Investigating the effective removal of fat, oil and grease (FOG) in water treatment plants of the Mangaung Metropolitan Municipality

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DECLARATION

I, Mpho Gladness Sello, hereby declare that the dissertation titled *Investigating the effective removal of fat, oil and grease (FOG) in water treatment plants of the Mangaung Metropolitan Municipality*, submitted to the Central University of Technology, Free State, for the degree Master of Engineering in Civil Engineering, is my own independent work, and complies with the Code of Academic Integrity, as well as other relevant policies, procedures, rules and regulations of the Central University of Technology, Free State. This dissertation has not been submitted before to any institution by myself or any other person in fulfilment of the requirements for attainment of any degree or qualification.

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ABSTRACT

The most common type of wastewater under low-strength waste streams is municipal wastewater. It is characterised by low organic strength and high particulate organic matter constituents. Common pollutants in municipal wastewater include viruses, bacteria, protozoa, helminths, suspended solids, total dissolved solids, a few chemicals, nitrates, phosphates and fats, oil and grease (FOG). The presence of high concentrations of nitrates and phosphates in wastewater effluent can cause eutrophication of receiving water bodies. On the other hand, FOG in the wastewater treatment plants leads to inefficiencies of the wastewater system, resulting in severe environmental degradation and contamination of water resources. As a result, optimal wastewater treatment technology is one of the most used criteria for the treatment of wastewater.

The activated sludge and trickling filter systems are both known to remove FOG; however, the degree of efficiency of each method against the other in the removal of FOG is not known. The effectiveness and degree of the activated sludge compared to the biological trickling filter system in the removal of FOG showed no difference, since both treatment plants release FOG in their effluents.

This study presented findings from investigating the effectiveness of the wastewater treatment technologies in two treatment plants in the Mangaung Metropolitan Municipality (MMM) in South Africa. The study was conducted to compare the efficiency of the trickling filter and activated sludge systems in the treatment of FOG, nitrogen and phosphorus and the possible correlation of nitrates and phosphates to FOG. The effects of other parameters such as pH, atmospheric pressure, temperature, dissolved oxygen, salinity, conductivity, resistivity and total dissolved solids were also investigated.

Twenty grab samples of both the influent and effluent of the NEWTP and the BWTP were collected in total for the months; June, July, August, September and October. Samples were analysed at the laboratory of the MMM situated at the BWTW. The sampling and laboratory analysis of FOG followed the description of the Environmental Protection Agency (EPA 1664B). The hexane extraction and gravimetric method was used in the analysis. Nitrates were sampled and analysed using a SOP Chem 005 Spectroquant nitrate test, while phosphates were sampled and analysed using a Spectroquant Prove spectrophotometer in the laboratory. The Hanna HI98192 and Hanna HI98193 multimeters were used for field measurements of pH, dissolved oxygen, temperature, atmospheric pressure, conductivity, resistivity, salinity and total dissolved solids.

The results showed that the trickling filter system from BWTP removed FOG by 61.36%, while the activated sludge system from NEWTP removed FOG by 52.81%, which showed that the trickling filter system is more effective than the activated sludge system in the removal of FOG. On the other hand, the removal of nitrates and phosphates was found to be within the effluent discharge standards. The regression analysis for both BWTW and NEWTP showed a strong correlation between nitrates and FOG. In addition, the regression analysis for phosphates and FOG in both wastewater treatment plants also indicated a strong correlation between the two variables. Furthermore, the removal of nitrates and phosphates was found to be satisfactory and complying with the South African discharge standards. Similarly, phosphate levels in the effluents of the two plants were also found to be complying with the South African effluent discharge standards.

This concluded that the volume of FOG found in the effluents of these plants was influenced by the volume of nitrates and FOG. In addition, the comparison of the trickling filter and activated sludge systems indicated that the trickling filter system is an efficient treatment method for the treatment of FOG, compared to the activated sludge system.

Key terms: activated sludge, FOG, nitrates, phosphates, trickling filter, wastewater treatment

DEDICATION

This study is dedicated to God Almighty, my creator, for giving me the inspiration, wisdom, strength and endurance to complete this dissertation.

I also dedicate this work to my mother, Pauline Sello, and grandmother, Mamotsoari Sello, for their encouragement in my studies.

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LIST OF ABBREVIATIONS

ABR	Anaerobic baffled reactor
BOD	Biological oxygen demand
BWTW	Bloemspruit wastewater treatment works
COD	Chemical oxygen demand
DAF	Dissolved air flotation
DO	Dissolved oxygen
EGSB	Expanded granular sludge beds
EPA	Environmental Protection Agency
FOG	Fats, oil and grease
MMM	Mangaung Metropolitan Municipality
NEWTW	North eastern wastewater treatment works
PVC	Polyvinyl chloride
TDS	Total dissolved solids
UNESCO	United Nations Educational, Scientific and Cultural Organization
UASB	Up-flow Anaerobic Sludge Blanket
USEPA	United States Environmental Protection Agency

LIST OF UNITS

°C	degrees Celsius
°F	degrees Fahrenheit
%	percentage
ℓ	litre
g/ℓ	gram per litre
mℓ	millilitre
mg/ℓ	milligram per litre
m/h	metre per hour
mm	millimetre
mmHg	millimetres of mercury
mg	milligram
mm^3	Cubic metre
ML	Megalitres
mS/cm	milliSiemens per centimeter
N	Normality
Pa	Pascals
ppm	Parts per meter
ppt	Parts per trillion
S/cm	Conductivity Siemens per meter

ACADEMIC OUTPUT FROM THIS DISSERTATION

Conference paper

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CHAPTER 1

INTRODUCTION TO THE STUDY

1.1 Background to the problem

A sufficient, unpolluted and palatable supply of water is essential for various users (Bos et al., 2016). A great volume of wastewater is brought about by urbanisation advancement and human population increase, which results in an unsafe environment (Jonnalagadda & Mhere, 2001). As a result, poorly treated wastewater effluent creates an unfavorable environment for the surrounding habitat, therefore wastewater treatment technologies are frequently modified to address the current concerns. For this reason, adequately treated wastewater is of great significance before its disposal or reuse to avert pollutants from entering the receiving water bodies (Edokpayi et al., 2017).

Different technologies are used to treat different types of wastewater. Along with home wastewater treatment systems, there are systems for the treatment of industrial, municipal, and terrestrial wastewater. Municipal wastewater treatment deals with wastewater from household sewage, both run-off, domestic and institutional. It involves basic processes such as primary treatment which eliminates solid material, secondary treatment to break down dissolved and suspended organic material, and tertiary treatment to disinfect (Wells, 2016). Wastewater treatment is a combination of processes used in steps to remove, kill, or "inactivate" a large portion of the pollutants and disease-causing organisms in wastewater.

There are many technologies used for treating wastewater. Some of the technologies for treating municipal wastewater are the biological trickling filter system, which was used in the old days, and activated sludge which is a more recently introduced technology. The biological trickling filter technology is an aerobic treatment system that utilises microorganisms connected to a medium to eliminate organic matter from wastewater, while the activated sludge process is a part of the anaerobic process that falls under the biological treatment process (Gray, 2004).

Water quality and safety can be evaluated by assessing the concentration of dispersed fats, oil and grease (FOG) (Osibanjo et al., 2011; Westerhoff et al., 2018). FOG in discharged water can cause surface films and shoreline deposits contributory to environmental deterioration which poses health risks for humans when discharged in surface or groundwater (Pisal, 2010). Disposal of FOG in the wastewater treatment plants leads to inadequate wastewater treatment which leads to serious environmental deterioration and pollution of receiving water bodies (Edokpayi et al., 2017). In addition, FOG draws on an additional load of organic matter onto the secondary aerobic treatment stage, consequently increasing the total aeration requirement (Collin et al., 2020). FOG can also interfere with the co-digestion process because of its settling or floating characteristics. Settling is an important process in wastewater treatment plants that happens in primary sedimentation tanks and secondary sedimentation tanks, (Torfs et al., 2016). FOG is also implicated in causing sewer blockages leading to sewerage system overflows (Lasmin et al., 2014).

Apart from FOG, high concentrations of nitrogen and phosphorus in wastewater can cause eutrophication of receiving water bodies (Mujtaba et al., 2018). Nitrates and phosphates in wastewater emanate from wastes of animals and humans (De Girolamo & Lo Porto 2020; Li et al., 2018). In the aquatic environment, nitrates are contributory to several issues. For instance, the existence of nitrate in water causes algal revolution or eutrophication, which is the formation of algae mats, which obstruct sunlight and speed the use of dissolved oxygen (DO), resulting in the death of aquatic life (Guo et al., 2013). The rise in nitrate concentration has a serious effect on water ecosystems, leading to eutrophication and toxic algal blooms (Hoagland et al., 2019), while phosphate increase largely impairs the aquatic ecosystem, thus creating an environmental concern (Mavhungu et al., 2019).

1.2 Problem statement

The biological trickling filter system is used at the Bloemspruit wastewater treatment works (BWTW) of Mangaung, which was built in 1902. However, as a result of the population growth, it became hydraulically overloaded, which is why the North Eastern wastewater treatment works (NEWTW), using the activated sludge, was built in 2014 (Mail & Guardian, 2014). The rate of efficiency of the activated sludge technology in the elimination of FOG in comparison to the trickling filter system, is the same as the two treatment facilities release FOG as well as nutrients from their effluents.

It has been noted that there are repetitive incidents of sewer blockages in Mangaung, which are the result of FOG buildup in pipes. Furthermore, both municipal treatment facilities discharge entering the river catchment which negatively affects the surrounding habitat. Stams and Elferink (1997) reported inadequate treatment of FOG in septic system maintenance has dangerous environmental impacts. On this basis, an investigation of the treatment works' execution and their efficiency in the removal of FOG, phosphorus and nitrogen was completed. No previous studies have established a connection between nitrogen, phosphorus, and FOG in municipal wastewater treated with activated sludge and biological trickling filters.

This study examined the efficacy of several treatment methods in removing nutrients and FOG as well as any potential connections between the levels of FOG and nutrients discharged to the catchment following treatment. Rittman and McCarty (2010) state that the pollutants eliminated and the efficiency of the two treatment facilities are influenced by the concentration of the contaminants treated, the availability of oxygen, the efficiency and dependability of the treatment, operating costs, and construction times.

1.3 Research questions

- Is the activated sludge technology more effective than the trickling filter system in the elimination of FOG?
- Is the activated sludge system more effective than the trickling filter technology in the elimination of nutrients?

1.4 Research hypotheses

Associated hypotheses with the above research questions include a null hypothesis that the activated sludge is more effective than the trickling filter technology in the removal of FOG and nutrients from wastewater in municipal wastewater treatment. Additionally, it is essential to conduct more scientific studies between the two technologies to fully establish the difference between the two technologies. In this way, the discrepancy between the two technologies would be clearer.

1.5 Aim and objectives

The main aim of this research was to investigate the effectiveness of two treatment technologies used in wastewater treatment for the elimination of FOG and nutrients, by measuring the amount of FOG in the influent and effluent of the BWTW and NEWTW in the MMM.

1.5.1 Objectives

The objectives of this study were:

- To determine the effectiveness of the two wastewater treatment technologies in the elimination of FOG and nutrients.
- To investigate and recommend extra pre-treatment measures to the plants for improvement in the elimination of FOG.
- To investigate the likely impact of FOG and nutrients released to the catchment after treatment.

1.6 Significance of the study

This investigation looked to see if there were any differences between the trickling filter and activated sludge techniques of eliminating FOG in two MMM wastewater treatment facilities. The NEWTW was built to relief the BWTW, which was hydraulically overloaded due to its capacity being unproportioned to the growing city of Mangaung. In addition, sewer blockages and overflows were frequently noted in Mangaung because of the accumulation of FOG in the pipes. Similarly, FOG was found in the effluent of the two plants, which is discharged in the river watershed, harming the ecology in the process. FOG in effluents causes detrimental environmental impacts to aquatic life and health risks to humans, hence necessitating effective wastewater treatment is critical.

1.7 Scope of the study

The research centred on the amount of FOG present in two municipal wastewater treatment facilities of the MMM, namely the BWTW which uses the trickling filter technology and the NEWTW which uses the activated sludge technique. The study further investigated the nitrogen and phosphate levels in the effluent. The BWTW discharges into a nearby stream, which can prove to be detrimental to the aquatic life if found in large quantities. The study also focused on other parameters such as salinity, conductivity, temperature, pH, atmospheric pressure, resistivity, total dissolved solids (TDS) and DO, which contributed to analysing the performance of the two technologies, the relationship between the parameters with regard to the performance of the two wastewater plants and the correlation of the parameters in the removal of FOG.

1.8 Limitations of the study

The study was restricted to examining how well the trickling filter and activated sludge systems removed FOG, and its correlation with nitrates, phosphates pH, conductivity, resistivity, salinity, atmospheric pressure, DO and temperature. The study did not consider the following:

- Investigation of the two techniques in the phosphorus and nitrogen removal.
- The effectiveness of the two systems in removing various pollutants.
- FOG removal in other treatment facilities in the MMM.

1.9 Structure of the dissertation

Chapter 1: Introduction

This chapter summarises the content of the study, starting with the background of the study, the problem statement, the research questions, the hypotheses and the research objectives. It also describes the significance and scope of the study as well as the limitations of the study.

Chapter 2: Literature Review

In this section, various studies, surveys, scientific articles and literature that provides a description, summary and critical evaluation of FOG in municipal wastewater treatment are reviewed.

Chapter 3: Study Area

This chapter describes the study area of the two wastewater treatment plants in detail. It surveys the significant demographic and environmental characteristics of the case study. It describes the relevant area directly related to the research and it defines FOG in municipal wastewater treatment by being location-specific.

Chapter 4: Research Methodology

In this chapter, specific procedures or techniques used to identify and analyse FOG in municipal wastewater systems are discussed. It outlines the research methodology, justification for using quantitative research, sampling, testing, data analysis, validation of data, control, challenges and implications of the project.

Chapter 5: Results and Analysis

This section presents the findings of the study derived from the methods applied to gather and analyse the information. It presents these findings in a logical sequence and breaks down the data into sentences that show its significance to the research questions.

Chapter 6: Conclusion

This chapter concludes the thesis. It includes a summary of the findings of the research, conclusions and recommendations based on the data analysed in the previous chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The result of an increase in human population and urbanisation growth is the production of a huge amount of wastewater that creates challenges for a safe environment (Jonnalagadda & Mhere, 2001). This causes a discharge of poorly treated wastewater that negatively affects the receiving water bodies (Edokpayi et al., 2017). As a result, proper wastewater treatment remains a critical issue globally, despite various technological advancements and breakthroughs (Chai et al., 2021). This necessitates the consideration of a more advanced technology in treating wastewater; hence, wastewater treatment technology is fast changing to meet the current daily challenges (Armah et al., 2020). Wastewater needs to be adequately treated prior to its disposal or reuse in order to protect receiving water bodies from contamination (Edokpayi et al., 2015).

Wastewater treatment makes use of a variety of methods. These are municipal, home, industrial wastewater treatment systems and terrestrial wastewater treatment systems. Municipal wastewater treatment deals with wastewater from household sewage, both runoff, domestic and institutional. It mainly comprises of 99.9% water, together with relatively small concentrations of suspended and dissolved organic and inorganic solids. The organic substances present in municipal wastewater may include carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals (Pereira et al., 2014). Furthermore, it involves basic processes such as preliminary treatment to separate easily removed particles such as bulky floating or suspended solids and grit (Enfrin et al., 2019; Pal, 2017a). Second is the primary treatment that removes up to 70% of solid material (Horan, 1990). Third is the secondary treatment to digest dissolved and suspended organic matter (Abdel-Raouf et al., 2012) and lastly the tertiary treatment to disinfect (Wells, 2016).

One of the common pollutants of municipal wastewater is FOG. FOG has been shown to have negative effects on wastewater treatment facilities and aquatic life when it is occasionally discharged hence, the effective removal of FOG is essential (Alade et al., 2011).

2.2 What is FOG?

Fat, oil and grease are the end products of cooking (Husain et al., 2014). FOG may include matter such as food scraps, slaughterhouse meat fats, soaps, detergents and certain dyes (Arthur & Blanc, 2013; Husain 2014). FOG exists in different forms such as solid and liquid, based on the saturation of the carbon chain (Husain et al., 2014).

2.2.1 Chemical composition of FOG

Oil and grease are quite similar chemically compounds (esters) of alcohol or glycerol with fatty acids (Biermann et al., 2011). At room temperature, liquid fatty acids at room temperatures are called oils, while solids are called grease (Franklin et al, 2004). Depending on the origin of the organism, the fatty acid composition of fats and oils, which are complex combinations of triacylglycerol, differs (Gunstone, 2004).

2.2.2 Physical properties of FOG

FOG is distinguished by its greasy feel and can exist as a liquid or a solid. FOG is flavourless, tasteless, and colourless when it isn't blended. Additionally, in organic solvents such as hexane, ether, and chloroform, FOG is soluble, but insoluble in water (Sincero & Sincero, 2003). FOG floats on the water's surface because it has a density that is less than that of water (4 gravity 1). Additionally, FOG will produce emulsions with an aqueous medium in the presence of soap or other emulsifying agents (Patrick, 2012).

Depending on the lipids composition and the double bonds presence, FOG has a high viscosity that fluctuates. Due to its looser-packed structure, FOG has a lower viscosity with an increasing amount of double bonds in the carbon chain (Firestone, 2006). A distinctively low pH of FOG is due to the existence of a significant number of non-esterified fatty acids, which are often created by the esterification and decomposition processes of fats as food is deep-fried (Patrick, 2012).

2.2.3 Where does FOG come from?

Restaurants and homes are FOG sources entering the sewage system (Husain et al., 2014). Despite the fact that all home greywater streams include oil and grease, kitchen greywater is said to contribute the most (Friedler, 2004). In addition, despite the fact that all home greywater streams include oil and grease, kitchen greywater is said to contribute the most. (Bustillo-Lecompte & Mehrvar, 2015). Additionally, non-vegetable manufacturing sectors like the Industries in metal cutting and forming, steel, machine, petroleum refining, and textiles produce wastewater that contains FOG (Wake, 2005). Municipal wastewater may also contain FOG from small industries. Oily effluent from the metalworking and finishing industries is produced by the application of coolants and lubricants required to cool the work pieces and machine tools, minimize friction and wear of tools and dyes, as well as increase the surface quality of work pieces (Busca, 2004). Therefore, the concentration of FOG in raw residential waste water is invariably ranging 50 mg/ℓ to 100 mg/ℓ (Franklin et al, 2004).

2.3 Problems caused by the presence of FOG

2.3.1 Sanitary sewer overflows

The reaction between FOG and calcium found in wastewater may cause sanitary overflows due to the built-up of insoluble calcium salts of fatty acids (Dominic et al., 2013). FOG deposits account for 40–50% of sewerage overflows nationwide and are an indirect cause of another 10–25% (Southerland, 2002; USEPA, 2003). Ultimately, this sewage may land in state water bodies as a pollutant (Husain et al., 2014). In the United Kingdom, sewer obstructions, clearing, and additional costs associated with cleaning up after flooding incidents total over 15 million pounds annually (Arthur & Blanc, 2013).

2.3.2 Clogging of pipes

FOG clogs sewers in treatment facilities that require cleaning and may necessitate replacing pipes (Keener et al., 2008). Due to this, wastewater treatment plants may lead to increased maintenance and running costs (Mueller et al., 2003). Furthermore, the capacity of the sewerage system is lessened because of a persistent FOG increase due to the FOG's tendency to solidify and accumulate on sewer inside walls, resulting in pipe blockages and a reduction in the flow of wastewater (Husain et al., 2014). Due to blockage, the quantity of solid rubbish that reaches the wastewater treatment works is significantly increased by FOG deposits, which may also damage the sewerage system and increase the frequency of cleaning and maintenance. An excessively loaded wastewater treatment plant may result in a decrease in the treatment process's quality results resulting in an effluent detrimental to the environment within the discharge catchment (Aymong, 2007).

2.3.3 Interference with wastewater treatment processes

Large levels of FOG can raise biological oxygen demand (BOD), float to the top, and solidify, leading to unsightly circumstances when they are discharged to receiving wastewater from municipal systems (Kasima, 2014). FOG reduces DO levels and elevates BOD in the water due to the lake surface developing an oil coating that prevents oxygen transfer from the atmosphere (Sahu et al., 2007). Furthermore, FOG could potentially jam sludge pumps, restrict screens and trickling filter systems, and, in high quantities, limit the activity of microorganisms that break down sludge (Fulazzaky & Omar, 2012). This could result in a decline in the quality of the treatment process' results (Aymong, 2007). Furthermore, FOG creates floating scum that disrupts wastewater treatment processes (Klaucans & Sams, 2018). This significantly increases the risk to the biological process that uses oxygen (Cammarota et al., 2001; Masse et al., 2001, Vidal et al., 2000). The impediment of anaerobic treatment has been reported to be caused by a high quantity of wastewater containing non-esterified fatty acids (Hwu et al., 1996). In addition, FOG causes issues like the development of offensive odours that hinder the efficient operation of sewage treatment facilities (Brooksbank et al., 2007). This concludes that the efficiency of both treatment techniques in the elimination of Fats, oils and grease is hindered by the presence of FOG hence, the plants can perform better in the absence of FOG hence the need for extra pre-treatment measures to the plants for improvement in the elimination of FOG.

2.3.4 Environmental impacts of FOG discharged into streams

The blockages and sewage flooding caused by FOG may result in environmental problems in the immediate and surrounding habitats (Chand and Kumar, 2017; Husain et al., 2014; Madanhire and Mbohwa et al., 2016). Due to this, the concentration of FOG in wastewater streams increases adverse effects on the ecology (Alade et al., 2011). FOG causes an oil coating to build in water bodies, which creates serious pollution issues such decreasing light penetration and photosynthesis (Alade et al., 2011). Furthermore, it prevents oxygen entering into the water medium from the atmosphere, which results in less DO at the bottom of the ocean and negatively impacts aquatic life's ability to survive in water (Mohammadi & Esmaelifar, 2005).

2.4 Removal of FOG

Numerous technologies utilised in municipal wastewater treatment across the world under aerobic technologies and anaerobic technologies were investigated to determine the efficacy of the two wastewater treatment methods in the eradication of FOG. Aerobic wastewater treatment systems use oxygen-feeding bacteria, protozoa and other specialty microbes to clean water, whereas anaerobic treatment systems use a biological process where microorganisms degrade organic contaminants in the absence of oxygen (Englande et al., 2015). Both biological trickling filter and the activated sludge are aerobic systems. The stages of treatment for these two methods include preliminary treatment, primary treatment, secondary treatment, and tertiary treatment (Templeton & Butler, 2011). Other methods of removing FOG include physical and chemical methods, physicochemical, combined methods, treatment using biosurfactant and biological treatment using enzymatic activity (Azhdarpoor et al., 2014; Lafi et al., 2009). Some of the processing factors include concentration, size of droplets and the physical nature of FOG that are the main governing parameters for the extent of removal of oil (Coca et al., 2011).

2.4.1 Aerobic treatment of FOG

2.4.1.1Preliminary treatment or primary treatment

Pre-treatment involves processes such as screening, catch basins, flotation, equalisation, and settlers for reclaiming of FOG (Mittal, 2006). Screens and filters are used to remove suspended solids in wastewater (Gibson et al., 2020). Solid particles may consist of FOG, paper, rags and hair. In addition, wastewater in this stage passes through strainers. Strainers are made of metal wire and can intercept particles of various sizes based on the mesh size of the strainer (Shengquan et al., 2008). Gravity-based FOG and finely suspended particles removal is another application for catch basins (Gutu et al., 2021). Catch basins can also be used to remove FOG and finely suspended solids by gravity. FOG and the fine solids will rise to the surface. While solids heavier than water, sink to the bottom (Kaya & Hung, 2021). In addition, a scraper is used to remove sludge from the bottom and a skimmer is used to remove FOG and scum from the top (Mbulawa, 2017). In order to eliminate free floating FOG, gravity separators can also be employed as a primary treatment (Pintor et al., 2016).

2.4.1.2Secondary treatment

Biological treatments eliminate organic compounds and pathogens from the effluent using microorganisms (Roy & Saha, 2021). Biological treatments may remove more than 90% of contaminants from wastewater (Mittal, 2006). In an activated sludge system, the process of biological treatment is called secondary treatment, and it involves secondary settling and aeration procedures.

2.4.1.3Tertiary treatment

Before water is reused, both organic microbes and nitrogen and phosphorus are completely eliminated during this stage by physical and biological processes. Bacterial elimination is another possible use for the disinfection unit. (Abdel-Fatah et al., 2016).

2.4.1.4Activated sludge

A suspended growth biological treatment technology is activated sludge. A mixture of wastewater and biological sludge made up of microorganisms must be stirred and aerated in order to accomplish this (Rezai & Allahkarami, 2021). Air is supplied by mechanical or dispersed aeration (Niaounakis & Halvadakis, 2006). The organic molecules are extensively combined with the bacteria, who use this organic stuff as nourishment (Hansen & Cheong, 2019). As they multiply and are disturbed by air agitation, the individual microorganisms clump together (flocculate) to generate a biological floc, an active mass of germs known as activated sludge (Yildiz, 2012).

A mixture of activated sludge and wastewater is called mixed liquor. This mixture contains a range of heterotrophic microorganisms, including bacteria, protozoa, fungus, and bigger microorganisms (Pike & Curds, 1971). This mixed liquor is sent into the final clarifier, which is where the activated sludge settles out, as it exits the aeration tank (Ahansazan et al., 2014). The activated sludge is then separated from the wastewater, with the majority of the settled sludge being returned to the aeration tank to maintain a high microbial population (Singh et al., 2016).

After the activated sludge is removed from the wastewater, the majority of the settled sludge is put back into the aeration tank to keep the microbial population high. (Sharma et al., 2021). If a lot of sludge is dumped, the concentration of microorganisms in the mixed liquor will fall too low for efficient treatment. If little sludge is wasted, a high concentration of microorganisms will accumulate, and the secondary tank will overflow into the receiving system (Theobald, 2014). The return sludge ensures that the hydraulic retention time is greatly outweighed by the mean cell residence time, also known as sludge age, which is the average amount of time that microorganisms are kept in systems. This is a crucial component of this technology (Deowan et al., 2015). This approach aids in maintaining a large population of microbes that may efficiently oxidize organic molecules in a short amount of time and subsequently be recycled. The aeration tank's retention period ranges from four to eight hours (Pal, 2017b).

In Figure 2.1, which depicts the activated sludge process, screening, flow monitoring, and grit removal make up the initial treatment (Pintor et al., 2016). To remove settleable suspended particles, utilize the primary clarifier, the second component (Henneman et al., 2018). The overflow travels to an aeration tank, while the underflow is used for sludge treatment and disposal (Kamizela & Kowalczyk, 2019). This stage is when dissolved and fine suspended organic matter undergoes biological oxidation.

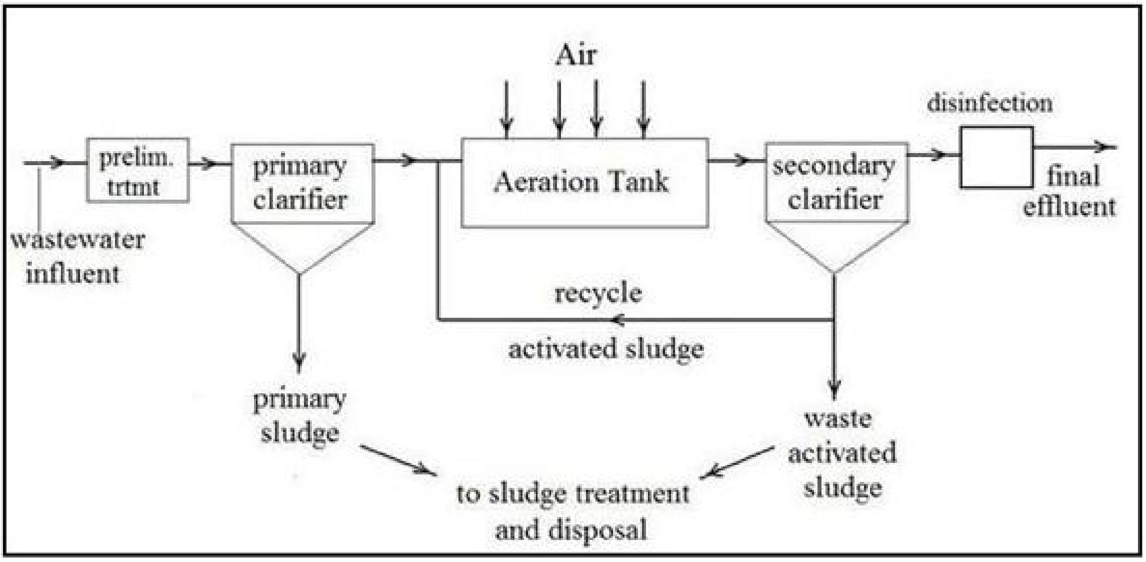

Figure 2.1 ***Activated sludge flow diagram*** (Sastry, Rao & Nahata 2013)

Because aerobic bacteria, organic debris, and DO are all combined in the aeration tank, biological oxidation occurs (Amin et al., 2020). After that, the primary effluent is joined by the organic matter. The DO is then maintained by forcing air through diffusers into the aeration tank (Piotrowski, 2015). By settling off the "activated sludge" in the secondary clarifier and returning them back into the aeration tank, a enough consolidation of microorganisms is maintained there. FOG chemicals are slowly metabolized after being absorbed into wastewater through flocculation (He et al., 2013). Another crucial enzyme for removing FOG is lipase (Mobarak-Qamsari et al., 2012; Rigo et al., 2008).

The mean effectiveness of removal was found to be 70% in a research conducted from June to September 2011 in Iran at the Shiraz Municipal Wastewater Treatment Facility (Dehghani et al., 2014) and the effluent criteria were met by the removal efficiency of FOG. The range of wastewater treatment's FOG removal effectiveness was 59–85% with an average of 70%. Furthermore, Dehghani et al. (2014) noted the average removal rate to be 70%. Nonetheless, it was discovered that the FOG volume in the wastewater treatment significantly influenced the rate of FOG removal using activated sludge.

Another study used FOG from the grease-trap of a fast-food restaurant to examine the evolution of numerous civilisations. It was found that the activated sludge had a more consistent clearance rate of more than 90% (Wakelin & Forster, 1997). Despite the fact that FOG had been successfully removed in prior investigations, Reddy et al., (2003) reported that the microflora in activated sludge systems did not successfully breakdown FOG due to the short retention durations. Furthermore, according to Chipasa and Mdrzycka's (2008) study, the retained FOG volume could not be larger than 15% of the initial FOG.. The results showed that single fatty acid accumulation varied in wastewater, which was also utilised as a fuel by bacteria. The results showed that single fatty acid accumulation varied in wastewater that had also been used as a feedstock by bacteria. The results showed that single fatty acid accumulation varied in wastewater that had also been used as a feedstock by bacteria.

2.4.1.5Trickling filter

A trickling filter is a bed with a specific surface area material, such as shredded polyvinyl chloride (PVC) bottles, crushed rocks, gravel, or special pre-formed plastic filter media to form a biofilm (Rezai & Allahkarami, 2021). Trickling filters are used to eliminate organic matter from wastewater (Dhokpande et al., 2014). The aerobic trickling filter removes organic materials from wastewater by using microorganisms attached to a media (Jalowiecki et al., 2016). Figure 2.2 shows the trickling filter.

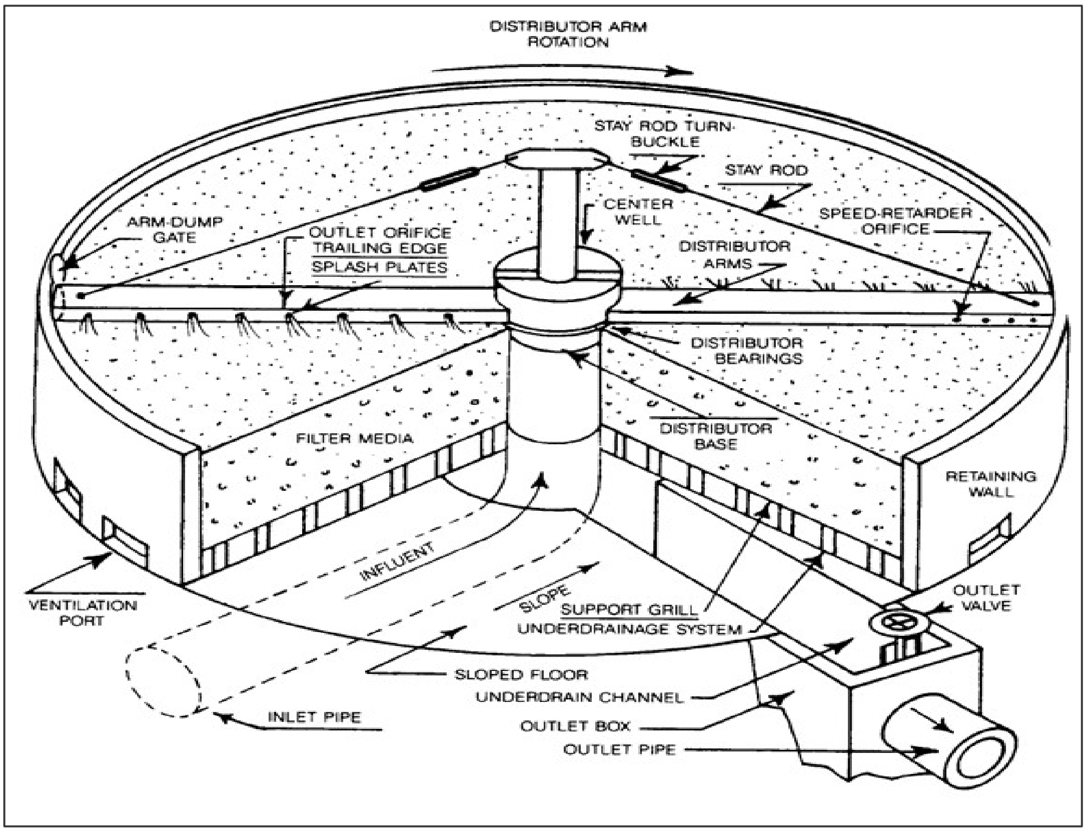

Figure 2.2 ***Trickling filter*** Tchnobonaglous et al. (1991)

The trickling filter system shown in Figure 2.2 includes a distribution system (Daigger & Boltz, 2011). Although a fixed nozzle distributor is also utilized in square or rectangular reactors, a rotating hydraulic distribution is typically the norm for this operation (Cabrera et al., 2019). Although a fixed nozzle distributor is also utilized in square or rectangular reactors, a rotating hydraulic distribution is typically the norm for this operation (Solum & Deming, 1992). The underdrain system of a trickling filter also gathers sediments and filtrate while also providing air for microbial development on the filter. The separated solids from the treated wastewater are pumped to a settling tank (Voutchkov, 2005).

Most often, a small amount of liquid from the settling chamber is injected once again to hasten the process, quicken the wetting and flushing of the filter media, and enhance the rate of removal. (Daigger & Boltz, 2011). There must be enough air In order for the trickling filter to function properly. Natural draft and wind forces have been shown to be proportionate for supplying air to the system if there are adequate ventilation openings at the bottom of the filter and enough void space in the medium (Butler & Boltz, 2014). Based on the organic loading of the trickling filter, there are four fundamental groups of filter designs: low-rate filters, intermediate-rate filters, high-rate filters, and roughing filters (Muralikrishna & Manickam, 2017).

The filter is continuously "trickled" with pre-settled wastewater. The biofilm that covers the filter material causes organics to degrade aerobically as water passes through the holes of the filter. Rocks, gravel, crushed PVC bottles, or specialized pre-formed plastic filter media can all be used as this filter material. In addition to producing new biomass, the organisms that populate the thin biofilm that forms over the surface of the media oxidize the organic load in the wastewater to carbon dioxide and water. The filter is "trickled" with the incoming pre-treated wastewater. The filter media undergoes cycles of dosing and exposure to air in this manner. The inner layers of the biomass may be anoxic or anaerobic and use oxygen (Rezai & Allahkarami, 2021).

The trickling filter is a very popular biological treatment method since it is simple to maintain and regulate (Abou-Elela et al., 2017). Conversely, the trickling filter technique' major flaw is how inconsistently it removes phosphorus and nitrogen when compared to activated sludge (Franklin, 2004). The trickling filter technique' major flaw is how inconsistently it removes phosphorus and nitrogen when compared to activated sludge (Cramer et al., 2021). Additionally, a study conducted by Kurian and Nakhla (2006) investigated various FOG removal techniques. The outcomes showed that more than 90% of FOG was removed using membrane techniques. The efficacy of FOG removal by membrane techniques was higher than that of active sludge as usual.

2.4.2 Anaerobic technologies of treating FOG in municipal wastewater

Using a variety of microbial communities and a lack of oxygen, anaerobic digestion is a biochemical process that breaks down complex insoluble organic matter to produce methane and carbon dioxide (Jiang et al., 2015). Like the majority of biological processes, anaerobic digestion depends on a variety of environmental conditions for optimal operation, including temperature, pH, the availability of nutrients, carbon-to-nitrogen and carbon-to-phosphorus ratios, and the presence of inhibitory and poisonous chemicals (Elalami et al., 2021). With so many interconnected parameters, digesters are frequently damaged as a result of little changes (Mata-Alvarez et al., 2000). Without oxygen, bacteria carry out their respiration through anaerobic processes, and oxygen can occasionally be hazardous to them (Zia & Sreekrishnan 2016).

The anaerobic digestion of high-strength lipid wastes has been discovered to have certain operational challenges, but co-digestion is thought to have a number of benefits. Some of these issues include the reduction of acetoclastic and methanogenic bacteria, constraints on substrate and product transport, digester foaming, pump and pipe blockages, system clogs, and sludge flotation (Shea et al., 2010). Studies show that excessive FOG in wastewater results in filamentous thickening during wastewater treatment, which results in mechanical problems and clogging in anaerobic treatment units.

2.4.2.1Anaerobic lagoons

According to studies, wastewater with a lot of FOG causes mechanical issues and clogging in anaerobic treatment units due to filamentous thickening during wastewater treatment (Woodard & Curran 2006). Due to their ease of application and construction, lagoons have been widely used in Australia to treat agricultural wastewater (Laginestra & Van-Oorschot, 2009). Due to its effectiveness in reducing BOD and COD by nearly 90%. In the meat business, anaerobic ponds are widely used as the initial stage of secondary treatment for high-strength abattoir wastewater (McCabe et al., 2014). However, there are several substantial downsides, including the production of methane and odour emissions (Selvakumar et al., 2022). Nonetheless, anaerobic lagoons are known to be highly adequate in the removal of FOG (Astals et al., 2014; Jensen et al., 2011; McCabe et al., 2014).

2.4.2.2Up-flow anaerobic sludge blanket

An up-flow anaerobic sludge blanket (UASB) reactor's granular sludge bed, which extends as wastewater is forced to flow vertically upwards through it, is what makes the reactor function (Abbasi & Abbasi 2012). The UASB structure enables an impressively successful blending of the wastewater and biomass, leading to an accelerated anaerobic decomposition (Tauseef et al., 2013). In this technology, wastewater enters the reactor at the bottom and rises through the so-called "sludge blanket," which is a bed of granular sludge (Tauseef et al., 2013). The microflora associated with the sludge particles eliminates contaminants from wastewater; as a result, biofilm features and the degree of sludge–wastewater interaction are some of the crucial factors influencing the UASB reactor performance. A UASB reactor's typical design and functional characteristics include a height-to-diameter ratio of 0.2 to 0.5 and an up-flow velocity of 0.5 to 1.0 m/h (Lim & Kim 2014). The UASB are very effective in the removal of FOG. A study done by Musa et al. (2019), assessing three UASBs, revealed that the FOG removal rates using a UASB, were 89%, 81% and 74% in slaughterhouse effluent.

2.4.2.3Expanded granular sludge beds

Expanded granular sludge beds (EGSBs) are much the same as the UASB technology, with the main difference being that the wastewater is recirculated through the system to enhance substantial contact with the sludge (Cruz-Salomón et al., 2019). EGSBs are capable of treating streams with lots of organics (Gutierrez et al., 2022). Furthermore, the EGSB is an affordable, powerful and more favoured technology due to its ability to function using a fluidised bed that permits a rising organic load during cell retention times, increasing treatment efficiencies (up to 95%) and renewable energy (Cruz-Salomón et al., 2019). Nevertheless, the effectiveness of this bioreactor is mainly dependent on the functional conditions (Mahat et al., 2013). Furthermore, the drawback of the EGSB is that it needs a DAF system in the removal of FOG, as the performance of the entire process was noted to decline gradually as a result of the presence of a high quality of FOG (Basitere et al., 2015). However, in a research done by Meyo et al. (2021), the effectiveness of the EGSB in removal of FOG was reported to be greater than 95%, following pre-treatment, and 83% FOG removal during pre-treatment.

2.4.2.4Anaerobic baffled reactors

In order to allow interaction between influent wastewater and biomass, anaerobic baffled reactors (ABRs) are designed with semi-enclosed chambers storing a significant active microbial mass and placed to push the wastewater under and over (or through) the baffles (Pal 2017a). In order to allow interaction between influent wastewater and biomass, anaerobic baffled reactors (ABRs) are designed with semi-enclosed chambers storing a significant active microbial mass and placed to push the wastewater under and over (or through) the baffles (Motteran et al., 2013). Similarly, only 50% of FOG was removed by the ABR is a study investigating the treatment of domestic wastewater using an ABR (Nasr et al., 2009).

2.4.2.5Anaerobic filter reactors

An anaerobic filter is made of packed material produced using any non-degradable, shaped material or polymer that has a high surface-area-to-volume ratio (Chelliapan et al., 2020). An anaerobic channel mat is produced when anaerobic bacteria may connect to and spread through the packed materials like a biofilm (Heeg et al., 2014). Different matter such as plastics, sandstone, granular activated carbon, granite quartz or reticulated foam polymers can be used for the packed materials (Selvakumar et al., 2022). Low or high quality water can be treated using this reactor (Kosseva 2011). However, because of its considerable advantages over aerobic processes such as lower nutrient requirement, less surplus sludge production, and energy recovery via methane production, the anaerobic filter process has recently been frequently used for the treatment of miscellaneous wastewaters (Lee et al., 2006).

Anaerobic filter reactor has overall adequate support and filter media function as a natural boundary against biomass decrease, particularly in the treatment of wastewater containing FOG (Alves et al., 2000, Martin et al., 2010). This is an evident dominance for anaerobic filters compared to other anaerobic processes (Chanakya & Khuntia, 2014). However, there as some drawbacks with this method, which are mostly physical difficulties to the degeneration of the composition of the bed by the growth of non-biodegradable solids; hence, the need for channelling and shortcutting the flow (Chelliapan et al., 2020). Additionally, the performance of the bioreactor fluctuates, based on the organic loading rate, hydraulic retention time, and wastewater type (Omil et al., 2003). Nearly full elimination of phenol was recorded from oil refinery wastewater at an eight hour hydraulic retention time (Jou & Huang 2003).

2.4.3 Chemical methods of removing FOG in wastewater

2.4.3.1Dissolved air flotation

In the realm of water treatment, when water contains low-density particles that tend to float or sink slowly, the DAF method has frequently been used as an alternative to sedimentation. (Kempeneers et al., 2001). To achieve a high oil-water separation rate, Li et al. (2007) tried DAF and column flotation in combination with the tower separation system for treating oily wastewater. Additionally, Dassey and Theegala (2012) found a FOG removal efficiency of nearly 100% in a study assessing coagulation pre-treatment on poultry processing wastewater for DAF.

2.4.3.2Induced air flotation

Induced air flotation is a flotation process with a backup bubble generation system (Fagkaew et al., 2022) which relies on gravity (Chalermsinsuwan et al., 2016e; Silva et al., 2018). Using a high-speed backspin impeller's centrifugal force, induced air flotation introduces liquid and gas at the top and bottom, respectively (Zheng & Zhao, 1993). Following passage through a disperser external to the impeller and forming an assembly of gas bubbles, the gas and liquid entirely entangle, completing the liquid-liquid or solid-solid heterogeneous system flotation separation process. One of the best methods for removing FOG from wastewater is induced air flotation (Zlokarnik, 1998). However, the efficacy of this technology is built upon the introduction of chemical additives. Bennett and Shammas (2010) conducted a study that reported that FOG elimination ranged from 48% outside the use of chemical additives to 63% with them. A treatment of oily wastewater by an induced air flotation study was executed by Mohammed et al. (2013). The removal efficiency of FOG rose with the rising initial oil concentration and extended up to 76%.

2.4.3.3Coagulation

A coagulant is a substance or chemical that is added to water to start and perform the coagulation−flocculation process (Zainol et al., 2011). There are different types of coagulants in the chemical market such as inorganic metal-based coagulants. Some examples of inorganic metal coagulants are aluminium sulphate (alum), ferric chloride and ferric sulphate (Bratby 2016). One of the best ways to remove FOG from wastewater is by coagulation. After completing a study in Malaysia, Daud et al. (2015) showed that coagulation is noticeably effective in the elimination of FOG from wastewater in biodiesel wastewater. Furthermore, coagulation is one of the best ways to increase flotation performance. From a grease filter wash water, 80% reusable water was successfully retained together with 20% sludge The condition of the liquid portion was similar to that of drinking water. Due to its flexibility, chemical technology is capable of eliminating emulsified oil, dissolved oil and challenging biodegradable organic polymers in FOG treatment of wastewater (Ahmad et al., 2006).

2.4.3.4Ultrafiltration

Ultrafiltration is filtration on a molecular level and its basis is a film of structured pore size, which segregates between large and small particles (Singh & Hankins, 2016). Ultrafiltration membrane separation is dependent on membrane pore size, pore size distribution, solution flow and degree of hydrophilicity (Vishali & Kavitha, 2021). The molecules held by the membrane may be dissolved in a solution or they may be detectable aggregates. The stream that passes through the membrane is called *permeate*. The larger molecular components are retained on the membrane and get dissolved in the water; this stream is termed the *concentrate* (Arvanitoyannis et al., 2008).

Treatment of the FOG-containing wastewater of the Tehran refinery using an ultrafiltration system was studied. Outcomes of various determining domains such as transmembrane pressure, cross-flow velocity, temperature and pH on permeate flux, fouling resistance and rejection were evaluated. A contrastive study revealed that ultrafiltration is highly more efficient than the traditional biological method in the removal of FOG (Salahi et al., 2009). Furthermore, in a study done by Sardari et al. (2018), it was reported that 95% of FOG was eliminated from poultry processing wastewater.

2.4.3.5Electrocoagulation

Electrocoagulation (or electrofiltration) can be described as a process in which suspended, emulsified and dissolved pollutants in the aqueous phase are impaired by instituting an electric current (Emamjomeh & Sivakumar 2009). Aluminium or mild steel is commonly used as sacrificial electrode (Balasubramanian et al., 2009). It has been noted that electrocoagulation is capable of efficiently removing FOG in wastewater (Chen et al., 2000; Stephenson & Tennant 2003). The first time electrocoagulation was performed was in 1946 (Bonilla, 1947; Stuart, 1946). In a study conducted by Xu and Zhu (2004), electrocoagulation was used to remedy refectory wastewater with a high volume of oil and grease constituents. The removal efficiency of FOG, based on standard circumstances, surpassed 95%.

2.4.4 Physical methods of removing FOG in wastewater

2.4.4.1Grease separator

Extra pre-treatment measures to the plants have proven to be quite effective for in the elimination of FOG hence the general immediate technique for the degradation of FOG in wastewater is by using grease separators (Alves 2013). In this technique, FOG is eliminated from the wastewater in the preliminary stage. Wastewater is then channelled from the silt trap tank, kept in the settling tank for approximately 4–6 hours. Meanwhile, the floating FOG stays at the top in the tank. The bottom layer then exits the tank leaving the floating FOG behind. The activated sludge process is mostly suitable for this process as it prevents foaming in the secondary treatment (Pintor et al., 2016).

Ducoste et al. (2008) conducted a study to assess the elimination of FOG from food service establishments using a FOG flow-based grease interceptor. Assessment of the grease interceptor achievement was assumed on measurement of the influent and total oil and grease concentrations in effluent. The maximum FOG removal was 80%. However, Livingston et al. (2007) noted a slow rise in the oil and grease volumes in the effluent of grease separators with and without bioaugmentation.

2.4.4.2Tilting plate separators

The installation of inclined plates into a wastewater treatment tank allows for several parallel gravity separators with low liquid depth, but a high surface area. These are termed tilting plate separators (Willey, 2001). The tilting plate separators conceivably take up below 10% of the space of a traditional fat trap. Furthermore, these components are package plants, which are movable to adjust to site developments. However, there are particular complications with edible oils and fats that demand attention, specifically: (1) The narrow gaps (20 mm) between the plates may be prone to fouling in the event that solid or semisolid fat is present in the effluent; (2) removal of the plate pack for cleaning is cumbersome and demands crane age; and (3) as a result, proper choice of pumps and flow control is essential to avert rising and unwanted changes in liquid depth. Plate separators are efficient and are a commonly used equipment for the segregation of droplets from FOG and water (Rommel et al., 1992).

2.5 Conclusion

How well wastewater treatment technologies remove FOG depends on the physical and chemical characteristics of the FOG, the environment, and the effectiveness of the wastewater treatment facility. As briefly described, numerous technologies have been extensively studied. The literature makes it obvious that much more research has to be done to determine the best method for removing FOG. How well wastewater treatment technologies remove FOG depends on the FOG`s chemical and physical properties, the environment, and the effectiveness of the wastewater treatment facility. The targeted result (e.g., effluent and biogas) and the quality of the input (e.g., municipal wastewater) have a significant impact on the technology that will be used.

CHAPTER 3

BACKGROUND OF THE STUDY AREA

3.1 Introduction

This chapter describes the study area of the research. It also explains the different steps of the two technologies that were used in the treatment of the wastewater. The study area is situated in Bloemfontein, South Africa. Bloemfontein is in the Mangaung Metropolitan Municipality and is located in the Free State province in central South Africa. It is the sixth largest city in South Africa and currently has a population of approximately 567 000 (United Nations World Population Prospects 2021). The BWTW is located east of Bloemfontein, while the NEWTW is located north east of Bloemfontein.

3.2 Bloemspruit wastewater treatment works

The BWTW was initially built in 1904 and is situated at McKenzie Street close to Schoeman Park Golf Club. It employs a biological trickling filter system.

The NEWTW receives 17 Mℓ of the 57 Mℓ of wastewater that the BWTW receives each day in order to relieve its system. Influence at BWTW primarily comes from nearby schools, old Bloemfontein neighbourhoods, and municipal offices. A portion of the BWTW's effluent runs into a neighboring discharge stream and then down to the Modder River, while other portions are transferred by pumps to the Schoeman Park golf course, which is behind the BWTW. A map of the BWTW is shown in Figure 3.1.

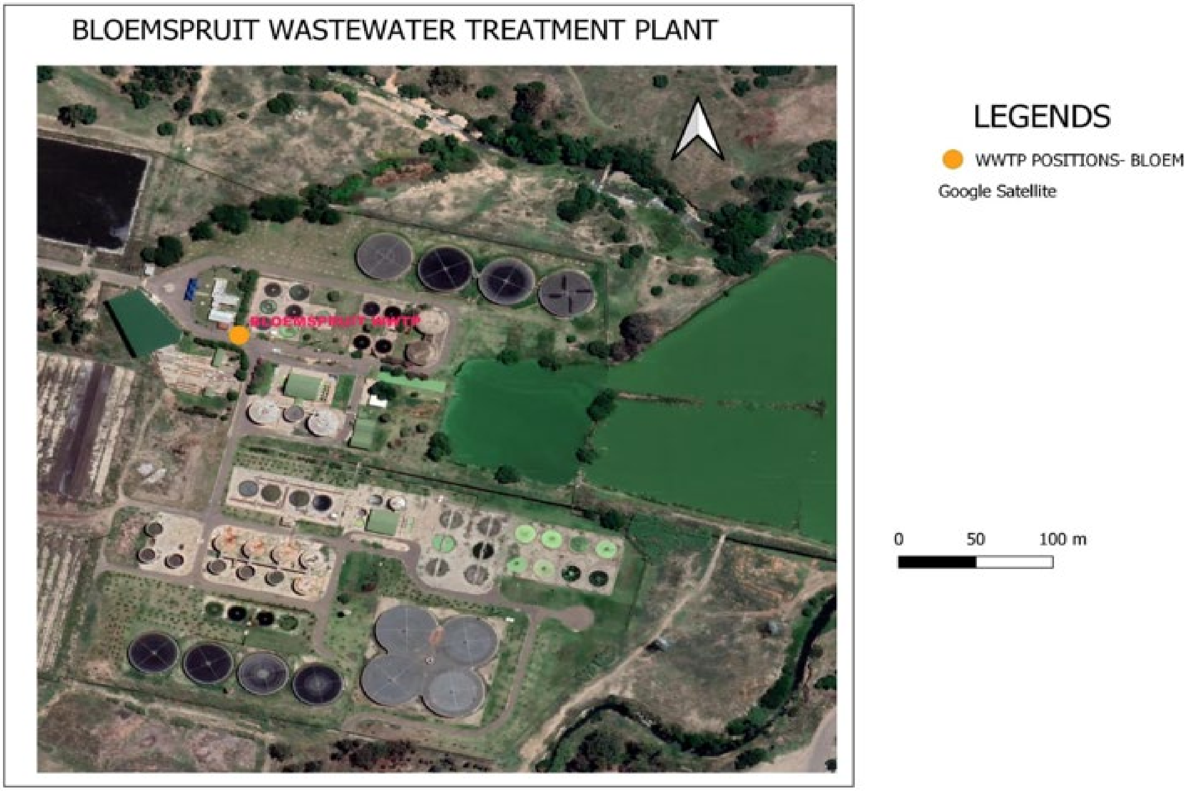

Figure 3.1 The location of the BWTW (VYMaps, 2020)

3.2.1 Preliminary treatment

The first stage in the wastewater treatment process is the preliminary treatment. Raw wastewater entering the treatment plant contains many kinds of impurities; therefore, the purpose of preliminary treatment is to protect plant equipment from damage that may be caused by these materials, such as clogging, jams, or excessive wear to the machinery (Guyer, 2011). Preliminary treatment at the BWTW includes pumping, screening and grit removal.

3.2.1.1Screw pumps

The screw pumps transport wastewater from the bottom of the screw pump inlet to the exit of the pump (Jasim & Aziz, 2020). It is effective in pumping water filled with waste and debris with the least maintenance and highest effectiveness. Only one screw pump is currently working at the BWTW. Figure 3.2 shows pumping at the BWTW.

Figure 3.2 Screw pumps at the BWTW (Author's own, 2023)

3.2.1.2Screening

Before the flow passes on to downstream operations, screening is used to remove big particles from the flow, such as rags, cans, pebbles, branches, leaves, and roots (Ljunggren, 2006). As wastewater influent goes through a bar screen, material is caught. In most cases, a bar screen is made up of a row of parallel, equally spaced bars or a perforated screen that is positioned in a channel (Bhargava, 2016). The screen is cleaned once a week and the debris collected has been piled at the back of the plant for incineration at a later stage. Figure 3.2 shows screening at the BWTW.

Figure 3.3 Bar Screen at the BWTW (Author's own, 2023)

3.2.2 Primary treatment

Primary treatment removes settleable organic and flotable materials (primary sedimentation or primary clarification) (Sonune & Ghate, 2004). Each primary clarity unit should typically remove 90–95% of the settleable solids, 40–60% of the TSS, and 25–35% of the BOD (Babu, 2007). Primary treatment removes a significant amount of settleable, suspended, and floatable solids, which lowers the organic loading on subsequent treatment procedures (Iyare et al., 2020). Lighter solids float to the surface whereas heavier solids sink to the bottom. When the materials have settled, the liquid is discharged or sent on to the demanding secondary phase of wastewater treatment while the materials are kept back (Smarzewska & Morawska, 2021).

3.2.2.1Primary settling tanks

These are substantial tanks with motorised scrapers at the bottom that continuously move collected sludge to a hopper and then pump it to the sludge treatment tank (Micek et al., 2020). Out of six primary settling tanks, only two are working well, the other four are clogged or working quite slowly compared to the other two. Figure 3.3 shows the primary settling tanks at the BWTW.

Figure 3.4 Primary settling tanks at the BWTW (Author's own, 2023)

3.2.2.2Sludge drying beds

The sludge that is collected from the settling tanks at the BWTW is piled at the back of the plant. Local farmers frequently load it without a fee. Figure 3.5 shows sludge drying beds at the BWTW. Figure 3.5 shows the sludge drying beds at BWTW.

Figure 3.5 Sludge drying beds at the BWTW (Author's own, 2023)

3.2.3 Secondary treatment

The secondary treatment of wastewater removes biodegradable organic matter that is either suspended or dissolved in wastewater by allowing bacteria to feed on the organic parts of the wastes (Varjani et al., 2020).

3.2.3.1Trickling filter

The trickling filter consists of a fixed bed of rocks that has microorganisms attached to it that aid in the removal of organic matter from wastewater (Buchanan, 2014). The trickling filters at the BWTW worked well. There was no routine maintenance. The trickling filter is fixed whenever there is a breakdown. Figure 3.6 shows the trickling filter at the BWTW.

Figure 3.6 Trickling filter at the BWTW (Author's own, 2023)

3.2.3.2Secondary settling tanks

The secondary settling are circular tanks with a rotating mechanical sludge and scum collectors (Gao & Stenstrom, 2020). They remove microbes that are washed off the rocks by the flow of wastewater (Sonune & Ghate, 2004). In the BWTW, there are two secondary settling tanks as shown in Figure 3.7.

Figure 3.7 Secondary settling tanks at the BWTW (Author's own, 2023)

3.2.4 Tertiary treatment

The most commonly used method of disinfection is chlorination (Mazhar et al., 2020). Chlorination is one of the best disinfection processes, despite the fact that it necessitates a considerable amount of contact time due to its high oxidation potential (Lu et al., 2020). It is primarily used to treat wastewater with a high level of organic components (Franklin et al., 2004). There was no chlorination at the BWTW.

3.3 North east wastewater treatment works

The NEWTW was constructed in 2014 and is located near Ribblesdale Road behind the Bram Fischer Airport. It is currently 85% complete and the sludge digesters are the missing operation. The plant receives 17 Mℓ of influent from the BWTW from two neighbouring abattoirs and some of the recently built suburbs of Bloemfontein. As a result of its low influent and being incomplete, the plant is not used to full capacity. Furthermore, the tertiary stage (chlorination) of the plant is not in use. The effluent of the plant goes to the Maselspoort wastewater treatment works that purifies the water into drinking water. The map in Figure 3.8 shows the NEWTW.

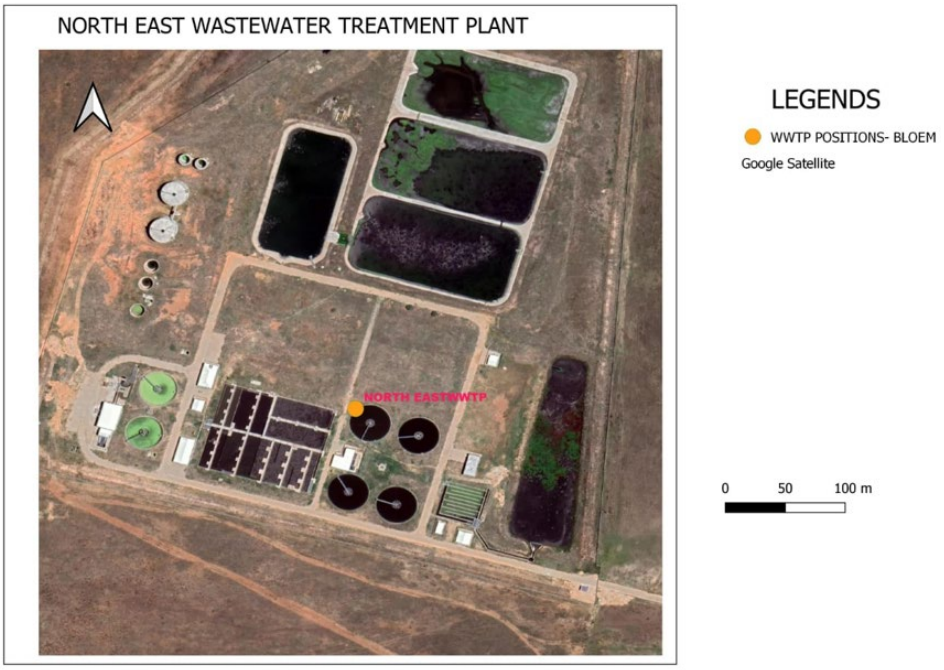

Figure 3.8 Location of the NEWTW AfriGIS (2022)

3.3.1 Preliminary treatment

One of the critical parts of preliminary treatment is pumping. Its purpose is to transport large amounts of organic solids, rags and other waste matter (Spellman & Drinan, 2001). At the NEWTW, the screw pumps work interchangeably. The screw pumps are programmed to alternate after a certain period of time. Figure 3.9 shows pumping at the NEWTW.

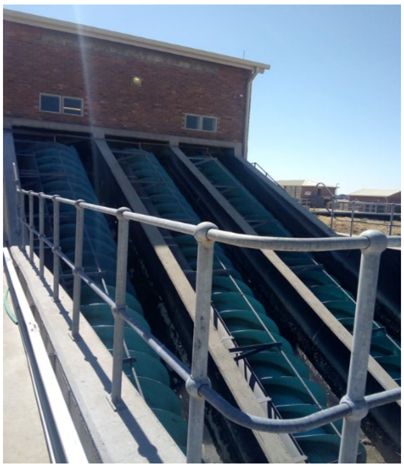

Figure 3.9 Screw pumps at the NEWTW (Author's own, 2023)

3.3.1.1Screening

Screening removes large solids such as rags, paper, plastics and metals that can cause damage and clogging to the wastewater plant equipment (Pankratz, 2017). At the NEWTW there are two types of screens. First, the coarse screen that consists of parallel bars of rectangular shape with clear openings. It is used to remove coarse solids such as rags and large objects that may clog the machinery. Second, the drum screens that are rotating cylinders. They mainly remove fine solids. Figure 3.10 shows the bar screen, while Figure 3.11 shows the drum screen.

Figure 3.10 Bar screens at the NEWTW (Author's own, 2023)

Figure 3.11 Rotary drum screens at the NEWTW (Author's own, 2023)

3.3.2 Primary treatment

Primary treatment of wastewater is a sedimentation process that removes settleable solids; however, chemicals are sometimes used to remove small impurities that cannot settle (Rashed et al., 2013). There are two primary settling tanks at the NEWTW; however, both of them are not in use, therefore stagnant water with a layer of algae is visible in the tanks. Figure 3.12 shows one of the primary settling tanks at the NEWTW.

Figure 3.12 Primary settling tank at the NEWTW (Author's own, 2023)

3.3.3 Secondary treatment

Secondary tanks are used to separate the biomass generated during the secondary treatment process from the treated plant effluent (Voutchkov, 2005). There are two secondary settling tanks at the NEWTW and both of them are functioning well. Figure 3.13 shows one of the secondary settling tanks at the NEWTW.

Figure 3.13 Secondary settling tank at the NEWTW (Author's own, 2023)

3.3.3.1Aerated grit chamber

This is a system that removes particles by forcing water that has passed through bar screens into a grit chamber which has air pumped into it (Ghawi, 2018). The heavier particles settle to the bottom of the tank, while the lighter organic particles are suspended and eventually passed through the tank. It removes sand, silt and grit from wastewater (Plana et al., 2018). Figure 3.14 shows one of the aerated grit chamber tanks at the NEWTW.

Figure 3.14 Grit settling tank at the NEWTW (Author's own, 2023)

3.3.3.2Aeration

In the aeration process, air is directly added directly to wastewater (Mareddy, 2017). This allows for aerobic biodegradation of any remaining pollutants contained in the wastewater (Skouteris et al., 2020). The aeration process uses microorganisms that are already present within the wastewater to degrade the contaminants (Ahammad & Sreekrishnan, 2016). Figure 3.15 shows one of the aeration tanks at the NEWTW.

Figure 3.15 Aeration tank at the NEWTW (Author's own, 2023)

3.3.3.3Sludge treatment

Following the settling tanks (primary and secondary), the wastewater is directed to the sludge treatment tanks (Muralikrishna & Manickam, 2017). The sludge treatment tanks at the NEWTW are not in use, therefore, the water collected from the humus tanks is led to the sludge drying tanks and out to Maselspoort for purifying it as drinking water. Figure 3.16 shows the digester tanks at the NEWTW.

Figure 3.16 Digester tanks at the NEWTW (Author's own, 2023)

A high concentration and thickening process are needed for the produced and collected sludge at primary and secondary levels. This is accomplished by placing them in the thickening tanks, allowing it to settle, and then removing it from the water. Up to 24 hours may pass throughout the sludge treatment process. Some of the residual water is collected and returned to the huge aeration tank after the sludge has been treated in order to facilitate further treatment. This is called sludge dewatering (Kamizela & Kowalczyk, 2019). The water above the sludge is led out to Maselspoort, where it is purified into drinking water. Once the sludge has been dewatered, it is stored near the dams or used as fertiliser by neighbouring farmers who occasionally collect it. Figure 3.17 shows the sludge at a settling tank at the NEWTW.

Figure 3.17 Sludge settling tank at the NEWTW (Author's own, 2023)

3.3.4 Tertiary treatment

Chlorination occurs in the tertiary treatment. The most common disinfection method is chlorination. It is primarily used to treat wastewater with a high level of organic components (Franklin et al., 2004). There is no chlorination at the NEWTW since the water is not discharged into the environment. Figure 3.18 shows the chlorination room at the NEWTW.

Figure 3.18 Chlorination room at the NEWTW (Author's own, 2023)

3.4 FOG in the Bloemspruit wastewater treatment works

The FOG at the BWTW comes from soaps, detergents, and the mostly the abattoir in Estoire, which dumps a minimum of 4 000 ℓ per day, and on maximum, two loads (8 000 ℓ). The abattoir dumps in mornings and late afternoons and the wastewater dumped is blood coloured, and occasionally with traces of visible fats. The abattoir and some trucks carrying domestic wastewater dump directly into the plant, whereas some of the domestic wastewater from homes and nearby shops, offices and schools flows into the treatment plant through sewerage channels. The wastewater from domestic homes in septic tanks also contains a high fat content from soaps, detergents and plant and animal fats. Visually, the raw wastewater looks creamy white, except just after it has been dumped by the abattoir.

Because of the high content of fats from the abattoir, the wastewater at the BWTW daily contains a high amount of fat. There are no definite boundaries as to exactly which institutions and domestic homes discharge their wastewater to the BWTW. Most old suburbs and institutions that date as far back as the beginning or the middle of the twentieth century discharge their wastewater into the BWTW.

3.5 FOG in north east wastewater treatment works

At the NEWTW, FOG is mostly from recent suburbs of Bloemfontein located to the north and north-west of the central business district, a nearby abattoir located opposite the Schoeman golf course and a greater part of FOG being from the 17 Mℓ it receives daily from the BWTW. The abattoir does not directly discharge the blood-coloured wastewater, but it is rather discharged from their drainage into a nearby manhole and is then directed to the NEWTW. There are no definite intervals as to when the abattoir discharges the wastewater; however, it was noted that it is mainly on either Tuesdays or Thursdays at least each week. Apart from the times when the abattoir just released wastewater into the plant, the raw wastewater at the NEWTW is visually creamy white but a little less than that of the BWTW.

The following chapter discusses the methodology used in this study.

CHAPTER 4
RESEARCH METHODOLOGY

4.1 Introduction

The description of the research procedure is included in this chapter. It explains the research methodology employed and explains why it was chosen. This chapter also discusses the steps in the research process, including sampling and data processing.

This research investigated the effective removal of FOG in water treatment plants of the Mangaung Metropolitan Municipality and the effect of different wastewater parameters on the effective removal of FOG.

This study was based on the following objectives:

- To determine the effectiveness of the two wastewater treatment technologies in the removal of FOG and nutrients.
- To investigate and recommend extra pre-treatment measures to the plants for improvement in the removal of FOG.
- To investigate the likely impact of FOG and nutrient released to the catchment after treatment.

4.2 Research methodology

A research methodology or strategy is determined by the nature of the research question and the subject being investigated (Denzin & Lincoln, 2005). In addition, it is important to consider the research design utilised in an inquiry as a tool to address the research topic.

The BWTW, which uses an older technology, namely the biological trickling filter, was servicing the greater Bloemfontein and was hydraulically overloaded due to many reasons, among which were plant capacity, increase in the population of Mangaung, new and emerging contaminants present in wastewater and wear and tear of plant equipment; hence, the construction of the new NEWTW in Mangaung that uses a newer treatment technology: the activated sludge system (Mail & Guardian, 2014). In addition, Mangaung scored 38% in the Green Drop Assessment in 2013 (South Africa, Department of Water and Forestry, 2014) due to the poor wastewater discharge to the catchment.

Both of these technologies remove FOG as an impurity in the wastewater, but as both treatment plants discharge FOG to the catchment, there is no difference in the efficacy and degree of the new technology, activated sludge, compared to the older technology, biological trickling filter system. The efficacy of the new technology in comparison to the older technology was examined in terms of the FOG present because FOG is still present in the water released from the NEWTW. As a result, the study determined the amount of FOG present.

4.3 Justification for using quantitative research

Burns and Grove (2005) described quantitative research as a formal, objective and systematic process to illustrate and test relationships, and investigate cause and effect interactions among variables. Furthermore, as outlined by Creswell (2009), a quantitative approach is appropriate when a researcher seeks to understand relationships between variables. A quantitative research approach was chosen as methodology to evaluate the effect that different parameters exert over each other and the impact on the removal of FOG.

4.4 Sampling

From June to November 2021, once a week, 20 influent samples and effluent from the NEWTW and the BWTW were collected and evaluated for the following parameters: COD, oxygen absorbed and FOG. pH, TDS, temperature and conductivity which were measured on site using a Hanna HI 98195 meter. Dissolved oxygen was also measured using a Hanna HI 98193 DO meter. These parameters were selected from the South African water quality guidelines for the protection of the freshwater aquatic ecosystems (SA Department of Water Affairs and Forestry, 1996). For FOG grab samples were collected weekly every Tuesday, while grab samples for COD and oxygen absorbed were collected once after every two weeks. In June, July, and August, sampling was done at noon when the temperature reached 17 °C, while in September and October, sampling was done at roughly 10:30 when the temperature reached the same level. A thorough defence of the decision to choose the particular techniques and methodologies is provided in the following paragraphs.

There are many methods of measuring FOG; however, these methods differ according to the composition of FOG. One of the FOG procedures that has been approved is the Environmental Protection Agency's method (EPA 1664B), which makes use of n-hexane as a solvent. Anything that is soluble in hexane is regarded as FOG for the purposes of this test. This includes some organic dyes, sulphur compounds, waxes, animal fats, mineral and vegetable oils, soaps, chlorophyll, and non-volatile petroleum hydrocarbons and substituted hydrocarbons but does not include heavier petroleum residuals. For this reason, the EPA 1664B was the chosen method for this study

4.5 Testing

The following tests were grouped under the specific headings which are the objectives of the study

To determine the effectiveness of the two wastewater treatment technologies in the removal of FOG and nutrients, the following tests were carried out:

- FOG, Chemical oxygen demand, oxygen absorbed, dissolved oxygen, temperature, pH, atmospheric pressure, salinity, conductivity, resistivity

To investigate the likely impact of FOG and nutrients released to the catchment after treatment, the following tests were made:

- Nitrates, phosphates

To investigate extra pre-treatment measures to the plants for improvement in the elimination of FOG:

- Total dissolved solids

4.5.1 FOG

A method called Hexane Extraction and Gravimetric Analysis was utilised for FOG testing. Oil and grease (material that may be extracted with hexane) can be quantified in water using this approach. Non-volatile, hexane-extractable oils and greases are provided by oil and grease in measureable amounts (USEPA, 2010).

The samples were taken in 2l glass bottles, which had not been washed with the sample beforehand. Since they oil and grease prefer to stick to glass containers over the water in the sample collection, oils and grease are termed hydrophobic. For this analysis, grab samples were used to obtain all of the samples.. The samples were then refrigerated if the analysis could not done on the same day. Upon analysis, if the pH was not less than 2, hydrochloric acid was added to adjust it to 2. The sample was added to a separatory funnel, agitated violently for two minutes with 30 ml of n-hexane were added, and after that, the organic and aqueous phases were allowed to separate by settling (USEPA, 2010).

The separatory funnel was then rinsed with acetone to ensure that all the oil has been retrieved from the separatory funnel. Gravimetric measurements of sample volumes were made, at least to the nearest 10 mℓ. Prior to gravimetric measurement of the residue using a four-place balance, residual water, solvent, and other volatiles were eliminated by heating in an oven at 60 °C for 30 minutes. In order to eliminate oil and grease compounds from the initial sample so that it could be analyzed, the operation was repeated twice more. The solvent was then evaporated after the three extract parts had been gathered, and the preweighed container was weighed to a constant weight. The extract was then dried by evaporating it at room temperature (25 °C). After evaporation, leftover solvent, water, and other volatiles are eliminated by heating the mixture for 30 minutes at 60 °C in an oven (USEPA, 2010).

4.5.2 Chemical oxygen demand

Chemical oxygen demand (COD) is a critical analytical parameter for water quality assessment. COD was determined using the potassium dichromate method. COD represents the degree of organic pollution in water bodies (Li et al., 2018). The COD

Method 410: Chemical oxygen demand (titrimetric, mid-level) was used to determine the COD in the wastewater.

Equipment

- Erlenmeyer flask
- Small beaker
- Titration apparatus
- 50 mℓ burette, graduated in 0.1 mℓ
- Burette support
- 100 mℓ graduated cylinder

Reagents

- Standard potassium dichromate solution, 0.250 N or 0.025 N
- Sulfuric acid reagent containing silver sulphate catalyst
- Standard ferrous ammonium sulphate titrant
- Ferroin indicator solution
- Ammonium ferrous sulphate hexahydrate
- Concentrated sulphuric acid
- Distilled water

Procedure

1. The sample (2.5 mℓ) was placed in a culture tube and $K_2Cr_2O_7$ digestion solution (1.5 mℓ) was added.
2. Sulphuric acid reagent (3.5 mℓ) was carefully run down inside of the vessel so an acid layer was formed under the sample digestion solution layer. The cap tubes were tightly closed.
3. The tubes were placed in a block digester preheated to 150 °C and refluxed for two hours.
4. The tubes were then placed in a test tube rack and cooled to room temperature.
5. Three drops of Ferroin indicator were added and the mixture was shaken.

6. The mixture was then titrated with standardised 0.10 M Ferrous Ammonium Suphate (Method: 5220 C. Closed Reflux Titrimetric Method).

Preparation of the blank sample

1. A 500 mℓ refluxing flask was pipetted with distilled water in a volume equal to the sample.
2. 1 g of ammonium ferrous sulphate hexahydrate was added to the distilled water.
3. 5 mℓ of sulphuric acid reagent was added very gradually, followed by the addition and mixing of 0.250 N potassium dichromate solution.
4. The samples and the blank flask were then refluxed for two hours.

4.5.3 Oxygen absorbed

Oxygen absorbed in four hours is calculated by evaluating the amount of standard potassium permanganate solution consumed by the sample while kept under specific conditions for four hours (Bureau of Indian Standards, 1989).

Apparatus

- Incubator
- Air oven

Reagents

- Stock potassium permanganate solution: Distilled water was used to make up to 1000 mℓ from 3.951 g of dry potassium permanganate (at 105 °C). The strength of the solution was periodically monitored while it was kept in the dark.
- Standard solution of potassium permanganate. This solution was made immediately before use by diluting of a stock potassium permanganate solution to the proper strength.
- Dilute sulphuric acid

  130 mℓ of pure water and 50 mℓ of concentrated sulfuric acid were combined, chilled, and then dilute to 200 mℓ with distilled water. After four hours, the

standard permanganate solution was added until a very faint pink color appeared.

- Crystals of potassium iodide
- Stock solution of sodium thiosulfate

Procedure

1. A clean, 400 ml glass bottle with a glass stopper was filled with 259 mℓ of the thoroughly mixed sample.
2. 10 mℓ of dilute sulphuric acid was added, followed by an accurately measured volume of standard potassium permanganate solution.
3. The contents were then mixed by gentle rotations and placed in a water-bath at 37±1 °C for four hours.
4. The liquid was cooled to roughly 15 °C and a few crystals of potassium iodide were added when the four hours were up. A few drops of the starch indicator solution were used to titrate the combination with a typical sodium thiosulphate solution.
5. Titrating was also done on the blank sample for oxygen absorption.
6. A 10-fold dilution was carried out for mixtures that fell out of range after titration.

Procedure

- The correction was to take 10 mm^3 of the sample and dilute it to 90 mm^3 of distilled water.

4.5.4 Nitrates

Nitrates were analysed using the Spectroquant nitrate test, SOP Chem 005. Prior to analysis, the test tubes were dried in the oven after being washed with distilled water (Sigmaaldrich, 2017).

The following steps were followed in the testing of nitrates in wastewater:

1. 4.0 mℓ of NO_3^{-1} was pipetted into an empty, dry, round cell.
2. The sample was pipetted into the cell in a volume of 0.50 ml

3. 0.50 mℓ of NO_3^{-2} was pipetted, the cell was sealed, and it was violently shaken.
4. After that, the answer was read and placed into the relevant rectangle cell.

4.5.5 Phosphates

Using a Spectroquant Prove spectrophotometer, the phosphate findings were examined in the lab. In order to prepare the test tubes for analysis, distilled water was used, and they were then baked to dry.

The following steps were carried out in the testing of phosphates in wastewater:

1. The pH was tested if it fell between the predetermined ranges of 0–10. The pH was adjusted as needed by adding sulphuric acid drop by drop.
2. The test tube received 5.0 ml of the sample
3. To the test tube, five drops of PO4-1 were introduced.
4. Micro-spoon was raised by PO_4^{-2} one level. One level of micro-spoon PO_4^{-2} was added.
5. The mixture was then forcefully agitated to break down the solid ingredient.
6. The solution was then put into the appropriate cell.
7. The reading was then taken.

4.5.6 Dissolved oxygen

The specifications for the DO meter were as follows:

Table 4.1 Specifications of dissolved oxygen on the Hanna HI98193 multimeter

Range	**0.00 to 50.00 mg/ℓ (ppm); 0.0 to 600.0% saturation**
Resolution	0.01 mg/ℓ (ppm): 0.1% saturation
Accuracy	±1.5% of reading ±1 digit
Calibration	Automatic one or two points at 100% (8.26 mg/ℓ) and 0% (0 mg/ℓ) manual one point using a value entered by the user in % saturation or mg/ℓ

Source: Hanna (2021)

4.5.7 Temperature

The specifications for the temperature were as follows:

Table 4.2 Specifications of temperature on the Hanna HI98193 multimeter

Range	**−20.0 to 120.0 °C; −4.0 to 248.0 °F**
Resolution	0.1 °C; 0.1 °F
Accuracy (@ 25 °C / 77 °F)	±0.2 °C; ±0.4 °F (excluding probe error)
Calibration	One or two points at any in range temperature value

Source: Hanna (2021)

The specifications for pH were as follows:

Table 4.3 Specifications of pH on the Hanna HI98192 multimeter

Range	**0.00–14.00 pH**
pH resolution	0.01 pH
pH accuracy	±0.02
pH calibration	Automatic one, two, or three points with automatic recognition of five standard buffers (pH 4.01, 6.86, 7.01, 9.18, 10.01) or one custom buffer

Source: Hanna (2021)

4.5.8 Atmospheric pressure

The specifications for the atmospheric pressure were as follows:

Table 4.4 Specifications of atmospheric pressure on the Hanna HI98193 multimeter

Range	**450 to 850 mmHg**
Resolution	1 mmHg
Accuracy	±3 mmHg within ±15% from the calibration point
Calibration	One point at any in range pressure value

Source: Hanna (2021)

4.6.1 Salinity

The specifications for salinity were as follows:

Table 4.5 Specifications of temperature on the Hanna HI98192 multimeter

Range	**Percentage NaCl: 0.0−400.0%; Practical salinity scale: 0.00−42.00 (PSU); Natural seawater scale (UNESCO, 1966): 0.00−80.00 (ppt)**
Resolution	0.1%; 0.01
Accuracy	±1% of reading
Calibration	Maximum one point only in percentage range (with HI7037 standard); use conductivity calibration for all other ranges

Source: Hanna (2021)

4.6.2 Conductivity

The specifications for conductivity were as follows:

Table 4.6 Specifications of conductivity on the Hanna HI98192

Range	**0.000−9.999 S/cm; 10.00−99.99 S/cm; 100.0−999.9 S/cm; 1.000−9.999 mS/cm; 10.00−99.99 mS/cm; 100.0−1000.0 mS/cm (actual conductivity; temperature compensated to 400 mS/cm)**
Resolution	0.001 S/cm; 0.01 S/cm; 0.1 S/cm; 0.001 mS/cm; 0.01 mS/cm; 0.1 mS/cm
Accuracy	±1% of reading (±0.01 S/cm or 1 digit, whichever is greater)
Calibration	Automatic up to five points with seven memorised standards (0.00 S/cm, 84.0 S/cm, 1.413 mS/cm, 5.00 mS/cm, 12.88 mS/cm, 80.0 mS/cm, 111.8 mS/cm)

Source: Hanna (2021)

4.6.3 Resistivity

The specifications for resistivity were as follows:

Table 4.7 Specifications for resistivity on the Hanna HI98192 multimeter

Range	**1.0−99.9 Ω•cm; 100−999 Ω•cm; 1.00−9.99 KΩ•cm; 10.0−99.9 KΩ•cm; 100−999 KΩ•cm; 1.00−9.99 MΩ•cm; 10.0−100.0 MΩ•cm**
Resolution	0.1 Ω•cm; 1Ω•cm; 0.01 KΩ•cm; 0.1 KΩ•cm; 1 KΩ•cm; 0.01 MΩ•cm; 0.1 MΩ•cm
Accuracy	±1% of reading (±10 or 1 digit)

Source: Hanna (2021)

4.6.4 Total dissolved solids

The specifications for TDS were as follows:

Table 4.8 Specifications of total dissolved solids on the Hanna HI98192 multimeter

Range	**0.00–99.99 ppm; 100.0–999.9 ppm; 1.000–9.999 ppt (g/ℓ); 10.00–99.99 ppt (g/ℓ); 100.0–400.0 ppt (g/ℓ)**
Resolution	0.01 ppm; 0.1 ppm; 0.001 ppt (g/ℓ); 0.01 ppt (g/ℓ); 0.1 ppt (g/ℓ)
Accuracy	±1% of reading (±0.05 mg/ℓ [ppm] or one digit, whichever is greater)

Source: Hanna (2021)

4.7 Data analysis

Data analysis is the process of breaking down a phenomenon into its constituent parts in order to comprehend it better (Mouton & Marais, 1991).

4.7.1 FOG

To analyse FOG with the EPA gravimetric method 1664B, the following equation was used to demonstrate initial precision and recovery to establish the ability to generate acceptable precision and accuracy.

$$s = \frac{\sum x^2 - \frac{(\sum x)^2}{n}}{\mathrm{n} - 1} \qquad (1)$$

(USEPA, 2010)

Where:

s = Standard deviation of the percent recovery

n = Number of samples

x = recovery in each sample

The equation below was used to show the percentage recovery of FOG in each aliquot:

$$\mathrm{P} = \frac{100(\mathrm{A} - \mathrm{B})}{\mathrm{T}} \qquad (2)$$

(USEPA, 2010)

Where:

P = Percent recovery of hexane extractable material

A = Measured concentration of the sample after spiking

B = Measured background concentration of FOG

T = True concentration of the spiked sample

The following equation was used to calculate the extract volume that contains 1 000 mg extractable material:

$$\mathrm{V_a} = \frac{1\,000\ \mathrm{V_t}}{\mathrm{W_h}} \tag{3}$$

(USEPA, 2010)

Where:

V_a = Volume of the aliquot to be withdrawn (mℓ)

V_t = Total volume of solvent used

W_h = Weight of extractable material from FOG measurement (mg)

4.7.2 Chemical oxygen demand

The following formula was used to calculate COD:

$$COD = \frac{(v_1 - v_2) \times C \times 8\,000}{v_0} \tag{4}$$

(Indian Institute of Technology, 2013)

Where:

v_0 = the volume of the sample aliquot, in millimetres

v_1 = the volume of ammonium iron (ii) sulphate used in blank titration, in millimetres

v_2 = the volume of ammonium iron (ii) sulphate used in sample titration, in millimetres

C = the exact concentration after standardisation of the ammonium iron (ii) sulphate, in moles per litre

4.7.3 Oxygen absorbed

The formula below was used to calculate the oxygen absorbed:

$$Oxygen\ absorbed = \frac{(A - B) \times 200}{volume\ of\ sample} \tag{5}$$

(Bureau of Indian Standards, 1989)

Where:

A = the titration value of the blank sample

B = the titration value of the sample

4.7.4 Nitrates

Nitrates were analysed using the Spectroquant nitrate test, SOP Chem 005. Prior to analysis, the test tubes were dried in the oven after being washed with distilled water (Sigmaaldrich, 2017).

$$r = \frac{\sum(x_{i-\bar{x}})(y_{i-\bar{y}})}{\sqrt{(x_{i-\bar{x}})^2}\sum(y_i - \bar{y})^2} \tag{6}$$

(Benesty et al., 2009a)

Where:

x_1 = the sample's values for the x variable

$\bar{x}$ = the sample\`s values of the $\bar{x}$ variable

y = the sample\`s values of the y variable

$\bar{y}$ =the sample\`s values of the $\bar{y}$ variable

4.7.5 Phosphates

Using a Spectroquant Prove spectrophotometer, the phosphate findings were examined in the lab. In order to prepare the test tubes for analysis, distilled water was used, and they were then baked to dry.

$$r = \frac{\sum(x_{i-\bar{x}})(y_{i-\bar{y}})}{\sqrt{(x_{i-\bar{x}})^2}\sum(y_i - \bar{y})^2} \tag{7}$$

(Benesty et al., 2009a)

Where:

x_1 = the sample`s values for the x variable

$\bar{x}$ = the sample`s values for the $\bar{x}$ variable

y = the sample`s values for the y variable

$\bar{y}$ = the sample`s values for the $\bar{y}$ variable

4.7.6 pH, conductivity, resistivity, salinity, atmospheric pressure, dissolved oxygen and temperature

A mean of the readings was taken for analysis, while the ranges of the different parameters measured are given in the tables mentioned above.

4.6 Validation of data

The validity of an instrument is the degree to which an instrument measures what it is intended to measure (Polit & Hungler, 1993). For all parameters measured by the multimeter, the readings were taken at an average temperature of 17 °C, which was achieved around midday for the months of June, July, August and September and around the morning hours for the summer month, October.

The experiments conducted in the laboratory – COD, oxygen absorbed and FOG – were repeated three times to ensure validation of the data, whereas the data collected using multimeters was verified by checking the range of the multimeters and recalibrating for the different parameters each time. For the nitrates and phosphates, the spectrophotometer was reset every time before taking a new reading.

Reliability of measuring tools and the experiments was ensured. For all the parameters investigated in the laboratory and parameters measured using a multimeter, the experiments were carried out three times to ensure accuracy. Polit and Hungler (1993) referred to reliability as the degree of consistency with which an instrument measures the attribute it is designed to measure.

4.7 Control

4.7.7 FOG

FOG samples were extracted within 28 days of collection. If they weren't analysed the same day, they were cooled at or below 6 °C before examination to avoid microbial deterioration. Furthermore, samples were kept at ≤ 10 °C during transport to the laboratory. Before analysis, the pH was adjusted to 2 for all samples. All equipment used to analyse FOG was washed in hot soapy water and dried thoroughly in an oven before the next experiment to ensure all FOG has left the container. All data collection bottles were labelled appropriately and accordingly used for collection of data.

4.7.8 Nitrates and phosphates

The samples were examined right away, and distilled water was used to rinse the test tubes for analysis to remove any potential impurities. The test tubes were cleaned with distilled water and baked to remove any remaining moisture. The spectrophotometer read the parameter to be checked as soon as the representative cell was introduced into the parameter slot to make sure the proper parameter was being read.

4.7.9 Chemical oxygen demand and oxygen absorbed

Blank samples were formulated for COD and oxygen absorbed. Moreover, the samples were collected in glass bottles that were not prerinsed and the samples were analysed immediately or refrigerated at ≤ 6 °C to minimise microbial degradation. The containers for analysing the samples were always washed and rinsed with distilled water to ensure accurate results. All the water used in the experiment for the reactions and the experiment itself was distilled water.

4.7.10 pH, resistivity, conductivity, salinity, dissolved oxygen, atmospheric pressure, and temperature

The samples were all taken when the temperature was 17 °C. The equipment was calibrated every Tuesday prior to sampling using the Hanna calibration liquid, which was fit for the equipment in the experiment. Furthermore, the readings were taken at the very time that the samples were collected to ensure accuracy.

4.8 Challenges and implications

- There was a shortage of laboratory glassware, hence the analysis had to be postponed on some days to first give preference to the staff of the laboratory. As a result, data was collected on Tuesdays and analysed on Wednesdays. This resulted in a fewer analysis than had been planned initially, which in turn, had adverse effects on the analysis of the research.
- It was challenging to sample and analyse parameters consistently in terms of time due to delays in transport. The research sampling and analysis relied on hired transport, hence the parameters affected by temperatures were negatively impacted.
- The constituents of the wastewater were inconsistent due to the nearby abattoirs dumping at different time intervals. This meant that the samples varied each time and contributed to the inaccurate results.
- There were frequent power outages, hence the validity of the results was compromised due to sampling being done at different times.

The following chapter discusses the results obtained from the study and analyses the findings.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

This chapter contains a detailed presentation and discussion of the data analysis and the results of this study. The findings are presented under the following headings: FOG, nitrates, phosphates, pH, resistivity, temperature, dissolved oxygen, TDS, salinity, conductivity, atmospheric pressure and COD.

The aim of the study was to investigate the effective removal of FOG of two technologies by two wastewater treatment plants of the Mangaung Metropolitan Municipality, thus the following results show the different parameters and their relationship with the elimination of FOG in the two treatment plants.

5.2 Analysis of results

5.2.1 FOG

Low biodegradability is a characteristic of FOG. This is why the biosphere may suffer as a result of its release into the environment leading to deadly consequences like fish asphyxiation, waterfowl drowning, or unsightly shorelines and beaches. Even the tiniest coating of FOG will negatively impact aquatic life (Pintor et al., 2016). FOG from discharge streams is one of the most frequent types of water pollutants that can harm aquatic life. It primarily originates from wastewater effluents, where due to the usage of FOG in highly desired oil-processed meals, municipal growth, and the indiscriminate discharge of FOG into water drains within municipalities, FOG concentrations have been increasing recently.

According to earlier studies on FOG levels and their management, anticipated FOG removal does not correspond to measured FOG removal (Ducoste et al. 2008; Lopez-Vazquez & Fall, 2004). Whenever there are detergent surfactants and proteins together, measurement interference is evident, according to research on the effectiveness of FOG recovery. The mass that is transmitted can be increased by introducing proteins into the solvent. Additionally, the surfactant molecules form micelles around the FOG droplets to stop hexane solvation. According to earlier studies on FOG levels and their management, anticipated FOG removal does not correspond to measured FOG removal (Ducoste et al. 2008; Lopez-Vazquez & Fall, 2004). When protein and/or detergent surfactants are present, measurement interference is evident, according to research on the effectiveness of FOG recovery. Since proteins may be transported into the solvent, the total mass can be increased while the surfactant molecules form micelles around the FOG droplets to prevent hexane solvation.

The average FOG removed in each technology was calculated and the mean was used to determine the efficiency of each technology. The two wastewater treatment facilities' influents and effluents are depicted in Figures 5.1 and 5.2.

Figure 5.1 The BWTW influent and effluent (Author's own, 2023)

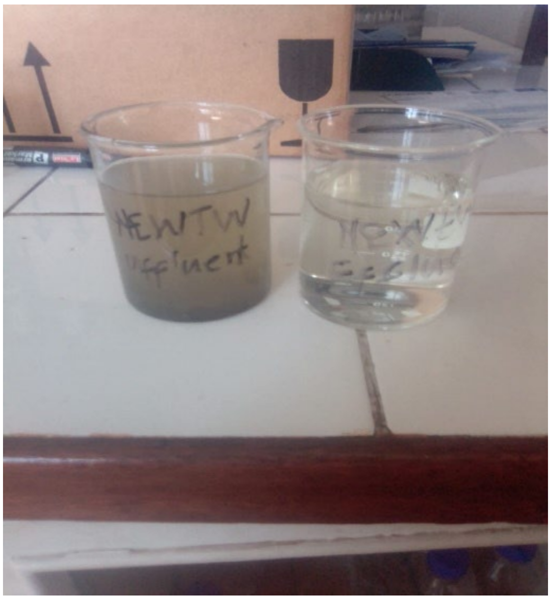

Figure 5.2 The NEWTW influent and effluent (Author's own, 2023)

The above figures visually show that there is a little difference in the influent and effluent in the BWTW, whereas there is a significant difference in the NEWTW. The BWTW receives more volume of wastewater than the NEWTW, which explains why it is more concentrated than the wastewater at the NEWTW.

FOG was also calculated using the EPA 1664B method. Table 5.1 shows the FOG that was calculated over a period of 20 consecutive weeks at the two plants.

Table 5.1 FOG values in the BWTW and NEWTW

Period	BWTW influent FOG in mg/ℓ	BWTW effluent FOG in mg/ℓ	NEWTW influent FOG in mg/ℓ	NEWTW effluent FOG in mg/ℓ
Week 1	21.12	19.76	14.62	7.90
Week 2	21.18	19.98	14.62	9.76
Week 3	10.66	3.26	17.42	3.02
Week 4	8.06	6.14	3.32	1.98
Week 5	1.72	0.70	6.62	2.66
Week 6	7.08	6.00	16.96	5.22
Week 7	13.6	10.86	18.88	13.12
Week 8	12.60	10.42	6.02	3.98
Week 9	23.52	6.40	14.40	3.98
Week 10	23.4	5.04	10.20	4.64
Week 11	24.06	6.34	14.24	6.02
Week 12	21.26	5.44	8.56	5.66
Week 13	6.22	5.38	11.48	5.80
Week 14	7.62	6.82	8.54	6.96
Week 15	13.28	7.84	1.32	0.42
Week 16	6.96	1.37	3.18	2.84
Week 17	11.54	10.82	9.52	7.28
Week 18	14.96	13.82	7.98	6.84
Week 19	9.04	8.54	9.02	3.34
Week 20	13.34	11.56	6.18	5.86
Average FOG	13.56	8.32	10.15	5.36
Percentage removal	61.36%		52.81%	

The results in Table 5.1 show that the two wastewater treatment plants' FOG removal performance was below average. The range of FOG removal efficiency for wastewater treatment, according to Dehghani et al. (2014), was 59% to 85%, with an average of 70%. The BWTW removal efficiency of 61.36% resulted in an average effluent of 8.32 mg/l. The NEWTW showed an average of 5.36 mg/l and a clearance efficiency of 52.81%. According to South Africa's Department of Forestry, Fisheries, and the Environment (2014), the maximum quantity of FOG that can be discharged into a water source is 2.5 mg/l, hence neither of the two wastewater treatment facilities met this requirement. According to South Africa's Department of Forestry, Fisheries, and the Environment (2014), the maximum quantity of FOG that can be discharged into a water source is 2.5 mg/l, hence neither of the two wastewater treatment facilities met this requirement. Similar studies were carried out in Iran, where 90% of the FOG was removed by the trickling filter, and 70% by the wastewater treatment facility in Shiraz (Dehghani et al., 2014). In a study by Porwal et al. (2015), dairy sludge was mixed into the activated sludge, and the removal efficiencies were over 90%. FOG may be effectively removed from wastewater with this technique, much like with the trickling filter. When Pontes and Chernicharo (2011) examined the lipids in raw sewage, they discovered that there had been a sizable degree of FOG removal. El-Masry et al. (2004) also stated that the trickling filter approach has a 100% success rate in removing vegetable oil and grease from wastewater.

The trickling filter eliminated FOG in the current experiment more successfully than the activated sludge. The South African Department of Forestry, Fisheries, and the Environment (SA Department of Forestry, Fisheries, and the Environment, 2014) lists 2.5 mg/l as the limit that can be discharged into a water source, indicating that neither of the wastewater effluents met this standard. The removal rate of FOG in residential water using the activated sludge system was found to be 15.2% in Waipio and 97.8% in Pohakapu, which used the trickling filter, according to a related study conducted in the United States (Young & Chan, 1970). The outcomes of the present investigation also concurred with those of Young and Chan (1970) in light of their findings.

The findings of the analysis of how well the two wastewater treatment techniques removed FOG revealed that the trickling filter was more effective at doing so, eliminating 61.36% of it as opposed to the activated sludge, which removed 52.81%. These results led to the conclusion that further pre-treatment procedures were required by the plants in order to increase their capacity to remove FOG. Additionally, the findings suggested that nutrients and FOG that were released into the catchment after treatment are likely to have an impact.

5.2.2 Nitrates

To ascertain how nitrates and FOG interact, the Pearson Correlation Coefficient was employed.

The following equation shows the Pearson formula which was used to measure the dependence of FOG to nitrates.

$$r = \frac{\sum(x_{i-\bar{x}})(y_{i-\bar{y}})}{\sqrt{(x_{i-\bar{x}})^2}\sum(y_i - \bar{y})^2}$$

Nitrate levels in the BWTW and NEWTW were measured in the effluents for a period of nine alternating weeks from June 2021 to October 2021.

Figure 5.3 shows correlation of FOG and nitrates in the BWTW.

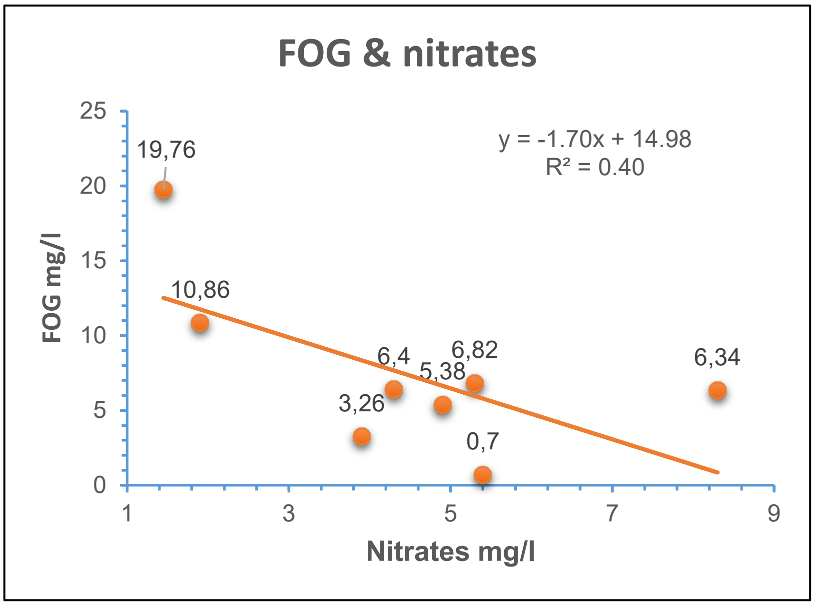

Figure 5.3 Correlation of FOG and nitrates in the BWTW

Figure 5.4 shows correlation of FOG and nitrates in the NEWTW.

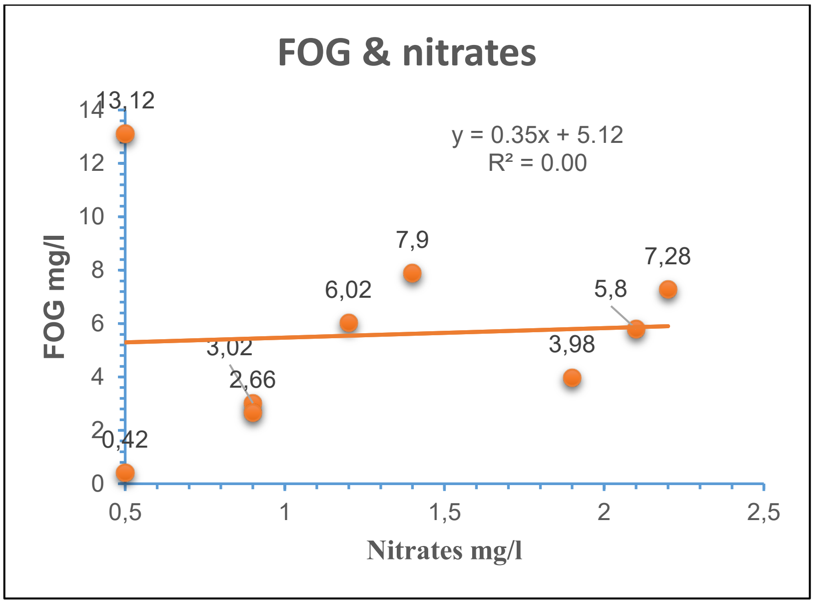

Figure 5.4 Correlation of FOG and nitrates in the NEWTW

The BWTW effluent's average nitrate concentrations were found to be 4.43 mg/l and 1.29 mg/l, respectively, satisfying the country of South Africa's discharge standards of 15 mg/l (SA Department of Forestry, Fisheries, and the Environment, 2014). The trickling filter appears to be effective at nitrifying waste, according to a study by Kim et al. (2014). Like Persson et al. (2002), Almstrand et al. (2011) and Almstrand et al. (2012) concurred that the trickling filter is quite good at removing nitrates. These findings demonstrate that the trickling filter is less efficient than activated sludge at removing nitrates. The average nitrate concentration in the BWTW effluent was 4.43 mg/l, compared to 1.29 mg/l for the NEWTW. The results show that the two wastewater treatment facilities are equally effective at eliminating nitrates since both met the South African wastewater discharge standard of 15 mg/l in the effluent. Additionally, it was mentioned that the wastewater from the two facilities contained nitrates, which might lead to eutrophication and put the aquatic life in the watershed in danger.

Additionally, the regression coefficient for both the BWTW and the NEWTW was 1.0, demonstrating a significant link between nitrates and FOG. The coefficient of determination for nitrates and FOG was 0.0, indicating no low variance, and 0.4 in the BWTW, showing a roughly medium variance. Nitrates and FOG were strongly correlated, as shown by the regression figures of 1.0 for both the BWTW and the NEWTW.

5.2.3 Phosphates

Phosphate enrichment largely impairs aquatic ecosystem functions and services, thus comprising an emerging problem of environmental concern (Mavhungu et al., 2019). Figures 5.5 and 5.6 shows the relationship between phosphate levels and FOG levels in the BWTW and NEWTW, respectively.

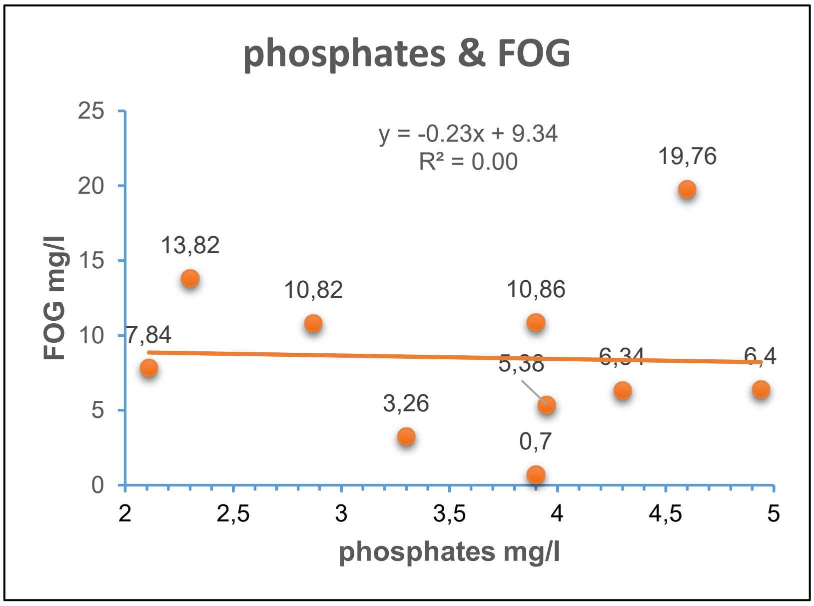

Figure 5.5 Correlation between FOG and phosphates in the BWTW

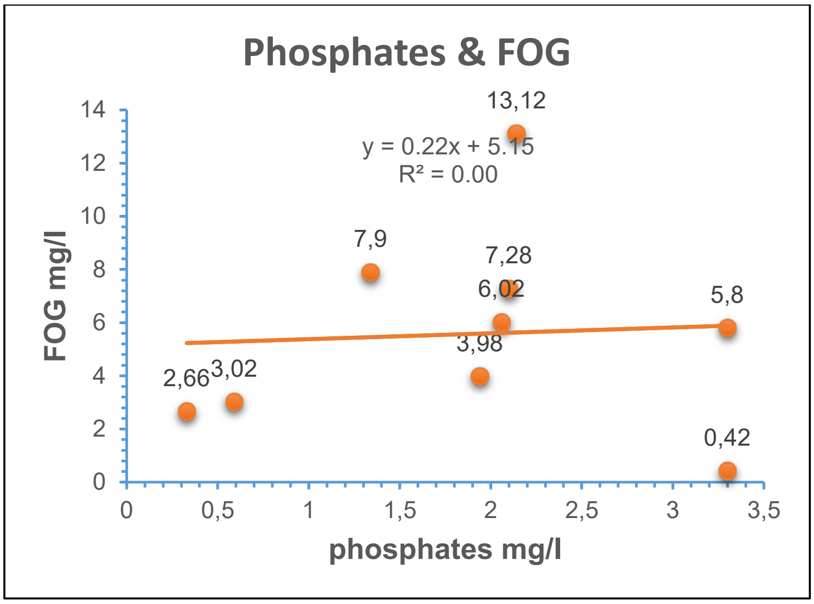

Figure 5.6 Correlation between FOG and phosphates in the NEWTW

In the effluents of the two plants, phosphate levels were reported to be 3.6 mg/l for the BWTW and 1.9 mg/l for the NEWTW, both of which met the effluent limits of 10 mg/l. The outcomes demonstrated that activated sludge was more effective at removing phosphates. The two wastewater treatment plants' effluent contains phosphates, which increases the risk of eutrophication and raises concerns for the catchment environment.

The removal rate of phosphorus from activated sludge was 97%, according to a study (Gebremariam et al., 2012). This investigation's findings are consistent with those of a study by Rdemez et al. (2006), which discovered that 90.1% of the phosphorus was eliminated.

Additionally, the coefficient of determination for phosphates and FOG in the NEWTW was found to be 0.00, indicating no weak correlation, and 0.00 for the BWTW, also showing no correlation, while the coefficient of correlation was 1.0 in both the BWTW and the NEWTW, showing a strong fit for regression in both plants. Additionally, a study conducted by Vialkova et al. (2019) revealed that wastewater mixture was characterised by an elevated concentration of nitrates, ammonium and phosphates, which indicated the curd and cheese in the effluent that contained fats. Hence, the FOG seen in the effluents of the two plants was of a large proportion from domestic homes.

5.2.4 pH

It is known that pH is a measure of acidity and alkalinity (Hailu & Ayenew, 2015). The optimal pH range for biological therapy is between 6.5 and 8.5. (Eckenfelder, 1989). The concentration of DO can have an impact on pH, which affects which organisms can survive and grow. Figure 5.7 shows the correlation between FOG and pH in the BWTW.

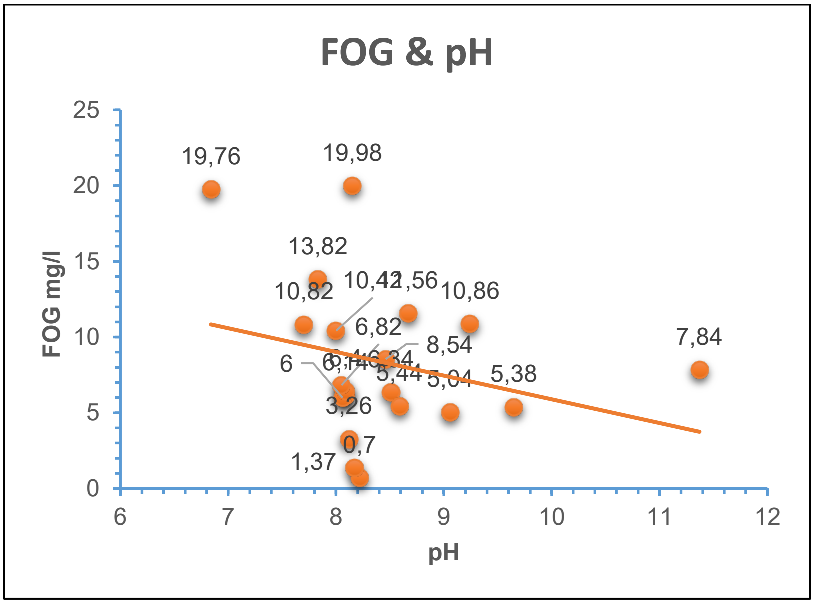

Figure 5.7 Correlation between FOG and pH in the BWTW

Figure 5.8 shows the correlation between FOG and pH in the NEWTW.

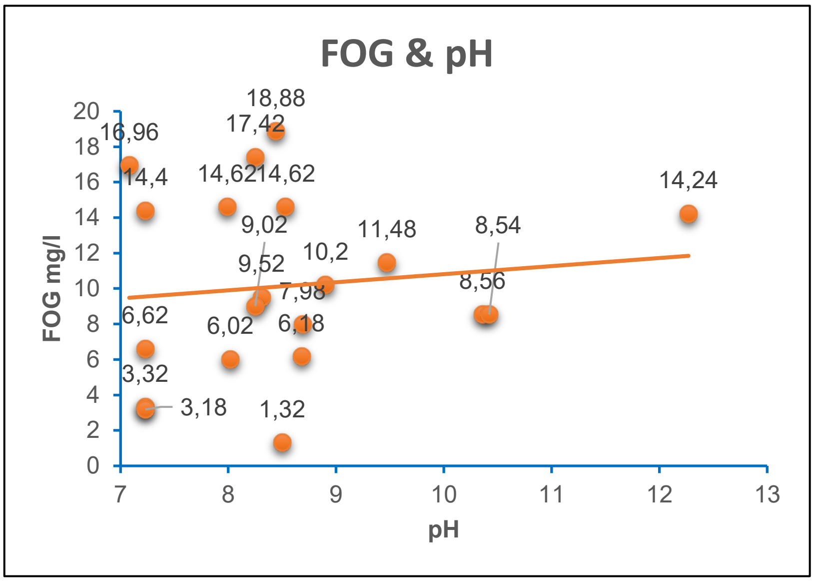

Figure 5.8 Correlation between FOG and pH in the NEWTW

The results indicated that FOG in both wastewater treatment plants had an alkaline pH due to the presence of fatty acids. In a study done by Sawain et al. (2009), the results of the experiments showed that the change of emulsion and coalesce of oil was observed when the pH value decreased to about 5. Furthermore, Eckenfelder and Wesley (2000), Fujiia et al. (2007) and Reynolds and Richards (1996) reported that the separation of FOG could be noted when pH was lower than 3.

The results indicated that FOG in both wastewater treatment plants had an alkaline pH due to the presence of fatty acids. The mean pH in the BWTW influent was 8.83 and 8.44 in the effluent, which indicated a basis for both readings. The mean pH in the NEWTW influent was 8.55 and 8.14. As a result, FOG removal in the two wastewater treatment plants was low.

The effect of pH in wastewater was used to determine the effectiveness of the two wastewater treatment technologies in the elimination of FOG and nutrients. After evaluation, the effluents of both plants were found to be slightly alkaline, with NEWTW being the weaker of the two. BWTW had a pH of 8.44 and NEWTW had a pH of 8.14. This is a desirable result as treated effluent that is too acidic can harm aquatic life hence no likely impact of FOG and nutrients released to the catchment after treatment was reported. This also concludes that the activated sludge is more effective in the removal of FOG and nutrients that the trickling filter.

5.2.5 Resistivity

The amount of dissolved salts in the water has a direct impact on its resistivity (Sensorex, 2020). Low resistivity is caused by a large amount of dissolved salt content of the water. Subsequently, a high resistivity equates to cleaner and purer water. The average resistivity in the NEWTW influent was 0.00143 and 0.0015 in the NEWTW effluent. The average resistivity was 0.0011 in the BWTW and 0.0014 in the BWTW effluent. A high resistivity in the effluent means the wastewater is cleaner than in an effluent with lower resistivity. The average resistivity in the NEWTW influent was 0.00143 and 0.0015 in the NEWTW effluent. The average resistivity was 0.0011 in the BWTW and 0.0014 in the BWTW effluent. This means that the trickling filter removes nutrients and FOG more effectively than activated sludge. Furthermore, based on how low resistivity was in the NEWTW, the need for extra pre-treatment measures for improvement in the elimination of FOG was established in the NEWTW which uses the activated sludge compared to the BWTW which uses the trickling filter and had a lower resistivity. In contrast to the trickling filter, it was shown that the catchment of the activated sludge is more likely to be affected by the discharge of FOG and nutrients. Comparing the influent and effluent in both plants, this results imply that there was a little volume of oxygen dissolved in the wastewater of the two plants.

5.2.6 Temperature

The presence of oxygen in wastewater is affected by solubility (Akan et al., 2008). In addition, the toxicity of particular chemicals in wastewater is affected by temperature (Dojlido & Best, 1993; Mayer & Ellersieck, 1988). As a result, secondary wastewater treatment processes heavily rely on the use of bacteria to eliminate organic matter from sewage. Bacteria used in water treatment plants function optimally at temperatures between 20 °C and 35 °C. Lower temperatures are still functional for bacteria; however, the rate of microbial action decreases with a decrease in temperature. On the other hand, very high temperatures have proven to be detrimental to these microorganisms and resulted in ineffective microbial processes (Marrone et al., 2020). Figure 5.9 shows the effect of temperature on FOG removal efficiency.

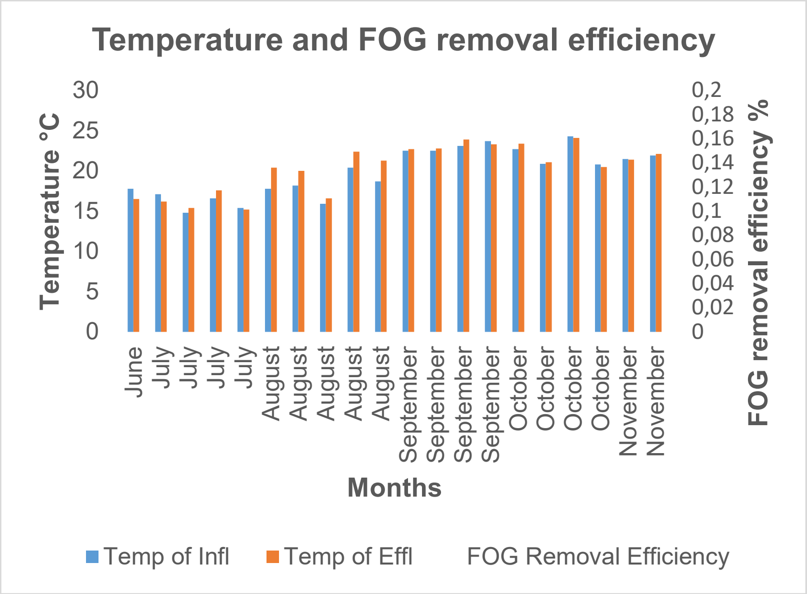

Figure 5.9 Relationship between FOG removal efficiency and temperature in the BWTW

Figure 5.10 shows the relationship between temperature and FOG removal efficiency in the NEWTW.

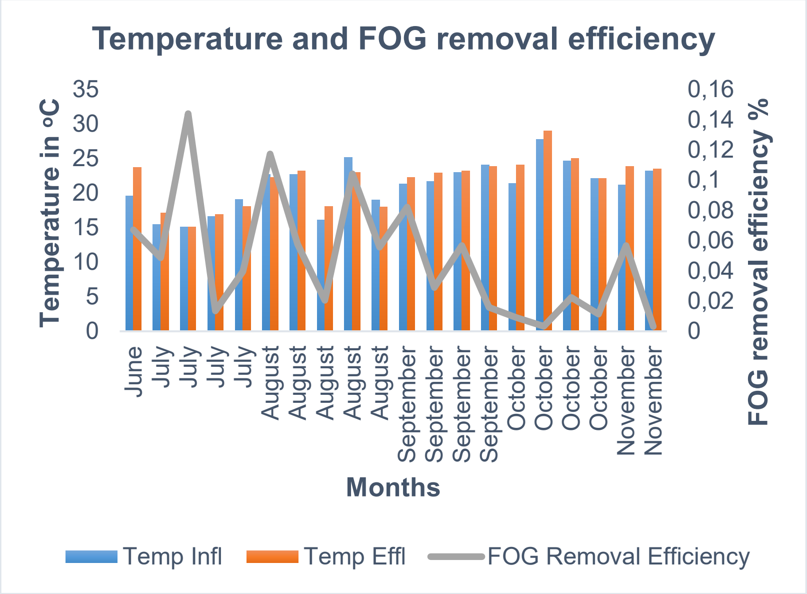

Figure 5.10 Relationship between FOG removal efficiency and temperature in the NEWTW

The results indicated that FOG removal efficiency varied considerably with regard to temperature. The results showed that FOG removal efficiency was lower in the warmer months of September, October and November. Furthermore, the results indicated that in the colder months of June, July and August, FOG removal efficiency was higher, which mean that FOG removal efficiency is indirectly proportional to temperature.

The results demonstrated that the fluctuation of FOG removal effectiveness was significantly influenced by temperature. The findings showed that FOG removal effectiveness was reduced in September, October, and November because of the increased temperatures. Furthermore, the results indicated that in June, July, and August, which are the colder months, FOG removal efficiency was higher, which mean that FOG removal efficiency is indirectly proportional to temperature. FOG in low temperatures solidifies, emulsifies and floats in wastewater. As a result of this, the lower the temperature of FOG the less effective the technology removing the FOG. The results indicated that FOG removal efficiency in both plants was lower in September, October, and November because of the weather. In the colder months of June, July and August, FOG removal efficiency was higher, which means that FOG removal efficiency is indirectly proportional to temperature. However, FOG removal efficiency was higher in the NEWTW than in the BWTW for the same months which concludes that the activated sludge was effective than the trickling filter under the same temperature. When solidified FOG is released into the catchment, it forms a blanket in the receiving body which prohibits sunlight and air from penetrating the water. This contributes to eutrophication. FOG was found in the effluents of both plants. This indicates that there is likely impact of FOG and nutrients released to the catchment after treatment in both plants, however, the BWTW showed a lesser removal efficiency than the NEWTW meaning its effluent is likely to contribute to eutrophication than that of NEWTW. As a result, extra pre-treatment measures such as grease traps are necessary to prevent FOG from entering the plants, particularly, the BWTW.

5.2.7 Dissolved oxygen

The amount of oxygen in wastewater is called DO (Zareie et al., 2021). The level of contamination in wastewater is determined by the DO levels that are significantly reduced by the presence of organic waste, domestic and animal waste, together with waste from commercial activities. In addition, DO solubility is directly proportional to atmospheric pressure and inversely proportional to water temperature and salinity (Trick et al., 2018). Because the system may lack oxygen or nutrients, some processes may not work properly. This may also be because of an increase in fibrous microorganisms in the sludge that causes deteriorated sedimentation properties in the sedimentation tank. Figure 5.11 shows the DO levels of the BWTW.

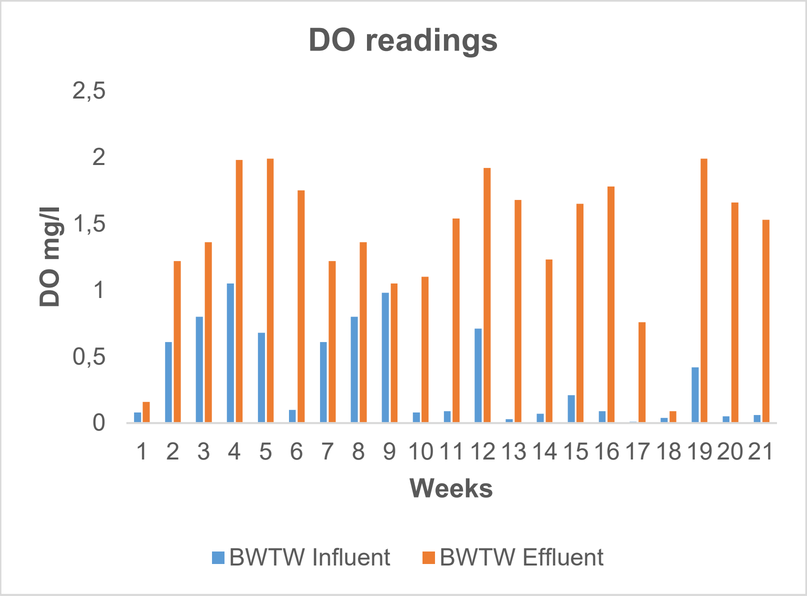

Figure 5.11 Dissolved oxygen levels in the BWTW

Figure 5.12 shows the DO levels in the NEWTW.

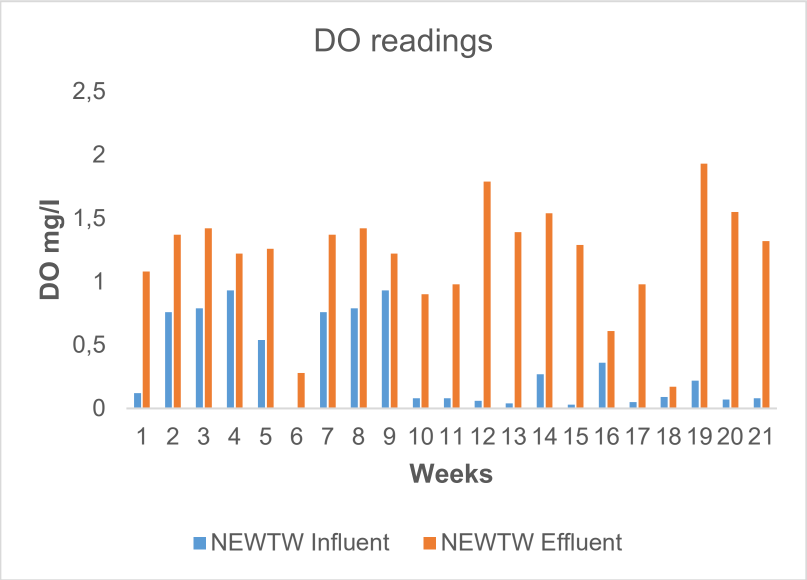

Figure 5.12 Dissolved oxygen levels in the NEWTW

According to Torres-Bejarano et al. (2018), one of the metrics most impacted by FOG is DO. Levels of DO vary in each stage in the wastewater treatment. However, by keeping the critical bacteria alive, the presence of dead zones in the biological floc can be avoided by having at least 2 mg/ℓ of DO (Online, 2021). At both influents, the readings were very low, but rose at the effluents, which is a result of aeration in the activated sludge. However, neither plants reached a DO of 2 mg/ℓ. The average DO in the BWTW influent was below the suggested amount, ranging from 0.35 mg/l to 1.39 mg/l. On the other hand, it was discovered that the average DO in the NEWTW influent was 0.33 mg/l and 1.17 mg/l in the outflow. Furthermore, during warmer weeks, the rate of biological oxidation was highly increased and this resulted in a low DO concentration compared to the colder weeks; hence, the DO levels fluctuated throughout the study. DO was also used to determine the effectiveness of the two wastewater treatment technologies in the elimination of FOG and nutrients. The dissolved oxygen concentration in the activated sludge technology should be adequate enough to supply oxygen to microorganisms in the sludge hence for the NEWTW, the dissolved oxygen was inadequate which possibly lead to poor removal of FOG. This concludes that the trickling filter is more effective than the activated sludge in the removal of FOG. As a result, the need for extra pre-treatment measures to the plants for improvement in the elimination of FOG in the NEWTW was recognised. However, because of the presence of nutrients in the effluents of the two plants, the likelihood of the eutrophication was noted particularly in the NEWTW.

5.2.8 Total dissolved solids

TDS is the measure of the amount of solid materials that can pass through a filter. This material can include carbonate, bicarbonate, chloride, sulphate, phosphate, nitrate, calcium, magnesium, sodium, organic ions, as well as other ions. Figure 5.13 shows TDS in the BWTW.

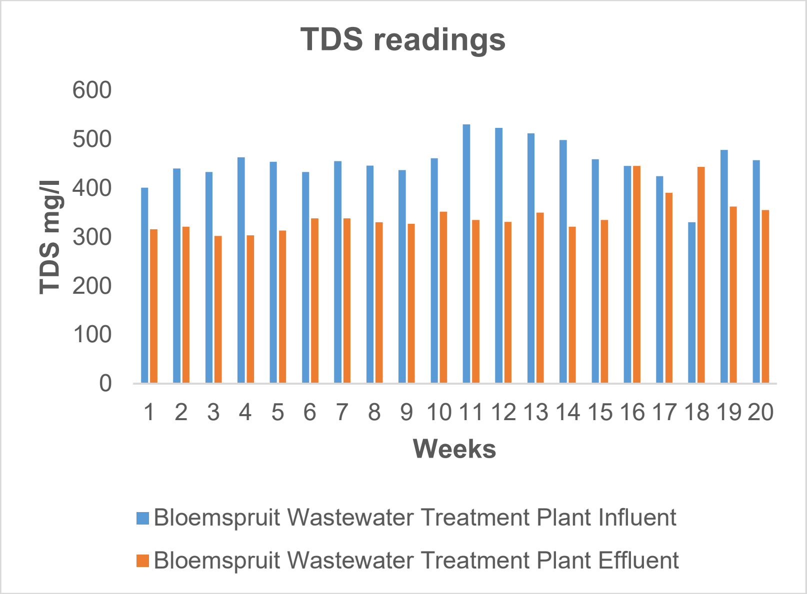

Figure 5.13 Total dissolved solids volume in the BWTW

Figure 5.14 shows TDS readings in the NEWTW.

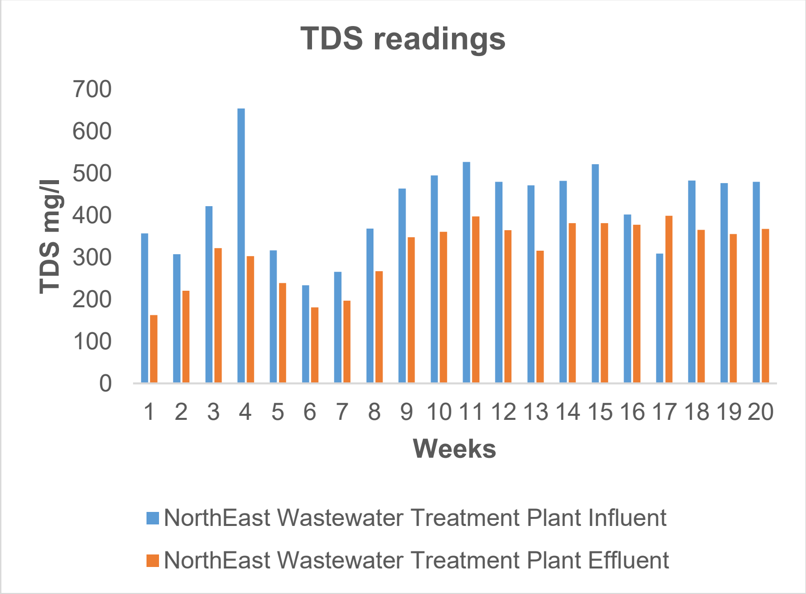

Figure 5.14 Total dissolved solids volume in the NEWTW

The results showed that the BWTW had higher readings of TDS than the NEWTW. The BWTW received a higher volume of wastewater, which correlates with a high TDS level. Additionally, most of the wastewater entering the BWTW comes from homes and nearby small manufacturers; hence, a high volume of TDS. High TDS interfere with oxygen transfer necessary for biological metabolism hence affecting the effectiveness of the treatment plant. NEWTW had an average TDS volume of 329.45mg/l while BWTW had an average volume of 345.35mg/l. As a result, extra pre-treatment measures for improvement in the elimination of FOG are recommended for the two treatment plants particularly the BWTW which had a higher volume of TDS than the NEWTW. Furthermore, upon investigation, due to the presence of a large volume of nutrients and FOG being present, the likely impact of FOG and nutrients released to the catchment after treatment was noted in the BWTW.

5.2.9 Salinity

The efficacy of the activated sludge wastewater treatment process was impeded by a high level of salinity (Ahanger and Agarwal et al., 2017). Solubility of oxygen was reduced by a high volume of salinity. The pH of urine, which was 6.2 because it contains potassium, phosphate, and nitrogen in varying amounts (Rose et al., 2015). Canfield et al., 1963, Guyton and Hall, 2000, Kien et al., 1981, Rivero-

Marcotegui et al., 1998 and Wierdsma et al., 2011 reported that fats found in the wet weight of faeces was between 2.4% and 8%. Similarly, Calloway & Kretsch, 1978, Stephen et al., 1986 and Tarpila et al., 1978 reported that the fats found in the dry weight of faeces was 8.7–16.0%. Furthermore, daily fat loadings in faecal fraction were evaluated in eight studies and an average of 4.1 g/cap/day as well as a span of 1.9-6.4 g/cap/day were noted.

Figure 5.15 shows the salinity levels in the BWTW.

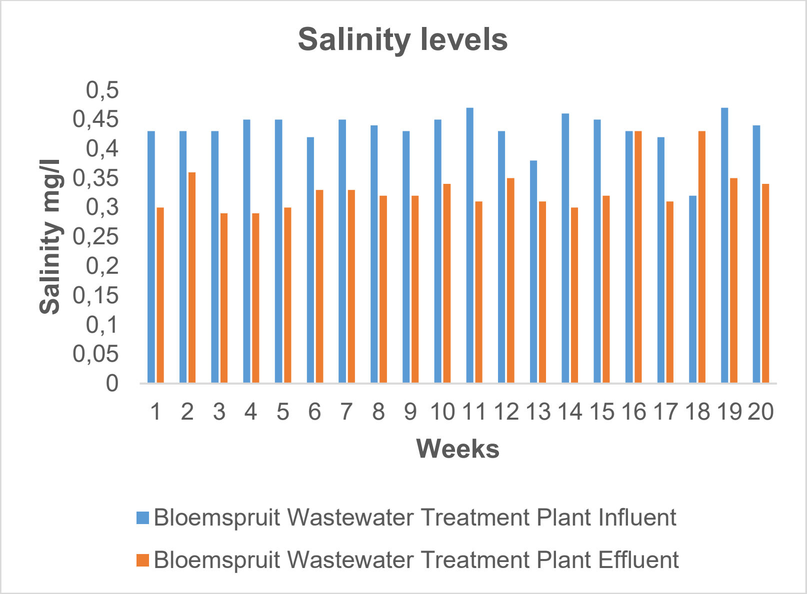

Figure 5.15 Salinity levels for the BWTW

Figure 5.16 shows the salinity levels in the NEWTW.

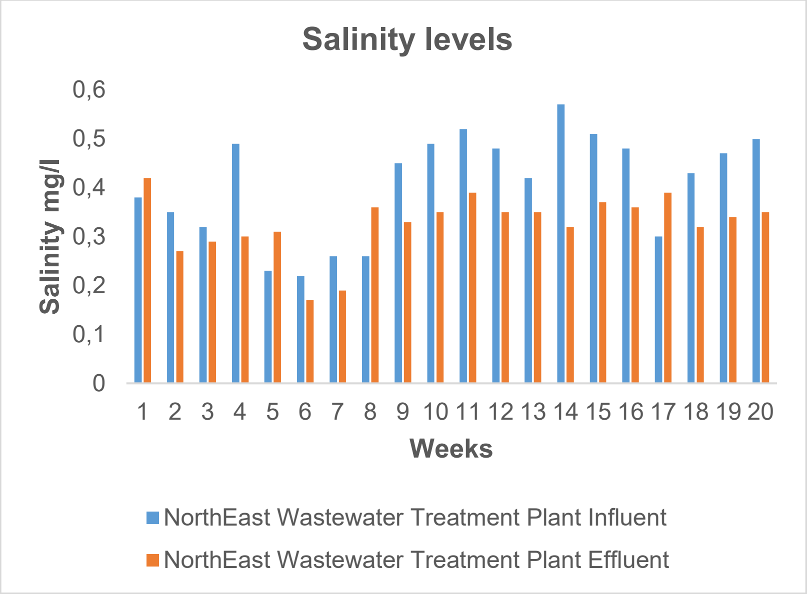

Figure 5.16 Salinity levels in the NEWTW

. Both plants showed a significant difference in salinty volumes in the inflow and in the outflow. However, the salinity levels in the BWTW were high because it received a greater volume of influent, and a large percentage of its influent was from gray water from homes and institutions. Salinity levels were used to investigate the likely impact of FOG and nutrients released to the catchment after treatment. NEWTW had an average salinity of 0.33. BWTW had an average salinity of 0.32. High levels of inorganic salts in the water does not only reduce treatment efficiency, it may be dangerous to aquatic life in the catchment in which it is released. FOG and nutrients were found in the effluent of the two plants hence threatening aquatic life in the catchments in which the effluent flows.

4.8.1 Conductivity

The conductivity of water is an expression of its ability to conduct an electric current (Mulu et al., 2015). Conductivity also indicates the amount of dissolved salt and can be used to assess processes on which the change in total salt concentration relies and subsequent changes in conductivity (Levlin, 2010). The presence of inorganic dissolved solids such as chloride, nitrate, sulphate and phosphate anions or sodium, magnesium, calcium, iron and aluminium cations affect conductivity (Rice et al., 2012). Many municipalities require that discharge effluents measure conductivity that is not higher than 500 mS/m (Levlin, 2010).

In a study done on two wastewater treatment plants in Stockholm, no reduction of conductivity was noted in the pre-sedimentation, while 28% reduction in the activated sludge was observed (Levlin, 2010). In addition, conductivity in the inflowing wastewater to the Lotsbroverket wastewater treatment plant in Mariehamn, Aland, during 2006 varied from 58 m/S to 137 mS/m, with roughly 23% reduction of conductivity in the activated sludge process (Levlin, 2010). Figures 5.17 and 5.17 shows the conductivity levels in the BWTW and NEWTW, respectively.

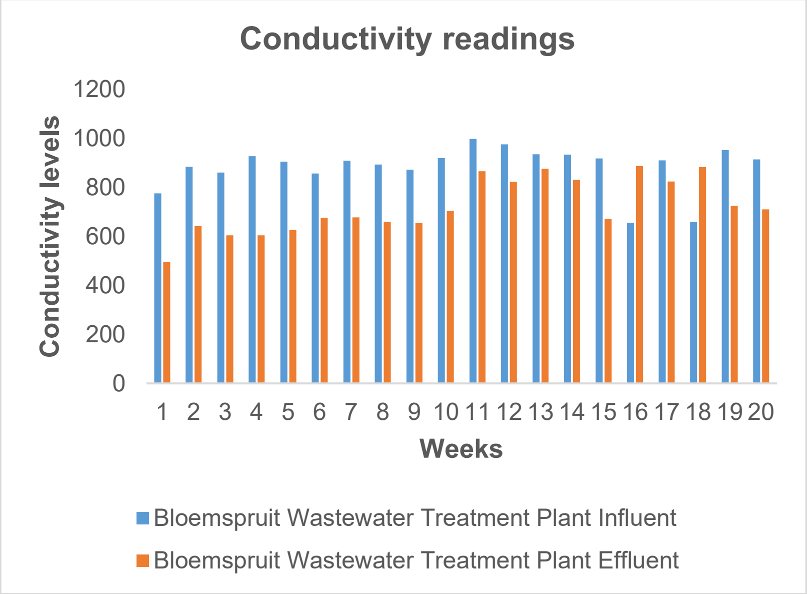

Figure 5.17 Conductivity levels in the BWTW

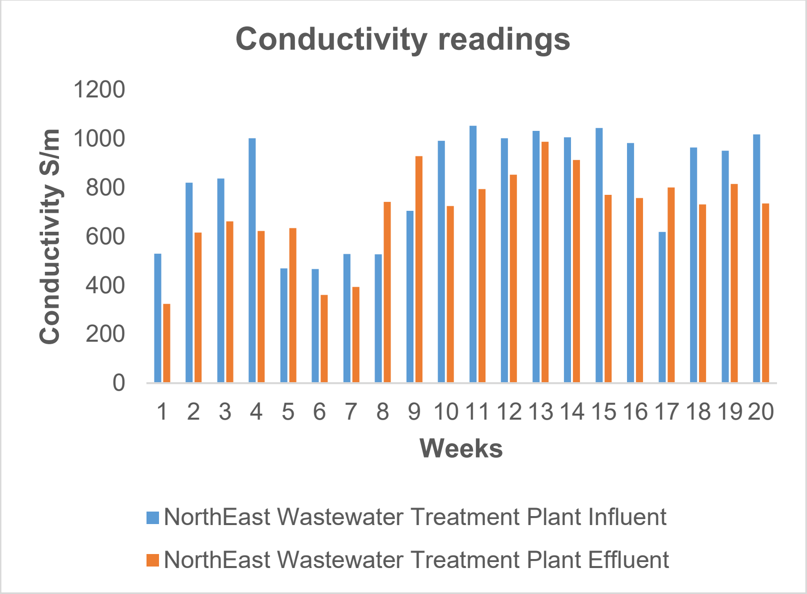

Figure 5.18 Conductivity levels in the NEWTW

. The results indicated that in the BWTW, conductivity increased by an average of over 50% after wastewater treatment, which is not normal. This could result from the plant not functioning well. In addition, the conductivity in the influent was still found to be above 500 mS/m. On the other hand, the NEWTW had a satisfactory conductivity increase rate of about 200%, although the effluent had conductivity levels of close to 1 000 mS/m, which is detrimental to the environment. Conductivity was used to determine the effectiveness of the two wastewater treatment technologies in the elimination of FOG and nutrients. During investigation, the high conductivity level in BWTW indicated that there is need for extra pre-treatment measures to the plant for improvement in the elimination of FOG and to avoid the likely impact of FOG and nutrients released to the catchment after treatment. Conductivity in NEWTW effluent was 707.85 and 722.1 in BWTW effluent.

5.2.10 Atmospheric pressure

Atmospheric pressure changes with the temperature. Warm air rises, resulting in lower pressure; hence, the atmospheric pressure was lower during the warmer months when sampling was done. On the other hand, cold air sinks, making the air pressure higher, which was seen during the winter months. The average atmospheric pressure for each treatment plant taken over a period of 20 weeks, were as follows: the BWTW influent was 642.14 Pa and the BWTW effluent was 642.48 Pa, while the NEWTW influent was 646.69 Pa and the NEWTW effluent was 646.43 Pa.

5.2.11 Chemical oxygen demand

The COD is defined as the amount of oxygen equivalents consumed in the chemical oxidation of organic matter by strong oxidants (e.g., potassium dichromate) (Jain & Singh, 2003). The importance of COD is to provide an index that assists in assessing the potential effect of wastewater discharge on the environment. The COD test also gives the value of the total quantity of oxygen required for the oxidation of the organic matter present in the wastewater to carbon dioxide and water (Kang et al. 1999).

In a study done by Yapicioğlu and Yeşilnacar (2020), the COD removal efficiency was found to be 70% and a FOG removal efficiency of 97%, while assessing wastewater containing dairy wastes. There were higher levels of COD at the NEWTW than at the BWTW. This is because the BWTW receives a higher volume of wastewater than the NEWTW, with mostly wastewater from domestic homes that contains organic matter. Figure 5.19 shows the COD levels for the BWTW.

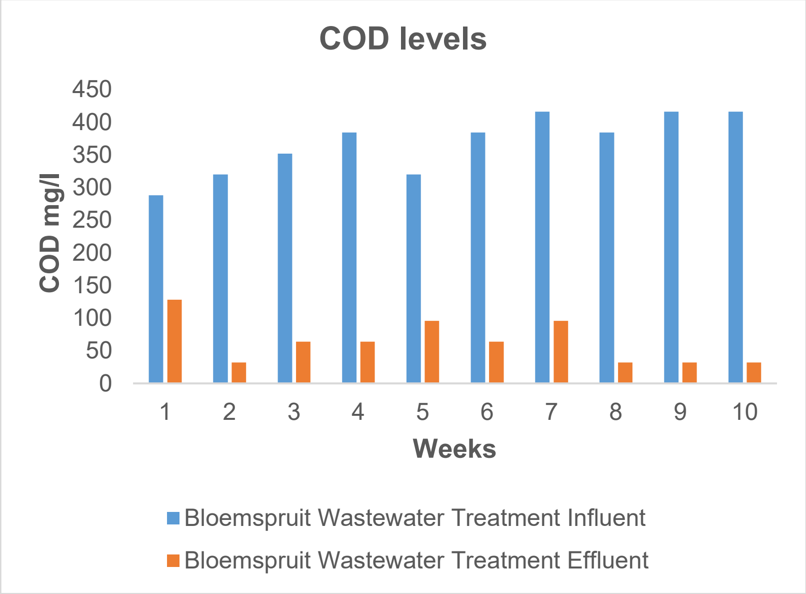

Figure 5.19 Chemical oxygen demand levels in the BWTW

Figure 5.20 shows the COD levels for the NEWTW.

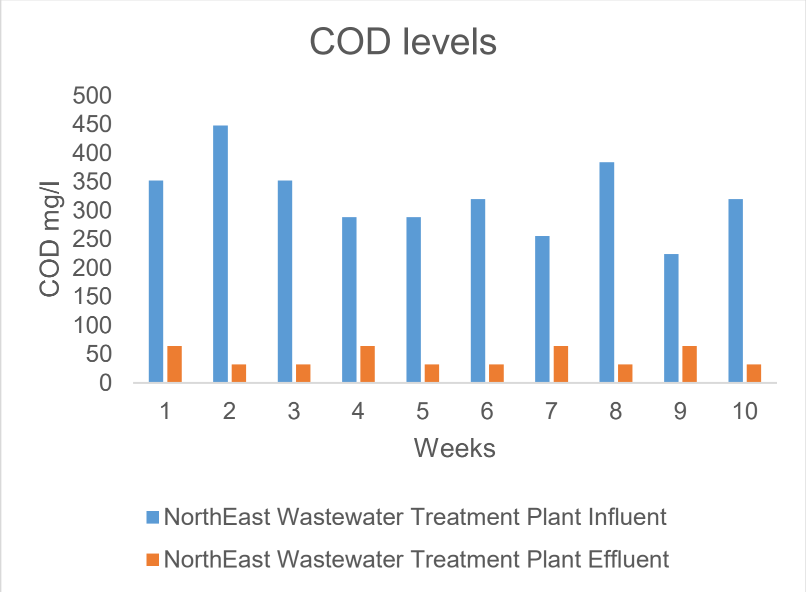

Figure 5.20 Chemical oxygen demand levels in the NEWTW

The average COD was found to be 368 mg/ℓ and 64 mg/ℓ in the inflow and outflow of BWTW respectively while NEWTW had 323.55 mg/ℓ and 46.22 mg/ℓ in the inflow and outflow of NEWTW respectively. These results indicated that both wastewater treatment plants were functioning well in the removal of pollutants. This results were used to determine the effectiveness of the two wastewater treatment technologies in the elimination of FOG and nutrients was COD. Chemical oxygen demand was significantly reduced from the influents and the effluents of the two plants therefore, the volume of nutrients also dropped leaving a minimal risk for eutrophication in the catchment. From this investigation, it was concluded that there was no need for extra pre-treatment measures to the plants for improvement in the elimination of FOG as significant volumes of COD reduction were noted in the inflow and outflow of the two plants. Additionally, due to the COD in the effluents of both plants, no likely impact of FOG and nutrients released to the catchment after treatment was noted. The average COD in the BWTW influent was 368 and 64 in the effluent while it was 291.2 in the influent of NEWTW and 41.6 in the effluent.

5.3 Summary of the study

The research examined the effectiveness of the activated sludge and trickling filter technologies in the removal of FOG and the potential relationship between FOG and phosphates and nitrates in the effluent of the two wastewater treatment facilities in the Mangaung Metropolitan Municipality. Although activated sludge is the more recent technique of the two, the NEWTW was constructed to relieve the hydraulically overburdened BWTW. Nevertheless, these two wastewater treatment facilities both discharge FOG into the watershed.

The research was conducted from June 2021 to November 2021. In June, July, and August, sample was conducted around 12:00 when the temperature was 17 °C, and in September and October, sampling was taken at roughly 10:30. Once a week, 20 influent samples and 20 effluent samples from the BWTW and NEWTW were collected and examined for the presence of FOG, nitrates, and phosphates, COD, oxygen absorbed, salinity, conductivity, temperature, ambient pressure, DO, pH, and TDS. In the laboratory, FOG was analysed using the EPA 1664B method, phosphates were examined using the phosphate Spectroquant test, and nitrates were examined using the SOP Chem 005 Spectroquant nitrate test.. Furthermore, the link between nitrates, phosphates, and FOG was examined using the regression formula. The laboratory version of the potassium dichromate technique was used to analyze COD. The Part 63 oxygen absorbed in four hours method was used in the laboratory to analyze oxygen absorption. The Hanna HI98193 multimeter was used to measure salinity, conductivity, temperature, air pressure, and TDS, whereas the Hanna 98192 multimeter was used to measure DO and pH.

Additionally, in terms of removal rate, trickling filter technology surpassed activated sludge technology. At the BWTW, FOG was removed in a percentage of 61.36%, compared to 52.81% at the NEWTW. Both of the wastewater effluent standards fall short of the South African wastewater effluent standards limit of 2.5 mg/l with relation to the discharge into a water source.

Furthermore, the regression coefficient for the BWTW and NEWTW was 0.99 and 1.00, respectively, demonstrating a clear relationship between nitrates and FOG. For the NEWTW, there was no correlation coefficient. The coefficient of determination for the NEWTW was zero. This indicated a negligible variation of FOG in nitrates, but the BWTW's coefficient of determination was discovered to be 0.4039, indicating a nearly equal variation of FOG in nitrates. This means that the nitrate and FOG volume had an impact on the amount of FOG that was present in the effluents of both facilities.

According to the findings for the NEWTW, phosphate levels in the effluent were lower over the course of the trial, indicating that the plant is doing a good job of removing phosphate. Phosphates are an ingredient in many soaps and detergents, hence the wastewater influent of the two facilities contains a sizable amount of phosphates. The BWTW, however, had the highest concentration of phosphates since it gets more influent. The coefficient of determination for FOG in the BWTW was 0.07, showing that the regression is poorly fitted, and 0.00 for phosphates, also showing a poor fit for regression. In addition, the coefficient of correlation of phosphates and FOG in the BWTW was found to be 0.00, showing a weak to moderate correlation, 0.999 in the NEWTW, showing a strong correlation. In the NEWTW, phosphates demonstrated a higher dependent on FOG of 0.67, whereas FOG demonstrated a negligible dependency of 0.02.

However, because there were so many organic chemicals in the water, it was discovered that only a little amount of oxygen was being absorbed in the two wastewater treatment facilities. It was discovered that the average oxygen absorption in the BWTW was 47.50 mg/l and 60.80 mg/l in the inflow and outflow respectively. Additionally, NEWTW's influent recorded 41.33 mg/l of oxygen absorption and its effluent 11.88 mg/l. This happened as a result of power interruptions, which caused the plant to malfunction and account for the decline in oxygen absorption levels in the effluent.

Furthermore, despite the BWTW receiving a greater amount of wastewater than the NEWTW, the COD levels at the NEWTW were higher than those at the BWTW. While the NEWTW exhibited 323.55 mg/l and 46.22 mg/l in the influent and effluent respectively while the BWTW influent showed 368 mg/l and 64 mg/l in the mean COD. These findings showed that both wastewater treatment facilities were performing efficiently in terms of removing contaminants.

The activated sludge's aeration caused the DO readings at both influents, which were very low, to rise at the effluents. But neither plant achieved the suggested 2 mg/l. The BWTW influent's average DO was between 0.35 to 1.39 mg/l, which was below the suggested level. Contrarily, it was discovered that the average DO in the NEWTW was 0.33 mg/l and 1.17 mg/l in the influent and effluent respectively.

As can be seen from the data, the presence of fatty acids gave both wastewater treatment plants' FOG a base. The average pH in the influent of the BWTW was 8.83, and it was 8.44 in the effluent, both of which suggest alkalinity. The NEWTW influent's mean pH was between 8.55 and 8.14. Both readings also showed alkalinity.

Additionally, both facilities demonstrated a notable variation in salinity levels between influent and effluent. The BWTW influent's mean salinity was 0.41 ppt, while the effluent's was 0.33 ppt. Salinity was found to be 0.41 ppt in the NEWTW influent and 0.33 ppt in the effluent, on the other hand. However, because of the higher volume of influent it gets and the fact that the majority of it is grey water from households and institutions, the BWTW has high saline levels.

Conductivity of water is typically increased by the presence of chloride, nitrate, sulfate, phosphate, sodium, magnesium, calcium, iron, and aluminum. It is unusual for effluent conductivity to be over 50% greater in the BWTW. These findings imply that the plant is not operating efficiently. Similar results for conductivity in the NEWTW showed that the plant was not operating as intended and posed a threat to the discharge environment with values close to 1000 mS/m. As a result, the average conductivity in the NEWTW influent was 827.05 mS/m and the conductivity in the BWTW influent was 882.95 mS/m and the effluent was 722.1 mS/m.

The outcomes showed that temperature strongly influenced the variability of FOG removal efficiency. Findings indicated that FOG removal effectiveness was reduced in September, October, and November because of the increased temperature. The findings also showed that FOG removal efficiency increased in June, July, and August, indicating that FOG removal efficiency is indirectly correlated with temperature.

Additionally, over a 20-week period, the average atmospheric pressure for each treatment facility was as follows: for the BWTW influent, it was 642.14 Pa, for the BWTW effluent, it was 642.48 Pa, and for the NEWTW influent, it was 646.69 Pa, for the NEWTW effluent, it was 646.43 Pa.

The results, however, revealed that the BWTW had greater TDS levels than the NEWTW. The mean TDS in the influent from the BWTW was 453.95 mg/l, while that in the effluent was 345.35 mg/l. TDS was also 412.67 mg/l in the NEWTW influent and 314.32 mg/l in the effluent. The BWTW receives more wastewater, which corresponds to more TDS being present. Additionally, a large amount of TDS is present because most of the wastewater that enters the BWTW originates from surrounding small enterprises and residential areas.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The research objectives were achieved. Below are the objectives and how they were achieved.

6.1.2 To determine the effectiveness of the two wastewater treatment technologies in the elimination of FOG and nutrients.

The trickling filter and activated sludge are both efficient at removing FOG and nutrients. Although the trickling filter was determined to be more effective than the activated sludge in the removal of FOG, the NEWTW, which uses a newer technology, the activated sludge, was built to relieve the hydraulically overloaded BWTW.

Despite the fact that the trickling filter eliminated FOG more successfully than the activated sludge in the current study, there was FOG discovered in the effluents of the two facilities. The limit for the discharge into a water source, set by the South African Department of Forestry, Fisheries, and the Environment (SA Department of Forestry, Fisheries, and the Environment, 2014), was fulfilled by both effluents. Additionally, it was found that the amount of nutrients in the effluent from the two wastewater treatment facilities was within South African discharge standards, proving that both technologies are effective at removing nutrients. However, activated sludge outperformed trickling filters in this regard. There were phosphates in the effluent of the two water treatment plants, which created concerns for the watershed ecosystem and heightened the danger of eutrophication. It was also reported that the two facilities' effluent contained nitrates, which could also cause eutrophication and endanger the aquatic life in the watershed.

6.1.3 To investigate the need for extra pre-treatment measures to the plants for improvement in the elimination of FOG.

The findings of the analysis of how well the two wastewater treatment techniques removed FOG showed that the trickling filter was more effective than activated sludge at doing so. However, it was discovered that effluent FOG concentrations of the two water treatment plants exceeded South African wastewater discharge requirements.

These results led to the conclusion that further pre-treatment procedures, such as tilting plates in the preliminary stage, were necessary for the plants to improve their capacity to remove FOG.

6.1.4 To investigate the likely impact of FOG and nutrients released to the catchment after treatment.

The two plants' effluent was found to contain levels of FOG that were higher than the permitted South African wastewater discharge requirements. The influence of FOG released to the catchment after treatment is therefore likely. However, it was discovered that nutrient concentrations in the outflow from the two water treatment facilities were within limits for South African wastewater discharge, and there was no evidence of a potential effect of nutrients.

The concentration of phosphates levels of the two plants both met the South African wastewater discharge standards. However, the two wastewater treatment plants' effluent contains phosphates, which increases the risk of eutrophication and raises concerns for the catchment environment. The outcomes demonstrated that activated sludge was more effective at removing phosphates than the trickling filter. In addition, the findings indicated that the two wastewater treatment facilities are equally efficient at eliminating nitrates since both satisfied the South African wastewater effluent discharge standards. Although, since wastewater from the two facilities contained nitrates, this might lead to eutrophication and put the aquatic life in the watershed in danger.

6.2 Recommendations

The current findings will serve as a useful information concerning FOG found in effluents. FOG was found in the effluent of the two treatment plant, therefore the following pre-treatment measures are recommended:

- Reinforcement of laws that prohibit the discharge of food industry FOG into the wastewater treatment plants.

- Introducing pre-treatment methods such as tilting plates the first phase of the two wastewater treatment facilities.

- Recycling FOG found in the effluent into biodiesel.

- Ensuring that the wastewater treatment plants are functioning efficiently can not only properly reduce FOG, but it can promote the need for commercialising by-products such as sludge for biogas.

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APPENDIX A

SUPPLEMENTARY INFORMATION TO CHAPTER 5

Fats, oil and grease (FOG)

Parameters	**BWTW**		**NEWTW**	
	Influent	**Effluent**	**Influent**	**Effluent**
Week 1 23/06/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.44	44.80	47.42	47.83
Mass before drying (g)	83.55	78.5	77.77	75.23
After drying (g)	56.0	54.68	54.73	55.73
FOG	21.12	19.76	14.62	7.90
Week 2 30/06/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.41	44.69	47.42	47.85
Mass before drying (g)	83.55	77.5	77.76	54.73
Mass after drying (g)	56.00	54.68	54.73	52.73
FOG	21.18	19.98	14.62	9.76
Week 3 07/07/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	47.42	49.42	45.41	47.90
Mass before dying (g)	53.34	52.89	69.42	51.55
Mass after drying (g)	52.75	51.05	54.12	49.41
FOG	10.66	3.26	17.42	3.02
Week 4 14/07/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.44	44.80	47.80	47.90
Mass before drying (g)	53.20	56.70	50.45	57.79
Mass after drying g)	49.47	47.87	49.46	48. 89
FOG	8.06	6.14	3.32	1.98
Week 5 21/07/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.44	44.80	47.48	47.90
Mass before drying (g)	57.25	55.96	57.45	56.76
Mass after drying (g)	46.30	45.15	50.79	49.23
FOG	1.72	0.70	6.62	2.66

Parameters	BWTW		NEWTW	
	Influent	Effluent	Influent	Effluent
Week 6 28/07/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.41	44.69	47.42	47.83
Mass before drying (g)	57.90	53.55	57.70	52.50
Mass after drying (g)	48.95	47.69	55.90	50.44
FOG	7.08	6.00	16.96	5.22
Week 7 04/08/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.41	44.69	47.42	47.83
Mass before drying (g)	53.26	50.31	57.70	52.50
Mass after drying (g)	52.21	50.12	56.86	54.39
FOG	13.6	10.86	18.88	13.12
Week 8 11/08/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.40	44.69	47.42	47.83
Mass before drying (g)	57.64	53.37	57.15	57.52
Mass after drying (g)	51.70	49.90	50.43	49.82
FOG	12.60	10.42	6.02	3.98
Week 9 18/08/2021				
pH before analysis	2.00	2.00	2.00	2.00
Mass of container (g)	45.40	54.39	45.37	47.83
Mass before drying (g)	61.10	66.81	57.61	55.34
Mass after drying (g)	57.16	57.59	52.57	49.82
FOG	23.52	6.40	14.40	3.98
Week 10 25/08/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	51.84	59.77	45.42	47.85
Mass before drying (g)	66.41	72.93	57.70	60.29
Mass after drying (g)	63.54	62.29	55.62	52.49
FOG	23.4	5.04	10.20	4.64
Week 11 01/09/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container(g)	51.83	59.77	45.37	47.86
Mass before drying (g)	65.15	69.45	58.42	59.52
Mass after drying (g)	63.86	62.94	52.49	50.87
FOG	24.06	6.34	14.24	6.02

Parameters	BWTW		NEWTW	
	Influent	Effluent	Influent	Effluent
Week 12 08/09/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	47.83	52.51	59.77	50.66
Mass before drying (g)	62.60	61.35	69.01	59.23
Mass after drying (g)	58.46	55.23	64.05	53.49
FOG	21.26	5.44	8.56	5.66
Week 13 15/09/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	53.27	51.45	54.40	47.96
Mass before drying (g)	58.36	53.31	63.91	58.86
Mass after drying (g)	56.38	54.14	60.14	50.86
FOG	6.22	5.38	11.48	5.80
Week 14 22/09/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	51.94	56.42	59.95	45.50
Mass before drying (g)	61.26	63.05	66.89	51.59
Mass after drying (g)	55.75	59.83	64.22	48.98
FOG	7.62	6.82	8.54	6.96
Week 15 29/09/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	53.25	52.48	54.39	50.65
Mass before drying (g)	63.33	61.89	64.08	60.69
Mass after drying (g)	59.89	56.40	55.05	50.86
FOG	13.28	7.84	1.32	0.42
Week 16 06/10/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	53.20	49.66	47.43	45.41
Mass before drying (g)	62.91	57.73	58.09	57.13
Mass after drying (g)	56.68	56.51	49.42	46.83
FOG	6.96	1.37	3.18	2.84
Week 17 13/10/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	47.83	44.69	59.77	47.83
Mass before drying (g)	57.89	54.30	66.26	55.30
Mass after drying (g)	53.60	50. 10	64.53	51.47
FOG	11.54	10.82	9.52	7.28

Parameters	**BWTW**		**NEWTW**	
	Influent	**Effluent**	**Influent**	**Effluent**
Week 18 20/10/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	53.20	49.66	47.43	45.41
Mass before drying (g)	62.91	57.73	58.09	57.13
Mass after drying (g)	60.68	56.57	51.42	48.83
FOG	14.96	13.82	7.98	6.84
Week 19 27/10/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	51.83	49.67	45.32	45.41
Mass before drying (g)	65.04	58.85	57.86	55.22
Mass after drying (g)	56.35	53.94	49.83	47.08
FOG	9.04	8.54	9.02	3.34
Week 20 03/11/2021				
pH before analysis	2.01	2.01	2.01	2.01
Mass of container (g)	53.20	49.66	47.43	45.41
Mass before drying (g)	62.58	59.63	59.18	55.22
Mass after drying (g)	59.87	55.44	50.52	48.34
FOG	13.34	11.56	6.18	5.86

Multimeter readings

Parameters	NEWTW		BWTW	
	Influent	Effluent	Influent	Effluent
Week 1 30/06/2021				
pH	8.53	8.61	7.25	6.84
Conductivity	530	324	776	495
Atmospheric pressure	644	643	642	642
Resistivity	0.0017	0.0013	0.0014	0.0012
TDS	357	163	401	316
Salinity	0.38	0.42	0.43	0.30
Temperature	19.6	23.7	17.8	16.5
DO	0.12	1.08	0.08	0.16
Week 2 06/07/2021				
pH	7.99	7.85	8.81	8.15
Conductivity	820	616	884	643
Atmosphere pressure	647	647	642	642
Resistivity	0.0018	0.0015	0.0016	0.0014
TDS	221	308	440	321
Salinity	0.35	0.27	0.43	0.36
Temperature	15.5	17.1	17.1	16.2
DO	0.76	1.37	0.80	1.36
Week 3 13/07/2021				
pH	8.25	7.23	8.14	8.12
Conductivity	837	661	861	604
Atmosphere pressure	644	644	649.8	649.6
Resistivity	0.0015	0.0012	0.0012	0.0017
TDS	422	332	433	302
Salinity	0.32	0.42	0.43	0.29
Temperature	15.1	15.1	14.8	15.4
DO	0.93	1.22	1.05	1.98
Week 4 20/07/2021				
pH	7.23	7.23	8.05	8.09
Conductivity	1001	622	927	605
Atmospheric pressure	647	645	643	643
Resistivity	0.0010	0.0016	0.0011	0.0017
TDS	654.4	303	463	303
Salinity	0.49	0.30	0.45	0.29
Temperature	16.6	16.9	16.6	17.6
DO	0.54	1.26	0.68	1.99

Parameters	NEWTW		BWTW	
	Influent	Effluent	Influent	Effluent
Week 5 27/07/2021				
pH	7.23	8.20	8.12	8.22
Conductivity	469	634	905	626
Atmospheric pressure	657.3	657.5	643	643
Resistivity	0.0021	0.0016	0.0011	0.0016
TDS	239	317	454	313
Salinity	0.23	0.31	0.45	0.30
Temperature	19.1	18.1	15.4	15.2
DO	0.00	0.28	0.10	1.75
Week 6 03/08/2021				
pH	7.08	8.90	8.11	8.06
Conductivity	467	361	857	676
Atmospheric pressure	650	649	645	645
Resistivity	0.0021	0.0017	0.0012	0.0015
TDS	234	181	433	338
Salinity	0.22	0.17	0.42	0.33
Temperature	22.7	22.3	17.8	20.4
DO	0.76	1.37	0.61	1.22
Week 7 10/08/2021				
pH	8.44	8.70	8.37	9.24
Conductivity	528	393	909	678
Atmospheric pressure	658.2	656.6	646	646
Resistivity	0.0019	0.0025	0.0011	0.0015
TDS	266	197	455	338
Salinity	0.26	0.19	0.45	0.33
Temperature	22.7	23.2	18.2	20.0
DO	0.79	1.42	0.80	1.36
Week 8 17/08/2021				
pH	8.02	8.13	8.07	8.00
Conductivity	527	741	893	659
Atmospheric pressure	652.4	652.5	640	640
Resistivity	0.0019	0.0014	0.0011	0.0015
TDS	267	369	446	330
Salinity	0.26	0.36	0.44	0.32
Temperature	16.1	18.1	15.9	16.6
DO	0.93	1.22	0.98	1.05

Parameters	NEWTW		BWTW	
	Influent	Effluent	Influent	Effluent
Week 9 24/08/2021				
pH	7.23	8.28	8.19	8.09
Conductivity	705	928	873	655
Atmospheric pressure	644	644	642	642
Resistivity	0.0011	0.0014	0.0011	0.0015
TDS	464	348	437	327
Salinity	0.45	0.33	0.43	0.32
Temperature	25.2	23.0	20.4	22.4
DO	0.08	0.90	0.08	1.10
Week 10 31/08/2021				
pH	8.90	8.30	8.37	9.06
Conductivity	991	724	920	704
Atmospheric pressure	644	643	642	643
Resistivity	0.0010	0.0014	0.0011	0.0014
TDS	495	361	461	352
Salinity	0.49	0.35	0.45	0.34
Temperature	19	18.0	18.7	21.3
DO	0.08	0.98	0.09	1.54
Week 11 07/09/2021				
pH	12.27	7.60	10.42	8.51
Conductivity	1052	794	998	866
Atmospheric pressure	643	643	640	641
Resistivity	0.0010	0.0013	0.0002	0.0005
TDS	527	398	530	335
Salinity	0.52	0.39	0.47	0.31
Temperature	21.3	22.31	22.5	22.7
DO	0.06	1.79	0.71	1.92
Week 12 14/09/2021				
pH	10.36	8.25	12.22	8.59
Conductivity	1002	852	976	823
Atmospheric pressure	643	643	640	640
Resistivity	0.0021	0.0023	0.0011	0.0016
TDS	480	365	523	331
Salinity	0.48	0.32	0.43	0.35
Temperature	21.7	22.9	22.5	22.8
DO	0.04	1.39	0.03	1.68

Parameters	NEWTW		BWTW	
	Influent	Effluent	Influent	Effluent
Week 13 21/09/2021				
pH	9.47	8.30	11.05	9.65
Conductivity	1032	987	935	876
Atmospheric pressure	643	643	640	640
Resistivity	0.0012	0.0015	0.0011	0.0015
TDS	472	316	512	350
Salinity	0.42	0.35	0.38	0.31
Temperature	23.0	23.2	23.1	23.9
DO	0.27	1.54	0.07	1.23
Week 14 28/09/2021				
pH	10.42	8.26	9.24	8.05
Conductivity	1005	913	934	831
Atmospheric pressure	643	643	640	640
Resistivity	0.0015	0.0017	0.0010	0.0013
TDS	482	382	498	321
Salinity	0.57	0.32	0.46	0.30
Temperature	24.1	23.9	23.7	23.3
DO	0.03	1.29	0.21	1.65
Week 15 05/10/2021				
pH	8.50	8.45	10.17	11.37
Conductivity	1044	770	919	671
Atmospheric pressure	644	644	640	640
Resistivity	0.0010	0.0013	0.0011	0.0015
TDS	522	382	459	335
Salinity	0.51	0.37	0.45	0.32
Temperature	21.4	24.1	22.7	23.4
DO	0.61	0.36	0.09	1.78
Week 16 12/10/2021				
pH	7.23	7.88	8.18	8.17
Conductivity	982	757	656	887
Atmospheric pressure	643	643	640	641
Resistivity	0.0010	0.0013	0.0011	0.0015
TDS	402	378	445	445
Salinity	0.48	0.36	0.43	0.43
Temperature	27.8	29.0	20.9	21.1
DO	0.05	0.98	0.01	0.76

Parameters	**NEWTW**		**BWTW**	
	Influent	Effluent	Influent	Effluent
Week 17 19/10/2021				
pH	8.31	7.98	8.98	7.70
Conductivity	618	800	911	824
Atmospheric pressure	642	643	640	640
Resistivity	0.0016	0.0017	0.0015	0.0018
TDS	309	399	424	390
Salinity	0.30	0.39	0.42	0.31
Temperature	24.7	25.0	24.3	24.1
DO	0.09	0.17	0.04	0.09
Week 18 26/10/2021				
pH	8.69	7.50	7.68	7.83
Conductivity	964	731	659	883
Atmospheric pressure	648	646	644	644
Resistivity	0.0010	0.0014	0.0015	0.0011
TDS	483	366	330	443
Salinity	0.47	0.35	0.32	0.43
Temperature	22.1	22.1	20.8	20.5
DO	0.22	1.93	0.42	1.99
Week 19 2/11/2021				
pH	8.25	8.55	8.47	8.46
Conductivity	950	814	952	725
Atmospheric pressure	648	648	643	643
Resistivity	0.0011	0.0014	0.0010	0.0014
TDS	477	356	478	362
Salinity	0.47	0.34	0.47	0.35
Temperature	21.2	23.9	21.5	21.4
DO	0.07	1.55	0,05	1.66
Week 20 9/11/2021				
pH	8.68	8.65	8.68	8.67
Conductivity	1017	735	914	711
Atmospheric pressure	646	646	645	645
Resistivity	0.0010	0.0014	0.0011	0.0014
TDS	480	368	457	355
Salinity	0.50	0.35	0.44	0.34
Temperature	23.2	23.5	21.9	22.1
DO	0.08	1.32	0.06	1.53

Chemical Oxygen Demand, Oxygen Absorbed, Ammonia, Phosphate

Parameters	BWTW						NWTW					
	Blank	Titrated value	Influent	Blank	Titrated value	Effluent	Blank	Titrated value	Influent	Blank	Titrated value	Effluent
Week 1 23/06/2021												
COD	1.6	0.7	288	1.6	1.2	128	1.6	0.5	352	1.6	1.4	64
OA	9.8	5.6	42	9.8	9.2	6	9.8	6.0	38	9.8	8.9	9
NH_3						1.45						1.4
PO_4			5.3			4.6			3.7			1.34
Week 2 07/07/2021												
COD	1.6	0.6	320	1.6	1.5	32	DATA UNAVAILABLE DUE TO MALFUNCTIONING OF THE NEWTW PLANT					
OA	9.8	6.2	36	9.8	8.0	18						
NH_3						3.9						
PO_4			4.83			3.3						
Week 3 21/07/2021												
COD	1.6	0.5	352	1.6	1.4	64	1.6	0.2	448	1.6	1.5	32
OA	9.8	4.8	50	9.8	8.9	9	9.8	6.5	33	9.8	9.1	7
NH_3						5.4						0.9
PO_4			8.7			3.9			3.25			0.59
Week 4 28/07/2021												
COD	ELECTRICITY CABLE STOLEN AT BWTW. NO DATA ANALYSED DUE TO ABSENCE OF POWER.											
OA												
NH_3												
PO_4												

Parameters	BWTW						NWTW					
	Blank	Titrated value	Influent	Blank	Titrated value	Effluent	Blank	Titrated value	Influent	Blank	Titrated value	Effluent
Week 5 04/08/2021												
COD	1.6	0.4	384	1.6	1.4	64	1.6	0.8	352	1.6	1.5	32
OA	9.8	2.8	70	7.5	6.5	10	9.8	6.1	37	9.8	8.5	13
NH_3						1.9						0.9
PO_4			6.06			3.90			4.61			0.33
Week 6 18/08/2021												
COD	1.6	0.6	320	1.6	1.3	96	1.6	0.7	288	1.6	1.4	64
OA	9.8	5.2	46	9.8	8.7	11	9.8	6.0	38	9.8	8.4	14
NH_3						4.3						0.5
PO_4			5.85			4.94			4.14			2.14
Week 7 01/09/2021												
COD	1.6	0.4	384	1.6	1.4	64	1.6	0.7	288	1.6	1.5	32
OA	9.8	3.4	64	9.8	6.7	31	9.8	1.9	60	9.8	8.0	28
NH_3						8.3						1.9
PO_4			3.18			4.30			4.69			1.94
Week 8 15/09/2021												
COD	1.6	0.3	416	1.6	1.3	96	1.6	0.6	320	1.6	1.5	32
OA	9.8	4.5	53	9.8	7.9	19	9.8	5.0	48	9.8	9.2	6
NH_3						4.90						1.2
PO_4			3.34			3.95			4.23			2.06

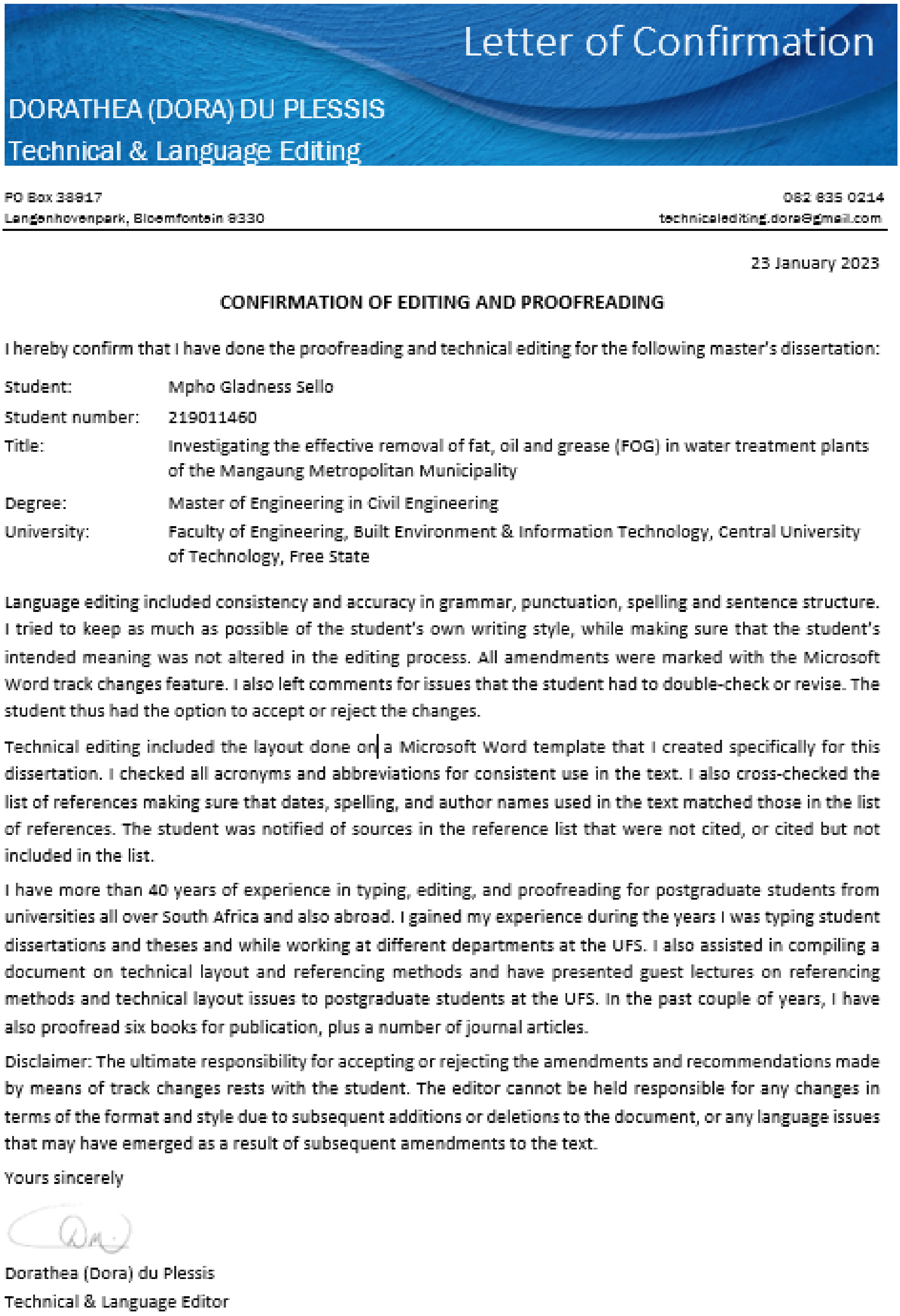
Parameters	BWTW						NWTW					
	Blank	Titrated value	Influent	Blank	Titrated value	Effluent	Blank	Titrated value	Influent	Blank	Titrated value	Effluent
Week 9 29/09/2021												
COD	1.6	0.4	384	1.6	1.5	32	1.6	0.8	256	1.6	1.4	64
OA	9.8	6.6	32	9.8	8.8	10	9.8	5.6	42	9.8	8.5	13
NH_3						5.30						2.1
PO_4			4.5			2.11			4.5			3.3
Week 10 13/10/2021												
COD	1.6	0.3	416	1.6	1.5	32	1.6	0.4	384	1.6	1.5	32
OA	9.8	5.9	39	9.8	7.8	20	9.8	6.0	38	9.8	9.1	7
NH_3			15.1			8.90						0.5
PO_4			4.09			2.87			3.9			3.3
Week 11 27/10/2021												
COD	1.6	0.3	416	1.6	1.5	32	1.6	0.9	224	1.6	1.4	64
OA	9.8	5.5	43	9.8	8.9	9	9.8	6.0	38	9.8	8.8	10
NH_3						6.50						2.2
PO_4			5.2			2.30			4.3			2.1

APPENDIX B

TURNITIN REPORT

APPENDIX C

LANGUAGE EDITOR REPORT



Letter of Confirmation

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23 January 2023

CONFIRMATION OF EDITING AND PROOFREADING

I hereby confirm that I have done the proofreading and technical editing for the following master's dissertation:

Student:	Mpho Gladness Sello
Student number:	219011460
Title:	Investigating the effective removal of fat, oil and grease (FOG) in water treatment plants of the Mangaung Metropolitan Municipality
Degree:	Master of Engineering in Civil Engineering
University:	Faculty of Engineering, Built Environment & Information Technology, Central University of Technology, Free State

Language editing included consistency and accuracy in grammar, punctuation, spelling and sentence structure. I tried to keep as much as possible of the student's own writing style, while making sure that the student's intended meaning was not altered in the editing process. All amendments were marked with the Microsoft Word track changes feature. I also left comments for issues that the student had to double-check or revise. The student thus had the option to accept or reject the changes.

Technical editing included the layout done on a Microsoft Word template that I created specifically for this dissertation. I checked all acronyms and abbreviations for consistent use in the text. I also cross-checked the list of references making sure that dates, spelling, and author names used in the text matched those in the list of references. The student was notified of sources in the reference list that were not cited, or cited but not included in the list.

I have more than 40 years of experience in typing, editing, and proofreading for postgraduate students from universities all over South Africa and also abroad. I gained my experience during the years I was typing student dissertations and theses and while working at different departments at the UFS. I also assisted in compiling a document on technical layout and referencing methods and have presented guest lectures on referencing methods and technical layout issues to postgraduate students at the UFS. In the past couple of years, I have also proofread six books for publication, plus a number of journal articles.

Disclaimer: The ultimate responsibility for accepting or rejecting the amendments and recommendations made by means of track changes rests with the student. The editor cannot be held responsible for any changes in terms of the format and style due to subsequent additions or deletions to the document, or any language issues that may have emerged as a result of subsequent amendments to the text.

Yours sincerely

Dorathea (Dora) du Plessis
Technical & Language Editor