BINDURA UNIVERSITY OF SCIENCE EDUCATION
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AN ASSESSMENT OF THE BREWERY INDUSTRY'S WASTEWATER FOR NON-POTABLE INDUSTRIAL REUSE: A CASE OF CHITUNGWIZA SORGHUM BREWERY, DELTA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF A BACHELOR OF SCIENCES HONORS DEGREE IN SAFETY HEALTH AND ENVIRONMENTAL MANAGEMENT.

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This dissertation, submitted in partial fulfilment of the requirements for the degree of Safety Health and Environmental Management at Bindura University of Science Education, has been examined and approved for submission.

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DEDICATION

To my family and friends, for their support and love throughout this journey.

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I am extremely grateful to the Almighty for giving me the courage and assurance whilst conducting my research. In order for the research to be a success, I want to thank my supervisor Dr L. Mabhungu for her patience and support throughout this era. Delta Beverages Safety, Health and Environment team is greatly appreciated for their assistance and support.

ABSTRACT

A lot of water is needed in industries for production, therefore generating a lot of wastewater in the process. Industries looking for ways to conserve the resource can reuse their wastewater after proper treatment. The study assessed the physiochemical quality of wastewater from Delta Beverages sorghum plant in Chitungwiza to find out if it is suitable for non-potable industrial reuse. Some of the non-potable processes at the Chitungwiza plant include cleaning, cooling, gardening, steam production, vehicle washing and others. The selected physiochemical water parameters analysed were chemical oxygen demand, permanganate value, biological oxygen demand, total settable solids, nitrogen, phosphorus, total dissolved solids, electrical conductivity, pH and temperature. The study first evaluated the volume of treated wastewater to see if it is sufficient for use in the plant's non-potable processes. The average weekly volume of treated wastewater at the plant was 46673.67hectolitres and this amount proved to be sufficient for reuse.

To perform the required statistic calculations, a software named SPSS version 31 was used for conducting one-sample t-tests and paired sample t-tests. The physiochemical parameters of treated and untreated wastewater were compared using a paired sample t-test and showed that the treatment process at the plant is effective in removing contaminants. The one sample t-test indicated that chemical oxygen demand, biological oxygen demand and total nitrogen of treated wastewater were not in range with the World Health Organization (WHO) standards, showing a p value of less than 0.005. The physiochemical parameters of the treated wastewater that were within the standard ranges showing a p-value of greater than 0.05 were total settleable solids, electrical conductivity, total dissolved solids, permanganate value, phosphorus, temperature and pH. The findings from the study indicated that wastewater from Delta Beverages could be reused in the plant's non-potable processes.

Keywords: wastewater, physiochemical parameters, reuse

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LIST OF ACRONYMS AND ABBREVIATION

FAO	Food and Agriculture Organization
EMA	Environmental Management Agency
UNEP	United Nations Environment Programme
SDG	Sustainable Development Goal
CIP	Clean In Place
VOC	Volatile Organic Compounds
APHA/AWWA/WEF	American Public Health; American Water Works Association; Water Environment Federation

WHO	World Health Organization
SPSS	Statistical Package for the Social Sciences

CHAPTER ONE: INTRODUCTION

1.1 Background

As the global population grows and demands for freshwater rise, the idea that water is an infinite renewable resource becomes a thing of the past (Sedlak, 2019). Freshwater scarcity is a worldwide concern attributable to anthropogenic activities like the utilization of large water volumes in industrial processes resulting in enormous volumes of wastewater being produced (Benard et al, 2021). Freshwater sources cannot be easily replaced by natural methods at a rate that can keep up with the current consumption of freshwater resources (Haroon et al, 2013). In order to solve the issues of an increasing global population, increased water demands for production and economic expansion, industries need to treat and reuse their wastewater (Vergine, et al, 2017). Breweries use water for routine plant activities such as bottle cleaning, cooling, packaging, boiler feeding, gardening and plant wash-downs (Haroon et al, 2013).

Given that water regulations for effluent discharge have become stricter and more stringent, an urgent need has risen to undertake water reclamation programs across all industrial sectors (Shrivastava, 2022). Therefore, in order to safeguard water consumption, improvements in water management are now more important than ever before (Kirby et al, 2003). One of the major global water consumers worldwide is the food processing industry (FAO, 2021). The type of activity, process variables, industrial unit size, cleaning techniques, and equipment utilized in the activities all affect the quantity of water needed for production (Shrivastava, 2022). As a result, different amounts of water are utilized when producing beverages. The European Union carried out an evaluation of water usage and outflow in order to improve water management and promote water recycling throughout their continent (Garnier, 2023). Programs for water recycling and reuse have been in introduced in Australia, Singapore, China, Israel and the United States including Florida and California, as well as industry-specific water reuse rules (Meneses et al, 2017).

Namibia being an arid country in Africa started wastewater recycling projects in 1968 to increase its water supply (Maquet, 2020). In Namibia, the reuse of wastewater has been promoted through the implementation of wastewater treatment plants in food processing industries (Duong&Saphores, 2015). A new treatment facility was developed in the nation in

2002 and Veolia Africa was given control of the operations (Maquet, 2020). The Water Study Commission of South Africa undertook a study on the possibilities of industrial wastewater reuse in the nation, emphasizing the need for legal frameworks and public acceptance (Water Research Commission, 2016). Reuse of reclaimed wastewater guidelines in the industry have been developed by the South African Department for Water and Sanitation (Department for Water and Sanitation, 2017). Despite developments in the collection and treatment of industrial runoff, the release of untreated wastewater into the environment is still a widespread practice in underdeveloped nations, particularly in Africa (Onu et al, 2023).

Despite being a significant economic sector for a nation, the beverage industry uses a lot of water in the brewing process (Simate et al, 2011). As a result of Zimbabwe's Environmental Management Agency's tight prohibitions on the release of effluents into water bodies on many companies including the brewing industry, the industry has been encouraged to look into the possibility of reusing their wastewater (EMA, 2018). Industries in brewing have various operations from beer production, bottle washing, packaging, cooling, steam production, and plant wash-downs to floor cleaning which all require large quantities of freshwater (Ranade&Bhandari, 2014). The beverage sector must make informed judgments for their future water use and estimated effluent discharges in order to minimize costs by investing in water conservation technologies (Gumbo, 2003). Due to the extensive water use, the local authorities will raise water charges (Gumbo, 2003).

In Zimbabwe, there is still limited development and information on the progress made on industrial wastewater reuse. It is essential to consider the most recent legislation and regulations, like the Environmental Management Act of 1998 (Chapter 20:27) and the Water Act (Chapter 20:24), when evaluating the effluent water quality for industrial operations. Analysis of the physiochemical parameters of wastewater to determine its suitability for reuse in industrial operations is crucial. The parameters to be considered when assessing the suitability of wastewater include suspended solids, pH, total dissolved solids, biochemical oxygen demand, turbidity, chemical oxygen demand and Electrical conductivity as specified in the S. L 240 of 2000, which is enforced by the Environmental Management Agency (EMA).

1.2 Problem Statement

Delta Beverages produces a large amount of wastewater because of amount of water required for its manufacturing process. The plant uses approximately 4 8852 litres of water per week which is 488.52 hectolitres. The plant utilizes much more water than what is authorized by the global standard of 650 litres of drinking water for every beer produced (UNEP, 2017). This is as a result of the rise in beer demand (UNEP, 2017). Many operations done at the plant need a lot of water for example boiler feeding, packaging, gardening, use of fire fighting equipment, cleaning, cooling, and plant wash downs. Given that a large portion of water must be heated during the brewing processes, excessive water consumption also translates into high energy consumption. One of the ways in which Delta Beverages, can manage wastewater is through the reuse of wastewater in its non-potable operations which are plant wash-downs, cooling, gardening, vehicle cleaning, steam production and water for fire hydrants. By determining if the treated wastewater from the plant complies with the World Health Organization (WHO) requirements for the non-potable use of water, the research’s goal is to assess the quality of treated effluent at the plant for prospective recycling in the facility's operations. The quality of the wastewater will depend on the beverage produced, production processes, chemicals used, and the treatment method used.

1.3 Aim

- To assess the suitability of treated wastewater from Delta Beverages plant operations for reuse in its non-potable industrial processes.

1.4 Objectives

- To determine the quantity of treated wastewater for potential reuse
- To determine the water quality by analysing the Chemical Oxygen Demand, Permanganate Value, Biological Oxygen Demand Total Settable Solids, Nitrogen, Phosphorus, Total Dissolved Solids, Electrical Conductivity, pH and Temperature of the wastewater before it is treated.
- To determine the water quality by analysing the Chemical Oxygen Demand, Permanganate Value, Biological Oxygen Demand Total Settable Solids, Nitrogen, Phosphorus, Total Dissolved Solids, Electrical Conductivity, pH and Temperature of the treated wastewater

1.5 Justification

The focus of this study is to promote sustainable water management in industrial operations at the brewery. The research will come up with a way to reduce environmental pollution by promoting water reuse in non-potable processes. By assessing the quality of treated wastewater, the company will be able to identify if its treated wastewater meets the required standard for reuse in industrial processes, thereby reducing its dependency on freshwater sources or municipal water. The study will also assess the treatment efficiency of the effluent treatment plant located at site, in treating wastewater.

The study will encourage resource conservation and lessen wastewater's negative environmental effects. The study will be useful to interested parties like the government and regulatory bodies as less pressure is put on its municipal treatment systems, leading to increased economic growth and development for the country. Wastewater reuse in a company will increase workplace morale as employees will feel that their employer is taking a step towards environmental responsibility. The company or industry will benefit from reduced water costs and operational expenses, improved public reputation, and image to be recognized as socially responsible and environmentally conscious. The company will be able to conform to effluent regulations, therefore, increasing competition in the industry due to adopting sustainable practices. In return, water reuse will cause water bodies to become less polluted, less strained for water, and benefit the surrounding community as the water bodies thrive. In order to ensure that there are no threats to the health of the general public, the study clarifies the potential health and safety issues connected with using effluent water in industrial processes. The treating and reuse of wastewater for non-potable operations will lessen the amount of freshwater needed and help ease the effects of water scarcity. Overall, wastewater reuse supports public health, environmental preservation, and the economic prosperity of the nation.

CHAPTER TWO: LITERATURE REVIEW

2.1 Industrial wastewater reuse

The application of treating wastewater for reuse is a result of the brewing industry's increasing energy and water demands as well as the emergence of new environmental challenges (Werkneh et al, 2019). The food production industry can use the technique of partially or completely recycling and reusing water from industrial processes (wastewater) which contains a wide range of contaminants that must be analysed physically and chemically before usage (Bailone, 2022). Most of these contaminants include bacteria, viruses, parasites, natural poisons, chemicals, pesticides, and nutrients (Bailone, 2022).

Wastewater reuse has become more important globally because urbanization and industrialization have worsened environmental contamination, making it a crucial requirement for supplying water (Simate et al, 2011). Organizations in the brewing sector are implementing water reuse systems as effluent discharge rules are tightened to safeguard the condition of natural reservoirs (Shrivastava, 2022). Water reuse is a good option for manufacturing industries, but it is still a highly sensitive issue due to public perceptions on the characteristics of recycled water and its contamination risks (Meneses et al, 2017). Some of the contamination risks that come with recycled water are the presence of pathogens, viruses and bacteria that might come in contact with the skin. For wastewater to be appropriate for reuse, it should be treated effectively through the means of a wastewater treatment plant which can be situated at a brewery, thus making it safe for reusing.

The primary forces influencing wastewater reuse in the brewing industry are adherence to environmental legal requirements, water shortages, and corporate sustainability (Werkneh et al, 2019). The wastewater from the plant's operations will be treated in the wastewater treatment plant to meet the required Word Health Organization (WHO) standards for reuse. It is important to consider the number of environmental, social, cultural, economic, nutritional, and other aspects impacting potential exposure when setting national water standards. Wastewater reuse should accomplish three key goals from a comprehensive management of water resources which are environmental sustainability, economic efficiency and help countries achieve food security by using the nutrients in wastewater instead of chemical fertilizers (Philips et al, 2012).

2.2 Water reuse and SDGs (Sustainable Development Goals)

The Sustainable Development Goals 6 and 9 promote water reuse and recycling in industries while SDG 12 promotes sustainable water management. Target 6.3 intends to achieve better water quality by 2030 by lowering pollution, restricting the disposal of dangerous chemicals and lowering untreated wastewater. This goal supports sustainable water management in industries and encourages global water reclamation and reuse (Qadir, 2020). It demands a significant increase in water reclamation and safe reuse on a global scale, including in industrial activities.

By 2030, target 9.4 intends to improve infrastructure and modify industries while advancing environmentally friendly industrial practices and technology. These initiatives to retrofit industries include implementation of green technologies, reducing water consumption, increasing reuse efficiency and minimizing environmental impact (Georgiou, 2022).By using prevention, reduction, recycling and reuse, target 12.5 seeks to minimize waste production. Water reuse and recycling minimizes waste by reducing water requirements and wastewater discharge (Qadir, 2020). Achieving these targets requires policy reforms, stakeholder engagement and capacity building to ensure safety and quality industries

2.3 Characteristics of brewing industry wastewater

Characterization of wastewater is the first stage in developing a solution for wastewater treatment, recycling and reuse (Ranade&Bhandari, 2014). Wastewater is categorized into three main categories namely physical, chemical, and biological (United Nations Environment Programme, 2003). Brewing wastewater has a high moisture content because of the high chemical oxygen demand (COD) from organic compounds such as volatile fatty acids, sugar, soluble starch and ethanol (Golddammer, 2008). These organic components can quickly decompose through anaerobic and aerobic processes in which the BOD/COD ratio will be between 0.6 and 0.7(Goldammer, 2008). A study done on two brewing plants located in Bulawayo, Zimbabwe showed results indicating high levels of COD and BOD in wastewater and in some cases exceeding 30000mg/l (Ikhu-Omoregbe et al, 2005). The same research also revealed that no or very little heavy metals, were discovered in the wastewater from the food processing plant.

While the amount and type of chemicals used at clean in place (CIP) units, such as caustic acid, phosphoric acid, and nitric acid determine pH values, the quantity of spent yeast and raw materials in the effluent significantly affect nitrogen and phosphorous levels (Simate et al, 2011). The ratio of water to cleaning agents and their level of concentration in wastewater are controlled by phosphorus levels from both sources (Werkneh et al, 2019). The wastewater is also characterized by a dark brown colour originating from total settable solids (TSS) that also requires pre-treatment to minimize the suspended particles and biological loads (Amenorfenyo et al, 2019). Reconditioned water from a processing operation could have impurities from the processing plant's surroundings, the food product's quality, the processing operation that produced the wastewater and the reconditioning technique used (Meneses et al, 2017).

2.4 Treatment of brewing industry wastewater for reuse

When reusing or recycling water, understanding the quantity, particular makeup and quality of water required for each unit operation is vital for the water network optimization and for choosing the appropriate treatment procedure (Garnier et al, 2023). Several treatment processes can be used for brewing wastewater to make it suitable for non-potable industrial reuse. The processes aim to change the feed water’s biological, chemical and physical characteristics of the wastewater (Simate et al, 2017).

2.4.1 Physical treatment

The physical treatment method applies physical forces to remove coarse solids leaving out dissolved contaminants and uses a passive process like sedimentation to let pollutants that are suspended in the water to settle out or rise naturally to the top. This treatment also separates oil and grease from the effluent (Amenorfenyo et al, 2019). When used alone, the physical techniques of screening, flow equalization, mixing, flotation and sedimentation used to treat wastewater are ineffective at removing pollutants.

2.4.2 Chemical treatment

The chemistry of wastewater is changed by pH adjustment or flocculation/coagulation by adding various chemicals for treatment (Huang, 2009). The first stage of wastewater chemical treatment is coagulation which includes stirring or churning chemically treated wastewater to promote coagulation (Olajire, 2012). By increasing particle size, coagulation enhances sedimentation performance and increases settling efficiency. Aluminium sulfate and ferric chloride are inorganic coagulants utilized in the chemical treatment of wastewater. Furthermore, pH is maintained through the addition of a base or acid to the effluent to make it pH neutral (Onu et al, 2019). Pathogens and other dangerous impurities can be eliminated using coagulation, flocculation and disinfection.

2.4.3 Biological treatment

The process of biological treatment uses microorganisms to break down organic chemicals in wastewater through aerobic, anaerobic, and composting processes (Onu et al, 2019). To remove organic debris and nutrients from water, biological treatment methods such as activated sludge and built wetlands are used. The treatment techniques used have to be effective in reducing the organic levels in the wastewater being treated. A significant disadvantage of aerobic treatment of water is the simultaneous formation of biomass in large quantities (clarification sludge), whereas its advantage is that the energy needed for the growth of microorganisms that support biocatalyst growth is provided by the oxidative breakdown of the carbon substratum (Ranade&Bhandari, 2014).

2.5 Wastewater generation in industries

Water shortages limit how much water can be drawn from surface and ground water sources. These shortages are caused by human activities from industrial operations, and are inescapable in all countries (Garnier et al, 2023). UNESCO has established an aim to lower the quantity of water utilized by industries by 20% by 2030 in order to support efficient use of water (UNESCO, 2014). In all types of enterprises, water serves a variety of purposes and practically all of the water utilized in industries becomes industrial wastewater (Ranade&Bhandari, 2014). Breweries are one of the biggest water users in manufacturing industries and their effluent is characterized by high amounts of organic pollutants that need to be remedied before being used again (Jaiyeola & Bwapwa, 2016).

Voluminous amounts of water are used for production, washing empties, boiler feed for heat, cooling, general plant cleaning and packaging. Cleaning bottles frequently accomplishes two goals which are making the product look appealing and making the container safe for humans use by eliminating germs and other contaminants (Haroon et al, 2013). Sodium hydroxide detergents, and chlorine solution are just a few of the different chemicals that can be used to wash bottles. The production of an alcoholic beverage requires a lot of high-quality water and its makeup of water is more than 90% therefore an effective brewery will normally need 4 to 6 litres to manufacture one bottle of beer (Goldammer, 2022). Managing wastewater production of any type entails integrating process improvements such as waste minimization and efficiency in water usage to reduce the generation of wastewater (Environmental, Health, and Safety Guidelines, 2007).

2.6 Challenges and limitations of wastewater reuse

Werkneh et al (2019) stated that the adoption of wastewater reuse in the brewing business is difficult because of the industry's adherence to safety and health regulations. Handling wastewater exposes workers to chemical, physical and biological hazards. Inhaling volatile organic compounds (VOCs), exposure to methane, contact with infections and vectors are some of the dangers associated with wastewater reuse (Environmental Health and Safety Guideline, 2007). Taking a bath in untreated or only partially treated wastewater causes gastroenteritis and upper respiratory illnesses results in hepatitis, a damaged liver, and death (UNEP, 2003).

The public does not view wastewater as a resource but rather as waste, therefore ongoing campaigns to educate the public are crucial if the public is to shift its perception and start viewing wastewater as a resource (Onu, et al, 2023). In addition, people are willing to utilize treated wastewater for reuse purposes such as irrigation but are hesitant to use wastewater for more intimate interactions like bathing, cleaning, and drinking (Wang et al, 2008).

In the United States, plans for water recycling have been opposed by the public and a number of well-known initiatives have been shelved despite extensive planning and financial investment (Voulvoulis, 2018). The lack of water reclamation standard requirements related to health of the public, cleanliness, quality of the product and safety concerns is another barrier to water reuse (Fatta et al, 2005). Water reuse might solve water scarcity issues but the issue of linked wastewater management and the accompanying expenditures still remains (Hardy et al, 2015). Treating wastewater to a suitable or required quality can be expensive, making it more expensive for industries that produce high contaminated wastewater. Arising costs may also come from infrastructure requirements such as new pipe lines, storage tanks and treatment plants. Particularly in large-scale enterprises, assessing the quality of wastewater that has been treated to make sure it doesn't endanger human health is more expensive (Wang et al, 2008).

Various pollutants that may be found in wastewater pose major risks to both people's health and the natural environment if they are not adequately controlled. Due to exposure to chemicals and microbiological threats, wastewater or grey water reuse poses a risk to one's health. Kesari (2021) states that contact with sewage may result in infectious diseases like helminth disorders, which are connected to anaemia and a decline in physical and cognitive development. Demand in technical expertise might also be a drawback in water reuse as skilled personnel may not be available in some regions or may be too expensive for some companies (Simate et al, 2011).

2.7 Benefits of wastewater reuse

Commercial organizations are very motivated to reuse wastewater as it benefits businesses from a legal standpoint as well as helps them establish a solid reputation for corporate social responsibility (Barbera&Gurnari, 2018). Corporate social responsibility enhances an organization’s standing as a socially and environmentally conscious business which is beneficial for luring clients and investors. Technologies for desalination and water recycling are usually cited as having a high potential for bridging the gap between supply and demand for freshwater sources (Hardy et al, 2015). Freshwater is becoming increasingly scarce and economic development is accompanied with a rise in water usage (Hardy et al, 2015).

Reusing water will reduce the amount of freshwater needed for production, which is crucial in areas where water shortage is a problem. Reusing wastewater has a numerous benefits such as less stress on groundwater or surface water resources and less usage of valuable water supplies for cultivation and consumption (Reuse of Treated Wastewater Guidance Manual, 2012). Reusing wastewater can reduce the amount of pollutants that are added to surface waters, save money, and restore both surface and groundwater supplies. The decrease in water usage and water treatment requirements has led to cost savings via wastewater reuse. Recycling wastewater is typically cheaper than using fresh water thus reducing costs for businesses (General Environmental Health and Safety Guideline, 2007).

Mehta (2015) argues that wastewater reuse is not only necessary but has numerous environmental advantages. These advantages include a dependable locally controlled water supply, decreased wastewater discharges, decreased and prevented pollution, the creation or improvement of riparian habitats and wetlands, a decreased water divert from sensitive ecosystems and a decreased discharge to sensitive water bodies. Reusing water from industrial processes will also help reduce cost of municipal water bills as the cost of treated wastewater has been found to be lower (Adewumi et al, 2010).

CHAPTER THREE: METHODOLOGY

3.1 Description of study area

The study was conducted at Chitungwiza Sorghum Brewery, which is located in the industrial area of Chitungwiza, Harare province. Fig 3.1 shows Chitungwiza Brewery where the area is geo referenced as -18º 01' 17" South and 31º 02' 55.7" East. The plant is in natural region 2A in Zimbabwe with an average annual rainfall of 750mm to 1000mm which tends to occur during the hot season (FAO, 2006). The Brewery produces traditional beers made from sorghum. The traditional beer is produced using a variety of ingredients including water. The water is used for many processes including for boiler feeding, brewing, packaging, bottle washing, plant wash-down, fire hydrants, vehicle cleaning, cooling and many more.

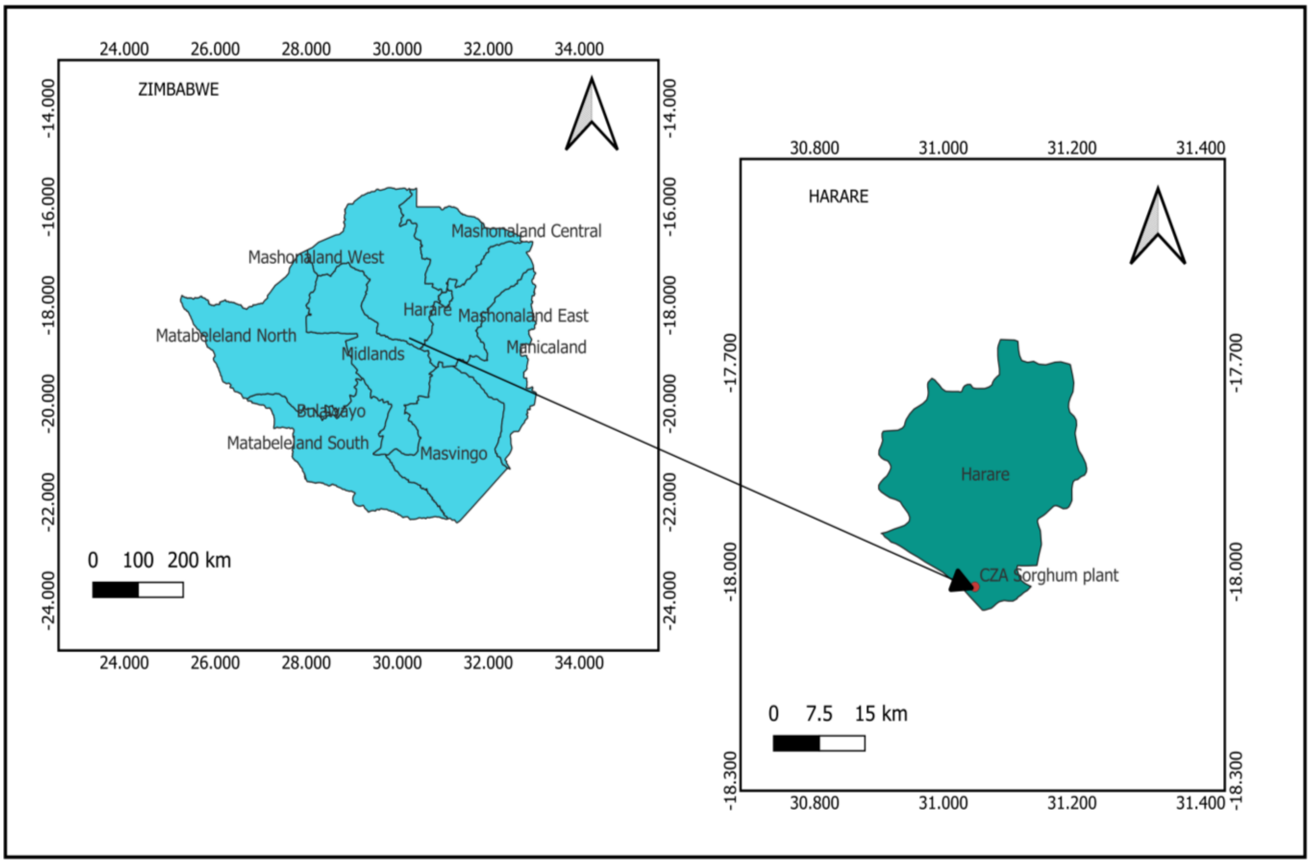


Figure 3.1 Study area map

3.2 Research design

An experimental method design was employed for the research. The flow rate of wastewater entering the effluent plant was measured to determine the quantity of wastewater treated at the effluent plant. Water samples from both untreated and treated wastewater were collected for the analysis of physiochemical parameters, including Chemical Oxygen Demand (COD), Permanganate Value (PV), Total Settable Solids (TSS), Biological Oxygen Demand (BOD), Nitrogen, Phosphorus, Total Dissolved Solids (TDS) Electrical Conductivity (EC), pH, and Temperature. These physiochemical parameters were used to investigate the treatment efficiency between treated and untreated wastewater. World Health Organization (WHO) standards were also used to assess the suitability of the physiochemical parameters of treated wastewater for non-potable industrial use.

3.3 Determination of the quantity of the treated wastewater produced at Delta Beverages

The volume of water into the effluent treatment plant was measured per unit time using a flow meter (see appendix 1). The flow rate of untreated wastewater entering the effluent treatment plant was tracked over time using a flow meter model SUP-LDG. The meter uses a magnetic field to measure the flow of water. To determine the volume (quantity of the treated wastewater), the flow rate and the duration of the treatment period were multiplied. The formula used was:

The volume of water for potential reuse = flow rate m^3/ minute × the duration of the treatment period

3.4 Water sample collection

Collection of water samples was done for a period of six weeks from 13 February to 24 March 2023 at the Chitungwiza effluent treatment plant. Sampling was done for twelve days in the six weeks period. On each sampling day 2 samples were collected for untreated wastewater and another 2 samples for treated wastewater. Two replicas for each sample collected was done to improve accuracy of measurement. A systematic random sampling technique was used to determine the two sampling points which were the treated wastewater outlet and the untreated wastewater inlet. After that, water samples were collected from the two sampling points using a grab sampling technique. The water samples collected were labeled for both untreated and treated wastewater for analysis of physiochemical parameters at the Quality Control Laboratory which is which is accredited for ISO 9001:2015 and NOSA 5 star by the Standard Association of Zimbabwe and NOSA, South Africa respectively (see appendix 2).

During collection of water samples, 500ml polythene containers treated with nitric acid were used to preserve and prevent contamination of the sample. Nitric acid raises the pH of the samples, which inhibits the development of microorganisms that could otherwise cause the sample to decay or become contaminated. Laboratory temperatures of +2 to +8 0C were used to preserve samples. These temperature prevent the growth of bacteria. The samples were analyzed within four to twelve hours after sampling time. Gloves and eye protection goggles were worn during the collection of the samples to prevent contact with hazardous chemicals, water splashes and aerosols (US EPA, 2016).

3.4.1 Water Sample analysis

Chemical Oxygen Demand, Permanganate Value, Phosphorus, Total Settable Solids, Biological Oxygen Demand and Nitrogen were analyzed at the Quality Control laboratory whereas Total Dissolved Solids, Electrical Conductivity, pH and Temperature were measured at the sampling point. Electrical Conductivity and Total Dissolved Solids were measured using a universal meter named Hannah, HI-991300. Temperature and pH were determined using an MRC pH meter model INE-M310F and a PCE thermometer model T 318 respectively. For the lab analysis shown in Table 3.1, Standard Operation Procedures (SOP) from the (APHA/AWWA/WEF, 1999) were used (see appendix 3).

Table 3.1: Analysis methods used and parameters analysed (APHA/AWWA/WEF,1999)

PARAMETER	ANALYSIS METHOD	UNITS
Total setteable solids	Gravimetric analysis	mL/L
Nitrogen	Kjeldahl	mg/L
Phosphorous	Vanadomolybdophosphoric Acid Colometric method	mg P/L
COD	Colometric method	mgO_2/L

BOD	Ultimate BOD test	mgO_2/L
pH	On-site conductrimetric	pH scale
TDS	On-site temperature measurement	mg/L
Temperature	On-site temperature measurement	Degree Celsius(°C)
EC	On-site conductrimetric	µS/m
PV	Spectrophotometric	mg/L

3.5 Quality control procedures

During the research, analytical assurance and quality control procedures were observed. The Samples collected accurately represented the element from which they were retrieved from meaning the two sampling locations were chosen carefully to ensure that they are representative of the water sample being taken. Calibration of all equipment before analysis was also done to ensure accuracy of the results obtained.

Additionally, in order to prevent external communication with foreign elements, sample bottles were to be initially rinsed three times with the sample water. Reagent quality measurement, cleaning of the apparatus, accuracy and precision of the methodology and instrumentation were also followed. Some specific concerns such as analytical blanks, replicate analysis and laboratory control samples, were used to ensure the results will be trustworthy. The samples were taken to the laboratory soon after collection to prevent contamination and were kept under an appropriate temperature during transportation.

3.6 Data analysis

Statistical Package for the Social Sciences (SPSS)-Software, version 31 was used to determine the effluent treatment plant's treatment effectiveness by using a paired sample t-test to contrast the parameters for treated and untreated wastewater (see appendix 4). A paired-sample t-test compares the mean of two matched groups of instances (Ross&Wilson,

2017). The second test conducted was a one sample t-test to compare the treated wastewater against the World Health Organization (WHO) standards (see appendix 5). A one sample t-test compares the sample's mean to the population mean or an a priori score (Ross&Wilson, 2017). The test makes use of a sample standard deviation or a known population standard in this case, the World Health Organization (WHO) standard values. The data was then visualized by Excel using graph to have a better comprehension of the distribution of the physiochemical parameters by identifying outliers or trends **(**appendix 6*).*

CHAPTER 4: RESULTS

4.1 Comparison of means between amount of treated wastewater and water required for non-potable processes

Figure 4.1 presents a one sample t-test that was made between treated wastewater and the required amount of water in a week for non-potable processes as the test variable. At 95% significance level, the mean value of treated wastewater in 6 weeks was not different from the required test value. It showed a p-value of 0.60 greater than 0.05 and a mean of value of 46673.67±1163.26h/l. Fig 3 shows the values of treated wastewater obtained in six weeks compared to the required amount of 48852h/l per week for non-potable operations. The highest treated amount recorded was 49567h/l in week 4 and the lowest was 42756h/L in week 6.

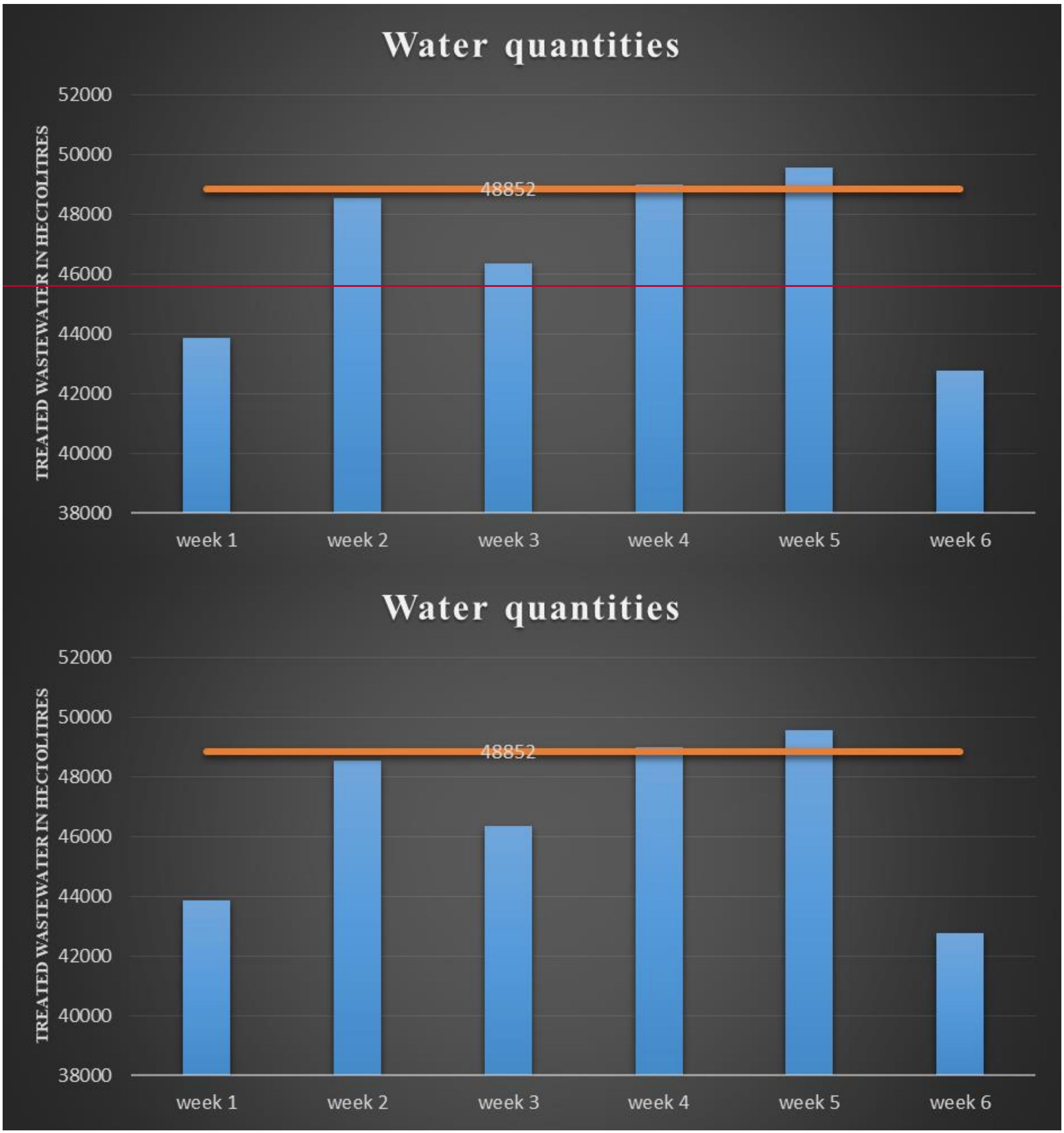


Figure 4.1: Comparison of means between amount of treated wastewater and water required for non-potable processes

4.2 Mean Comparison of Selected physiochemical parameters of untreated and treated wastewater

Figure 4.2 shows different mean values of pH, Total Settleable Solids, Total Nitrogen, Phosphorous and Temperature found in treated and untreated wastewater. For pH, the mean value in treated wastewater is relatively higher than that of untreated wastewater where the values are 7.31+0.25 and 4.41+0.73 respectively. Total Settleable Solids shows a sharp decrease in mean values from untreated to treated wastewater, which are 13.60+0.69 to 1.76+0.15mg/L. Total Nitrogen's mean values decreased from 25.85+0.67mg/L in untreated wastewater to 19.61+1.99mg/L in treated wastewater. Phosphorous and Temperature also showed a decrease after treatment. The Phosphorous mean value decreased from 15.66+0.66mg/L to 8.84+1.79 mg/L whereas the Temperature changed from 27.71+0.60°C to 21.33+0.48 °C.

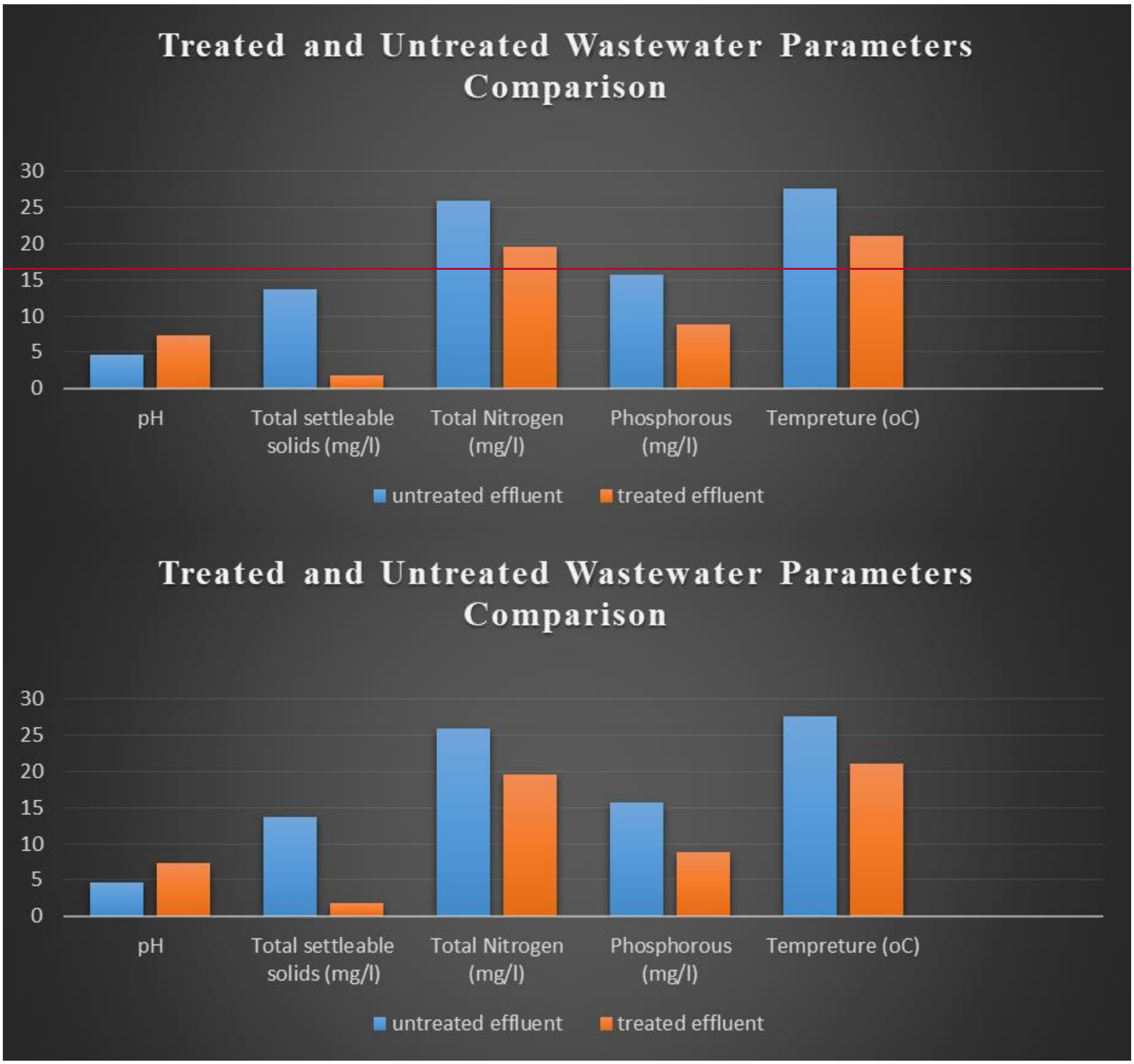
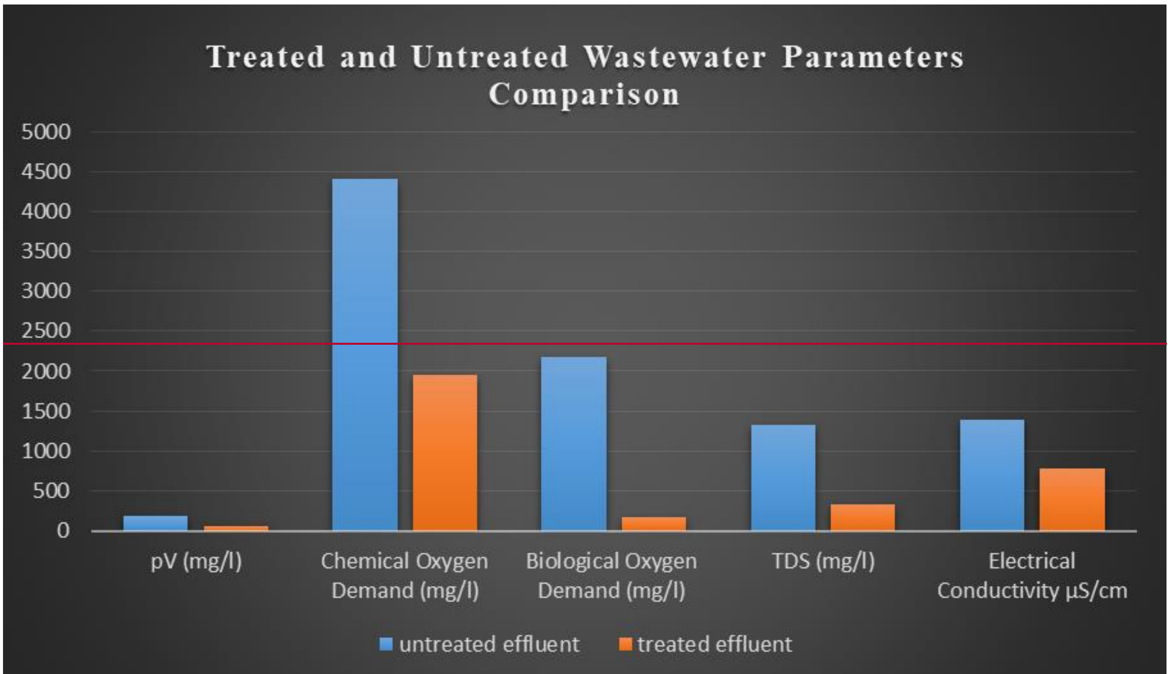


Figure 1.2: pH, Total Nitrogen, Total Settleable Solids, Phosphorous and Temperature mean comparisons for treated and untreated wastewater

Figure 4.3 below represents the mean values of physiochemical wastewater parameters namely Permanganate Value (PV), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Total Dissolved Solids (TDS) and Electrical Conductivity (EC). Treated and untreated wastewater parameters are compared using their mean values. PV mean values decreased from 166.91±22.84mg/L to 50.18±2.80mg/L. BOD and COD values showed a sharp decline in values where COD changed from 4488±313.20 mg/L to 2021.91±618.17mg/L and BOD decreased from 2182.67±142.832mg/L to 167±15.68mg/L. TDS values moved from 1344±86.92mg/L to 308.45±25.51mg/L and EC from 1340.91±118.89µS/m to 682.09±172.24µS/m.



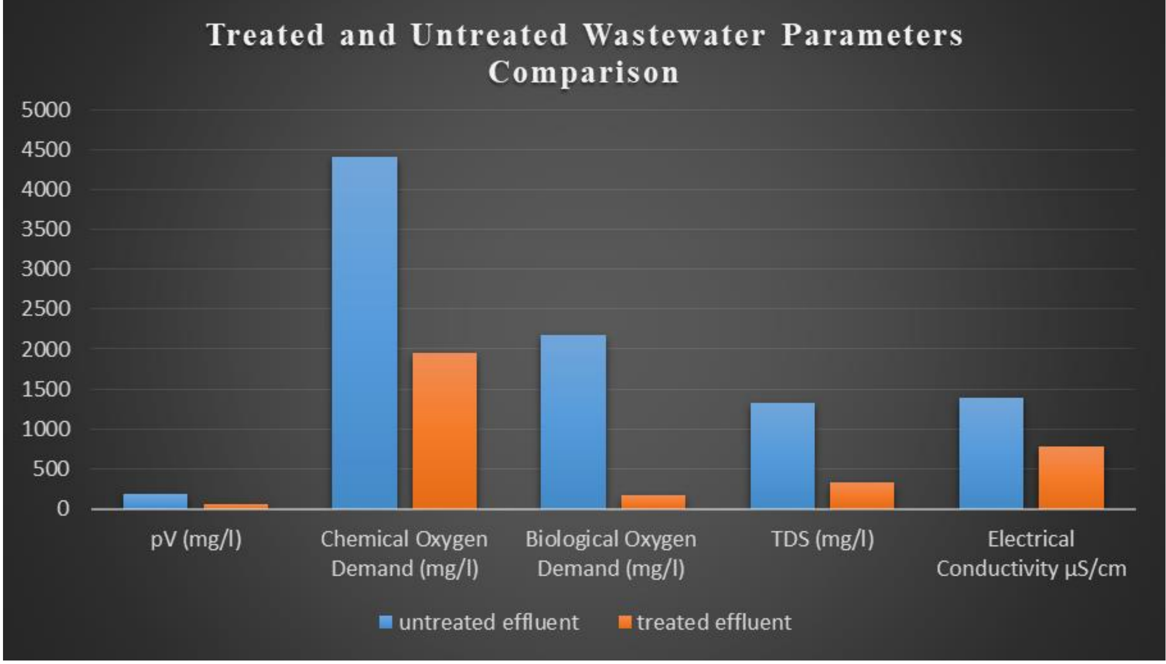


Figure 4.3: PV, COD, BOD, Total Dissolved Solids (TDS) and EC mean comparisons for treated and untreated wastewater

4.3 Comparison of Mean±SE and P-value between untreated and treated wastewater physiochemical parameters

Table 4.1 shows selected physiochemical wastewater parameters namely, Temperature, Phosphorous, Total settable solids, Total Nitrogen, pH, PV, COD, BOD, Electrical Conductivity and TDS. The p-values and mean are for the paired sample t-test of treated and untreated wastewater. A paired sample t-test revealed all the stated physiochemical parameters of treated wastewater are significantly different from those of untreated wastewater, all with a p value ≤0.005. The highest recordings of the p value were from Total Nitrogen and Phosphorous, showing 0.015 and 0.005 respectively.

Table 4.1 Mean±SE and P-values of the paired sample t-test of treated and untreated wastewater

Parameter	Unit	Mean±SE	P-value
Temperature	°C	6.38±1.03	0.003
Total Nitrogen	mg/L	6.23±2.16	0.015
Phosphorous	mg/L	6.81± 1.97	0.005
Total settable solids	mg/L	11.84±0.74	<0.001
pH	-	2.900±.49	<0.001
PV	mg/L	116.72±21.72	<0.001
COD	mg/L	2466.72±307.60	<0.001
BOD	mg/L	2015.66±139.11	<0.001
Electrical Conductivity	µS/m	658.81±157.06	0.002
TDS	mg/L	1035.54±84.25	0.001

4.4 Comparison of mean Mean±SE and P-value concentrations of water quality parameters against drinking water standards.

In order to compare the mean value of each parameter to WHO standard ranges, a one sample t-test was used. Table 4.2 below shows that Total Nitrogen, COD and BOD's mean values were different ($p \leq 0.05$) from WHO standard drinking values. The mean values of Total

Nitrogen, COD and BOD were out of the range stated by WHO as shown in the table below. Temperature, Phosphorous, TSS, pH, PV, EC and TDS's mean values showed no difference ($p>0.05$) to the WHO standard drinking values, therefore were in the specified range. TDS recorded the highest p-value of 0.374 while COD had the highest mean value.

Table 4.2 Comparison of mean concentrations of selected physiochemical parameters with drinking water quality standards.

Parameters	**Mean±SE**	**P-value**	**WHO Standard**
Temperature(°C)	21.33±0.48	0.058	12-25
Total Nitrogen(mg/L)	19.40±2.17	<0.001	<10
Phosphorous(mg/L)	8.29±1.85	0.344	<15
Total settleable solids(mg/L)	1.74±0.162	0.071	<5.5
pH(mg/L)	7.31±0.25	0.126	6.5-7.5
PV(mg/L)	50.18±2.80	0.063	<80
COD(mg/L)	2021.91±186.38	<0.001	<10
BOD(mg/L)	172.82±15.95	<0.001	<6
Electrical Conductivity (µS/m)	682.09±172.24	0.066	<400
TDS(mg/L)	308.48±25.51	0.374	<600

CHAPTER 5: DISCUSSION

5.1 Water quantity required for non-potable processes

To be able to reuse water, we need to know if the treated wastewater is enough for reuse in the processes chosen. The results obtained showed a p-value of 0.60 indicating that the mean of the amount of treated water (46673.67±1163.26h/l) was not significantly different from the required amount (48852h/l) for a week in the plant's non-potable processes. The lowest amount of treated wastewater was 42756h/L as recorded in week 6. The plant at times experiences low production levels due factors such as the unavailability of raw materials, ingredients and machine failures. These factors will contribute to the plant not running its operations and therefore less water is utilized resulting in less wastewater produced.

5.2 Physiochemical parameters of treated and untreated wastewater

The pH, Total Settleable Solids, Phosphorous, Total Nitrogen and Temperature of treated wastewater showed a significant difference from those of untreated wastewater indicating a p-value of less than or equal to 0.05. This result showed that the treatment plant at the site is working well and that treatment of wastewater is being done. Phosphorous and Nitrogen recorded a p-values of 0.005 and 0.015 respectively, this could have been as a result of increased use of phosphorous based cleaning detergents used around the plant for Clean in place (CIP) and bottle washing (Simate et al. 2011). Nitrogen levels could also have been affected by spent grain from straining flowing into the treatment plant and the disposal of expired product at the plant. Rejected beer batches as a results of poor quality are also disposed at the effluent treatment plant.

TDS and EC show a similar trend in means as illustrated by the results. The mean values show a relation for both treated and untreated wastewater for EC and TC indicating a relationship between the two. Electrical Conductivity is a measure of the water’s capacity to carry an electrical current and indirect indicator of the amount of ions present (Wu&Brant, 2020). The trend could be as a result of the relationship between TDS and EC as the presents of dissolved solids which are salts and minerals increase the number of ions present in the water. The ions in the water carry an electric charge contributing to the conductivity of water (Rusydi, 2018).

The Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) showed high values in untreated wastewater and this may be due to the presence of sugars, proteins and yeast (Golddammer, 2008). The COD to BOD ratio was less than that of a study conducted by Golddammer, 2008. The COD to BOD ration shows that the organic pollutants are easier to biodegrade using either aerobic or anaerobic digestion since they degrade more quickly (Wang et al, 2022).

5.2 Physiochemical parameters of treated wastewater compared to who drinking standards

The one sample t-test compared the physiochemical water parameters of treated effluent against WHO standard values. The test was to see if the treated wastewater parameter values were in range with WHO standards. pH, Phosphorous, Total settleable solids, PV, Electrical Conductivity and TDS all had p-values greater than 0.05 indicating that they were within the acceptable WHO standard ranges. The mean value of pH which was 7.31±0.25 was almost outside of range of 6.5-7.5. This could be due to the spent grain from the strainer entering the wastewater treatment plant as runoff and from washing it down into the inlet. Another reason could be because of beer being disposed into the treatment plant after it has been rejected from Quality Control and also expired beer from the market.

The mean values of COD, BOD and Total Nitrogen all resulted a p-value of less than 0.05 therefore showing a difference from the WHO standard values. COD, BOD and Nitrogen‘s mean values failed to be in WHO standard ranges. COD and BOD showed a high mean value of 2021.91±186.38mg/L and this could have occurred from the plant only treating COD for release into the municipal drains and not for potential reuse. Total Nitrogen was also high and not within the required range by WHO with a mean of 19.40±2.17mg/L compared to a standard of <10mg/L.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The main aim of the study was to assess the suitability of effluent wastewater from Delta Beverages plant operations for reuse in its non-potable industrial processes. Treated wastewater from the effluent was assessed to see its suitability for non-potable use industrial operations at the plant as the mean amount of the treated wastewater in 6 weeks was compared to the required amount of water needed for use. This indicated that treated wastewater is enough and significant for reuse. A comparison between untreated and treated water parameters indicated that the treatment plant is efficient in removing contaminants from wastewater, as the paired sample tests showed a significant difference. This research also noted the treatment plant is prone to a lot of contaminants during treatment therefore disrupting the treatment process at times

The selected physiochemical namely Chemical Oxygen Demand, Permanganate Value, Total Settable Solids, Biological Oxygen Demand, Nitrogen, Phosphorus, Total Dissolved Solids, Electrical Conductivity, pH, and Temperature were compared against World Health Organization (WHO) standards. The results revealed that COD, BOD and Total nitrogen mean values did not meet the required standards of WHO for reuse. pH, Phosphorous, Total settleable solids, PV, Electrical Conductivity and TDS were also compared against WHO standard values and were found to be within the acceptable range. In the end, this research concludes that the treated wastewater at Chitungwiza Brewery can be reused as most of the selected physiochemical parameters are within the WHO standard ranges and the treatment process is effective.

6.2 Recommendations

- The plant needs to improve its treatment efficiency as some values fluctuated because of outside contaminants. Treatment can be improved by controlling what enters at the treatment plant inlet therefore making sure there is no external contamination during treatment.
- A combination of treatment methods are needed to be able to achieve high quality water for reuse, as one treatment technology might not be enough to remove all pollutants.
- The Quality Control Laboratory should upgrade on technology and equipment to be able to conduct more tests.
- The government should open funds for students who want to conduct research on water quality research

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APPENDICES

Appendix 1

To measure the quantity of treated wastewater

1. Calculate the flow rate:
   Measure the volume of wastewater that is entering the treatment system per unit time, e.g. cubic meters per minute
2. To determine the duration of the treatment period
   This is the amount of time that wastewater is treated in the effluent plant, measuring the start time and end times of the treatment process
3. Determine the total amount of treated wastewater
   To determine the volume (quantity) we multiply the flow rate and the duration of the treatment period
   The volume of wastewater for potential reuse = flow rate multiplied by the duration of the treatment period
   e.g. 10 cubic metres per minute multiplied by 24 hours = 240cubic meters

Appendix 2

Record of effluent water quality parameters to be obtained

Physiochemical Parameters	Values before treatment						Values after treatment					
	Week one		Week two		Week three		Week one		Week two		Week three	
Temperature												
COD												
BOD												
pH												
Nitrogen												
Phosphorus												
Electrical Conductivity												
PV(Permanganate Value)												
Total Settable Solids												
Total Dissolved Solids												

Appendix 3

Parameter	**Standard Operating Procedure for analysis**
Total setteable solids	A fully blended sample should be poured into an imhoff cone. 45 minutes should pass while you gently spin it or agitate the material near the cone's borders with a rod. After giving the cone another 15 minutes to settle, measure the amount of setteable solids in the cone as mg/L.
Nitrogen	An 800 ml kjeldahl flask should be filled with a measured amount of sample. Add 25ml of borate buffer and 6N NaOH to achieve a pH of 6.5. After adding a few glass beads of Hengar granules No. 12, boil off 300ml.
Phosphorous	A drop of phenolphthalein indicator should be added if the sample's pH is higher than 10. The sample's excess colour can be eliminated by shaking 50 m/L of carbon that is activated in the Erlenmeyer flask for a time frame of five minutes. The carbon can is removed via filtration. Addition of less than or equal to 35 mL material between 0.05 and 1.0 mg. A reagent named Vanadate-molybdate should be added, followed by 10 mL of distilled water in order to dilute to the required concentration. Create a series of calibration curves for one set of reference solutions at different wavelengths when the ferric ion is low enough to prevent any interference. For each batch of sample, make a blank by replacing the sample with 35 mL of purified water. Depending on the required level of sensitivity, measure the sample's absorbance in comparison to the blank after 10 minutes or longer. Calculation of Phosphorous = $\frac{\text{milligram(Phosphorous)(in 50mL final volume)} \times 1000}{\text{miliitre sample}}$
COD	Measure the required or sufficient quantity of sample and reagents

	into a tube or ampule. Note the safety precautions. The overall volume must be equal to each reaction vessel and must be known for each component. Bring the sample to room temperature over time to prevent precipitation. The contents of the reaction containers should be blended with any insoluble materials and condensed water. Make sure the optical path is clear and give any particles in the air a chance to settle. Each sample's blank and standard absorbance should be measured at the chosen wavelength of 420nm or 600nm. Calculation: 50 mL (the final amount) = 1000 mL sample x mg P. Use a blank that hasn't been digested as the reference solution at 600 nm. Analyse a digested blank with reagent water in a place of sample to assess the quality of the reagent and estimate how much they contributed to the drop in absorbance during a particular digestion. Plot absorbance differences between digested samples and blanks versus COD levels to calculate sample COD. Create five standards using potassium hydrogen phthalate and COD equivalents following the same digesting procedures and reagent dosage. Use reagent water to dilute to desired volume. Create a curve for calibration for each new lot of tubes. Curves must all be straight. Depending on the instrument and the required levels of accuracy, deviations may develop Calculation: Chemical Oxygen Demand as milligram/litre = $\frac{\text{milligram/litre in final volume} \times 1000}{\text{millilitre sample}}$
BOD	The sample should be placed in a big bottle for BOD (>2 L) or six or lesser than BOD bottles each holding 300 millilitre. Before each bottle is airtight sealed, the DO content should be measured. Incubate at 20 °C in no light. Over a period of 30 to 60 days (or longer in unusual circumstances), take measurements of the DO in each bottle at intervals of at least 2 to 5 days (minimum of 6 to 8

	readings). Until nitrification has occurred, measure Dissolved Oxygen (DO) more frequently to prevent depletion of oxygen in samples having ammoniacal nitrogen. When Dissolved Oxygen (DO) reaches around two mg/L, reaerate as described below. Add one to two mL of sample from the reservoir bottle to replace the sample that was lost due to the displacement of the DO probe and cap. Reaerate when the DO reaches 2 mg/L and transfer a little bit of the sample inside a clean container, then vigorously shake or bubble the remaining sample inside the bottle with medical-grade filtered air. Measure DO after refilling the bottle with the storage reservoir. The subsequent measurement's starting DO is determined by this concentration. If you're utilizing 300-mL BOD bottles, combine all of the sample from the various bottles you used, reaerate, and then refill the little bottles. High-quality reagent water devoid of nutrients normally uses little more than 1 mg DO/L over the course of 30 to 90 days. Aim for a higher-quality dilution water for UBOD tests and report adjustment for DO absorption over 20 or 90days. A nonlinear regression method determines final BOD for weekly DO intake below 2%. For dilution water, use high-quality reagent water. Adding nitrification inhibitors is not necessary if desired degradation rates. Put an equal amount of seed and nutrients to the dilution water blank if they are required. The final sample of diluted BOD must, on average, fall between 20 and 30 mg/L. To achieve a level of dilution and prevent DO concentrations from dropping below 2 mg/L, two or three sample reaerations will likely be necessary. Use BOD bottles that are 2L or greater (or several 300-mL BOD bottles) for every dilution. Each bottle should be filled with dilution water after adding the desired amount of sample. To act as a water blank for dilution, add dilution water to a BOD bottle. The incubation period for the UBOD test must be at least as long as the incubation period for the

	blank. The following first-order model can be used to estimate UBOD: Calculation $BODt = UBOD (1 - e–kt)$ Therefore BODt = Uptake of Oxygen at time t, mg/L, and k = first-order uptake of oxygen rate.
pH	On-site condumetric using MRC pH meter model INE-M310F
TDS	In-situ using universal meter, Hannah HI-991300
Temperature	In-situ using PCE thermometer model T 318
EC	On-site conductrimetric using universal meter, Hannah HI-991300
PV	By using a diluted standard potassium permanganate solution, create calibration curve. For a certain cell length of the route and range create dilutions. Plot the absorbance (y axis) on the concentration of KMnO4 (x axis). Find the line that fits the points the best. Before doing any analysis, it is preferable to run a check for calibration using a recognized KMnO4 standard to make sure the equipment is in good operating condition. Check the spectrophotometer's zero with deionized water at 525 nm. Add 1 mL of CaCl2 solution per litre of sample water (111 mg/L as CaCl2) if the water is soft (i.e., has a CaCO3 hardness of less than 40 mg/L) to help remove any suspended particles and manganese dioxide left. Fifty millilitre of the sample must pass a filter of 0.22-m. Use two or three volumes of the filtrate to rinse the spectrophotometer cell. Check sure there are no bubbles of air in the solution or on the cell's sidewalls after filling it. At 525 nm, measure the absorbance (Reading A). Reduce the amount of time between filtering and reading absorbance for the best results. Then, put 0.1 mL of CaCl2 mixture to the 100 mL sample. In accordance with Reading A, add a solution of sodium thiosulfate n for 1 mg/L

	of KMnO4. Measure absorbance after going through a 0.22-m filter (Reading B). Calculation Absorbance = (A)–(B)

Appendix 4

Steps on how to use SPSS-Software to perform a paired-sample t-test

The test will be used to compare the parameters of untreated wastewater against treated wastewater values

1. Import your data into SPSS software by selecting “file” from the menu, and choose the file containing the data you want to use. Making sure the data is in a format that can be read by SPSS such as CSV or Excel.
2. Choose “variable view” to define variables, for example which variables represent water parameters before and after treatment.
3. Go to the “transform” tab to create a new variable representing the difference between wastewater parameters before and after treatment. Write a formula to calculate the difference between the two variables for example “after treatment-before treatment”.
4. Select “analyze” and “descriptive statistics” to run descriptive statistics to calculate means, standard deviations and ranges for the variables.
5. Conduct a hypothesis testing to compare the wastewater parameters before and after treatment by selecting “analyze” and select compare means for the two groups, followed by selecting “paired samples t-test”.
6. Interpret the results.

Appendix 5

Steps on how to use SPSS-Software to perform a one-sample t-test

The test will be used to compare the parameters of treated wastewater against standard values

1. Import your data you want to use into SPSS software by selecting “file” from the menu, and choose the file containing the data you want to use. Making sure the data is in a format that can be read by SPSS such as CSV or Excel.
2. Define “variable view” to define variables, for example which variables represent water parameters after treatment and those for standard quality values.
3. Select “analyze” and “descriptive statistics” to run descriptive statistics to calculate means, standard deviations and ranges for the variables.
4. Conduct a hypothesis testing to compare the treated water quality parameters against standard quality values. Select “compare means and then independent t-test to conduct a one-sample t-test.
5. Interpret the results.

Appendix 6

Visualizing data using Excel

1. Input data into your excel sheet, clearly labelling the treated wastewater parameter values and the standard values for each parameter.
2. Click “insert” tab to create an appropriate graph to visualize your graphs.
3. Interpret your results