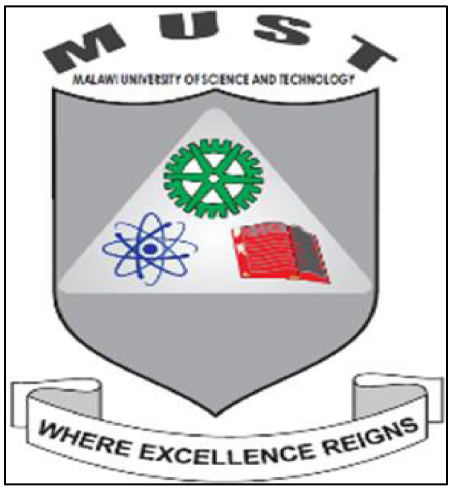


INVESTIGATING THE POTENTIAL OF FITRATION SYSTEAMS FOR WASTEWATER RECYCLING FOR IRRIGATION: CASE STUDY OF THE MUST WASTEWATER TREATMENT PLANT

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ABSTRACT

The impact of water scarcity on food production is enormous. Communities are unable to water crops to feed an ever-increasing population. Wastewater reuse is one of the most promising water supply management approaches for managing water scarcity. Malawi University of Science and Technology (MUST), is one of the universities with a wastewater treatment plant. Unfortunately, because the wastewater does not fulfill irrigation water quality criteria, it cannot be used for irrigation. As a result, an alternative method for wastewater recycling for irrigation purposes at the MUST WWTP was evaluated.

The Study objectives were to evaluate the physico-chemical and microbiological wastewater quality at the plant, to evaluate the efficacy of various filtration systems for wastewater recycling, and to evaluate the effects of plant operational parameters on the filter's efficacy in wastewater treatment. To address these objectives, the study used a quantitative approach that included field and laboratory studies. The two-filtration systems sand and granular activated carbon (GAC), were utilized to quantify the removal effectiveness of different parameters and see which system is suitable to treat wastewater for irrigation. After 6 hours, different flowrates (0.072 and 0.096 (m3/day)) were employed to monitor the HLR and OLR. At varying flow rates, each HLR and OLR were calculated. The data was analyzed using the T-test, and the results were compared to FAO irrigation water standards and Malawi government industrial discharge tolerance limits.

With regard to the Malawi government's industrial tolerance discharge limit. Several parameters were found to be outside of the limits, including TC, FC, DO, SS, ammonia, COD, BOD, TDS, and turbidity. The wastewater quality is greatly contaminated, according to the effluent samples gathered. The results for goal two demonstrated that there was no significant change between the effluent quality of both filtration systems. Despite the removal efficiency, the effluent quality of both systems did not meet irrigation standards. Although Sand was considered a better filtration system to improve the effluent quality by looking at the efficiency. The results of objective three revealed that there were no significant differences,

which indicated that the operational parameters had no effect on effluent quality. The results, on the other hand, revealed that lowering the flowrate, particle size, organic loading, and hydraulic loading rates improves efficiency.

The study will aid future studies by allowing them to learn about alternative technologies that are ideal for recycling wastewater depending on their efficiency. as well as the achievement of Sustainable Development Goal 2, which aims to end hunger, ensure food security, improve nutrition, and promote sustainable agriculture by 2030

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ACRONYMS/ABBREVIATIONS

COD chemical oxygen demand

TDS total dissolved solids

ORP oxidation reduction potential

BOD Bio-chemical demand

pH Power of hydrogen

EC electrical conductivity

DO Dissolved oxygen

FC feacal coliforms

TC total coliforms

HRT hydraulic retention time

HLR Hydraulic loading rate

OLR Organic loading rate

Mg/l Milligrams per liter

NTU Nephelometric Turbidity Units

Ppt parts per thousand

°C degrees Celsius

(µS/cm) Siemens per meter

GAC Granular activated carbon

CFU Colony forming unit

WWTP wastewater treatment plant

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1.1. CHAPTER 1: GENERAL INTRODUCTION

1.2. Introduction

Water is becoming increasingly limited in many nations due to a variety of factors including climate change, natural disasters (droughts and floods), increased human use, overuse, and waste (Tyne et al., 1992). According to the Global Water Institute, 700 million people are affected by water scarcity, which is anticipated to increase by 2025. Water scarcity has a significant impact on food production. Without water, people are unable to water crops in order to feed an ever-increasing population. One of the most promising supply management methods to be researched to cope with water scarcity is wastewater reuse (Hamdy & Aly, 2015).

1.2.1. Wastewater background

Tuser (2020) defines wastewater as used water that has been contaminated by domestic, industrial, or commercial use. Wastewater contains 99.9% water and 0.1 percent organic debris, bacteria, and inorganic substances, all of which are eliminated during the wastewater treatment process (Gerald, Rebecca, & Virginia, 2007). The wastewater effluents are discharged into a range of habitats, including rivers and lakes. Before the effluents are discharged, the wastewater is treated to prevent detrimental effects on the environment and human health (Akpor O & MUchie, 2011). As a result, the wastewater is treated at several levels: primary, secondary, and tertiary treatment.

1.2.2. Wastewater reuse in irrigation

The reuse of wastewater in agriculture is an important technique for developing countries to reduce pollution while also addressing the difficulty of increasing food production in water-scarce places (Jaramillo & Restrepo, 2017). The advantages of recycling water in agriculture are numerous and undeniable. It saves a lot of first use water that could be used for more important things, it offers nutrients that could

replace artificial fertilizers, increases soil fertility and crop output while lowering production costs, it allows for the expansion of agricultural land in arid places, it is a reasonably inexpensive raw wastewater disposal option and it may prevent pollution of surface water. Furthermore, it has been proved that recycling water in agriculture has little health hazards as long as the biological quality fulfills set standards (Navarro, Chavez, & Maya, 2015).

1.2.3. Why further treatment of wastewater

Toxicity occurs when ions are taken up by plants with soil water and build in the leaves during water transpiration to the point that the plant is destroyed, according to Mei Li (2020). The extent of damage is determined by time, poisonous chemical concentration, crop sensitivity, and crop water use. Chloride is a toxic ion that is commonly present in irrigation water and sewage. The toxicity adds to the problem of salinity and infiltration. Furthermore, urban wastewater may contain heavy metals, which give rise to higher levels in the soil, unwanted accumulations in plant tissue, and a reduction in crop development (Borecka & Biak-Bieliska, 2016). As a result, additional wastewater treatment should be explored to address such issues.

1.2.4. Wastewater treatment at MUST

Malawi University of Science and Technology is one of the public universities found in Malawi. Various human activities generate wastewater containing urine, faeces, hair shampoo, hair, food scraps, fat, laundry powder, toilet paper, dirt and pathogenic micro-organisms. However, due to the increase in the intake of students per every academic year, there has been an increase in the wastewater generated. As a result, the university decided to build a wastewater treatment plant (WWTP) to treat the waste generated on campus. MUST wastewater treatment plant is made up of two basic stages in the treatment of wastes thus primary and secondary. In the primary stage, solid particles are allowed to settle in a septic tank, sink to the bottom to form sludge

and then removed from wastewater through primary sedimentation. The sludge is pumped and get disposed of in a landfill. The sewage flows through a screen which removes floating objects such as papers, plastics, rags and sticks to prevent them from clogging the wastewater treatment pipes. After screening, the sewage passes into a grit chamber for sand, gravel, glass, dense plastic pieces and metal fragments to settle the bottom. Thereafter, the sewage goes to holding tanks beneath the plant, passes through a unit where chlorine is added to kill bacteria. Lastly, in the secondary stage, biological processes take place to further purify wastewater by removing organic matter and nutrients via a slow sand filtration unit mainly the Jazzi Top-Mount Multi-purge sand filtration unit. Since the wastewater is chlorinated some microorganism can die as a result an air bower equipment is used to supply oxygen in order to activate the bacteria. This filter operates under high pressure to help in the removal of biochemical oxygen demand and nutrients by the sand bed as water flows through the filter. Water enters the filter through the valve on top of the filter and is distributed evenly downward across the sand bed.(Pentair Water Pool and Spa, 2017)

1.3. Problem statement

Climate change has resulted in a decrease in the availability of fresh water, which has raised demand (McDonald, Green, & Balk, 2011). As a result of this impact, a large number of people are experiencing water scarcity and food insecurity has become an issue too. According to Ungureanu, Viadut, & Voicu (2020), wastewater provides farmers with a reliable water source to irrigate crops. The preliminary data of the MUST WWTP in appendix 6 was obtained and compared with the effluent water quality with FAO standards. The values showed that the current treated effluent does not fulfill irrigation water quality standards hence cannot be used for irrigation. As a result an alternative was required to improve the water to meet the standards. This will aid in the growth of various crops due to the availability of water, as well as the achievement of Sustainable Development Goal 2, which aims to end hunger, ensure

food security, improve nutrition, and promote sustainable agriculture by 2030 (DeYoung, 2015) .

1.4. Research questions

- What are the current wastewater treatment efficiencies at the MUST WWTP?
- Are there any differences in treatment efficiency for different filtration systems?
- Do plant operational parameters affect the efficiency of wastewater treatment filtration systems?

1.5. Main Objective

To assess the potential of different technologies for wastewater recycling for irrigation purposes at the MUST WWTP

1.5.1. Specific objectives

- To assess the physico-chemical and microbiological wastewater quality at the plant
- To assess the efficiency of different filtration systems for wastewater recycling
- To assess the effects of plant operational parameters on the efficiency of the filter on wastewater treatment.

1.5. Significance

Treatment of wastewater is critical, according to Msilimba & Wanda, (2007), because wastewater can pose major environmental and health hazards. The intake of water that is concentrated with dangerous chemical elements puts the health of a large portion of Malawi's population at risk. Food generated using wastewater is consumed

by more than ten percent of the world's population, according to WHO estimates. As a result, determining the quality of wastewater used for irrigation is critical for proper development planning that protects customers' health and safety. Therefore, this research will aid in bridging the gap of water scarcity by increasing the quantity of water that can be used to irrigate various crops. It will also aid future studies by allowing them to learn about alternative technologies that are ideal for recycling wastewater depending on their efficiency.

2.0. CHAPTER 2 LITERATURE REVIEW

2.1. Introduction

Many countries have made wastewater reuse an important part of their water resource planning (AZIZ & FARISSI, 2016). Wastewater is used in agriculture in dry areas of Australia and the United States. Some countries, such as Jordan's Hashemite Kingdom and Saudi Arabia's Kingdom, have a national policy of reusing all treated wastewater effluents and have made significant progress. Since 1958, sewage has been used in agriculture in China, and approximately 1.33 million hectares have been irrigated by sewage effluent (Jiménez, 2006). Wastewater usage in agriculture is widely acknowledged as being acceptable on agronomic and economic reasons.

2.2. Global status of wastewater production and treatment for irrigation

Untreated wastewater is a major problem in many developing countries when irrigation is practiced. Approximately 1.8 billion people drink faecal-contaminated water, putting them at risk of contracting cholera, dysentery, typhoid, and polio (United nation, 2021). Furthermore, 10% of the world's population eats food grown on wastewater-irrigated crops (Nicoleta Ungureanu, 2020). The Middle East and North Africa (MENA) region, for example, is the world's driest, accounting for only 1% of global freshwater resources. Around 43% of the wastewater in the region is treated. Only a few countries in the region have created wastewater programs, despite the region's potential for beneficial wastewater reuse. Because there is a high demand for wastewater as a source of irrigation, there are a lot of pathogens in the food chain that cause problems in young children and women.

2.3. Wastewater treatment technology

To accomplish recycled water quality goals, treatment techniques in wastewater recycling are used separately or in combination (Smith, 2015). When considering the most typical unit processes and operations in wastewater recycling, an almost infinite number of treatment

procedures can be constructed to suit the water quality criteria of a specific reuse application. The choice of water recycling technology is influenced by a variety of factors. These criteria include the wastewater characteristics of the source water, as well as operating, maintenance, and chemical requirements (Lori, 2018).

2.3.1. Active carbon filtration

Activated carbon filters are small pieces of carbon, typically in granular or powdered block form, that have been treated to be extremely porous (Cobb, 2012). Activated carbon works by chemically bonding to contaminants when they are run through the filter. It is widely used for the removal contaminants in water due to their high capacity for adsorption of such compound, arising from their large surface area and porosity. Activated carbons have varied surface characteristics and pore sizes distribution, these characteristics of activated carbon play an important role in adsorption of contaminants in water. These contaminants produce bad tastes and odors, and also may constitute a source of infection. Activated carbon can remove the total suspended solids (TSS) and the biological oxygen demand (BOD) effectively over 99%, to 1 mg/l and also improve the tastes and odors

2.3.2. Sand filtration

Sand filtration is used for the removal of suspended matter, as well as floating and sinkable particles (Hammes, Velten, & Egli, 2011). The wastewater flows vertically through a fine bed of sand and gravel and the larger particles are unable to pass through. The mechanisms of purification vary depending on the type of filter. Proper choice of the filter depth, sand type, sand size and filtration rate affect the pollutant removal performance and purification efficiency of the sand filter (Bagundol, Awa, & Enguito2, Efficiency of Slow Sand Filter in Purifying Well Water, 2013). The biological activity is enhanced with increasing filter depths. Microorganisms and other suspended particles have to travel more through the sand; thus, a higher removal efficiency is expected at higher sand depths. Though the technology is cheap and simple, using sand filter for water treatment offers unique advantage for solving water

shortage problem. It was observed that the reduction efficiency of turbidity is about 70% and the reduction in pH and electrical conductivity is also noticeable (Thomas & Kani, 2016). Thus, it can be concluded that the slow sand filter is efficient in treating wastewater from a particular source.

2.4. Wastewater production and treatment in Malawi

Chemical, physical, and biological parameters in effluents from the three major wastewater treatment works in the city of Blantyre and the Kauma treatment plant in Lilongwe City have been found to be higher than the recommended Malawi standards and WHO guidelines. (Chipofya, Kraslawski, & Avramenko, 2010). The Malawian government currently has no information on the amount of wastewater created in the country. There are no wastewater guidelines or information accessible, and how wastewater will be managed for reuse is also unknown. Despite the fact that it is against Malawian policy, raw wastewater has been seen in some high-density suburbs (Consult, 2006).

2.5. Constituents in wastewater

Water is regarded a part of society; one person's use can have an impact on others because wastewater treatment is a cycle, and one user's discharge might become the supply for others (Chaplin, 2001). To achieve good water management, it is necessary to comprehend the nature and constituents of wastewater in order to design and operate efficient wastewater collection, treatment, and reuse facilities and regulations, which drive wastewater treatment by knowledge of harmful components to living beings and the environment. Some constituents of concern in wastewater treatment are: Total solids, composed of floating matter, settleable matter, colloidal matter and matter in solution; Biodegradable organics, usually measured in terms of biochemical oxygen demand (BOD) and of chemical oxygen demand (COD),Pathogens, Nutrients, priority pollutants that could be carcinogens, mutagens or highly toxic; Refractory pollutants, like pesticides, phenols and surfactants, that can resist to conventional methods of treatment; Organic pollutants, like oil; dissolved inorganics such

as sodium, calcium and sulphate; and Pharmaceuticals that can affect humans and animals (Hultman & Plaza, 2009). These constituents, among others make the wastewater be characterized in terms of physical, chemical and biological composition. Almost all human activities generate wastewater; therefore, treating this water and returning clean and safe water is critical for both people and the environment. However, the presence of specific components in the water makes the wastewater treatment procedure more difficult.

2.6. Wastewater treatment processes

2.6.1. Preliminary and primary treatment

According to Stewart (2018), the bulk of solids are removed at the preliminary and primary levels of treatment using screens and settling tanks. Solids account for roughly 35 percent of the contaminants that must be eliminated, thus this stage is critical. The screens generally have holes of around 10 millimeters, which are tiny enough to filter out big objects like sticks, garbage, and other large items from the wastewater. This waste is removed and dumped in a landfill. The water is then pumped into settling tanks (also known as clarifiers), where it remains for many hours, allowing sludge to settle and a scum to form on the surface. After the scum is skimmed off the top and the sludge is scraped from the bottom, the partially treated wastewater is sent to the secondary treatment level. The primary treatment eliminates up to 50% of the Biological Oxygen Demand, thus contaminants that deplete the oxygen in the water are removed (environmental protection agency act, 1997).

2.6.2. Secondary treatment

Bacteria are used in secondary wastewater treatment to digest the leftover contaminants. The wastewater is mixed with bacteria and oxygen to achieve this. The oxygen aids the microorganisms in digesting contaminants more quickly. The water is then pumped to settling tanks, where the sludge settles and the water becomes 90 to 95 percent pollutant-free (Msilimba & Wanda, 2007). Following that, the water is disinfected with chlorine, ozone,

or UV radiation before being discharged. The water is treated separately from the sludge that is collected from the settling tanks and the scum that is skimmed off the top during the primary processes. At temperatures about 38 degrees Celsius, anaerobic bacteria (those that do not require oxygen) feed on the sludge for 10 to 20 days (Kor-bicakci, Ubay-cokgor, & Eskicioglu, 2020). The odor and organic matter in the sludge are reduced, and a highly flammable gas of methane and carbon dioxide is produced, which can be utilized to heat the treatment plant (Oladejo, Shi, Luo, Yang, & Wu, 2019). After that, the sludge is sent to a centrifuge (a machine forcing the liquid to separate from the solid). The liquid is then combined with wastewater, and the solid is applied to fields as fertilizer.

2.6.3 Tertiary treatment

Color, metals, organic compounds, and nutrients like phosphorus and nitrogen are all removed during tertiary (or advanced) treatment. It uses the Biological Nutrient Removal (BNR) process which occur in the bioreactor. The BNR procedure digests pollutants in the water by using bacteria in various settings in numerous tanks. The three tanks each have their own ecosystem, with varying levels of oxygen. After passing through the three tanks, the water is phosphorus-free and the ammonia is broken down into nitrate and nitrogen gas. Traditional procedures remove far less than 90% of phosphates, but the BNR technique removes over 90%. (Ogunlaja, 2015). The water spends around nine hours in the bioreactors before moving on to the secondary clarifier, a settling tank, where the bacteria-laden sludge settles to the bottom.

2.7. Utility of treated wastewater

Despite its apparent high level of use, wastewater's potential worth as a resource is sometimes overlooked. Instead of being a source of issues, wastewater may be a source of benefits for society, the economy, and the environment if it is properly handled and usage rules are followed (weller, 2019). Wastewater components contain helpful and important nutrients that plants require, reducing the need for artificial fertilizers. Furthermore, agriculture is a

substantial water consumption, according to Writer (2020). As a result, employing recycled, treated wastewater can help to relieve pressure on freshwater supplies used for agricultural purposes like crop irrigation. Treated and recycled wastewater provides a cost-effective supply that reduces pressures on freshwater sources like groundwater, rivers, and reservoirs. This is especially significant in locations where water scarcity and drought have occurred (Tortajada, 2020).

2.8. Effects of untreated wastewater for irrigation

Despite the numerous advantages of recycled water, there are several environmental and health issues. If not, correctly managed recycled water could harm soil health by increasing salinity, accumulating heavy metals, and lowering hydraulic conductivity. Other researchers have reported similar increases in the salt content of soils after wastewater irrigation, according to Keser & Buyuk (2012). Based on the research, the increased electrical conductivity of the wastewater caused an increase in soil salinity. In fact, soils watered with treated wastewater had lower electrical conductivity and salinity than soils irrigated with untreated wastewater. The soils have higher levels of organic matter and total nitrogen than the other irrigated soils. The amount of organic matter and nitrogen in the soils fell dramatically with treated wastewater. The soils had high available phosphorus concentrations, which was likely attributable to the considerable organic matter delivered with the wastewater. Other researchers discovered that wastewater irrigation resulted in 4-, 10-, and 8-fold increases in N, P, and K beyond the prescribed fertilizer rates for forage crops, respectively (Burns, Westerman, & King, 1985). Furthermore, there were concerns about the accumulation of heavy metals in the irrigation wastewater. Total heavy metal concentrations in plants were lower in all soils watered with treated wastewater than in soils irrigated with untreated wastewater. 2008 (Kiziloglu, Turan, Sahin, & Kuslu)

2.9. Wastewater irrigation standards and parameters

Table 1. showing the food and agriculture organization of the united nation (FAO) irrigation standards.

Parameters	None	Moderate	Severe
Dissolved oxygen	>5	-	-
Suspended solids	<50	50-100	>100
Alkalinity	30-100	-	-
Total coliforms	1000	-	-
Temperature	17.4-23.7	-	-
pH	6.5-8.4	-	-
Total dissolved solids	<450	450-2000	>2000
Turbidity	<10		
Conductivity	<0.7	0.7-3	>3
Nitrates	<5	5-30	>30
Ammonia	0-5		
COD	-	-	-
BOD	15	-	-
Fecal coliforms	1000	-	-

2.9.1. Physico-chemical parameters

a. Salinity

Salinity is defined as the total concentration of salts dissolved in water or soil, according to Babel & Schreiber (2014). Total dissolved solids or electric conductivity are commonly used

to measure it. Salinity must be considered because a large amount of it might be toxic. It also causes physiological drought, impairing plants' ability to take water from the soil (Lazarovitch & Schwartz, 2014).

b. Suspended solids

Suspended solids are the amount of tiny solid particles that remain suspended in water and act as a colloid (Lemon, 2019). Suspended solids are common in wastewater applications because when suspended solids are left untreated, can contribute to sewer pipe blockage and cause damage to irrigation systems such as sprinkles.

c. Total dissolved solids

TDS is related to the amount of dissolved salts in the water. Higher salinity results in higher electrical conductivity. When used for irrigation, water with high dissolved solids can reduce crop yield because the dissolved salts make it more difficult for plants to extract dissolved nutrients in water from fertilizer and the soil. Dissolved solids in irrigation water can cause salts to build up in soils and aquifers and can eventually make the land unsuitable for growing crops (Gray, Gylsson, Turcios, & Schwarz, 2000)

d. Electric conductivity

Electrical conductivity reflects the capacity of water to conduct electrical current, and is directly related to the concentration of salts dissolved in water, though TDS (Helmenstine, 2020). This is because the salts dissolve into positively charged ions, as well as negatively charged ions, that conduct electricity. Therefore EC is actually a measure of salinity and high salinity can affect plants in several ways such as toxicity of a particular ion (such as Sodium) and Higher osmotic pressure around the roots which prevents an efficient water absorption by the plant (Sela, 2008)

e. pH

A measurement which determines the level of acidity or alkalinity of the water. Most water samples have a pH greater than 7.0. Acidic water (<6) could cause corrosion of metal parts in irrigation equipment. pH is an important parameter to consider because it influences several soil factors affecting plant growth such as soil bacteria, nutrient leaching, nutrient availability, toxic elements and soil structures (Neina, 2019).

f. Dissolved oxygen

Measured in milligrams per liter, dissolved oxygen in irrigation water is an untapped tool in horticulture. Increasing the DO level in water increases root mass and fine root hairs resulting in increased growth, better fertilizer utilization and overall plant health. According to Roy, Finck, Blair, & Tandon (2006), plants require at least 5 to 6 ppm of DO for healthy growth. Irrigation water with levels of DO lower than this can actually cause oxygen to leave the plant through the roots, impacting plant health and growth.

g. Temperature

At elevated temperatures, bacterial metabolism can become inhibited. Inhibited metabolism can cause elevated effluent BOD via two different mechanisms: Bacterial metabolism reduction or failure. Elevated effluent TSS – bacteria are organic in nature and contribute oxygen demand to the BOD test (Talebizadeh , Rahimzadeh , Babaie, & Ghomi, 2015)

h. Alkalinity

The number of dissolved elements in water that can buffer or neutralize acids is known as alkalinity. Carbonates (CO32-), bicarbonates (HCO3-), and hydroxides are examples (OH-). Alkalinity is usually measured in milligrams per liter of calcium carbonate. Total alkalinity is the most relevant water test result in terms of irrigation. The optimal range for total alkalinity is around 30 to 100 mg/L, but many plants can tolerate amounts up to 150 mg/L. High alkalinity levels exceeding 150 mg/L can create an elevated pH in the growth media, which

can lead to nutrient deficiencies (e.g., iron and manganese insufficiency, calcium and magnesium imbalance).

i. Nitrates and Ammonia

Nitrate and ammonium are the most readily available nitrogen compounds. Nitrogen is a nutrient that promotes crop development in plants. The traditional sources of nitrogen are natural soil nitrogen or added fertilizers, however nitrogen in irrigation water has a similar impact to nitrogen in soil-applied fertilizers, and an excess will cause difficulties, just as too much fertilizer would. Over-stimulation of growth, delayed maturity, or poor quality, production of some regularly produced crops may be disrupted if excessive quantities are present or applied. Despite the fact that nitrates and ammonia in irrigation water contribute nutrients to the crop, they must be checked to ensure that they are not excessive.

j. BOD

BOD is a measure of the amount of oxygen required to remove waste organic matter from water in the process of decomposition by aerobic bacteria (those bacteria that live only in an environment containing oxygen). The waste organic matter is stabilized or made unobjectionable through its decomposition by living bacterial organisms which need oxygen to do their work. BOD is used, often in wastewater-treatment plants, as an index of the degree of organic pollution in water

k. COD

Chemical oxygen demand is the amount of oxygen needed to oxidize the organic matter present in water. The chemical oxygen demand (COD) is a measure of water and wastewater quality. The COD test is often used to monitor water treatment plant efficiency. This test is based on the fact that a strong oxidizing agent, under acidic conditions, can fully oxidize almost any organic compound to carbon dioxide.

2.9.2. Biological parameter

a. Fecal coliforms

Fecal coliforms, also known as thermotolerant coliforms, are a subset of the total coliform group which shows water contamination. Fecal Coliform provides a risk because of the many diseases that spread through fecal transmission. Large numbers of fecal coliform, indicates the possibility of the presence of pathogenic bacteria as well hence high reason to remove fecal matter in all water applications. According to Weiner (2007), Escherichia coli is a common lead indicator and disease-causing pathogens.

b. Total coliforms

Total Coliform bacteria (TC) are a group of bacteria that are regularly present in environmental waters. It encompasses both pathogenic and non-pathogenic micro-organisms. Fecal coliforms (FC) and E. coli are a sub-group of TC. FC or E. coli presence can indicate contamination of water supplies resulting in an increased risk of the presence of waterborne pathogens. Bacterial indicators such as TC and E. coli are also valuable indicators of the performance of drinking water treatment processes and distribution system integrity.

2.10. plant operational parameters

a. Hydraulic loading rate

One of the principle parameters used in wastewater system design is the hydraulic loading rate, thus volume of wastewater applied to the surface of the processing unit per time period, expressed in volume per unit area per unit time or depth of water per unit area per unit (Khaire, 2020). According to Larson (2011), increasing loading rates when using wastewater that is not likely to cause clogging will decrease wastewater retention times in the soil and could reduce treatment efficiency. Therefore, longer travel distance or separation distance may be needed to reach acceptable treatment.

b. Organic loading rate

The organic loading rate is expressed as a certain amount of BOD applied to a certain volume of media. According to Bhattacharya, Dev , & Das (2018), organic loading rate plays an effective role in designing the wastewater treatment process. The optimum range of organic loading rate depends on the nature of the organic substrate to be added and type of wastewater to be treated. Research has shown that giving smaller doses of organic matter rather than whole at a time will increase the efficiency allowing for the application of higher hydraulic and organic loading rates.

2.11. Literature review Summary`

This literature is structured as follows: It begins looking at the wastewater reuse and for irrigation at the global followed by local situation. It also reviews different wastewater treatment technology and the issues with each and their applicability in different environment.

3.1. CHAPTER 3: METHODOLOGY

3.2. Site description.

The MUST wastewater treatment plant (WWTP) is located inside MUST campus in M'mina village, Traditional authority Chimaliro, Thyolo district in the southern region of Malawi. The plant started operating in April 2014 when the school enrolled its first cohort of students. Currently the school has close to 3000 students. The plant is made up of primary and secondary stage whose processes has been described in Chapter one above (section 1.1.4. Wastewater treatment at MUST).

3.3. Research design

To acquire the necessary data, a quantitative research design and methodology was used. The goal of this study was to assess the efficacy of filtration systems in wastewater recycling by examining changes in water quality characteristics after each treatment. Under quantitative research method, water quality was tested by evaluating physical, chemical, and biological characteristics. In general, the project consisted of three major steps: sample collection, sample treatment, and laboratory analysis.

3.4. Materials and methods

The following materials were used in this study: Multiprobe meter (Aqua-Read AP 800), hydrotest photometer, spectrophotometer, polyethylene bucket and bottles, Membrane Filtration Technique, hand lens, sand, gravel, charcoal, 15% nitric acid, 15% sodium chloride, hydrochloric acid, phenolphthalein indicator, methyl orange indicator, motor, mixer, and 20l basin . AMMONIA No. 1, AMMONIA No. 2, nitrate test powder, and nitrate test tablets were among the reagents used.

3.5. Sampling and treatment

Physico-chemical parameters of wastewater including DO, temperature, salinity and oxidation reduction potential (ORP) were gathered across three days in June. In order to confirm the quantitative data collected composite sampling was performed. Instruments were calibrated before use according to the user handbook. Glass bottles were washed with distilled water and labeled with a permanent marker with a unique identifying number. The samples were kept in a hard cartoon to protect them while transportation to the laboratory for further investigation. Thirteen (13) parameters were measured in total.

3.5.1. Assessing the physico-chemical and microbiological wastewater quality at the plant

Water quality parameters including dissolved oxygen (DO), pH, salinity, TDS, temperature, oxidation reduction potential (ORP) and electrical conductivity (EC) were recorded both in the influent and effluent. The parameters were measured in-situ using a multiprobe aqua-Read AP 800. Calibration of the instrument was done prior to each measurement as prescribed by the user manual.

3.5.1.1. Experimental procedure

Water samples were collected using standard sampling procedure of American public health association (APHA, 2005). The first sample set was collected in a cleaned 10L polyethylene bucket. The multiprobe meter (Aqua- Read AM 800) was connected and the probe was dipped into the bucket till it immersed. After 10 seconds, readings were recorded.

For further chemical and biological analysis, samples were collected in a sterile glass bottle. The samples were analyzed in the water quality laboratory at Malawi University of Science and Technology. A hydrotest photometer was used to measure parameters such as total suspended solids, nitrates and ammonia using colorimetric method. Titration method was used to measure alkalinity. Other parameters such as COD used acid digestion method while

Total coliforms and fecal coliforms used membrane filtration method. After measuring the ratio of BOD to COD, the BOD value was discovered.

a. Determination of ammonia

Using calorimetric method, a black sample was placed on the photometer to set the equipment to measure ammonia and to prevent light from interfering with the instrument .10ml of the water sample was added into a beaker and diluted with 390ml distilled water. A clean vial was filled with a 10 ml of water sample. one AMMONIA No. 1 was added straight from the foil to the water sample in a vial. The tablet was crushed using a clean stirring rod. Another tablet AMMONIA No. 2 was added straight from the foil to the same water and the tablet was crushed. The vial was closed with a cap and swirled several times until the tablets dissolved. the vial was placed on the photometer aligning the marks. Then the test key was pressed to run the sample for 10 minutes. After the reaction the measurement was recorded.

b. Determination of nitrates

Using calorimetric method, wastewater samples were filtered using a membrane filtration unit to remove total suspended. A black sample was placed on the photometer to set the equipment to measure nitrates and to prevent light from interfering with the instrument .10ml of the water sample was added into a beaker and diluted with 90ml distilled water. A clean vial was filled with a 10 ml of water sample. one level of spoon of nitrate test powder was added to the water sample in a vial. one tablet of nitrate test tablets was added straight from the foil to the same water sample and then crushed using a clean stirring rod. The vial was tightly closed with the cap and swirled several times until the tablets dissolve. The vial was placed on the photometer aligning the marks. Then the test key was pressed to run the sample for 2 minutes. After the reaction, the measurement was recorded.

c. Determination of COD

Using acid digestion method, 2 ml of water was transferred to the mercury test tube as a black sample. A pipette was also used to transfer 2 ml of the wastewater samples to each mercury test tube containing sulfuric acid. The contents in each tube was constantly mixed. The samples were placed in an acid digestor(spectrophotometer) for 2 hours at a temperature of 150°. After reaching ambient temperature, each sample tube was analyzed using a photometer to obtain COD values.

d. Determination of faecal and total coliforms

Fecal and total coliforms was measured using Membrane Filtration Technique (MFT) by following standard procedures in the laboratory. The absorbent pads were added to the sterile labeled petri dishes. The pads were soaked with membrane lauryl sulphate broth as a nutrient medium. The sterile membrane filter was removed from the package and placed in the membrane filtration unit for filtration process. 100ml volume of diluted water samples was poured in the membrane filtration unit. At the suction flask, a vacuum was applied until all the samples were filtered. Then the membrane filter was removed from the instrument and placed in labeled petri dish using the sterile forceps ready for incubation. For faecal, the samples were incubated at a temperature of 44.5 degrees Celsius for 18 hours while total was at 37 degrees Celsius for 24 hours. Then the coliforms were counted using hand lens.

e. Alkalinity determination

Titration method was used to measure alkalinity, Titration test was done three times for each sample. 50 ml of wastewater sample was poured into a conical flask. Phenolphthalein indicator was added to determine the presence of hydrocarbons. If no color was indicated, 2-3 drops of methyl orange was added in the flask. If the color changed into orange, the sample was titrated with hydrochloric acid while shaking the flask. The end-point of titration was obtained if the red color was seen. The initial and final burette readings were observed.

Alkalinity was calculated by summing up the values of hydrocarbons and carbonate. The following equation was used to calculate the carbonate.

Carbonate= (Molarity of HCL * Volume of carbonate)/ (2*volume of wastewater sample) .....equation 1

3.5.2. Assessing the efficiency of different filtration systems for wastewater recycling



Picture 1: shows the experimental set up in the lab

For the experimental design, dimensions for different materials to be used was considered as prescribed by the table in the appendix 5. The bottles were sliced across the width with a knife. A fabric plug was placed over the aperture to prevent charcoal, sand, or gravel out of the water collection container. The sand filter contains Gravel, about 5cm thick and sand 21cm thick. While the other filter contained charcoal about 26 cm thick Activated carbon was prepared using standard sampling procedure and test for granular activated carbons of India 2752 (1995). Granular carbon was washed to remove impurities and then dried at 105 °C for 24 hours. Charcoal was impregnated with 15 % of nitric acid for activation. The mixture was soaked for 24 hours and then heated for 2 hours at 80 degrees to allow modification to be completed. Then the activated charcoal was washed with sodium chloride to neutralize the acid. The solution was prepared with deionized water. Wastewater was pumped at a rate of

0.072 (m3/day). After going through the two-filtration system, the effluent quality was compared to FAO irrigation standards. The removal efficiency for each parameter was calculated as follows:

Removal/Improvement efficiency (%) = $\frac{C0 - Ce * 100}{C0}$ ……equation 2

Where, C0 is influent concentration of the constituent (mg/ L) and Ce is the effluent concentration of the constituent (mg/ L)

3.5.3. Assessing the effects of plant operational parameters on the efficiency of the filters

To achieve this objective, two different flowrates (i.e. 0.072 and 0.096 (m3/day)) were used to monitor the HLR and OLR after 6 hours. Equation 2 was used to compute the removal changes at various HLR and OLR. In addition, the HLR and OLR were calculated using the formulae below.

HLR (m3/ m2.day) = Discharge/Surface area …….. equation 3

OLR (kg BOD/ m3.day) = (BOD*Discharge)/volume……. equation 4

3.6. Data analysis

The data for physico-chemical and biological parameters used to assess the wastewater quality at the MUST WWTP was analyzed in Excel using various graphs and tables, and the results were compared to Malawi bureau of standards. Industrial effluent tolerance limits for objective two, T-Test: Two-Sample Assuming Equal Variances was used to test for statistical differences in treatment efficiency for different filtration systems and the results were compared to food and agriculture organization of the united nation (FAO) irrigation standards. For objective three, T-test was also used to assess how the plant operational parameters affect the efficiency of the filters.

4.0. CHAPTER 4: RESULTS AND DISCUSSIONS

4.1. Results- physico-chemical and biological compositions of the MUST WWTP

The results for measured physico-chemical and microbiological wastewater quality at the plant are summarized below

Table 2 showing a Summary of results of physico-chemical and biological compositions of the MUST WWTP at the influent and effluent and also it shows the tolerance limits for industrial effluents (Adapted from Government of Malawi, MS:539, 2nd Edition, pg. 1, 2013). All values are in mg/L except pH, temperature (°C), electrical conductivity (EC) (µS/cm), Salinity (ppt), turbidity (Nephelometric turbidity units) and ORP (mV).

Table 2. of physico-chemical and biological compositions of the MUST WWTP

PARAMETER	MEAN INFLUENT	MEAN EFFLUENT	INFLUENT STD.DEVIATION	EFFLUENT STD.DEVIATION	Tolerance limits for industrial effluents discharge
pH	7.72	7.99	0.026457513	0.177763888	9
Temperature	14.6	14.8	0.536780526	0.535288084	40
DO	1.44	2.99	0.938243039	0.597578447	5
Suspended solids	182	67.3	96.1925153	8.504900548	30
Ammonia	41.8	35.7	9.258509599	6.0044428	10

COD	280	72	0	0	60
BOD	173.6	17.28	0	0	20
TDS	1303.7	1178	67.48580098	40.70626487	500
ORP	-30.1	-35.13333333	8.487048957	1.5011107	++++
EC	1763.7	1782.7	369.310619	2.309401077	++++
Turbidity	150.7	67	64.37649675	3.464101615	5
Total coliforms	1006	599	107.5313908	137.7146809	0
feacal coliforms	897	383	95.04384953	76.37626158	0
Alkalinity	546.3	519.4s	42.69492398	65.80638368	++++
Salinity(ppt)	1.003333333	0.896666667	0.06350853	0.028867513	++++

++++ No data found

The Following Graphs below compares the influent and effluent results above with the tolerance limits for industrial effluents discharge.

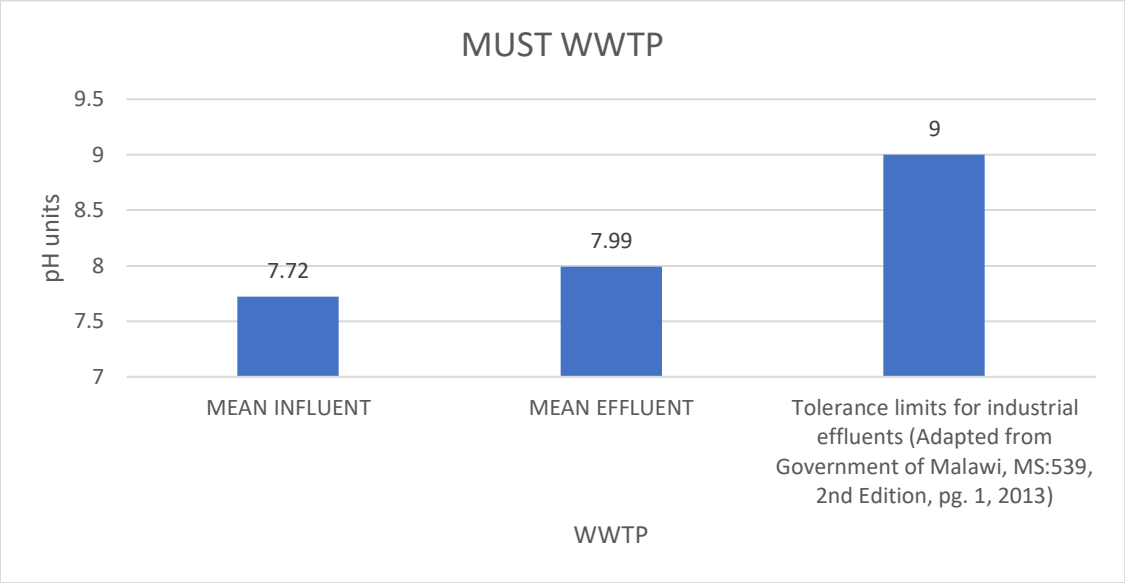


Figure 1: Plot of pH for pre and post treatment wastewater treatment. Also shown on the plot is a bar representing tolerance limits for industrial effluents maximum permissible concentration.

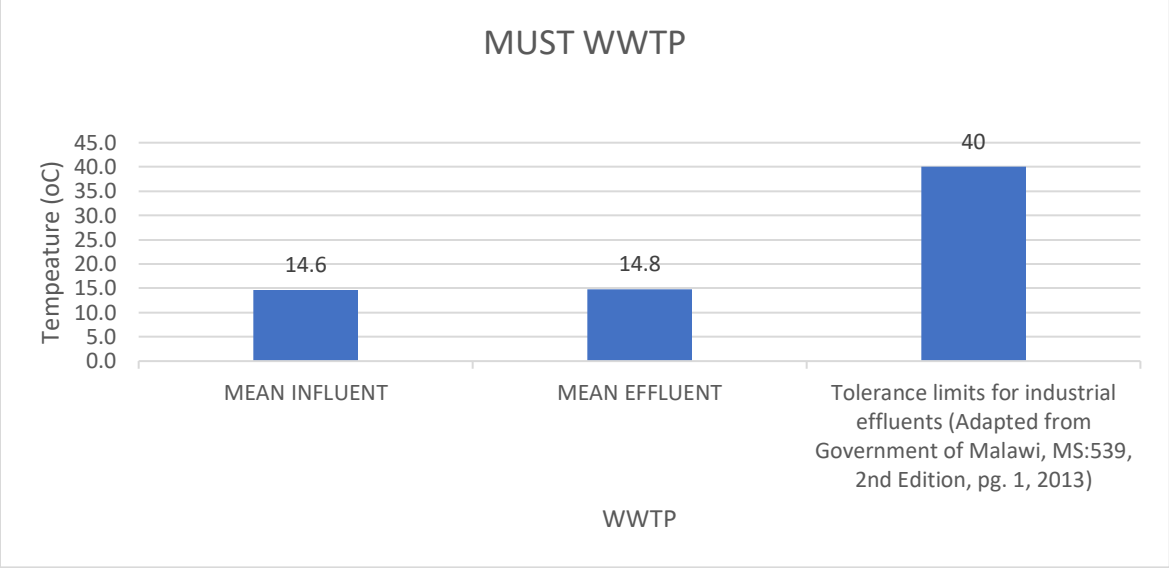


Figure 2. Plot of temperature for pre and post treatment wastewater treatment. Also shown on the plot is a bar representing tolerance limits for industrial effluents maximum permissible concentration.

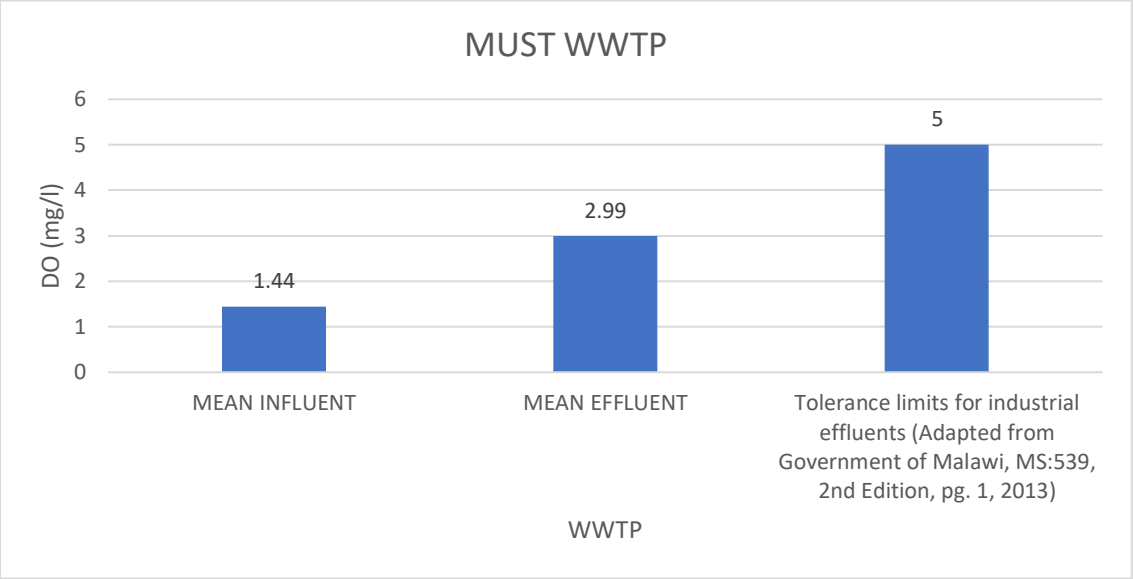


Figure 3. Plot of Dissolved oxygen for pre and post treatment wastewater treatment. Also shown on the plot is a bar representing tolerance limits for industrial effluents maximum permissible concentration.

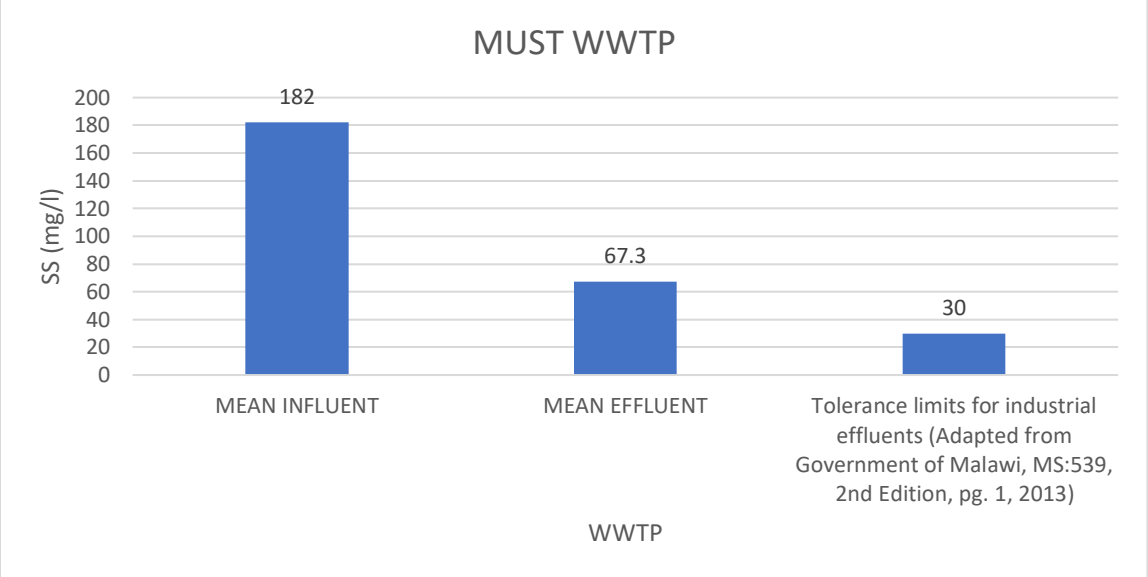


Figure 4. Plot of suspended solids for pre and post treatment wastewater treatment. Also shown on the plot is a bar representing tolerance limits for industrial effluents maximum permissible concentration.

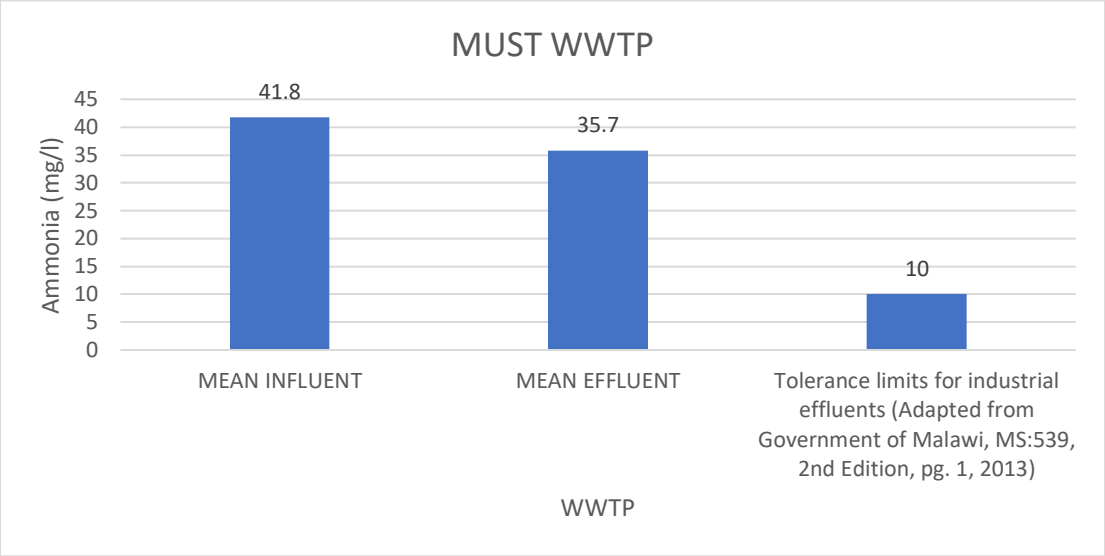


Figure 5. Plot of Ammonia for pre and post treatment wastewater treatment. Also shown on the plot is a bar representing tolerance limits for industrial effluents maximum permissible concentration.

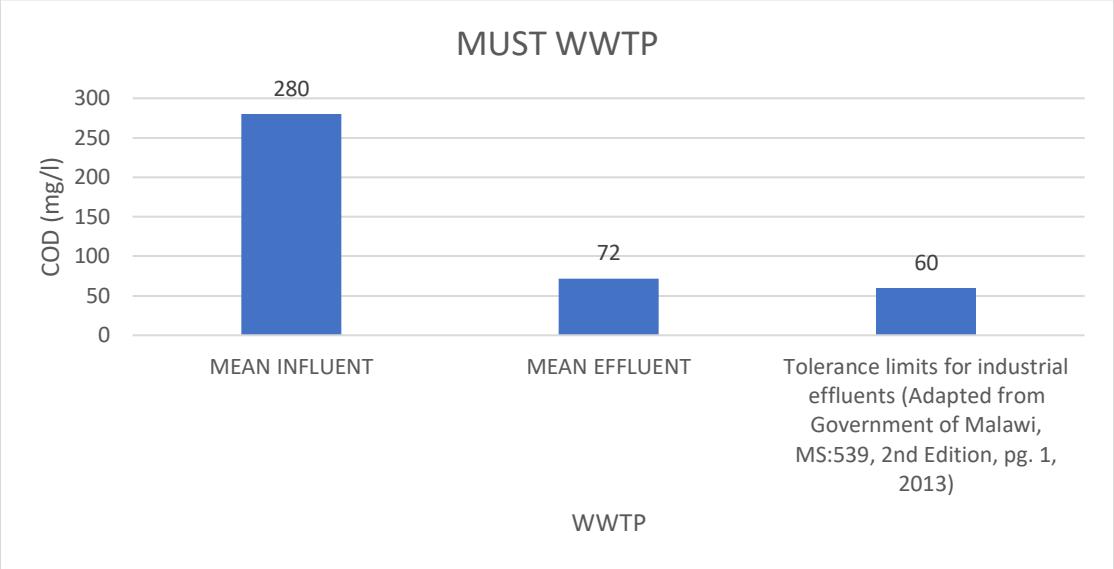


Figure 6. Plot of chemical oxygen demand for pre and post treatment wastewater treatment. Also shown on the plot is a bar representing tolerance limits for industrial effluents maximum permissible concentration.

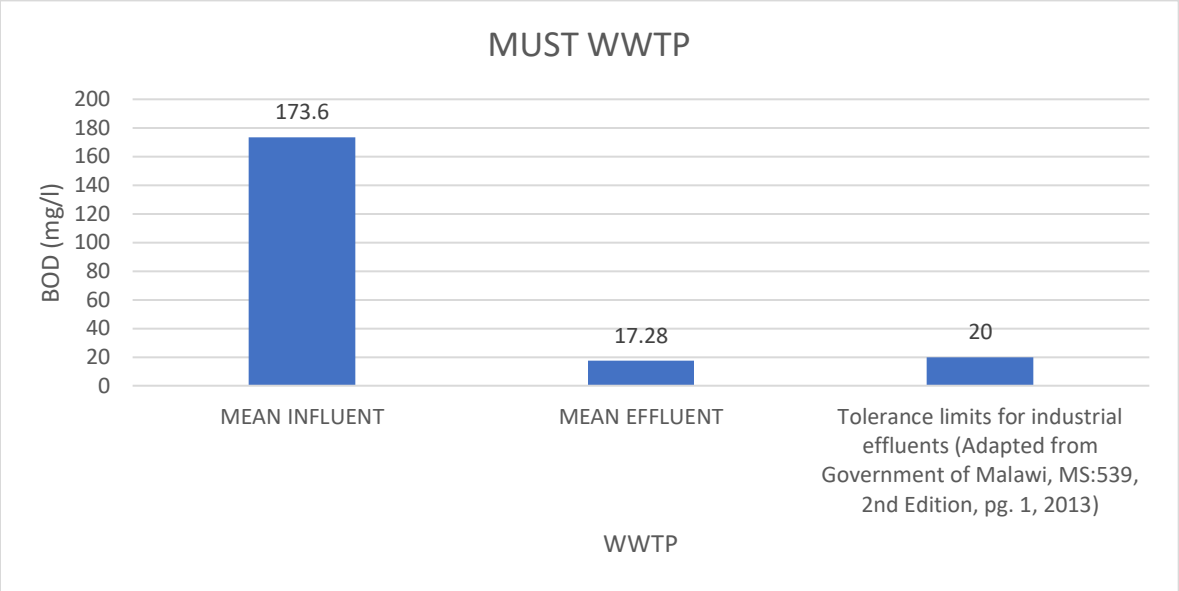


Figure 7. Plot of biochemical oxygen demand for pre and post treatment wastewater treatment. Also shown on the plot is a bar representing tolerance limits for industrial effluents maximum permissible concentration.

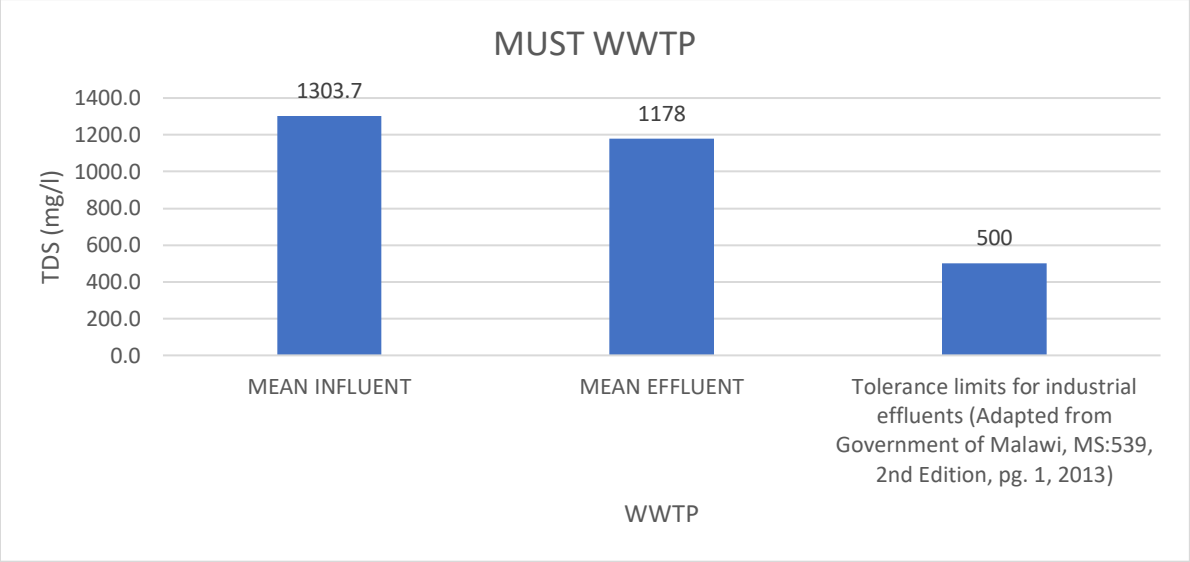


Figure 8. Plot of total dissolved solids for pre and post treatment wastewater treatment. Also shown on the plot is a bar representing tolerance limits for industrial effluents maximum permissible concentration.

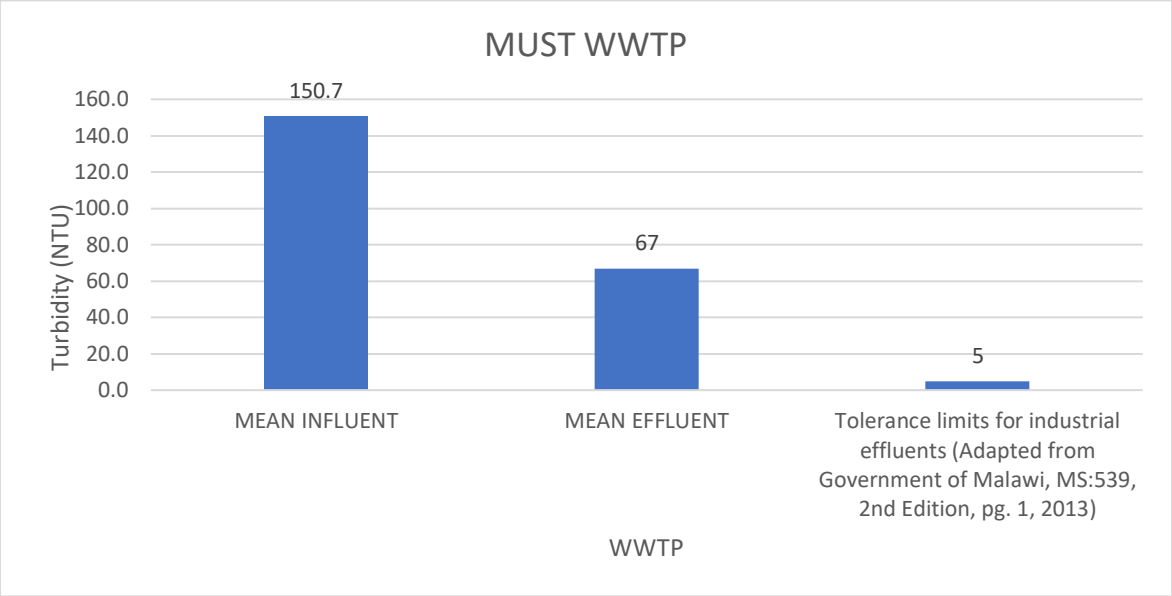


Figure 9. Plot of turbidity for pre and post treatment wastewater treatment. Also shown on the plot is a bar representing tolerance limits for industrial effluents maximum permissible concentration.

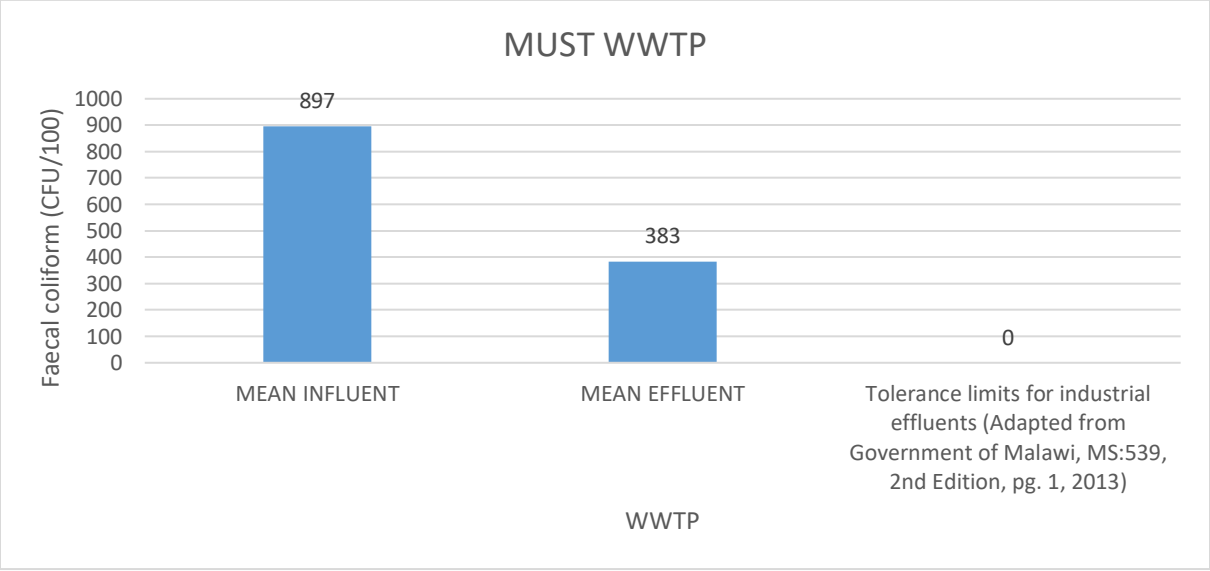


Figure 10. Plot of feacal coliforms for pre and post treatment wastewater treatment. Also shown on the plot is a bar representing tolerance limits for industrial effluents maximum permissible concentration.

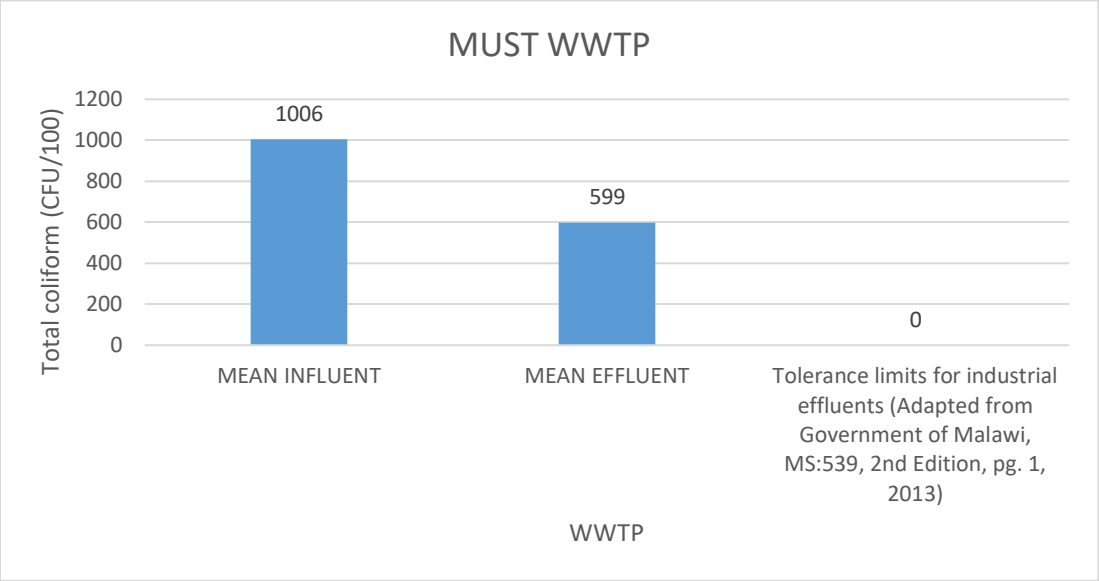


Figure 11. Plot of Total coliforms for pre and post treatment wastewater treatment. Also shown on the plot is a bar representing tolerance limits for industrial effluents maximum permissible concentration.

4.1. Discussions

4.1.1. pH

The pH was recorded to be 7.72 for influent and 7.99 for effluent. According to Ophardt (2004), defined a pH of 7 considered neutral, pH less than 7 as acidic and a pH greater than 7 as alkaline. As such the wastewater treated is slightly alkaline, the pH values are below the maximum acceptable limit of 9 recommended by Malawi government for tolerance limits for industrial effluent. Therefore, the pH values of the treated wastewater in the study area was within the acceptable limits and hence does not affect the rivers heath.

4.1.2. Temperature

The temperature was 14.6 and 14.8 degrees Celsius for influent and effluent respectively. Maximum surface temperature that a product intended for use in a potentially hazardous

environment is permitted to function at, in comparison to an ambient temperature of -20°C to +40°C (Schuller & Heuwieser, 2013).Although the discharge of post-treated wastewater is within the operation range, it will have no effect on the river's health since the measured value is less than the highest permitted tolerance limits for industrial effluent, i.e. 40 ^{O}C.

4.1.3. Total dissolved solids

The post-treatment wastewater had a TDS of 1178 mg/L while pre-treatment had 1303.7 mg/l. Riya (2021) defined fresh water as having a TDS of less than 1,000 ppm, brackish water as having a TDS of 1,000 to 10,000 ppm, saline water as having a TDS of 10,000 to 35,000 ppm, and hypersaline as having a TDS of greater than 35,000 ppm. As a result, the pre- and post-treatment wastewater is classed as Brackish (TDS: 1000-10,000 mg/L). The value of TDS exceeds the permissible limit for industrial wastewater discharge of 500 mg/L. High TDS concentrations alter the mineral composition of water (Weber-Scannell & Duffy, 2007). Because TDS is linked to key ions, salinity will be a problem for the environment.

4.1.4. Turbidity

Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates. The more total suspended solids in the water, the murkier it seems and the higher the turbidity. Turbidity values for pre and post treatment were 150.7 and 67 (NTU) respectively. Both water from the plant reported turbidity value above the limit of 5 NTU. Therefore, the turbidity water can provide food and shelter for pathogens which can increase the potential pollution in the water body (Wetzel, 2001)

4.1.5. Dissolved oxygen

The Do measured thus 1.44 and 2.99 mg/l of pre- and post-treatment respectively, was lower than the minimum required concentration of 5mg/l. According to Edokpayi, Odiyo, & Durowoju (2016), the presence of degradable organics in wastewater is responsible for the

lower levels of DO. These contribute to oxygen demand level of the receiving water. Therefore, can have negative effects on aquatic organisms in the water resources.

4.1.6 COD and BOD

BOD and COD give an estimate of organic pollution in wastewater. They are used to measure the efficiency of most wastewater treatment facilities. The surface water is expected to have low BOD or COD values to sustain aquatic life. But according to the values obtain, the COD value which is 72 was above 60 the maximum value of the required concentration. While the BOD which had a value of 17.28 was below the maximum concentration of 20. Although the BOD was within the limit, but due to the high concentration of COD, the DO is consumed by bacteria. Such decrease can affect fish growth and reproduction (Edokpayi, Odiyo, & Durowoju, 2016)

4.1.7 Ammonia

The tolerance limit for ammonia industrial effluents is 10mg/l. The value of ammonia was 35.73. This shows it was above the required discharge amount. Therefore, influx of nutrients into the waterbodies can induce eutrophication. It can also increase turbidity, plant, animal biomass and sedimentation (Edokpayi, Odiyo, & Durowoju, 2016).

4.1.8 Total and faecal coliforms

Total and faecal industrial effluents have a tolerance limit of 0 mg/l. The faecal and total values were 383 and 598, respectively. The results revealed that the maximum tolerance limit had not been reached. As a result, high levels of faecal and total coliforms in water bodies suggest an increased risk of developing waterborne illnesses.

4.2. Conclusions

When the effluent mean of the MUST WWTP is compared to the Tolerance limits for industrial effluents in table 2, various parameters, such as TC, FC, DO, SS, ammonia, COD,

BOD, TDS, and turbidity, are found to be outside of the limits. The effluent samples gathered demonstrate that the wastewater quality is extremely contaminated, indicating that the plant is inefficient because it fails to bring all of the mentioned criteria within regulatory limits.

4.3. Results- Efficiency of different filtration systems for wastewater recycling

Data for physico-chemical and biological parameters were entered and analyzed for pH, TSS, Turbidity, Dissolved Oxygen, alkalinity, ammonia, nitrates, COD,BOD, faecal coliform, total coliform and temperature using excel to calculate the percent removal or improvement efficiency .T-test was used to test for statistical differences in effluent quality between the sand filtration and activated carbon.

Table 3. Results for measured physico-chemical and microbiological wastewater to assess the efficiency of different filtration systems for wastewater recycling at the plant.

Parameters	sand % removal or improvement	GAC % removal or improvement
pH	3.466666667	8.466666667
Temperature	13.15280464	13.15280464
Do	62.18487395	64.18067227
TSS	92.03539823	74.77876106
Total coliform	65.51724138	46.55172414
Feacal coliforms	58.10055866	24.58100559
BOD	67.19845722	45.01227209
COD	67.20215633	45.01347709
Ammonia	9.154113557	28.62108922
Alkalinity	25.45470836	47.81829585
Turbidity	85.41666667	57.63888889
Nitrate	28.97196262	39.25233645

Table 4. shows results of measured physico-chemical and microbiological wastewater which are compared to food and agriculture organization standards (FAO) in Table 1

	Sand filtration		Activated carbon (GAC)	
Parameters	Mean	St. Deviation	Mean	St. Deviation
pH	7.76	0.0141421	6.865	0.06363961
Temperature	22.45	0.0707107	22.45	0.070710678
Do	7.72	0.6505382	7.815	0.261629509
TSS	9	1.4142136	28.5	0.707106781
Total coliform	500	141.42136	775	35.35533906
Feacal coliforms	375	35.355339	675	106.0660172
BOD	37.42	0	62.73	0
COD	60.84	0	102	0
Ammonia	39.2	6.7882251	30.8	11.87939392
Alkalinity	416	0	291.2	58.83128419
Turbidity	10.5	0.7071068	30.5	6.363961031
Nitrate	0.38	0.0141421	0.325	0.021213203

The Following Graphs below compares the Effluent results above to assess efficiency of different filtration systems for wastewater recycling.

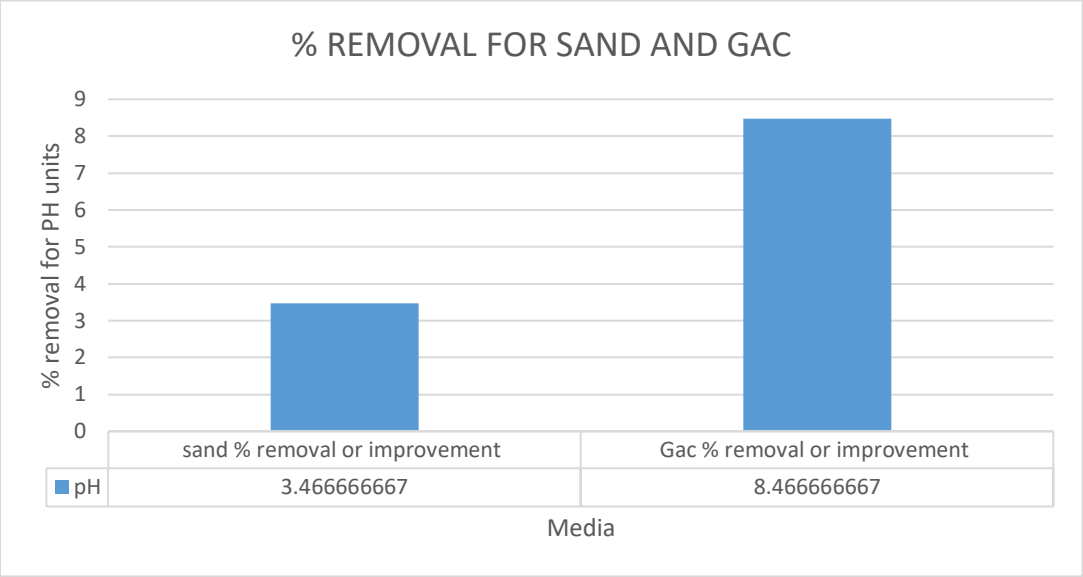


Figure 2.1. Plot of pH showing bars representing efficiency improvement for sand and GAC.

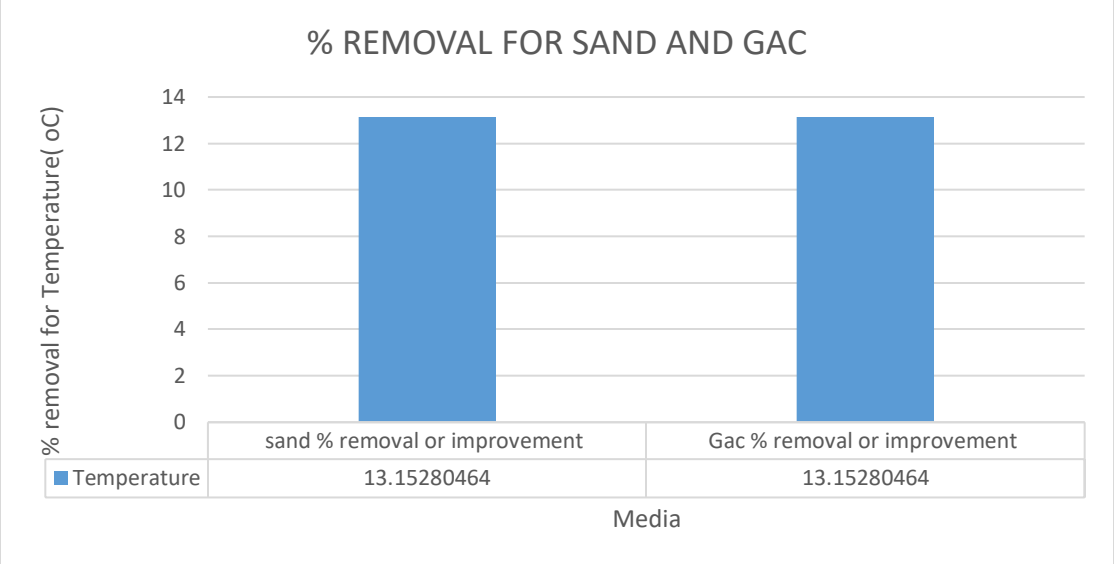


Figure 12. Plot of Temperature showing bars representing efficiency improvement for sand and GAC.

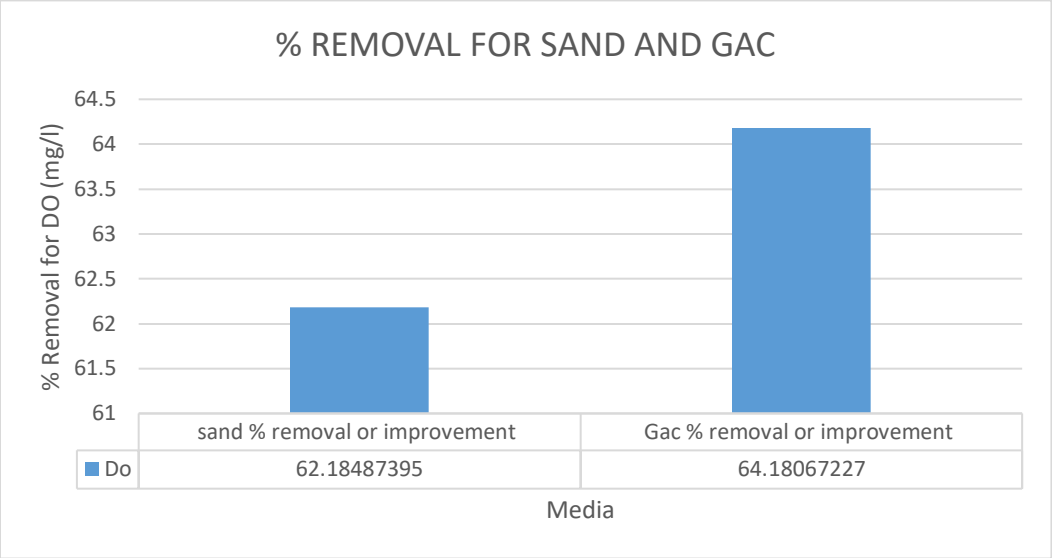


Figure 13 Plot of DO showing bars representing efficiency improvement for sand and GAC.

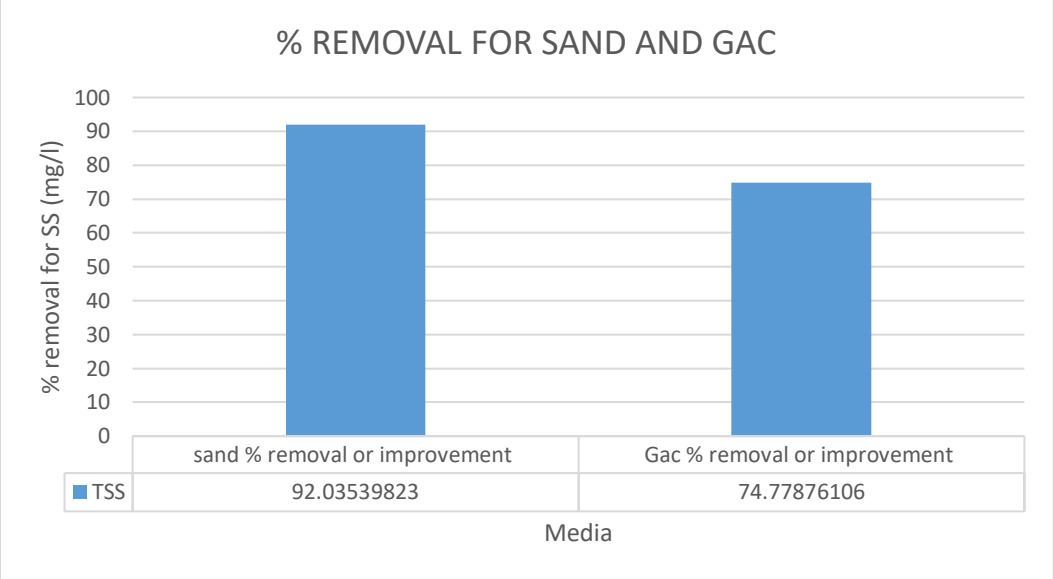


Figure 14. Plot of TSS showing bars representing efficiency removal for sand and GAC.

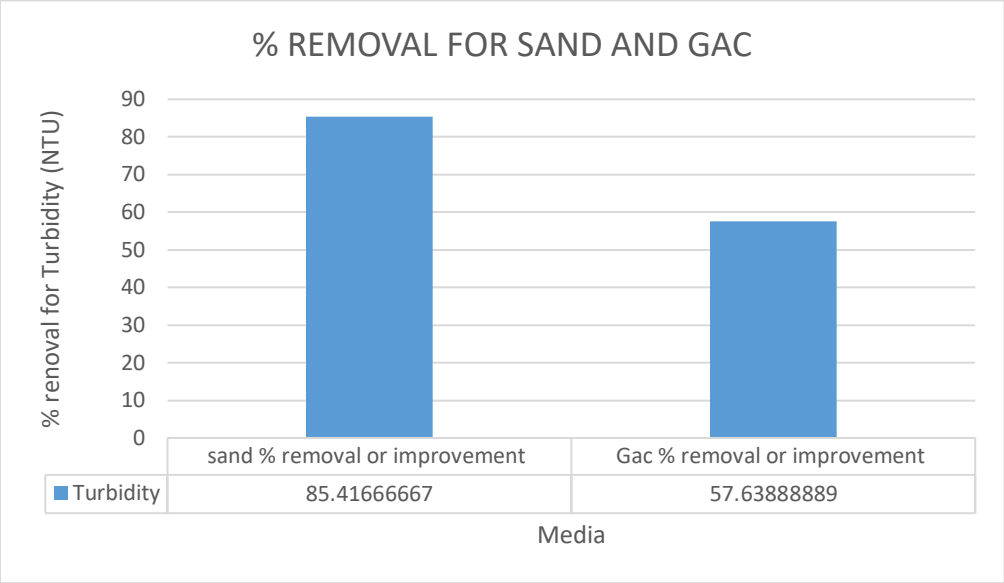


Figure 15. Plot of Turbidity showing bars representing efficiency removal for sand and GAC.

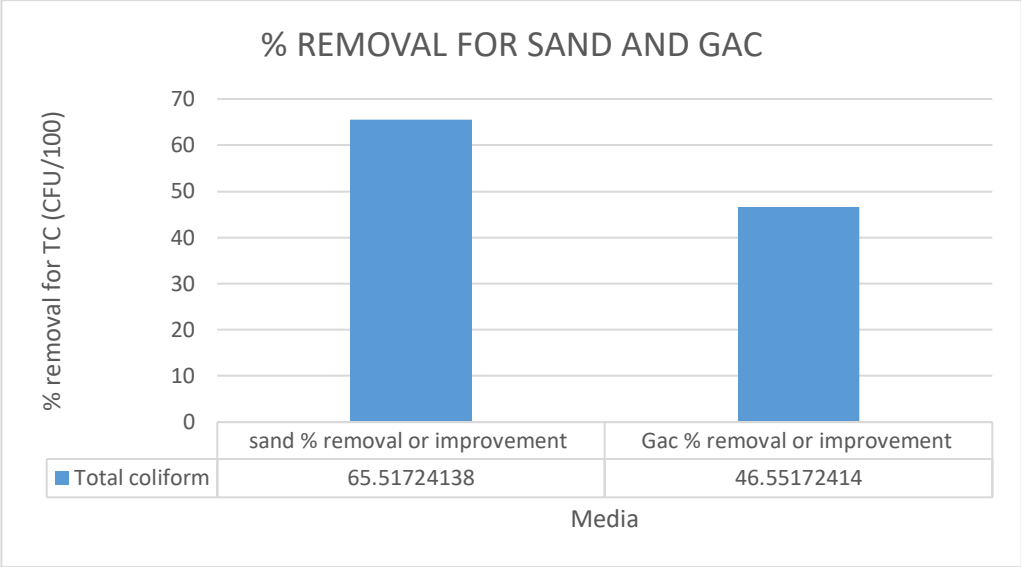


Figure 16. Plot of Total coliform showing bars representing efficiency removal for sand and GAC.

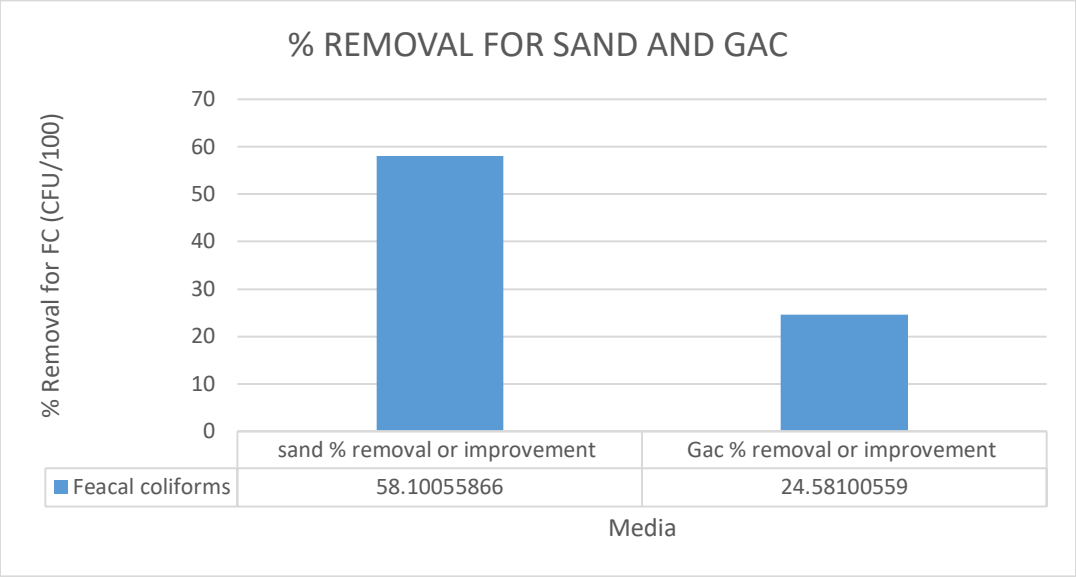


Figure 17. Plot of Faecal coliforms showing bars representing efficiency removal for sand and GAC.

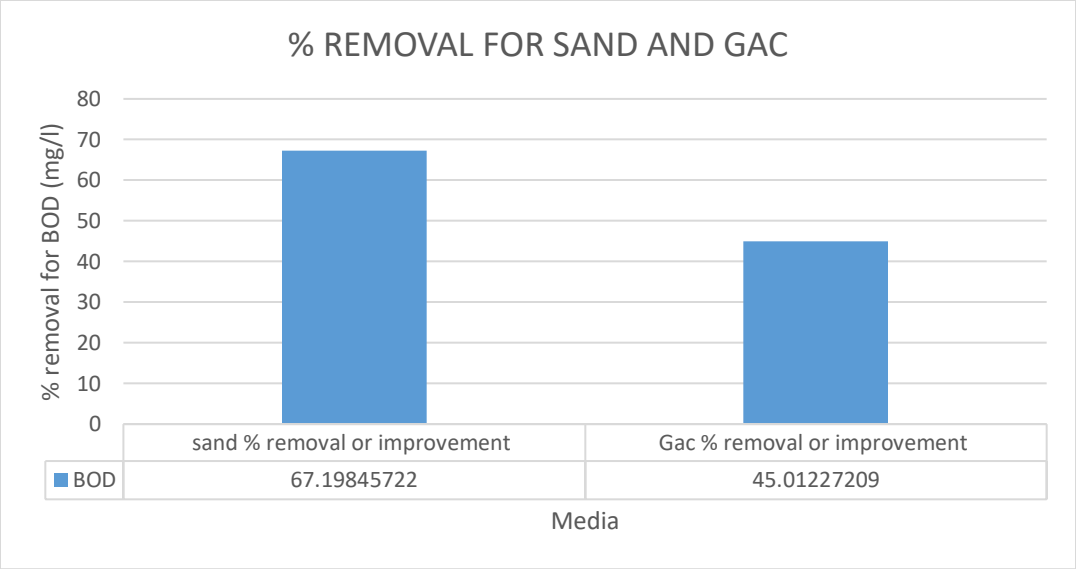


Figure 18. Plot of BOD showing bars representing efficiency removal for sand and GAC.

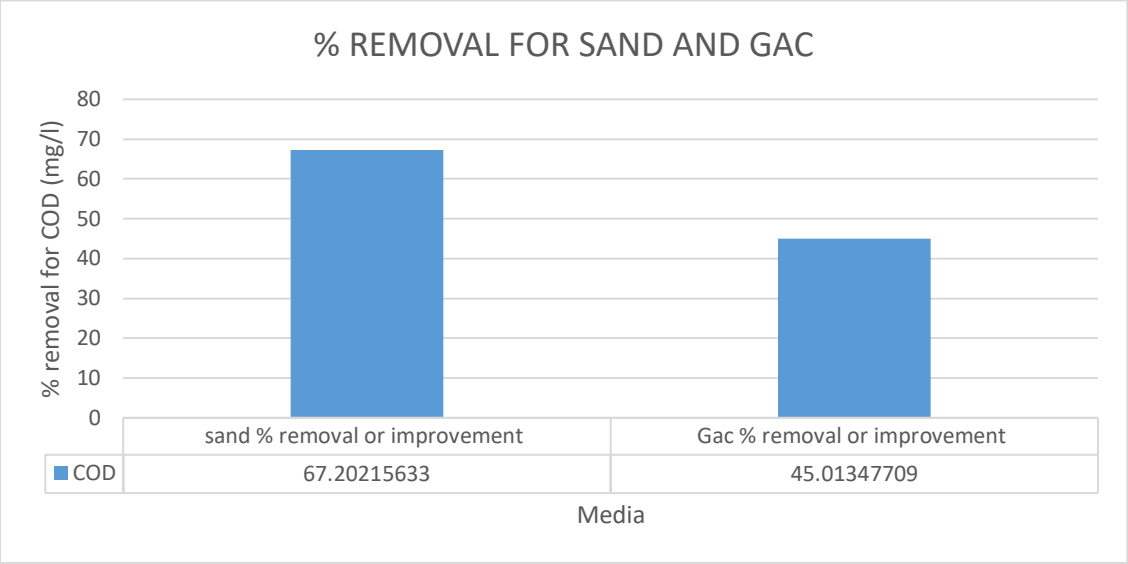


Figure 19. Plot of COD showing bars representing efficiency removal for sand and GAC.

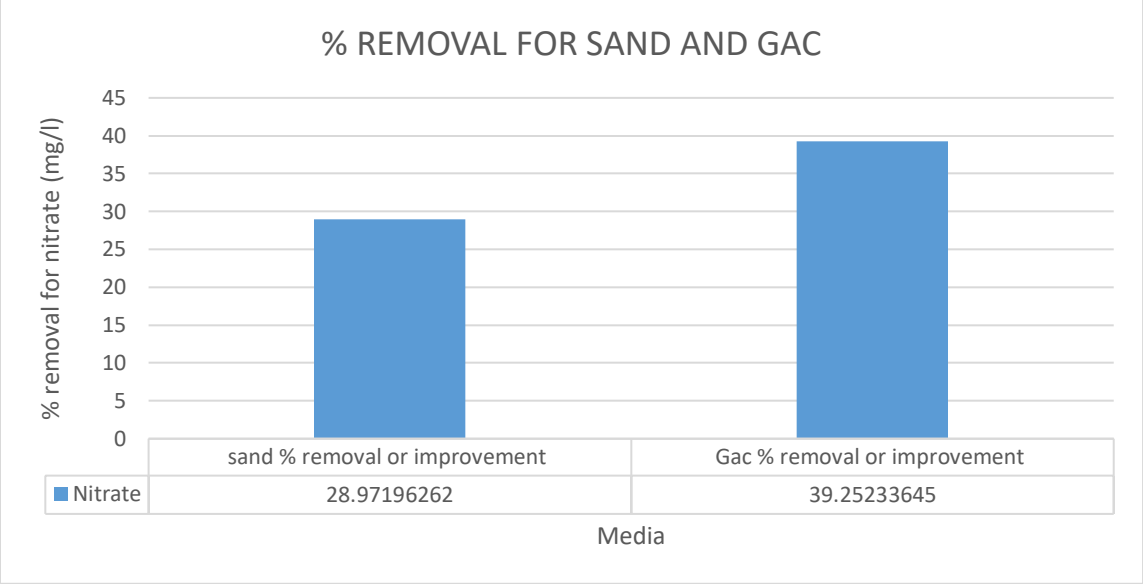


Figure 20. Plot of Nitrate showing bars representing efficiency removal for sand and GAC.

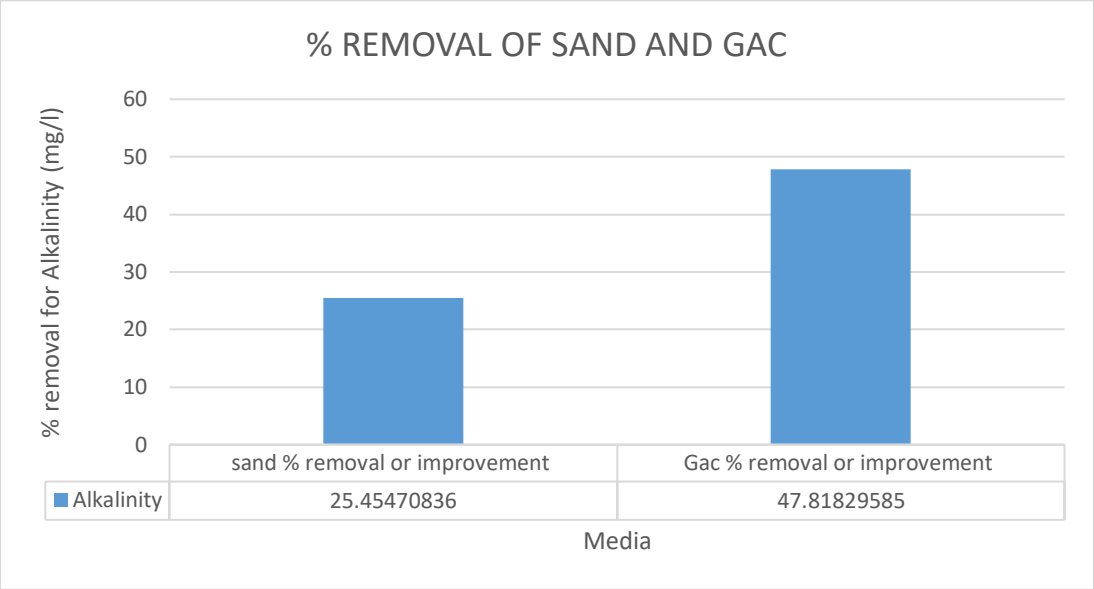


Figure 21. Plot of alkalinity showing bars representing efficiency removal for sand and GAC.

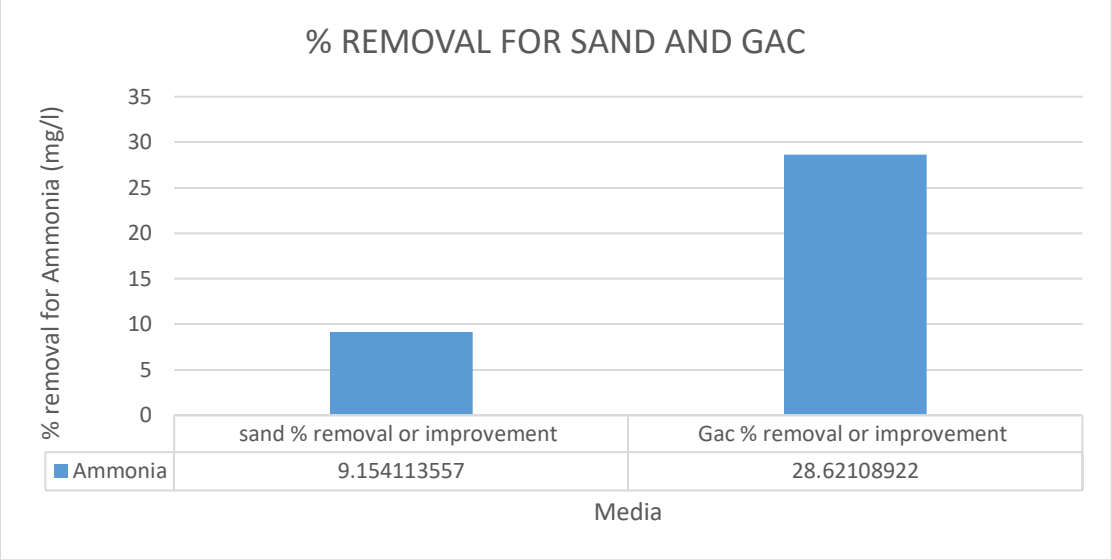


Figure 22. Plot of ammonia showing bars representing efficiency removal for sand and GAC.

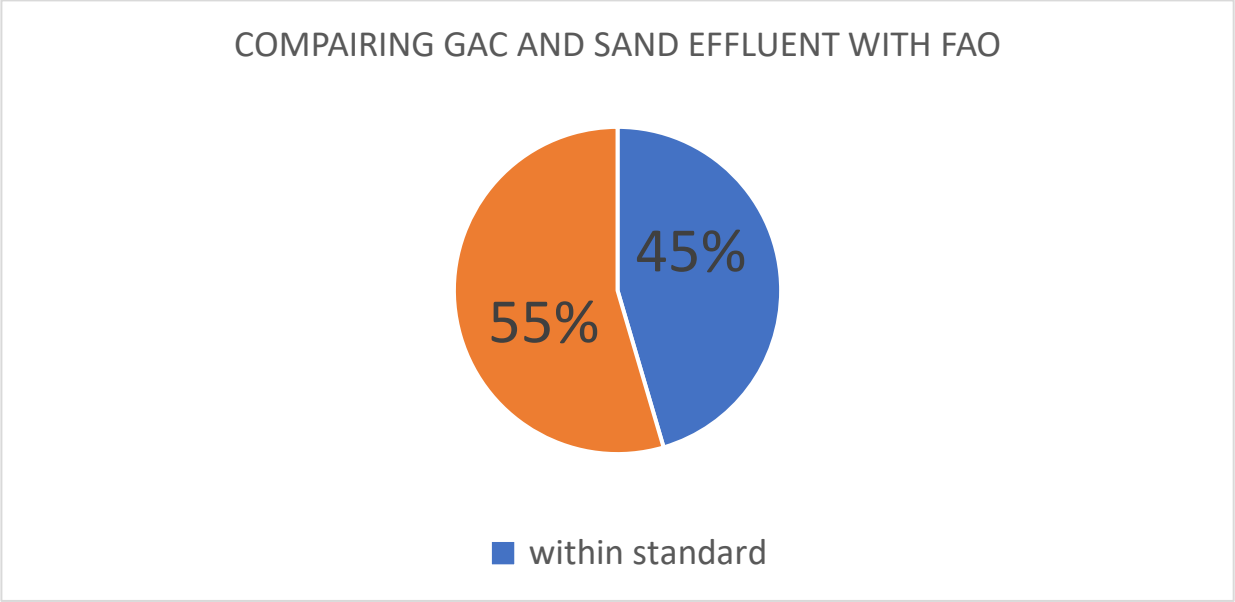


Figure 23: plot of percentage of GAC and sand comparing with FAO irrigation standards

4.4. Discussions

4.4.1. Percentage removal/improvement for sand and GAC

a. Percent Improvement for pH

The pH of the filtered water had an improvement percentage of 3.47 for sand while GAC was 8.47. The percentage increases in GAC as compared to Sand. According to DeSilva (2001), a bad taste is defined by high pH, hence GAC filters can be used to eliminate compounds that cause unpleasant odors or tastes.

b. Percent improvement for temperature

The percentage improvement of both GAC and sand was 13.15. Most chemical and biological processes are affected by temperature. Therefore, high temperatures might hasten the formation of odors (Alisawi, 2020).

c. Percent improvement for DO

The DO percentage improvement for GAC was 64.1 while for sand was 62.1. There was a slightly difference between the two but GAC had high percentage improvement.DO is a gas, therefore GAC is used mostly to remove gases (Cobb, 2012).

d. Percent removal for Suspended solids, turbidity

High percent removal for Suspended solids and turbidity was seen in sand than in GAC. Sand hand the percent of 92 while GAC was 74.7 of suspended solids. While for turbidity, sand hand the percent of 85.4 while GAC was 57.6. According to Bash & Berman (2001), high total suspended solids levels raise water temperatures while lowering dissolved oxygen This is due to the fact that suspended particles absorb more heat from the sun. It also restricts growth rates by limiting food supplies and trapping bacteria and organic wastes.

e. Percent removal for total coliforms and feacal coliforms

The percent removal for TC and FC in sand was 65.5 and 58.1 respectively. While in GAC TC was 46.5 and FC was 24.5. Both percentages show that sand had high removal efficiency. pathogen populations are often high on particles (Bennett, 2009). Since there is high removal efficiency of TSS in sand therefore high removal of bacteria will also be noticed.

f. Percent removal for BOD and COD

The percent removal for BOD and COD in sand was 67 while for GAC was 45 for both parameters. The efficiency increased in sand because sand has the ability to collect microorganisms through filtration, allowing them to survive and multiply to remove pollutants (Efstratiou, 2018).

g. Percent removal for nitrate and Ammonia

The percent removal for nitrate and ammonia in sand was 28.9 and 9.1 respectively. In GAC the percentage were 28 for ammonia while 39.2 for nitrate. In sand the value obtained for ammonia was low. This means ammonia was nitrified to nitrite to nitrate. According to Fan, Bolhuis, & Stal (2015), the most common chemical form of nitrogen absorption from soil or water is nitrate. Therefore, can be applied as fertilizer.

4.4.2. comparing the effluent quality of the filtration systems

The comparison investigation of sand filtration and gac yielded a p-value of 0.496. As a result, because $P > 0.05$, there is no significant difference in effluent quality between the sand and GAC. Hence, the null hypothesis wins and the alternative loses. Activated carbon, however, did not contribute considerably to the removal of some parameters as compared to sand because activated carbon is used mostly to remove gases and does not remove TSS (Cobb, 2012). TSS, FC, TC, BOD, COD, turbidity, ammonia and other important irrigation

parameters were removed more effectively in sand, whereas activated carbon was proven to improve pH and DO. According to Golovko (2020), sand filters Purify water through chemical sorption in which contaminates stick to the surface of the sand and to the biological growth on the sand surface. Despite the contaminants being removed, the percentage values in figure 23 shows that 45% of the measured samples were within the irrigation standards (table 1) while 55% were not. Therefore, looking at the removal efficiencies for both systems, there are some observed differences in the effluent quality. The values obtained from the effluent quality of sand show high percent removal as compared to GAC.

4.5. conclusion

With the results obtained, Sand filtration can be suitable for recycling wastewater for irrigation with time. A Secondary treatment should be used also to improve the effluent quality or both technologies (sand and GAC) should be merged to improve its efficiency.

4.6. Results-Effects of plant operational parameters on the efficiency of the filters

Table 5. Shows the results of the HLR and OLR at different flowrate.

	Flowrate (m3/day)	Volume(m3)	Area(m2)	HLR(m3/m2/day)	OLR (Kg BOD/m3/day)
First	0.072	0.0017	0.0085	8.48	$4.8*10^{-10}$
Second	0.096			11.3	$6.4*10^{-10}$

Table 6. Shows the results of the effect of plant operational parameters on the efficiency of the filter on wastewater treatment

	% changes at different HLR and OLR			
	Sand filtration		GAC	
Parameters	HLR/ OLR 1	HLR/ OLR 2	HLR/ OLR 1	HLR/ OLR 2
pH	3.466667	3.133333	8.466667	1.8
Temperature	13.1528	11.99226	13.1528	11.79884
Do	62.18487	50.52521	64.18067	43.38235
TSS	92.0354	83.18584	74.77876	61.06195
Total coliform	65.51724	46.55172	46.55172	34.48276
Feacal coliforms	58.10056	30.1676	24.58101	13.40782
BOD	67.19846	64.68268	45.01227	18.55715
COD	67.20216	64.68464	45.01348	18.56065
Ammonia	9.154114	61.06605	28.62109	45.30707
Alkalinity	25.45471	22.48006	47.8183	32.90924
Turbidity	85.41667	78.47222	57.63889	43.75
Nitrate	28.97196	83.17757	39.25234	26.16822

The Following Graphs below compares the Effluent results above to assess the effects of operational parameters on the effluent quality.

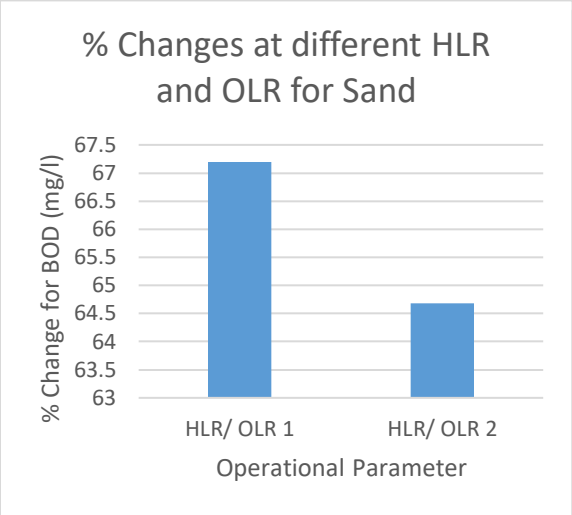


Figure 24

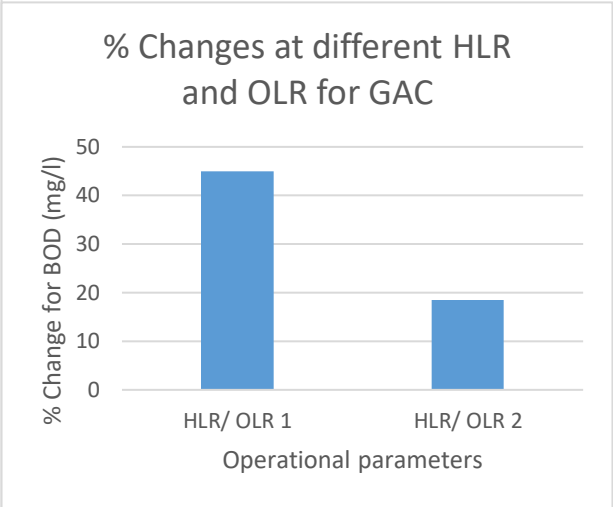


Figure 25

Figure 24 & 25: Plot of BOD percentage change for GAC and Sand at different HLR and OLR

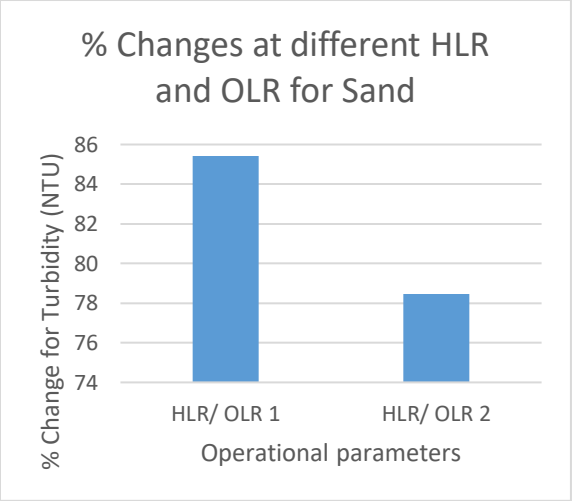


Figure 26

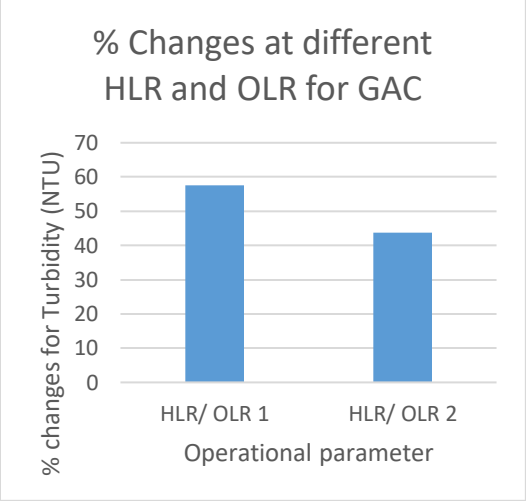


Figure 27

Figure 26 & 27Plot of turbidity percentage change for GAC and Sand at different HLR and OLR

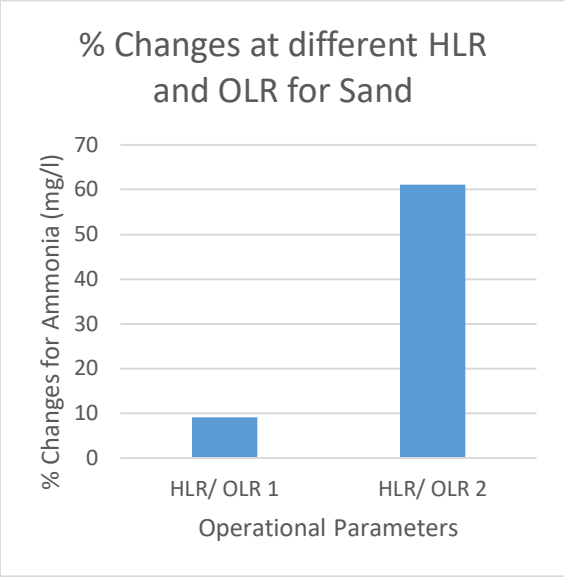


Figure 28

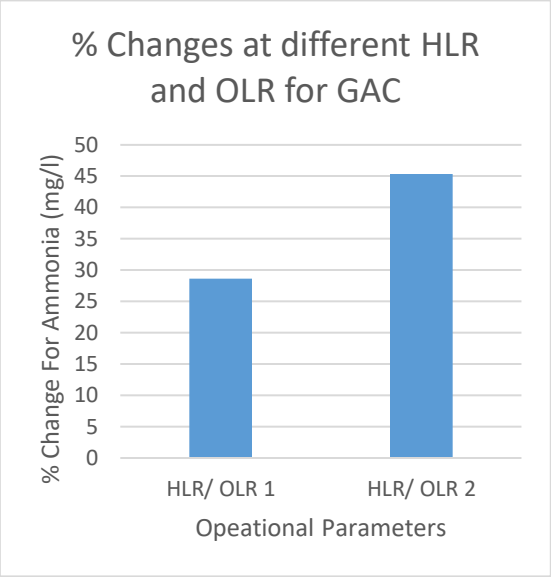


Figure 29

Figure 28 & 29: Plot of Ammonia percentage change for GAC and Sand at different HLR and OLR

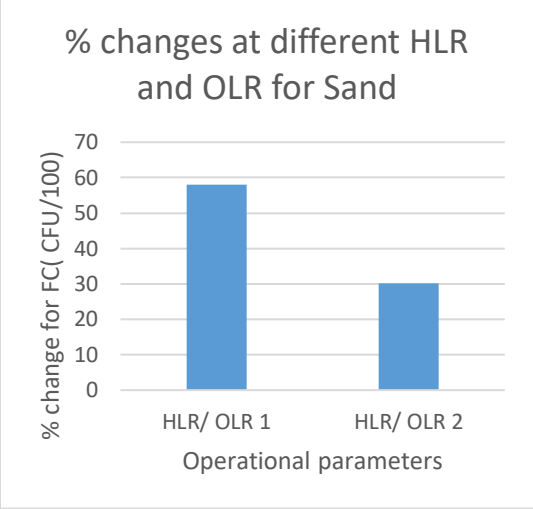


Figure 30

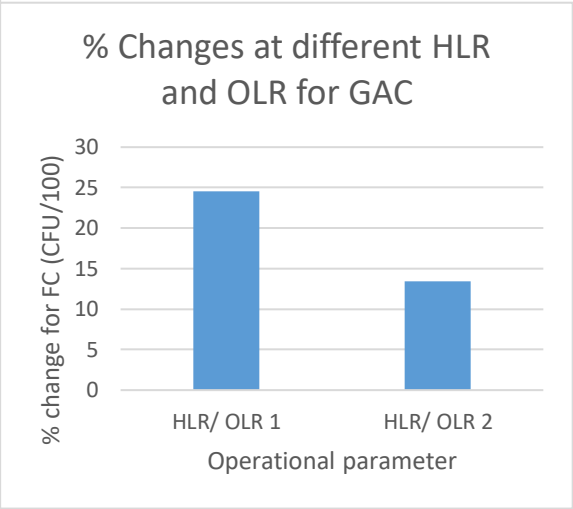
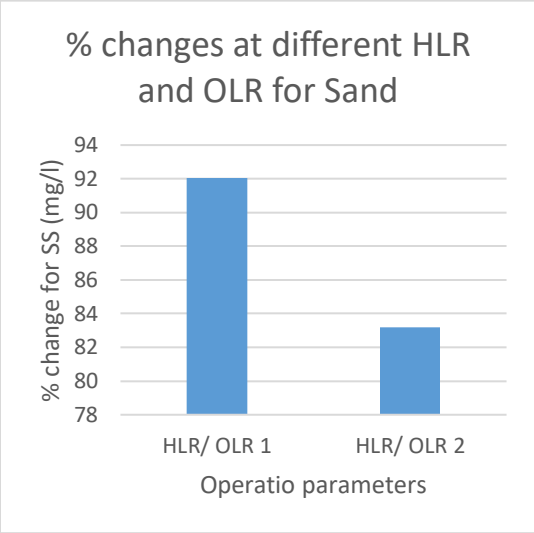


Figure 31

Figure 30 & 31: Plot of FC percentage change for GAC and Sand at different HLR and OLR



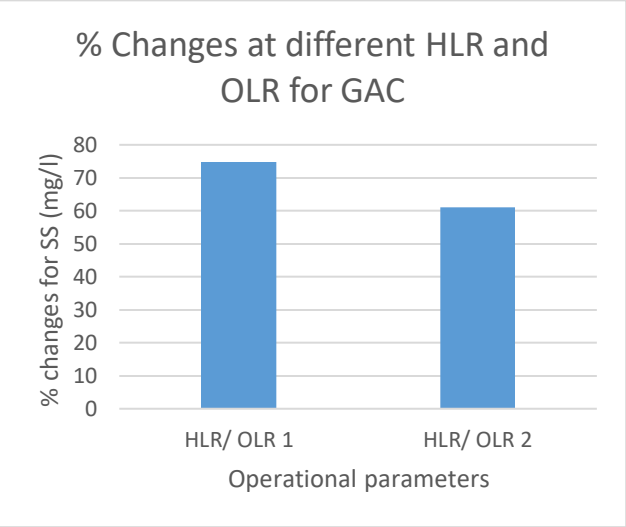
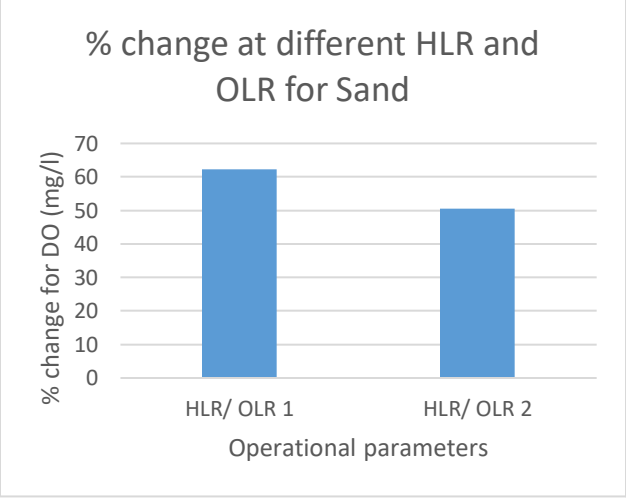


Figure 32 Figure 33

Figure 32 & 33: Plot of SS percentage change for GAC and Sand at different HLR and OLR



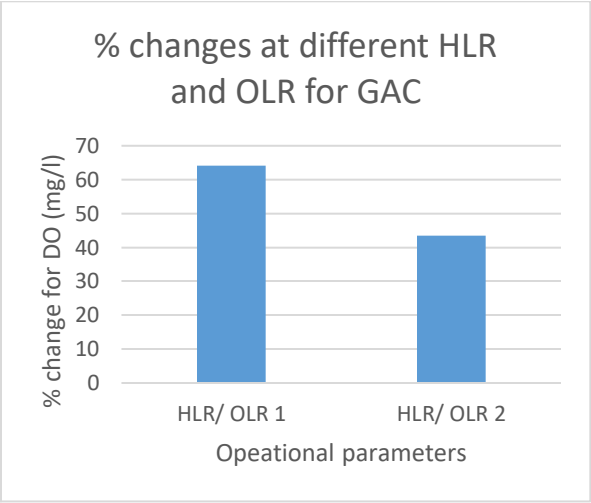
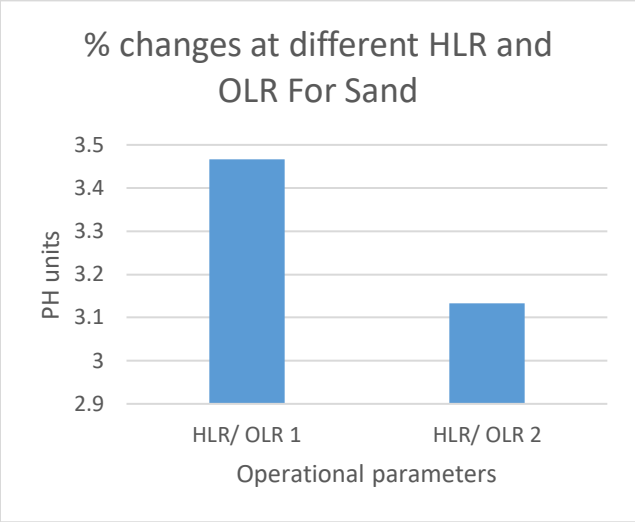


Figure 34 Figure 35

Figure 34 & 35: Plot of DO percentage change for GAC and Sand at different HLR and OLR



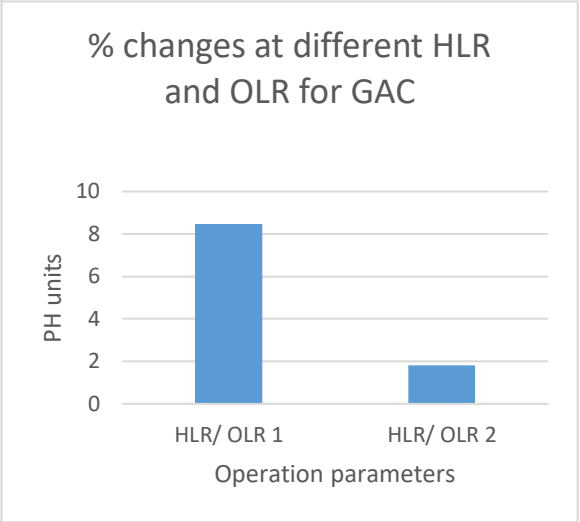


Figure 36 Figure 37

Figure 36 & 37: Plot of pH percentage change for GAC and Sand at different HLR and OLR

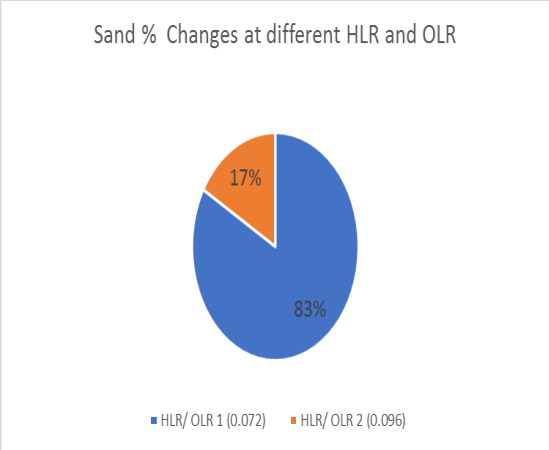
4.7. discussion

4.7.1. Comparing the effects of operational parameters on effluent quality

The comparative analysis of sand filtration at different HLR and OLR yielded a p-value of 0.87, while GAC yielded a p-value of 0.128. There is no significance difference because both p values are bigger than 0.05. This suggests that the operational parameters had no effect on the wastewater discharge quality. As a result, the null hypothesis was accepted whereas the alternative hypothesis was dismissed.

Despite the fact that there was no statistical difference, the flowrate of 0.072 (m3/day) eliminated more trash than the flowrate of 0.096 (m3/day). This indicates that as the flowrate is reduced, the particles have greater contact time with the media (sand or activated charcoal), resulting in a higher percentage of removal (Ramadan, 2012). Furthermore, the time required by microorganisms to decompose organic matter reduces as the flow rate increases. As a result, each parameter's average removal efficiency was very low. However, efficiency rose

as organic loading and hydraulic loading rates were reduced. This is demonstrated by figure 38 and 39 below which shows the overall percentage of samples at HLR and OLR. The blue color indicate higher removal efficiency while the orange indicate low removal efficiency This reveals that HLR of 8.48(m3/m2/day) and OLR of 4.8*10-10 (Kg BOD/m3/day) cleared more waste than HLR of 11.3(m3/m2/day) and OLR of 6.4*10-10 (Kg BOD/m3/day).



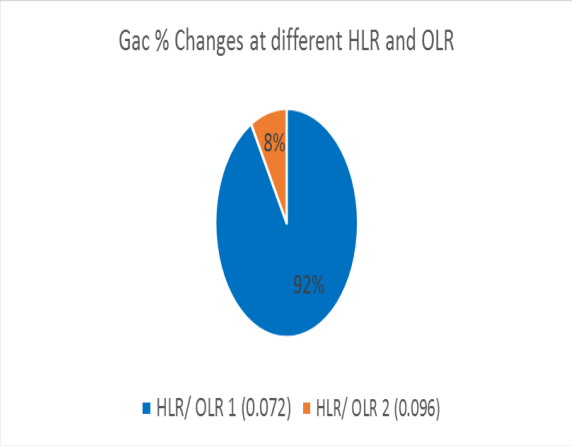


Figure 38 Figure 39

Figure 38 & 39: Plot of overall percentage change for GAC and Sand at different HLR and OLR

4.8. conclusion

The filter's efficiency is influenced by the plant's operational parameters, but it also depends on the flowrate, as well as the particle size and distribution of the media. Particle size and size distribution are crucial parameters to consider, according to Aim, Vigneswaran, and Prasanthi (1997), because separation efficiency decreases as particle size increases. As a result of its small particle size compared to Gac, the sand filter exhibited a high removal effectiveness.

5.0. CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

The general goal of this study was to evaluate the potential of different technologies for wastewater recycling for irrigation purposes at the MUST WWTP. To meet the study's goals, a series of field data gathering and laboratory tests were carried out. The following are summary results related to the study's goal and particular objectives.

5.1.1. Summary Conclusions

A literature review on how wastewater is used in agriculture in different countries was undertaken in chapters one and two of this thesis. The study uncovered significant knowledge gaps about how wastewater at MUST cannot be used for irrigation because it does not meet irrigation water quality standards. As a result, the potential of various wastewater recycling methods for irrigation was evaluated. The following are some broad conclusions based on the study's specific goals.

Specific objective 1: To Assess the physico-chemical and microbiological wastewater quality at the plant

The MUST plant's influent and effluent wastewater were evaluated. The values of physiochemical and biological parameters collected at the effluent were compared to the industrial tolerance discharge limit set by the Malawi government. Various parameters, including TC, FC, DO, SS, ammonia, COD, BOD, TDS, and turbidity, were discovered to be outside of the limits. The effluent samples collected show that the wastewater quality is significantly polluted, implying that the plant is inefficient because it fails to meet all of the mentioned criteria within regulatory limits.

Specific objective 2: To assess the efficiency of different filtration systems for wastewater recycling

The objective was formulated based on the hypothesis that the effluent quality from the sand filtration is different from activated carbon. Sand filtration and GAC filtration systems were used to quantify the removal efficiency of different parameters and see which system is suitable to treat wastewater for irrigation. Findings from this study revealed that there were no significance differences and that activated carbon and sand filtration effluent wastewater cannot be utilized for irrigation on its own, despite the fact that other parameters fulfill the specifications. As a result, both technologies (sand and GAC) should be merged to improve its efficiency.

Specific objective 3: To Assess the effects of plant operational parameters on the efficiency of the filters

The objective was formulated based on the hypothesis whether the operational parameters affect the effluent quality from the sand filtration is different from activated carbon. Different flowrates (i.e. 0.072 and 0.096 (m3/day)) were used to monitor the HLR and OLR after 6 hours. Calculation of each HLR and OLR at different flowrate was conducted including the removal efficiency. The findings revealed that there were no significance differences and that decrease in flowrate, particle size, organic loading and hydraulic loading rates increases efficiency.

5.2. Recommendations

According to the findings of this study, the following recommendations are made:

- The study recommends that wastewater monitoring programs should be put in place to monitor frequently the quality of effluent wastewater being discharge at MUST.

- Combination of sand filtration and Gac should be considered to enhance removal efficiency.

- Flowrate and time for removal efficiency should be considered. The time should be more than 6 hours while the flow rate should be less than of 0.072 (m3/day).

- More Irrigation standards should be developed in Malawi

- More studies on assessment of filtration systems suitable for wastewater treatment for irrigation should be undertaken.

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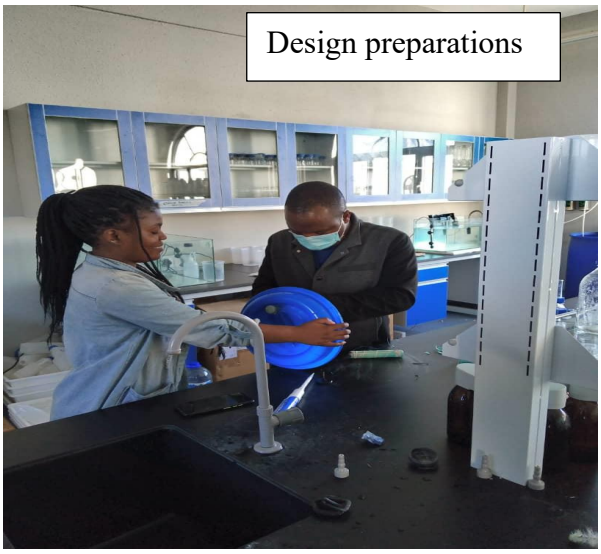
APPENDICES

Appendix 1: MUST WWTP and point of wastewater collected





Appendix 2: design setup





Appendix 3: in-situ measurements and laboratory experiments



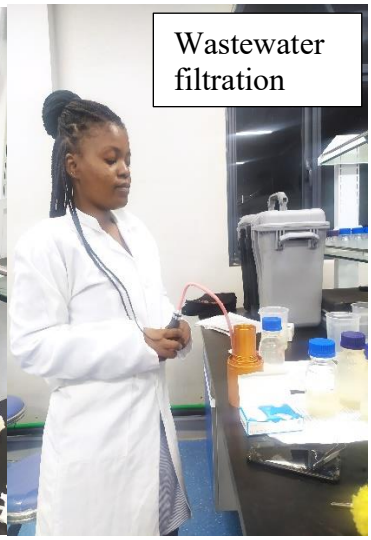
Photometer instrument



wastewater collection, testing and data collection



Nitrate measurements



Wastewater filtration



Sterilization process



Media preparation

Appendix 4: Post and Pre wastewater test results of the MUST WWTP, and also for the design experiment at different flowrates

PARAMETER	PRE-TREATMENT	POST-TREATMENT	PRE-TREATMENT	POST-TREATMENT	PRE-TREATMENT	POST-TREATMENT
pH	7.75	7.79	7.7	8.13	7.71	8.05
Temperature	14.4	14.9	15.2	15.3	14.18	14.24
DO	2.42	2.3	0.55	3.33	1.35	3.34
suspended solids	130	76	123	67	293	59
ammonia	32	29.6	50.4	36	43	41.6
COD	280	72	280	72	280	72
BOD	173.6	17.28	173.6	17.28	173.6	17.28
TDS	1226	1154	1337	1155	1348	1225
ORP	-20.3	-33.4	-35	-36	-35	-36
EC	1889	1780	2054	1784	1348	1784
Turbidity	114	71	113	65	225	65
Total coliforms	1115	500	1003	756	900	540
feacal coliforms	800	300	900	400	990	450
Alkalinity	557.44	443.46	582.4	557.44	499.2	557.44
Salinity	0.93	0.88	1.04	0.88	1.04	0.93

Objective 2 and 3 data

Flowrate of 0.072 m3/day

	Initial effluent		sand filtration		Activated carbon	
Parameters	Value 1	Value 2	Value 1	Value 2	Value 1	value 2
pH	7.49	7.51	7.75	7.77	6.82	6.91
Temperature	24.9	26.8	22.4	22.5	22.5	22.4
Do	4.71	4.81	7.26	8.18	7.63	8
TSS	116	110	10	8	28	29
Total coliform	1500	1400	400	600	800	750
Feacal coliforms	900	890	350	400	600	750
BOD	110.08	118.08	37.42	37.42	62.73	62.73
COD	179	192	60.84	60.84	102	102
Ammonia	41.8	44.5	44	34.4	39.2	22.4
Alkalinity	560.5	555.6	416	416	249.6	332.8
Turbidity	73	71	10	11	35	26
Nitrate	0.54	0.53	0.39	0.37	0.34	0.31

Flowrate of 0.096

	Initial effluent		sand filtration		Activated carbon	
Parameters	First value	second value	First value2	Second value2	First value3	First value 3
pH	7.49	7.51	7.74	7.73	7.36	7.37
Temperature	24.9	26.8	22.7	22.8	22.7	22.9
Do	4.71	4.81	7.2	7.13	6.67	6.98

TSS	116	110	20	18	43	45
Total coliform	1500	1400	750	800	900	1000
Feacal coliforms	900	890	650	600	700	850
BOD	110.08	118.08	40.29	40.29	92.91	92.91
COD	179	192	65.51	65.51	151.07	151.07
Ammonia	41.8	44.5	19.2	14.4	21.6	25.6
Alkalinity	560.5	555.6	416	449.2	332.8	416
Turbidity	73	71	14	17	42	39
Nitrate	0.54	0.53	0.1	0.08	0.43	0.36

Appendix 5: showing dimensions for experimental setup

	Dimensions(mm)	
Storage tank	Height	360
	Diameter	300
Y- connecter	Diameter	25
Delivery pipes	Length	300
	Diameter	25
Filters	Base diameter	165
	Height	260
	Neck diameter	41
Stand 1	Length	700
	Width	200
	Height	700
Stand 2	Length	350

	Width	350
	Height	1100
	Length	400
Collecting tanks	Height	360
	Diameter	300

Appendix 6: preliminary data foe MUST WWTP

Paramete	influent	influent	influent	effluent	effluent	effluent	Mean influent	Mean effluent
pH	7.75	7.5	7.71	7.65	7.2	7.73	7.65	7.53
EC	328	524	417	480	378	60	423.00	306.00
TDS	204	342	270	310	36	245	272.00	197.00
DO	0.357	3.9	1.55	4.3	5.2	2.28	1.94	3.93
Salinity	0.09	0.2	26.2	26.93	0.15	0.02	8.83	9.03
Temperat	27.53	28.4	26.2	25.9	28.15	26.93	27.38	26.99
BOD	22	89	177	5	21	20	96.00	15.33
COD	90	150	80	68	60	60	106.67	62.67