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Performance Evaluation of Water Treatment Plants (WTPs): A Comparative Study between Gaborone and Mmamashia WTPs (Botswana)

A Thesis Report Submitted to Africa Center of Excellence for Water Management/ AAU in fulfillment of the requirement for an Award of degree of masters of science in Water Management (Water Supply and Sanitation)

By

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July, 2020, Addis Ababa

DECLARATION

I, **Josephine Tshepho Tombo**, do confirm and declare that this research report is my original effort and work, and that the findings of the research have never been used for any academic award in any institution.

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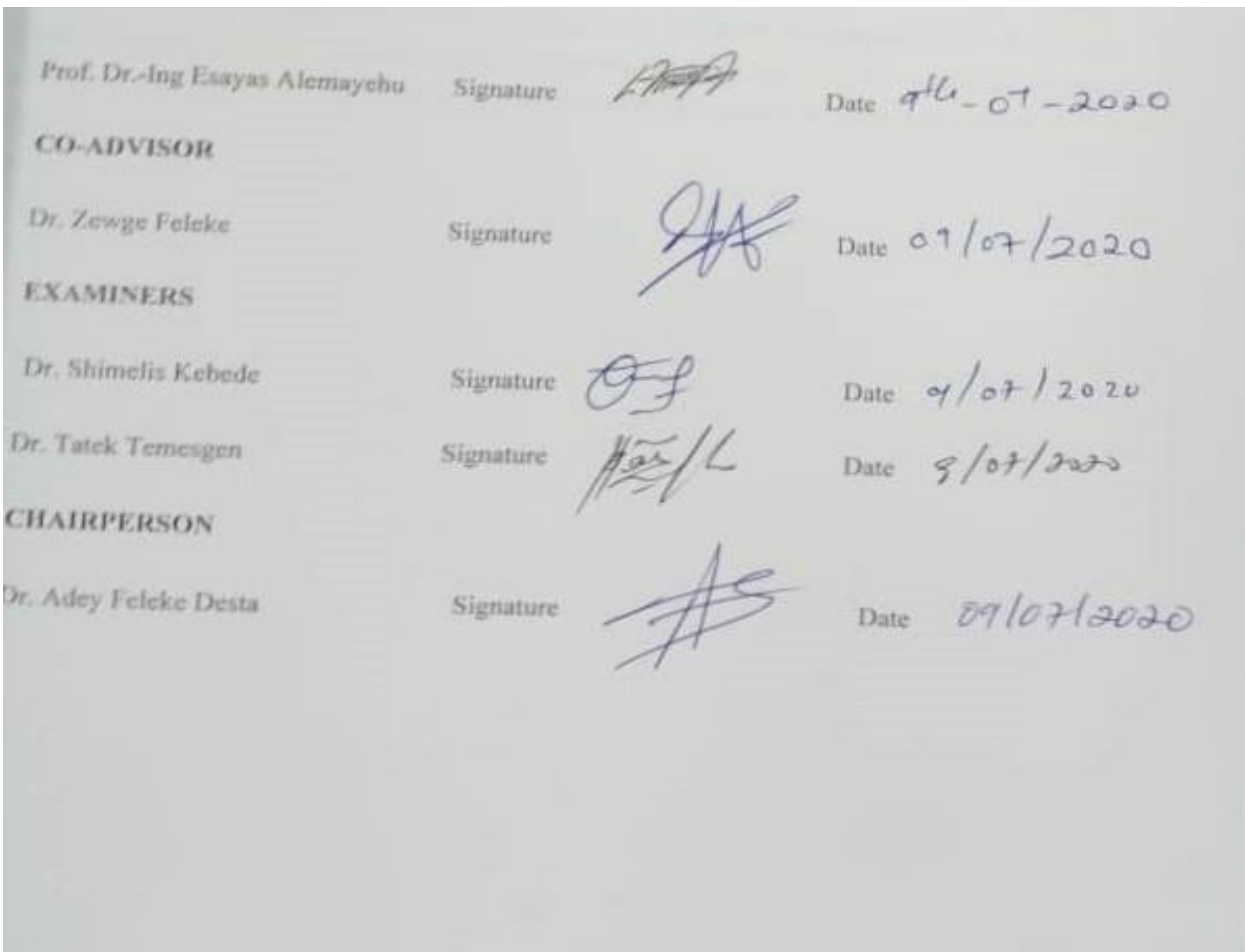

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ABSTRACT

One of the ways to protect public health and environment by the elimination of waterborne diseases and pathogens is water undergoing treatment before consumption, making this process very important. Hence there is a need for regular monitoring of the performance of water treatment plants as this will ensure public water supply quality control management, consequently ensuring consumers' safety. Performance evaluation of a water treatment plant (WTP) is a process to measure the functioning efficiencies based on some established performance indicators such as turbidity, color, suspended impurities, *E-coli*, Total Dissolve Solid, Residual Chlorine. Therefore, the overall objective of this study was to evaluate the performance of Gaborone and Mmamashia treatment plants (Botswana) with regard to their ability to produce quality water and control pathogens.

The water parameters, pH, Total Coliform, *E-coli*, turbidity and conductivity, were analyzed based on the years 2019 and 2020 Autumn season. Secondary data was obtained for the year 2019 while sampling and standard laboratory tests and analysis were done for the year 2020. One hundred and twenty samples were collected from each water treatment plant (WTP) for five weeks. Samples were taken from raw water entering the water treatment plants and after disinfection stage. The weighted arithmetic water quality index method was used to classify the quality of treated water. The log removal value and turbidity removal efficiency were determined using the respective formulas. Correlation statistical technique was carried out to find out if there was any direct or indirect relationship between the parameters.

The results from the study showed that, all the water parameters analyzed after disinfection stage for both treatment plants fall within the permissible limit for World Health Organization and Botswana bureau of standards. The water quality index for both plants was below 50 hence the water quality was classified as excellent. Overall, log removal value for Mmamashia, for the years 2019 and 2020 were, 1.96 and 1.3 respectively, for Gaborone, the values obtained were 2.24 and 1.52. Overall turbidity removal efficiency for Mmamashia for the years 2019 and 2020 was, 98.34% and 83.04% respectively while for Gaborone, 99.31% and 96.83% values were obtained for the years 2019 and 2020. There was significant correlation between parameters for both treatment plants. The treatment plants were found to be doing well with respect to providing the public with safe water and there was no significant difference between the

treatment plants except for the quality of raw water each is receiving. This study, therefore, acts as a baseline for further research regarding the efficiency of the Gaborone and Mmamashia treatment plants.

Key words: Gaborone, Mmamashia, Water treatment plant, Water quality parameters, Performance Evaluation, Turbidity removal efficiency

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ABBREVIATIONS AND ACRONYMS

BOBS	Botswana Bureau of Standards
DWA	Department of Water Affairs
DWQR	Drinking Water Quality Regulator
EPA	Environmental Protection Agency
GDWQ	Guidelines for drinking-water quality
G-WTP	Gaborone Water Treatment Plant
LRV	Log Removal Value
M-WTP	Mmamashia Water Treatment Plant
RW	Raw Water
SDG	Sustainable Development Goals
SDWF	Safe Drinking Water Foundation
SPSS	Statistical Package for Social Sciences
TC	Total Coliform
TW	Treated Water
WHO	World Health Organization
WUC	Water Utilities Corporation
WQI	Water Quality Index
WTPs	Water Treatment Plants

CHAPTER 1 INTRODUCTION

1.1 Background

Globally, the quality of water has declined especially for surface water due to increased population, industrialization let alone urbanization (Walakira & Okot-okumu, 2011; Owa, 2013). The influence of water quality in public health and aquatic life due to the toxicity, persistence, and bio-accumulative nature of some trace elements, microbial compounds raises a great need to good water quality (Dong, *et al.*, 2017). Surface waters are the most polluted resources due to that discharges from industrial as well as municipal treatment facilities flow into the river especially in urban areas of developing countries. (Suthar, *et al.*, 2010). Then again, anthropogenic activities have led to a decline or deterioration of the water quality in many countries (Tessema, *et al.*, 2014).

Water supply intended for domestic use and consumption in urban area particularly those in the semi-arid environments is a challenge for governments involved consequently leading to a serious worldwide concern (Albiero, et al., 2018). According to WHO (2017) up to 80% of all sickness in the world are instigated by inadequate sanitation, polluted water or unavailability of safe water. The World Health Organization also stated that each year over 3.4 million people perish due to water related diseases, making it the foremost cause of disease and death around the world. Most of the victims are young children, the huge majority of whom die of illnesses caused by organisms that grow well in water sources contaminated by raw sewage.

The provision of clean water improves public health by preventing water-borne diseases, thus saving financial and natural capital resources (Shabbir, *et al.*, 2016). Therefore, availability and quality of water are both very vital. Water, water provision, and water management have a direct connection (Fonjong & Fokum, 2017).

In order for people residing in both urban let alone rural settlements to lead healthier life, there is need for water to meet the residents' needs not only by its quantity but quality standard as well. However, a large number of people still do not have access to clean water. This poses a threat to their health consequently leading to death hence around 75% of three million early deaths are due to water bourne (Ali, *et al.,* 2012) and prominent in developing countries. This then leads to ensure that public health is improved or maintained through water treatment thus being of paramount importance to policy makers. (Hong & Thi, 2017)

Ibrahim *et al.,* (2014) stated that water quality treated by water purification systems and the performance assessment of its unit operations and processes is very crucial for public health safety hence requires regular monitoring. Ensuring that consumers receive water that is free of waterborne pathogens is the main purpose of water treatment then again multiple barriers are desirable because one treatment process will not be able to remove all the different types of pathogens that may be found in water. This will ensure additional safety in a case where a single treatment system is not working optimally. The quality of the source water influences the number of treatment processes.

The performance evaluation of a WTP is “a process to measure the functioning efficiencies based on some established performance indicators such as a degree of removal of pollutants such as turbidity, color and suspended impurities” (Omar & Aziz, 2020). Treatment of water is regarded as an important facility to protect the public health and environment by eliminating waterborne diseases and pathogens. Therefore, this research was focusing on the performance evaluation of Gaborone and Mmamashia WTPs, taking turbidity as the main indicator.

1.2 Problem Statements

Treatment of public water supply is a service of paramount importance in both developed and developing countries in providing safe drinking water and minimizing the occurrence of waterborne diseases (Tadesse *et al.*, 2017). It is vital that public water supply and quality control management is monitored to ensure consumers’ safety. Although there is an alarming rate of water pollution and huge disease burden associated with unsafe water supply, very little effort has been done to investigate the performance of existing water treatment systems in developing and some developed countries. Gaborone, Botswana is no exception since the efficiency of treatment plants is not known.

Drinking water safety is one of the concerns faced globally. Contaminated drinking water has the great impact on human health especially in developing countries**.** Botswana has been experiencing an outbreak of diarrhea mainly affecting children below five years of age since the beginning of September 2018 (WHO, 2018) hence the need to closely monitor the quality of water, which is usually the main cause of diarrhoea diseases.

Due to some daily problems in operation and maintenance of the WTPs, there is need for research to focus on detailing performance assessment system for treatment plants. Safe and potable water is of paramount importance in promoting good health and well being of people. Then again there is a realisation that most of the conventional WTP in urban area are unable to consistently provide safe drinking water due to rapidly growing population and industrialization (Mota, *et al.*, 2013) hence it is necessary to evaluate performance of WTPs.

Therefore, this research is envisaged with the aim to assist in addressing this, consequently acting as a baseline research for the performance evaluation for the WTPs in Botswana.

1.3 Objectives

1.3.1 General Objective

To evaluate the performance of Gaborone and Mmamashia water treatment plants with regard to their ability to produce quality water and control pathogens.

1.3.2 Specific Objective

1. To assess and compare measured values of pH, Total Coliform, *E-coli*, turbidity and conductivity, of treated water with the World Health Organization and Botswana Bureau of Standards guidelines for drinking water consequently determining the water quality using Water Quality Index
2. To determine the Log Removal Value of water treatment system in removing water quality contaminants
3. To determine the removal efficiency of turbidity

1.3.3 Research Questions

1. Is the water quality after treatment suitable for public consumption?
2. To what measure/degree is the treatment process of the water treatment plants able to remove water quality contaminates?
3. How are the water treatment plants performing in terms of removal efficiency of turbidity?

1.4 Significance of the study

In most developing countries the efficiency of WTPs is unknown, Botswana is no exception thus drawing the inspiration to conduct the study. For this reason, this study will; act as baseline for future research reference regarding Botswana, it will also, contribute in giving a report of the quality of potable water in the urban area of Botswana as well as the performance of water treatment systems in removing water quality contaminants. Hence, providing a clear assessment of the WTPs consequently giving policy makers an idea on what has worked and what has not worked and ultimately what needs to be done to improve the performance of the treatment plants. Then again, it will also give an understanding of the status of drinking water quality and associated health risks which is the basic to making wise decisions on drinking water quality protection and management (Li & Wu, 2019).

1.5 Scope of the study

The study was focused on G-WTP and M-WTP regarding their performance, efficiency as well as their water quality after treatment. Among the areas studied include:

- Efficiency of water treatment systems in removing water quality contaminates taking turbidity as a performance indicator.
- Compliance of water quality to WHO guidelines and Bureau of Standards of Botswana

This study only considered pH, Total Coliform, *E-coli*, turbidity and conductivity water quality parameters.

1.6 Limitations

Due to resource constraint, the study did not consider all and/most water quality parameters, it was done in a single season then again evaluation of the design capability of major treatment unit processes was also not done as well as assessment of proper and optimum chemical dosage needed for optimal coagulation. The outbreak of the pandemic, Corona Virus Disease 2019, also disrupted the study.

CHAPTER 2 LITERATURE REVIEW

2.1 Water Quality and Public Health

One of the ultimate factors affecting human health is drinking water quality. In several countries, especially developing countries, drinking water quality is not desirable thus has induced many waterborne diseases (Li & Wu, 2019). The quality of water is described by four categories being biological parameters, where microbiological agents are considered very important in their relation to public health and can as well be significant in modifying the physical and chemical characteristics of water. Physical parameters (eg. turbidity, temperature), chemical parameters where is chemical characteristics of waters are at times evidenced by their observed reactions, such as the comparative performance of hard and soft waters in laundering. Lastly, radiological parameter where radiological factors are considered in areas where there is a possibility that the water may have come in contact with radioactive substances (Davis, 2010).

Access to safe drinking water is a basic human right, regardless of nationality, religion, color let alone wealth. Cholera and diarrhea are some of the diseases which are linked to contaminated drinking water and poor sanitation (WHO, 2019). According to Li & Qian (2018), reducing waterborne diseases and development of safe water resources has been set as a major public health goal by several developing countries leading to a slight improvement. Nonetheless, the situation is far from perfect, due to an increased to population growth and economic development consequently leading to an increase in water demand let alone reduction of water availability.

Joshi, *et al* (2018) stated that drinking water quality was one of the major determinants on enteroviral diseases after assessing the association of drinking water quality with the incidence of enterovirus diseases among children in seven metropolitan provinces of Korea. The quality of source water as well as the treatment in WTPs before distribution are some of the factors that affect drinking water quality. The promotion of health and well-being of the people is accompanied by a continuous supply of safe and potable drinking water (Khan & Ahmad, 2018)

2.2 Drinking Water Quality Parameters

According to WHO (2018) The following are some of the parameters affecting drinking water acceptability and their standard or limit; Conductivity, pH, Taste and odour and Turbidity.

2.2.1 pH

pH describes the measure of hydrogen ions concentration and has a scale of 0 – 14, where 0 - 6 is considered to be acidic state, 7 – neutral, 8- 14 is considered alkaline. Dissolved substances do affect pH as they can cause it to either be more acidic or alkaline. In most cases surface water has high pH values especially in low discharge water as a results of solutes. pH can also indicate optimal performance of major unit process (Talling, 2010; Stone et al., 2013).

2.2.2 Conductivity

According to Johnson & Scherer (2019), conductivity refers to the ability to transmit electrons or flow of electrons and it is closely associated with or to total dissolved solids. It can also give an indication of dissolved solids in the water. Conductivity is as well associated with salt content and it is determined by how much of the dissolved solids are in the water (Anhwange, *et al.,*2012). Despite the fact that conductivity cannot give specific information regarding chemicals in the water, it can indicate when there are some water quality issues regarding poor taste let alone consumer dissatisfaction (Hussain, et al., 2016).

2.2.3 Total coliform and Escherichia coli (*E-coli*)

Total coliform and *E-coli* are some of the indicators of drinking water quality. Total coliform incorporates a wide range of bacteria. For this reason, if a sample of water is found to have total coliform then it will be tested for faecal coliform as well as *E-coli*. The bacteria are found mostly in human excreta, sewerage, natural water as well as treated effluents including drinking water (Osman, *et al.,* 2017). According to WHO (2017), they should not be detected in drinking water.

2.2.4 Turbidity

The measure of the degree at which the water loses its clearness or transparency accounting to the presence of total suspended solids defines turbidity (Matta, 2014). When there are high total suspended solids, water will be murkier indicating a higher turbidity. Turbidity can be used to show if there are any issues with the treatment process. Then again, it can as well be used to find out what level of treatment is needed and which kind or type. High turbidity at 4 NTU (nephelometric turbidity unit) and above can be seen by consumers and may be unacceptable at the tap. For disinfection to be effective turbidity has to be as low as possible (Hussain, et al., 2016; WHO, 2018).

2.3 Conventional Water (potable) Treatment Plant Processes

Conventional treatment consists of the following unit processes: coagulation, flocculation, clarification, and filtration, and it is followed by disinfection at full-scale (Khan *et al.,* 2018).

2.3.1 Coagulation/ flocculation

In this stage a coagulant such as aluminium is added in the raw water in order to neutralize the colloidal charges. This will then make particles to attract each other thus forming a floc. To make sure that the coagulant is thoroughly mixed in the water there is need for rapid mixing and mechanical mixers let alone in-line blenders can be used to facilitate this process. This process takes place quickly hence poor mixing will mostly lead to flocs which are poor. As for the flocculation, here smaller particles are formed then agglomerate into bigger ones which are able to settle. There should be gentle mixing as this will give way for maximum particle contact for floc to be formed on the other hand if turbulence is reduced this might lead to flocs being destroyed or damaged (Ministry of Health, 2017).

According to DWQR (2016) these processes are used to facilitate colour and turbidity removal as well as microorganisms. The advantage part regarding these processes is that it effectively removes many bacteria and viruses. Coagulation/flocculation is good in the sense that it reduced the time they would have probably been taken for suspended solids to settle then again it effectively removes fine particles which are really not easy to remove. If the processes are used for treatment regarding small supplies, then a challenge will be faced with respect to the need to have accurate dosing as well as frequent monitoring. Challenges concerning costs will also be faced in such a situation.

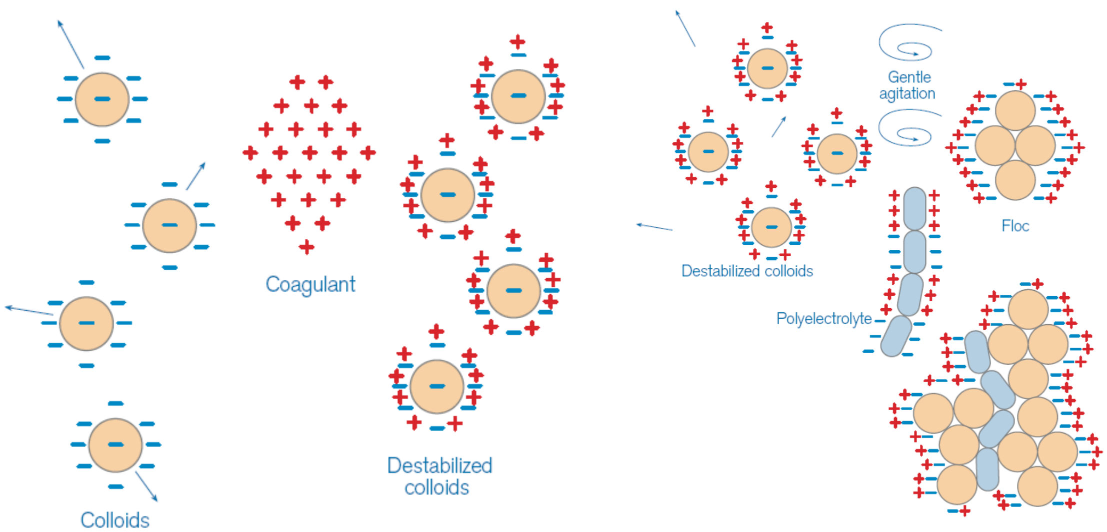


Figure 1: illustration of how the coagulation processes takes place (DWQR, 2016)

2.3.2 Sedimentation

Sedimentation involves the process whereby particles in turbid water settle at the bottom of the basin containing that water. Usually the water is left over a period of time to actually allow for the particles to settle. Rectangular horizontal basins are the commonly used basins for sedimentation process even though they do take up a lot of space. Then again there is also a need to speed up settling, so tube settlers can be used to ensure this or water being allowed to flow through a buoyant media (Howe, *et al.*, 2012).

Usually Sedimentation is considered prior to filtration and disinfection. Unwanted suspended particles or particulate matters such as clay and sand let alone biological contaminates with the influence of gravity are removed through this process. The advantage of sedimentation is that it helps in improving the virtual qualities of water thus making it easy for consumers to accept it (Mehran & Mohammad, 2018).

2.3.3 Filtration

SDWF (2017) stated that filtration gets rid of particulate matter by means of a porous media which the water passes through. The system in most cases is made up of gravel, sand let alone charcoal and as well, consists of filters which differ in sizes with respect to pores. Sand filtration can either be slow sand filtration which involves the use of bacteria for treating water or rapid sand filtration which involves the removal of suspended solids from water. The use of bacteria in slow sand filtration is to digest the contaminant present in the water as it passes through the biofilm. There is also a need to clean the biofilm when the flow of water through it has decrease and be given time to rebuild before the next filtration. With rapid sand filtration (figure 4), the flow rate is high and it operates in a much small space. Then again cleaning of the filters have to be done at most two times a day with the aid of backwashing filters do not require some time before the next filtration (SDWF, 2017).

2.3.4 Disinfection

The primary role of this process is to reduce the presence of microorganisms in the water. Various chemical let alone physical agents can be used to disinfect the water. There are many disinfection methods which can be used, however, chlorine being used for disinfection is a commonly used method especially when a large supply of water is involved while ultraviolet irradiation is used when private supply is involved (Haas, 2011)**.**

2.3.5 Why Treat Water

Water treatment is of paramount importance as it removes any pollutants present in the water hence making it suitable for drinking. Purification is through the of removal pathogenic organisms, taste, smell, unpalatable brownish discharge as well as excess dissolved metals (Mohammed, *et al.*, 2012)

According to the sources found in Selman, *et al.*, (2015) the earliest knowledge regarding water quality and treatment was in Sanskrit literature which was compiled around 2000 BC. The document gives details that the treatment involved drinking water being stored in copper vessels, it being exposed to the sun let alone filtering it by means of sand and charcoal. In the summer of 1849, cholera hit London leading to death close to fifteen thousand and Dr John snow came up with the relation between water quality and disease incidence.

Water treatment is necessary in order to remove pathogens, bacteria as well as viruses making it ideal for consumption. This involves processes such as sedimentation, filtration and disinfection. This will then lead to water being protected against impurities and this can be facilitated by operating the disinfection process properly. One method which is mostly used for monitoring the removal of particles from surface water and can as be used as a performance indicator (Sadhwani & Bhave, 2016).

2.4 Water Quality index

Water Quality Index (WQI) is considered as the most effective method of measuring water quality. A number of water quality parameters are included in a mathematical equation to rate water quality, determining the suitability of water for drinking (Ochuko, *et al.*, 2014).

There are a number of WQIs which include;

2.4.1 Oregon WQI

When needs arises to assess the quality of water for recreational purposes this index is used. The good part of using this index is that it is simple and that the parameters needed for the index are readily available. The index is very sensitive to high temperatures. Even though it is sensitive to variations of the parameters, at sometimes it can present ambiguity (Garcia, *et al.*, 2018).

2.4.2 Wilcox indicator WQI

The index is used to classify water meant for agricultural purpose. Only elecrical conductivity and sodium adsorption ratio are used and there is a total of 16 groups after dividing each parameter in to four (Darvishi, *et al.*, 2016).

2.4.3 National Sanitation Foundation WQI

The index was based on the Delphi approach, using a panel of 142 personel. Its advantage is that changes in water quality can be identified by means of different areas being evaluated. Another good part of the index is that index values relate to potential water use. However the index's short coming may include loss of data during handling let alone its representation of general water quality compared to a specified representation of the use of water (Phadatare & Gawande, 2016).

2.4.4 Canadian WQI

The model adopted the "conceptual model of the British Colombia Water Quality Index which is based on relative sub- indices" (Kizar, 2018). Scope, frequency and amplitude are measures of variability aopted on the model. It is also considered to be of great assistance regarding the evaluation of the quality of lakes (Kafrawy, *et al.*, 2017).

2.4.5 The weighted arithmetic WQI

According to Kizar (2018) this index method is mostly adopted when calculating the index for treated water. The good part about using the index is that different water quality parameters can be used along with their comosition hence playing a hand in assing the quality of water. It also gives certainity regarding the suitability of water for human consumption. However, the value obtained from the index may not represent the actual quality of water. Then again if one parameter is bad then the overrall outcome of feedback from the index is affected (Phadatare & Gawande, 2016).

2.5 Performance Evaluation of WTPs

Studies relating to evaluation of the performance of WTPs are of paramount importance as they give way for the physical, chemical and bacteriological aspects of water quality to be assessed in order to find out the efficiency of the WTPs let alone the quality of water supplied to consumers (Baroniya, *et al.*, 2012).

Performance assessment of WTPs can be implemeted through;

2.5.1 Comprehensive Performance Evaluation (CPE) Technique

This involves design, administrative let alone operation of a water treatment plant assessment in order to analysis the impact regarding overall WTP performance. The components involved in order to come up with the evaluation include; using low, average and peak demand, evaluation of major unit processes, identification of performance limiting factors, preparation of a CPE report and assessment of the applicability of CPE recommendations (O'Brien, 2018).

2.5.2 Performance Indicators (PI)

This is where by the effectiveness and efficiency of a specified aspect of a system (utility) is measured quantitatively. The PI is structured in such a way that it can be applicable to wide range of WTPs irrespective of the primary objective of that particular treatment plant. Performance indicator framework of a WTP consists of, treated water quality, plant reliability, use of national resources and raw materials, by-products management, safety, human resources and as well economical and financial resources. The advantage of using the PI to determine the performance of a WTP is that it gives room to incorporate management, technical part of the WTP, treatment process as well as the components of a water supply system (Vieira, et al., 2008). Performance indicators can also be turbidity, color, suspended impurities of which their degree of removal will determine the performance of a WTP (Omar & Aziz, 2020).

2.6 Related/ Similar Studies

Akter, *et al.,* (2016) carried a study based on Water Quality Index for measuring drinking water quality in rural Bangladesh using the weighted arithmetic WQI. Their study showed that from the total sampling sites, 33 % had good-quality water for drinking while 67 % drinking water quality was not good based on the WQI.

Recent study by Issa (2017) involved the removal potency between the turbidity of the raw water and treated water turbidities within the treatment plant, at alluviation and filtration stages. The study showed that the raw water supplied to the WTP was moderately of poor quality, whereas the treated water was comparatively satisfactory. The study also showed an overall removal potency of water turbidity within the WTP to be 97.88%.

Tadesse, *et al* (2017) conducted a study based on assessing drinking water quality and treatment plant efficiency in Southwest Ethiopia. Their results from the study indicated that the physicochemical quality of all water sources in the area of study was in compliance with the WHO recommended limits and in both water sources. Their study as well showed that the treatment plants were suitable to supply safe water to consumers.

Ibrahim, *et al.,* (2014) conducted a study where the overall average LRV and percentage efficiency of the treatment plant were found to be 0.56 and 64% respectively within the period of study. Treated water quality was found to be in line with the WHO Guideline Values for safe drinking. The study concluded that the WTP was appropriate to deliver safe water to the public within the period under study.

According to Hassan & Mahmood their study relating to two drinking water treatment plants in Baghdad City, Iraq was carried out from December 2016 to July 2017 with respect to the WTPs efficiencies. Their study showed a variation in drinking water quality parameter values for both treatment plants. Furthermore, their study showed that there was presence of a number of bacteria greater than permissible limit.

Omar & Aziz (2019) carried out a study where he determined the removal efficiecy of turbidity using the following equation;

Equation 1: Removal efficiency = $(C_o - C_f)/Co * 100$

Where: -

C_o = Turbidity of the water sample before treatment, NTU.

C_f = Turbidity of the water sample after treatment, NTU.

Their study showed that, the overall removal efficiency of the WTP was 97.29 %. Their results as well indicated that the water quality was good according to the computed WQI of 51.87.

Khan & Ahmad (2018) conducted a study regarding performance evaluation of WTP at Nangloi, Delhi which showed that at all times the turbidity in treated water remains within the desirable limit.

Madhu & Soumyashree (2016) also carried out a similar study on WTP at Davangere, Karnataka where raw water was observed to be less turbid in summer. In another study done by Mahinge & Khedikar (2016) on WTP in India, the results showed that turbidity in mansoon period was generally high compared to the other part of the year.

It is to be noted that in all the similar and/ or related studies, no research work was identified from any treatement plant in Botswana regarding their performance evaluation. Therefore, this research acts as a baseline for future research reference regarding the performance of water treatment plants in Botswana.

CHAPTER 3 MATERIALS AND METHODS

3.1 Description of the study area

Botswana is a land-locked country located in southern Africa, with South Africa to the east and south, Namibia to the west and north, Zambia to the north and Zimbabwe to the north-east. Gaborone is the capital city of Botswana, located in the south-eastern part of the country, on latitude of -24.65 and longitude of 25.91 (Odirile, *et tal.*, 2018; World Atlas, 2015). Issues relating to water are what the country is currently focusing on because of the water challenges that it is facing with respect to water. Non point and point sources which include solid waste disposal, agricultural runoff led to the quality of surface water to deteriorate. Pit latrines, solid waste, industrial agricultural activities as well as domestic waste pose as a threat to Botswana's water resources which may lead to their decline in quality (DWA, 2013).

Figure 2: Shows the location of Botswana (Google Maps)

G-WTP and M-WTP

Water Utilities Corporation (WUC), is a parastatal organization wholly owned by the Botswana Government and it is responsible for water supply and wastewater (Vielra, *et al.*, 2008). According to

WUC (2019), conventional treatment method is used in both WTPs. In coagulation/ flocculation stage aluminum chloride is added. Chlorine or chlorine dioxide is used in the disinfection.

G-WTP lies within 24.6923187 South and 25.9137593 North.

Figure 3: shows G-WTP

The sources for G-WTP are Gaborone dam with a flow of 57.6 mega litres per day and Molatedi dam, with an inflow of 14 mega litres per day maximum. Gaborone Dam is fed by Notwane and Segoditshane rivers. A study carried out by (Gaboutloeloe, *et al.*, 2018) indicated that Notwane river is polluted by runoff inflow of organics form land use let alone nearby settlements, where waste from domestic use concerning these settlements is dumped near the river. The water in Segoditshane river was found to be polluted having high concentrations of cadmium and aluminium let alone pollution from hydrocarbons. There was no detection of *E-coli* from the microbiology results however there was an indication of enteric and potentially pathogenic bacteria thus sewage contamination in the river might be the case (Andersson & Johansson, 2015).

Figure 4: shows M-WTP

Water sources for M-WTP include, Bokaa dam and North South Carrier from Dikgatlhong dam with an inflow of 1100 litres per second (WUC, 2019).

Dikgatlhong Dam is situated in the north east part of Botswana within Limpopo river basin. There are anthropogenic activities taking place near the dam which poses threat of it being polluted. These activities include, urbanization and agriculture. After conducting a research pertaining to the dam's water quality, it was found out that the water was contaminated with high levels of turbidity and total dissolved solids which were above the permissible limit (Mosimanegape, 2016).

3.2 Research Design and Period

The study was an observational, cross-sectional one because the water parameters which were studied/ analyzed in the water samples were not manipulated in anyway. It was conducted from Mid-February 2020 until June 2020. It involved quantitative data. Data was collected through interviews and observation. Standard laboratory tests were carried out and secondary data for the year 2019 was obtained.

3.3 Data collection

3.3.1 Primary Data Collection

3.3.1.1 Sampling Size and Procedure

Water samples were collected three times a day, from designated points in raw water entering the first treatment stage and the one leaving the last stage. The collection of samples was done four times a week for five weeks, making a total of 120 samples for each WTP. The samples were collected at, 8am, 10am and 12 noon and sampling was done in accordance to the standard methods and procedures according to Basu (2017) and EPA (2016).

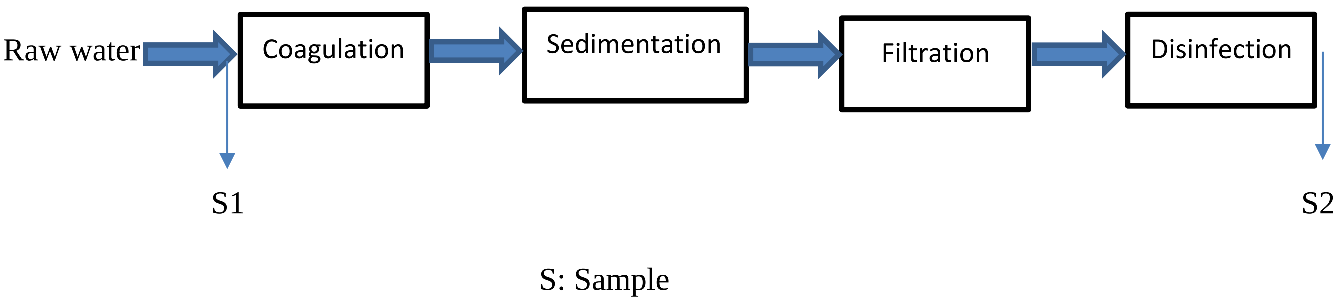


Figure 5: Schematic diagram of a conventional treatment plant showing location of the samples

Labeled plastic bottles were used for collected water samples at designated points and they were cleaned thoroughly let alone rinsed with distilled water before use. The outlet tap at each point of sampling was allowed to run for one-two minutes before collecting the representative samples.

3.3.2 Secondary Data

Secondary data regarding the WTPs data for the year 2019 Autumn season was also obtained from WUC records (Appendix II) in order to compare the variations if any regarding the performance of the WTPs during the specified season.

3.3.2 Laboratory analysis

After collecting the samples, they were transported and in some case carried to respective laboratories for analyses. The following parameters were analyzed; pH, Total Coliform, *E-coli*, turbidity and conductivity.

Figure 6: HQ40D Portable Multi Meter

Smart phone was used to capture the pictures. Figure 10 shows a Hach multi meter which was used to take pH and conductivity readings. Samples were poured in a beaker and the probes inserted then a stable reading was recorded from the device'screen. The advantage of this instrument is that it has precalibrated Hach intelliCAL smart probes that store testing parameters as well as calibration history. The meter has a way of recognising each probe hence the need to recalibrate can be omitted and this does minimise errors and setup time.

Figure 7: TL2350 Turbidimeter

The Hach turbidimeter (figure 11) was used to measure turbidity. It uses a touch screen user interface. The water sample was put in a transparent glass bottle which was then sealed and placed in the meter. Once the meter senses the sample stability it would give out the reading. If the sample was not stable it gave out a message stating that the sample was unstable hence the need to open the meter and position the sample again. Before placing the glass bottle containing the sample in the meter for a reading, there was a need to wipe the bottle of any fluids and finger prints on it to avoid wrong reading by the meter. It also records or locks in every measurement. Calibration was done when the instrument was used for the very first time and every three months or when it is needed, this follows what is on its manual.

As for *E-coli* and total coliform, an observation was done while the laboratory analyst was conducting the test analysis. Analysis was only done for treated water. Most of the water samples were not analyzed immediately so they were refrigerated at temperatures below 4˚C allowing for slow chemical reactions in the water. Membrane filtration method was used, where the water samples were filtered through a 0.45µm membrane filter. A 100ml of water was filtered. The membrane filter was placed on MLGA plate ensuring that there were no air-bubbles trapped. The plates were then incubated for 4hours at 30 degrees, then 37 degrees for 14 hours to allow the indicator bacteria to grow into colonies on the upper surface. After that, colonies recognized by color were counted, green would show presence of *E-coli*, yellow presence of total coliform. If nothing was detected the results were recorded as < 1.

3.3.3 Data Processing and Analysis

Water Quality Index was calculated following the following steps;

Equation 2: $Wi = \frac{wi}{\sum_{i=1}^{n} wi}$

Equation 3: $qi = \frac{Ci}{Si} \times 100$

Equation 4: $Si = wi.qi$

Equation 5: $WQI = \Sigma Si$

Relative weight (Wi), n is the number of parameters. Σwi is the sum of all the parameters, qi is the quality rating scale, wi is the weight of each parameter, Ci is the concentration of each chemical parameter in each water sample in mg/L, and Si is the World Health Organization standard for each parameter in Mg/L according to the guidelines.

Table 1: Water quality rating and index values

WQI Value	Water quality rating	Grading
0-25	Excellent	A
26-50	Good	B
51-75	Poor	C
76-100	Very poor	D
>100	Unsuitable	E

Source: (Tyagi, *et al.*, 2014)

The present trend to monitor the treatment plants is on the basis of Log Removal Efficiency of the parametric values of input and output of the treatment system (Kamhambete & Christian, 2011). The removal efficiency of turbidity was calculated using equation 1.

According to Water Research Australia (2014) a log removal value (LRV) is a measure of the ability of a treatment processes to remove pathogenic microorganisms. LRVs are determined by taking the logarithm of the ratio of pathogen concentration in the influent and effluent water of a treatment process (Equation 6).

Equation 6: LRV = $log_{10}\left[\frac{influent\ pathogen\ concentration}{effluent\ pathogen\ concentration}\right]$

3.4 Statistical Analysis

Data in appendix I was used to compute the weekly values for water quality parameters which were analyzed and Microsoft Excel 2016 was used to calculate the averages. Descriptive (average, mean) statistical analysis was done using data in appendix II, this data was put in SPSS 16.0 and the descriptive analysis was run. Data obtained from the descriptive analysis, displayed in appendix III, was used to assess the water compliance with WHO and BOBS standards. Independent T-test was also conducted for overall turbidity mean to compare with the permissible value. The relationship between the parameters within the treatment units were established using Pearson's correlation coefficient (r) and data used to run this on SPSS is displayed in appendix II. Data presentations and analyses were done by using Microsoft Excel 2016 and SPSS 16.0 statistical packages.

3.5 Data Quality Control

Bottles which were used to collect water samples were properly labelled. The bottles were cleaned thoroughly and rinsed with distilled water. When one measurement exceeded the limit, the analysis was repeated immediately. For samples which could not undergo analysis on the same day of sampling, they were refrigerated under 4ºC for not more than 24 hours. Absolute checking and data entry was done.

CHAPTER 4 RESULTS AND DISCUSSION

In this section the results from the water quality analysis and computations were presented separately. The water samples were obtained from raw water entering the treatment plants and after disinfection stage hence the results for both were presented. For WQI calculations and water compliance with WHO and BOBS only the results from disinfection stage were used. The presentation of the results in graphs and tables was followed by discussion based on the aim and research questions.

4.1 Water Quality of the WTPs

pH of WTPs

According to WHO (2011) it is imperative to monitor it pH as it is one of the parameters of paramount importance which gives an idea regarding the quality of water. Hence monitoring it will lead to identifying extreme pH values which might be an indicator for treatment breakdown let alone spills in or during the treatment process.

Table 2: Shows pH in raw and treated water of both treatment plants in the year 2019.

		G-WTP	M-WTP
week 1	raw	7.49	7.04
	final	7.93	7.06
week 2	raw	7.55	7.78
	final	7.99	8.14
week 3	raw	7.42	8.09
	final	7.57	9.02
week 4	raw	7.48	7.39
	final	7.35	7.25
week 5	raw	7.32	8.16
	final	7.38	7.9

In table 2, pH of raw water for G-WTP is seen to slightly decrease through the weeks compared the one registered for M-WTP which kept fluctuating. From the same figure, the pH for M-WTP is seen to have reached the highest value in week three where it was recorded to be 9.02 in treated water. This value indicated that the water was more alkaline compared to Raw Water which recoded a value of 7.57. The highest pH value for treated water regarding G-WTP was 7.99. The lowest values for G-WTP and M-WTP were 7.32 and 7.04 respectively. However, the pH for treated water with respect to both plants for all the weeks increased consequently leading to the overall average increase from 7.08 to 7.64 (table 3) for G-WTP and 7.70 to 7.90 (table 3) for M-WTP. The findings are similar to a research carried out by Bhosale, *et al.*, (2019).

Table 3: pH Average values in 2019

WTPs	pH	N	Minimum	Maximum	Mean/Average	Std. Deviation
M-WTP	Raw Water	5	7.04	8.16	7.692	0.47473
	Treated Water	5	7.06	9.02	7.874	0.7805
G-WTP	Raw Water	5	7.32	7.55	7.452	0.08701
	Treated Water	5	7.35	7.99	7.644	0.3013

Table 4: Shows pH fluctuation through the different treatment units during the study period (2020).

		M-WTP	G-WTP
week 1	raw	7.34	8.35
	final	7.27	8.78
week 2	raw	8.14	8.35
	final	8.14	8.54
week 3	raw	8.03	7.68
	final	7.87	7.57
week 4	raw	8.12	7.41
	final	6.98	8.74
week 5	raw	7.69	7.95
	final	7.89	8.41

The results shown in table 4 were used to calculate the mean values, it was also observed from the calculations that the overall pH increased from 7.41 to 8.41 (table 5) for G-WTP and decreased from 7.87 to 7.63 for M-WTP (table 5). Compared to the study carried out by Mota, *et al.*, (2013), the findings of this research are in agreement with their findings, in the sense that, after coagulation pH is lowered because of consumption of alkalinity. However, for G-WTP, pH is not lowered thus an indication of the coagulation process performance being poor. Then again in week three (table 4) regarding M-WTP, a value of 7.87 was recorded compared to the 9.02 which was recorded for the same week in 2019. G-WTP was the one which recorded the highest pH regarding treated water compared to M-WTP. However, M-

WTP showed a good performance regarding coagulation process due to an overall decrease in pH (Hussaina, *et al.*, 2011) compared to G-WTP.

Table 5: pH Average values in 2020

WTPs	pH	N	Minimum	Maximum	Mean/Average	Std. Deviation
M-WTP	Raw Water	5	7.34	8.14	7.864	0.34428
	Treated Water	5	6.98	8.14	7.63	0.4841
G-WTP	Raw Water	5	7.41	8.35	7.948	0.41367
	Treated Water	5	7.57	8.78	8.4085	0.49248

Turbidity of the WTPs

Good removal of turbidity leads to a more efficient disinfection hence after sedimentation and filtration, turbidity should be should be less than 30 NTU (Fontan-Sainz et al., 2012; Bitton (2014).

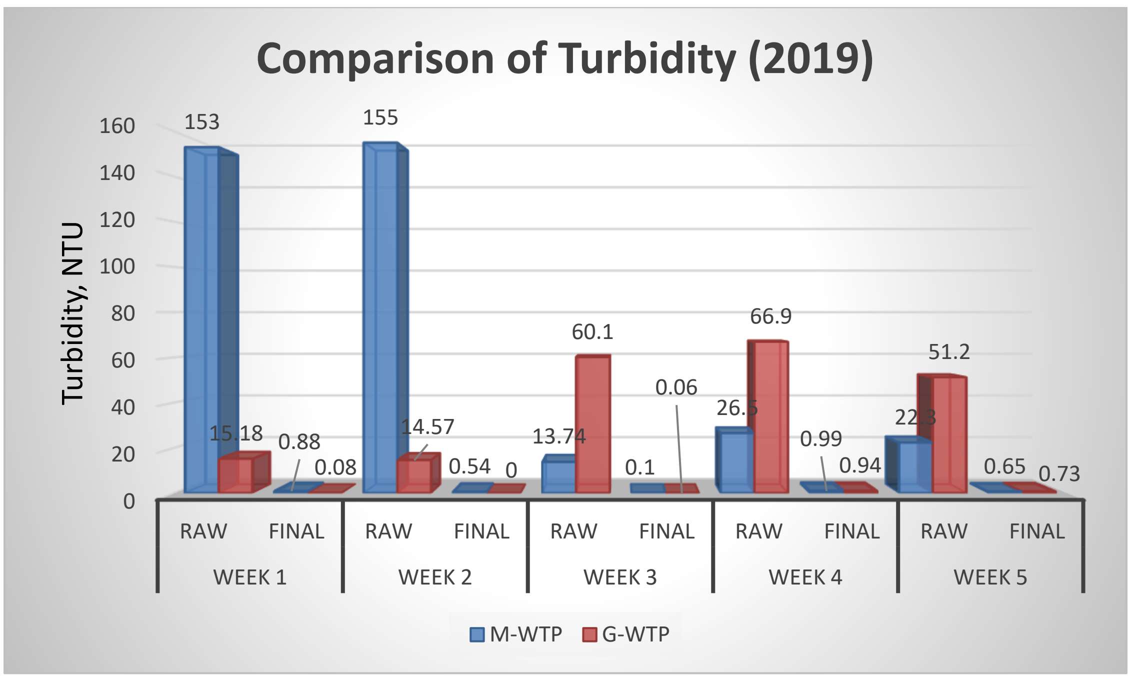
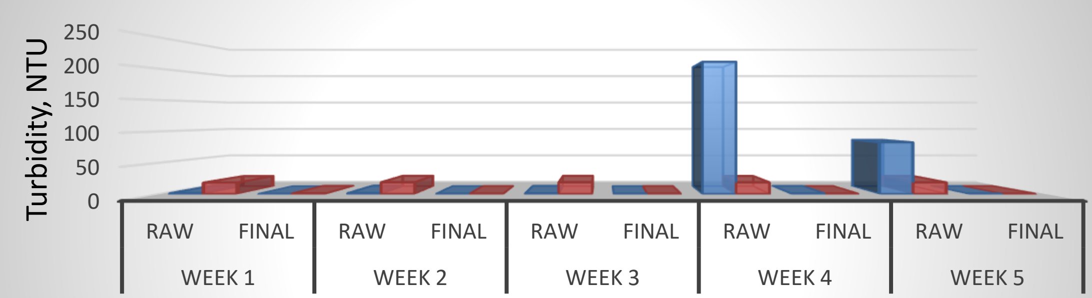


Figure 8:Shows turbidity variation through the weeks (2019)



	week 1		week 2		week 3		week 4		week 5	
	raw	final	raw	final	raw	final	raw	final	raw	final
M-WTP	1.48	0.19	1.31	0.36	0.85	0.37	211	0.76	82.5	0.47
G-WTP	18.28	0.9	18.83	0.43	18.83	0.44	18.6	0.59	18.63	0.59

Figure 9: Shows turbidity variation through the weeks (2020)

It is to be noted that turbidity of raw water during autumn season of 2019 was at pick in week four for G-WTP where a value of 66.90 NTU was recorded, this might have been due to that the raw water contained more clay and dissolved organic let alone inorganic matter (Jachimowski, 2018) and there was rainfall during week four which may have accounted for water flowing into the source river having carried with many impurities. Round about the same time in 2020 a value of 18.6 NTU was recorded as shown in figures 12 and 13. Comparatively on the same week, M-WTP recorded a value of 26.5 NTU raw water and 0.99 NTU treated water. Despite M-WTP recording a lower value for raw water, G-WTP proved to have reduced turbidity after treated more.

For M-WTP, the highest value was recorded in week two being 155 NTU as shown in figure 14 and treated water gave out a value of 0.54 in 2019 compared to G-WTP which recorded 14.57 NTU and 0 NTU in the same week. For the year 2020, there was a considerable notice with respect to very low turbidity values being recorded (raw and treated water) for both plants with an exception of M-WTP during week 4 where a value of 211 NTU was recorded. The lowest recorded values include, 0.85 NTU and 0.19 NTU for raw and treated water respectively with respect to M-WTP. A similar study was conducted by (Ahmed, *et al.*,2013; Braun, 2019), the findings indicated a decrease in turbidity. However, in both studies, turbidity of treated water did not reach below zero compared to the findings of this study.

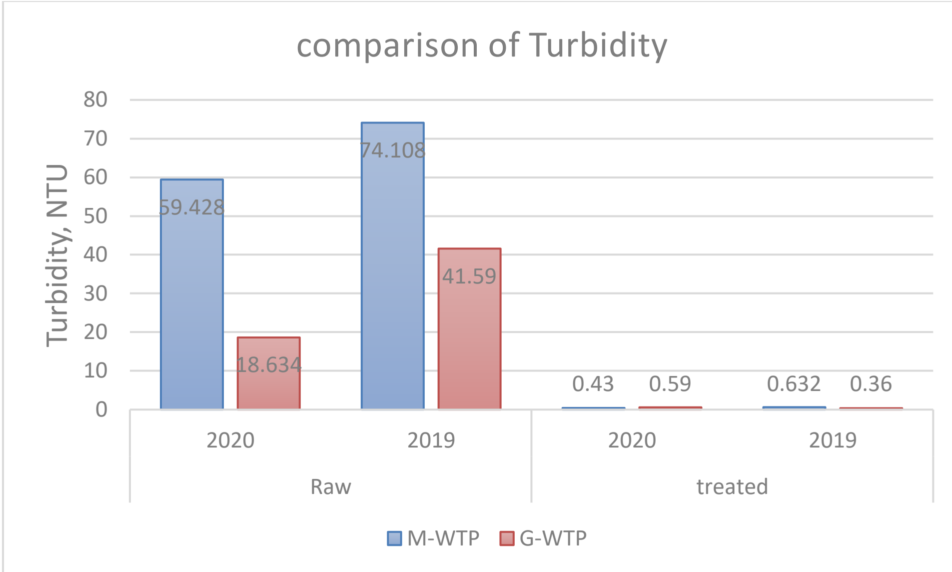


Figure 10: shows the overall turbidity for the plants

The overall turbidity for both plants were calculated. Figure 14 shows the average values for raw and treated water for both WTPs. Table 6 gives the minimum and maximum values together with standard deviation for the two years.

Table 6: Turbidity Average values in 2019 and 2020

	WTPs	Turbidity	N	Minimum	Maximum	Mean/Average	Std. Deviation
2019	M-WTP	Raw Water	5	13.74	155	74.108	73.07932
		Treated Water	5	0.1	0.99	0.632	0.34694
	G-WTP	Raw Water	5	0.85	211	59.428	91.75163
		Treated Water	5	0.19	0.76	0.43	0.21012
2020	M-WTP	Raw Water	5	14.57	66.9	41.59	25.01568
		Treated Water	5	0	0.94	0.362	0.43911
	G-WTP	Raw Water	5	18.28	18.83	18.634	0.22546
		Treated Water	5	0.43	0.9	0.5897	0.19047

Conductivity of the WTPs

Conductivity has to do with the measure of its ability to conduct electricity. It is also one way of monitoring the performance of water purification systems (Johnson & Scherer, 2019). From the two figures below, conductivity is seen to have increased in treated water as compared to raw water. The increment might be due to introduction of coagulants meant for removing turbidity. Hence, the more solids are dissolved in water the higher the conductivity. The highest recorded conductivity as shown in figure 15 was for M-WTP as compared to G-WTP. Indicating that at the time M-WTP had more inorganic compounds in treated water hence an indication of direct discharge or other source of pollution in the water (Nugusu, 2015).

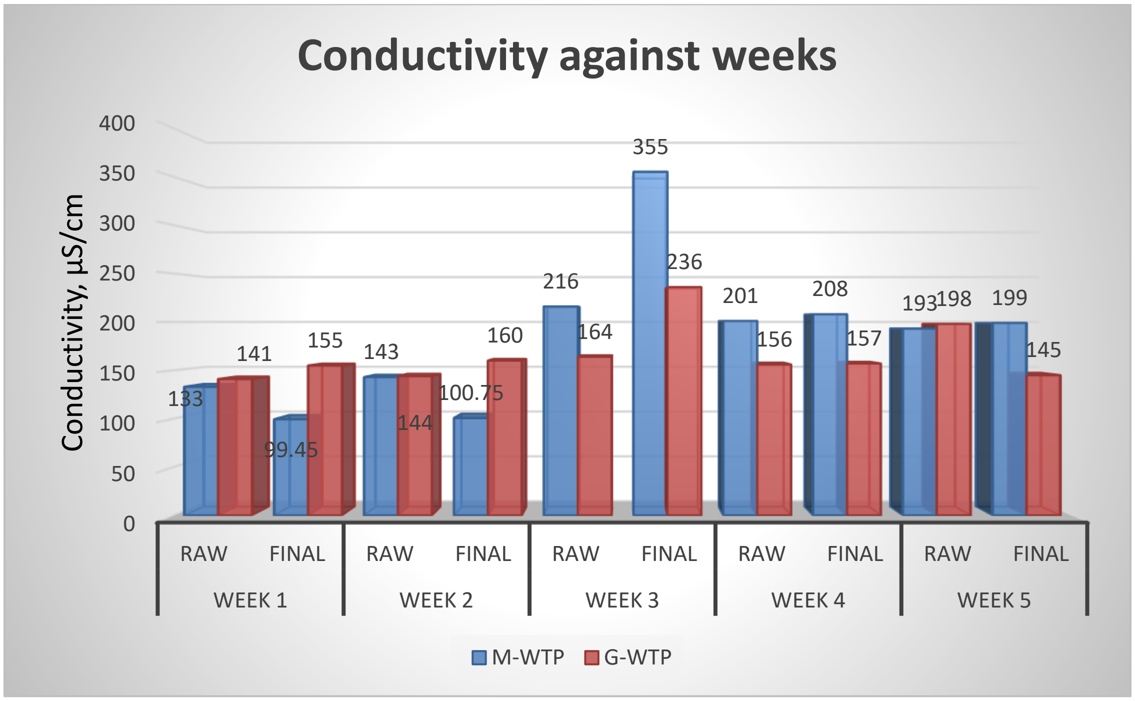
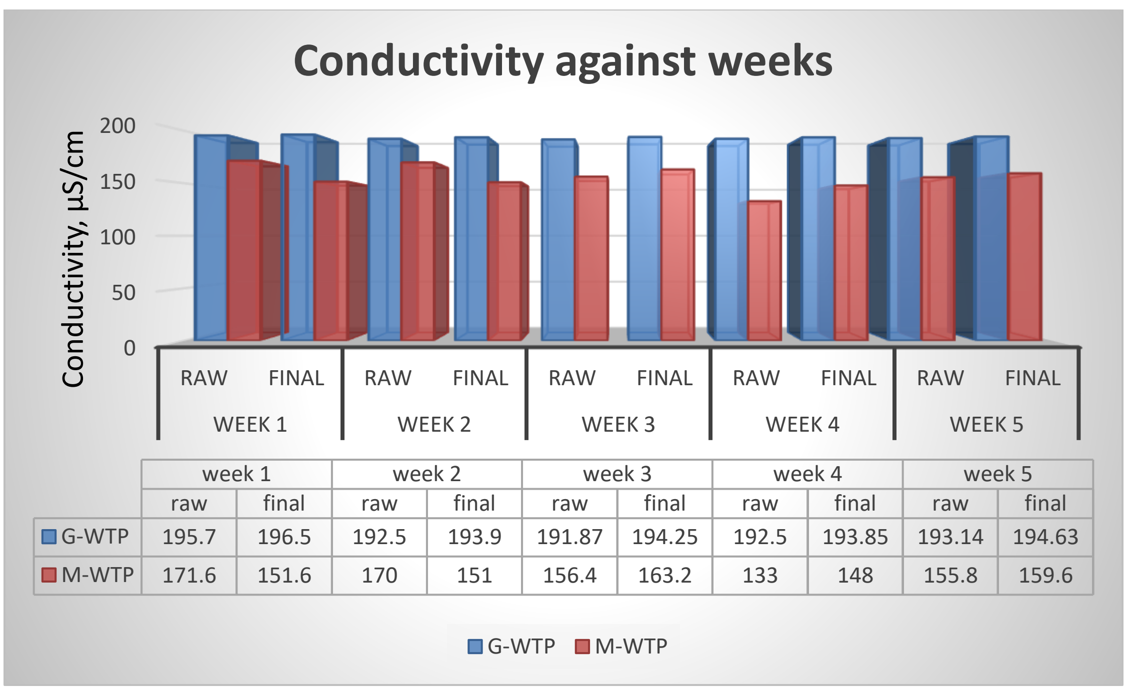


Figure 11: Shows conductivity of raw and treated water for both WTPs in 2019 (Autumn season)



	week 1		week 2		week 3		week 4		week 5	
	raw	final	raw	final	raw	final	raw	final	raw	final
G-WTP	195.7	196.5	192.5	193.9	191.87	194.25	192.5	193.85	193.14	194.63
M-WTP	171.6	151.6	170	151	156.4	163.2	133	148	155.8	159.6

Figure 12: Illustrates conductivity in different treatment units in 2020 (Autumn season)

In figure 16, both plants there seemed not to be much variation of conductivity in raw and treated water. G-WTP recorded the highest value being 196.5 µS/cm whereas M-WTP recorded its highest at 159.6 µS/cm with respect to treated water. Bârjoveanu, *et al.*, (2019) carried out a study evaluating the performance of a drinking water treatment plant in Iasi City by life cycle assessment and the values of conductivity were significantly higher than the ones recorded for this study.

Table 7: Conductivity Average values in 2019 and 2020

	WTPs	Conductivity	N	Minimum	Maximum	Mean/Average	Std. Deviation
2019	M-WTP	Raw Water	5	133	216	1.77E+02	36.89444
		Treated Water	5	99.45	355	1.92E+02	104.60055
	G-WTP	Raw Water	5	133	171.6	1.57E+02	15.48638
		Treated Water	5	148	163.2	1.55E+02	6.41186
2020	M-WTP	Raw Water	5	141	198	1.61E+02	22.86482
		Treated Water	5	145	236	1.71E+02	36.99054
	G-WTP	Raw Water	5	191.9	195.7	1.93E+02	1.49265
		Treated Water	5	193.9	196.5	1.95E+02	1.08074

Total coliform and *E-coli*

Total coliform bacteria are a big group of different type of bacteria. Total coliform can be harmful but most of them are harmless. They can be found naturally in the environment such as vegetation, soil, and also human and animal faeces. Their presence in water give a strong indication of faecal contamination (Kanangire, 2013). E - coli is a sub-group of faecal coliform bacteria which usually live in intestines of human and animal. Their detection also are simple, and the bacteria can survive longer than other bacteria in water (Jessoe, 2013).

The test results were denoted by using <1 which indicates that the microbiological parameters were not detected in the water. Low readings regarding TC and *E-coli* can be due to the success of the treatment process regarding application of chlorine Haydar, *et al.,* (2009). However, a related study was carried out by Zulfiqar, *et al.,* (2016) where the presence of both parameters were noted in drinking water thus indicating water contamination with human faeces. Then again the results are in agreement with a similar study regarding evaluation of conventional drinking water treatment plant efficiency which was done by (Al-Tmemy & Al-Azawi, 2018) who tested both raw and treated water for total coliform and *E-coli*. Influent water was found to range from 5 to 5000 CFU/100ml while the parameters were not detected in treated water.

4.2 Water Compliance standards/ limit

Drinking water has a set of standards set by WHO of which each parameter has its limit which must not be exceeded. Then again each country as well has its drinking standards which are mostly in line with the WHO standards. Therefore, if parameters exceed both limits the water will then be rendered not suitable for consumption (Selman, *et al*, 2015; WHO, 2018, WUC, 2020).

4.2.1 Water compliance for the year 2019

Table 8:Drinking water quality compliance with the WHO and BOBS for G-WTP & M-WTP

parameters	**Treated Water G-WTP**	**Treated Water M-WTP**	**WHO**	**BOBS**
pH	7.64	7.87	6.8-8	5.5-9.5
Turbidity, NTU	0.36	0.632	5.00	5.00
Conductivity µs/cm	158.38	192.44	1000	1500
Total coliforms, CFU/100ml	< 1	< 1	0	0
E. coli, CFU/100ml	< 1	< 1	0	0

4.2.2 Water Compliance for the year 2020

Table 9: Drinking water quality compliance with the WHO and BOBS for G-WTP

Parameter	**Treated Water G-WTP**	**Treated Water M-WTP**	**WHO**	**BOBS**
pH	8.41	7.63	6.8-8	5.5-9.5
Turbidity	0.59	0.43	5	5
Conductivity	194.63	154.68	1000	1500
E. coli, CFU/100ml	< 1	< 1	0	0
Total Coliform	< 1	<1	0	0

Table 8 and 9, indicate that both WTPs proved to be performing really well given that the overall measurements, that is the average, values of the parameters fall within both WHO and BOBS permissible limit. M-WTP however showed to be performing much better than G-WTP as it also recorded lower values in both years when it comes to the overall final turbidity, pH, conductivity of treated water exception given to 7.874 of pH recorded in 2019. This can be attributed to the fact that M-WTP is new project compared to G-WTP plus the quality of raw water each plant receives. With the final values falling within the permissible limit for WHO and BOBS, this therefore means that the water is safe for consumption (Ogutu & Otieno, 2003; Akoto, *et al.*, 2014).

It is to be noted as well that the overall value for pH and conductivity has increased for W-WTP in 2020 compared to the when the values were 7.24 and 158.38 respectively. Then again with M-WTP, the values did decrease. For conductivity the reason for decrease might be due to less dissolved solids found in the water. The overall values of conductivity are lower than the ones carried out in other studies (AbdAL-Hussein, 2015; Bârjoveanu, *et al.,* 2019) reason for this can be attributed to the fact that an increase in concentration of ions usually happens during cooler seasons. Turbidity as well has decreased for both treatment plants having recorded 0.59 NTU and 0.43 for G-WTP and M-WTP respectively.

4.3 Water Quality Index

According to Batabyal & Chakraborty (2015) the water quality parameters are turned into one number by the use of WQI. To calculate WQI values at each sampling point, the weight values were determined for each water quality parameter according to their relative importance (Şener, *et at.,* 2017) in the overall quality of water for drinking purposes (Table 10). The highest weight of 5 was assigned to parameters such as turbidity, total coliform and *E-coli*.

Table 10: WQI for G-WTP M-WTP (2019)

parameters	**Treated Water G-WTP**	**Treated Water M-WTP**	**WHO**	**wi**	**relative weight**
pH	7.64	7.87	8	3	0.14
Turbidity, NTU	0.362	0.63	5	5	0.23
Conductivity µs/cm	158.38	154.68	1000	4	0.18
Total Coliform	<1	<1	0	5	0.23
E-coli	<1	<1	0	5	0.23
				22	

The WHO standards and wi let alone the relative weight were the same for both plants since the same parameters were used for analysis. What made the difference was the overall value of the parameters analyzed, as shown in table 10.

The WQI was computed using equations 3-6 and, for G-WTP, it was found to be 9.5 falling under water quality rating of Excellent (Shabbir & Ahmad, 2015) comparatively that one of M-WTP was found to be 16.7 for the same year. Due to the lower value of WQI recorded for G-WTP, the plant seemed to be performing better in this year compared to M-WTP although they fall in the same water quality rating. This means that the water quality for the WTPs Autumn season 2019 was excellent for consumption. A possible reason may be that the water treatment plants efficiency was controlled throughout the season and it is inferred that the treatments units were functioning well at the time.

Table 11: WQI for G-WTP and M-WTP (2020)

Parameter	**Treated Water G-WTP**	**Treated Water M-WTP**	**WHO**	**wi**	**relative weight**
pH	8.41	7.63	8	3	0.14
Turbidity, NTU	0.59	0.43	5	5	0.23
Conductivity µs/cm	194.63	154.68	1000	4	0.18
E-coli	< 1	<1	0	5	0.23
Total Coliform	< 1	<1	0	5	0.23
				22	

The values displayed on table 11 were used to calculate WQI for both treatment plants. From the outcomes, G-WTP came out with the value of 25.5 regarding WQI comparatively M-WTP's results showed a WQI of 13.4. Both plants do fall under excellent with respect to water quality category. However, G-WTP water quality was 0.45 away from being categorized as good. This means the water quality of G-WTP somehow did not improve or the feeding water source was highly polluted compared to 2019 and probably the treatment process was not as good as the previous year round about the same time. In comparison, M-WTP's water quality improved from 16.7 to 13.4, which could mean that the treatment process is or was improving then again the feeding water source could be less polluted hence making the treatment process more efficient.

Previous studies have been carried out regarding the WQI and the water quality was classified as good. For instance, Mohammed Z. B (2015) carried a similar study in four water treatment plants using the Canadian water quality index and the water quality for all of them was found to be good.

4.4 Log Removal Value and Turbidity Removal Efficiency

Log removal value is the most common way of monitoring WTPs. The concentrations of water parameters entering and leaving the WTP(s) are recorded thereafter the log the ratio of the two is calculated (Kamhambete & Christian, 2011). Turbidity removal efficiency can give an idea of the performance of a WTP. The concentration of turbidity in raw and water leaving the WTP(s) are recorded then the difference between the two is divided by the value of its presence in raw water, the ratio is then multiplied by a 100 to give the percentage removal (Mahinge & Khedikar, 2016; Omar & Aziz, 2020).

Table 12: LRV for 2019 Autumn Season G-WTP

	LRV G-WTP		LRV M-WTP	
	Turbidity	Conductivity	Turbidity	Conductivity
week 1	2.28	-0.00177	2.24	0.126
week 2	n/a	-0.00315	2.46	0.152
week 3	3.00	-0.00535	2.14	-0.216
week 4	1.85	-0.00304	1.43	-0.0149
week 5	1.845	-0.00334	1.54	-0.0133

Table 12 shows the LRV for the two treatment plants for the specified parameters in the year 2019 during the five weeks of the Autumn season. It was calculated using equation 6. It is seen that in week two G-WTP had no value for the LRV because the effluent was 0 comparatively M-WTP on the same week had a LRV of 2.46. Negative values for the LRV for conductivity were recorded as indicated on table 6 due to that the effluent value was greater than the influent value.

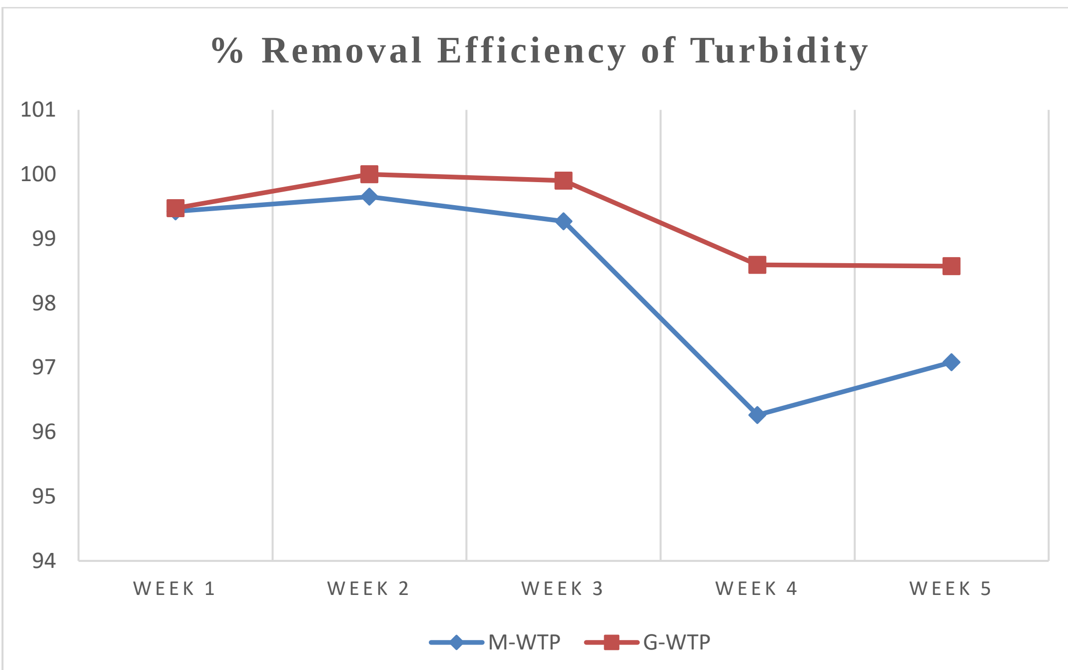


Figure 13: Percentage turbidity removal against weeks (2019)

Figure 17 illustrates the variation of percentage turbidity removal for the treatment plants. For G-WTP the highest percentage removal was recorded in week 2 whereas the lowest in week 5, with values of 100% and 99.57% respectively. The percentage removal during the weeks showed the effectiveness of the disinfection process. It is also inferred that in week three 99% (figure 17) of turbidity removal is equivalent to LRV of 3 (table 8) as stated on Water Research Australia (2014).

As for M-WTP, the highest percentage turbidity removal was recorded in week two with a value of 99.65% and the lowest was in week three with a value of 96.26%. The high percentage values let alone LRV indicates the efficiency of the treatment plants in removing the water contaminant. A similar study was carried out by Ibrahim, *et al.*, (2014) who found out the LRV for turbidity to be 0.52 and percentage removal being 69%.

Table 13: LRV for 2020 Autumn Season G-WTP and M-WTP

	LRV G-WTP		LRV M-WTP	
	Turbidity	Conductivity	Turbidity	Conductivity
week 1	1.31	-0.00177	0.892	0.0538
week 2	1.65	-0.00314	0.561	0.0515
week 3	1.6333	-0.0053615	0.361	-0.0185
week 4	1.4961	-0.00304	2.44	-0.0464
week 5	1.4997	-0.00332	2.24	-0.0105

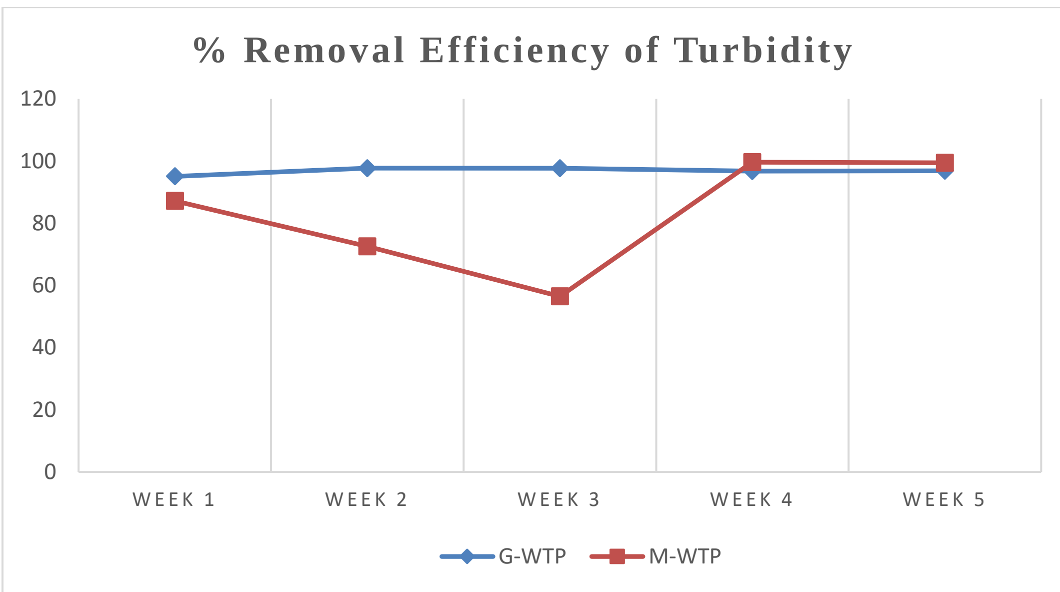


Figure 14: Percentage turbidity removal against weeks (2020)

The highest removal efficiencies recorded in figure 18 for G-WTP and M-WTP were 97.74% and 99.64% respectively (figure 18). The corresponding LRVs were 1.65 and 2.44 (table 12 and 13) respectively. A lower percentage was calculated for M-WTP in week three and this might be due to the fact that the turbidity of raw water was very low, recorded 0.85 NTU which is in line with a study conducted by Mirbagheri, *et al.*, (2017) who stated that a rise in influent turbidity gives a rise in its removal efficiency. The findings of this research are also in agreement with the study done by Mota, *et al.*, (2013) where they observed that inffluent (raw water) with high values of turbidity gave high percentage turbidity removal values whereas raw water with lower turbidity values gave a lower turbididity percentage removal. The reason for lower influent turbidity giving out lower removal efficiency may be attributed to that there will be less impurities which need to be removed compared to if turbidity was high in the influent water.

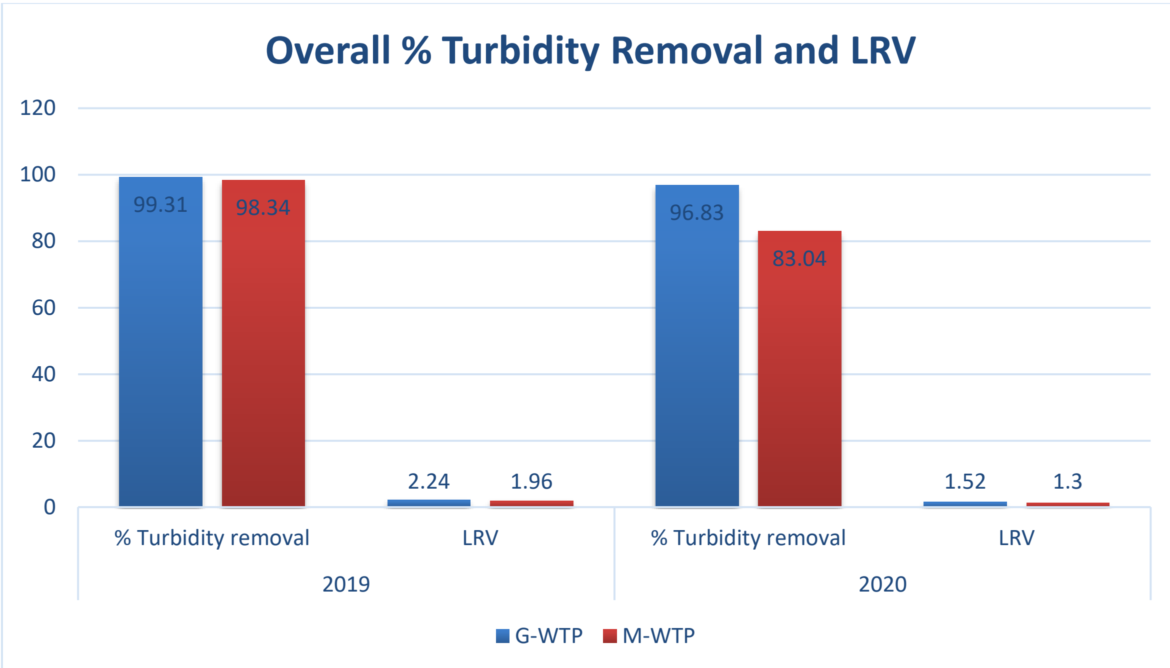


Figure 15: Overall % turbidity removal and LRV

From figure 19, it is clear that in the year 2019 G-WTP's efficiency was better than M-WTP as it recorded the overall % removal value of 99.31% and LRV of 2.24 compared to G-WTP, recording 98.34% and 1.96 accordingly. However, despite the fact that M-WTP recorded lower values of raw water turbidity compared to G-WTP in 2020, its overall percentage decreased to 83.04% and LRV to 1.3. Even though G-WTP still performed better than M-WTP, its overall removal percentage decreased to 96.83%. It was also noted that the values of raw water turbidity do affect the removal percentage as stated by Mota, *et al.*, (2013).

4.5 Statistical Results

To come up with correlation among the physicochemical parameters, Pearson's correlation was obtained as shown in the tables below.

Table 14: M-WTP correlation 2019

		RW pH	RW Turbidity	RW Conductivity	TW pH	TW Turbidity	TW Conductivity
RW pH	Pearson Correlation	1	-0.564	0.592	0.817	-0.73	0.582
	Sig. (2-tailed)		0.322	0.293	0.091	0.161	0.303
	N		5	5	5	5	5
RW Turbidity	Pearson Correlation		1	-.978**	-0.366	0.259	-0.839
	Sig. (2-tailed)			0.004	0.545	0.674	0.076
	N			5	5	5	5
RW Conductivity	Pearson Correlation			1	0.494	-0.384	.909*
	Sig. (2-tailed)				0.398	0.524	0.033
	N				5	5	5
TW pH	Pearson Correlation				1	-.978**	0.698
	Sig. (2-tailed)					0.004	0.19
	N					5	5
TW Turbidity	Pearson Correlation					1	-0.657
	Sig. (2-tailed)						0.228
	N						5
TW Conductivity	Pearson Correlation						1
	Sig. (2-tailed)						

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 15: G-WTP correlation 2019

		RW pH	RW Turbidity	RW Conductivity	TW pH	TW Turbidity	TW Conductivity
RW pH	Pearson Correlation	1	-.552	-.948*	.703	-.451	-.056
	Sig. (2-tailed)		.335	.014	.185	.446	.928
	N		5	5	5	5	5
RW Turbidity	Pearson Correlation		1	.556	-.937*	.678	.356
	Sig. (2-tailed)			.33	.019	.208	.556
	N			5	5	5	5
RW Conductivity	Pearson Correlation			1	-0.73	.538	-.056
	Sig. (2-tailed)				0.161	.349	.928
	N				5	5	5
TW pH	Pearson Correlation				1	-.852	-.05
	Sig. (2-tailed)					.067	.937
	N					5	5
TW Turbidity	Pearson Correlation					1	-.443
	Sig. (2-tailed)						.455
	N						5
TW Conductivity	Pearson Correlation						1
	Sig. (2-tailed)						

*. Correlation is significant at the 0.05 level (2-tailed).

Tables 14 and 15 displays correlations taking place between the parameters. For M-WTP, there was an increase in the pH of treated water corresponding to a decrease in turbidity of treated water (r = -0.978) suggesting that when an alkaline treatment that is coagulant is added in water, in this case aluminiun coagulant turbidity removal will be higher while the pH value increases (Zhang et al., 2012). It is seen in table 14 that conductivity in raw water correlating with the one in treated water. There was a fluctuation of an increase and decrease of conductivity in both treatment units hence the reason for the positive correlation might be that the same ions or dissolved solids were the same ones which were either released or reduced during treatment. Another correlation (negative) is observed between turbidity of raw water and conductivity of raw water. The reason for this might be due to that M-WTP received a high in flow from the source and the two contaminants are from the same source which have relatively lower turbidity but high dissolved solids suggesting that the source might be polluted with industrial waste. Comparatively, for G-WTP, correlation was observed between turbidity in raw water and pH in treated water (r = 0.937). There is also negative correlation between pH and conductivity of which this finding is not in line with the finding of Grande et al 2005 and Younger et al 2002 who found no correlation between the two. However, a study carried out by Grande, *et al.*, (2010) showed high negative correlation between pH and conductivity, where a decrease in pH led to an increased conductivity. Given that pH deals with the number of hydrogen ions and hydroxyl ions in a molecule and conductivity has to do with flow of electrons a partial conclusion can be made that the two (pH and conductivity) have no relation. However, conductivity does depend on the concentration and mobility of ions. Therefore, if water is more acidic, it means that there is higher mobility of hydrogen ions compared to the hydroxyl ions hence water which does not contain more hydroxyl ions would have a higher conductivity opposed to a strong base thus the reason for the negative correlation which is identified between the two parameters.

Table 16: M-WTP correlation 2020

		RW pH	RW Turbidity	RW Conductivity	TW pH	TW Turbidity	TW Conductivity
RW pH	Pearson Correlation	1	-0.262	0.586	0.306	0.309	0.525
	Sig. (2-tailed)		0.67	0.299	0.616	0.613	0.363
	N		5	5	5	5	5
RW Turbidity	Pearson Correlation		1	-.931*	-0.636	-.997**	-0.867
	Sig. (2-tailed)			0.022	0.249	0	0.057
	N			5	5	5	5
RW Conductivity	Pearson Correlation			1	0.578	.951*	.950*
	Sig. (2-tailed)				0.307	0.013	0.013
	N				5	5	5
TW pH	Pearson Correlation				1	0.592	0.3
	Sig. (2-tailed)					0.293	0.624
	N					5	5
TW Turbidity	Pearson Correlation					1	.904*
	Sig. (2-tailed)						0.035
	N						5
TW Conductivity	Pearson Correlation						1
	Sig. (2-tailed)						

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 17: G-WTP correlation 2020

		RW pH	RW Turbidity	RW Conductivity	TW pH	TW Turbidity	TW Conductivity
RW pH	Pearson Correlation	1	0.312	-0.473	0.236	0.601	-0.063
	Sig. (2-tailed)		0.61	0.421	0.702	0.283	0.92
	N		5	5	5	5	5
RW Turbidity	Pearson Correlation		1	-.921*	-0.649	.939*	-0.427
	Sig. (2-tailed)			0.027	0.236	0.018	0.473
	N			5	5	5	5
RW Conductivity	Pearson Correlation			1	0.551	-.949*	0.142
	Sig. (2-tailed)				0.336	0.014	0.82
	N				5	5	5
TW pH	Pearson Correlation				1	-0.412	0.556
	Sig. (2-tailed)					0.49	0.331
	N					5	5
TW Turbidity	Pearson Correlation					1	-0.282
	Sig. (2-tailed)						0.645
	N						5
TW Conductivity	Pearson Correlation						1
	Sig. (2-tailed)						

*. Correlation is significant at the 0.05 level (2-tailed).

Table 16 shows corrections with 0.05 and 0.01 significant amongst the water parameters. There was correlation between turbidity in treated water and conductivity then again, correlation was recorded between the two parameters in water (r = 0.931). A study conducted by Silva, *et al.,* (2007) indicated that a decomposed organic matter in higher concentrations leads to more ions being released in the water consequently an increase in conductivity. The findings are in a way similar to the findings of this research because in this study, negative correlation was found in raw water where turbidity was significantly lower corresponding with higher values of conductivity. There was correlation between treated water turbidity and reason might be due to lower values recorded in each treatment unit. Correlation was as well observed at a significant level of 0.05 between conductivity in raw and treated water. Comparatively, correlations with 0.05 significance were observed for G-WTP with respect to, turbidity and conductivity in raw (r = -0.921), turbidity in raw water and that one in treated water (r = 0.939) and conductivity in raw water and turbidity in treated water.

Table 18: T-Test for Turbidity 2019

One-Sample Test

	Test Value = 5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Turbidity: M-WTP 2019	-28.152	4	.000	-4.36800	-4.7988	-3.9372
Turbidity: G-WTP 2019	-23.618	4	.000	-4.63800	-5.1832	-4.0928

Table 19: T-Test for Turbidity 2020

One-Sample Test

	Test Value = 5					
					95% Confidence Interval of the Difference	
	t	df	Sig. (2-tailed)	Mean Difference	Lower	Upper
Turbidity: M-WTP 2020	-48.634	4	.000	-4.57000	-4.8309	-4.3091
Turbidity: G-WTP 2020	-51.559	4	.000	-4.41035	-4.6478	-4.1729

Turbidity in treated water was tested using the 5NTU as the test value (null hypothesis)

$H_o \leq 5$; $H_1 > 5$

H_o denotes the null hypothesis and H_1 alternative being that the mean value of turbidity will be higher than 5NTU. From the table 18 and 19 due to the p value, the null hypothesis for both plants in the two years cannot be rejected. Meaning the means will or are equal or less than 5NTU, however, there is still a possibility of turbidity exceeding the limit given the previous studies (Omar & Aziz, 2019).

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

In this chapter the overall and major findings of the study were stated based on the results which were directed by the objectives. A way forward was also outlined for future or further research(es).

5.1 Conclusion

Major findings of this research include;

All the water parameters which were analyzed for both treatment plants fall within the permissible limit for WHO and BOBS. Total coliform and *E-coli* were not detected in treated water for both WTPs.

The WQI for both plants in the two years were found to fall under excellent water classification with values ranging from 9.5 to 25.5. In 2020 G-WTP was 0.45 away from being classified as good. M-WTP proved to be performing well compared to G-WTP and this might be due to that it is a newer project than G-WTP.

The overall log removal value and removal efficiency of turbidity were found to respectively be, 2.24 and 99.32% (G-WTP, 2019), 1.96 and 98.34% (M-WTP, 2019), 1.3 and 83.04% (M-WTP, 2020) lastly 1.52 and 96.83% (G-WTP, 2020). Source of drinking water (raw water) for M-WTP contained less amount of contaminates, much emphasis on turbidity than G-WTP in Autumn of 2020.

Significant correlation positive and negative, was found between water quality parameters, turbidity, conductivity and pH.

All in all, both treatment plants seemed to be performing well hence appropriate to feed or supply safe water to the public. There was not any significant variation observed between the two treatment plants with respect to treatment except for the difference in water quality of the water sources supplying the plants.

5.2 Recommendations

Despite the findings of the research, it is recommended that;

Further research concerning the performance of both treatment plants should be done, taking into consideration;

- Different seasons and treatment units
- Operation of the WTPs
- Management of the WTPs
- Most if not all water quality parameters

Water quality of the feeding sources must be analyzed and sources of pollution be identified, delineated, as this will help in how the water will be treated appropriately let alone reduce the pollution rate or status of the sources. Then again measures taken to curb pollution of the water sources.

WTPs must be open to accept researchers and allow them access to all the needed information, transparency must be allowed to obtain satisfactory results.

Policy makers should work closely with researchers and have access to recent studies to see the outcomes thus modifying where needs be regarding water issues and seeing to it if other technological means of water treatment should be explored. This is because there are still water bourne diseases yet the water quality seems to be acceptable and the WTPs performing well.

Consumers as well have to seek knowledge regarding the status of the water they are supplied with. They should show interest by at least requesting for site visits at the WTPs. This will help them to acknowledge and appreciate the processes involved in them accessing clean water suitable for their consumption thus leading to them conserving the water resources by avoiding pollution.

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APPENDICES

APPENDIX I: Daily water quality of the WTPs

					M-WTP 2020							
	week 1											
	pH (day1)	day2	day3	day4	Turb (day 1)	day2	day3	day4	cond (day 1)	day2	day3	day4
raw	7.3	7.3	7.36	7.4	1.7	1.2	1.6	1.4	176.8	174	168.7	167
final	7.22	7.24	7.2	7.4	0.14	0.24	0.18	0.2	155.8	134.4	150.4	165.9
	week 2											
	pH	day2	day3	day4	Turb	day2	day3	day4	cond	day2	day3	day4
raw	8.2	8.12	8.12	8.1	1.5	1.4	1.1	1.2	185	192	154	150
final	8.2	8.12	8.1	8.12	0.4	0.22	0.31	0.52	148.6	153.2	130.1	175.3
	week 3											
	pH	day2	day3	day4	Turb	day2	day3	day4	cond	day2	day3	day4
raw	7.7	8.2	8.1	8.13	0.25	1.5	0.92	0.74	184.2	161.2	140	140.1
final	7.4	7.64	8	8.4	0.43	0.32	0.4	0.34	164.7	157.6	164.8	165.8
	week 4											
	pH	day2	day3	day4	Turb	day2	day3	day4	cond	day2	day3	day4
raw	8.06	8.51	7.75	8.14	180	182.4	198.8	283.2	182	157.2	144	140.2
final	6.52	6.2	7.1	8.11	0.44	1.32	0.44	0.85	192.4	193.6	194.1	195.3
	week 5											
	pH (day1)	day2	day3	day4	Turb (day 1)	day2	day3	day4	cond (day 1)	day2	day3	day4
raw	7.6	8.15	7.5	7.48	82.7	77.5	83.5	86.8	155.7	147.5	151.8	168
final	7.7	8.52	7.57	7.78	0.5	0.42	0.48	0.46	167.8	157.9	164.5	148.5

					G-WTP							
	week 1											
	pH (day1)	day2	day3	day4	Turb (day 1)	day2	day3	day4	cond (day 1)	day2	day3	day4
raw	9.89	7.64	8.81	7.04	19	17.4	18	18.7	194.1	195.4	197.6	194
final	10.8	7.89	9.18	7.18	0.86	1.05	0.88	0.8	195.2	196.7	197.6	200.3
	week 2											
	pH	day2	day3	day4	Turb	day2	day3	day4	cond	day2	day3	day4
raw	9.89	7.64	8.81	7.04	21.2	17.4	18	18.7	191.1	192.4	194	192.3
final	10.57	7.9	7.18	8.11	0.433	0.426	0.406	0.44	192.6	193.6	194.1	195.3
	week 3											
	pH	day2	day3	day4	Turb	day2	day3	day4	cond	day2	day3	day4
raw	7.94	7.64	8.1	7.04	20.2	17.5	18.9	18.7	194.2	191.4	190	191.2
final	8.06	7.5	7.18	7.14	0.435	0.456	0.421	0.44	190.8	195.6	194.8	195.8
	week 4											
	pH	day2	day3	day4	Turb	day2	day3	day4	cond	day2	day3	day4
raw	7.29	7.04	8.27	7.04	19	18.4	18.8	18.2	191.1	192.4	194	192
final	10.57	7.9	7.18	8.11	0.427	1.02	0.462	0.465	192.4	193.6	194.1	195.3
	week 5											
	pH (day1)	day2	day3	day4	Turb (day 1)	day2	day3	day4	cond (day 1)	day2	day3	day4
raw	8.35	8.35	7.68	7.41	18.27	18.82	18.83	18.6	195.7	192.5	191.87	192.5
final	8.78	8.54	7.57	8.74	0.9	0.43	0.438	0.59	196.5	193.9	194.25	193.85

APPENDIX II: weekly water quality of the WTPs

		M-WTP 2019				
		pH	Turbidity ,NTU	Conductivity, µs/cm	TC	*E-coli*
week 1	raw	7.04	153	133		
	final	7.06	0.88	99.45	<1	<1
week 2	raw	7.78	155	143		
	final	8.14	0.54	100.75	<1	<1
week 3	raw	8.09	13.74	216		
	final	9.02	0.1	355	<1	<1
week 4	raw	7.39	26.5	201		
	final	7.25	0.99	208	<1	<1
week 5	raw	8.16	22.3	193		
	final	7.9	0.65	199	<1	<1
		G-WTP - 2019				
week 1	raw	7.49	15.18	141		
	final	7.93	0.08	155	<1	<1
week 2	raw	7.55	14.57	144		
	final	7.99	0	160	<1	<1
week 3	raw	7.42	60.1	164		
	final	7.57	0.06	236	<1	<1
week 4	raw	7.48	66.9	156		
	final	7.35	0.94	157	<1	<1
week 5	raw	7.32	51.2	198		
	final	7.38	0.73	145	<1	<1

		M-WTP 2020				
		pH	Turb,NTU	Cond, µs/cm	TC	*E-coli*
week 1	raw	7.34	1.48	171.6		
	final	7.27	0.19	151.6	< 1	< 1
week 2	raw	8.14	1.31	170		
	final	8.14	0.36	151	< 1	< 1
week 3	raw	8.03	0.85	156.4		
	final	7.87	0.37	163.2	< 1	< 1
week 4	raw	8.12	211	133		
	final	6.98	0.76	148	< 1	< 1
week 5	raw	7.69	82.5	155.8		
	final	7.89	0.47	159.6	< 1	< 1
		G-WTP 2020				
Week 1	raw	8.35	18.25	195.7		
	final	8.7825	0.95	196.5	< 1	< 1
Week 2	raw	8.35	18.82	192.5		
	final	8.54	0.42625	193.9	< 1	< 1
Week 3	raw	7.68	18.83	191.87		
	final	7.57	0.44	194.25	< 1	< 1
Week 4	raw	7.41	18.6	192.5		
	final	8.74	0.59	193.85	< 1	< 1
Week 5	raw	7.95	18.63	193.14		
	final	8.41	0.59	194.62	< 1	< 1

APPENDIX III: Descriptive Statistics

M-WTP 2019

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Raw Water pH	5	7.04	8.16	7.6920	.47473
Raw Water Turbidity	5	13.74	155.00	74.1080	73.07932
Raw Water Conductivity	5	133.00	216.00	1.7720E2	36.89444
Treated Water pH	5	7.06	9.02	7.8740	.78050
Treated Water Turbidity	5	.10	.99	.6320	.34694
Treated Water Conductivity	5	99.45	355.00	1.9244E2	104.60055
Valid N (listwise)	5				

G-WTP -2019

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Raw Water pH	5	7.32	7.55	7.4520	.08701
Raw Water Turbidity	5	14.57	66.90	41.5900	25.01568
Raw Water Conductivity	5	141.00	198.00	1.6060E2	22.86482
Treated Water pH	5	7.35	7.99	7.6440	.30130
Treated Water Turbidity	5	.00	.94	.3620	.43911
Treated Water Conductivity	5	145.00	236.00	1.7060E2	36.99054
Valid N (listwise)	5				

M-WTP 2020

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Raw Water pH	5	7.34	8.14	7.8640	.34428
Raw water Turbidity	5	.85	211.00	59.4280	91.75163
Raw water Conductivity	5	133.00	171.60	1.5736E2	15.48638
Treated Water pH	5	6.98	8.14	7.6300	.48410
Treated Water Turbidity	5	.19	.76	.4300	.21012
Treated Water Conductivity	5	148.00	163.20	1.5468E2	6.41186
Valid N (listwise)	5				

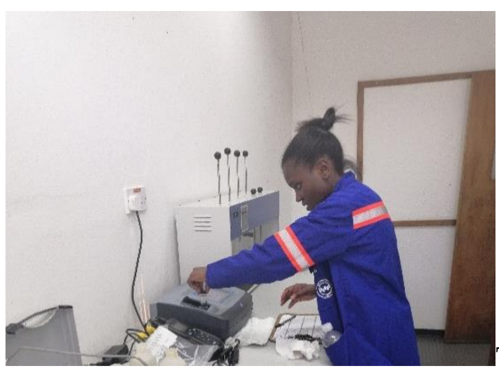
Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Raw Water pH	5	7.41	8.35	7.9480	.41367
Raw Water Turbidity	5	18.28	18.83	18.6340	.22546
Raw Water Conductivity	5	191.90	195.70	1.9314E2	1.49265
Treated Water pH	5	7.57	8.78	8.4085	.49248
Treated Water Turbidity	5	.43	.90	.5896	.19127
Treated Water Conductivity	5	193.90	196.50	1.9464E2	1.08074
Valid N (listwise)	5				

APPENDIX IV: Photos during the research study


The pictures above were taken during induction at G-WTP

 This picture was during sample collection.


This was when conducting laboratory tests.