric
MBR	Membrane bioreactor
MF	Microfiltration
MLVSS	Mixed liquor volatile suspended solids
MWCO	Molecular weight cut-off
NF	Nanofiltration
NH_4N	Ammonium nitrogen
NO_3	Nitrates
NWA	National Water Act
NWF	Nonwoven fabric
Pi	Pollution Index
PO_4	Phosphate
PST	Primary setting tank
PTFE	Polytetrafluoroethylene
RO	Reverse osmosis
SANS	South African National Standards
SRT	Sludge retention time

SS	Suspended solids
SST	Secondary setting tank
TMP	Trans-membrane pressure
TOC	Total organic carbon
UF	Ultrafiltration
UNEP	United National Environmental Programme
WQI	Water Quality Index
WUL	Water Use License
WCW	Wastewater Care Works
WWT	Wastewater treatment
WWTP	Wastewater treatment plant

Chapter 1: Introduction

1.1 Background of the Study

South Africa is currently facing problems of water scarcity in most of its provinces. Water continues to become one of the most valuable resources and will continue to be in the coming years. Without rigorous innovative ideas that forces change within this sector, it remains difficult to see how the current environment will improve. The biggest challenge with water shortage has to do with suitability. This is because all available water does not have its own suitable usage (Donnenfeld et al., 2018). The relationship that users and suppliers of water have with the resource is not healthy. As a result, more than 90% of the potable water is used for purposes for which non-potable water would suffice. The uses include cooling systems, swimming pools, flushing of toilets, and irrigation of gardens (Colvin & Muruven, 2017).South Africans know two major types of water that is, water for drinking and wastewater effluent. The piped availability of alternative water supplies used in other countries, as far as water usage is concerned, such as flushing toilets or doing laundry, is not available in South Africa (Bahri1 et al., 2007).

The United Nations Environmental Programme (UNEP) Global Environmental Outlook reports that one third of the world's population is currently living in countries suffering from moderate to high water stress areas, where water consumption is more than 10% of renewable freshwater resources (Jacobsen et al., 2013). Most of these countries are found in Asia and Africa. South Africa, though one of the most developed countries in Africa, still experiences water shortages in many of its provinces. According to the Department of Water and Sanitation (DWA, 2013a) report, South Africa is the 30^{th} driest country in the world with a mean annual precipitation of approximately 500 mm/a, which is well below the world average of 800 mm/a. This paints a gloomy picture for the future as far as water availability in South Africa is concerned (Howard & Bartman, 2003).

Over the past two decades, water scarcity has largely been seen as a rural problem in South Africa. Provinces with large rural populations, like Limpopo, were and, unfortunately, are still mostly affected. The City of Cape Town crisis of 2018 exposed a shortcoming in the water sector (Donnenfeld et al., 2018). The population growth and an increase in urbanisation threatens to overpower the current water infrastructures within our cities. This is one of the challenges that entities dealing with this, the water bodies of South Africa, are currently facing this.

South Africa has almost 979 wastewater treatment works which produce 7589 ML/day of effluent. This is a huge potential source of water (Jacobsen et al., 2013). Currently, only a small fraction of this effluent is re-used for purposes such as irrigation of parks, sports fields, and golf courses, and for use in industrial cooling systems. A criteria of moderate water quality for the previously mentioned facilities is a prerequisite. Very little has been done in the direction of water re-use in South Africa. The regulatory bodies and other water bodies have just initiated to incentivise the wastewater sector to come up with ways and means to further treat their water for possible human consumption or any other re-use opportunity for instance the Beaufort West municipality in the Western cape that build a wastewater reclamation plant (ATSE, 2013) and (Skosana, 2016). The amount of wastewater treated should incentivise many wastewater bodies of South Africa to utilise this great source of water (Jacobsen et al., 2013).

1.2 Membrane Technologies

Functioning as selective barriers that separate two different phases, membranes allow the passage of certain components and the retention of others. The energy required for this separation is derived from one or more of the following: gradient pressure, chemical potential, electrical potential, or temperature across the membrane (Al-Shammiri, et al., 2005). Membrane technologies have been at the forefront of solving the current global water crisis by either merging membrane technology with existing wastewater/industrial water treatment infrastructure or by using membrane technology directly (Quist-Jensen et al., 2015).

The membrane used in this study is pressure/gravity driven. Microfiltration (MF) membranes were selected and used for this study because they are considerably more cost-effective than the other four options and runs at a lower pressure of less than 0.2 MPa. (Chang et al., 2006). Because of its low-cost nature, this technology presents an opportunity to relieve the stress that drinking water production is currently experiencing in South Africa.

Microfiltration (MF) consists of large porous membranes with a pore size range of 0.1 μm to 10μm. This pressure-driven process can remove certain sized organics, nutrients, micro-organisms, inorganic metal ions, micro plastics, and other oxygen depleting pollutants. The microfilter utilised in this test is ideal for potential use in municipal wastewater reclamation projects since it has cleaning capabilities by means of reverse pressurised air. This makes the efficiency even better (Jacobsen et al., 2013).

1.2.1 Nonwoven Membranes

The microfilters that were used in this study consist of nonwoven membranes. Nonwovens are composed of a random network of overlapping fibres creating multiple connected pores through which liquids can flow. It has controllable pore size distribution and a high fibre surface area per unit weight and volume. Low-cost fibres may be utilised in water treatment which lowers the total cost drastically. Limited information was found in the literature on the use of nonwoven material for membranes in the membrane bioreactor (MBR) process (Xianghao et al., 2010).

This system utilises these nonwoven membranes in a filter bag configuration that can be easily replaced at low cost when compared to other filters. Therefore, this concept appears to offer advantages for small-scale wastewater treatment where low cost and operational simplicity are required (Zhaohuan, 2013).

1.3 Location of Study Area

The Waterval Wastewater Treatment Plant is located within the Midvaal catchment and drains to the Waterval Klip River downstream catchment that feed the Riet River.

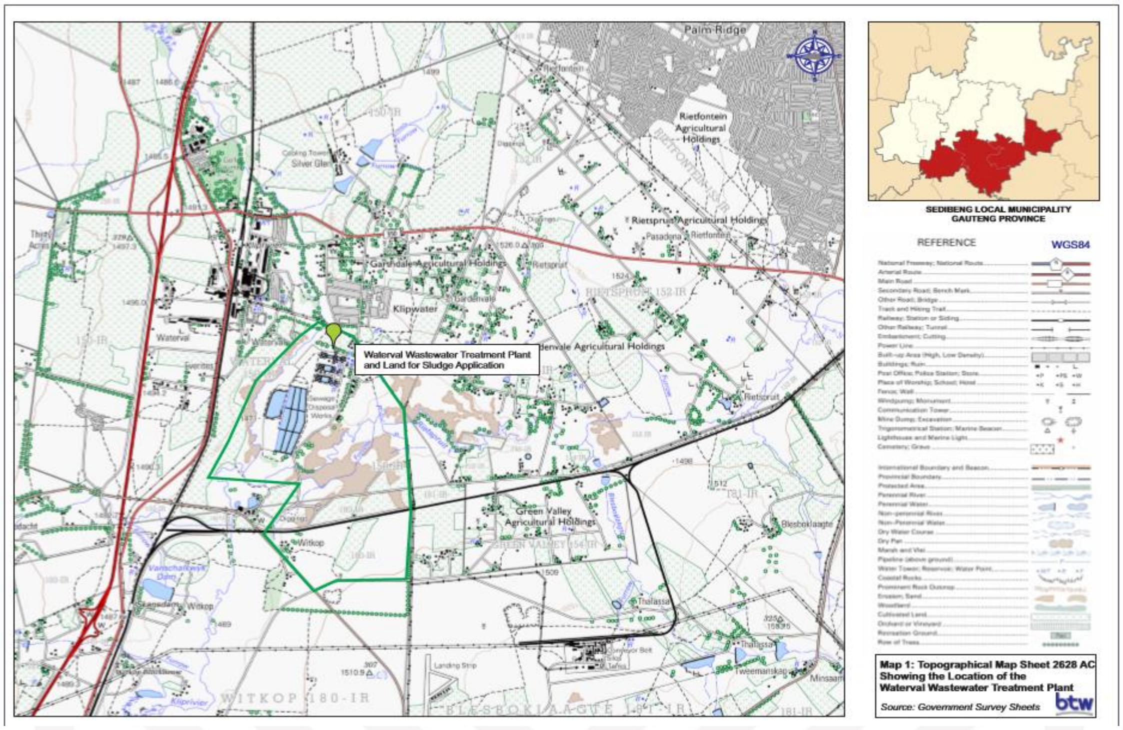

Figure 1.1: Location of the study area (Topkin & ERWAT, 2017)

1.4 Problem Statement

The current South African water usage trends are not sustainable. South Africa has been walking a thin line with water scarcity for decades now. The example of Cape Town's recent drought exposed this gap in the water sector. It is, therefore, vital to consider alternative sources for water (Donnenfeld, 2018). Furthermore, depleting ground water sources by farming activities and the use of potable water to flush toilets and irrigate gardens is not sustainable (Howard & Bartman, 2003). According to the 2014 Green Drop audit, close to a quarter of South Africa's wastewater treatment facilities are in a critical state (defined as needing urgent intervention) while roughly an additional quarter are defined as high risk (Donnenfeld et al., 2018).

South Africa's limited water resources will limit economic and social development. Wastewater reclamation, re-use, and recycling are important alternatives to reduce demand in domestic, agricultural, and industrial sectors (Nikiema et al., 2014). For efficiency improvement and expansion throughout the world, different methods, traditional and modern, exist. Therefore, it is necessary to develop improved wastewater treatment (WWT) technologies appropriate for rural areas or isolated residential areas in emerging countries (Donnenfeld et al., 2018). For wastewater treatment, membrane bioreactors (MBRs) are amongst the technologies that have been enhanced. MBRs are increasingly being specified as a viable alternative for the reclamation of wastewater for re-use (Chang et al., 2006). MBRs produce excellent effluent quality using a small footprint. In developed economies, the driving forces behind the use of MBRs are:

- The strict effluent discharge standards by the Department of Water and Sanitation. In many cases, the MBR effluent quality is so good that it can be re-used directly in non-potable applications.
- Their small footprint.
- The continuous decrease in membrane costs is increasing the competitiveness of MBR compared with conventional activated sludge processes (CASP).
- The possible usage gap that their effluent can fill (Quist-Jensen et al., 2015).

A lack of knowledge on the application of nonwoven microfiltration membranes at the selected study area justifies this study. Currently, the study has not been done and final effluent quality for wastewater cannot be re-used for different activities. Thus, this information is critical and, therefore, this study needed to be done to improve wastewater effluent quality. Currently in South Africa, there are less than five water reclamation plants. This means that most of the water is returned to the environment, whilst it can be further treated to augment water supply.

1.5 Research Questions

The research questions for this study were:

a) What are the factors that affect wastewater treatment efficiency of nonwoven membrane microfiltration?
b) Does nonwoven membrane microfiltration improve water quality to meet Water Use License (WUL) standards?
c) Does nonwoven membrane microfiltration improve wastewater quality for re-use?
d) What would the specifics of filtrated water be in helping to reduce the usage of drinking water for nondrinking purposes, e.g., flushing of toilets and bathing?

e) What is the effectiveness of the nonwoven membrane microfiltration system (NWMMS) in terms of filling the water gaps in South Africa? Can the NWMMS be used on a larger scale to practically solve the gap?

1.6 Objectives

1.6.1 Main Objective

The primary aim of this study is to improve effluent wastewater quality prior to disinfection for re-use. This will be attempted by using a nonwoven filtration medium together with the effect of aeration within the system with respect to particulate, physicochemical, and microbial removal.

1.6.2 Specific Objectives

a) To investigate the efficiency of nonwoven fabric media for effluent microfiltration within the type of design being used in the study.

b) To analyse filtrated water quality from nonwoven fabric membrane microfiltration against the WUL.

c) To determine the water quality improvements by nonwoven fabric membrane microfiltration.

d) To determine the fitness of water quality for re-use.

e) To investigate if nonwoven membrane microfiltration can solve the water scarcity gap in South Africa.

1.7 Approach

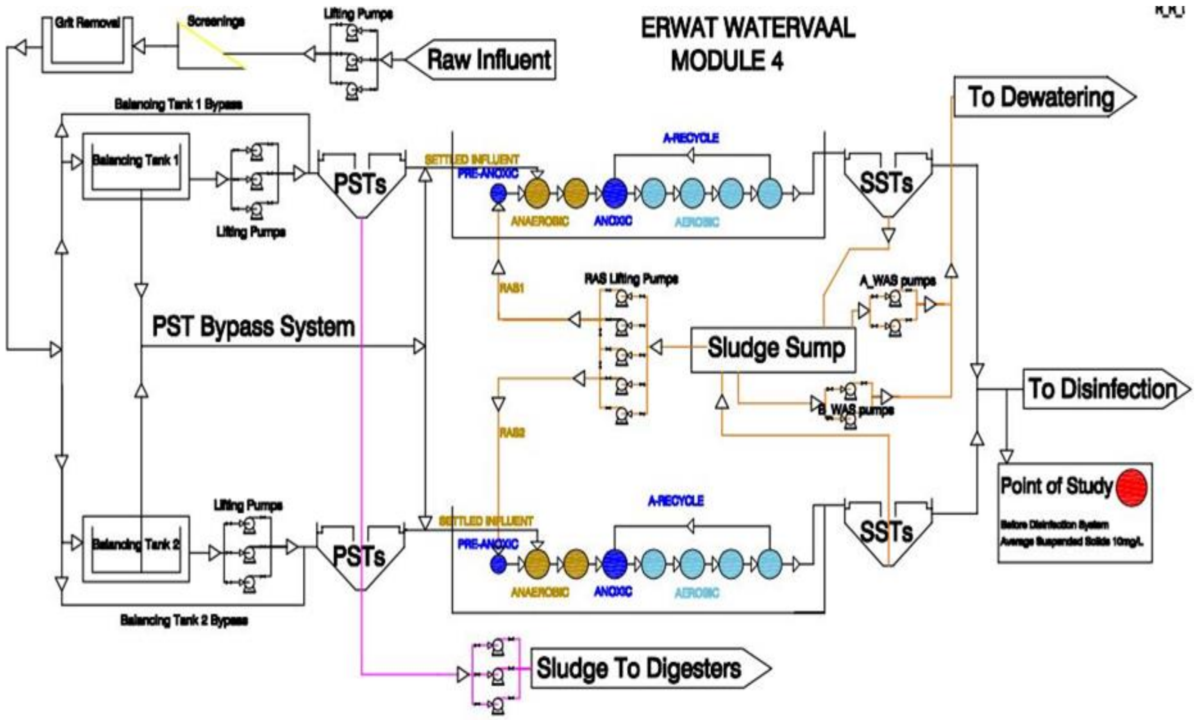

Figure 1.2: Overview of the study area (Waterval Module 4)

The study was conducted on Module 4 of the Waterval Wastewater Care Works. This is a new wastewater care works that utilises activated sludge processes to treat its influent. This 50 ML/day module has surface aeration for its biological nutrient removal reactor. There are four secondary sedimentation tanks (SSTs), each 36 m in diameter, as shown in Figure 1.2. The microfiltration plant will be positioned next to the SSTs. This area was chosen because the wastewater from the SSTs has lower turbidity. This should allow for a longer lifespan of the filters during the testing process. It should be noted that the average of suspended solids in the effluent is 10 mg/L however, this is during the times where there is no bulking within the SSTs.

Figure 1.3: Nonwoven microfiltration

A 12 mm inner diameter polyvinylchloride hose was utilised to divert effluent from the SST to the pilot plant. Samples of both the effluent from the SSTs and the filtered effluent were taken in 1 L sampling containers. Parameters that were tested are ammonium, nitrite, nitrate nitrogen, total nitrogen (NH_4-N, NO_2-N, NO_3-N, Nt), phosphate phosphorus (PO_4-P), and chemical oxygen demand (COD). The results from these experiments were compared to other similar filtrated effluent. From the results obtained, recommendations of usage will be made and/or possible further treatment for adequate usage will be suggested.

The methods that were used to interpret the water quality data are:

- Water Quality Index (WQI) to determine the fitness of the water for re-use.
- Single Factor Pollution Index (Pi) to determine the extent of water pollution.
- Water Use License (WUL) to determine the water quality compliance with the limits set for the plant.
- Water quality removal efficiency to determine how efficient the pilot plant is in terms of removing targeted water quality parameters.

1.8 Overview

Chapter 1 covers the introduction of the study which includes the background, problem statement, and the objectives of the study.

The literature review is presented in Chapter 2. This chapter looks at the research work that has been done by other researchers and introduces the general knowledge and findings that are critical to the current study.

Chapter 3 describes the methods used to achieve the objectives of this study. Details of the research methodology are described, which includes the Water Use Licence, Water Pollution Index, Water Quality Index, experimental setup, test procedures, removal efficiency, and correlation of data.

The results from the experiments that were performed and a discussion thereof are presented in Chapter 4 of this dissertation. The results and discussion are formulated to answer the specific objectives.

Chapter 5 presents the conclusion of this study and the recommendations for future studies.

Chapter 2: Literature Review

This chapter presents a short outline of wastewater treatment, focusing on the activated sludge process. Membrane technology with nonwoven fabric was developed that can be classified as a microfilter which is different from the traditional membranes utilised in many MBR operations. This pilot micromembrane arrangement was submerged in a tank setup as a polishing step for influent received from a secondary settling tank.

2.1 Membrane Preamble

Membrane process technology in water and wastewater has become more welcomed and competitive with conventional activated wastewater treatment. It has advanced with time and proved to be a treatment process that may be considered. Due to high initial capital costs associated with membrane processes, rapid development was slow since 1960 (Fani, 1996). Manufacturing of better quality and lower priced membranes positioned this technology more economically favourable compared to traditional water treatment processes (Braak et al., 2011).

2.2 Wastewater Treatment

Wastewater is the terminology given to used water that contains suspended or dissolved solids collected from commercial businesses, industries, farms, and household industries (Mara & Horan, 2003). The main purpose of wastewater treatment is to improve the water quality and reduce polluting surface water or groundwater. This brings in another factor of consistent quality effluent for re-use. Wastewater treatment proves to be the key contributor to water pollution control (Mara & Horan, 2003). Influent wastewater may consist of storm water, domestic or industrial generated wastewater, inflow, and infiltration water. The wastewater from industrial operations differs in composition, strength, and quantity, depending on the industry (Mihelcic & Zimmerman, 2010). The biggest portion of the pollutants detected in wastewater is organic material. Many pathogenic micro-organisms, toxic compounds, and nutrients, such as nitrogen and phosphorus, are also present, which may be harmful to human health (Bitton, 2005). Secondary treatment processes in activated sludge follows the primary treatment. This includes a biological nutrient removal process, activated sludge treatment, trickling filters, and rotating biological contractors (Cicek, 2003).

2.2.1 Conventional Activated Sludge (CAS) Process

Conventional wastewater treatment is widely used although it has high initial capital costs, high energy usage, a large footprint, and requires experienced operators to run the plant (Judd, 2011). It is mostly used for treatment of both industrial and domestic effluent (Tchobanoglous et al., 2003). The conventional activated sludge process consists of four sections which are: preliminary, primary, secondary, and tertiary treatment (Judd, 2011). The flow diagram in Figure 1.2 demonstrates the activated sludge process as utilised at Waterval Wastewater Treatment Works.

2.2.1.1 Preliminary treatment

The initial step in this pre-treatment is to remove the coarse solids, large debris, and heavy inorganic particles contained in the wastewater influent. Screens remove these large objects consisting of plastic, rags, papers, and metals. This screened influent is then further treated in a grit separation channel. This grit chamber slows down the flow to allow sand, eggshells, and cinder to settle out of the wastewater so it can be removed. These contaminants could affect the biological process or might cause damage to pumps and recirculating equipment (Mihelcic & Zimmerman, 2010).

2.2.1.2 Primary treatment

During this treatment step, the settled organic and inorganic solids are removed by sedimentation (Mihelcic & Zimmerman, 2010). The wastewater becomes free of the visible debris and overflows into the secondary treatment regions. This overflowing liquid stream is mostly made up of floatable solids, dissolved ammonia, and dissolved organic compounds. Skimming is a term that describes the removal of floatable solids (Tchobanoglous et al., 2003). The solids are diverted to an underflow that goes to the anaerobic digester for further treatment. This waste stream is known as the primary sludge and is composed of organics (biological oxygen demand – BOD), phosphates, and suspended solids (Mihelcic & Zimmerman, 2010).

2.2.1.3 Secondary treatment

Secondary treatment moves away from just being a physical separation process and sustains a biomass of various micro-organisms. The overflow from the primary setting tank (PST) enters the anaerobic, anoxic, and aeration reactors. In the aeration reactor, air is forcefully mixed with wastewater to ensure an oxygen-rich environment that acts as an electron accepter during the nitrification of ammonia to nitrites and nitrate. Biodegradable organic used as building material for new biomass formation (Tchobanoglous et al., 2003). The effluent from the aeration is further cleaned in the secondary sedimentation tank. It allows the micro-organisms established as flocs from the biomass to settle at the bottom of the clarifier. This process removes close to 80-90% of all the contaminants and toxic chemicals adsorbed to these floc structures (Mihelcic & Zimmerman, 2010).

2.2.1.4 Tertiary treatment

The tertiary treatment process is the last section of wastewater treatment. The main objective of this process is to remove the contaminants that could not be removed in the previous stages. This step also ensures that the effluent quality complies with specified bylaws (Cele, 2014). Other wastewater treatment plants utilise sand filters to eliminate organics and pathogens not removed in the previous steps. Before clarified water can be discharged to a nearby stream, it must be disinfected. Disinfection is the process where pathogenic organisms are eliminated to decrease the risks posed to human health (Tchobanoglous et al., 2003). This can be achieved by common disinfectants like chlorine gas, sodium hypochlorite, ozone, and ultraviolet light (Mihelcic & Zimmerman, 2010).

2.2.2. Wastewater Effluent Quality

The use of water in South Africa is governed by the National Water Act, No. 36 of 1998, as amended. The act states that: "… water extracted for industrial purposes shall be returned to the source from which it was abstracted, in accordance with quality standards gazetted by the Minister from time to time". The standards of wastewater discharge to the streams in South Africa is summarised in Table 2.1.

Table 2.1: Special Wastewater Standards

Parameter	Limit
pH	5.5 – 9.5
Electrical Conductivity (at 20ºC)	70 mS/m
Nitrate (N)	15 mg/L
Free and Saline Ammonia (N)	6 mg/L
Chemical Oxygen Demand (O)	75 mg/L
Orthophosphate (P)	10 mg/L
Suspended Solids	25 mg/L
Free and Saline Ammonia	N/A
Total Coliform	1000 org/100 mL
E. coli	0 org/100 mL

2.3 Membrane Classification

Membrane separation processes commonly used in the industry are Ultrafiltration (UF), Nano Filtration (NF), Reverse Osmosis (RO), and Microfiltration (MF). These barrier-like separation processes are classified by their operation mechanisms, separation size, separation driving force, configuration, and the membrane material used (Tchobanoglous et al., 2014). The effluent from such a membrane process, the permeate, should always contain less particulate matter then the retained material, or the retentate. This is the case in a functional membrane. The pressure used to force the permeate through the membrane wall is known as trans-membrane pressure (TMP). The flux is the resultant rate of fluid transferred across a specified membrane area (Tchobanoglous et al., 2003).

2.3.1 Ultrafiltration

The pore sizes of ultrafiltration membranes are roughly 0.002 to 0.1 microns. They have a molecular weight cut-off (MWCO) of roughly 10,000 to 100,000 daltons, and roughly 200 kPa to 700 kPa of operating pressure. Microbiological species, some viruses, and humic materials that are partially removed by MF will be removed by UF. Disinfection is still recommended even though viruses may be retained (Howell et al., 2004).

The main advantages of low-pressure UF membrane processes compared with the traditional clarification and disinfection processes are:

- Chemicals are not needed.
- Size-removal filtration as compared to media depth filtration.
- Continuous good quality of treated water regarding microbial and particle removal.
- Plant and process compactness.
- Simple automation (Cele, 2014).

2.3.2 Nanofiltration

The average pore size of a typical Nano Filtration (NF) membrane is roughly 0.001 microns and has a MWCO of 1000 to 100,000 daltons. NF is a smaller pore membrane and forcing water through this requires higher operational pressure than UF or MF. Operating pressures of NF membranes are normally around 600 kPA and can reach a maximum of 1000 kPa. The NF system can eliminate almost all bacteria, cysts, viruses, and humic materials. The addition of disinfection after the membrane filtration step produces a superior safeguard from disinfection byproducts (DBP) formation (Iorhemen et al., 2016).

The effluent water from an NF membrane may be corrosive because the membrane also eliminates alkalinity. Therefore, initiatives such as adding alkalinity or blending raw water effluent may be required to reduce corrosivity. NF membranes are also referred to as softening membranes because they eliminate hardness from water. However, the water feeding this NF membrane needs to be pretreated to avoid precipitation of hardness ions on the membrane. Nevertheless, more energy is needed for NF than UF and MF (Howell et al., 2004).

2.3.3 Reverse Osmosis

This separation process is very unique with the smallest pore size. Almost all inorganic contaminants in water can essentially be removed by Reverse Osmosis (RO). RO can also essentially remove natural organic substances, radium, cysts, viruses, and bacteria. RO is used in series with multiple units and still requires disinfection (Tchobanoglous et al., 2003). Advantages of Reverse Osmosis are:

- It eliminates almost all contaminant ions and dissolved non-ions.
- RO operates instantly without any minimum break-in period.
- It is totally insensitive to total dissolve solids and flow.
- Possible low effluent concentration.
- It eliminates bacteria and particles.
- Simple to operate and can allow less operator attention if automated and can be fit for a small system (Srisukphun et al., 2010).

Some of the limitations of RO include:

- Controlling wastewater is likely a challenge.
- In some cases, it needs a high level of pretreatment.
- High capital and operating costs.
- 25% to 50% of the influent is produced when applied in wastewater treatment.
- The membrane is subjected to fouling (Srisukphun et al., 2010).

2.3.4 Microfiltration

Microfiltration is described as a separation process with membranes with roughly 0.03 to 10 microns as (1micron = 0.0001 millimeter) pore size, a MWCO greater than 1000,000 daltons, and an operating pressure of approximately 100 kPa to 400 kPa. Materials eliminated by MF are clays, slit, sand, cryptosporidium cysts, Giardia lamblia, some bacterial species, and algae. MF does not completely remove viruses but when used together with disinfection, it controls the micro-organisms in water (Howell, 2004).

The emphasis on reducing the concentration and the amount of chemicals that are used during water treatment is growing and by physically and biologically eliminating the pathogens, membrane filtration may decrease chemical chlorination (Howell et al., 2004) By achieving lower turbidities in the final effluent through the use of microfiltration, other disinfectant technologies such as ultraviolet light become more feasible.

2.4 Operation Methods and Module Layout of Membranes

There are two foremost membrane operation methods - crossflow operation and dead-end operation. The two methods are schematically shown in Figure 2.1.

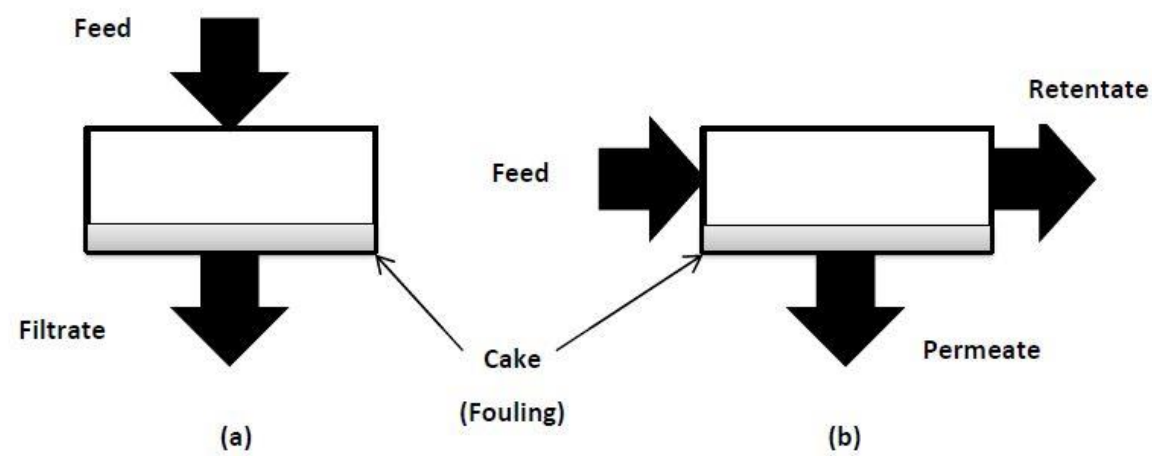

Figure 2.1: Membrane operation method: (a) Dead-end operation and (b) crossflow operation (Mihelcic & Zimmerman, 2010)

These two methods vary in the way the feed stream moves into the membrane. Most people are more familiar with the dead-end operation method because the membrane is fed on top, just like the sand filters. The smaller particles permeate through the membrane when the feed is fed on top, and the concentrated large particles are left on the surface of the membrane. This method is adequately simple to execute but the disadvantage is fouling on the membrane (Deelie, 2017).

The method of crossflow operation varies from the dead-end operation in that the direction of the feed flow is diverging to the surface of the membrane. This method permits permeates to flow through the membrane, but due to the diverging fluid flow, the remaining retentate is moved away from the membrane. These two operation methods are in some or other convection in most industrial membrane processes. For example, the dead-end operation method may be similar to an immersed membrane, but with the inclusion of air scouring, it may work as a crossflow operation method process (Deelie, 2017).

Membranes have different types of module layouts which are based on planar or cylindrical geometry. The different types are tubular modules, hallow fibres, capillary modules, pillow-shaped modules, flat-sheet modules, and spiral-wound modules (Judd, 2011). When selecting a module, the choice is mainly based on the method of operation. The advantages and disadvantages are different for each module layout (Munir, 2006). In this study, the investigation will focus on the use of flat-sheet, nonwoven fabric membrane modules.

2.4.1 Membrane Bioreactor Configuration

For membrane separation processes to occur, there are two types of configurations. These are pressure-driven filtration or side stream membranes (Figure 2.3) and vacuum-driven membranes (Figure 2.2) immersed into the bioreactor directly. Submerged MBR operates in the dead-end method. The submerged membrane is the most known MBR configuration in wastewater treatment (Iorhemen et al., 2016).

Submerged membrane configuration using hollow-fibre or flat-sheet membrane modules are mostly used because of the high capability of loading suspended solids in the flat sheet direction as needed by the treatment process. At a lower operating pressure, they operate well. The life-cycle cost and energy consumption needed are lower (Iorhemen et al., 2016). Waste characteristics such as high temperature need the utilisation of ceramic membranes in industrial systems where pressure-driven membranes are more common. The traditional wastewater treatment process stages, such as an activated sludge aeration tank, a secondary settling tank, and tertiary filters, can be combined in one tank using submerged MBR, but good filterability wastewater and a bigger membrane area is required in this MBR (Paul, 2006).

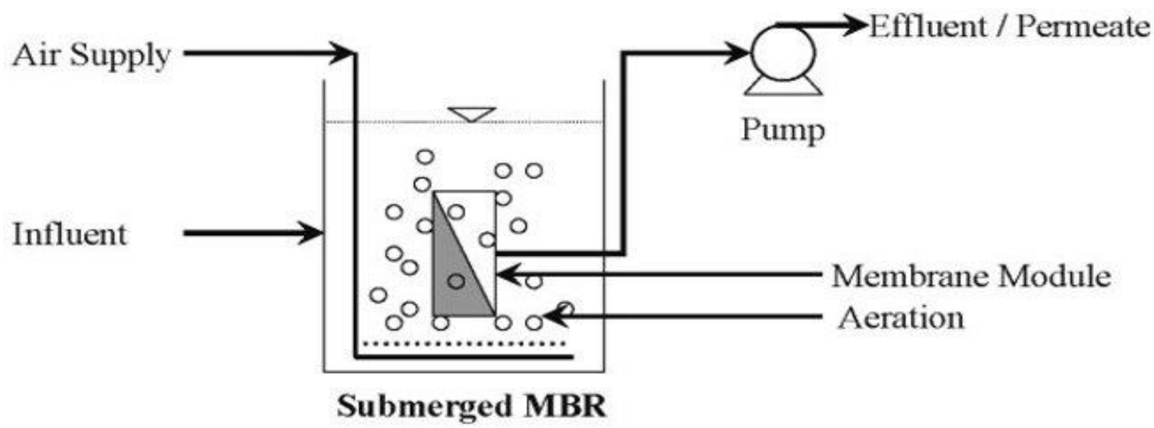

Figure 2. 2: Submerged MBR for suspended growth process (Tchobanoglous, et al., 2003)

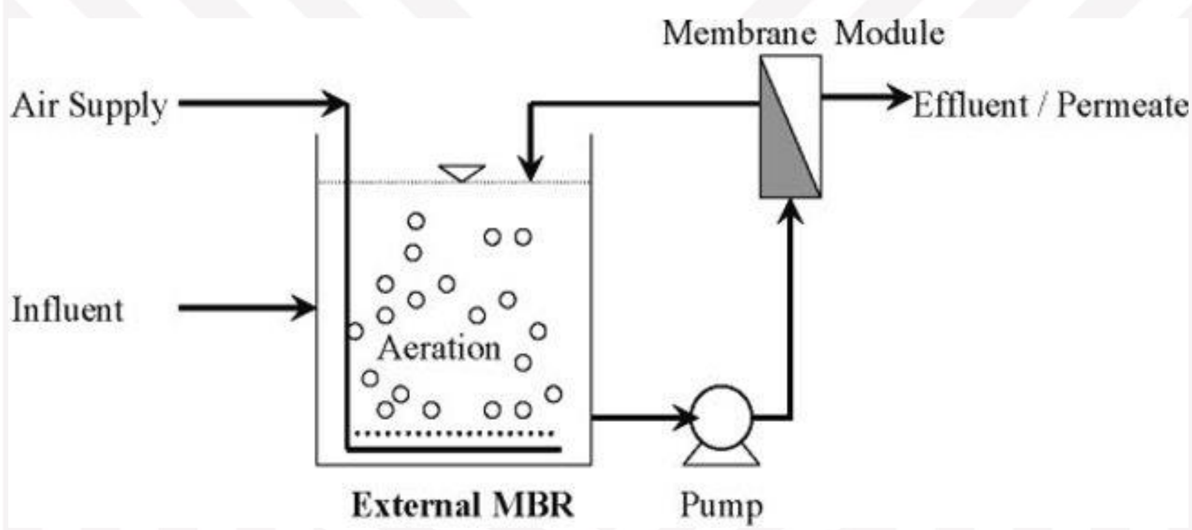

Figure 2. 3: External or side-stream MBR for suspended growth process (Tchobanoglous et al., 2003)

There are no clear-cut rules in selection of a membrane configuration. It depends on the application needed. Before implementing a configuration, there are differences between side-stream and submerged MBR that need to be considered as presented in Table 2.2 (Wang-Kuan et al., 2007).

Table 2.2: Comparison of submerged and side-stream MBR systems (Paul, 2006)

	Submerged MBR	***Side-Stream MBR***
Suitability	Low strength wastewater with good filterability.	High strength wastewater with poor filterability.
Membrane Flux	Lower membrane flux or lower permeate per unit area of membrane.	Higher membrane flux or higher permeate per unit area of membrane.
Trans-membrane Pressure	Entail lower TMP.	Entail lower TMP.
Power Requirement	Less power is required per m^3 of wastewater treated.	More power is required per m^3 of wastewater treated.
Sensitivity	Less sensitive to variations in wastewater characteristics and flow fluctuations.	More sensitive to variations in wastewater characteristics and flow fluctuations.
Membrane Area Requirement	More area is required.	Less area is required.
Economics	Generally, less expensive at lower wastewater influent rate.	Generally, more expensive at lower wastewater influent rate.
Membrane Backwashing and Cleaning	More frequent backwashing and cleaning required.	Less frequent backwashing and cleaning required.
Operation	Less operational flexibility.	More operational flexibility with control parameters like SRT, HRT and MLVSS.
Extension of WWTP Capacity	Difficult to extend.	Easier to extend.

2.4.2 Membrane Materials

In the water treatment industry, there are two primary categories of membrane materials, which are polymeric and ceramic. To comply with both cleaning a specific effluent and functioning long-term, membranes are commonly manufactured to have small pore size distribution and high surface porosity (Judd, 2011).

In terms of performance, polymeric membranes are mainly used in the wastewater industry since they are practically and economically beneficial and very competitive. Most polymeric membranes are normally hydrophobic. In terms of a water droplet test, this would indicate that these hydrophobic membranes, such as polypropylene, polyethylene, and polytetrafluorethylene (PTFE), have a contact angle with water droplets of more than 90º. Membrane materials are hydrophilic when they produce a contact angle smaller than 90º. These hydrophilic types, such as cellulose acetate (Judd, 2011), are commonly used. When it comes to the role of the fouling mechanism in wastewater, hydrophobicity is very important since it influences whether organic material readily attaches to the membrane surface or not (Krauth & Stabb, 1993). The membrane material should possess high resistance to oxidant concentration, high temperatures and pH (Munir, 2006).

2.4.3 Membrane Performance Measures

Membrane performance refers to the difference in flow and recovery characteristics of membranes. The total resistance is calculated from the membrane rejection and the permeate flux. In wastewater, membrane water recovery is an additional measure to evaluate membrane performance (Deelie, 2017).

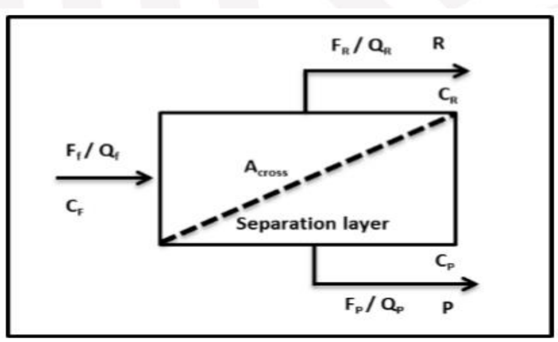

Figure 2. 4: Membrane stream designation (Deelie, 2017)

2.4.3.1 Permeate flux

The volume or mass flow rate per square meter of used membrane surface area is indicated by the permeate flux. Different membrane processes are compared by means of membrane flux. The membrane material, operating pressure or the trans-membrane pressure drop (TMP), and the membrane nominal pore size largely affect the flux (Ji & Zhou, 2006). Equations (2.1) and (2.2) are used to calculate the permeate flux.

$$J_m = \left(\frac{F(P)}{A}\right) = \left(\frac{m}{A\Delta t}\right) \tag{2.1}$$

$$J_m = \left(\frac{Q(P)}{A}\right) = \left(\frac{v}{A\Delta t}\right) \tag{2.2}$$

The permeate of the flux is J (kg/m^{2}h), m (kg) the collected sample mass, *v (l)* the collected sample volume, FP (kg/h) the permeate mass flow, Q (l/h) the permeate volumetric flowrate, Δt (h) the time taken to collect the sample, and A (m^2) the membrane area open to the separated fluid. The abbreviation for volume flux is LMH (l/m^{2}h).

2.4.3.2 Total resistance

The other important measure in membrane processes is total resistance, where time differs with both TMP and the flux of the membrane. A fouling layer initiate is an outcome of the non-linear relationship between the flux and the TMP (Merdaw, 2010). Darcy's Law is used to calculate total resistance in this membrane process (Ji & Zhou, 2006), as shown in Equation (2.3).

$$RT = \frac{TMP}{J_p \mu} \tag{2.3}$$

Total resistance is represented by RT (m^{-1}), fluid viscosity is μ (Pa.s), permeate flux is J_p (m^{3}m^{-2}s^{-1}), and trans-membrane pressure drop is TMP (Pa).

2.4.3.3 Membrane rejection

The rejection of a membrane is characterised as the measure of particles that have been separated from the feed water (Ji & Zhou, 2006). The rejection is calculated using Equation (2.4).

$$r = \left(1 - \frac{CP_i}{CF_i}\right).100 \tag{2.4}$$

In the permeate stream, the concentration of particles is represented by CPi (mg/l), and in the feed water, the initial concentration of particles is represented by CFi (mg/l).

2.4.3.4 Water recovery

The ratio of water that is reclaimed via permeate of the membrane is shown by the water recovery. The closer the value is to unity, the higher the segment of water that is recovered (Ji & Zhou, 2006). The water recovery is calculated by Equation (2.5).

$$WR = \left(\frac{QP}{QF}\right) \tag{2.5}$$

Feed flow rate is represented by QF (m^3/h) and permeate flow rate is represented by QP (m^3/h).

2.4.3.5 Membrane fouling

In the design of membranes and MBR systems, membrane fouling is the biggest concern. Chemical contamination, precipitation, or particulate build-up can cause membrane fouling. When wastewater gathers on the outside of the membrane, particulate fouling happens. The membrane pores can be blocked, decreasing the flux through the membrane and enlarging the TMP as the layer builds up (Layson, 2003). Membrane fouling is classified in different types: organic fouling, inorganic fouling, and biofouling (Thamaraiselvan & Noel, 2015).

A. Organic fouling

Displacement of colloidal or dissolved organic matter on the surface of the membrane causes organic fouling. The influent to the membrane together with extracellular microbial material forms layers on the membrane surfaces. This gel layer that develops on the surface of the membrane as a result of organic fouling is called gel layer fouling (Chang et al., 2006).

B. Inorganic fouling

Metal ions and other crystalline precipitates in the influent cause inorganic fouling to develop. Large blockages are formed on the membrane by inorganic matters that reside in the membrane pores.

C. Biofouling

The growth of micro-organisms on the surface of a membrane causes biofouling to develop. Membrane bioreactors are operated at high organic matter concentrations and are largely exposed to this type of fouling. With time, the membrane flow capacity is affected due to drawbacks in observing the thickness of the biofouling layer. In submerged MBR, a biofouling layer can function as an extra layer for enhancing the quality of the water, if maintained properly (Wang & Waite, 2009).

2.4.4 Membrane De-Fouling Strategies

Membrane de-fouling strategies are categorised into two broad categories, namely flux enhancement and cleaning. The intensity and the frequency of the applied de-fouling strategies are generally used to define whether it is classed as a flux enhancement method or a cleaning method. For this reason, a particular de-fouling strategy could be classified as both flux enhancement and cleaning, depending on how it is applied (Deelie, 2017).

2.4.5 Flux Improvement Methods

Flux improvement methods are regularly performed and run parallel to the operation of the membrane. Dealing with the transmission of the fouling layer on the surface of membranes is the focal point of this sort of de-fouling. The intensity cleaning method is still needed because these methods cannot completely eliminate or stop the initiation of fouling. The flux improvement strategies enable the membrane to work for longer before it requires disconnection and thorough cleaning. Well-known examples of flux improvement methods that are used are membrane backflush, relaxation, and air scouring (Wang & Waite, 2009).

2.4.5.1 Backflush

A procedure where the membrane fluid stream is switched to try and unstick the particles entering inside the membrane pores is named membrane backflush. The stream switch is made by utilising a bit of permeate to go in the opposite direction of the normal membrane filtration (Wang & Waite, 2009 and Mahmoud & Soumaya, 2020).

2.4.5.2 Relaxation

Relaxation is a procedure where filtration is paused to enable particles loaded on the surface of a membrane to unstick. For the low TMP membrane process, relaxation can be successful. Due to a shortage of force, this method is not enough as a cleaning procedure or for removing a fouling layer (Wang & Waite, 2009).

2.4.5.3 Air scouring

This is a well-known and utilised method in membrane bioreactors for the elimination of a fouling layer on the surface of the membrane. Two-phase fluid flow above the surface of the membrane is formed through the airstream. The upwards airstream sweeps the present particles with the flow as it proceeds up inside the membrane vessel. This is the outcome of two-phase fluid flow. Shear force is involved through the two-phase stream that is used to eliminate the fouling layer (Wang & Waite, 2009).

2.4.5.4 Cleaning methods

Cleaning methods are carried out on disconnected membranes with the emphasis on recovering what was lost as an outcome of fouling. It is commonly more thorough than flux improvement methods. Chemical and physical cleaning are commonly utilised for this (Wang & Waite, 2009). Sodium hydroxide is the generally used chemical for cleaning the membrane. However, other chemicals such as chlorine, hydrogen peroxide, and citric acid, may be used based on the manufacturer's manual (Brepols et al., 2008).

2.5 Woven and Nonwoven Fabric Membranes

2.5.1 Woven Membrane

New technology of membranes is being developed such as woven fabric membranes. Woven membranes are manufactured through weaving processes. Chemical pretreatment steps are not required before using woven membranes. Even after using it, no harm will be done to the membrane if left out to dry. It is made of high strength fabric, but it cannot be backwashed at a high flow rate. Permeate turbidities produced by woven membranes in a loose microfilter are between 0.5 and 1 NTU, whilst permeate produced by commercial microfilters is less than 0.5 NTU (Deelie, 2017).

2.5.2 Nonwoven Membrane

Originally, nonwoven fabric filters were utilised for the thickening of sludge (Seo et al., 2003). Since the fabric filter has the below main characteristics, it has lately been used in wastewater treatment in combination with activated sludge processes (El-Khateeb et al., 2018). The main characteristics are:

- The cost of fabric filter material is more cost-effective compared to normal membrane materials.
- It has low filtration resistance and a high permeate.
- The fabric does not require energy for gravity filtration (El-Khateeb et al., 2018).

The production procedure involves needle-punching layered fibres into a fabric. The membrane pore sizes of nonwoven fabrics range between 1 to 10 µm. Colloids, bacteria, smaller size organic micro-contaminants, such as humic acid in water treatment, and inorganic ions can be eliminated by these membranes (Landage et al., 2013). Even though little research has been done, in a hybrid MBR for wastewater, it was proposed that a fabric filter has great potential to substitute membrane MF (Xianghao et al., 2010). Flat-sheet polyacrylic nonwoven fabric microfiltration (NWFMF) is the specific membrane and method that the study focused on and it was produced in South Africa. Problems such as fouling, energy demand, and low flux may potentially be solved with this unique configuration plant of polyacrylic nonwoven fabric membranes.

Landage et al. (2013) studied the application of microfiltration at the Ichalkaranji Wastewater Treatment Plant where woven and nonwoven fabric membranes were used and configured at the final effluent before chlorination (Landage et al., 2013). The results of the study concluded that nonwoven fabric membranes improved the water quality by using a double layer nonwoven fabric with an 800 needle-punching density and showed a high filtration efficiency of 90% at 0.5 lit/min. It was shown in the results that an NWF membrane with low air permeability was responsible for better filtration efficiency. It was reported that at a lower flow rate, the grams per square meter (GSM) of nonwoven fabric increased in contrast to woven fabric. Landage et al. (2013) also recommended that a high needle-punch density nonwoven fabric should be used for high filtration efficiency in an effluent treatment plant.

Chang et al. (2014) studied the possibility of utilising enhanced nonwoven fabric membranes as separation media in MBR to treat wastewater from a fibrous product manufacturing plant. The study was done at a 20.83 lit/min capacity pilot plant. The results of the study indicated that if a suitable backwashing method and pore size of a nonwoven fabric membrane is selected, stabilised permeate flux can be obtained. Regarding the backwashing method, it was found that the efficiency of air backwashing was more improved than that of water backwashing (Chang et al., 2014). The effect of nonwoven fabric membrane pore sizes on backwashing efficiency was found to be minor at experimental backwashing air velocity. The study indicated that nonwoven membrane is a promising technology for industrial wastewater treatment.

Seo et al. (2003) investigated nonwoven fabric membranes experimentally for the separation of solid-liquid in an activated sludge reactor as unusual membrane. In this study, a polypropylene fabric filter membrane of 70, 50, and 30 g/m^2 was utilised. The operation type of the pilot system was anaerobic/oxic (A/O), where the filter unit was immersed into the oxic section. The unit for filtration consisted of 10 rectangular-type, plate filter components with an operative filtration area of 2 m^2. For solid-liquid separation, gravity filtration was executed by varying the water head from 0.05 m to 0.5 m during the process operation without backwashing. Permeate flux initially was set at 0.4 m^3/m^2/d. On the matter of BOD/T-N, the C/N ratio of raw wastewater was measured at 4.5. Good performance was shown by nonwoven fabric membranes and was sufficient for treatment of domestic wastewater coupled with the activated sludge system. The SS effluent concentration was 3.2 mg/L which showed 93.4% removal. The COD effluent concentration was around 13 mg/L, indicating 91.6% organic removal. At the regulated C/N ratio of wastewater influent, a 66% removal efficiency of total nitrogen could be attained. Nevertheless, a very low removal efficiency of 23% was observed for phosphorus. For a steady operation of the process, it was established that an initial flux of 0.4 m^3/m^2/d should be preserved (Seo et al., 2003).

Shivaranjani and Sankari (2018) investigated the efficiency of polyethylene nonwoven fibre filters for treating institutional wastewater with the MBR process. Institutional wastewater is classified as domestic wastewater, which consists of a great quantity of inorganic and organic pollutants, for instance COD, BOD, and turbidity. A polyethylene fibre filter membrane has pore sizes of 0.2 µm which results in it being categorised as microfiltration. A membrane reactor was invented at the laboratory for treating institutional wastewater in this study. The combination of an activated sludge process and membrane filtration was involved in the operation. Aeration was observed to be an essential process in the biodegradation of organic matters and hydraulic retention time (HRT) was also observed for maximum removal efficiency. After the treatment process, parameters such as turbidity, pH, iron, hardness, and dissolved oxygen was discovered to be within the set limits for drinking water according to Indian standards (IS) 10500 in India. The HRT for BOD and turbidity was differentiated between 2.5 – 6 hours. Turbidity effluent was decreased to 9.3 NTU at 97% removal efficiency and BOD effluent was decreased to 2.8 mg/L at 98% removal efficiency. When compared to a common membrane used for the MBR process, it was observed that the polyethylene nonwoven fibre membrane is cost-efficient and gave promising results (Shivaranjani & Sankari, 2018). It was also concluded that treated wastewater by MBR can be utilised for drinking purposes.

Chang et al. (2006) also studied the application of microfiltration at a municipal sewage treatment works in Japan by using nonwoven fabric membranes coupled with activated sludge. The results of the study showed that wastewater quality can be improved by a nonwoven fabric membrane if it is properly designed. Without backwashing or chemical cleaning for more than 50 days, the results indicated that nonwoven membranes achieved a filtration efficiency of 95% at a flux of 0.18 $m^3/m^2/d$. With low filtration resistance, the results showed that nonwoven membranes held solids in the reactor successfully and it did not change during operation. Where the total bacterial count was 1000 CFU/mL in the disinfection of effluent, the results demonstrated that the use of nonwoven fabric in MBR is less successful but mentioned that if a small pore-size nonwoven membrane is used, there can be an improvement. It is further suggested that a proper working technique, for example enhancing the operating flux or enforcing the fouling control strategy, is needed in the utilisation of nonwoven fabric in MBR for a long lifespan and steady operation. Controlling the fouling layer for this type of membrane is critical, because for a specific product quality to be obtained, a fouling layer is needed. Nonetheless, Chang et al. (2006) also mentioned that whenever left to accumulate too much, the efficiency of the membrane will be critically affected. Strategies for cleaning are needed which can reduce the fouling layer buildup to the degree that the efficiency of the membrane improves, while the residual fouling layer remains sufficient to obtain the needed quality product. The de-fouling membrane strategy used in this study is air scouring.

For submerged MBR, air scouring is a well-known strategy for membrane de-fouling. Two-phase flow on the surface of the membrane is formed by utilising an airstream. When developing the air sparger for a specific membrane process, factors that should be considered are flow rate, bubble size, and duration. For membrane de-fouling, there are two sectors for air sparging to choose from - coarse bubble and fine bubble. Coarse bubble is the one utilised in this study. Membrane process geometry configuration is moderately significant to improve fluid flow in the membrane process and to advance the air scouring impact (Judd, 2011).

2.6 Water Quality Monitoring and Parameters

2.6.1 Turbidity

Turbidity is the level of darkness or the losing of clearness of a water sample because of suspended solids (SS) (Mihelcic & Zimmerman, 2010). The measurement of turbidity is Nephelometric Turbidity Units (NTU). It is important to measure turbidity in wastewater treatment because it can act as a shield to pathogens and particles. High turbidity is shown by a high value of NTU and a high concentration of SS in the sample (Mucha & Kulakowski, 2016).

2.6.2 Classification of Solid Particles

Solid particle characterisation depends on the particle size. Generally, solid particles are bigger than molecules but too small to see with the unaided eye. Particles smaller than 0.001 µm are termed as dissolved solids. Particles that range between 0.001 µm and 1µm are called colloidal particles. Particles bigger than 1 µm are characterised as suspended solids in the field of water treatment (Mihelcic & Zimmerman, 2010).

2.6.3 Dissolved Solids

Metals, salts, minerals, anions, and cations are particles that dissolve in water, and they are called dissolved solids. The combination of an organic substance and inorganic salts in water can be in a solid, colloidal molecular, or ionized state and are termed total dissolved solids (Mihelcic & Zimmerman, 2010).

2.6.4 Coliform Bacteria and Pathogens

Bacteria called coliforms are present in human and animals stomachs and are, therefore, found in their waste as well as in soil and plant matter (Mihelcic & Zimmerman, 2010). Bacteria such as these mostly do not present health dangers, but the presence of these bacteria is usually used as a measure for the existence of other disease-creating organisms. The organisms creating these diseases are largely named pathogens (Ajonina et al., 2015). Testing for pathogens in water is expensive and takes time: thus, the existence of the measure for coliforms is tested rather than testing samples of water to check the existence of pathogens. Coliforms are simple to distinguish since they are present in more concentrations than pathogens. The total coliforms test is the well-known technique of testing for the existence of pathogens. The existence of coliforms from animal and human waste, and coliforms bacteria that develop in soil and plant matter, are shown by the total coliforms test. An indirect test is utilised by the total coliforms test to discover the potential existence of pathogens in water samples (Deelie, 2017).

2.6.5 Organic Matter

Animal and plant life deliver organic matter into water. Monitoring organic concentrations in wastewater outflow is essential because esterification of dams and lakes can occur due to high organic concentrations. In the industry, there are various techniques that can be utilised to discover the organic concentration of matter, such as COD, TOC, and BOD, in water samples (Deelie, 2017).

2.6.6 Biochemical Oxygen Demand

Aerobic biomass needs oxygen for oxidation of all organic matter found in water samples and the quantity of oxygen needed is tested by the biochemical oxygen demand (BOD) method. In the wastewater field, the BOD test is used as a sign of the success of the bioprocess for eliminating organics in wastewater. The quantity of oxygen needed to oxidise only organic matter is shown by the BOD test (Mihelcic & Zimmerman, 2010).

2.6.7 Chemical Oxygen Demand

The concentration of organic matter in water samples is discovered by an indirect technique called the chemical oxygen demand (COD) test. The COD test shows the concentration of organic contaminants in water samples. It is utilised in the drinking and wastewater industries. The quantity of oxygen absorbed per litre of water is shown by the COD technique. To create ammonia, water and carbon dioxide organic matter can be oxidised and the COD test is established on this theory (Mihelcic & Zimmerman, 2010). Acidified potassium dichromate is a powerful oxidising agent utilised to oxidise organic matter and is preferred above the BOD test where bacteria is utilised. Inorganic matter present during the COD test can also be oxidised and that is the downside of the COD method (Hu & Grasso, 2005).

2.6.8 Total Organic Carbon

The quantity of carbon in suspended and dissolved organic matter within the water sample is discovered by an analytical technique of total organic carbon (TOC). From the plants, an effluent TOC test is also performed to observe the total organic removal to the environment. It is significant to test TOC because organic carbons reacts with disinfection chemicals such as chlorine and forms DBP that can be harmful to humans and animals (Deelie, 2017).

2.7 Water Re-use

2.7.1 Wastewater Re-use Drivers

Many countries were forced to search for a different supply of water to complement their conventional sources due to a growth in population, ground and surface water pollution, constant drought, and irregular water resource distribution (Asano et al., 2007). An increase in the production of untreated and/or treated wastewater effluent released into the surface water, that in some instances work as a potable raw water source, is due to the growth in population and urbanisation. Due to the growth in population and people searching for a better life in developing countries and, also, in South Africa, in provinces such as Gauteng there has been an increase in water strain due to the level of urbanisation. Over the previous few decades, there has been a demand for simple services, for example potable water, electricity, and sanitation, due to urbanisation and the growth in population (Skosana, 2016). Naturally, water resources are limited in South Africa and vast water resources are needed for the economy to grow and for the provision of other dynamic services. Social and economic development can be limited by this resource in some areas (Muller et al., 2009). Economic and social development is not restricted by water scarcity but rather by understanding and acknowledging the water quality of the country and it is important to live within these means (Muller et al., 2009). In South Africa, unfortunately, this is missing. To close the water scarcity gap in South Africa, it is essential to acknowledge wastewater reclamation, recycling, and re-use to reduce the demand in the agricultural, domestic, and industrial sectors.

2.7.2 Worldwide Existing Wastewater Re-use

High population numbers and water demand in arid and semi-arid countries result in municipal wastewater plants utilising reclamation and the re-use of water. This is also true for other countries with problems of decreasing nutrients discharged into the environment (USEPA, 2012). The development of wastewater reclamation is regarded as a water resource rather than a liability due to water pollution and an increase in water shortages (Asano & Cotruvo, 2004). The largest and oldest instance of water re-use is reported in the irrigation sector. The other alternatives for water re-use are non-potable re-use such as flushing of toilets, swimming pools, industrial uses, indirect potable, and not often, direct potable re-use (Skosana, 2016).

In the early 1960s in the arid west of the United States, the implementation of reclaimed water use happened in Colorado Springs where reclaimed water is commonly utilised for irrigation (Asano et al., 2007). Wastewater is re-used for agricultural purposes in Israel as their strategic objective. A small section of treated wastewater is utilised in the South African agriculture field even though it accounts for 60% of water use in the country (Skosana, 2016). Direct potable re-use alternatives have been implemented in Windhoek, Namibia, for more than 30 years where domestic water supplies use a multi-barrier method and no negative effects have been discovered for this treatment (Huertas et al., 2008).

Almost 14% of the total water use in South Africa is accounted for by the re-use of water which is unplanned and indirect, and it is commonly credited to flowback, primarily through released outflow into the streams (DWA, 2013a). The wastewater reclamation plant (WRP) that South Africa built in the Karoo in Beaufort West after a recent drought makes use of the direct potable re-use of wastewater. The design capacity of this plant is 2.1 ML/day and the water should be treated to potable water standard (ATSE, 2013). The planned direct and unplanned indirect re-use instances show wastewater re-use and reclamation phases already implemented in South Africa, and in the future, it will be an element to establish arranged use.

2.7.3 Wastewater Re-use Options

Irrigation, urban, residential, and recreational uses, bathing water, groundwater recharge, industrial cooling water, aquaculture, and drinking water production are the greatly known direct and indirect re-use alternatives (Huertas et al., 2008). The reclaimed water quality requirements are based on the application of water, which can incorporate the following (de Koning et al., 2008):

- Industrial re-use - the quality of water is good enough to be used in power plants for cooling towers. Sedimentation, corrosion, clogging, and health aspects are functional characteristics that cannot be overlooked in this application.
- Non-potable household - this quality of water can be used for laundry, showering, car washing, toilet flushing, and gardens. In this type of re-use application, the main effect is safety of animals and humans associated with functional effects such as hardness caused by heavy metals.
- Irrigation - this quality of water can be used in urban areas for watering gardens and public parks. The effects on human health are also important.
- Natural water resource restoration - this is where refilling or synthetic recharging of natural water occurs. In this circumstance, created wetlands or boreholes are refilled using reclaimed water.

2.8 Method Utilised for Water Quality Interpretation

2.8.1 Water Quality Index

Water is the main requirement of life on earth, and in all forms of life, it is a crucial element, from human to micro-organisms (Priyanka, 2010). There is no other replacements for water, life is established from water (Muniyan & Ambedkar, 2011). Chemical, physical, and biological parameters are the definition of water quality. In any case, from a huge number of samples, the quality is challenging to assess, with each having concentrations of numerous parameters (Almeida, 2007). Information of water quality trends is communicated effectively with indices. Since, at that point, the advancement of the index method was given a huge deliberation. A single number is provided by the Water Quality Index (WQI) that indicates general water quality at an established area on a few water quality parameters, and changes complex water quality information into data that is clear and easily used by the public (Semiromi et al., 2011). The main objective of the WQI is to outline a huge amount of water quality information into easy words, such as excellent, good, poor, very poor, and unsuitable, for reporting to the public and managers in a reliable way (Hulya, 2009). In differentiating water quality of various sources, the WQI can be utilised as an instrument and it provides the people with a common idea of the potential harms within water in a specific district (Singh et al., 2016).

Originally, the development of the WQI was done by Horton (1965) in the United States by choosing the 10 best generally used water quality parameters such as alkalinity, pH, DO, coliforms, specific conductance, chloride, etc. It has been recognised and is commonly used in Asia, Europe, and African countries. The importance of a parameter was reflected by the allocated weight for a certain use and has a great effect on the index (Singh et al., 2016).

The Water Quality Index is calculated by using the following formula:

$$Q_i = \left\{\left[\frac{(V_{actual} - V_{ideal})}{(V_{standard} - V_{ideal})}\right] 100\right\} \quad (2.6)$$

Where, Q_i is Quality rating of ith parameter for a total of n water quality parameters, V_{actual} (mg/l) is Actual value of the water quality parameter obtained from analysis, V_{ideal} (mg/l) is Ideal value of that water quality parameter which can be obtained from the standard tables.

The relative (unit) weight (W_i) will then be calculated by a value inversely proportional to the recommended standard (Si) for the corresponding parameter using the following equation:

$$W_i = \frac{I}{S_i} \quad (2.7)$$

where, W_i is Relative (unit) weight for nth parameter, S_i is Standard permissible value for n^{th} parameter, and I is Proportionality constant. The relative (unit) weight (W_i) to various water quality parameters are inversely proportional to the recommended standards for the corresponding parameters. Finally, the overall WQI is calculated by aggregating the quality rating with the unit weight linearly by using the following equation:

$$WQI = \frac{\sum Q_i W_i}{\sum W_i} \quad (2.8)$$

Where, Q_i is Quality rating and W_i is Relative (unit) weight.

Singh et al. (2016) did a study on the Nambul River Imphal in Munipur, India. Water samples were collected from six stations. The analysed physicochemical water parameters were turbidity, water temperature, TDS, BOD, COD, pH, DO, calcium, chloride, and magnesium.

The Arithmetic Index method was used for calculations. The range of the WQI value for samples collected was 103.89 – 115.34. This showed that the water is unsuitable for drinking purposes (Singh, et al., 2016).

Petr (2019) evaluated the quality of treated and raw wastewater utilising the Principal Component Weighted Index (PCWI). It was described as a total amount of component scores weighted in line with their eigenvalues. For this reason, five principal components (PC_s) describing 83% and 88% of the overall variability of treated and raw wastewater samples, respectively, were taken out from 11 initial physicochemical parameters by robust principal component analysis (PCA) (Petr, 2019). The treated and raw wastewater $PCWI_s$ were tested according to their temporal changes, statistical distributions, mutual corrections, correction with initial parameters, and ordinary WQI. Temporal wastewater quality was observed by one parameter other than a few using PCWI. Not at all like other weighted indexes, PCWI is composed of independent factors with minimum details and accurately intent weights (Petr, 2019).

2.8.2. Wastewater Polishing Index

The main objective of implementing the Wastewater Polishing Index was to further improve water quality by decreasing the primary contaminant parameters concentration to the standards set for discharging to the surface water bodies, recycling, or re-using. Depending on the selection of treatment, the attainable refinement of the water quality may differ. Suspended solids, phosphorus, nitrates, and micro-organisms can be largely decreased by utilising the method of conventional process, mostly fast filtration, physical and chemical disinfection (Paola et al., 2011).

For this new index, a rating curve is utilised. The definition of this rating curve involves the assumption of two key points that has been done for each indicator equivalent to the expected standard of each specific range in the table (Paola et al., 2011):

- 0 is the minimum value.
- The maximum value is equal to the Italian legal standards for discharged effluent to the surface water bodies $C_{i,\ law}$, with *i* is COD, BOD, SS, NH_4, P and *E. coli.*

The assumed rating curve for all six parameters is a straight line between the two extremes as reported in Figure 2.5. The equivalent sub-index is described in this manner. In a case where the measured $C_{i,}$ is greater than $C_{i,\text{ law,}}$ extrapolation should be applied over the drawn range of Figure 2.5 in the same linear correlation, causing the sub-index value of more than 100 (Paola et al., 2011).

The new index is defined by Equation 2.9 where I_i is the sub-index equivalent to the main parameter, *i* is COD, BOD, SS, NH_4, P and *E. coli*. For all parameters, n_i is equal to 1, with an exception for *E. coli* where it is 1.4 (Paola et al., 2011).

$$WWP1 = \frac{\sum_i I^{ni}}{\sum_i 100^{ni}} \times 100$$

$$= \frac{I^1 BOD_5 + I^1 COD + I^1 SS + I^1 NH_4 I^1 P + I^{1.4} E.coli}{5 \times 100^1 + 100^{1.4}} \times 100 \qquad (2.9)$$

In order to improve the disinfection capability of the polishing system under the study, a higher value is assumed for the peak of the *E. coli* sub-index.

Table 2.3: Range of variables and key points for rating curves (Paola et al., 2011)

	COD (mg/L)	BOD (mg/L)	SS (mg/L)	NH_4 (mg/L)	P (mg/L)	*E. coli* (counts/L)
	0	0	0	0	0	0
$C_{i,\text{ law}}$	125	25	35	15	1	5000

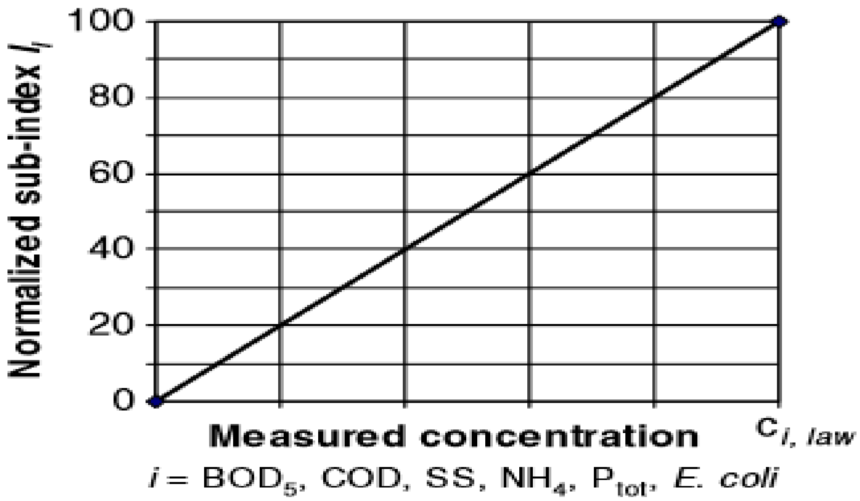

Figure 2. 5: Normalisation curve for each parameter (Paola et al., 2011)

Paola et al. (2011) proposed a new index, which is the wastewater polishing index (WWPI). This new index was determined for fast evaluation of the quality attained by various treatments of polishing water released into the external water bodies and for purposes such as re-use. A weighted average of six parameters - COD, BOD_5, ammonia, suspended solids, total phosphorus, and *Escherichia coli*, is used to explain the index. Each parameter is converted into a sub-index scale from 0 – 100. Amongst other indicators, *E. coli* has been given a larger weight. If none of the six parameters are present in the effluent, the index is equal to 0. When the Italian legal limits for the effluent discharged into surface water bodies is equal to all six parameters in the effluent, the index is equal to 100. The WWPI is 36 when all six parameters are equivalent to the Italian legal limits for re-use (Paola et al., 2011). The validation and testing of the index was done on a pilot plant as well as slow filtration through a horizontal subsurface flow system, quicksand filtration, and a lagoon. This index is a good instrument for:

- Quickly comparing the quality of water attained by various treatment sequences, especially natural systems.
- Quickly assessing whether the anticipated sequences it will be able to yield are satisfactory for re-use.
- Quickly assessing if water quality improved by various systems.

When arranging for resources of water, specifically for differentiating the quality level accomplished by various wastewater sequences, managers and decision-makers can utilise WWPI.

2.8.3. Single Factor Pollution Index

Another interesting and simple mathematical model is the Single Factor Pollution Index which is used in corporation with statistical computations in the statistical package for social sciences (SPSS) (Tanjung et al., 2019). The formula below can be used in single factor analysis:

$$P_i = \frac{C_i}{S_i} \quad (2.10)$$

where Pi refers to the pollution index of i units pollutant. Ci refers to the measured concentration of i units pollutant (mg / L), and Si the III level water quality standard category value of i units pollutant according to the Environmental Quality Standards for Surface Water. Table 2.4 shows the categories of the Single Factor Pollution Index in determination of water quality status and pollution.

Table 2.4: Standards of Single Factor Pollution Index

Pi	≤ 0.4	0.4 - 1.0	1.0 - 2.0	2.0 - 5.0	> 5.0
Pollution level	Non-pollution	Slight polluted	Medium polluted	Heavy polluted	Serious polluted

Yan et al. (2015) assessed the water quality and also identified polluted risky areas based on the site observation Geographical Information System (GIS) in the Watershed River in China. The Comprehensive Pollution Index and the Single Factor Index were used to discover the primary water pollutants and assess the water quality pollution level. Evaluation techniques that were utilised to find possible polluted risky regions and to picture the spatial pollution characteristics are geo-statistical analysis and GIS. The general water quality in the Watershed River has been exposed to different pollutants and this was revealed in the results. The primary pollutants were total phosphorus (TP), nitrite nitrogen (NO_2-N), and total nitrogen (TN) and it extremely exceeded the limits of Category III. TP, TN, DO, NO_2-N and NH_4-N areas pollution represented 99.07%, 62.22%, 59.72%, 37.34% and 13.34% of the watershed correspondingly, and were grouped from moderate to serious polluted. In total, 83.27% of the Watershed River was polluted by comprehensive pollutants (Yan et al., 2015).

2.8.4 Water Use License (WUL)

The main purpose of the National Water Act (NWA), 1998 (Act 36 of 1998) is to ensure that water is properly managed, used responsibly, controlled, conserved, developed, sustained, fairly distributed, and protected to help all people in South Africa. Under section 21(f) and 21(g) of the NWA, (Act 36 of 1998), discharging waste or water containing waste into water resources and disposing of waste in a manner which may detrimentally impact a water resource, requires a license from the Department of Water and Sanitation (DWA, 1998). A Water Use License (WUL) has been implemented to achieve the National Water Act goals. The main purpose of a WUL is to monitor the water quantity and quality discharged into the downstream. This is achieved by setting limits on parameters analysed for discharge to the river (WRFMC, 2007). A WUL is therefore pertinent to all the divisions and people in South Africa. Wastewater treatment works do water quality analyses based on the WUL, and trends are also done against the WUL standards to determine water quality compliance.

Chapter 3: Methodology

3.1 Preamble

This section describes the methods used to achieve the objectives of this study. Details of the research methodology are described and include Water Use Licence, Water Pollution Index, Water Quality Index, experimental setup, test procedures, removal efficiency, and correlation of data.

The current objectives of the research were to investigate the efficiency of a specific type of nonwoven fabric membrane. This was to determine whether the microfiltration process can improve wastewater quality post-treatment with BNR (biological nutrients removal). In addition, to test whether microfiltration may assist with the re-use of treated wastewater. The permeate quality was compared against guidelines such as a Water Use Licence, water research commission guidelines, and agricultural irrigation guidelines. This helped to make output-dependent recommendations on the suitability of water treated for re-use purposes.

3.2 Pilot Plant and Material

3.2.1 Pilot Plant

The pilot plant consisted of a high-density polyethylene (HDPE) tank with a volume of 10 000 L. This tank was sourced from a 15 000 L container that was cut to provide a 10000L tank. As seen in Figure 3.1, the container was cut in such a manner that 66% of the bottom half could be used as a tank.

The pilot plant is a support structure that holds the fitted membrane together. The membranes allow flow through it and act as a barrier between the water in the tank and the water that penetrated through the membranes. Thus, it separates the water that is within the HDPE tank and the filtered water to be sucked out of the inner section of the filters.

Figure 3.2 shows a schematic of the membrane system that was adopted in this study. As seen in Figure 3.2, two WATSON MARLOW 530 series pumps were used. This type of pump has a maximum throughput of 3.5 L/min and a minimum of 0.04 mL/min. These pumps are equipped with flow control meter. One of the pumps is used for suction and the other for the delivery of the filtered effluent. The 12 mm inner diameter PVC within a 50 mm PVC guide pipe was connected to the peristaltic suction pump that provided wastewater to the pilot. The pump for the delivery of the filtered effluent was essential for creating a pressure gradient for the smooth running of the process. Fittings in the tank enabled filtered wastewater to exit from the bottom under assistance of gravity as seen in Figure 3.3.

An airline was connected to an oil-less fuel motor compressor to supply air for aeration and also cleaning the membranes when required. Making this process aerobic resulted in additional nitrification.

The second drum on the right of Figure 3.1 houses the equipment that were used in the setup. Pumps and a compressor were inside the drum to avoid ingress of rainwater. The tubing used for the peristaltic pumps were Marprene tubes of standard FDA regulation 21, CFR 177.2600 for contact with aqueous food. These tubes are capable of working within the range of 5ºC to 80°C. Figure 3.4 shows a complete setup at Waterval Wastewater Care Works when filled with wastewater.

Figure 3.1: Tank sourced from previous installations

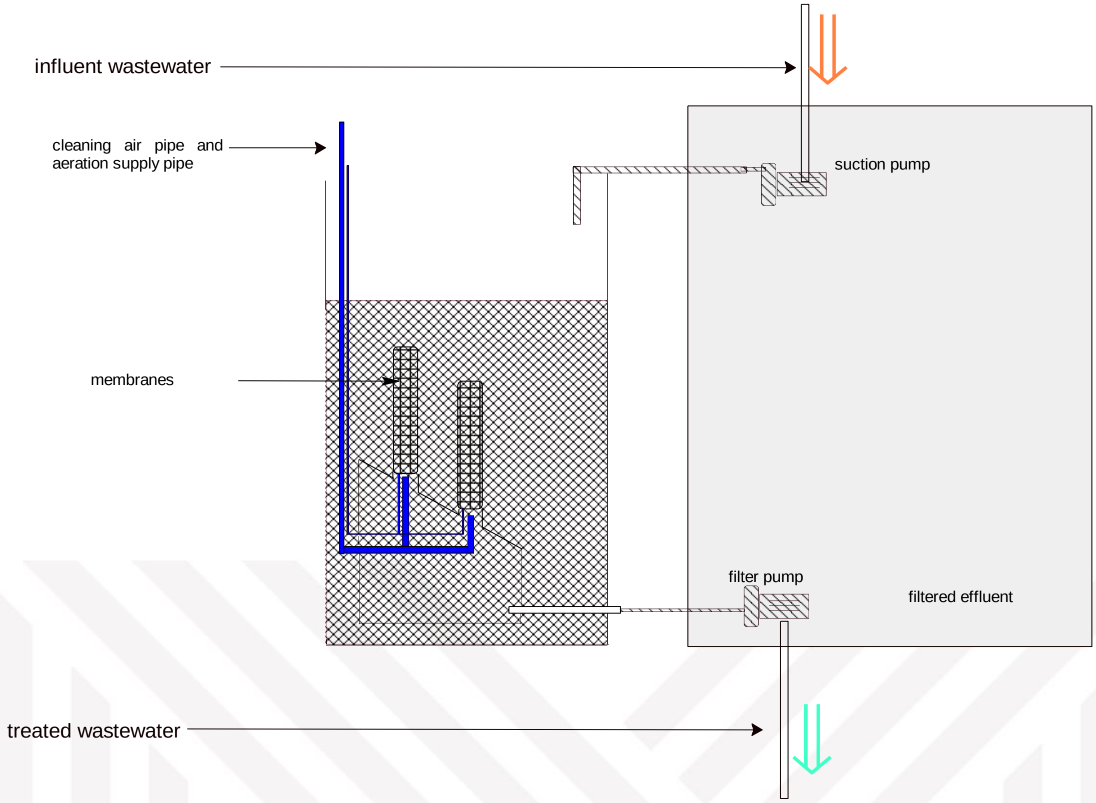

Figure 3.2: Microfiltration system modified from WRC report number (Topkin & ERWAT, 2018)

Figure 3.3: Fitting at the bottom of the tank to allow the filtered wastewater to exit under gravity assistance

Figure 3.4: Completed unit when filled with wastewater

3.2.2 Material of Nonwoven Fabric

Table 3.1 shows the specifications of the filter that was used in the study. These were obtained from a local company named Filtaire SA CC. As can be seen in Table 3.1, these filters are made of 100% Acryl Needle felt fibres. They have a pH range starting from 3 to 11 and can withstand a temperature of 130°C of continuous operation. The fibres used in these filters are between hydrophobic and hydrophilic. Hydrophilic filters are easily wet with water and hydrophobic filters will not wet in water but will wet in low surface tension liquid such as organic solvents.

Table 3.1: Nonwoven membrane filters specifications

PRODUCT NAME	AR550 – HOMOPOLYMER ACRYLC NEEDLE FELT		
CHARACTERISTICS	**SPECIFICATION**	**RANGE**	**RESULTS**
FIBER COMPOSITION	Acrylonitrile Staple Fiber	100 %	Acrylic Needle Felt
SCRIM COMPOSITION	Acrylic Staple Yarn	100 %	Heat Set
FEATURES	High filtration efficiency, long service life with good anti-abrasion. The high porosity of Acrylic gives good air permeability and tends to be a stiff fabric, itchy to the touch and irritate the skin.		
APPLICATION	Mainly used in Detergent, Waste Incinerators, Asphalt, Dance spray dryer, coal mill and power plants.		
CHEMICAL PROPERTIES	Anti-acid Excellent, Anti-alkali Excellent, Anti-abrasion Good, Hydrolysis Stability Excellent.		pH ranges from 3 - 11
FLAMMABILITY	F1 (DIN 53438)		
ROLL SIZE	2.1 × 100 m	2 %	
HEIGHT	2.2 mm	5 %	
WEIGHT	550 g / m^2	5 %	
AIR PERMEMEABILITY	13 - 15 m^3/m^2 / min at 12.7 mm W.G	20 %	
TEMPERATURE	140˚C Continuous Operating 160 ˚C - Maximum Dry Surge		
RELATIVE HUMIDITY	≤ 30 %		Beware of the oxidation
BREAK STRENGTH	Wrap - ≥ 600 N /5 0 mm Welt -≥800 N /5 0 mm	MD CMD	
FINISH	Singeing, Glazed, Scrim Supported	ISO 9001: 2008	Calendared
COUNTRY OF ORIGIN	China	100 %	DT01610

3.3 Experimental Procedure

This assembly was placed inside a HDPE tank. Secondary clarifier effluent passed through the filters at a flow rate of 1.0 lit/min at atmospheric pressure. The membrane was operated in dead-end mode. The operational flux was 11 L/hr/m^2. The membrane module was aerated continuously to reduce membrane fouling and the DO level was measured at 7.4 mg/L. Membrane cleaning was done only once during the study according to the method stated by Mahmoud and Soumaya (2020) where water/air flush was used for 15 minutes to create turbulence on the membrane to create the cleaning process. The duration of the cleaning process during this study was also 15 minutes. The results were studied and compared against clarifier effluent, the Waterval WUL, the Single Factor Pollution Index, and the Water Quality Index for different types of water usages.

3.4 Data Collection and Sampling

For data collection, a quantitative research approach was utilised (Greener & Martelli, 2015). A quantitative approach is related to a deductive approach as theory is tested frequently through the use of numbers and facts.

This technique was selected because it offers approaches for the formation of quantitative data needed for facilitation of the water quality data. Water quality parameters chosen for this study are described in Table 3.2.

In selection of the sampling units and location, a judgmental sampling method was used. The judgmental method entails choosing the quantity of samples, location, and time, based on the investigator's knowledge on the topic and the conditions being assessed (Li & Chaplin, 1998). Physical, chemical, and microbial samples were collected weekly as well as the influent and the permeate as listed in Table 3.2. This assisted in tracking the changes that were done on the system. Physical and chemical samples were collected in 1 litre plastic bottles preserved with sodium thiosulphate to keep the samples stable. The technique used to sample physicochemical parameters is grab sampling. Microbial samples were collected in 500mL sampling bottles preserved in the cooler box iced at the temperature of 1-4 ˚C to keep the sampling conditions constant when delivered to the laboratory. Samples were taken to ERWAT LAB for analysis and a SANAS accredited certificate was provided together with the results in Appendices A and B.

Table 3.2: Physicochemical and biological water quality parameters

Physical	Chemical	Microbial	Accreditation
Potential Hydrogen (pH)	Chemical Oxygen Demand (COD)	*Escherichia coli (E. Coli)*	No: T0082
Electro-Conductivity (EC)	Ammonium (NH_4-N)		
	Nitrite (NO_2-N)		
	Nitrate Nitrogen (NO_3-N)		
	Total Nitrogen (Nt)		
	Phosphate Phosphorus (PO_4-P)		

Monitoring of organic parameters such as COD concentrations in wastewater outflow is essential because eutrophication of dams and lakes can occur due to high concentrations (Henze, et al., 2002). Physical parameters such as extreme pH and high electric conductivity (EC) can affect aquatic life in surface water. Nutrients such as ammonia, nitrites, nitrates, total nitrogen, and phosphorus that are discharged as effluent from wastewater care plants to the environment, may result in the formation of microcystins that may pollute future drinking water and affect people's health (Mayo & Bibambo, 2005). Biological parameters such as E. coli shows the presence of pathogens that can cause intestinal or extra-intestinal infections (Kaper, 2005). These parameters assisted as indicators for wastewater treatment processes at the preliminary, primary, secondary, and tertiary stages, to ensure that the treated final wastewater effluent complies with the WUL before discharging it to the environment.

3.5 Data Analysis Method

After the collected samples were analysed by the laboratory using the methods described in Table 3.2, further comparisons with actual standards, such as the Water Use License and the SANS 241 standard were performed. The Water Quality Index was utilised to determine the suitability for filtered water. The Single Factor Pollution Index was also used to determine the extent of pollution for effluent discharged to the surface and the permeate from the pilot. Descriptive statistics were used to make correlations and deductions.

3.5.1 Physicochemical and Microbial Water Analysis Methods

3.5.1.1 Microbial analysis

a) *E. coli*

The standard method 9222K for water and wastewater 23rd edition (APHA, 2017) was utilised in this study. This method is a fast way to estimate bacterial populations in water and useful when evaluating large samples volumes. Sample sizes of 100mL were filtered through a 47mm diameter, 0.45µm pore size cellulose membrane filter. This step preserved the presence of bacteria in the sample. The filter was placed on a 5mL of membrane infiltration (MI) agar solution and the plate was placed in an incubator for 24 hours at a constant temperature of 35ºC. The blue colonies on the MI plate were counted under normal light and the results were recorded. This was regarded as the *E. coli* count. In less than 24 hours, positive results were obtained, and the results were validated. Where the results were negative, they could not be recorded until the 24-hour incubation period was completed. MI plates were exposed to longwave ultraviolet light (366nm), and all fluorescent colonies (blue/green fluorescent E. coli) were counted. The data was recorded. The final value was calculated by this formula:

$$E.coli/100ml = \frac{Number\ of\ blue\ colonies}{\text{Volume of sample filtered(ml)}} \times 100 \qquad (3.1)$$

3.5.1.2 Chemical parameters analysis

a) Suspended solids analysis

The standard method 2540D for water and wastewater 23rd edition (APHA, 2017) was used. This method is suitable for the determination of solids in portable and surface water, as well as domestic and industrial wastewater. The method has a detection limit of 10 mg/L. Samples were collected in 1 L plastic polyethylene bottles. The samples were filtered through a glass fibre filter with 47 mm diameter and pore sizes of <2.0 µm into a receiving 1L glass beaker. An analytical balance weighted the filter with trapped residues. This was then placed in a filter pan by using forceps carefully. The filter pan together with a filter was placed in an oven heated to 103 – 105 ºC for an hour. The filter pan was removed from the oven and allowed to cool to room temperature. After that, the filter paper was weighted, and the mass was recorded as $A_{mass.}$ The same procedure was repeated by heating the filter paper at 103 – 105 ºC and the second mass was taken. The first mass was subtracted from the second mass and a variance of <.5 mg was necessary to record the final mass. The final mass of suspended solids was calculated by:

$$Total\ suspended\ solids = \frac{(A_{Mass-}\ F_{mass})}{Sample_v} \quad (3.2)$$

where A_{mass} is the final weight of suspended solids at 103 – 105 ˚C in mg, F_{mass} is the original mass of filter in mg before it was used, S_v is the volume of sample filtered.

b) Conductivity analysis

The standard method 2510B for water and wastewater 23rd edition by APHA (2017) was utilised in this study. This method is well known to covers the determination of conductivity in wastewater, surface and also drinking water. Firstly, a cell constant was determined. This was done by rinsing the conductivity cell with three portions of 0.01 M KCl solution. The temperature was adjusted to 25ºC ± 0.1ºC. The resistance was measured when the conductivity meter displayed a constant resistance and temperature. The cell constant was calculated:

$$C, cm^{-1} = (0.001412)R_{KCl}[1 + 0.0191(t - 25)] \quad (3.3)$$

where R_{KCl} is measured resistance in ohms, and t is temperature observed in ºC.

After the cell constant was calculated, conductivity was determined using the following formula:

$$k = \frac{(1000000)(\mathrm{C})}{\mathrm{Rm}[1+0.0191(\mathrm{t}-25)]} \quad (3.4)$$

where K is conductivity in µmhos/cm, C is cell constant, cm^{-1}, R_m is measured resistance of sample, ohms, and t is measured temperature.

c) pH analysis

The spectrophotometer method was used to analyse the pH range. The reagent that was recommended when using the photometer was HI-93719-03. Five drops of HI-93719-03 were added to the testing tube containing the sample in order to get the pH reading. The colour range varied between yellow to red and the photometer was used to determine the intensity showing the pH value (Muller, et al., 2017).

3.5.1.3 Physical parameters analysis

a) COD analysis

A colorimetric method was used for analysing chemical oxygen demand (APHA, 2005). This method is broadly used in wastewater treatment since it permits for measurements of oxygen relatively equal to the proportion of organic material in the sample which is strongly oxidised by a chemical oxidant. A sample from a 1 L plastic bottle was poured into a 1 L volumetric flask. The solution of potassium hydrogen phthalate (KHP) was prepared by adding 85 g of initially dried chemical at 120 ºC into 1 L of distilled water. The solution was allowed to dissolve. This was followed by adding 2 mL of KHP solution into a 100 mL sample. A volume of 3 mL of COD 2 reagent was added. The sample was heated for two hours in the oven set at 150 ºC and allowed to cool to room temperature. Dichromate ions ($Cr_2O_7^{2-}$) were reduced to green chromic ion (Cr^{3+}). The sample vial was placed in the adapter of the colorimeter and the COD measurements were recorded.

b) Ammonia analysis

In this study, the spectrophotometer method was used for analysing ammonia according to the standard method 4500- NH_3^- F for water and wastewater 23rd edition (APHA, 2017). This method is widely used in wastewater treatment since it is based on the Berthelot reaction, it is simple and reliable. 25 mL of the sample was poured into a 50 mL Erlenmeyer flask. 1 mL of phenol, 1 mL of sodium nitroprusside, and 2.5 mL of oxidising solution were added to the sample and mixed well. The sample was covered with a paraffin wrap film. The sample was left for an hour at room temperature so the colour could develop and to protect it from light. The colour did not change for 24 hours. The blank and standard solutions were prepared and treated the same as the sample. A 640 nm absorbance was measured.The ammonia value of the sample was obtained directly from the standard curve and reported in mg/L.

c) Nitrates analysis

The spectrophotometer method was used for analysing nitrates according to the standard method 4500- NO_3^- B for water and wastewater 23rd edition by ALPHA (2017) in this study. This method was selected because it is suitable for screening low in organic matter water.1

mL of a 1 M hydrochloric acid (HCl) reagent was added to a clear 50 mL sample and mixed well. A nitrate standard calibration solution was prepared from a range of 0 to 7 mg/L by diluting 50 mL of intermediate NO_3^- N solution from 0 to 35 mL. The standard nitrate was treated the same way as the sample.

After five minutes, the absorbance was measured at 220 nm using a spectrophotometer to obtain NO_3^- N and the interference due to dissolved organic matter was measured at a wavelength of 275 nm.The nitrates value of the sample was obtained directly from the standard curve and reported in mg/L.

d) Orthophosphate

The spectrophotometer method was used for analysing orthophosphate according to the standard method 4500P for water and wastewater 23rd edition by ALPHA (2017). This method is commonly known for quantifying compounds in different field such as wastewater and chemistry. 1 mL of sulfuric acid (H_2SO_4) reagent and 4 mL of ammonium molybdate-antimony potassium tartrate reagent was added to a 50 mL sample and mixed. A volume of 2 mL of ascorbic acid solution was also added to the sample and mixed. After five minutes, the absorbance was measured at 650nm using a spectrophotometer. The colour did not change for an hour. For a concentration range of 0.3 – 1.2 mg/L of phosphorus a 1 cm cell was used. The phosphorus concentration was determined from the standard curve.

3.5.2 Removal Efficiency

The water quality usually varies from time to time. However, water quality may deteriorate or improve at the final effluent depending on the conditions of the plant. Removal efficiency was done to determine how efficient the pilot plant is in terms of removing targeted water quality parameters (Gangwar, et al., 2013). Equation 3.4 was used to calculate the removal efficiency:

$$EA = CA_1 - CA_2 \qquad (3.5)$$

where CA1 is the mass concentration in final settling tanks (FSTs) at the system input [mg/L], CA2 is the mass concentration of final effluent for membrane filtration at the system output [mg/L], and EA is the concentration increment of pollution in percentage [mg/L].

3.5.3 Water Use License (WUL)

Wastewater testing differs depending on the different categories in the WUL. For domestic wastewater, physical, chemical, and biological variables need to be analysed. In a case where there is an industrial discharge, heavy metals must also be analysed. The WUL was utilised to analyse the water quality of the influent and the permeate. A graphical representation of the results against the WUL standards was employed.

3.5.4 Water Quality Index

The physical, chemical, and microbial quality for the membrane filtration final effluent was analysed using the Water Quality Index (WQI). The water quality of any specific area or specific source can be assessed using physical, chemical, and biological parameters. The values of these parameters are harmful for human health if they occurred within more than the defined limits. Therefore, the suitability of water sources can be described in terms of the Water Quality Index (WQI), which is one of the most effective ways to describe the quality of water (Gangwar et al., 2013). The water quality was categorised according to Table 3.3.

Table 3.3: Categorisation of water quality based on the WQI level

Water Quality Index Level	Description	Possible Usages
0-25	Excellent	Drinking, Irrigation and Industrial
26-50	Good water	Domestic, Irrigation and Industrial
51-75	Poor water	Irrigation and Industrial
76-100	Very poor water	Irrigation
>100	Unsuitable water	Restricted Use for Irrigation

3.5.5 Single Factor Pollution Index

The Single Factor Pollution Index is used in collaboration with statistical computations in the statistical package for social sciences and was used to determine the extent of water pollution.

3.6 Descriptive Statistics

Descriptive statistics were used for analysis of the results received from the wastewater samples from this pilot plant configuration. Descriptive statics involve data organisation so that it can be easily understood. Descriptive statistics are different from inferential statistics as its main purpose is to describe the data without inferences (Amrhein et al., 2019). Descriptive statistics include mean/average, median, mode, measure of dispersion, standard deviations, mean deviation, variance, range, percentile, skewness, kurtosis, etc. (Morgan, 1999). Data representation is in the form of tables, pie charts, and graphs. Trend analysis is sometimes the most useful tool in data analysis. This data analysis method will help with the representation of data for easy and simple arrangements.

3.7 Experimental Design

The experimental design of this project is the one-at-a-time method. It focuses on keeping other parameters constant while one is varied. In this case, parameters that were tested were pressure and DO. Table 3.4 lists the parameters and their levels.

Table 3.4: Experimental design table

Parameter	Units	Levels		
Pressure	Bar	1*	1.5	2
DO	mg/L	1*	7.4	7.5
Time	weeks	1	2	3

*Variables kept constant throughput the experiment while others remained constant

Responses to the parameters being tested are E. coli, COD, ammonia, and nitrates, as per the study of this membrane.

The final effluent values of wastewater were studied. The results obtained were categorised into data obtained before the pilot plant treatment, post-pilot plant values recorded as filtered samples, and samples that were taken in the pilot plant system itself.

3.8 Quality Assurance: Reliability and Validity

A measurement that gives stable and consistent results is referred to as reliable (Blumberg et al., 2005). Repeatability, precision, consistency, and trustworthiness of a study is measured by reliability (Chakrabartty, 2013). Errors are minimised through dependable, reliable measurements (Blumberg et al., 2005). Validity of data is a reflection on how well the data describes a specific area being investigated (Robson, 2011). Current research protocols during sampling focused on using the correct sampling bottles and sampling procedures. Samples were stored in cooler boxes and ice packs prior to submitting to a SANAS accredited laboratory.

Chapter 4: Results and Discussion

4.1 Preamble

This chapter gives a detailed presentation of the results and discussions. The water quality results against the Water Use Licence standard are presented in graphs and references are made on appendix tables. The data was analysed using the Water Quality Index (WQI) and Single Factor Pollution Index to determine the suitability of water re-use and the extent of pollution in the downstream of effluent discharge. The Water Quality Index and Simple Factor Pollution Index results are presented in tables and due references are made to justify the discussions of results in relation to the research objectives and questions.

4.2. Water Quality Improvement

4.2.1. Ammonia Concentrations Water Quality Trends and Removal Efficiency

In this section, the results for ammonia concentrations and removal efficiency are presented graphically and discussed. The results indicated a concentration of effluent in the biological nutrients removal (BNR) treatment and membrane filtration in the pilot tank and the permeate against the Water Use License (WUL). This was done to compare the concentrations of ammonia after BNR and membrane filtration as well as their removal efficiencies. The standard for ammonia for final effluent as per WUL is 4mg/L.

According to Figure 4.1, the final effluent results treated from BNR and sampled in the clarifier was within the WUL limit of 4 mg/L, except on week 17 where it was 5.3 mg/L. The pilot plant concentrations were also within the WUL limit from week 1 to week 21. The ammonia water quality trends shows that ammonia was not within the guideline in week 15 and 19 with concentrations of 4.6 mg/L and 7.3 mg/L, respectively. The high concentrations of ammonia in the clarifier were due to the failure of BNR which could be due to critical equipment failures linked to nitrification. In the pilot tank, it was noted that ammonia trends were consistent and complied with the WUL limit on the samples, as indicated by Figure 4.1. Various reasons can be attributed to a more consistent ammonia concentration. One of these could be the additional residence achieved in the pilot tank which is aerated and kept close to an average of at 7.4 mg/L dissolved oxygen. This is ideal for nitrification, autotrophic conditions. The non-compliance with the WUL standard in the permeates in week 15 and 19 could be possible due to membrane fouling that would also limit oxygen transfer to the wastewater in the pilot tank as the aeration takes place from the inside of the membrane as in the case of a membrane aerated biological reactor (MABR). (Li & Chen, 2010).

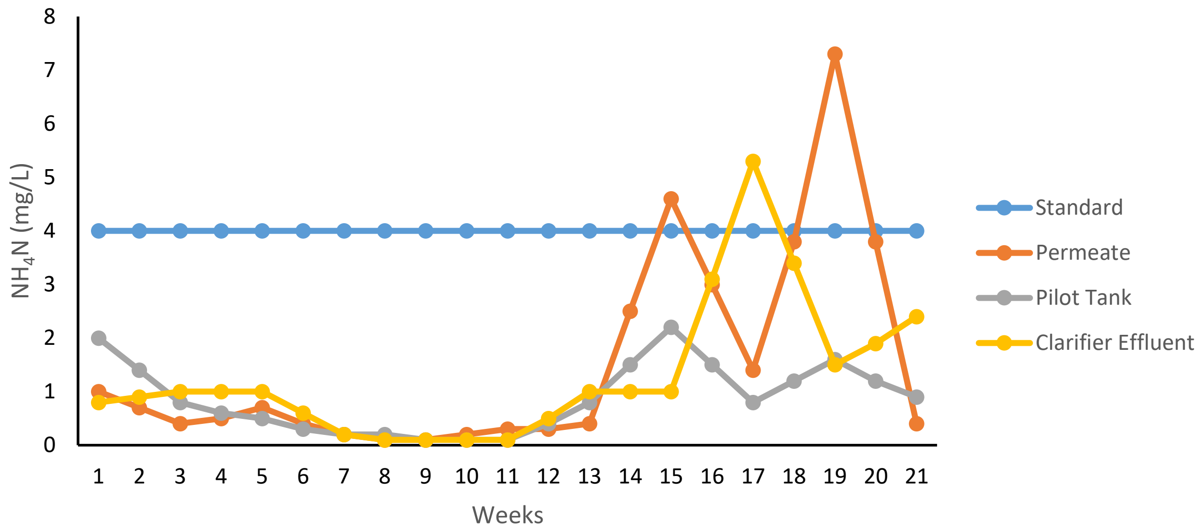

Figure 4.1:NH_4-N Water quality trends for a 21-week period

According to studies done by Mahmoud and Soumaya (2020), it was noted that membrane fouling contributes to high ammonia concentrations in the permeate and can be reduced through backflushing and air scouring. After the high concentrations of ammonia in the permeate, the membranes were backflushed and cleaned through air scouring following the procedure stated by Seo et al. (2003), Wang and Waite (2009), and Mahmoud and Soumaya (2020). The membrane flux before the backflushing and air scouring was 7 L/hr/m^2 and after the cleaning process it was 11 L/hr/m^2. This indicates the significance of the cleaning process to improve water quality in the membranes.

The ammonia water quality trends for the pilot plant and the permeate were good when the membranes were commissioned. The deterioration in ammonia water quality was experienced gradually as the membranes were accumulating with solids which led to fouling. In contrast with the current results, Mahmoud and Soumaya (2020) reported a removal efficiency of 10.64% from secondary wastewater effluent using hollow fibre MF for a NH_4N concentration due to fouling.

Figure 4.2 presents results for the BNR ammonia removal efficiency from week 1 to week 21. The removal efficiency for BNR ranges between 73.1 and 99.7%. This is an indication that there were ammonia water quality failures which affected the removal efficiency. This was likely seen in week 17. The reduced ammonia removal efficiencies could be linked to factors which have been discussed as stated by Power (2002). Figure 4.3 indicates the removal efficiency of membrane filtration based on the effluent received in the pilot plant and the permeate. As the membranes were commissioned from week 1, the removal efficiency increased from 0% to 60% in week 3. However, there was a gradual decrease from week 4 to week 7 ranging from 50%, 30%, 33% and 0% respectively. There was a decreased removal efficiency with an average of 0% in most samples between week 7 to 21 which is attributed to membrane fouling. This was addressed by membrane backflushing and air scouring between week 15 and 21. The total average removal efficiency of ammonia achieved in this study was 22% which showed good improvements.

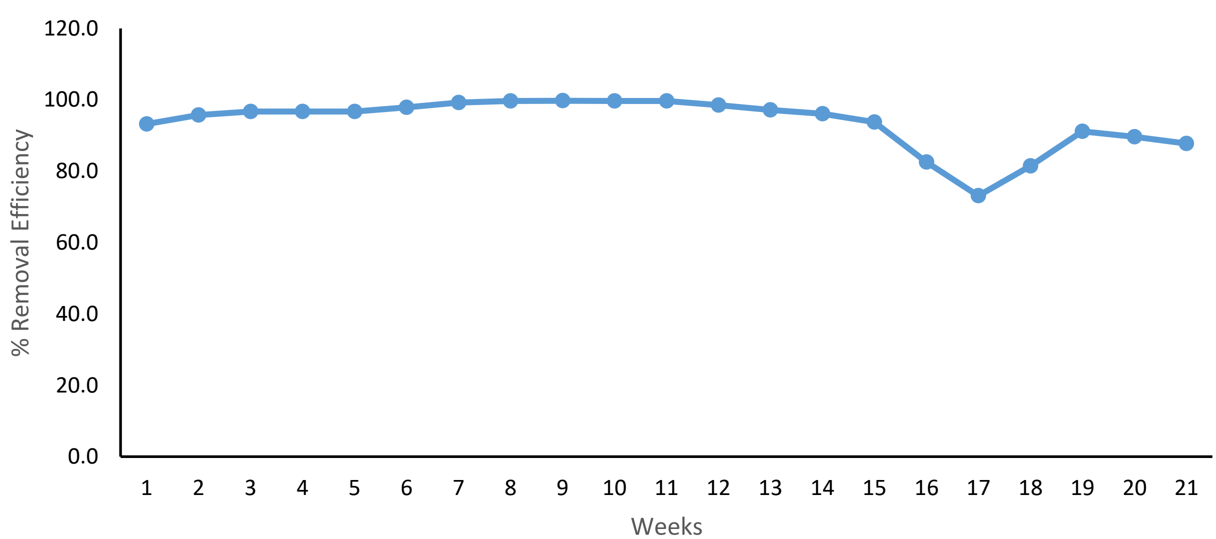

Figure 4.2: NH_4-N BNR removal efficiency for a 21- week period

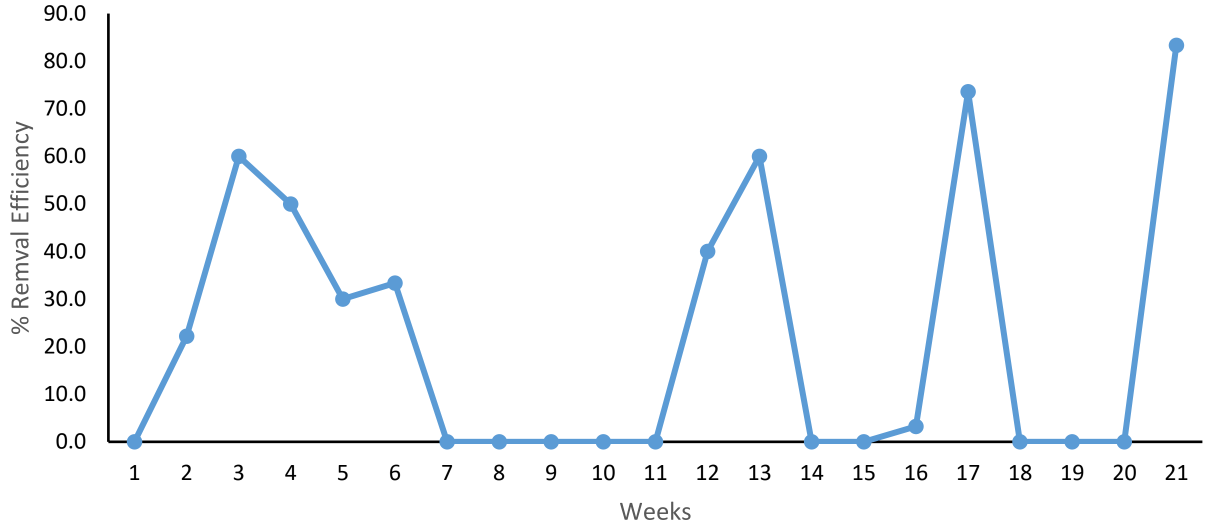

Figure 4.3: NH_4-N permeate removal efficiency for a 21-week period

4.2.2. Nitrates Concentrations Water Quality Trends and Removal Efficiency

The results of the NO_3^- concentration and removal efficiency are discussed in this section. Figure 4.4 presents the concentration of BNR effluent, membrane filtration in the pilot tank, and the permeate against the WUL. The standard for nitrates for final effluent as per the WUL is 9 mg/L. Figure 4.4 shows that the concentration of nitrates from BNR clarifier effluent, the pilot plant, and the permeate were all within the limit of the WUL from week 1 to week 21.

Water quality trends for the nitrates pilot tank and permeate were higher than the BNR clarifier effluent when the membrane plant was commissioned from week 1 to week 6. According to a study done by Villaverde et al. (2000), it was noted that at the startup of the process, a buildup of nitrates might occur in the reactor due to a quicker growth of ammonium oxidisers than nitrite oxidisers.

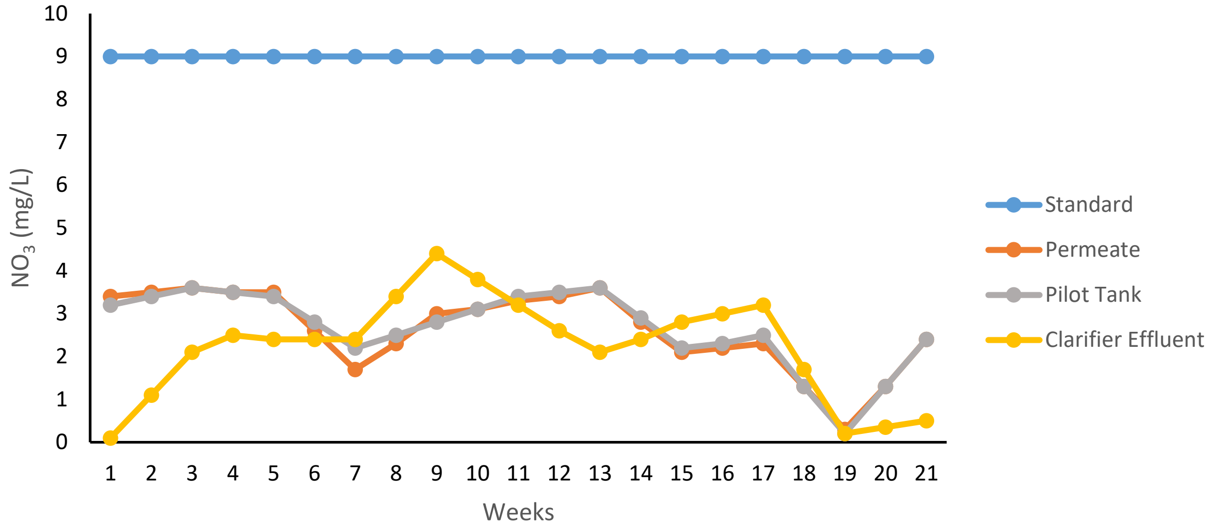

Figure 4.4: NO_3^- water quality trend for a 21-week period

It was again noticed that from week 11 to 14 and week 19 to 21 the nitrate concentration of the pilot and the permeate was higher than the clarifier effluent. This shows that there was further nitrification occurring in the process. It indicates that there was no excess NH_3 available and that the pH was lower at the permeate. This is comparable with results obtained by Villaverde et al. (1997) who reported that when the pH is low, nitrous acid concentration increases. Villaverde et al. (2000) also reported that nitrite oxidisers show that the activity of micro-organisms is plainly reliant on the particular available ammonia concentration. The samples were collected during the winter season and the temperature recorded during operation was between 13°C to 20°C. In agreement with the current results, Stark (1996), Villaverde et al. (2000), and Weon et al. (2004) reported that only when the temperature is above 15°C, peak nitrification can be reached because nitrifying organisms are sensitive to temperature.

During week 7 to 10 and week 15 to 18, it was observed that the nitrates in the pilot tank and the permeate was lower than the clarifier effluent. This indicated that there was no further nitrification occurring. Instead, denitrification was taking place in the process as micro-organisms were converting nitrates into nitrogen. This could be due to fouling of the membrane where the oxygen supplied was no longer enough since NH_3 was accumulating. In agreement with current results, Makaya, et al. (2007) reported that dissolved oxygen (DO) has low effects in low nitrification, therefore, a concentration of nitrates is low. They also reported that effluent with a low concentration of nitrates could be an indicator of an extremely effective denitrification process where more nitrates are converted into molecular nitrogen.

The removal efficiency for BNR nitrates was not done due to nitrates not being available at the raw wastewater/sewer. It only becomes available when ammonia is broken down into nitrite and nitrates. This is in agreement with the study done by Meghdad et al. (2015) who found that raw wastewater has a low concentration of nitrite and nitrate.

Figure 4.5 represents the removal efficiency of nitrates based on the influent received in the pilot plant and the permeate. When the pilot plant was commissioned from week 1 to 6, the removal efficiency was 0%. However, there was a gradual increase from week 7 to 9 ranging from 8.3%, 26.5% and 36.4%, respectively. A decrease in removal efficiency was observed with the average of 0% in most of the samples between week 11 to 21 due to further nitrification that was taking place in the process. The total average removal efficiency of nitrate achieved in this study was 12.6% which showed fair improvements.

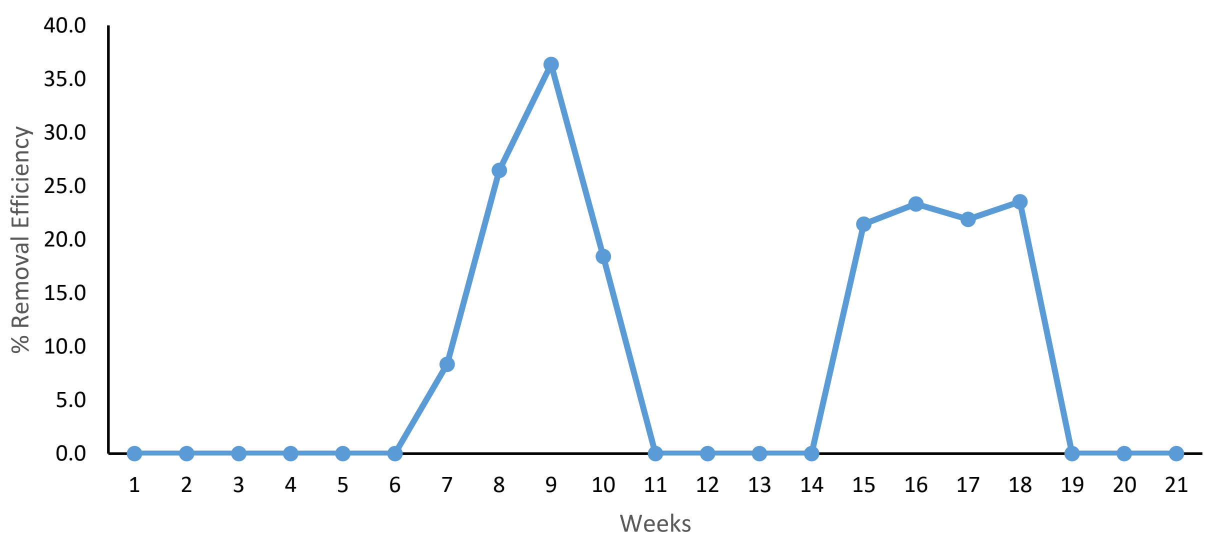

Figure 4.5: NO_3^- permeate removal efficiency for a 21-week period

4.2.3. Orthophosphate Concentrations Water Quality Trends and Removal Efficiency

Orthophosphate concentrations and removal efficiency results are discussed in this section. Figure 4.6 demonstrates the results of orthophosphate concentrations in the BNR, the pilot tank, and the permeate against the WUL. The standard of PO_4^{3-} for final effluent as per the WUL is 0.7 mg/L. Figure 4.6 illustrates that the concentration of PO_4^{3-} from the BNR clarifier effluent, the pilot plant, and the permeate were all within the limit of the WUL from week 1 to 21.

Orthophosphate water quality trends were good when the membranes were commissioned, but during week 4 and 5 it was observed that the permeate concentration slightly increased to 0.2 and 0.3 more than the clarifier effluent, respectively. This could be due to a high chemical oxygen demand (COD) concentration in the reactor resulting in less phosphate uptake due to less oxygen being available. This is comparable with the results found by Marchetto (2013) who reported that when the DO supply is low, the orthophosphate concentration starts to increase. Another increase of 0.3 mg/L on the permeate was noticed during week 19. This could be due to a suspended solids (SS) concentration caused by membrane fouling which was addressed by backflushing and air scouring. The results are in agreement with what Henze et al. (2002) reported. According to them, SS and COD affect the concentration of phosphate. The trend is the same for most samples which is 0.1 mg/L. This was due to the instrument detector limit of 0.1 mg/L. The results show that the pilot plant is capable of further reducing phosphate.

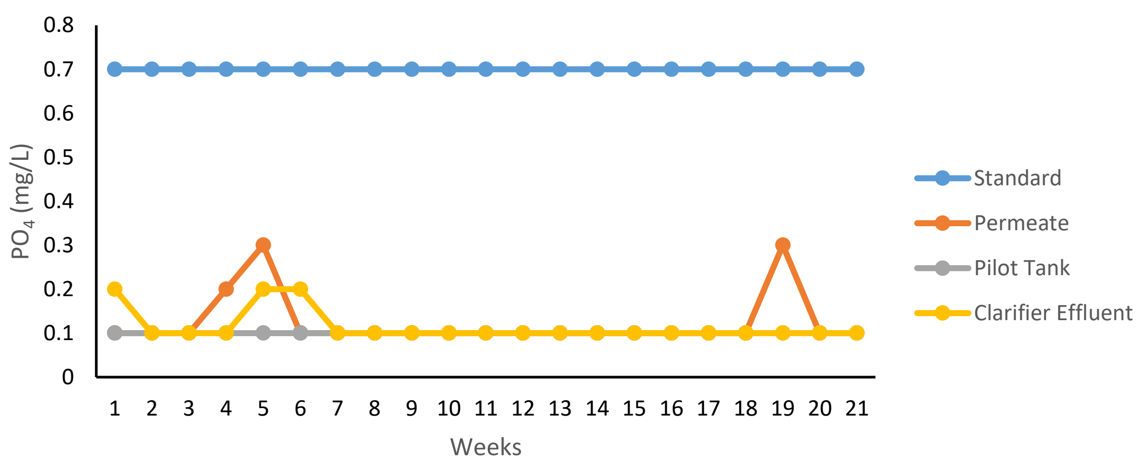

Figure 4.6: PO_4 water quality trend for a 21-week period

Figure 4.7 demonstrates the removal efficiency of phosphate for BNR from week 1 to 21. The removal efficiency for BNR ranges between 85.7% and 98.9%. This indicates that the removal efficiency of the BNR was good and is comparable with the studies done by Finger and Cybis (1999), Cho et al. (2009), and Marchetto (2013) who reported a removal efficiency ranging from 80% to 96% when there is alternation of anaerobic and aerobic conditions in the reactor.

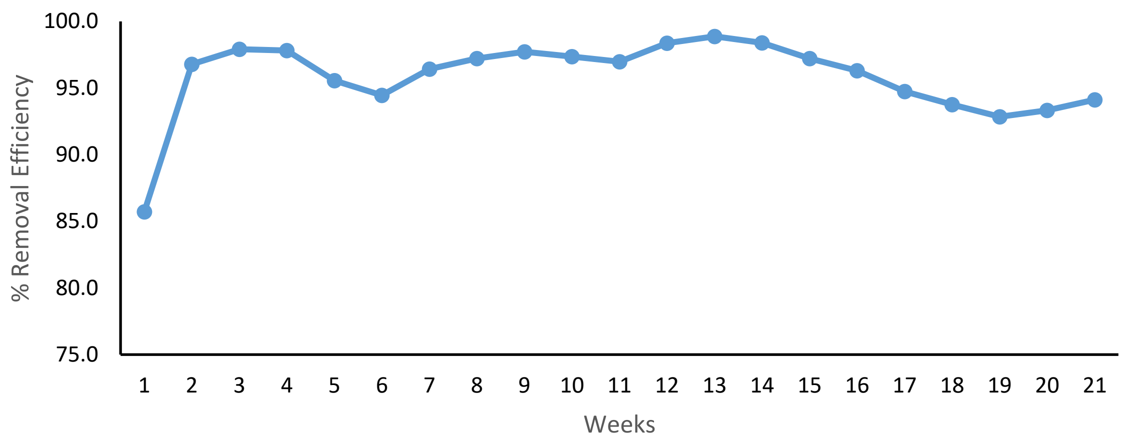

Figure 4.7: PO_4 BNR removal efficiency for a 21-week period

Figure 4.8 demonstrates the removal efficiency of phosphate for the membrane filtration based on the clarifier effluent and the permeate. When the membrane was commissioned, the removal efficiency was 50% at week 1. However, it was noticed that from the 2nd to the 5th week, the removal efficiency decreased to 0% and in the 6th week, there was an increase of 50% removal efficiency. From the 7th week to the 21st week, the removal efficiency dropped to 0%. This was attributed to high COD in the reactor, fouling, and the instrument detector spectrophotometer that had a limit of 0.1 mg/L. The average removal efficiency obtained was 7.8% which showed fair improvements.

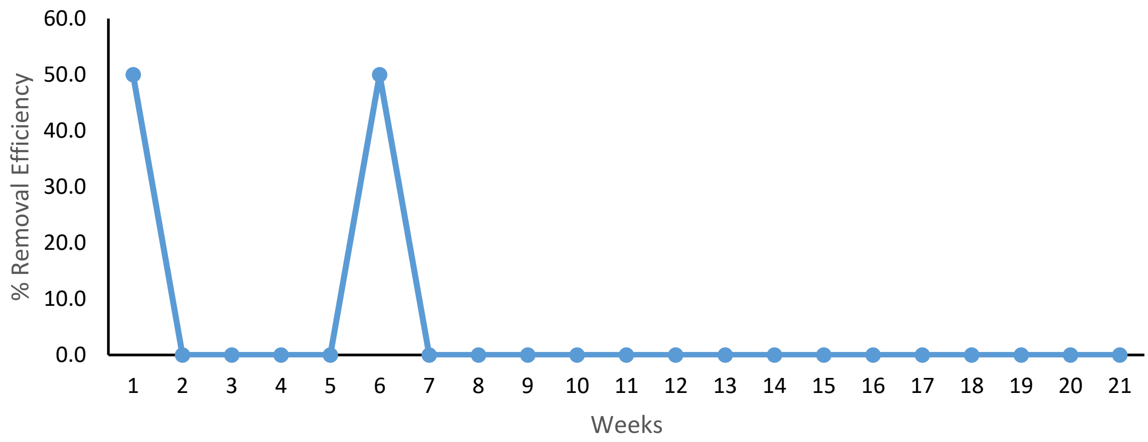

Figure 4.8: PO_4 permeate removal efficiency for a 21-week period

4.2.4. pH Water Quality Trends

In this section, the pH results are discussed. Figure 4.9 demonstrates the clarifier effluent, the pilot tank, and the permeate against the WUL. The standard for pH ranges between 6.5 and 8.5 for final effluent as per the WUL. As seen in Figure 4.9, the pH results show that the clarifier effluent and the pilot tank were within the limit from week 1 to 21 and the permeate was below the standard only in week 17.

The water quality trend for pH shows that when the membrane was commissioned, the pilot tank pH and the permeate pH were higher than the clarifier effluent pH from week 1 to 4. This indicated that there was poor consumption of alkalinity and denitrification was taking place. This was also observed on the ammonium water quality trend where the ammonia was less. The results obtained are in agreement with the results reported by Villaverde et al. (1997), Lackner et al. (2008), and Belmonte (2017) who state that when the free ammonia concentration increases, the pH value also increases. An increase in pH value was also seen in weeks 12 to 16 may indicate that denitrification process continued to take place.

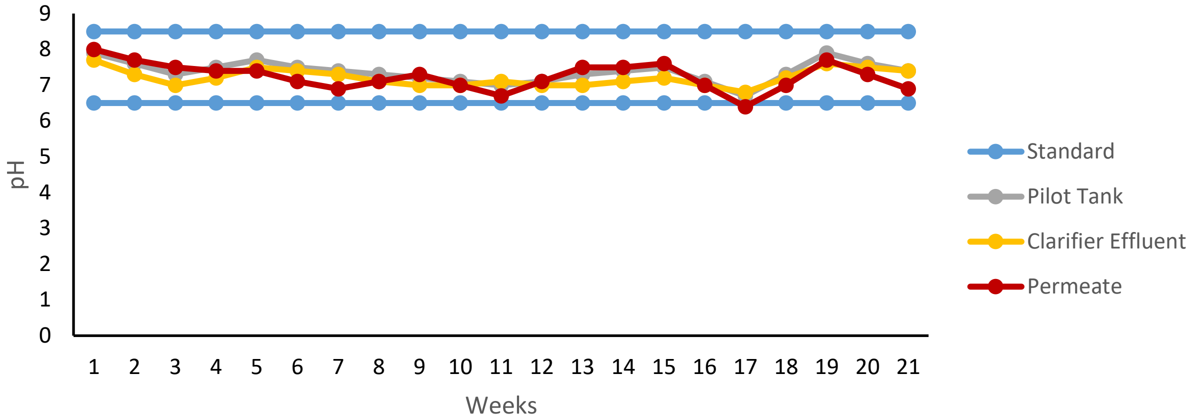

Figure 4.9: pH water quality trend for a 21-week period

The water quality trend shows that in weeks 5 to 8, the pH value decreased in the permeate from 7.4 to 7.1. In weeks 11 and 17, the pH also decreased to 6.7 and 6.4, respectively, which was noted as non-compliance since it was below the standard of 6.5. This indicated that there was alkalinity consumption and nitrification was taking place. The results are comparable with the results obtained by Hwang et al. (2000), Hou et al. (2014), and Belmonte et al. (2017) who reported that a reduction in the alkalinity concentration increased the nitrite accumulating efficiency in the process and that this can be attributed to the pH value decreasing inside the reactor which stimulated the inhibitory effect of free nitrous acid on nitrite oxidising bacteria. Loyless and Malone (1997) also reported that carbon dioxide accumulation normally reduces pH due to poor aeration or oxygen transfer. This was observed between week 15 and 19 when fouling of the membrane was experienced and it was addressed by membrane backflushing and air scouring. Further nitrification was observed in the permeate after cleaning the membrane when the pH dropped in weeks 20 and 21.

The pH water quality trend for the pilot tank for most of the samples' pH was higher than the permeate which indicated that the denitrification process continued to take place in the pilot plant.

4.2.5. Electrical Conductivity Water Quality Trends and Removal Efficiency

In this section, the results of electrical conductivity and removal efficiency are discussed. Figure 4.10 presents the EC of the clarifier effluent, the pilot tank, and the permeate against the WUL. The EC standard at final effluent as per the WUL is 80 mS/m.

According to Figure 4.10, the clarifier effluent, the pilot tank, and the permeate results were within the standard limit of 80mS/m from week 1 to 3 and constant at 78 mS/m. This indicated that there was no net change ion content and conductivity remained the same. This is comparable with the results obtained by Howard et al. (2004) and Levin (2007) who reported that when the nitrate content increases, the phosphate content decreases resulting in conductivity remaining the same for influent and effluent, indicating that there is no net change in the ion content. Levin (2007) further illustrated that a small reduction of ammonia and phosphate was observed. This reduction was also observed in the current study during weeks 1 to 3.

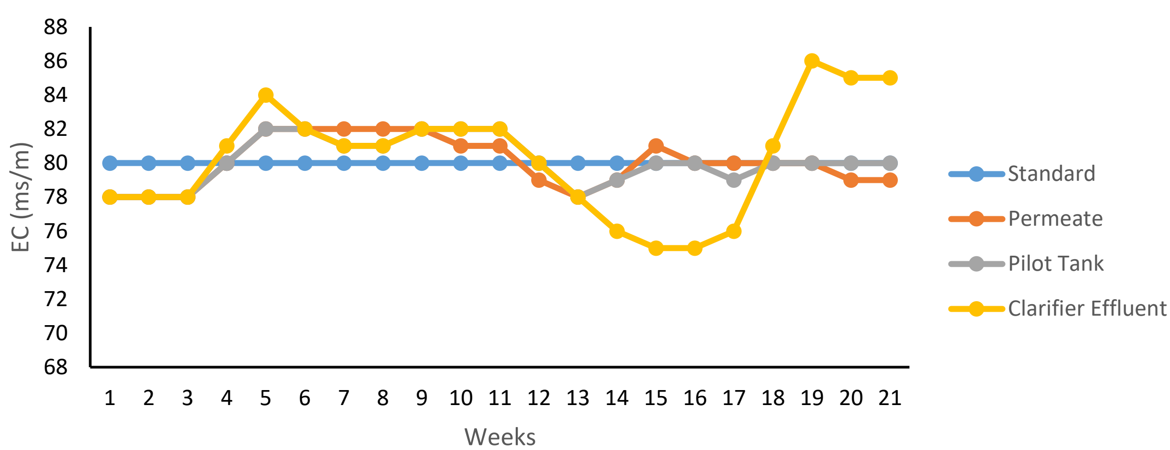

Figure 4.10: EC water quality trend for a 21-week period

As illustrated by Figure 4.10, the water quality trend shows that from week 4 to 11, the clarifier effluent conductivity was above the WUL limit and ranging between 81mS/m and 84 mS/m. During weeks 18 to 21, conductivity was ranging between 81 mS/m and 86 mS/m. High conductivity in the clarifier effluent was due to the failure of BNR which might be due to critical equipment failures linked to nitrification in the BNR. This might also be due to plant operation and optimisation.

Pilot tank and permeate water quality trends show that, from week 5 to 11, conductivity was above the WUL limit as they were both ranging between 81 mS/m and 82 mS/m. The non-compliance of the pilot tank and the permeate was due to poor nitrification and poor alkalinity consumption resulting in an increase in conductivity. In agreement with the current results, Levin (2007) found that conductivity increases if the transformation of ammonium to nitrate produces hydrogen ions, and no alkalinity consumption results in high conductivity. Poor nitrification was also noticed in weeks 14 to 17 when the pilot tank and the permeate conductivity were higher than that of the clarifier effluent.

The trend also shows that conductivity of the permeate in week 15 was 81 mS/m which is above the WUL limit. This was due to membrane fouling. According to the study done by Khairia et al. (2015), it was noted that membrane fouling contributes to high conductivity in the permeate.

Figure 4.11 demonstrates the removal efficiency of BNR conductivity from week 1 to week 21. The removal efficiency for BNR ranges between 0% and 38.1%. This is an indication that there were conductivity water quality failures which affected the removal efficiency. This was seen throughout the study. The small removal efficiencies could be linked to factors which have been discussed above, as stated by Howard et al. (2004).

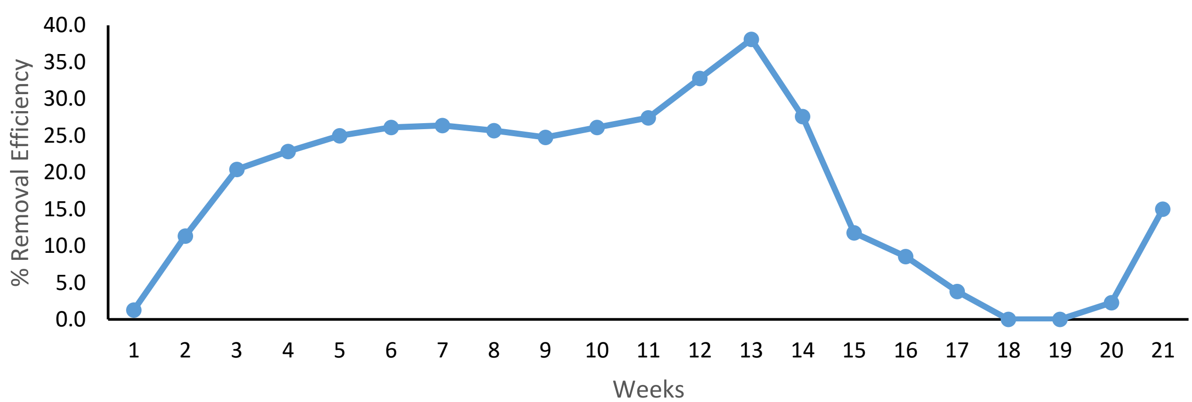

Figure 4.11: BNR removal efficiency for a 21-week period

Figure 4.12 represents the removal efficiency of conductivity based on the influent received in the pilot plant and the permeate. When the pilot plant was commissioned from week 1 to 3, the removal efficiency was 0%. However, there was a gradual increase from week 4 to 5 ranging from 1.2% and 2.4%, respectively. The maximum removal efficiency observed in this study was 7.1% in weeks 20 and 21. A decrease in the removal efficiency was noticed with an average of 0% in most of the samples between weeks 6 to 21 due to poor nitrification and low alkalinity consumption that was taking place in the process. The total average removal efficiency of conductivity achieved in this study was 5.2% which showed fair improvements.

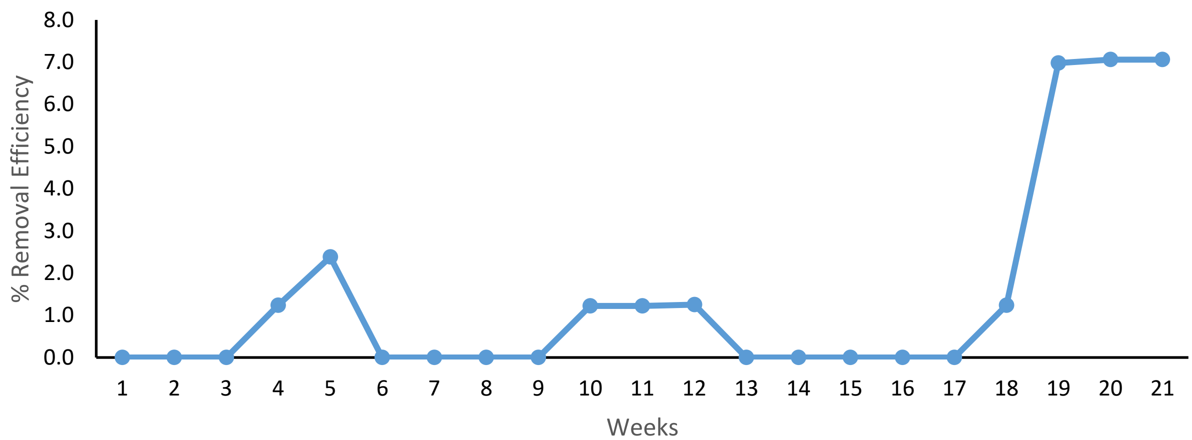

Figure 4.12: EC permeate removal efficiency for a 21-week period

4.2.6. Chemical Oxygen Demand Concentration Water Quality Trends and Removal Efficiency

In this section, results of the chemical oxygen demand (COD) concentration and removal efficiency are discussed. Figure 4.13 demonstrates the COD concentration of the clarifier effluent, the membrane filtration in the pilot, and the permeate against the WUL. The COD standard for final effluent as per the WUL is 70 mg/L. Figure 4.13 illustrates that the concentration of COD from the BNR clarifier, the pilot plant, and the permeate were all within the limit of the WUL from weeks 1 to 21.

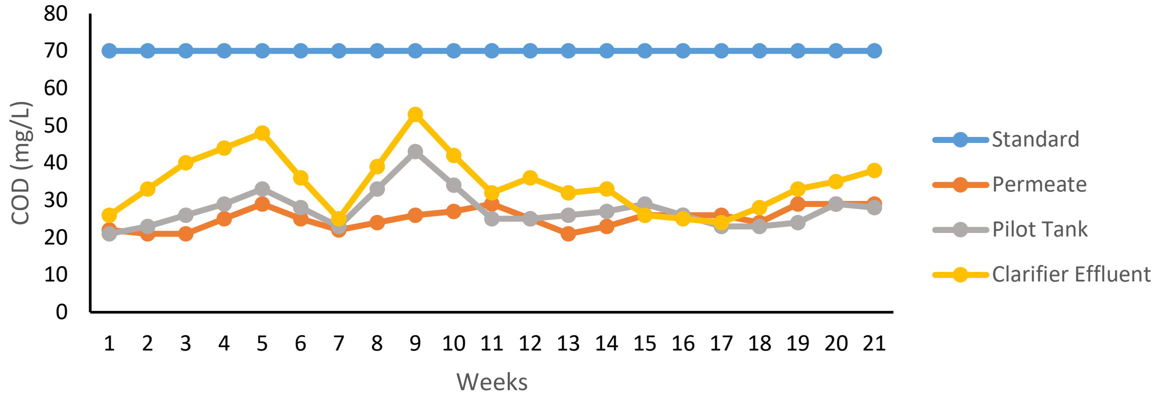

Figure 4.13: COD water quality trend for a 21-week period

The COD water quality trends show that when the pilot plant was commissioned, the quality was good for both the pilot tank and the permeate. The concentrations were lower than that of the clarifier effluent. The trend shows that when the clarifier effluent concentration increases, the pilot tank and the permeate concentrations also increase. This was seen in weeks 1 to 5 and from week 6 to 7. It was also observed that when the clarifier effluent decreases, the pilot tank and the permeate concentrations also decrease. This trend continued to repeat until week 14. This indicated that there was further oxidation of organic matter taking place in the membrane pilot plant due to sufficient oxygen supply. According to the study done by Shivaranjani and UmaSankari (2018), it was noted that oxygen eliminates the organic contaminants, and it is required for the bacteria to allow biodegradation to take place.

The trend also shows that from week 15 to 16, the pilot tank concentration which was 29 mg/L and 26 mg/L, respectively, was slightly higher than that of the clarifier effluent which was 26 mg/L and 25 mg/L, respectively. From week 15 to 17, the permeate concentration of COD was constant at 26 mg/L. The slight increase in the pilot tank and the permeate concentrations indicated that there was no further oxidation of organic matter taking place in the membrane pilot plant due to insufficient oxygen supply as a result of solids accumulating which led to membrane fouling. According to studies done by Yang et al. (2014), Han et al. (2014), and Gasim et al. (2015), it was noted that membrane fouling contributes to high COD concentrations in the permeate and can be reduced through backflushing and air scouring. After backflushing of the membrane, there was an improvement in the water quality trend from week 18 to 21 and further oxidation of organic matter continued to take place in the pilot plant.

Figure 4.14 shows the results for the BNR COD removal efficiency from week 1 to 21. The removal efficiency of the BNR ranges between 91% and 98.3%. This indicated that the removal efficiency of BNR was good, and this is comparable with the studies done by Bhave et al. (2000) who reported a COD removal efficiency ranging from 90.15% and 96.15%.

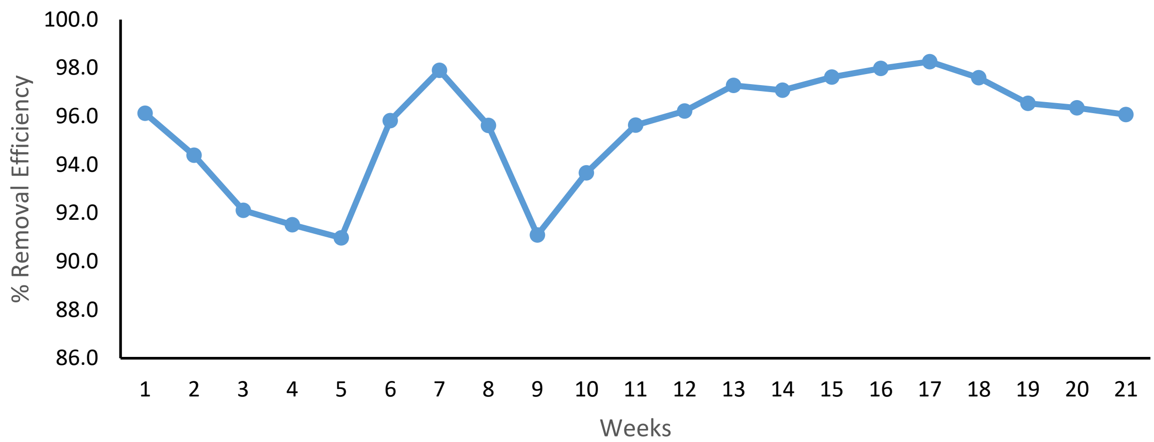

Figure 4.14: COD BNR removal efficiency for a 21-week period

Figure 4.15 shows the COD removal efficiency based on the influent received in the pilot plant and the permeate. When the pilot plant was commissioned from week 1 to 3, the removal efficiency increased from 15.4% to 47.4%. However, there was a gradual decrease in weeks 4 to 5 to 43.2% and 12%, respectively. A maximum removal efficiency of 50.9% was observed in week 9, and in weeks 15 to 17, the lowest removal efficiency of 0% was observed. This is attributed to membrane fouling which was addressed by membrane backflushing and air scouring. The total average removal efficiency of COD achieved in this study was 25% which showed good improvements.

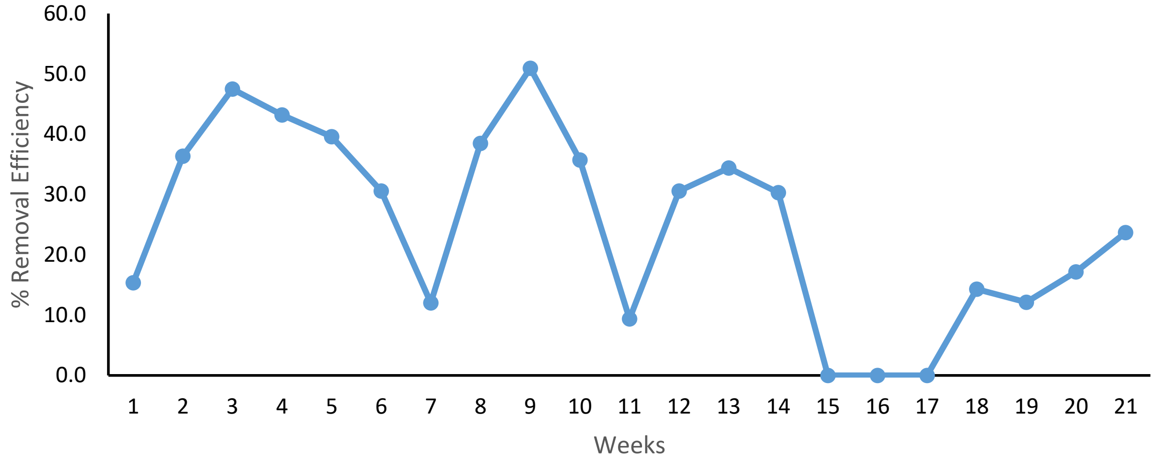

Figure 4.15: COD permeate removal efficiency for a 21-week period

4.2.7. Suspended Solids Concentration Water Quality Trends and Removal Efficiency

The results of the suspended solids concentrations and removal efficiency are discussed in this section. Figure 4.16 presents the results of the SS concentrations in the BNR, the pilot tank, and the permeate against the WUL. The standard of SS for final effluent as per the WUL is 20 mg/L. Figure 4.15 shows that the concentration of SS from the BNR, the pilot tank, and the permeate were all within the limit of the WUL from week 1 to 21.

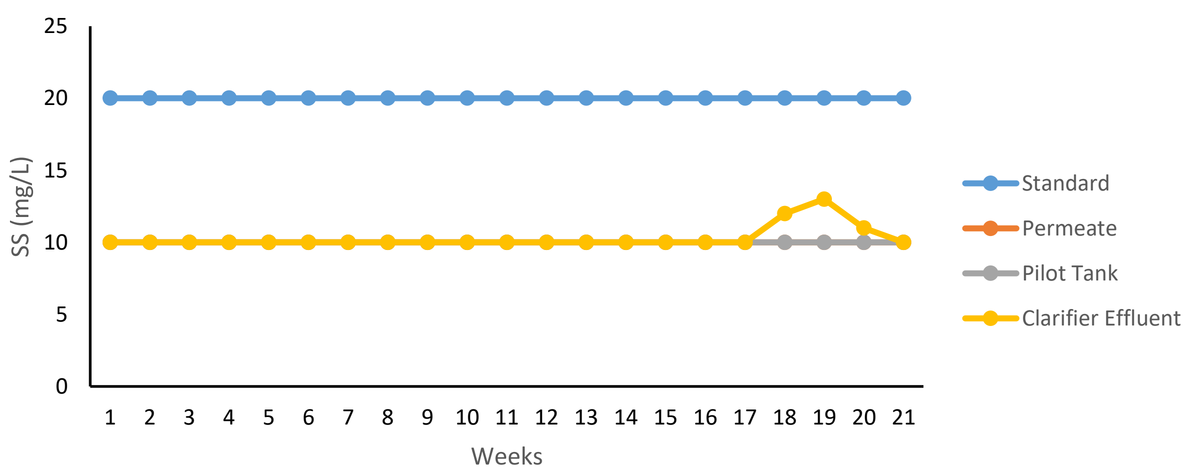

Figure 4.16: SS water quality trend for a 21-week period

Suspended solids water quality trends for the pilot tank and the permeate from week 1 until week 21 was constant at 10 mg/L. This is due to the standard method 2540D for water and wastewater used. The method detection limit of 10 mg/L. For water quality improvement to be observed, the methodology needs to be improved to limit the detection of 0 mg/L. In the clarifier effluent, a slight increase was noticed in weeks 17 to 20. This could be due to failure of the BNR which could be due to critical equipment failures. The results show that the pilot plant is capable of further reducing SS.

The removal efficiency of the suspended solids for the BNR from week 1 to 21 is demonstrated in Figure 4.17. The removal efficiency for the BNR ranged between 82.5% and 97.7%. The results indicated that the removal efficiency of BNR was good and in agreement with the studies done by Bhave et al. (2000) and Ravi Kumar et al. (2010) who reported removal efficiency ranging from 89.47% to 99% in the operation of a BNR plant. Figure 4.18 demonstrates the removal efficiency of suspended solids for membrane filtration based on the clarifier effluent and the permeate. The removal efficiency for most of the samples was 0% from week 1 to 21 and this was attributed to the instrument detection limit of 10 mg/L. The maximum removal efficiency observed was 23.1% in week 19 when the clarifier effluent was 13 mg/L. The average removal efficiency of SS obtained in this study was 6.3% which showed fair improvements.

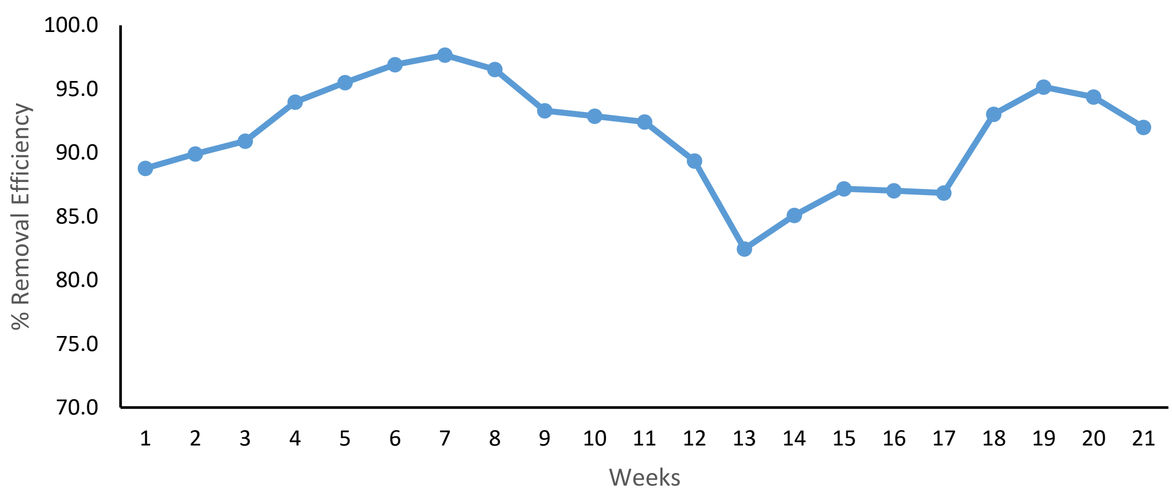

Figure 4.17: SS BNR removal efficiency for a 21-week period

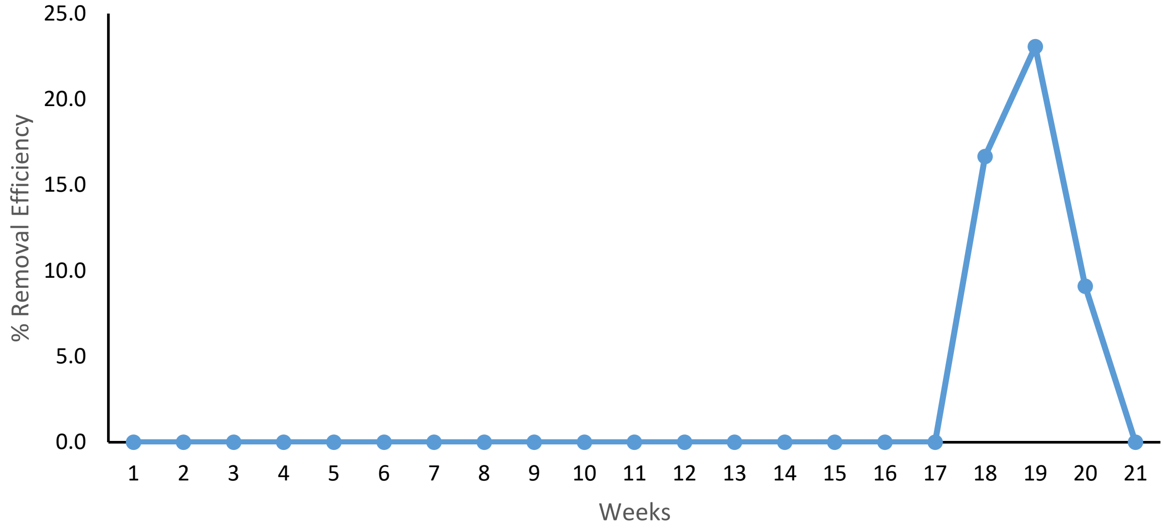

Figure 4.18: SS permeate removal efficiency for a 21-week period

4.2.8. *Escherichia Coli (E. coli)* Water Quality Trends and Removal Efficiency

Figure 4.19 presents the results and water quality trends for E. coli. Samples were taken from the clarifier effluent, which was not disinfected, and from the membrane filtration inside the pilot plant and the permeate. The *E. coli* WUL limit for final effluent is 500 counts/l. The average *E. coli* counts from clarifiers ranged between 1 730 and 12 000 counts/l. This is attributed to disinfection (chlorination) not being done in the clarifier effluent. The *E. coli* counts decreased in the pilot plant as the water was introduced into the pilot tank. The lowest counts of *E. coli* in the pilot tank were 182 counts/L in week 20.

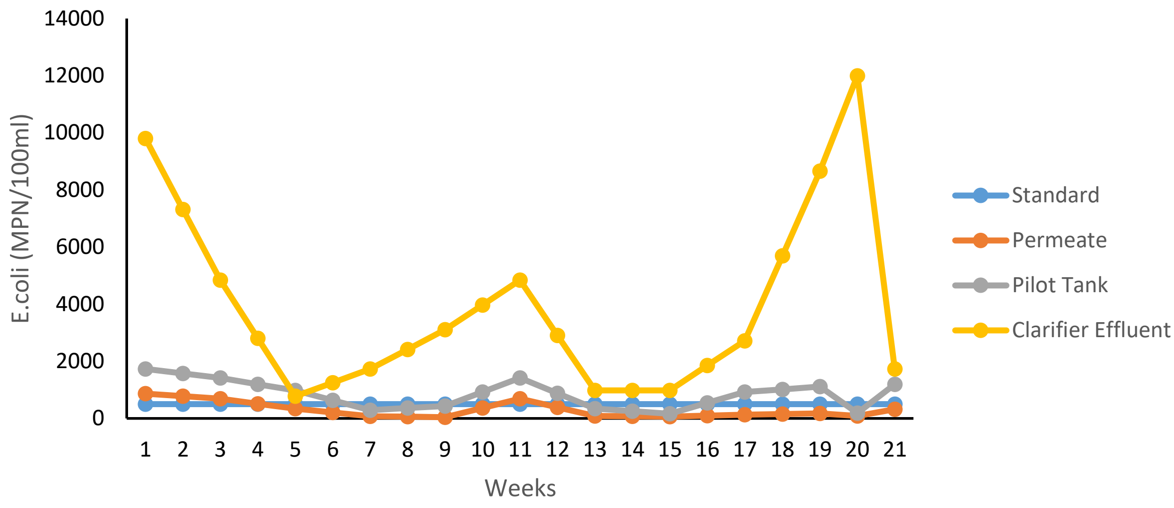

Figure 4.19: *E. coli* water quality trend for a 21-week period

This was due to microbial attachment and formation of biofilm on the membrane surface that can also lead to biofouling. Wang and Waite (2009) reported that a biofouling layer can work as an additional layer in the submerged MBR for improving the water quality if it is well maintained. In addition, Doyle (1991) also reported that in bacteria and biofilm formation, extracellular polymeric substance (EPS) produced by bacteria plays an important role. According to studies done by Aybar et al. (2019), re-aeration of the final effluent affects the bacterial activities of *E. coli* as the conditions become unfavourable for their enzymes. Similarly, as discussed earlier with ammonia trends, the membrane pilot tank's *E. coli* counts gradually improved during the early stages of commissioning. The *E. coli* counts dropped significantly as effluent was introduced into the pilot tank. The WUL limits of 500 counts/L was achieved. The total counts of *E. coli* were within the WUL limit of 500 counts/L in the pilot tank between week 7 and 9 and during weeks 13, 14, 15 and 20. In contrast to E. coli trends in the permeate, the counts gradually improved as the membranes were commissioned. As the water passed through the membranes, counts of less than 500 per liter were recorded from week 6 to 21. According to findings of studies done by Bolzonella et al. (2010) and Hendricks and Pool (2012), *E. coli* was less than 1 count in the permeate of the membrane. It was outlined that the membranes have the capability to reduce *E. coli* due to the aerated membrane and the formation of biofilm on the membrane.

The removal efficiencies for *E. coli*, as presented in Figure 4.20, ranged between 55.4% to 98.7%. This is a significant reduction without the addition of chemicals required for disinfection. These findings are similar to findings from studies done by Bolzonella et al. (2010) and Hendricks and Pool (2012). The high removal efficiencies on *E. coli* is attributed to factors relating to nonwoven membranes such as its ability to transfer oxygen to the microbial bacteria attached on the biofilm, and the growth of micro-organisms (Shivaranjani and Sankari, 2018 and Aybar, et al., 2019). The average removal efficiency obtained in this study was 90% which showed great success.

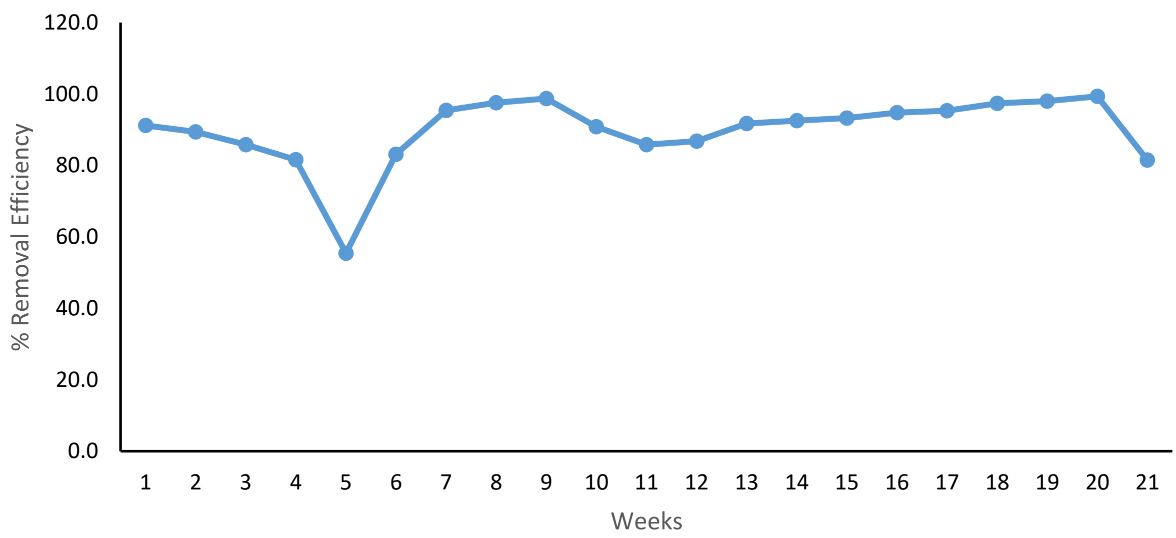

Figure 4.20: *E. coli* permeate removal efficiency for a 21-week period

4.3 Single Factor Pollution Index

4.3.1. BNR Water Pollution Index

The Single Factor Pollution Index was calculated to determine the extent of pollution in the final effluent discharge from BNR clarifier effluent and the permeate. It was significant to determine the BNR clarifier effluent and the permeate pollution impacts on the final effluent to enable continuous improvement on treatment and monitoring of the water quality downstream. Table 2.4 was used as a reference scale for the Single Factor Pollution Index with a scale of pollution magnitude. According to Table 4.1, the Single Factor Pollution Index was calculated for all monitored parameters which included NH_4-N, NO_3, COD, EC, PO_4-P, pH, SS and *E. coli*.

Table 4.1: Single Pollution Index BNR

	Ci	Si	Pi=(Ci/Si)
NH_4-N	1.63	4	0.41
COD	36.67	70	0.52
EC	85.28	80	1.07
NO_3	2.63	6	0.44
PH	7.24	8.5	0.85
PO_4-P	0.15	0.7	0.21
SS	10.38	20	0.52
E.coli	4974.48	500	9.95
Average			1.74

Table 4.2: Single Factor Pollution Index Permeate

	Ci	Si	Pi=(Ci/Si)
NH_4-N	1.28	4	0.32
COD	25.19	70	0.36
EC	80.04	80	1.00
NO_3	2.22	6	0.37
PH	7.21	8.5	0.85
PO_4-P	0.11	0.7	0.16
SS	10	20	0.50
E.coli	294.33	500	0.59
Average			0.52

A. Pollution level: Serious pollution

The Single Factor Pollution Index for *E. coli* in the BNR clarifier effluent was calculated at 9.95 which is greater than 5 and indicates that the effluent is seriously polluted according to the standard (Table 2.4). The seriously polluted range shows that there is excessive pollution occurring at the downstream in which the effluent is discharged. A high *E. coli* concentration specifies faecal pollution in the environment, which also indicates water quality problems. E. coli is a pathogenic bacterium which causes waterborne diseases, therefore, the presence of high *E. coli* concentrations may present health problems in the receiving environment and limit re-use purposes. Other authors including Okoh et al. (2007) and Akpor and Muchie (2011), have studied the presence of *E. coli* in streams in which wastewater is discharged. The results confirmed that *E. coli* can cause infections such as diarrhea for adults and kidney failure for children. For re-use purposes such as irrigation, Ishii and Sadowsky (2008), Delaquis et al. (2007), and Jang et al. (2017) reported that E. coli can survive and reproduce in soil which can cause food poisoning outbreaks for vegetables such lettuce and spinach.

B. Pollution level: Medium polluted

The Single Factor Pollution Index for electrical conductivity in the BNR clarifier effluent was calculated at 1.07. According to the standard (Table 2.4), this indicates that the final effluent is medium polluted. The medium pollution range shows that there is pollution taking place at the downstream where final effluent is discharged. High conductivity shows that saline conditions are taking place which illustrate that the total amount of dissolved salts or chemical ions are high, which indicates water quality problems. High conductivity affects the aquatic ecosystem because the organisms cannot survive in salty conditions. According to Masters and Ela (2007) and Pal et al. (2015), who have studied the presence of conductivity on lakes, dissolved ion concentrations control the survival, reproduction, and growth of aquatic organisms.

C. Pollution level: Slightly polluted

The Single Factor Pollution Index for COD, pH, and SS in the BNR clarifier were calculated at 0.52, 0.85 and 0.52, respectively, which shows that the effluent is slightly polluted according to the standard (Table 2.4). The slightly polluted range shows that there is pollution occurring at the downstream in which the final effluent is discharged. High COD shows the presence of biodegradable organic matter in water which indicates water quality problems. Higher COD results in bacteria consuming DO, and this causes the DO level to drop in the streams which affects the functioning of the aquatic ecosystem. Van den Brand et al. (2015) and Edokpayi et al. (2017) have studied the presence of COD in streams in which wastewater is discharged. The results confirmed that a high COD level decreases the DO level in streams and affect the aquatic life. The pH value must range between 6.5 and 8.5 for proper functioning of the aquatic ecosystem. If the pH level is lower than 6.5 and greater than 8.5, it indicates the occurrence of industrial pollution which will result in aquatic life not being able to survive in the streams. Akpor and Muchie (2011) and Singh et al. (2016) studied the presence of pH at the streams and reported that pH that is low, kills the aquatic life, causes physical damage, and leaves it vulnerable to diseases. High SS concentrations result in the reduction of photosynthesis which physically harms the aquatic life and causes toxic outcomes from pollutants linked to suspended particles. Horner et al. (1994) and Akpor and Muchie (2011) studied the presence of SS at receiving water bodies and reported that SS reduces the penetration of sunlight and physically harms aquatic life.

D. Pollution level: Non-pollution

The water pollution index for NH_4-N, NO_3^-, and PO_4^{3-} in the BNR clarifier were calculated at 0.40, 0.40, and 0.21, respectively, which indicated non-pollution according to the standard table for the Single Factor Pollution Index presented in Table 2.4. Therefore, NH_4-N, NO_3^-, and PO_4^{3-} concentrations from the BNR clarifier did not indicate pollution in the downstream in which the final effluent is discharged.

E. BNR overall pollution index

Although NH_4-N, NO_3^-, PO_4^{3-}, EC, COD, pH, and SS falls within the non-pollution, slightly polluted, and medium polluted ranges, there is still a need for continuous monitoring of those parameters to avoid further deterioration of the water quality. The overall Single Factor Pollution Index for the BNR clarifier effluent was calculated at 1.75 which indicates medium pollution according to the standard (Table 2.4). This shows that pollution was taking place. The overall pollution index was mostly affected by *E. coli*, which was seriously polluted, EC which was medium polluted, and COD, pH, and SS which were slightly polluted.

4.3.2. Water Pollution Index Permeate

A. Pollution level: Slight pollution

The Single Factor Pollution Index for EC, pH, SS, and *E. coli* in the permeate were calculated at 1.0, 0.85, 0.50, and 0.59, respectively, which shows that the permeate was slightly polluted according to the standard (Table 2.4). The slightly polluted range shows that pollution is taking place at the downstream in which the permeate is discharged. As discussed earlier for the BNR, according to Masters and Ela (2007) and Pal et al. (2015), the presence of conductivity affects aquatic organisms' survival, reproduction, and growth due to high concentrations of dissolved salts or chemical ions. According to Akpor and Muchie (2011) and Singh et al. (2016), the unbalanced level of pH in the streams physically damages the aquatic life and leaves it vulnerable to diseases which might also impact the environment. According to Horner et al. (1994) and Akpor and Muchie (2011), the presence of SS at the downstream reduces photosynthesis and aquatic life is physically affected. According to Okoh et al. (2007) and Akpor and Muchie (2011), the presence of *E. coli* in the downstream causes diseases such as kidney failure for children and infections such as diarrhea for adults. Ishii and Sadowsky (2008), Delaquis et al. (2007), and Jang et al. (2017) also reported that *E. coli* can cause food poisoning for vegetables since it can survive and reproduce in soil. This is relevant where the wastewater effluent is used for irrigation purposes.

B. Pollution level: Non-pollution

The water pollution index for NH_4-N, NO_3^-, PO_4^{3-}, and COD in the permeate were calculated at 0.32, 0.37, 0.16, and 0.36, respectively, which indicated non-pollution according to the standard table for the Single Factor Pollution Index presented in Table 2.4. Therefore NH_4-N, NO_3^-, PO_4^{3-}, and COD concentrations from the permeate do not indicate pollution in the stream in which the permeate is discharged.

C. Permeate overall pollution index

Continuous monitoring of NH_4-N, NO_3^-, PO_4^{3-}, COD, EC, pH, SS, and *E. coli* remains necessary to avoid further deterioration of the water quality, even though all these parameters fall within the non-pollution and slightly polluted ranges. The permeate overall Single Factor Pollution Index was calculated at 0.52. According to the standard as shown in Table 2.4, this indicates that the permeate is slightly polluted. The overall pollution index was mostly affected by EC, pH, SS, and *E. coli* that were slightly polluted.

The use of nonwoven membrane filtration showed significant improvement on the extent of pollution reduction in the effluent discharged into the downstream. This was seen by comparing the overall Single Factor Pollution Index for the BNR and the permeate. The pollution index for the BNR was 1.74 and for the permeate it was 0.52.

4.4 Water Quality Index

4.4.1. Water Quality Index for BNR

All the water quality parameters were within the water quality guidelines as presented in Table 4.3 except for conductivity and *E. coli*, which were not within the water quality guideline of 80 ms/m and 500 counts/L, respectively. The water quality information was used to determine the Water Quality Index below.

Table 4.3: Water quality index BNR

Parameter	Observed value (Va)	Standard value (vs)	∑(1/Si)	Constant (I)=1/∑(1/Si)	Unit weight wi=I/Si	Videal	Quality rating (Qi)	WiQi
NH_4-N	1.63	4	0.25	0.4897949	0.1224487	0	40.75	4.989786
COD	36.67	70	0.014286	0.4131121	0.0059016	0	52.385714	0.30916
EC	85.28	80	0.0125	0.4131121	0.0051639	0	106.6	0.550472
NO_3	2.63	6	0.166667	0.4131121	0.068852	0	43.833333	3.018013
pH	7.24	8.5	0.117647	0.4131121	0.0486014	7	16	0.777623
PO_4	0.15	0.7	1.428571	0.4131121	0.5901601	0	21.428571	12.64629
SS	10.38	20	0.05	0.4131121	0.0206556	0	51.9	1.072026
E.COLI	4974.48	500	0.002	0.4131121	0.0008262	0	994.896	0.822007
	5118.46		2.041671	∑	0.8626096		∑	24.18537
					WQI	28.03745		

The overall WQI was calculated using the standard (Table 3.3) for the final effluent from the clarifier and the permeate from the membrane filtration pilot plant. The WQI was performed to determine the possible re-use options of water treated by biological nutrients removal (BNR) and the membrane filtration plant. The WQI calculated for the BNR was 28.03 and is presented in Table 4.3. According to the standard table for classification of WQI, the water quality falls within the range of 26-50, therefore, it can be classified as good water. Good water refers to the re-use options that include domestic, irrigation, and industrial purposes. However, it is limited to water treatment re-use for drinking purposes. The WQI was affected by high conductivity and *E. coli* counts from the final effluent clarifiers, thereby limiting the direct re-use without chlorination for *E. coli*. In agreement with the results obtained, Mahomad (2019) reported the presence of *E. coli* in the BNR effluent discharged to the downstream which affected the WQI and resulted in water effluent categorised as good water suitable for re-use purposes such as irrigation for plants. Rim-Rukeh and Agbozu (2013) reported the existence of conductivity in the BNR effluent which affected the WQI, and the effluent water quality was also categorised as good water.

The conventional BNR process is designed to remove nutrients and other physical contaminants. However, water must undergo chlorination to eliminate pathogenic organisms. The cost of chlorination may be very high, thus, using membrane filtration may improve water quality and reduce the chemical dosing and thereby cut the cost of disinfection. Detailed discussions on the WQI calculated for the permeate from the membrane filtration pilot plant are presented in the subsequent section.

4.4.2. Water Quality Index Permeate

Effluent from clarifiers was diverted to membrane filtration in order to further treat the water to improve the quality and reduce the cost of disinfection. The WQI was calculated for the parameters in Table 4.4 and all the parameters were within the water quality guidelines. According to Table 4.4, the WQI for membrane filtration is 21.13, which falls within the range of 0-25. According to the standard rating (Table 3.3), the WQI category presents excellent water quality which can be re-used for drinking, domestic, irrigation, and industrial purposes. The water quality in the permeate showed a major improvement in *E. coli* counts from 4974.48 counts/L to 294.33 counts/L, thereby indicating the strength of membrane filtration to improve microbial contamination and reduce the chlorine demand for disinfection of wastewater final effluent. The COD also showed improvement from 36.67 mg/L to 25.19 mg/L. This indicates that a nonwoven membrane has the strength to further oxidise organic matter with a sufficient oxygen supply. Conductivity also showed improvement from 85.28 mS/m to 80.04 mS/m. The membrane showed that with good nitrification and good alkalinity consumption, it is capable of improving water quality.

The assessment phase of the WQI on membranes is still in its inception. Most research has been done on wastewater BNR treatment and potable water. Al-Baidhani and Mokif (2018) reported an excellent water quality from nine water treatment plants for raw and treated water quality and it was suitable for drinking. Mohamad (2019) also reported an excellent water quality from one wastewater treatment plant using BNR. The water was suitable for drinking, irrigation, domestic, and industrial use. Wintgens et al. (2005) obtained a drinking water quality standard for BNR clarifier effluent treated by using UF membranes. Major successes were achieved with the removal of microbial and chemical components without disinfection for the study that was done in Windhoek, Namibia. The water quality was suitable for direct re-use. Wintgens et al. (2005) also studied water reclamation of BNR clarifier effluent in Singapore using MF hollow fibre membranes but disinfection was needed for microbial purposes. The water quality was recommended for indirect potable re-use.

Table 4.4: Water quality index permeate

Parameter	Observed value (Va)	Standard value (vs)	∑(1/Si)	Constant (I)=1/∑(1/Si)	Unit weight wi = I/Si	Videal	Quality rating (Qi)	WiQi
NH_4-N	1.28	4	0.25	0.4897949	0.1224487	0	32	3.918359
COD	25.19	70	0.014286	0.4131121	0.0059016	0	35.985714	0.212373
EC	80.04	80	0.0125	0.4131121	0.0051639	0	100.05	0.516648
NO_3^-	2.22	6	0.166667	0.4131121	0.068852	0	37	2.547524
pH	7.21	8.5	0.117647	0.4131121	0.0486014	7	14	0.68042
PO_4	0.11	0.7	1.428571	0.4131121	0.5901601	0	15.71428	9.273944
SS	10	20	0.05	0.4131121	0.0206556	0	50	1.03278
E.COLI	294.33	500	0.002	0.4131121	0.0008262	0	58.866	0.048637
	420.38		2.041671	∑	0.8626096		∑	18.23069
					WQI	**21.13434**		

4.4.3. Benefits of Nonwoven Membrane Filtration

South Africa is a water scarce country and very little work has been done in the direction of water re-use and reclamation. The use of nonwoven membrane filtration for direct water reclamation can improve the water scarcity gap in South Africa. A large amount of wastewater can be treated because the water does not have to go through extensive treatment. The water quality obtained can be re-used for drinking, domestic, irrigation, and industrial purposes.

The use of nonwoven membranes showed significant improvement in water quality, especially for *E. coli* reduction from 4974.48 counts/L to 294.33 counts/L. The standard of *E. coli* at Waterval WCW is 500 counts/L. Therefore, if nonwoven membranes are used for further treatment of wastewater, there is no need for disinfection because it is already within the WUL standard. This will reduce the cost of disinfection at Waterval WCW. Currently, Waterval WCW is spending R4.6 million/annum for disinfection. This can be reduced to a reasonable amount if a functional large-scale membrane is established. The nonwoven membrane can also be distributed amongst ERWAT plants that are using general standards of 1000 counts/L as well as a WUL limit above the threshold removal efficiency of 90%, thereby saving on disinfection costs.

According to Duranceau (2016), the lifespan of a membrane filter is five to eight years. During the study of 21 weeks, the membrane was only cleaned once by means of backwashing and air scouring. This showed that the membrane filters can operate for a longer period. The nonwoven membrane filters used in this study were very cost-effective at R150.00 per square meter and only 4 m^2 of the membrane filters were used.

The advantages of these membranes are:

a) It does not need much of maintenance. It only requires backwashing and cleaning.
b) Electricity consumption is low. It was calculated at 0.35 kW/h and 8.4 kW/day (calculation attached in Appendix C).

Chapter 5: Conclusion and Recommendations

5.1 Introduction

In this section, the overall results are summarised, and conclusions are drawn based on the main objectives and research questions. Based on the findings of the study, recommendations are made to justify the need for further research.

5.2 Conclusion

The primary aim of this study was to improve effluent wastewater quality prior to disinfection for possible re-use. This was done by nonwoven membrane filtration together with the effect of aeration within the system to enhance particulate, physicochemical, and microbial removal.

Water quality results for the BNR clarifier effluent and the membrane permeate were used. The water quality trends for the physicochemical and microbial parameters were done against the Water Use Licence (WUL). Water quality parameters for the permeate that complied with the WUL standard from week 1 to week 21 are NO_3^-, PO_4^{3-}, COD, and SS. The parameters that did not fully comply with the WUL standard were NH_4N, pH, EC, and *E. coli*. The NH_4N concentration in weeks 15 and 19 were 4.6 mg/L and 7.3 mg/L, respectively. This was due to membrane fouling which was addressed by membrane backflushing and air scouring. The acidity (pH) level in week 17 was 6.4 and may be explained by alkalinity consumption during nitrification that was taking place in the pilot resulting in the drop in pH level. The EC in weeks 5 to 11 and week 15 ranged between 81 mS/m and 82 mS/m. This may be due to the microfibre filter's inability to retain dissolved ions. In week 15, fouling may also have contributed to an increase in EC. The *E. coli* concentration during weeks 1 to 6 ranged between 632 counts/l and 866 counts/L. This lower efficiency compared to later stages can only be linked to biofilm augmentation on the microfilter. The highest removal efficiency obtained in this study using nonwoven membrane filtration was for *E. coli* at 90%, followed by COD at 25%, NH_4N at 22%, NO_3^- at 12.6%, PO_4^{3-} at 7.8%, SS at 6.3%, and the lowest was EC at 5.2 %. Therefore, it was concluded that nonwoven membrane filtration can improve the removal efficiency of the BNR clarifier effluent and it was mostly seen in the *E. coli*, COD, and NH_4N parameters.

According to the Single Factor Pollution Index, water quality for the BNR clarifier effluent showed serious pollution on *E. coli*. The level of pollution as per the standard table was above the rating of 5. Conductivity showed medium pollution with the rating between 1 and 2. COD, pH, and SS indicated slight pollution with the level rating between 0.5 and 1. Parameters that showed non-pollution in the BNR effluent were NH_4N, NO_3^-, and PO_4^{3-}. These parameters rated less than 0.4. The overall Single Factor Pollution Index for the BNR clarifier effluent was determined as medium polluted ranging between 1 and 2 according to the pollution standard. The Single Factor Pollution Index water quality for the permeate indicated a slightly polluted level for *E. coli*, EC, pH, and SS. These parameters rated between the level of 0.5 and 1. NH_4-N, NO_3^-, PO_4^{3-}, and COD in the permeate indicated a level of non-pollution since all these parameters rated less than 0.4 according to the pollution standard. The overall pollution index for the permeate indicated a slightly polluted level ranging between 0.5 and 1. Therefore, it was concluded that the use of nonwoven membrane filtration presented significant improvements to the effluent discharged into the downstream. The average pollution index for the BNR clarifier effluent and the permeate was determined as 1.74 and 0.52, respectively.

The water re-use options for wastewater treatment plants are complex and require thorough investigation. The Water Quality Index (WQI) was performed for the BNR clarifier effluent and the permeate at Waterval WCW. According to the results of the WQI BNR clarifier effluent, the water quality rating was 28.03 and falls within the range of 26-50. The water quality at the BNR clarifier effluent is regarded as good water and can be re-used for domestic, irrigation, and industrial purposes, except for drinking purposes. The WQI was affected by a high conductivity of 85.28 mS/m and *E. coli* concentrations of 4974.48 counts/L from the final effluent clarifiers, therefore limiting the direct re-use without chlorination for *E. coli*. According to the results of the WQI permeate, the water quality rating is 21.13 which falls within the range of 0-25. According to the standard rating of WQI, the water quality at the permeate is regarded as excellent water quality and can be re-used for drinking (with additional treatment such as activated carbon and additional disinfection), domestic, irrigation, and industrial purposes. A major improvement in permeate water quality was seen on *E. coli* counts improving from 4974.48 counts/L to 294.33 counts/L, COD improving from 36.67 to 25.19 mg/L, and conductivity improving from 85.28 to 80.04 mS/m. The standard of *E. coli* according to the WUL at Waterval WCW is 500 counts/L. Therefore, it was concluded that nonwoven membrane filtration is able to improve microbial contamination and decrease the demand of chlorine for disinfection of wastewater final effluent. It also showed that it can improve nitrification and alkalinity consumption and that it has the strength to further oxidise organic matter with a sufficient oxygen supply. Nonwoven membrane filtration also showed that it can improve the water scarcity gap in South Africa for direct water reclamation and a large quantity of wastewater can be treated because extensive water treatment will not be needed.

5.3. Recommendations

The current study was done on a pilot-scale treatment plant for membrane filtrations at Waterval WCW. The configuration was an additional treatment or commonly known as polishing. The results indicate positive trends. Therefore, it may be feasible to conduct the study on a larger scale as this will enable treatment of high volumes of wastewater that can be re-used or reclaimed in order to augment water supply. The membrane filtrations have proven to reduce microbial contamination by 90%. This system has the potential to either reduce or replace chemical disinfection. The replacement of disinfection with membrane filtration can reduce the costs associated with disinfection. The energy consumption of this polishing step could also be evaluated in much more detail together with pumping and/or vacuum pressures to transport the permeate through the microfilter. It is recommended that a longer water quality-monitoring programme be implemented on the membrane filtration in order to provide possible water quality variation of the membrane permeate attributed to seasonal changes.

References

Ajonina, C., Buzie, C., Rubiandini, R. H. & Otterpohi, R., 2015. Microbial pathogen in wastewater treatment plant (WWTP) in Hamburg. *Journal of Toxicology and Environmental Health,* 6(78), pp. 381-387.

Akpor, O. B. & Muchie, M., 2011. Enviromental and public health implications of wastewater quality. *African jounal of Biotechnology,* 10(13), pp. 2379-2387.

Al-Baidhani, J. & Mokif, L., 2018. Assessment of raw and treated water quality of main water treatment plants in Babylon Governorate/Iraq by Water quality Indices. *International Journal of Civil Engineering and Technology,* 9(10), pp. 1252-1264.

Almeida, C. A., 2007. Influence of urbanization and Tourist Activities on the water quality of the Potrero De Los Funes River (San Luis - Argentina). *Enviromental Monitoring and Assessment,* Volume 133, pp. 459-465.

Al-Shammiri, M., Al-Saffar, A., Bohamad, S. & Ahmed, M., 2005. Waste water quality and reuse in irrigation in Kuwait using microfiltration technology in treatment. *Desalination,* 185(1), pp. 213-225.

Amrhein, V., Trafimow, D. & Greenland, S., 2019. Inferential statistic as Descriptive Statistics: There Is No Replication Crisis if We Don't Expect Replication. *The American Statistician,* Volume 73, pp. 262-270.

APHA, 2005. *Standard methods for the Examination of Water and Wastewater.* 21 ed. Washington DC: American Public Htealth Association.

APHA, 2017. *Standard Methods for the Examination of Water and Wastewater.* 23 ed. Washington DC: American Public Health Association.

Asano, T. et al., 2007. *Water reuse: Issue, technologies and applications,* United States: Metcalf & Eddy, Inc.

Asano, T. & Cotruvo, J. A., 2004. Groundwater recharge with reclaimed municipal wastewater: Health and regulatory conciderations. *Water Research,* pp. 1941 - 1951.

ATSE, A. A. o. T. S. a. E., 2013. *Drinking water through recycling: The benefits and costs of supplying direct to the distribution system,* Australia: Melbourne.

Aybar, M. et al., 2019. Predation creates unique void layer in mebrane-aerated biofilms. *Water Research,* Volume 149, pp. 232-242.

Bahri1, A., Drechsel, P. & Brissaud, F., 2007. *Water reuse in Africa: challenges and opportunities,* Accra: International Water Management Institute.

Belmonte, M. et al., 2017. Effect of free ammonia, free nitrous acid and alkalinity on the partial nitrification of pretreated pig slurry, using an alternating oxc/anoxi SBR. *BioMed Research International,* Volume 2017, pp. 1-7.

Bhave, P. P., Naik, S. & Salunkhe, S. D., 2000. Performance Evaluation of Wastewater Treatment Plant. *Water Conservation Science and Engineering,* Volume 5, pp. 23-29.

Blumberg, B., Cooper, D. R. & Schindler, P. S., 2005. *Business Research Method,* Berkshine: McGrawHill Education.

Bolzonella, D., Fatone, F., di Fabio, S. & Cecchi, F., 2010. Application of membrane bioreactor technology for wastewater treatment and reuse in the Mediterranean region: Focusing on removal efficiency of non-conventional pollutants. *J. Environ. Man,* Volume 91, pp. 2424-2431.

Braak, E., Aliet, M. & Schetrite, S., 2011. Aeration and hydrodynamics in submerged membrane bioreactors. *Journal of membrane Science,* Volume 379, pp. 1-18.

Brepols, C. et al., 2008. Strategies for chemical cleaning in large scale membrane bioreactors. *Water Science Technology,* Volume 57, pp. 457-463.

Cele, M. N., 2014. *Development and evaluation of woven fabric immersed membrane bioreactor for treatment of domestic waste water for re-use,* university of Natal: Department of Chemical engineering.

Chakrabartty, S. N., 2013. Best Split-Half and Maximum Reliability. *Journal of Research & Method in Education,* 3(1), pp. 1-8.

Chang, M. C., Tzou, W. Y., Chuang, S. H. & Chang, W. K., 2014. Application of Non-woven fabric material in Membrane bioreactor Processes for Industrial Wastewater Treatment. *Material Science,* Volume 181, pp. 1-6.

Chang, W. K., Hu, A. Y., Y, H. R. & Tzou, W. Y., 2006. Membrane biorector with nonwoven fabrics as solid-liquid separation media for wastewater treatment. *Desalination,* Volume 202, pp. 122-128.

Cho, J., Song, K.-G. & Ahn, K.-H., 2009. Contribution of microfiltration on phosphorus removal in the sequencing anoxi/anerobic membrane bioreactor. *ResearchGate,* 32(23561222), pp. 593-602.

Cicek, N., 2003. *A review of membrane bioreactors and their potential application in the treatment of agricultural wastewater,* Winnipeg Minatoba: University of Manitoba.

Colvin, C. & Muruven, D., 2017. *Scenarios for the Future of Water in South Africa,* Cape Town: The Boston Consulting Group.

de Koning, J. et al., 2008. Characterisation and assessment of water treatment technologies for reuse. *Desalination,* Volume 218, pp. 92-104.

Deelie, M., 2017. *Energy Reduction in a Woven-Fabric Immersed Membrane Bioreactor,* Stellenbosch: Stellenbosch University (Faculty of Engineering).

Delaquis, P., Bach, S. & Dinu, L. D., 2007. Behavior of Escherichia coli O157:H7 in leafy vegetables. *J Food Protect,* Volume 70, pp. 1966-1974.

Donnenfeld, Z., 2018. *South Africa water crisis is bigger than the Cape,* Pretoria: Institute of Security Studies (ISS).

Donnenfeld, Z., Crookes, C. & Hedden, S., 2018. *A delicate balance "Water scarcity in South Africa",* Pretoria: Water Research Council.

Doyle, R. J., 1991. Strategies in experimental microbial research. In: N. Mozes, P. S. Handley, H. J. Busscher & P. G. Rouxhet, eds. *Microbial cell surface analysis.* New York: VCH, pp. 292-316.

Duranceau, S., 2016. *Re: What are the typical values for flux and lifetime of ultrafiltrition membrane?.* [Online]
Available at: https://www.researchgate.net/post/What-are-the-typical-values-for-flux-and-lifetime-of-a-ultra-filtration-membrane/5723b6ba96b7e477c56f48f2/citation/download
[Accessed 27 May 2021].

DWA, 1998. *Nation water Act No 36.* [Online]
Available at: www.dwa.gov.za/NWA
[Accessed 13 September 2019].

DWA, D. o. W. A., 2013a. *National Resource Strategy-2,* Pretoria: Department of Water Affairs.

DWS, 2013. *Green Drop Systems, Green Drop Report.* [Online]
Available at: www.dwa.gov.za/dir_ws/gds/Docs/DocsDefault.aspx

Edokpayi, J., Odiyo, J. & Durowoju, O., 2017. Impact of wastewater on surface water quality in developing countries: A case study of South Africa. *ResearchGate,* Issue 10.5772/66561, pp. 401-416.

El-Khateeb, M. A. et al., 2018. The feasibility of usingg non-woven fabric as packing material for wastewater treatment. *Desalination and Water Treatment,* Volume 111, pp. 94-100.

Fani, A. G., 1996. Membranes for Water Production and Wastewater Reuse. *Desalination,* Volume 106, p. 1.

Finger, J. & Cybis, F., 1999. *Biological phosphorus removal in sequential batch reactors.* Rio de Janeiro, Brazilian Congress of Sanitary and Enviromental Engineering .

Gangwar, R. K., Singh, J. & Singh, A. P., 2013. Assessment of water quality index: A case study of river ramganga at Bareilly U. P. India.. *scientific and engineering research,* 4(9), pp. 2229-5518.

Gasim, A., Heran, M., Hannachi, A. & Grasmick, A., 2015. Fouling analysis and biomass distribution on a membrane bioreactor under low ratio COD/N. *Membr.Water Treat,* Volume 6, pp. 263-276.

Greener, S. & Martelli, J., 2015. *Introduction to business method.* s.l.:Ventus Publishing.

Han , X. et al., 2015. Membrane bioreactors fed with different COD/N ratio wastewater: impacts on microbial community, microbial products, membrane fouling. *Environ.Sci.Res,* Volume 22, pp. 11436-11445.

Hendricks, R. & Pool, E. J., 2012. The effectiveness of sewage treatment processes to remove faecal pathogens and antibiotic residues. *Journal of Enviromental Science and Health ,* Volume 47, pp. 289-297.

Henze, M. et al., 2002. Effect of solids retention time and wastewater characteristic on biological phosphorus removal. *Water Science and Technology,* 45(6), pp. 137-144.

Henze, M. et al., 2002. Effects of solids retention time and wastewater characteristics on biological phosphorus removal. *Water science and technology: a jounal of the international Association on Water Pollution Research,* 45(6), pp. 137-144.

Horner, R. R., Skupien, J. J., Livingstone, E. H. & Shaver, H. E., 1994. *Fundamentals of urban runoff management,* Washington DC: Terrence institute.

Hou, B. et al., 2014. Effect of alkalinity on nitrite accumulation in treatement of coal chemical industry wastewater using moving bed biofilm reactor. *Journal of Enviromental Sciences (China),* 26(5), pp. 1014-1022.

Howard, G. & Bartman, J., 2003. *Domestic water quantity, service level and health, world health organisation (WHO).* [Online]
Available at: http://cdrwww.who.int/water_sanitation_health/diseases/WSH03.02.pdf

Howard, I. et al., 2004. Evaluation of microbiologigal and physiochemical inductors for wastewater treatment. *Enviromental Toxicology,* 19(3), pp. 241-249.

Howell, J. A., 2004. Future of Membranes and Membranes Reactors in Green Technologies and for Water Reuse. *Desalination,* Volume 162, pp. 1-11.

Howell, J., Chua, H. & Arnot, T., 2004. In situ manipulation of critical flux in a submerged membrane bioreator using aeration rates, and effects of membrane history. *Journal of membrane science,* 242(1), pp. 13-19.

Huertas, E. et al., 2008. Key objectives for water reuse concepts. *Desalination,* Volume 218, pp. 120-131.

Hulya, B., 2009. Utilization of the water quality index method as a classification tool. *Enviromental Monitoring and Assessment,* pp. 24-115.

Hu, Z. & Grasso, D., 2005. WATER ANALYSIS : Chemical Oxygen Demand . In: A. T. a. C. P. Paul Worsfold, ed. *Encyclopedia of Analytical Science.* Oxford: Elsevier, pp. 325-330.

Hwang, B. H. et al., 2000. Enhanced nitrite buid-up in proportion to increasing alkalinity / NH4 ratio of influent in biofilim reactor. *Biotechnology Letter,* 22(16), pp. 1287-1290.

Iorhemen, O. T., Hamza, R. A. & Tay, J. H., 2016. Membrane Bioreactor (MBR) Technology for wastewater treatment and reclamation:. *Membranes (Basel),* Volume 2, pp. 6-33.

Ishii, S. & Sadowsky, M. J., 2008. E.coli in the enviroment: implications for water quality and human health. *Microbes Environ,* Volume 23, pp. 101-108.

Jacobsen, M., Webster, M. & Vairavamoorthy, K., 2013. *The Future of Water in African Cities "Why waste water?",* Washington DC: International Bank for Reconstruction and Development / The World Bank.

Jang, J. et al., 2017. Enviromental Escherishia coli: ecology and public health implimentations- a review. *JJournal of Applied Microbiology,* Volume 123, pp. 570-581.

Ji, L. & Zhou, J., 2006. Influence of aeration on microbial polymers and membrane fouling in submerged mermbrane bioreactors. *Journal of membrane Science,* 276(2), pp. 168-177.

Judd, S., 2011. *The MBR Book: Principles and Applications of membrane Bioreactors for water and Wastewater treatment.* 2 ed. Langford Lane Oxford: Elsevier.

Kaper, J., 2005. Pathogenic Escherichia coli. *Int. J. Med. Microbiol.,* Volume 295, pp. 355-356.

Kerrn-Jespersen, J., Henze, M. & Strube, R., 1994. Biological phosphorus release and uptake under alternating anerobic and anoxic conditions in a fixed-film reactor. *Water Research,* Volume 28, pp. 1253-1255.

Khairia, K., Mahfoud, H. M., Youcef, T. & Abdeltif, A., 2015. Influence of secondary salinity wastewater on the efficiency of biological treatment of sand filter. *Energy Procedia,* Volume 74, pp. 398-403.

Kitao , T., Kim, B., Kiso, Y. & Yamamoto, K., 1991. Treatment of domestic wastewater with filtration bio-reactor and anaerobic contact sedimentation method. *Japan Sewage Works Association,* 28(334), pp. 21-31.

Kitao, T., Kim, B., Kiso, Y. & Yamamoto, K., 1991. Treatment of domestic wastewater with filtration bio-reactor and anaerobic contact sedimentation method. *Japan Sewege Works Association,* 28(334), pp. 21-31.

Krauth, K. H. & Stabb, K. F., 1993. Pressurised bioreactor with membrane filtration for wastewater treatment. *Wat.Res,* pp. 405-411.

Lackner, S., Terada, A. & Smets, B. F., 2008. Heterotrophic activity compromises autophic nitrogen removal in membrane aerated biofilm: results of modelling study. *Water Research,* 42(4-5), pp. 1102-1112.

Landage, S., Wasif, A. I. & Sapkal, P., 2013. Studies of nonwoven fabric for water filtration. *Journal of advanced research in management and social sciences,* 2(7), pp. 182-194.

Levin, E., 2007. Conductivity measurements for controlling municipal wasstewater treatment. *Researchgate,* Volume 15, pp. 51-62.

Li, F. & Chaplin, J., 1998. Evaluation of large field sampling methods for crop residue coverage measurement. *Transactions of the American Society of Agricultural Endineers,* 41(3), pp. 645-651.

Li, H. & Chen, V., 2010. Chapter 10 - Membrane Fouling and Cleaning in Food and Bioprocessing. In: Z. F. Cui & H. S. Muralidhara, eds. *Membrane Technology.* Oxford: Butterworth-Heinemann, pp. 213-254.

Loyless, J. C. & Malone, R. F., 1997. A sodium bicarbonate dosing methodolology for pH management in freshwater-recirculating aquaculturesystems. *The progressive fish culturist,* 59(1), pp. 198-205.

Mahmoud , B. & Soumaya, F., 2020. Removal of contaminats and pathogens from secondary wastewater effluents using Hollow fiber microfiltration membrane. *Internaational Journal of Enviromental Sciences & Natural Resources,* 23(3), pp. 78-83.

Makaya, E., Hoko, Z., Parawira, W. & Svotwa, E., 2007. An assessmentof the effectiveness of biological nutrient removal from wastewater: A case for hatcliffe sewage treatment works in Zimbabwe. *Electronic Journal of Enviromental, Agriculture and Food Chemistry,* 6(10)(1579-4377), pp. 2409-2419.

Mara, D. & Horan, N., 2003. *The handbook of Water and Wastewater Microbiology.* 1 ed. Great Britain: Elsevier.

Marchetto, M., 2013. Technologies used in the wastewater treatment for nutrient removal. *International Journal of Water Resources,* 3(2), pp. 1-4.

Masters, G. M. & Ela, W. P., 2007. *Introduction Engineerinng and Science.* 3rd ed. New york: Pearson .

Mayo, A. W. & Bibambo, T., 2005. Nitrogen transformation in horizontal subsurface flow constructed wetlands: Model development. *Physical and Chemistry of the Earth,* Volume 30, pp. 658-667.

Meghdad, P., Kiomars, S. & Esmaeil, A., 2015. Removal of nitrogen and phosphorus from municipal wastewater using intermittent cycle moving bed biofilm reactor (ICMBBR). *Journal of Chemical and Pharmaceutical Research,* 7(6)(0975-7384), pp. 979-987.

Merdaw, A., 2010. Water Permeability in polymetric membranes, part 1. *Desalination,* 260(1), pp. 180-192.

Mihelcic, J. R. & Zimmerman, J. B., 2010. *Environmental Engineering: Fundamentals, Sustainability, Design.* 2 ed. New York: Wiley.

Mohamad, N. I., 2019. Effluent quality assessment of selected wastewater treatment plant in Jordan for irrigation purposes: Water quality index approach. *Journal of Ecological Engineering,* 20(10), pp. 206-216.

Mucha, Z. & Kulakowski, P., 2016. Turbidity measurements as a tool of monitoring and control of the SBR effluent at the small wastewater treatment plant - preliminary study. *Archives of Enviroment protection,* 42(3), pp. 33-36.

Muller, J. D., Schneider, B., Abmann, S. & Rehder, G., 2017. Spectrophotometric pH mesurements in the presence of dissolved organic matter and hydrogen sulfied. *Association for the Science of Limnology and Oceanography,* 16(2).

Muller, M. et al., 2009. *Water Security in South Africa,* Midrand: Development Planing Division. Working Paper Series No.12, DBSA.

Munir, A., 2006. *Dead end membrane filtration, unknown: Laboratory Feasibility Studies in Environmental Engineering.* New York: Desalination.

Muniyan, M. & Ambedkar, G., 2011. Seasonal variations in physicochemical parameters of water collected from Kedilam River at Visoor Cuddalore District, Tamil nadu, India. *International Journal of Enviromental Biology,* 1(2), pp. 15-18.

Nikiema, J. et al., 2014. *Wastewater treatment practices in Africa - Experiences from seven countries,* Africa: Water Biotech.

Okoh, A. T., Odjadjare, E. E., Igbinosa, E. O. & Osode, A. N., 2007. Wastewater treatment plants as a source of microbial pathogens in receiving water sheds. *African Journal Biotechnolgy,* 6(25), pp. 2932-2944.

Osada, T., Haga KE & Harada, Y., 1991. Removal of Nitrogen and Phosphorus from swine wastewater by the activated sludge units with the intermittednt aeration process. *Water Research,* Volume 25, pp. 1377-1388.

Pal, M., Samal, N. R., Roy, P. K. & Roy, M. B., 2015. Electrical conductivity of Lake water as enviromental monitoring- A case of Rudrasagar Lake. *Journal of Enviromental Science, Toxicology and Food Technology,* 3(1), pp. 66-71.

Paola, V., Luigi, M. & Alessio, G., 2011. Wastewater polishing index: a tool for a rapid quality assessment of reclaimaed wastewater. *Environmental Monitoring and Assessment,* Volume 173, pp. 267-277.

Paola, V., Luigi, M. & Alessio, G., 2011. Wastewater polishing index: a tool for a rapid quality assessment of reclaimaed wastewater. *Environmental Monitoring and Assessment,* pp. 267-277.

Paul, S. M., 2006. *Membrane Bioreactors for Industrial Wastewater Treatment: Applicability and Selection of Optimal system configuration,* New York: WEFTEC.

Petr, p., 2019. Principal componet weighted index for wastewater quality monitoring. *Water,* p. 2376.

Power, S. P. B., 2002. Handbook for the operation of wastewater treatment works. In: T. A. Aveling, ed. *Nutrient Removal.* Pretoria: WISA, pp. 14.1-14.14.

Priyanka, T., 2010. Comparative study of Seasonal variation in Physico -Chemical Characteristics in Drinking water Quality of Kanpur, India with Reference to 200 MLD

Filtration plant and Ground water. *Nature and ScienceNature and Science,* Volume 8.

Quist-Jensen, C. A., Macedonio, F. & Drioli, E., 2015. Membrane technology for water productionin agriculture: Desalination and wastewater reuse.. *Desalination,* Volume 364, pp. 17-32.

Ravi Kumar, P., Liza Britta, P. & Somashekar, R. K., 2010. Assessment of the efficiency of sewage treatment plant: A comparative study between Nagasandra and Mailasandra sewage treatment plants. *Kathmandu University Journal of Science, Engineering and Technology,* 6(2), pp. 115-125.

Rim-Rukeh, A. & Agbozu, I. E., 2013. Impact of partially treated sewage effluent on the water quality of recipient Epie Creek Niger Delta, Nigeria using Malaysian Water Quality Index (WQI). *J.Appl.Sci.Environ.Manage,* 17(1), pp. 5-12.

Robson, C., 2011. *Real world Research: A Resource for Users of Social Research Methods in Applied Settings.* 2 ed. Sussex: A. John Wiley and Sons Ltd.

Semiromi, F. B. et al., 2011. Water Quality Index development using fuzzy logic: A case study of the karoon Riverr of Iran. *African Journal of Biotechnology,* 10(50), pp. 10125-10133.

Seo, G. T. et al., 2003. Non-woven fabric filter separation activated sludge reactor for domestic wastewater reclamation. *Water Science technology,* 47(1), pp. 133-8.

Seo, G. T. et al., 2003. Non-woven fabric filter separation activated sludge reactor for domestic wastewater reclamation. *Water Science and Technology,* 1(47), pp. 133-138.

Shivaranjani, S. K. & Sankari, S., 2018. Efficiency of polyethene non-woven fibre filter for treating institutional wastewater by membrane bio reactor process. *International Journal of Innovative Technology and Exploring Engineering,* 8(2S), pp. 357-359.

Shivaranjani, S. K. & UmaSankari, S., 2018. Efficiency of polyethene non-woven fiber filter for trating institutional wastewater by membrane bio reactor processs. *International Journal of Innovative Technology and Exploring Engineering (IJITEE),* 8(2S), pp. 357-359.

Singh, R. K. B., Singh, T. C., Singh, T. R. & Saikia, M. D., 2016. Assessment of water quality index of Nambul River, Imhal, Manipur, India. *International research journal of Engineering and Technology (IRJET),* 3(12), pp. 1462-1467.

Skosana, G. G., 2016. *Viability, from a quality perspective on the reuse of wastewater effluents in the Southern Gauteng region, South Africa,* Pretoria: University of Pretoria.

Srisukphun, T., Chiemchaisri, C., Urese, T. & Yamamoto, K., 2010. Foulant Interaction and RO productivity in textile wastewater reaclamation plant. *Desalination,* Volume 250, pp. 845-849.

Stark, J. M., 1996. Modeling the temperature response of nitrification. *Biogeochemistry,* 3(35), pp. 433-445.

Tanjung, R. H., Hamuna, R. & Alianto, B., 2019. Assesment of water quality and pollution index in Costal waters of Mimika, Indnesia. *Journal of Ecological Engineering,* 2(20), pp. 87-94.

Tchobanoglous, G., Burton, F. L. & Stensel, H. D., 2003. *Wastewater Engineering Treatment and Reuse: Metcalf and Eddy 4th Ed.* New York: McGraw Hill.

Tchobanoglous, G. et al., 2014. *Wastewater Engineering: Treatment & Resourse Recovery.* 5 ed. New York, USA: McGraw Hill.

Thamaraiselvan, C. & Noel, M., 2015. Membrane process for Dye Wastewater Treatment: Recent Progress in Fouling control. *Critical reviews in Enviromental Science and Technology,* 10(45), pp. 1007-1040.

Topkin, J. & (ERWAT), E. R. W. C. C., 2018. *Wader Project No: K5/2786/15,* Pretoria: Water research commision.

Topkin, J. & ERWAT, 2017. *Water quality report Waterval,* Ekurhuleni: ERWAT.

USEPA, U. S. E. P. A., 2012. *Guidlines of water reuse. EPA/600/R-12/004,* Washington, United States: USEPA office of wastewater management.

Van den Brand, T. P. et al., 2015. Effect of Chemical Oxygen Demand, Nutrients and Salinity on Sulfate- Reducing Bacteria. *Enviromental Engineering Science,* 32(10), pp. 1-7.

Villaverde, S., FDZ-Polanco, F. & Garcia, P. A., 2000. NItrifying biofilm acclimation to free ammonia in submedged biiofilters. Start-up influence. *Elsevier Science Ltd,* 34(2), pp. 602-610.

Villaverde, S., Garcia-Encina, P. A. & FDZ-Polanco, F., 1997. Influence of pH over nitrifying biofilm activity in submerged biofilters. *Elsevier Science,* 31(5), pp. 1180-1186.

Wang-kuan, C., Yen-Jung Hub, A., Reng-Yang, H. & Tzoua, W.-Y., 2007. Membrane bioreactor with nonwoven fabrics as solid-liquid separation media for wastewater treatment. *Science Direct Desalination,* 202(202), pp. 122-128.

Wang, X. M. & Waite, T. D., 2009. Role of Gelling soluble and colloidal microbial products in membrane fouling. *Environmental Science and Technology,* 43(4), pp. 9341-9347.

Weon, S. Y., Lee, S. I. & Koopman, B., 2004. Effect of temperature and dissolved oxygen biological nitrification at high ammonia concentrations. *Enviromental Technology,* 11(25), pp. 1211-1219.

Wintgens, T. et al., 2005. The role of membrane processes in municipal wastewater reclamation and reuse. *Desalination,* Volume 178, pp. 1-11.

WRFMC, W. R. F. M., 2007. *Extenal Guideline: Generic Water Use Authorisation Application Process,* Pretoria: Department of Water Affairs and Forestry.

Xianghao, R. H. et al., 2010. Novel membrane bioreactor (MBR) coupled with a nonwoven fabric filter for household watewater treatment. *Water Res,* 3(44), pp. 751-60.

Yan, C.-A.et al., 2015. Assessment of water quality and identification of polluted risky regions based on field observation and GIS in the Honghe river Watershed, China. *PLoS ONE,* 3(10), pp. 1-13.

Yang, Y. et al., 2014. New urban wastewater treatment with autotrophic membrane bioreactor at low chemical oxygen demand/N substrate ratio. *Water Sci. Technol,* Volume 69, pp. 960-965.

Zhaohuan, M., 2013. *Membrane processes for water and wastewater treatment : study and modeling of interactions between membrane and organic matter.,* Ecole Centrale Paris,: HAL .

Appendix

Appendix A: SANAS Accredited Certificate

sanas
South African National Accreditation System

CERTIFICATE OF ACCREDITATION

In terms of section 22(2) (b) of the Accreditation for Conformity Assessment, Calibration and Good Laboratory Practice Act, 2006 (Act 19 of 2006), read with sections 23(1), (2) and (3) of the said Act, I hereby certify that:-

EAST RAND WATER CARE COMPANY NPC

Co. Reg. No.: 1992/05753/08

Facility Accreditation Number: **T0082**

is a South African National Accreditation System accredited facility provided that all conditions and requirements are complied with

This certificate is valid as per the scope as stated in the accompanying schedule of accreditation, Annexure "A", bearing the above accreditation number for

CHEMICAL AND MICROBIOLOGICAL ANALYSIS

The facility is accredited in accordance with the recognised International Standard

ISO/IEC 17025:2005

The accreditation demonstrates technical competency for a defined scope and the operation of a quality management system

While this certificate remains valid, the Accredited Facility named above is authorised to use the relevant accreditation symbol to issue facility reports and/or certificates

Mr R Josias
Chief Executive Officer

Effective Date: 01 March 2017
Certificate Expires: 28 February 2022

Figure A1: SANAS Accredited Certificate

Appendix B: Results Obtained from the Study

Table B1: NH_4N results

Time (Weeks)	Standard (mg/L)	BNR Clarifier Effluent (mg/L)	Pilot Tank (mg/L)	Permeate (mg/L)
1	4	0.8	2	1
2	4	0.9	1.4	0.7
3	4	1	0.8	0.4
4	4	1	0.6	0.5
5	4	1	0.5	0.7
6	4	0.6	0.3	0.4
7	4	0.2	0.2	0.2
8	4	0.1	0.2	0.1
9	4	0.1	0.1	0.1
10	4	0.1	0.1	0.2
11	4	0.1	0.1	0.3
12	4	0.5	0.4	0.3
13	4	1	0.8	0.4
14	4	1	1.5	2.5
15	4	1	2.2	4.6
16	4	3.1	1.5	3
17	4	5.3	0.8	1.4
18	4	3.4	1.2	3.8
19	4	1.5	1.6	7.3
20	4	1.9	1.2	3.8
21	4	2.4	0.9	0.4

Table B2: COD results

Time (Weeks)	Standard (mg/L)	BNR Clarifier Effluent (mg/L)	Pilot Tank (mg/L)	Permeate (mg/L)
1	70	26	21	22
2	70	33	23	21
3	70	40	26	21
4	70	44	29	25
5	70	48	33	29
6	70	36	28	25
7	70	25	23	22
8	70	39	33	24
9	70	53	43	26
10	70	42	34	27
11	70	32	25	29
12	70	36	25	25
13	70	32	26	21
14	70	33	27	23
15	70	26	29	26
16	70	25	26	26
17	70	24	23	26
18	70	28	23	24
19	70	33	24	29
20	70	35	29	29
21	70	38	28	29

Table B3: PO_4 results

Time (Weeks)	Standard (mg/L)	BNR Clarifier Effluent (mg/L)	Pilot Tank (mg/L)	Permeate (mg/L)
1	0.7	0.2	0.1	0.1
2	0.7	0.1	0.1	0.1
3	0.7	0.1	0.1	0.1
4	0.7	0.1	0.1	0.2
5	0.7	0.2	0.1	0.3
6	0.7	0.2	0.1	0.1
7	0.7	0.1	0.1	0.1
8	0.7	0.1	0.1	0.1
9	0.7	0.1	0.1	0.1
10	0.7	0.1	0.1	0.1
11	0.7	0.1	0.1	0.1
12	0.7	0.1	0.1	0.1
13	0.7	0.1	0.1	0.1
14	0.7	0.1	0.1	0.1
15	0.7	0.1	0.1	0.1
16	0.7	0.1	0.1	0.1
17	0.7	0.1	0.1	0.1
18	0.7	0.1	0.1	0.1
19	0.7	0.1	0.1	0.3
20	0.7	0.1	0.1	0.1
21	0.7	0.1	0.1	0.1

Table B4: NO_3 results

Time (Weeks)	Standard (mg/L)	BNR Clarifier Effluent (mg/L)	Pilot Tank (mg/L)	Permeate (mg/L)
1	9	0.1	3.4	3.2
2	9	1.1	3.5	3.4
3	9	2.1	3.6	3.6
4	9	2.5	3.5	3.5
5	9	2.4	3.5	3.4
6	9	2.4	2.6	2.8
7	9	2.4	1.7	2.2
8	9	3.4	2.3	2.5
9	9	4.4	3	2.8
10	9	3.8	3.1	3.1
11	9	3.2	3.3	3.4
12	9	2.6	3.4	3.5
13	9	2.1	3.6	3.6
14	9	2.4	2.8	2.9
15	9	2.8	2.1	2.2
16	9	3	2.2	2.3
17	9	3.2	2.3	2.5
18	9	1.7	1.3	1.3
19	9	0.2	0.3	0.2
20	9	0.35	1.3	1.3
21	9	0.5	2.4	2.4

Table B5: pH results

Time (Weeks)	Standard	Standard	BNR Clarifier Effluent	Pilot Tank	Permeate
1	8.5	6.5	7.7	7.9	8
2	8.5	6.5	7.3	7.6	7.7
3	8.5	6.5	7	7.3	7.5
4	8.5	6.5	7.2	7.5	7.4
5	8.5	6.5	7.5	7.7	7.4
6	8.5	6.5	7.4	7.5	7.1
7	8.5	6.5	7.3	7.4	6.9
8	8.5	6.5	7.1	7.3	7.1
9	8.5	6.5	7	7.2	7.3
10	8.5	6.5	7	7.1	7
11	8.5	6.5	7.1	7	6.7
12	8.5	6.5	7	7.1	7.1
13	8.5	6.5	7	7.3	7.5
14	8.5	6.5	7.1	7.4	7.5
15	8.5	6.5	7.2	7.5	7.6
16	8.5	6.5	7	7.1	7
17	8.5	6.5	6.8	6.7	6.4
18	8.5	6.5	7.2	7.3	7
19	8.5	6.5	7.6	7.9	7.7
20	8.5	6.5	7.5	7.6	7.3
21	8.5	6.5	7.4	7.4	6.9

Table B6: EC results

Time (Weeks)	Standard (mS/m)	BNR Clarifier Effluent (mS/m)	Pilot Tank (mS/m)	Permeate (mS/m)
1	80	78	78	78
2	80	78	78	78
3	80	78	78	78
4	80	81	80	80
5	80	84	82	82
6	80	82	82	82
7	80	81	81	82
8	80	81	81	82
9	80	82	82	82
10	80	82	82	81
11	80	82	82	81
12	80	80	80	79
13	80	78	78	78
14	80	76	79	79
15	80	75	80	81
16	80	75	80	80
17	80	76	79	80
18	80	81	80	80
19	80	86	80	80
20	80	85	80	79
21	80	85	80	79

Table B7: SS results

Time (Weeks)	Standard (mg/L)	BNR Clarifier Effluent (mg/L)	Pilot Tank (mg/L)	Permeate (mg/L)
1	20	10	10	10
2	20	10	10	10
3	20	10	10	10
4	20	10	10	10
5	20	10	10	10
6	20	10	10	10
7	20	10	10	10
8	20	10	10	10
9	20	10	10	10
10	20	10	10	10
11	20	10	10	10
12	20	10	10	10
13	20	10	10	10
14	20	10	10	10
15	20	10	10	10
16	20	10	10	10
17	20	10	10	10
18	20	12	10	10
19	20	13	10	10
20	20	11	10	10
21	20	10	10	10

Table B8: E. coli results

Time (Weeks)	Standard (counts/L)	BNR Clarifier Effluent (counts/L)	Pilot Tank (counts/L)	Permeate (counts/L)
1	500	9800	1733	866
2	500	7320	1573	776
3	500	4840	1414	687
4	500	2807	1197	516
5	500	774	980	345
6	500	1253	632	212
7	500	1732	285	79
8	500	2419	360	60
9	500	3106	435	41
10	500	3973	924	364
11	500	4840	1414	687
12	500	2910	879	384
13	500	980	345	81
14	500	980	253	73
15	500	980	162	66
16	500	1850	541	96
17	500	2720	921	127
18	500	5690	1020	149
19	500	8660	1120	172
20	500	12000	182	80
21	500	1730	1190	320

Appendix C: Electricity Consumption Calculation

Voltage = 231.5v

Amps = 1.50A

Voltage × Amps

231.5 × 1.50 = 347.25 Wh

347.25/1000 = 0.35 KWh

0.35 ×24 h = 8.4 KWd