MASTER DIPLOMA PIECE

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EFFICIENCY OF EFFLUENT WASTE TREATMENT USING CHEMICALS (FLOCCULANTS, COAGULANTS, AND DISINFECTANTS), FILTER MEDIA, AND PUMPING SYSTEMS

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MASTER DIPLOMA PIECE TASK STATEMENT

Name of the author of diploma piece: *TITO KIPKOROR KIBET*

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Consultant: Dr. Andrea Vágvölgyi assistant professor, Eszter Visiné Dr. Rajczi associate professor

Tasks set for writing the diploma piece:
1. Motivation for choice of topic, objectives.
2. To assess the processes of effluent waste management using chemicals, filter media, and pumping systems.
3. To compare untreated and treated wastewater based on parameters such as BOD, COD, pH, TSS, Color, E. coli, and Total Coliform.
4. To evaluate the application of flocculants, coagulants, filter media, and pumping systems in wastewater treatment.
5. To identify challenges associated with current effluent waste management technologies.
6. To evaluate the contribution of Water Engineering and Pumping Technologies in treating effluent waste from Kenafric Industries Limited in Nairobi, Kenya.
7. To draw conclusions from the findings and provide recommendations for sustainable wastewater management.

The length of the essay is not limited. Please prepare the diploma piece following the formal requirements for this type of work, submit 1 hardcopy an electronic version to the university repository in pdf format, identical to the hardcopy by the deadline specified in the study regulations for the academic year 2024/2025.

Sopron, 27 February 2025

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THIS THESIS IS DEDICATED TO MY PARENTS ROBERT KIBET AND JANE KIBET, AND BROTHERS SILA KIBET AND NOAH KIBET.

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EFFICIENCY OF EFFLUENT WASTE TREATMENT USING CHEMICALS (FLOCCULANTS, COAGULANTS, AND DISINFECTANTS), FILTER MEDIA, AND PUMPING SYSTEMS.

The treatment of effluent wastewater destined for discharge into the environment or sewer systems is a core step in ensuring our environment is safe and clean, especially in towns and cities. Although significant global development efforts have been underway to provide more people with access to sound water treatment infrastructure, a major segment of the population currently doesn't have access to an adequately improved water supply. As urbanization and industrialization continue to increase, and with major world concern for environmental sustainability, the successful execution of such treatment methods is necessary to achieve the world's goals for sustainability. This study aims to select and evaluate various chemical and physical treatment technologies to remove pollutants to acceptable levels so that the treated effluent can be declared fit for the environment.

This particular research study used a case study design based on information from Water Engineering and Pumping Technologies. The samples were taken from important areas of the treatment process from 3-1-2023 to 21-6-2023. The measured parameters are the pH, color, temperature, chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), *E. coli*, and total coliform. Compliance with the National Environmental Management Authority (NEMA) and international standards of wastewater and industrial effluents was established.

The results obtained for the influent and effluent were as follows: TSS Removal: Reduced from 2900± 92.03 mg/L to 10± 0.45 mg/L, COD Reduction: Decreased from 2300± 128.36 mg/L to 29± 1.96 mg/L, BOD Reduction: Lowered from 2100± 75.04 mg/L to 14± 0.28 mg/L, Color Removal: Reduced from 352± 10.34 mgPt/L to 9± 0.58 mgPt/L, Microbial Reduction: *Escherichia coli (E. coli)* completely removed; total coliforms reduced from 900 MPN/100 mL to 15 MPN/100 mL, and pH optimization from 4.5± 0.27 of influent, indicating high acidity to 6.9± 0.22 after treatment. The influent wastewater temperature was 29°C and was further reduced to 21°C.

The wastewater treatment process demonstrated high efficiency in removing pollutants, stabilizing water quality parameters, and ensuring compliance with NEMA and international discharge standards. However, continuous monitoring and process optimization remain essential to sustaining long-term performance and efficiency.

Keywords: Effluent treatment, Wastewater management, Flocculants, Coagulants, Disinfectants, Filter media, and Pumping systems.

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1 CHAPTER 1: INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The treatment of effluent wastewater intended for discharge into the environment or sewer systems is a critical step in ensuring the environment's safety and cleanliness, particularly in towns and cities. Although there has been a tremendous global commitment to broaden the piped-in improved water supply to the people, there are 663 million people who do not have the privilege of having an improved water supply (Hlongwa et al., 2024). Thus, this situation has gotten worse due to many factors, such as the rate of poverty and unemployment, the rate of population growth, and the rate of growth in urban areas (Hlongwa et al., 2024). In addition, these social and economic factors contribute to the declining water resources and infrastructure capabilities, especially in developing areas. Thus, these factors make them the main factors for improved effluent waste treatment facilities for safe water for discharge into the environment.

According to Aghalari et al. (2020), effluent waste treatment represents a systematic process through which wastewater, which is mixed from different sources, like manufacturing and processing industries, mining operations, and agricultural processes, is gotten rid of contaminants before being released back to the environment. When wastewater treatment is inadequate, it poses a serious risk to the ecosystem and human health (Crin & Lichtfouse, 2018). Aghalari et al. (2020) argued that the existence of effective effluent waste treatment facilities is an informative measure of a municipality's level of advancement and social welfare since the overall quality and the amount of wastewater that enters the effluent waste treatment facilities affect the nearby water supply resources to which the effluent waste treatment plants distribute their treated effluents. Over the years, the amount of wastewater produced in urban areas has increased due to the growing population and the increasing number of industries (Crini & Lichtfouse, 2018). These reasons and dependence on the same water resources require monitoring of the existing effluent waste treatment facilities to verify the quality of the wastewater released.

Effluent is a complex mixture of many pollutants. The sources of wastewater affect the combined pollutants, which will then result in effluent waste. According to Crini & Lichtfouse (2018), effluents are generated from all human activities, such as domestic, commercial, and agricultural activities, mainly because of the organic compounds and synthetic materials produced by the chemical manufacturing unit. The major pollutants emitted in the effluent are heavy metals, organic wastes, pathogens, microbes, suspended solids, oil and grease, along with chemicals (Lin et al., 2022).

According to Odumbe et al. (2023), industrial growth results in an increase in industrial activities, leading to significant deposits and wastewater contamination with heavy metals. This is followed by heavy metals that include lead, mercury, cadmium, arsenic, and nickel as elements with a total atomic weight above 5 g / cm3 and with a relative atomic mass between 63.5 and 200.6, which are the common sources of contaminates of freshwater, supplies because they directly affect human health and living things (Odumbe et al., 2023). They do not biodegrade, and because of their persistence in wastewater, they have demonstrated to pollute the natural world globally (Odumbe et al., 2023). One of the biggest problems in the world has been the leakage of heavy metals into the ecosystem, facilitated by the increase in industrialization and the increase in the number of houses in the metropolitan area. Therefore, wastewater effluent must be brought into focus regarding eliminating metal ions through effective wastewater treatment technologies.

Besides heavy metals, the other predominant pollutants of continuous effluent in water bodies are microplastics. Synthetic textiles and cosmetic products are often responsible for introducing microplastics directly into effluent due to the direct introduction of plastic to effluent or the degradation of plastics into small particles (Qaiser et al., 2023). According to Talukdar et al. (2024), microplastics are small bits of plastic measuring about 5 mm, and plastic determines their significance, as well as the consequences. The industrial water supply chain is further broken down into a series of phases, ending with effluent waste treatment plants, where microplastics are collected from several sources, ranging from commercial and industrial practices (Talukdar et al., 2024). Therefore, the effectiveness of such treatment plants is vital, given that they are the last resort for containing such pollutants from reaching the external environment.

Oil and grease are also significant pollutants that affect the natural environment as much as microplastics. They can be defined as organic hazardous waste with effects of disrupting aquatic life, plants, and animals, as well as effects of being carcinogenic and mutagenic to humans (Mokif et al., 2022). Oil and grease originate from many sources and always produce a coating over the surface of the water, reducing the amount of dissolved oxygen in the water (Mokif et al., 2022). Removing oil and grease is often a major challenge; therefore, technically effective treatment processes are necessary.

According to Chahal et al. (2016), wastewater effluent contains a number of pathogens that can be harmful to human health, including bacteria, viruses, and protozoans. Wastewater from various sources, mostly human and animal wastes, is polluted with pathogens. Chahal et al. (2016) explained that the removal of the pathogen can be done by chemical processes, including chlorine, UV radiation, or ozonation.

The other major pollutant in effluent wastewater, due to its serious effect on water quality, is suspended solids (Spence et al., 2023). The appearance of water and the mobility of aquatic life are reduced if desirable soils are suspended. Moreover, in water treatment, suspended solids are a great worry because they block filters and make the process more costly (Spence et al., 2023). Lastly, significant contaminants in wastewater are toxic and carcinogenic chemical pollutants that have long-term effects on the environment and other living things (Kolya & Kamg, 2024). Common chemical contaminants include dyes, paints, pesticides and herbicides, pharmaceuticals, and other persistent organic pollutants, such as polychlorinated biphenyls (PCBs). Kolya and Kang (2024) reported that chemicals vary in nature, concentration, and persistence, therefore, chemical pollutants require effective processes that remove all the different kinds of pollutants.

Water pollution is gradually becoming a challenge to many countries and environmental organizations (Hlongwa et al., 2024). The impact of effluent waste is significant globally, given that it normally affects human health due to waterborne diseases, disrupts aquatic life, and impacts economic development. The various contaminants, too, make up for ways that seriously affect human health. The untreated wastewater has many pollutants, including pathogens, leading to cholera, diarrhoea, and hepatitis (Hlongwa et al., 2024). Furthermore, exposure to persistent contaminants, such as heavy metals and other chemical impurities, can make a person susceptible to cancer. Lin et al. (2022) found that there are an estimated 829, 000 annual deaths from diarrhea caused by contaminated water and personal and hand hygiene, comprising 300,000 cases of young people under five years of age when these cases are counted together (5.3% of all deaths) (Lin et al., 2022). Research conducted in Palestine showed that people consuming water from the municipalities are prone to develop diseases, such as diarrhea, from those using desalinated and domestically filtered water (Lin et al., 2022).

Besides having a serious impact on the lives of humans and animals, effluent waste also destroys the environment. The harmful contaminants in the wastewater can enter the water bodies and harm aquatic life, resulting in a major impact on the food chain (Backhaus et al., 2019). Additionally, contaminants such as grease and oils decrease the quantity of dissolved oxygen in water bodies, causing hypoxia (Mokif et al., 2022). Besides having a serious impact on aquatic life, the wastewater pollutant can have a significant effect on an area's economy. According to Backhaus et al. (2019), these contaminants damage aquatic life and lead to decreased fish populations. They are also unsuitable for irrigation, given that the use of contaminated wastewater results in a decrease in the yield of crops.

Additionally, increased cases of waterborne diseases, particularly in most developing countries, like cholera, malaria, malnutrition, diarrhea, and typhoid fever, among others, lead to increased healthcare costs associated with expenditure incurred to treat and prevent diseases (Ngowi, 2020). Finally, in most cases, the investment in water treatment infrastructure to eliminate contaminants is costly. One example is the ecological cost of wastewater pollution in China in 2022 which was calculated to be 286.28 billion yuan, which accounted for 55.9% of the overall environmental damage expenditures or 1.71% of the gross domestic product (Huang & Wang, 2022).

Developing water treatment infrastructure is a critical concern in most developing countries (Hlongwa et al., 2024). These countries need effective and sustainable treatment technology to enhance water quality and also meet global sustainable goals (Hlongwa et al., 2024). Developed countries have implemented more modern treatment technologies. However, even with advanced treatment methods, they still face several major obstacles, especially in handling new contaminants, including plastics and pharmaceutical products.

Considering the large variety of pollutants in wastewater effluent treatment, there is a great need for combining technologies, that is, chemical and physical methods, to ensure effective treatment of wastewater. Each treatment technology is used depending on the characteristics of pollutants and the required level of treatment (Talukdar et al., 2024). These treatment methods are common chemical methods, including coagulants, flocculants, and disinfectants. Besides chemical treatment, available common physical treatment technologies include Filtration, sedimentation, and screening (Talukdar et al., 2024).

Coagulation water treatment is the starting point of chemical treatment technologies (Aragaw & Bogale, 2023). This is in contrast to particulate flow, which regularly shuffles through the filtration system to enable debris to descend too slowly on the way to being covered up in coagulation wastewater treatment (Zaharia et al., 2024). By introducing an environmentally friendly substance such as alum, most of the fragments are forced to take positive electrical charges so that they may aggregate together and become easier to remove in subsequent treatment processes.

Flocculation is used, together with coagulation, in effluent waste treatment. After coagulation, clumps formed by contaminants are removed with flocculating chemicals (Zaharia et al., 2024). They are lightweight, medium-weight, and large polymer compounds that float in the solution and cause poor material clumps to collect and slide out of the solution, removing them entirely from water undergoing treatment (Zaharia et al., 2024). As a result of its simplicity and affordability, coagulation and flocculation technology are the most common systems used in wastewater treatment (Aragaw & Bogale, 2023). It is also used as an initial filter treatment to reduce filter clogging.

Disinfectants are another chemical method of effluent treatment that is mainly used. The effluent waste disinfection prevents humans from coming in contact with waterborne pathogenic microbes (Shi et al., 2021). The effluent treatment uses mainly chlorine, ozone, and ultraviolet radiation as disinfectants. Chlorine is mainly used in municipal and industrial effluent waste treatment facilities as it is effective against several microorganisms and is also highly cost-efficient (Shi et al., 2021). In contrast, ozone is a strong oxidizing agent employed in advanced wastewater treatment, where the quality of the effluent must be quite high. When introduced into the wastewater, ozone immediately starts to work and cannot leave a residue since it breaks into oxygen (Shi et al., 2021). Tertiary effluent waste treatment uses ultraviolet (UV) radiation to protect against the reproduction of microorganisms. Also, as indicated by (Shi et al., 2021), UV radiation leaves no harmful environmental effects.

The physical wastewater treatment methods, particularly Filtration and sedimentation, are equally important. The methods under consideration are mainly used depending on the characteristics of waste materials (Sathya et al., 2022). Usually, the same methods are used to eliminate suspended solids and dissolved pollutants. According to Sathya et al. (2022), filtration is a simple process of passing wastewater through a porous medium to remove pollutants. The three types of filtration systems are sand filtration medium, gravel filtration, and membrane filtration. On the other hand, the sedimentation process is gravity-driven, whereby pollutants settle at the bottom of the collection tank. In this case, the process relies mainly on reducing the stream of water to allow the transport of particles down the tank (Juraev et al., 2022). Discrete sedimentation, flocculant sedimentation, and zone settling are the main types of sedimentation.

Therefore, knowledge of these treatment methods and their effective implementation is imperative, especially given the expansion of urbanization and industrialization, in addition to serious global concerns over environmental sustainability. This study seeks to evaluate the effectiveness of various chemical and physical treatment technologies in removing pollutants.

1.2 PROBLEM STATEMENT

The waste from industries, agricultural processes, and municipal areas has high concentrations of pollutants and thus poses serious risks to the environment, specifically the quality of water and the ecosystem. Conventional wastewater treatment facilities, particularly in developing countries, face several challenges, such as inadequate removal of contaminants and high operational costs. As such, the utilization of flocculants, coagulants, disinfectants, filter media, and pumping systems offers a better approach to solving some of the challenges. As the demand for water due to increased population and industries around the world increases, there is a need for effective and economically and ecologically sustainable effluent waste treatment methods. Although the use of these numerous treatment methods has been widely implemented, the efficiency of these methods has not been extensively explored. Hence, this study seeks to evaluate the efficiency of the different chemical and physical treatment technologies, including coagulation, flocculation, and the use of disinfectants, filter media, and pumping systems.

1.3 OBJECTIVE OF THE STUDY

1.3.1 Main objective

The primary objective of this study is to evaluate the efficiency of effluent waste treatment by employing a combination of chemical treatment methods (flocculants, coagulants, and disinfectants), filter media, and pumping systems.

1.3.2 Specific objectives

1. To assess the efficiency of chemical treatment in removing pollutants from wastewater.
2. To evaluate the role of filter media in enhancing the removal of pollutants.
3. To examine the impact of pumping systems in enhancing the efficiency of treatment systems.

1.4 RESEARCH QUESTIONS

1. What is the efficiency of chemical treatment methods in removing pollutants?
2. How do different types of filter media contribute to enhancing the removal of pollutants in effluent waste?

3. What is the impact of pumping systems on enhancing the efficiency of treatment systems?

1.5 SCOPE AND LIMITATIONS OF THE STUDY

This study is confined to investigating the efficiency of effluent waste treatment technologies employed by Water Engineering and Pumping Technologies (WET) in Kenya through the use of various approaches, such as chemical treatment, filter media, and pumping systems. The study will focus on assessing the effectiveness of flocculants, coagulants, and disinfectants in removing pollutants. Additionally, it will evaluate the role of filter media and the impact of pumping systems on the operational efficiency of the treatment systems.

While the study aims to provide extensive insights into the efficiency of treatment systems, certain limitations may impact its scope. The study's duration may restrict the observation of long-term effects of treatment systems, including clogging of filter media and formation of by-products.

1.6 SIGNIFICANCE AND EXPECTED CONTRIBUTIONS

The results of this study will be useful in tackling the worldwide problem of polluted wastewater and the necessity of efficient and ecologically sound treatment techniques. This research study will contribute to preserving the health of aquatic ecosystems by enhancing the removal of pollutants. Additionally, through this research study, the integration of various treatment technologies will pave the way for better innovative methods of treating wastewater. Moreover, the findings of this study will identify treatment combinations that allow for efficiency and cost-effectiveness. Lastly, this study will provide useful insights for researchers and policymakers through publications and presentations.

2 CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION AND OVERVIEW OF EFFLUENT WASTE POLLUTION

Globally, a nation's industrial development can determine its overall growth (Sathya et al., 2022). Depending on the commodities it produces, the manufacturing industry can take many different forms. Increased industrialization and its concentration within or close to towns and cities have put extreme strain on the sustainability of the environment in certain areas. In these kinds of places, the discharge of pollutants into water sources, including rivers, lakes, and ocean waters, has usually had a negative impact (Sathya et al., 2022).

Effluents are mainly wastewater arising from various human activities related to industrial processes such as manufacturing and raw material processing (Azanaw et al., 2022). Some specific examples of wastewater sources include washing, heating, the extraction process, and the reaction of unwanted chemicals. Wastewater treatment is necessary in order to reduce impurities sufficiently and provide safe water for consumption (Azanaw et al., 2022). This measure is also critical in managing health and socio-economic concerns.

Ensuring that water for consumption is safe, the effective management of wastewater is essential. According to Esteki et al. (2023), the amount and the quality of industrial effluents are determined by the method of manufacturing, the materials that are used, and the final products that constitute each operational facility; thus, the chemical makeup of production discharges differs throughout industries. Hence, effluent waste treatment fails to achieve the required water safety standard. As such, there is an increased need to adopt more robust water treatment methods.

The combinations of physical and chemical effluent wastewater treatment techniques, including flocculation and coagulants, filter media, and disinfectants are critical and becoming ever more essential, particularly in urban areas, as well as commercial wastewater treatment in satisfying their reused water safety standards while maintaining the health of people (Azanaw et al., 2022). The primary function of these methods is to remove dissolved and particulate contaminants, distinctive metals, and other effluent waste constituents.

2.2 INDUSTRIALIZATION AND ITS ENVIRONMENTAL IMPACTS IN NAIROBI, KENYA

Industrialization is a vital component of economic expansion in any country, whether developed or undeveloped (Kyule & Wang, 2024). In Kenya, the vision of industrialization is at the center of the Vision 2030 initiative that seeks to transform the nation into a middle-class economy (Kyule & Wang, 2024). The development of industrial infrastructure in Kenya is mainly in the capital city. Because of its advantageous position, facilities, and economic policies, Nairobi, the capital of Kenya, has developed into a major industrial center since the middle of the last century. Nairobi's industries include manufacturing, agricultural processing, textile manufacture, chemicals, energy, and building construction. According to Kiongo et al. (2021), the data from the Kenya National Bureau of Statistics, Kenya had a total of 4861 industries, all classified as manufacturing, and at least 54 were found within Nairobi.

The industrialization of the metropolitan area has been vital to its economic growth, generating jobs and boosting Kenya's gross domestic product (Kyule & Wang, 2024). Nevertheless, this expansion has come at a high expense to the environment due to the lack of strict regulations and ecologically sound procedures have contributed to pollution of the air, water resources, and soil, as well as health hazards for local populations (Kiongo et al., 2021).

The industrialization that has taken place in Nairobi has led to the discharge of more effluents into the water sources (Bagnis et al., 2020). Among the biggest environmental issues in Nairobi, polluted water is directly connected to the city’s expansion. According to Bagnis et al. (2020), contamination of water within the metropolitan area is a result of effluent discharge into rivers. Water resources like the Nairobi and Athi Rivers often receive untreated or partly treated industrial wastewater discharges.

According to (Kiongo et al., 2021), heavy metals such as lead, cadmium, and chromium are also higher in water resources than the permissible limit WHO prescribes. These metals often originate from manufacturing sectors, including pharmaceuticals, soap, and paint industries. Kiongo et al. (2021) conducted a research study aiming to determine different kinds of waste generated by companies, evaluate the management and disposal of the trash, and investigate the impact of wastewater discharge on the Nairobi River. The findings indicated that there are four types of wastes generated, including solids, liquids, chemicals, as well as thermal wastes. They also pointed out that managing waste was ineffective as there were poisonous materials in the water and the soil (Kiongo et al., 2021). These results indicate the significance of pollution on the water for consumption and, in this case, warrant the sufficiency of the measures to eliminate these effluents.

2.3 EFFLUENT TREATMENT METHODS AND TECHNOLOGIES

Effluent waste treatment and management solutions are critical for enabling industries to attain their quality and safety goals for reused water (Esteki et al., 2023). Effluent treatment involves a combination of chemical and physical methods, suitable especially for different industrial needs. Obayomi et al. (2024) contend that the efficiency of a treatment method is very important in creating policy and technology advancement in a country.

2.3.1 Chemical Treatment

Chemical treatments are extensively utilized to destabilize and remove suspended particles, pathogens, and dissolved pollutants (Obayomi et al., 2024). This method is based on the physical or chemical change that allows for easy removal of contaminants (Esteki et al., 2023). Chemical treatment deals with organic and inorganic contaminants. Important chemical treatment methods include coagulation, flocculation, and disinfectants (Esteki et al., 2024). Agglomerate and settle suspended particles are treated by many coagulants and flocculants, such as alum, polyaluminium chloride (PAC), and polyacrylamide (PAM) (Esteki et al., 2024). Disinfectants like chlorine are also used to reduce the risk of pathogen transmission.

2.3.1.1 Coagulation and Flocculation

Water coagulation is a common phenomenon in natural and chemical systems; however, this is also an augmented treatment system due to its usefulness in water treatment (Cui et al., 2020). The coagulation process converts negligible particles into bigger particles (flocs) and dissolved organic matter into granular clusters (Cui et al., 2020).

Azanaw et al. (2022) explained that flocculation is a water treatment process in which solids produce larger floating particles that are then removed from the water. It may happen spontaneously or through the application of synthetic agents. Physical processes lead primarily to the breakdown of sedimentation in flocculation compared to chemical processes (Azanaw et al., 2022).

The mechanism for organics removal with the coagulation is composed of three primary components, which include first electrically destroying, weakening, and pulling the organics together through the positively charged metal ions and the naturally produced particles having negative charges; second, metal ions and dissolving naturally occurring compounds build insoluble solutions and precipitates; and third, organic substances are physically and chemically adsorbed on the alum surface (Cui et al., 2020). For advanced water and wastewater treatment, coagulation processes are implemented based on existing water purification facilities with a match of operational parameters to the following and preceding process flow rates (Cui et al., 2020).

A treatment process that includes multiple-layer filtration with decontamination of coagulation and flocculation systems can remove chemical, physical, and microbiological characteristics to such an extent that it is capable of being exhausted for use in both irrigation and specialized purification systems (Obayomi et al., 2024). In a research study, Esteki et al. (2024) explored the advanced treatment technologies being applied at a wastewater purification facility utilizing coagulation and flocculation to improve wastewater quality and reuse it in different industries. The coagulants used were polyaluminum chloride and Alum. The results of this study showed that the coagulation and flocculation processes eliminated turbidity, total suspended solids, total dissolved solids, fat, and chemical oxygen demand at percentages of 56.88, 46.66, 38.00, 23.19, and 91.43, respectively (Esteki et al., 2024). These findings demonstrate the effectiveness of coagulants and flocculants in reducing the major contaminants.

2.3.1.2 Disinfectants

Disinfectants are important in destroying pathogens (Sathya et al., 2022). Chlorine, ozone, and UV radiation are the most common disinfectants. Greenish-yellow gas, chlorine, can turn liquid when subjected to extreme stress. Chlorine added to water kills many harmful microorganisms (Sathya et al., 2022). Tertiary treatment also makes use of ultraviolet rays frequently. UV light disinfects microorganisms by breaking bonds of molecules in DNA, RNA, proteins, and radiation (Obayomi et al., 2024). Ozone has been used extensively as a potent disinfectant and oxidant in European water treatment plants since 1906 (Cui et al., 2020). Ozone is primarily used to purify, destroy color, remove algae, and, in the case of inorganic contaminants, minimize them. The benefits of ozone in water purification include: first, ozone destroys chlorine-resistant infectious agents and microorganisms. Second, wastewater pH and ambient temperature do not affect its work. It also removes color, scent, and chemical compounds from sewage, increases the oxygen dissolved content, and improves water quality (Cui et al., 2020).

2.3.2 Physical treatment

Physical effluent waste treatment methods complement chemical treatment. They help remove remaining contaminants and solids (Sathya et al., 2022). The treatment methods only depend on physical techniques without altering the chemical composition of contaminants.

2.3.2.1 Filter Media

Materials used in the filtration systems are called filter media. These materials are physical barriers or absorbents that help in the purification of water. Loh et al. (2021) mentioned the common filter media types, including granular, activated carbon, synthetic, and biofilter media. Azanaw et al. (2022) defined activated carbon as capturing reactive organic pollutants and eradicating any residual quantities of chemical compounds, including nitrogen and toxic metals. Esteki et al. (2024) explained that the usual range of the output Biological Oxygen Demand (BOD) and chemical-oxygen-demand (COD) ranges from 2 to 7 (mg/L) and 10 to 20 (mg/L), respectively, following the activated carbon procedure. The output COD can be lowered to less than 10 (mg/L) in ideal circumstances.

2.3.2.2 Pumping systems and settling tanks

Effluent waste treatment requires pumping systems and settling tanks to manage, transport, clear and treat effluent wastewater. The pumps in a pumping system include centrifugal, submersible, and diaphragm pumps. The pumps used are different according to the nature of the wastewater and the treatment plant requirements (Johnson et al., 2021). Another case is settling tanks, usually called across tanks or clarifiers, which are necessary for the primary and secondary treatment of wastewater processes (Sathya et al., 2022). The solid waste materials are suspended, and others destroyed in the tanks by sedimentation.

The continuous purification efficiency after coagulation can also be improved by sedimentation, as (Sathya et al., 2022). Specialization is required for disinfection tanks for sedimentation wastewater. The reinforcement for doing so is provided by a sedimentation tank (Sathya et al., 2022). In a study by Micek et al. (2020), the effluent removal efficiency of four onsite primary sedimentation tanks used in onsite wastewater treatment was studied. BOD, COD, total solids, total nitrogen, and total phosphorus were tested as the parameters. The reported results mean contaminant removal efficiencies were 68.3% (TSS), 50.4% (BOD) and 49.5% (COD) (Micek et al., 2020). However, the finding was that the tanks were insufficient to remove the biogenic compounds (Micek et al., 2020). Both of these findings are interpreted to mean that wastewater treatment cannot be effectively performed in the continuous purification process without using specialized settling tanks.

2.4 CHALLENGES IN EFFLUENT WASTE MANAGEMENT

Effluent waste management is an important environmental and national public health issue. Over the years, wastewater treatment and management technologies and systems have been developed to improve the quality and security of drinking water (Onu et al., 2023). However, there has been utmost effort in managing effluent waste, but little remains in the field (Onu et al., 2023). According to Omohwovo (2024), among other challenges, one major obstacle to wastewater treatment is the existence of inadequate wastewater treatment plants in many countries. Other than the absence of proper treatment facilities, wastewater quality inspection is often insufficient. According to Omohwovo (2024), some laboratories only monitor a limited number of parameters due to scarce implementation resources in the form of effective measurement equipment.

Moreover, many countries lack proper institutions, the fragile legislative frameworks, and inadequate water resource allocation that impede progress towards achieving the Sustainable Development Goals regarding wastewater management (Omohwovo, 2024). Wastewater treatment centres, as well as getting good monitoring systems, are hard to improve because of financial limitations (Omohwovo, 2024). These issues need comprehensive strategies, more investments and cooperation to set up wastewater management systems that prioritize and respect the safeguarding of the environment and public health.

2.5 CHALLENGES ASSOCIATED WITH CURRENT EFFLUENT WASTE MANAGEMENT TECHNOLOGIES.

According to Omohwovo (2024), the prevalence of ineffective effluent treatment infrastructure in many nations contributes to major challenges in wastewater treatment. Additionally, despite significant advancements in modern effluent waste treatment methods, several persistent challenges still undermine the efficiency of the treatment technologies. Omohwovo (2024) argued that chemical treatment methods, particularly coagulants, often face issues related to dosage optimization and residual toxicity. The chemical agents leave behind harmful byproducts as a result of the chemical residuals, thereby necessitating additional treatment steps.

The most common traditional compounds used for coagulation are solutions composed of iron or aluminum (Diver et al., 2023). Metal-based coagulating agents are most frequently used due to their many benefits, such as affordability, accessibility, and ability to remove turbidity, total suspended particles, and COD with removal performance of up to 98.8%, 99.7%, and 92.3%, respectively (Diver et al., 2023). However, the application of such metal-based coagulating agents to water detoxification does not come without challenges. Given that they decrease alkaline levels, they can influence the pH of the water; therefore, lime or sodium bicarbonate might have to be introduced to restore the appropriate pH values (Diver et al., 2023). Furthermore, excessive amounts of sludge are produced when metal-based coagulants are used, and the sludge contains persistent metals.

Besides the challenges associated with chemical treatments, physical treatment methods, particularly filter media, tend to suffer from clogging and reduced filtration efficiency, thereby contributing to increased maintenance costs and operational downtime (Sorrentino et al., 2025). According to Puteri et al. (2025), solid particles and plant residues are the main causes of clogging. In addition, the use of the wrong type of filter medium may cause premature clogging due to the accumulation of specific particles (Puteri et al., 2025). These challenges underscore the requirement for integrated and adaptable solutions that maintain the required treatment efficiency but exhibit minimal environmental impact.

3 CHAPTER 3: METHODOLOGY

3.1 RESEARCH DESIGN

This research examines the efficiency of integrated wastewater systems through a case study. Hence, the study was experimental and qualitative, with a qualitative assessment of treatment approaches incorporated. This research design provided an overall perspective of the role of the treatment methods used and the comprehension of the removal process of contaminants from wastewater.

In this regard, the quantitative analysis of the treated water parameters was obtained from laboratory experiments before and after the treatment. The major parameters were pH, BOD, COD, color, TSS, and temperature. Given the nature of the numerical data of the research, such an approach was useful in forming objective methods for evaluating the efficiency of the treatment, hence providing a balance between the accuracy of the concluding arguments.

Qualitative aspects of the research included evaluating the operational performance of wastewater treatment systems. The system considered other factors such as reliability, maintenance requirements, energy efficiency, and ease of implementation. Using quantitative and qualitative analysis methods, effluent treatment performance can be evaluated in terms of technical efficiency and operational viability.

This research used various stages of the treatment process as the data source. Furthermore, the data were collected daily over several six months to establish the discoveries' dependability, consistency, and comprehensiveness. The treatments were at various stages, including pre-treatment-treatment, screening, primary treatment (sedimentation and chemical addition), and filtration treatment. The data collection and analysis processes followed the standards of the National Environmental and Management Authority (NEMA) on acceptable water quality assessment parameters. Furthermore, several statistical methods, such as effluent removal efficiency calculation, trend analysis, and assessing process stability, were applied to the study to evaluate the treatment process thoroughly.

Given the objective of this study, it was appropriate to use the case study design since it provides an opportunity to evaluate an individual's effluent waste treatment facility thoroughly. The study design differs from extensive surveys or comparative studies as it ensures an exhaustive assessment of the technology performance of the effluent waste treatment process. Additionally, this method enables the evaluation of the treatment process on a stage-by-stage basis to obtain the contribution of each treatment phase to the treatment process as a whole.

3.2 CASE STUDY OF WATER ENGINEERING AND PUMPING TECHNOLOGIES

3.2.1 Overview of the Kenafric Industries Wastewater Treatment Facility

This research study's case study is the wastewater treatment plant for the Kenafric Industries facility. The wastewater treatment plant is a fully automatic and combined effluent treatment system that processes about 1 million litres of polluted water at each interval. Chemical, physical, and biological methods are utilized to discharge water properly according to environmental requirements.

Treatment of the facility is described in terms of applying chemical methods, including coagulants, flocculants, and disinfectants. Secondly, the facility's physical treatment methods are sedimentation and filtration. All the treatment plants use automated process control, which means that the amount of chemicals going into the plants is precisely equal to the amount of wastewater being treated. The integrated pumping technologies and automated systems bring the treated wastewater through all the treatment stages.

3.2.2 Effluent Waste Treatment Flow Process

3.2.2.1 Raw Wastewater Collection

The effluent waste treatment process begins with the collection and temporary storage of raw wastewater in an underground tank. The wastewater collection chamber is a 30 m^3 underground steel tank at Kenafric Industries. The facility has an underground storage system that can accommodate 1 million liters of effluent waste per cycle, so the flow into the next treatment stages will be controlled. The large capacity of storage facilitates the management of varying wastewater quantities from various industrial processes. Additionally, the storage tanks allow for the correct volume of wastewater during each treatment cycle, thereby preventing fluctuations in loading rates.

Underground tanks are also a key feature in the treatment process since submerged tanks prevent temperature fluctuations, insulating from surface temperature variations. Furthermore, unlike open-air storage tanks, underground collection chambers help minimize external contamination by isolating it.

Underground collection tanks also serve an important role in ensuring a steady flow prior to the treatment process. The wastewater is released from the storage tanks through the pumps and the automated flow control valves. For this reason, the subsequent treatment stages receive an equal volume of wastewater, reducing overload. Aside from that, a continuous flow of wastewater helps to increase the accuracy of chemical dosing and the liquid dissipation of solid waste.

3.2.2.2 Chemical Treatment: Coagulation and Flocculation

The key step of the process at Kenafric is chemical treatment, where wastewater is made free of contaminants. The process of coagulation is whereby chemical coagulants are added to destabilize and aggregate fine particles. The other process is flocculation, in which small aggregates come together to create larger aggregates, which are easier to remove.

Coagulation

The coagulants are then pumped into the wastewater, coagulants are then pumped into the wastewater and are dosed in precise amounts by automated chemical dosing units. The main coagulants added are liquid alum (aluminium sulphate) and liquid PAC (poly aluminium chloride). The primary goal is to destabilize the colloidal particles and allow them to form aggregates. The liquid Alum dosing target is 83.4 mL/s, and the PAC is 55.6 target mL/s. The doses to be administered depend on the specific parameters of the wastewater being treated and are specific to the optimization of the performance of the coagulants.

Once introduced into the wastewater, the coagulants neutralize the negative surface charges of colloidal particles, thereby permitting the colloidal particles to join small aggregates. Most contaminants have negative charges; therefore, the main coagulants carry positive charges, neutralizing these charges and preparing the wastewater for the flocculation phase of the water treatment process.

Flocculation

After the coagulation process, wastewater flows into a flocculation column. Inside the flocculation column, the wastewater is gently mixed, resulting in the formation of large and more stable flocs. Automated controls equipped in the treatment system enhance the separation efficiency through the regulation of the mixing speed and duration, as well as the floc size and density.

Premix Tank

Prior to entering the clarification unit, the wastewater is directed temporarily to a premix tank (Figure 1). The primary functions of the premix tank are to ensure a uniform flow rate to prevent hydraulic shocks in subsequent stages and to enhance the floc stability, which limits floc disintegration by providing steady mixing conditions.

Figure 1: Premix Tank

Clarification Units

The main function of the clarifiers is the separation of the majority of the suspended solids and flocs from the wastewater. The principle by which clarifiers work is gravity sedimentation. The heavier clumped particles settle at the bottom more easily, while the lighter ones move forward. The wastewater is introduced into the clarifier steadily to prevent turbulence and ensure easy settlement of the particles (Figure 2).

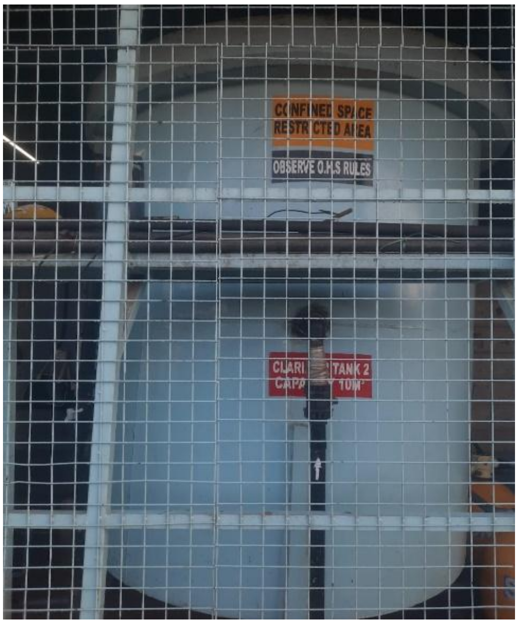

Figure 2: Clarification Tank.

Settling Tank

Settling tanks, also known as sedimentation tanks, are crucial in removing suspended solids from the partially treated water prior to the filtration stage (Figure 3). This process occurs as a result of gravity-driven sedimentation. Additionally, the sedimentation tanks increase the concentration of settled sludge, thereby reducing water content before further treatment.

Figure 3: Settling Tank.

Filtration

After coagulation, flocculation, and settlement, the chemically treated wastewater is pumped into the filtration using filter pumps. The filtration unit is fitted with a multi-layer media system that plays a significant role in removing the remaining suspended solids, fine particles, and organic matter (Figure 4). Cescon & Jiang (2020) indicate that the filter media is changed manually every three months to maintain the best efficiency filtration unit. Since clogging, maintaining flow rates, and increasing contaminant removal are essential with this periodic maintenance. The filtration layers include:

Coarse sand layer.

This is the first stage of the filtration process, where large particles are removed. The layer consists of granular and medium to coarse sand.

Fine sand layer.

It is the second stage of the filtration process and contains finer sand particles. The main purpose of this layer is to trap smaller suspended solids that pass the first stage.

Activated carbon layer.

It is the third stage of the filtration phase and is made up of granular activated carbon. Its primary function is the absorb dissolved organic compounds, residual color, and trace contaminants. Additionally, it enhances the removal of the wastewater odor and taste.

Figure 4: Filter Media pots

pH Adjustment

After the filtration process, pH adjustment is conducted to optimize the chemistry of the water. This step is crucial since it ensures that the pH of the treated water is stable to prevent corrosion. The main aim of the pH adjustment is to attain near-neutral to slightly basic pH conditions. pH adjustment is done through the introduction of low-dosage Sodium Hydroxide

(NaOH) solution into the treated water. The system is designed to achieve a final pH of about 7.2.

Continuous Monitoring and Effluent Release

A digital online pH meter is used to continuously monitor the pH levels of the treated water (Figure 5). The real-time monitoring and control ensure that overdosing or under-adjustment of the pH is prevented. Continuous monitoring of the water parameters is conducted to ensure that they meet the requirements of the National Environment Management Authority (NEMA) before it is released. An electric control panel is also installed to serve as the central control unit for managing and automating all electrical and mechanical processes involved in the treatment process (Figure 6). The key functions of the electrical control panel include the control and automation of pumps, the regulation of doses, motor control, and sensor integration. Besides pH level meters, turbidity sensors are set up to measure clarity and conductivity probes as well, in order to assess the presence of ions, thereby ensuring salinity remains at the required levels.

Figure 5: Online pH meter

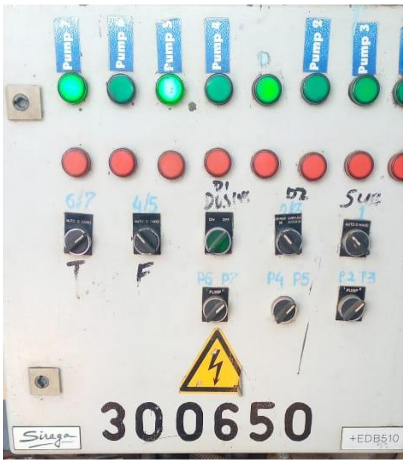

Figure 6: Electric Control Panel

3.3 MATERIALS AND METHODS

3.3.1 Data Collection.

The collection of samples followed a standardized approach to record the temporal variations and assess the treatment efficiency at different stages of wastewater treatment. The samples were collected from various critical points of the treatment process from 3rd January 2023 to 21st June 2023. First, samples of untreated effluent were collected from the underground raw wastewater collection tank. The second stage of sample collection was conducted after chemical treatment and then after the filtration unit.

The samples were collected every 24 hours to accommodate the diurnal variations in the wastewater parameters. Additionally, the data samples were collected at each point in three separate containers to ensure the reliability of the findings. The samples were then transported to the laboratory for quality analysis.

3.3.2 Sampling techniques

This study employed the sampling techniques that were used to obtain accurate as well as representative data over a period of 6 months. Different stages of the wastewater treatment were sampled daily to evaluate system performance over time. The revised sampling methodology is outlined in the following steps, and the key parameters recorded during the study are focused on:

1. **Sampling Frequency and Duration**
   - Frequency: Samples were collected daily for a total of 6 months.

- Duration: The sampling period spanned from Month 1 to Month 6, allowing for the assessment of daily variations and long-term treatment efficiency.

2. **Sampling Locations**

   Samples were collected at strategic points in the treatment process to evaluate the efficiency of each stage. The key sampling locations included:

   1. **Raw Influent:**
      - Collected from the underground raw wastewater storage tank before any treatment.
      - This sample represents the initial wastewater quality before any treatment processes.
   2. **Post-Chemical Treatment:**
      - Collected after the coagulation and flocculation stages.
      - This sample assesses the effectiveness of chemical treatment in removing suspended solids and other contaminants.
   3. **Post-Filtration:**
      - Collected after the multi-layer filtration process.
      - This sample evaluates the performance of the filtration system in removing fine particles and dissolved organic compounds.
   4. **Post-Disinfection/Oxidation:**
      - Collected after the disinfection and oxidation stages.
      - This sample measures the effectiveness of disinfection in reducing microbial contaminants and oxidizing residual organic matter.
   5. **Final Effluent:**
      - Collected from the clarifier before the treated water is released.
      - This sample represents the final treated water quality and is used to assess compliance with regulatory standards.

3. **Parameters Recorded**

   The following key parameters were recorded during each daily sampling event:

   1. **pH:**
      - Measured using a calibrated pH meter (American Public Health Association APHA 4500-H B).
      - Indicates the acidity or alkalinity of the wastewater.

2. **Color:**
    - Analyzed using the APHA 2120 B method.
    - Measures the presence of dissolved organic compounds and other color-causing contaminants.
3. **Temperature:**
    - Recorded using a calibrated thermometer (APHA 4500-S2-F).
    - Monitors the temperature of the wastewater, which can affect treatment efficiency.
4. **Chemical Oxygen Demand (COD):**
    - Analyzed using the APHA 5220 C method.
    - Measures the amount of oxygen required to chemically oxidize organic matter in the wastewater.
5. **Biological Oxygen Demand (BOD):**
    - Measured using the APHA 5210 B method.
    - Indicates the amount of oxygen required by microorganisms to biologically degrade organic matter.
6. **Total Suspended Solids (TSS):**
    - The APHA 2540 D method is employed to determine TSS.
    - Provides the concentration of suspended particles in the wastewater.
7. ***E. Coli:***
    - They were analyzed using the APHA 9223 A method.
    - That indicates the presence of fecal contamination in the wastewater.
8. **Total Coliform:**
    - The APHA 9223 A method is applied to analyze them.
    - Measures the overall microbial contamination in the wastewater.

3.4 LABORATORY ANALYSIS

The described parameters, Chemical Oxygen Demand, pH, Color, Temperature, Total Suspended Solids, and Biological Oxygen Demand, were analyzed with the help of the Laboratory Standard American Public Health Association (APHA) methods. Some organizations prepare the water and wastewater samples for dispatch, but in the United States, it is the American Public Health Association (APHA). APHA is a professional organizational body in America, employing and publishing scientific standards of water and wastewater to ensure that the certification methods used have certain qualities to address the requirements (Baird et al., 2017). The aforementioned treatment system formed the basis on which the treatment system was systematically examined and evaluated from all angles every single day for six months. The laboratory analysis procedures used in this experiment and the method to record the data are given below:

1. **pH**

Method: APHA 4500-H B

Instrument: An integrated table pH meter that is supported by sensors is used.

Procedure:

Procedure:

Sample collection and preparation: A sample of wastewater is collected into a clean 250 mL beaker or glass container. To avoid contamination of the electrodes, the suspended solids or debris in the sample are allowed to settle or be filtered using a mesh.

pH meter calibration: Make sure the pH meter is properly calibrated before using it. Standard buffer solutions of known pH, i.e., pH 4.00, pH 7.00, and pH 10.00, are used to calibrate. Place the electrode in the distilled water and turn on the pH meter. Blot the electrode gently (not rubbing directly) with lint-free tissue paper.

Measurement: Following this, immerse this electrode in the wastewater sample so that the sample encompasses the electrode homogenously and the side or the bottom of the container is not in contact with the sample. Look at the display screen and read the meter for 30–60 seconds until the pH value stops fluctuating and remains steady. If necessary, the sample should be stirred with a glass rod or a magnetic stirrer to keep the electrode well mixed, evenly with no air bubbles around it. After measurement, wash the electrode with distilled water and withdraw it from the sample to avoid cross-contamination. To ensure efficiency, it is recommended that the electrode be kept in the electrode storage solution or in a pH 4.00 buffer solution when not in use.

Frequency: Daily.

2. **Total Suspended Solids (TSS):**

Method: APHA 2540 D

Procedure:

Filter Preparation: First, dry the glass fiber filter in a watch glass and in an oven at 105°C for 1 hour. The filter is dried, removed by forceps, and transferred to a desiccator for cooling for at least 30 minutes. After cooling, weigh the dried filter on an analytical balance and note the initial weight of the dried filter (W_1) in milligrams (mg).

Sample Filtration: Then, set up the filtration apparatus and put the pre-weighed filter into the holder. Thoroughly shake the water sample, then take 500 mL of the well-mixed sample using a graduated cylinder. Measure the sample and carefully pour the measured sample onto the filter and apply vacuum suction for filtration. Rinse the filter and retained solids with 20 mL of distilled water after filtration to remove any dissolved substances that could interfere with the results.

Post-Filtration Drying and Weighing: After filtration is complete, take care to remove the filter and replace it in a clean watch glass. Place the filter on the watch glass and transfer the watch glass with the filter to the oven and dry at 105°C for at least 1 hour to remove all remaining moisture. The filter is dried and placed in a desiccator and allowed to cool for 30 min. Weigh the filter again when it is cooled and record the final weight (W_2) in milligrams (mg).

Calculation and Reporting: Then, the Total Suspended Solids (TSS) concentration in the sample is calculated by:

$$TSS(\frac{mg}{L}) = \frac{(w_f - w_i) \times 10^6}{V} \quad \text{Equation 3.1}$$

where W_1 is the initial weight of the filter, W_f is the final weight of the filter with the dried residue, and V is the volume of the sample filtered in millilitres (mL). Report the TSS concentration in mg/L, rounded to the appropriate precision of the analytical balance.

Frequency: Daily

3. Chemical Oxygen Demand

Procedure

Sample Preparation: First, prepare 100 mL of wastewater in a clean beaker or flask. Homogenize the sample by stirring or blending if it contains suspended solids or turbidity to make it uniform. Next, pipette 10 mL of the well-mixed sample into a COD digestion tube or a 250 mL reflux flask. The measurement may need to be diluted if the sample has a high COD concentration so that it is within the detectable range. Also, prepare a blank using 10 mL of distilled water instead of the sample.

Reagent Addition: Add carefully 5 mL of concentrated sulfuric acid (H_2SO_4) followed by 5 mL of standard potassium dichromate ($K_2Cr_2O_7$) solution (0.25 N or 0.1 N, depending on expected COD levels) to each sample and blank. Add 1 g of Mercury (II) sulfate ($HgSO_4$) to the mixture if chloride interference is expected to prevent oxidation of chlorides, which otherwise would give erroneous results. To prevent bumping during heating, place a few glass beads in the flask.

Digestion: Then, connect a condenser to the reflux flask and reflux the mixture at 150°C for 2 hours with a COD digestion apparatus or a water bath. For COD digestion tubes, put them in a preheated COD reactor and keep it at 150°C for the same duration. Leave the tubes or flasks to cool to room temperature after digestion.

4. **Biochemical Oxygen Demand**

Procedure

Sample preparation: For the incubation process, a 1 mL wastewater sample was diluted to 200 mL and put into 250 mL containers. After that, 1 mL of MnSO4 solution and 1 mL of alkali-iodide-azide substance were added. To prevent air bubbles, the incubation containers were properly sealed, and the fluid was mixed by continually flipping the container.

Reagent Addition: Once the precipitation had subsided, 1 milliliter of concentrated sulfuric acid was introduced, and the container was then recapped and inverted on several occasions to ensure full dissolving.

Incubation and Titration: Five additional days were then used for incubating the specimen. Following that, 0.0125 M NaS2O3.5H2O was used to titrate the mixture to a light-yellow color. After adding three drops of the starch mixture, the titration was maintained until the blue color initially vanished.

BOD Measurement: The same process was followed for the blank determination, but 1 milliliter of filtered water was utilized in place of the material being tested. Prior to and following the five days of incubation at 20°C, the diluted sample's dissolved oxygen content was measured. The variation provided the sample's biological oxygen demand.

5. **Color**

Procedure

Sample preparation: First, take 50 mL of the wastewater sample in a clean, colorless glass beaker. If the sample contains suspended solids, then filter it through a 0.45 µm membrane filter to remove particulate matter before determining the true color. If the sample is to be used for apparent color determination of both dissolved and suspended matter, use the unfiltered sample.

Visual color comparison: Fill a set of Nessler tubes or color matching cylinders with 50 mL of standard platinum cobalt color solutions of known values (5 to 500 Hazen units (HU)) for visual comparison. Then, pour the sample into an identical tube and visually compare it to the standard series under a white light source. Note the closest matching color intensity in Hazen units (HU), also referred to as Pt-Co units.

Spectrophotometric measurement: In spectrophotometric measurement, use 10 mL of the filtered or unfiltered sample in a quartz cuvette. The spectrophotometer is set to 455 nm (wavelength for color measurement) and is calibrated with distilled water as the blank. Use a calibration curve of standard color solutions to measure the absorbance of the sample and compare it to that of known color concentration in Hazen units.

Result reporting: Finally, report the color value in Hazen units (HU) as true color (filtered sample) or apparent color (unfiltered sample). Samples with excessively high color levels can be diluted as needed to bring the reading into the instrument's detection range if necessary.

Titration: Transfer the digested mixture to a clean Erlenmeyer flask and add 2–3 drops of ferroin indicator. The solution is titrated against 0.1 N ferrous ammonium sulfate (FAS) solution until color changes from blue-green to reddish brown. Measure the volume of FAS used for the sample and blank.

6. **Temperature**

Procedure

Transfer 100 mL of the sample into a glass beaker and measure the temperature immediately with a mercury-in-glass thermometer, alcohol thermometer, or digital thermometer with a temperature probe. Let the thermometer or probe stabilize for 30–60 seconds and record the temperature to the nearest 0.1°C.

3.4.1 Data Analysis

The datasets derived from the wastewater treatment process were then analyzed using descriptive statistics, comparative analysis, compliance check using regulatory standards, and graphical representation. The efficiency of the treatment system was evaluated using these methods, trends were identified, and regulatory standards were met. A description of the data analysis methods used in the study is given below:

1. Descriptive Statistics

Descriptive statistics were used to summarize the data and provide an overview of the treatment process's performance.

Means:

- The mean value of COD before and after treatment was 2188.33 mg/L and 25.04 mg/L, respectively.
- The mean value of BOD before and after treatment was 2169.45 mg/L and 14.88 mg/L, respectively.
- The mean value of pH before and after treatments was 3.9 and 6.95, respectively.

Ranges: The range (difference between the maximum and minimum values) was calculated to assess the variability in the data.

- The ranges of pH values before and after treatment were from 3.8 to 4 and 6.9 to 7, respectively.
- The ranges for BOD before and after treatment were from 1200 to 2650 and 14 to 15, respectively.
- The ranges for COD before treatment were 2100 to 2135, and after treatment were 23 to 26.
- The ranges for TSS before treatment were 2630 to 2800 and 9.8 to 10.2 after treatment.

Standard deviation (SD): The standard deviation was calculated to measure the dispersion of the data around the mean.

- SD for pH before treatment was 0.08 and 0.05 after treatment
- SD for COD was 19.04 before treatment and 0.796 after treatment
- SD for BOD was 503.04 before treatment and 0.04 after treatment
- SD for TSS was 49.78 before treatment and 0.35 after treatment

2. Regulatory Compliance

The measured values of the treated effluent were compared with the National Environment Management Authority (NEMA, 2023) standards to assess compliance.

Trends in pH over months

Table 1: pH values for the 6 months of data recording

MONTH	BEFORE TREATMENT	REMARKS	EFFLUENT	REMARKS
January	4	Below	7	Within
February	3.9	Below	6.9	Within
March	3.8	Below	6.9	Within
April	3.8	Below	7	Within
May	3.9	Below	6.9	Within
June	3.8	Below	7	Within

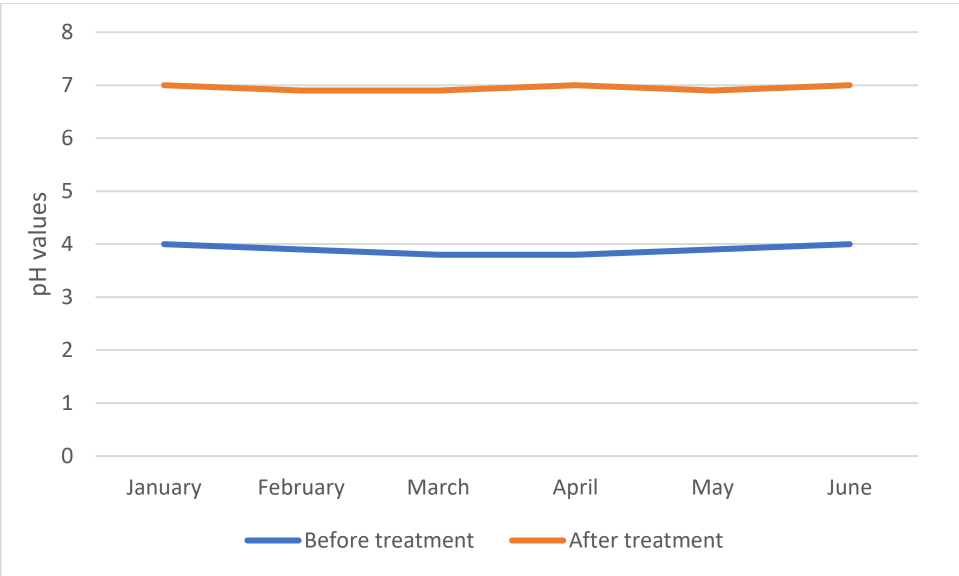

Figure 7: Trends of pH scale values over 6 months

Trends in TSS over months

From equation 0.1, The TSS values were calculated for the period. The table below shows the data for the period and the % reduction in efficiency. The graph of the efficiency over the period is also shown in (Figure 9).

Table 2: Analysis of TSS during the period of data collection

Month	Conc in influent (mg/L)	Remarks (250mg/L)	Conc After treatment (mg/L)	Remarks (25 mg/L)	Trends in TSS reduction efficiency (%)

January	2808.67	Higher	9.6	Lower	99.66
February	2735	Higher	9.36	Lower	99.66
March	2688	Higher	10.18	Lower	99.62
April	2674	Higher	10.43	Lower	99.65
May	2687	Higher	10.13	Lower	99.62
June	2743	Higher	9.64	Lower	99.65

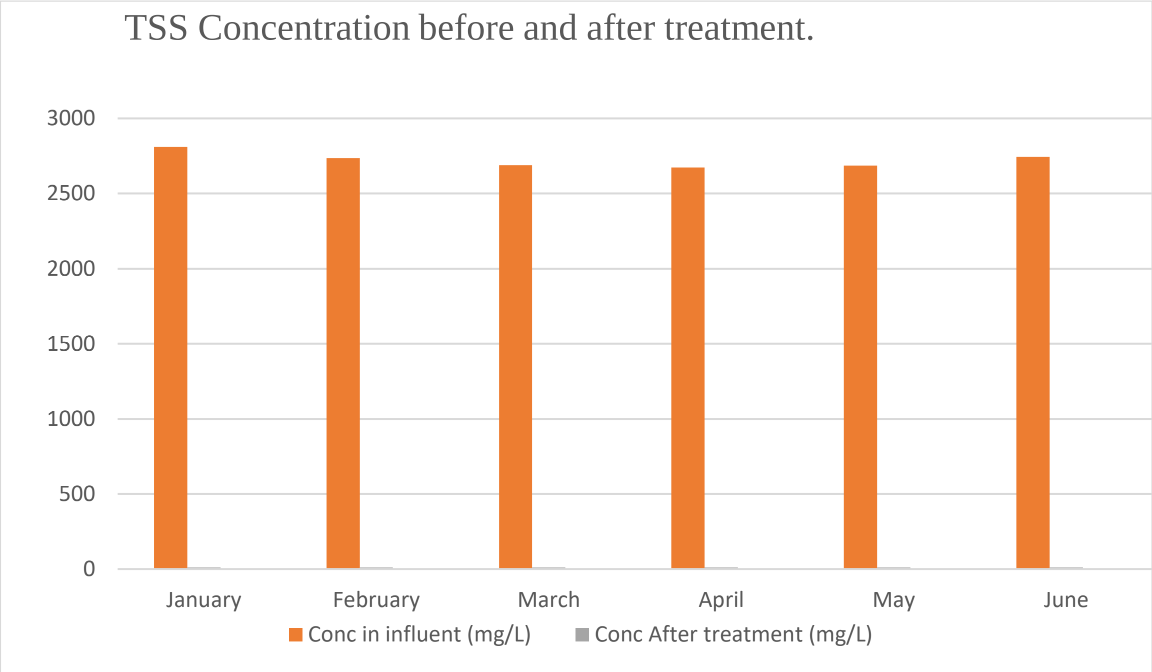

Figure 8: TSS Concentration before and after treatment.

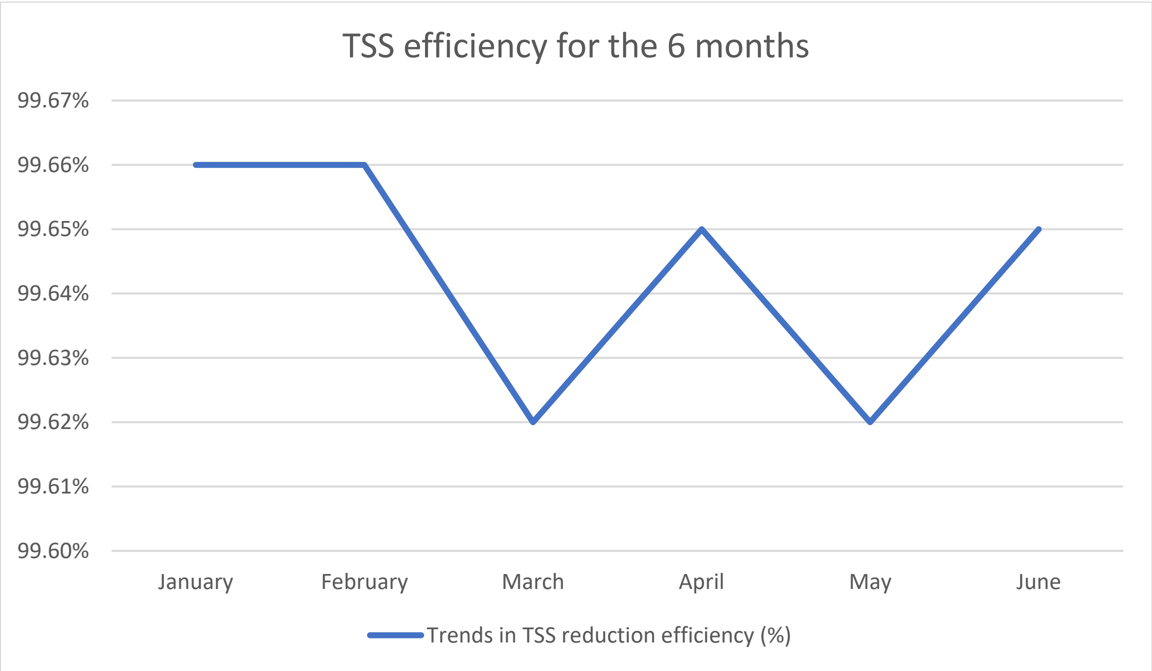

Figure 9: TSS efficiency for the 6 months

The maximum allowable concentration of effluent discharge into the environment as stipulated by NEMA was achieved throughout the data collection period, and the TSS after treatment ranged from 9.36 mg/l to 10.43 mg/L every month of the research. The TSS concentration was the lowest in February 2023, at 9.36 mg/L, compared to the highest, at 10.43 mg/L, in April 2023.

NEMA regulations state that the maximum permissible TSS concentration for discharge into public sewers is 250 mg/L. Influent TSS concentrations, however, were still significantly higher than the treatment plant loading, with values ranging from 2674 mg/L (April) to 2808.67 mg/L (January). When plotted on a graph, the influent concentrations ranging from 2674 to 2808.67 mg/L form very tall columns, while the effluent concentrations ranging from 9.36 to 10.43 mg/L fail to appear, showing a clear contrast and emphasizing the effectiveness of the treatment process (Figure 8). System overloading and the presence of solids-rich wastewater were potential causes of the exceptionally high influent TSS levels.

Despite such high influent levels, the treatment plant performed very well. In January and February, the TSS reduction efficiency was as high as 99.66% and similar throughout the period (99.62% to 99.66%). The removal rates of these high indicate an effectively functioning treatment process, probably because of well-maintained aeration and sedimentation systems.

Previously, the presence of algae in aeration and settlement tanks has reduced TSS reduction efficiency and increased solids in the final effluent. Nevertheless, the plant's post-renovation performance was very good and showed a significant and consistent improvement. Not only does it contribute to the compliance with environmental regulations, but it also helps to avoid sewer blockages and to reduce the burden on the sludge disposal system.

Trends in COD over the entire period

COD was then calculated using the following formula:

$$COD\ \left(\frac{mg}{L}\right) = \frac{(V_b - V_s) \times N \times 8000}{V_s}$$

where,

V_b = Volume of FAS used for the blank (mL)

V_s = Vol of FAS used for the sample (mL)

N = Molarity of FAS (N)

V_s = Volume of sample taken (mL)

The data was then recorded in the table below, Table 3, for before the wastewater was treated and after it was treated. The values were compared to see if they were up to the maximum allowed by NEMA to be released to the environment or not.

Table 3: COD values over the 6 months

MONTH	Conc in influent (mg/L)	Remarks (1000mg/L)	Conc in effluent (mg/L)	Remarks (50mg/L)	Trends in COD reduction efficiency(%)
January	2133	Higher	25.47	Lower	98.806%
February	2137	Higher	26	Lower	98.784%
March	2100	Higher	25.59	Lower	98.781%
April	2135	Higher	25.47	Lower	98.850%
May	2103	Higher	24.82	Lower	98.820%
June	2100	Higher	23.81	Lower	98.866%

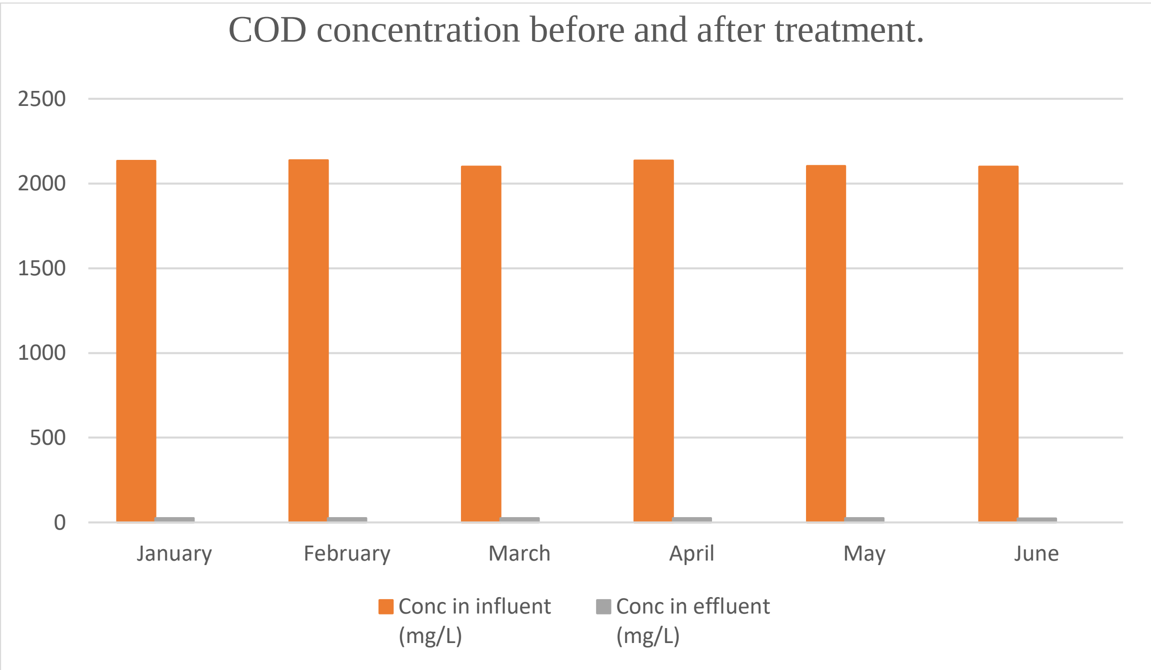

Figure 10: COD concentration before and after treatment.

The graph of efficiency over the entire months, when plotted, yields the figure as shown in (Figure 11). The trend indicates a high COD reduction efficiency. Despite minor fluctuations, there is a stable upward trend, suggesting consistent system performance.

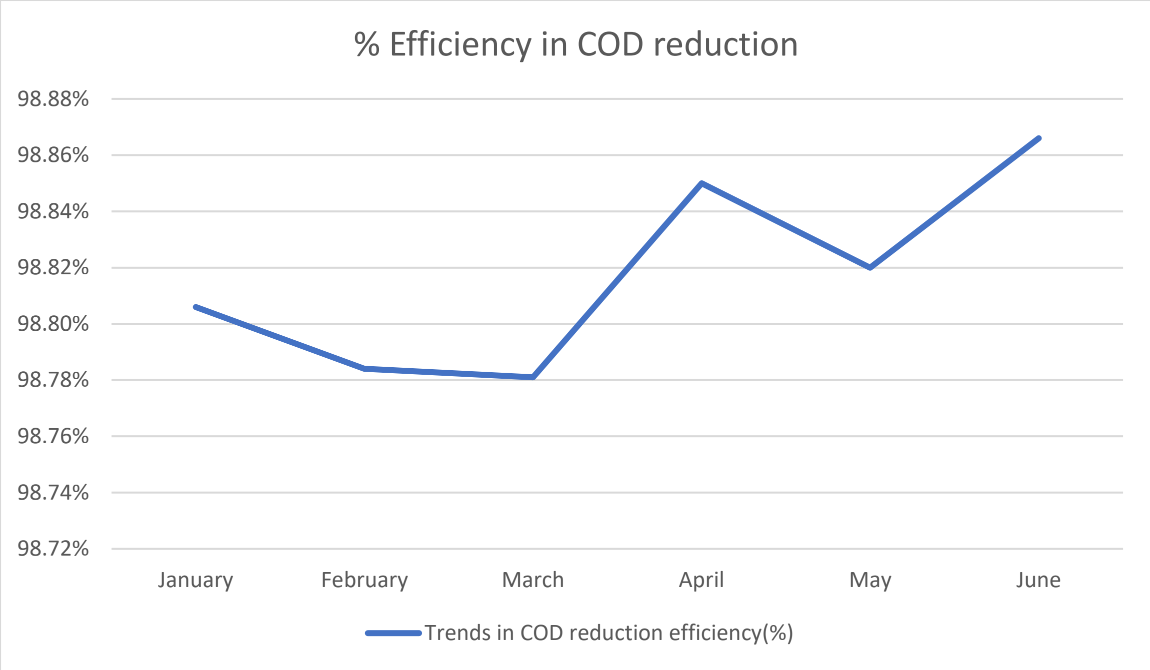

Figure 11: % Efficiency in COD reduction

The recorded COD values before and after wastewater treatment were analyzed and compared to NEMA recommended limits for effluent discharge. Influent COD concentrations were significantly higher than 1000 mg/L throughout the study period, and according to NEMA regulations, the maximum allowable COD concentration for direct discharge into the environment is 50 mg/L.

The influent COD concentrations (February: 2100 mg/L, March and June: 2100 to 2137 mg/L) were consistent with an organic load in the incoming wastewater before treatment. After treatment, the COD levels were significantly reduced with effluent concentrations in the range of 23.81 mg/L (June) – 26 mg/L (February), which comply with the effluent regulatory standard of ≤50 mg/L for environmental discharge.

The COD reduction efficiency had a consistently high range from 98.781% (March) to 98.866% (June). In June, the highest efficiency was 98.866%, and in March, the lowest was 98.781%. The excellent removal efficiency implies that the oxidation and degradation processes in the treatment plant were performing well.

Further, COD reduction efficiency over the months is represented graphically, showing the consistency of the wastewater treatment system (Figure 10). Preventing the depletion of dissolved oxygen in receiving water bodies is critical in removing COD, in order to minimize the environmental impact of discharged effluent.

Trends in the color over the entire period

The collected wastewater color data were recorded in Table 4. The maximum allowable discharge to the public sewer was 40 Hazen units, while to the environment was 15 Hazen units (NEMA, 2024).

Table 4: Influent and effluent wastewater color

Month	Before treatment	Remarks ≤ 40	After treatment	Remarks ≤ 15	Efficiency
Jan	457.47	Above	9.47	Within	97.93%
Feb	437.86	Above	9.64	Within	97.80%
Mar	407.65	Above	9.65	Within	97.63%
Apr	410	Above	9.5	Within	97.68%
May	438.13	Above	9.69	Within	97.79%
Jun	432.73	Above	9.4	Within	97.83%

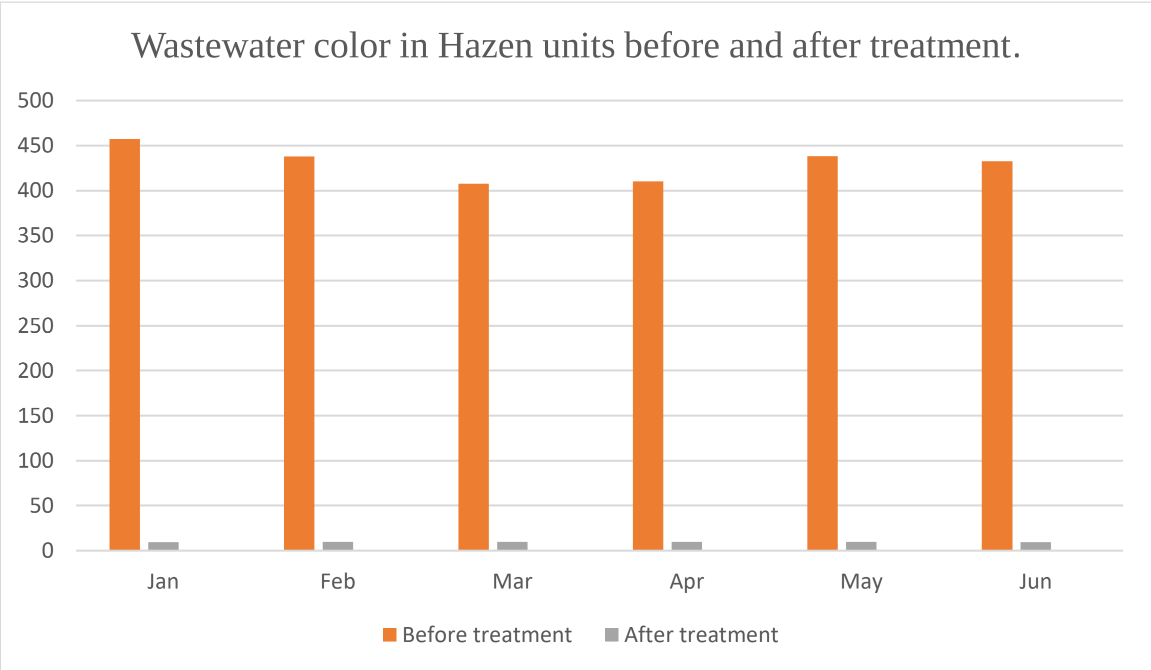

Figure 12: Wastewater color before and after treatment.

Wastewater quality assessment is an important parameter, which includes the presence of dissolved and suspended substances such as organic matter, industrial dyes, metallic compounds, and color. Maximum allowable color limits of 40 Hazen units for discharge into public sewer and 15 Hazen units for direct environmental discharge have been set by the National Environment Management Authority (NEMA, 2025).

Influent wastewater color levels were significantly above the permissible limit of 40 Hazen units during the monitoring period, with values from 407.65 Hazen units (March) to 457.47 Hazen units (January). The high values of these suggest a large amount of color-inducing pollutants in the incoming wastewater, which is most probably due to industrial and domestic sources.

Effluent color levels were drastically reduced to values of 9.4 Hazen units (June) to 9.69 Hazen units (May), all of which were below the NEMA recommended limit of ≤ 15 Hazen units for discharge into the environment after treatment. Effective treatment processes, such as sedimentation, filtration, biological oxidation, and possible chemical coagulation, have been responsible for the significant reduction in color.

Low color values in the effluent indicate that the wastewater treatment system was working well over the study period (Figure 12). Maintaining low effluent color is important to avoid visual pollution to the receiving water bodies and to meet the environmental discharge standards. The color reduction over the months would be further graphically analyzed to show the efficiency of the treatment process.

Trends in Temperature over the entire period

Table 5: Temperature ranges from January to June

Month	Influent Temperature (°C)	Remarks (20 – 35)	Effluent Temperature (°C)	Remarks (+/-3)	Trends in Temperature reduction efficiency (%)
January	29.3	Within	22.1	Within	24.57%
February	28.7	Within	21.5	Within	25.09%
March	29.1	Within	22.2	Within	23.71%
April	28.7	Within	22.4	Within	21.95%
May	28.9	Within	22.6	Within	21.80%
June	29.1	Within	22.6	Within	22.34%

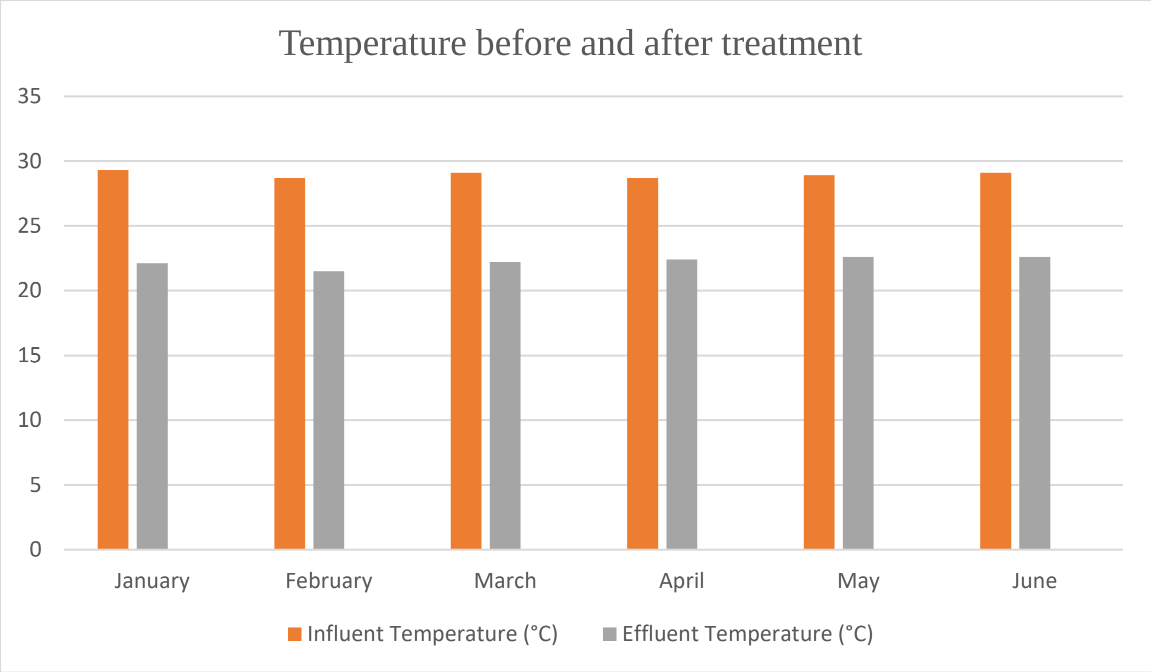

Figure 13: Temperature before and after treatment.

Temperature is a very important parameter in water treatment, as it affects microbial activity, reaction kinetics, and oxygen solubility. NEMA (2024) indicates that the influent temperature should be between 20°C and 35°C, and the effluent temperature should not be more than ±3°C from the natural receiving water temperature.

Throughout the monitoring period, with the exception of one day in February when influent wastewater temperatures exceeded the allowable limits and were 28.7°C, influent wastewater temperatures varied between 28.7°C (February and April) and 29.3°C (January). The values obtained from these suggest that the influent temperature is stable with no extreme thermal pollution from industrial discharges.

The effluent temperatures after treatment ranged from 21.5°C (February) to 22.6°C (May and June) and were all within the ±3°C variation limit. The reduction efficiency in temperature varied slightly across the months; the highest reduction efficiency was observed in February (25.09%) and the lowest in May (21.80%). Seasonal changes, treatment plant operations, and heat retention in treatment units could all be attributed to the variation in efficiency.

The temperature trends overall show that the wastewater treatment process was able to regulate thermal discharge in order to comply with environmental regulations (Figure 13). Proper effluent temperature is important to protect aquatic ecosystems since the heat can reduce the dissolved oxygen levels and disturb the aquatic life. Illustration of the plant's performance in thermal regulation would be further done through a graphical representation of temperature reduction efficiency over the months in (Figure 14). The trend shows a general decline in temperature reduction efficiency over the six months, with a slight rise in June, suggesting corrective measures or seasonal improvements.

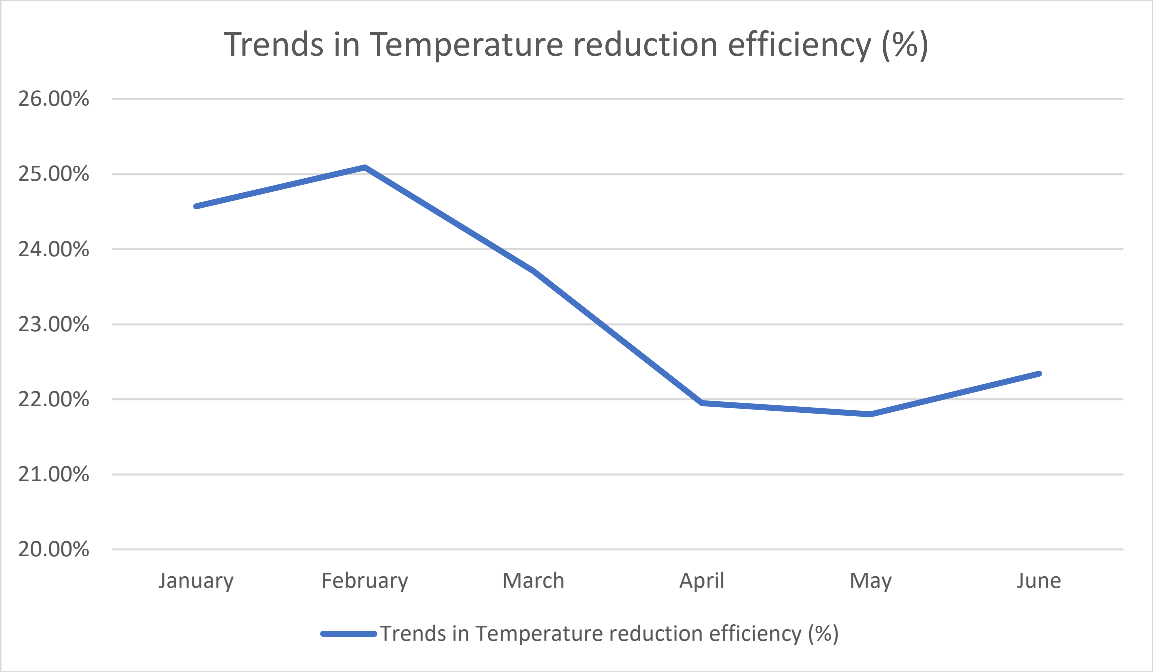

Figure 14: Trends in Temperature reduction efficiency (%)

4 CHAPTER 4: RESULTS

4.1 ANALYSIS OF EFFLUENT TREATMENT DATA

4.1.1 Efficiency of Coagulants, Flocculants, and Disinfectants

The two stages of coagulation and flocculation help eliminate suspended solids, organic matter, and other pollutants in the water. The effectiveness of these processes depends on the dosage and proper mixing of the particles for improved aggregation and sedimentation.

Coagulation and Flocculation Efficiency

Alum (Aluminum Sulfate) was coagulated at a dosing rate of 83.4 mL/s, and Polyaluminum Chloride (PAC) at 55.6 mL/s. The destabilization of colloidal particles suspended in the wastewater, neutralization of surface charges, and aggregation of particles into larger, more easily removable flocs are the ways these coagulants work. These coagulants were chosen based on their effectiveness in removing Total Suspended Solids (TSS) and turbidity with minimal effect on pH balance.

Jar tests were carried out in the laboratory to optimize coagulant dosage. The tests involved dosing wastewater samples with different concentrations of alum and PAC and rapid mixing (100–200 rpm, 1–2 minutes), after which the samples exhibited uniform dispersion of the coagulants. Afterward, the slow mixing at 20–40 rpm for 15–30 minutes was used to permit particle aggregation. Best results were obtained based on turbidity removal efficiency at a dosage that was sufficient to produce flocs large enough to settle effectively without excessive addition of coagulant.

The first was flocculation, where the fine, destabilized particles aggregated under controlled mixing conditions to form larger aggregates. Mechanical paddles at low speeds (10–40 rpm) were designed into the flocculation tank to allow gentle mixing without breaking up the forming flocs. To maintain optimal contact time for particle growth, flocculation retention time was held between 15 and 30 minutes. A significant decrease in TSS from 2900± 92.03 mg/L in influent to 10± 0.45 mg/L in treated effluent was confirmed as an indication of effective flocculation, implying that this is a case of successful sedimentation and separation.

Color was another major parameter affected by coagulation and flocculation, apart from TSS. The dissolved organic compounds that cause discoloration were removed from 352± 10.34 mgPt/L to 9± 0.58 mgPt/L through the treatment process. Activated carbon filtration step further removed color by adsorbing any remaining organic matter that may contribute to water tint.

Disinfection Efficiency

It was also disinfected to eliminate pathogenic microorganisms such as *Escherichia coli (E. coli)* and total coliform bacteria. Chlorine was the primary disinfectant used at approximately 2 mg/L of chlorine because it was a broad-spectrum disinfectant, cost-effective, and could maintain residual disinfection in the effluent discharge process.

Residual chlorine was continuously monitored to be in the range of 0.5–1.0 mg/L after treatment to optimize disinfection and prevent excessive formation of disinfection byproducts (DBPs) such as trihalomethanes (THMs), while inactivating bacteria.

Moreover, the chemical (hydrogen peroxide ~2 mg/L) and reaction outlet streams chlorine were introduced as advanced oxidation agents for microbial inactivation and degradation of organic pollutants. The action of hydrogen peroxide is to generate reactive oxygen species (ROS) that break down complex organic compounds and reduce Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). The combination of chlorine and hydrogen peroxide did a great deal in improving water quality and reduced the COD from 2300± 128.36 mg/L to 29± 1.96 mg/L and BOD from 2100± 75.04 mg/L to 14± 0.28 mg/L.

Microbiological tests for total coliforms and *Escherichia coli (E. coli)* were used to evaluate the effectiveness of disinfection. Total coliforms were present at 900 MPN/100 mL, and *E. coli* in the untreated influent. *E. coli* was completely eliminated (Not Detected - ND), and total coliform was reduced to 15 MPN/100 mL after disinfection. It showed that the disinfection process was able to remove harmful microorganisms and that there was no *Escherichia coli (E. coli)* detected in the effluent, which is in accordance with NEMA standards that require zero *Escherichia coli (E. coli)* detection in effluent.

Overall Process Efficiency

Significant improvement in the quality of the wastewater effluent was achieved when the coagulation, flocculation, and disinfection were integrated. The key efficiency indicators include:

- TSS Removal: Reduced from 2900± 92.03 mg/L to 10± 0.45 mg/L
- COD Reduction: Decreased from 2300± 128.36 mg/L to 29± 1.96 mg/L
- BOD Reduction: Lowered from 2100± 75.04 mg/L to 14± 0.28 mg/L.
- Color Removal: Reduced from 352± 10.34 mgPt/L to 9± 0.58 mgPt/L

- Microbial Reduction: *Escherichia coli (E. coli)* completely removed; total coliforms reduced from 900 MPN/100 mL to 15 MPN/100 mL

The results indicate that the applied treatment processes were highly effective in removing suspended solids, organic pollutants, and microbial contaminants. This helps to ensure that the effluent treated is discharged within the limits set by regulatory agencies and further minimizes environmental impact.

4.1.2 Performance of Filter Media and Pumping Systems

The performance of the filtration system and pumping mechanisms is paramount to successful wastewater treatment. Coagulation and sedimentation remove the bulk of the suspended solids and organic matter, but the filtration system is relied on to remove the remaining suspended solids and residual contaminants. This study is based on the above technique using a multilayer filtration unit consisting of coarse sand, fine sand, and activated carbon at each stage, thereby contributing differently to the overall efficiency of the system.

Filter Media Efficiency

The filtration unit is essential to increase the efficiency of removing fine particulates, organic compounds, and chemical residues. The details of the effectiveness of each layer are below:

- First Stage of Filtration: Coarse Sand Layer: This layer is used to remove larger suspended particles and flocculated material remaining after sedimentation. Capturing the larger particles allows the coarse sand layer to keep clogging from occurring in the layers below and lengthens the life and efficiency of the filtration system.
- Second stage of filtration: fine sand layer removes smaller particles, such as fine sediments and organic debris. This layer is important in lowering turbidity and making the final effluent clear. Fine sand filtration improves the removal of Total Suspended Solids (TSS) and prevents particulate matter from passing through to the final stage.
- Activated Carbon: The last stage of the filtration process is activated carbon, which adsorbs dissolved organic compounds, removes residual chlorine, and reduces color-causing substances. In particular, taste and odor compounds, as well as chemical pollutants that may contribute to organic instability in the treated effluent, are removed particularly well by activated carbon.

The filtration system was efficient in decreasing TSS from 2900± 92.03 mg/L to 10± 0.45 mg/L and color from 352± 10.34 mgPt/L to 9± 0.58 mgPt/L. It showed that the filtration system was able to remove both suspended and dissolved contaminants to meet environmental discharge standards. Regular backwashing of the filtration media was done to keep the filtration media clear and to maintain effective flow through the system for optimal efficiency.

Pumping System Performance

The pumping system in a wastewater treatment facility moves influent and effluent between the different treatment units. An automated pumping system was used in this study to allow the smooth transfer of the wastewater from one stage of treatment to another. The pumping system maintains good performance, which is critical to achieving hydraulic stability, preventing stagnation, and ensuring the efficient operation of treatment processes.

The functions of the pumping system were basically:

- Stable Hydraulic Conditions: The automated pumps are configured to maintain flow rates, thereby allowing for optimum retention times in sedimentation, filtration, and disinfection units. Hydraulic overloading would have the same effect on treatment efficiency and was thus prevented.
- Variable Flow Rate: The pumping system was designed to allow for varying flow rates and constant movement of influent and effluent regardless of variation in wastewater volume. This also guaranteed that the contaminants were fed to each treatment stage in a balanced fashion so as not to overload the system.
- Preventing Clogging and Sediment Accumulation: Schedules of periodic maintenance and cleaning are established to prevent clogging and sediment accumulation in the pipeline system so that the wastewater can flow continuously and unimpededly.
- Energy Efficiency and Sustainability: The pump speeds could be adjusted automatically and according to real-time flow needs, which helped save energy. This optimized energy consumption lowered the treatment facility's operating cost and enhanced the facility's sustainability.

The pumping system also included pressure monitoring sensors, which detected changes in flow rate and adjusted pumping speeds accordingly. Therefore, water levels in the treatment units stayed reasonably level most of the time, so starvation or overpressure of a treatment unit was less likely to occur.

Integration of Filtration and Pumping Systems for Process Optimization

Filtration and pumping integration determines the effectiveness of the wastewater treatment. The pumping system utilized ensures that the transport of treated water through the treatment process is efficient. On the other hand, the filtration system is responsible for contaminant removal. Because of the seamless operation of both components, there is:

- Consistent Contaminant Reduction: The filtration system reduced TSS to safe levels by up to 99.65 per cent.
- Even Distribution: The system provided stable hydraulic conditions by evenly distributing the wastewater across treatment stages, guarding against underloading or overloading of sedimentation and filtration units.
- Enhanced System Longevity: Since the filtration and pumping systems were regularly maintained, wear and tear on their key components was minimized. Those components' operational lifespan was extended with lower maintenance costs over time.

A highly efficient treatment system was achieved through the successful integration of multilayer filtration and automated pumping, which produced effluent of high quality meeting NEMA discharge requirements. This means adequate filters and pumping systems are needed to maintain the effectiveness and sustainability of wastewater treatment operations, not just their effectiveness. Hence, it demonstrated that the system must be working very well.

After coagulation, the suspension solids and organic matter are removed by sedimentation, and residual contaminants are removed by the filtration system in the treatment plant. The multi-layer filtration unit with coarse sand, fine sand, and activated carbon significantly improved the overall efficiency of the treatment system.

4.2 COMPARISON TO STANDARD REGULATORY REQUIREMENTS

The Wastewater Treatment results in this section were compared to National Environment Management Authority standards and international environmental guidelines. To assess the efficiency of the treatment system unit, permissible effluent limits of parameters such as pH, color, temperature, COD, BOD, TSS, and microbial contamination were considered.

4.2.1 Effluent Quality Assessment

The following table lists the quality of the final effluent before and after treatment, NEMA limits, and international environmental discharge standards.

Table 6: Final effluent quality before and after treatment

Parameter	**Unit**	**Analytical Method**	**Before Treatment**	**After Treatment**	**Standard Limit (Environment)**	**Standard Limit (Public Sewers)**	**International Standards (environment)**
pH	pH Scale	APHA 4500-H B	4.5	6.9	6.5 - 8.5	6 - 9	6.00-9.00
Color	mgPt/L	APHA 2120 B	352	9	-	40	≤436
Temperature	°C	APHA 4500-S2-F	29	21	+3 ambient temp.	20 - 35	≤37°C
COD	mg/L	APHA 5220 C	2300	29	50	1000	≤50
BOD	mg/L	APHA 5210 B	2100	14	30	500	≤30
TSS	mg/L	APHA 2540 D	2900	10	30	250	≤30
Escherichia coli (E. coli)	MPN/100 mL	APHA 9223 A	ND	ND	Nil	Not Applicable	200,000
Total Coliform	MPN/100 mL	APHA 9223 A	900	15	30	Not Applicable	100

The total coliform levels decreased from 900 MPN/100 mL to 15 MPN/100 mL, while the *Escherichia coli (E. coli)* level was also undetectable post-treatment, demonstrating the system's efficacy of microbial disinfection (APHA, 2017).

4.2.2 Compliance with NEMA and International Standards

4.2.2.1 pH Levels

The wastewater, before treatment, had a high acidity (pH 4.5). After treatment, the pH improved to 6.9, which was within NEMA and within the international standard range (6.0 to 9.0). This also indicates that the water treatment system fully eradicated the contamination of the water, making its disposal in the environment safe.

4.2.2.2 Color Removal

The unprocessed wastewater had a color concentration of 352 mgpt/l, significantly exceeding the international standard limit of ≤436 mgptl and the public sewer discharge limit of 40 mg/l. Following treatment, the color was further reduced to 9 mgPt/L, which is well within acceptable limits for NEMA and international discharge standards.

4.2.2.3 Temperature Compliance

The influent wastewater temperature was 29°C, within the acceptable NEMA range of 20 - 35°C and the international limit of ≤37°C. After treatment, the temperature was further reduced to 21°C, ensuring minimal thermal impact on receiving water bodies.

4.2.2.4 COD and BOD Reduction

The influent COD (2300 mg/L) and BOD (2100 mg/L) levels far exceeded the NEMA environmental limits of 50 mg/L and 30 mg/L, respectively. After treatment, COD was reduced to 29 mg/L, and BOD to 14 mg/L, meeting both NEMA and international discharge standards. This significant reduction indicates effective degradation of organic pollutants within the treatment system.

4.2.2.5 Total Suspended Solids (TSS) Removal

TSS in the untreated wastewater was 2900 mg/L, significantly higher than the NEMA standard of 30 mg/L for environmental discharge and 250 mg/L for public sewer discharge. After treatment, TSS was successfully reduced to 10 mg/L, meeting all regulatory and international standards.

4.2.2.6 Microbial Contamination Control

- *E. coli*: Before treatment, the presence of *Escherichia coli (E. coli)* was undetected (ND). Since both NEMA and international standards require *E. coli* to be nil and below 200,000 MPN/100 mL, the treated effluent met compliance requirements.
- Total Coliform: The initial total coliform concentration was 900 MPN/100 mL, exceeding the NEMA limit of 30 MPN/100 mL. After treatment, total coliform was reduced to 15 MPN/100 mL, which complies with national and international environmental discharge standards.

4.2.3 Summary of Compliance and Treatment Effectiveness

- Full Compliance Achieved: All tested effluent parameters met NEMA regulatory limits for environmental discharge and were within internationally accepted standards.
- Efficient Organic Pollutant Removal: The treatment system achieved over 98% COD and BOD reduction, effectively removing organic contaminants and ensuring compliance with effluent discharge limits.
- TSS was reduced effectively by >99.65%, whereas color was reduced greatly to produce clear water and better aesthetics.
- Microbial safety was achieved by reducing total coliform, and the elimination of *Escherichia coli (E. coli),* and ensuring compliance with environmental health guidelines was confirmed.

5 CHAPTER 5: DISCUSSION

5.1 OVERVIEW OF TREATMENT PERFORMANCE

The wastewater treatment process had high removal efficiency for pollutants, stabilized water quality parameters, and satisfied NEMA and international discharge standards. The high levels of Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), microbial contaminant, and color were effectively reduced to make it consistent with the National and Global Environmental Guidelines. In Chapter 4, performance evaluation data of treatment and operational considerations from this work are presented, and this chapter provides a detailed discussion of these results.

5.2 ANALYSIS OF COAGULATION, FLOCCULATION, AND DISINFECTION EFFICIENCY

5.2.1 Coagulation and Flocculation Efficiency

The coagulation and flocculation stages remove suspended solids, organic matter, and turbidity from wastewater. These processes destabilize colloidal particles and aggregate them into large flocs (which can be separated by sedimentation and filtration). However, coagulation and flocculation are inefficient when factors such as coagulant type, dosage, pH conditions, mixing speed, and flocculation time are involved.

Aluminum Sulfate, Alum (Aluminum Sulfate) and Polyaluminum Chloride, PAC were chosen as coagulants because these are effective in destabilizing particles. A jar test was conducted through which different dosages of Alum and PAC were tested to determine the optimal dosages to reach maximum turbidity removal with minimal coagulant waste (83.4 mL/s for Alum, 55.6 mL/s for PAC). The jar test consisted of rapid mixing (100–200 rpm) for 1–2 minutes and slow mixing (20–40 rpm) for 15–30 minutes to give enough time for floc growth.

The coagulant ions deposited on the negatively charged particles in the wastewater neutralized the charge and caused the formation of microflocs during the coagulation process. In the flocculation phase, the microflocs collided and fused into bigger, sounder flocs under controlled, gradual mixing conditions (10 to 40 rpm). Proper mixing ensured that flocs were strong enough to withstand shear forces but not so fragile that they would break apart before sedimentation.

The effectiveness of the coagulation and flocculation processes was demonstrated by:

- TSS Reduction: The influent Total Suspended Solids (TSS) decreased from 2900± 92.03mg/L to 10± 0.45 mg/L, indicating highly efficient removal of particulate matter.
- Color Removal: Wastewater color was significantly reduced from 352± 10.34 mgPt/L to 9± 0.58 mgPt/L, confirming the successful removal of dissolved organic compounds responsible for discoloration.
- Turbidity Reduction: The treatment process ensured that effluent clarity improved considerably, meeting regulatory standards.

One of the key factors contributing to the efficiency of coagulation and flocculation was maintaining the optimal pH range of 6.5–7.5, which ensured the best performance of both Alum and PAC. Deviations from this range could have resulted in poor coagulation and increased coagulant demand.

Coagulation and flocculation were particularly beneficial in treating water, as they significantly improved the final water quality and made the wastewater ready for further filtration and disinfection. This system's process can be highly efficient in ensuring it does not exceed the NEMA and international environmental discharge standards.

The stages of coagulation and flocculation were critical steps in lowering the TSS and color, thereby improving the water's clarity before filtration. Alum (83.4 mL/s) and PAC (55.6 mL/s) were optimally dosed, as determined from jar tests, to cause effective particle destabilization and aggregation. A 2900± 192.03mg/L to 10± 0.45mg/L TSS reduction of these processes indicated that they can remove suspended solids and organic particulates. In addition, the color was reduced significantly from 352± 10.34 mgPt/L to 9±0—58mgPt/L as further verification of coagulation and adsorption mechanisms.

5.2.2 Disinfection Performance

Disinfection is essential in destroying pathogenic microbes and reduction of waterborne diseases in wastewater treatment processes. This study's disinfection process involved chlorine (2 mg /L) and hydrogen peroxide (2 mg /L), responsible for microbial inactivation and organic matter oxidation. The dual disinfection strategy was especially effective in resolving bacterial contamination without creating excessive DBPs.

As a result of its ability to provide residual disinfection in treated effluent, cost-effectiveness, ease of application, and other advantages, chlorination is one of the most widely used disinfection methods. Chlorine was carefully dosed to provide 0.5–1.0 mg/L of residual chlorine after treatment. This guaranteed that the effluent would have sufficient disinfection capacity without being over-chlorinated, which could potentially produce trihalomethanes (THMs) and other DBPs.

Hydrogen peroxide was used as an additional oxidation agent to enhance the disinfection efficiency. Hydrogen peroxide helps in the breakdown of organic pollutants and microbial cell structures by producing reactive oxygen species (ROS), supporting the effects of chlorine. Hydrogen peroxide application in the form of chemical-assisted treatment brought the Chemical Oxygen Demand (COD) down from 2300± 128.36 mg/L to 29± 1.96 mg/L and was found to also reduce the Biological Oxygen Demand (BOD) from 2100 + 75.04 mg/L to 14 + 0.28 mg/L.

Microbial indicator tests of *E. coli* and total coliforms assessed the effectiveness of the disinfection process. Prior to treatment, levels of total coliform were 900 MPN/100 mL and could be considered a health risk. However, after disinfection, total coliforms were decreased to 15 MPN/100 mL, and the standard of ≤30 MPN/100 mL NEMA required was achieved. Hence, disinfection was found to reduce the total number of coliforms. Furthermore, *E. coli* was eliminated (ND - Not Detected), indicating that the treatment system completely disinfected the effluent.

The disinfection process overall had an excellent bacteria removal effect while successfully eliminating harmful microorganisms and satisfying regulatory compliance. The combination of chlorine and hydrogen peroxide enhanced microbial inactivation and contributed to overall organic pollutant degradation, resulting in improved treated water quality. Continuous monitoring and optimization of disinfectant dosing in the future will lead to improved process efficiency and the reduction of possible DBP formation.

The disinfection stage was highly effective in eliminating microbial contaminants. Microbial inactivation and organic matter oxidation utilized chlorine (2 mg /L) and hydrogen peroxide (2 mg /L). Elimination of *E. coli* (ND - Not Detected) and final step reduction of total coliforms from 900 MPN/100 mL to 15 MPN/100 mL indicated the correct operation of the disinfection system. Excessive DBP formation was avoided, and the residual chlorine levels were kept in the range of 0.5–1.0 mg/L to enable adequate pathogen removal.

5.3 EFFECTIVENESS OF FILTRATION AND PUMPING SYSTEMS

5.3.1 Filtration Performance

The multi-layer filtration system was highly essential in the last phases of the treatment, given that it facilitated the removal of the residual TSS, organic matter, and color-causing compounds before discharge. The whole filtration is achieved with coarse sand, fine sand, and activated carbon.

- When functional, the coarse sand layer acted as the first filtration stage, capturing larger particles after the coagulation and flocculation steps before reaching downstream treatment stages. The role of the coarse sand layer in trapping suspended solids arose and helped reduces turbidity.
- The second stage comprises a fine sand layer, which helps filtration by removing smaller particles like fine sediments and organic debris. The fine sand layer increased the retention time and enhanced finer particle capture, reducing TSS from 2900 ± 92.03 mg/L to 10 ± 0.45 mg/L.
- The final filtration stage is an activated carbon layer that adsorbs dissolved organic compounds, chlorine residues, and other trace pollutants. This layer was highly effective in color removal and lowered the concentration from 352 ± 10.34 mgPt/L to 9± 0.58 mgPt/L, improving water clarity overall.

The filtration system's performance was proven by the constant removal of particulate and dissolved contaminants to the extent that the final effluent satisfied both NEMA and international standards. Furthermore, cycles of backwashing were conducted to avoid clogging and preserve the filtration system's efficiency. Regular monitoring of the filter performance facilitated the adjustment of operational parameters to optimize the removal efficiency further.

Therefore, the filtration system produced high-quality effluent with little turbidity, low TSS, and improved color characteristics. The system also enhanced effluent quality because it combined different filter media to the extent that the final effluent quality is safe for discharge in the environment and observed the required government regulations.

5.3.2 Pumping System Efficiency

The wastewater pumping system is vital in ensuring uninterrupted water movement between the treatment units. This prevents system overloads, increases treatment efficiency, and ensures that each treatment stage has an optimal retention time. In this study, the automated pumping system contributed to the production system optimization through improved flow rates, prevention against clogging, and energy cost reduction.

5.3.2.1 Flow Rate Regulation and Hydraulic Stability

The automated pumps were designed to cope with variable flow rates and fluctuating influent volumes. This ensured that the wastewater was evenly distributed across treatment stages and prevented the sedimentation tanks and filtration units from being overloaded. The aim was to keep a stable hydraulic flow to achieve optimal coagulation, flocculation, and disinfection processes, given that any change in the flow rate could lead to inefficient mixing, short contact time, and incomplete treatment.

5.3.2.2 Prevention of Clogging and Sediment Accumulation

The pumps had sediment control mechanisms to prevent pipeline sludge and debris buildup. To combat the buildup of anything between the tubes that would interfere with performance, the pumping system was changed to a regular backwashing and flushing cycle. That meant that there would be no obstructions to wastewater flow through the system and, therefore, good operational reliability.

5.3.2.3 Energy Efficiency and Cost Optimization

Real-time flow requirement was used to set an energy-efficient pump system operation mode and thereby adjusting the pump speeds. As a consequence, excess energy is used, and compressors and pumps are mechanically worn out, thus reducing their lifetimes. VFDs provided perfect control over the motor speeds, while electric power utilization was also better, and the operation expenses were low.

5.3.2.4 System Reliability and Maintenance

The pumps were designed to last long in the maintenance schedules. Additionally, pressure sensors were placed to determine abnormal water flow and actuate the machine to keep it stable. Pump components were required to be inspected and lubricated frequently to reduce cases of failure and minimize the time taken to repair them.

5.3.3 Impact on Overall Treatment Performance

Looking at the different features introduced in the experiment, the pumping system was the most influential in increasing the efficiency of the whole treatment process. This was done by attaining a high level of water transfer, reducing the chances of clogging and energy usage while meeting all the required regulatory treatment standards. The inclusion of automation and smart monitoring tasks in the plant enhanced its work, making it a natural and efficient source of wastewater remediation.

5.4 COMPLIANCE WITH REGULATORY STANDARDS

5.4.1 National Compliance (NEMA Standards)

- In the case of the wastewater treatment system, it stated that the company's discharge fully complied with the required standard set in the National Environment Management Authority (NEMA) regulations. The measured operation parameters, pH, TSS, COD, BOD, microbial contamination, and color were effectively managed consistently with the required limits. The standards were successfully achieved by the treatment system, deeming it safe for the environment and public health.

5.4.1.1 pH Regulation

- The initial effluent wastewater was observed to have a pH of 4.5, which is highly acidic and cannot be discharged into the water system. The pH after treatment was 6.9, falling within the contractual limit for the public sewer, which is 6 – 9, and that of the NEMA environmental standard range, between 6.5 and 8.5. Since the pH affects the coagulant's efficacy and has stronger corrosive impacts on pipelines and the water body, managing it is essentially crucial.

5.4.1.2 TSS Compliance

- The influent Total Suspended Solids (TSS) was determined to be 2900 ± 92.03 mg/L, above the permissible limits of 30 mg/L for discharge into the environment and 250 mg /L for discharge to a public sewer. The treatment process brought TSS to 10±0.45 mg/L, achieving an overall removal efficiency above 99.65%, hence discharging within the legal standards.

5.4.1.3 COD and BOD Compliance

- Chemical Oxygen Demand (COD): The raw wastewater exhibited COD levels of 2300±128.36 mg/L, far exceeding the NEMA environmental standard of ≤50 mg/L and public sewer standard of ≤1000 mg/L. Post-treatment, COD was reduced to 29±1.96 mg/L, aligning with both national and international standards.
- Biological Oxygen Demand (BOD): The influent BOD concentration was 2100± 75.04 mg/L, surpassing the NEMA limit of ≤30 mg/L for environmental discharge. After treatment, BOD levels were reduced to 14±0.28 mg/L, ensuring regulatory compliance.

5.4.1.4 Microbial Contaminant Reduction

- *Escherichia coli (E. coli)*: Before treatment, *Escherichia coli (E. coli)* levels were undetectable (ND - Not Detected). Since NEMA standards require a nil detection of *E. coli* in treated effluent, the treatment system successfully met this criterion.
- Total Coliform: The influent total coliform count was 900 MPN/100 mL, exceeding the NEMA standard of ≤30 MPN/100 mL. After treatment, total coliform levels were reduced to 15 MPN/100 mL, confirming the system's ability to produce pathogen-free effluent.

5.4.1.5 Color and Temperature Compliance

- Color Reduction: The wastewater color was initially 352± 10.34 mgPt/L, exceeding the public sewer limit of 40 mgPt/L. After treatment, the final effluent color was reduced to 9±0.58 mgPt/L, ensuring compliance with national regulations.
- Temperature Control: The influent temperature was recorded at 29°C, within the NEMA allowable range of 20–35°C. After treatment, the effluent temperature remained stable at 21°C, ensuring no thermal pollution effects on receiving water bodies.

5.4.2 International Standards Compliance

Beyond national compliance, the treated effluent also adhered to international environmental discharge standards. These standards serve as benchmarks for the safe disposal of wastewater and the protection of global water resources.

Table 7: Compliance with international standards.

Parameter	Before Treatment	After Treatment	NEMA Standard (Environment)	International Standard (Environment)
pH	4.5± 0.27	6.9± 0.22	6.5 - 8.5	6.00 - 9.00
TSS (mg/L)	2900± 92.03	10± 0.45	≤30	≤30
COD (mg/L)	2300± 128.36	29± 1.96	≤50	≤50
BOD (mg/L)	2100± 75.04	14± 0.28	≤30	≤30
***E. coli* (MPN/100 mL)**	ND	ND	Nil	≤200,000
Total Coliform (MPN/100 mL)	900± 50.56	15± 0.44	≤30	≤100
Color (mgPt/L)	352± 10.34	9± 0.58	-	≤436
Temperature (°C)	29± 2.01	21± 0.93	≤35	≤37

The effluent continuously met international wastewater discharge standards, which made it environmentally safe and sustainable.

5.5 IMPLICATIONS OF COMPLIANCE ON ENVIRONMENTAL AND PUBLIC HEALTH

The high efficiency of the treatment system in removing pollutants ensures environmental conservation and public health protection.

- Reduction of Organic Pollutants: A substantial reduction in COD and BOD leads to minimum oxygen depletion in receiving water bodies, preventing eutrophication and retaining the balance of the aquatic ecosystem.
- TSS Reduction: It reduces the TSS levels, thereby producing clearer effluent that does not tend to accumulate sludge and instigate sedimentation-related problems.
- Microbial Safety: It reduces total coliform and effectively kills *E. coli* to prevent waterborne disease, hence safeguarding public health.
- Temperature and Color Control: Controlling temperature and color decreases aquatic habitat disruption and water aesthetic degradation caused by discharged wastewater.

5.6 RECOMMENDATIONS FOR CONTINUOUS COMPLIANCE

To ensure regulatory compliance and better treatment efficiency, the following strategies are recommended:

1. Online Sensors and Automation: Introduce online sensors and automation to monitor pH, COD, BOD, and microbial contaminants in real time and perform corrective adjustments.
2. Fine-tuning coagulant and disinfectant dosing to make the coagulation and disinfectant process cost-effective and avoid any disposal of potential residual chemicals in the effluent.
3. Alternative Disinfection Methods: More sophisticated methods, such as UV treatment or ozone disinfection, will eliminate disinfection by-products (DBPs).
4. Treatment Units Regular Maintenance: To maintain treatment unit operation, filter backwashing and cleaning, pump checkups, and chemical dosing calibrations should be conducted on a regular schedule.
5. Integrate Renewable Energy Sources: Utilize solar or biogas energy sources to improve sustainability and profitability while decreasing operational expenses.

6 CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

The first objective of this study was to determine the efficiency of a wastewater treatment system in removing major pollutants and compliance with NEMA and international discharge standards. The results showed that the treatment process was highly effective for removing Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), microbial contaminants, color, and optimizing the pH levels, resulting in improved water quality.

The integration of coagulation, flocculation, filtration, and disinfection ensured that the final effluent met the set environmental standards. Key findings included:

- TSS reduction from 2900± 92.03 mg/L to 10± 0.45 mg/L, meeting NEMA's limit of ≤30 mg/L.
- COD reduction from 2300± 128.36 mg/L to 29± 1.96 mg/L, achieving compliance with the ≤50 mg/L threshold.
- BOD reduction from 2100± 75.04 mg/L to 14± 0.28 mg/L, below the ≤30 mg/L requirement.
- Complete removal of *Escherichia coli (E. coli)* and considerable reduction of total coliforms to levels below water quality permitting levels.
- pH stability from 4.5 up to 6.9, satisfying the needed range of 6.5–8.5.
- Color reduction from 352± 10.34 mgPt/L to 9± 0.58 mgPt/L, significantly improving effluent clarity.

This case study demonstrated the significant role played by Water Engineering and Pumping Technologies in treating effluent waste from Kenafric Industries Limited in Nairobi, Kenya, by improving the wastewater quality, as evidenced by the findings, while ensuring compliance with the environmental discharge standards. The treatment process was enhanced by the utilization of flocculants and coagulants with the appropriate filter medium. Moreover, a specific treatment process adapted to the industry's effluent reaffirms the importance of solutions tailored to the relevant industry's wastewater management needs. Besides Kenafric Industries Limited, Water Engineering and Pumping Technologies also works in other industries in Kenya. The company treats the effluent waste produced by major manufacturers like Ramco Group of Industries, Glacier Products Ltd, Taifa Industries, Beta Health and International Industries, and Paper Converters Industries. As evidenced by this broader range of services, the company is central to promoting a safe and effective effluent control system in the country's industrial ecosystem.

These results were made possible by the system's automated pumping mechanisms, multi-level filtration units, and optimized chemical dosing. Furthermore, energy-efficient practices to reduce operating costs and ensure treatment efficiency were developed.

The wastewater treatment system as a whole effectively met the regulatory discharge standard, thus reducing the impact on the environment and ensuring the discharged effluent was safe. Nevertheless, ensuring the achievement of long-term performance and efficiency relies on continuous monitoring and optimization of the process.

6.2 RECOMMENDATIONS

6.2.1 Process Optimization and Monitoring

1. Advanced Real-Time Monitoring Systems: Automated sensors and digital tracking for pH, COD, BOD, and microbial contaminants will detect material shifts early and allow for timely corrective action.
2. Regularly adjusted Alum, PAC, chlorine and hydrogen peroxide dosages to influent variability offer an opportunity to improve the total cost of operation without sacrificing treatment effectiveness.
3. Enhance Sedimentation and Flocculation Efficiency: Increasing or decreasing the mixing speed or retention time can increase floc formation, consequently increasing sedimentation efficiency and reducing sludge volume.

6.2.2 Alternative Treatment Methods

1. Implementing Advanced Disinfection Technique: Advanced disinfection techniques, such as UV and ozonation, can be further implemented to improve pathogen removal with less disinfection by-product (DBP) formation.
2. Membrane Filtration Technologies: Ultrafiltration (UF) or reverse osmosis (RO) technology can increase the efficiency of pollutant removal for residual organics and dissolved solids.
3. Biologically Enhanced Treatment Methods: Using bio filters, constructed wetlands, or anaerobic digestion provides additional means of breakdown of organic matter and less reliance on chemicals.

6.2.3 Environmental and Energy Sustainability

1. Use Renewable Energy Sources: Solar or biogas-driven energy systems have lower running costs and are more sustainable.
2. Water Reuse Strategies: Treated effluent can be reused on campus for industrial cooling, irrigation, and groundwater recharge outside campus.
3. Sludge Thickening and Dewatering Technologies: This will help reduce the sludge volume and transportation and disposal costs.

6.2.4 Policy and Regulatory Compliance

1. Strengthen Compliance Monitoring: Routine laboratory testing and third-party audits will ensure continued discharge limits as per national and international limits.
2. Training Programs: Developing training programs for plant operators can enhance their technical skills in process control, equipment maintenance, and emergency response.
3. Wastewater Management and Engaging Stakeholders: Collaborative efforts between regulatory agencies, research institutions, and industrial stakeholders can foster the development of sustainable wastewater treatment innovations.

6.3 FINAL REMARKS

The wastewater treatment system complied with regulatory requirements and had a high treatment efficiency. The results also emphasized the need for continuous process optimization, technological innovation, and constant monitoring by regulatory authorities for long-term sustainability. The recommended strategies allow for the further improvement of the operational performance of wastewater treatment facilities, a reduction in environmental impact, and support for global water conservation.

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