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DESIGN, CONSTRUCTION AND PERFORMANCE TEST OF WASTEWATER SLUDGE FILTER IN THE TOLON DISTRICT OF THE NORTHERN REGION OF GHANA

DANIEL ALUAH

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BY

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(UDS/MID/0001/20)

A THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING, SCHOOL OF ENGINEERING, UNIVERSITY FOR DEVELOPMENT STUDIES IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF PHILOSOPHY DEGREE IN IRRIGATION AND DRAINAGE ENGINEERING

2022

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DECLARATION

DECLARATION BY CANDIDATE

I hereby declare that this thesis is the result of my original work and that no part of it has been presented for a degree at this university or elsewhere. The work of others, which served as sources of information for this study, has been duly acknowledged in the form of references.

Daniel Aluah		21/12/ 2022
(UDS/MID/0001/20)	Signature	Date

DECLARATION BY SUPERVISORS

I hereby declare that the preparation and presentation of the thesis were supervised per the guidelines on supervision of the thesis laid down by the University for Development Studies.

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ABSTRACT

Wastewater sludge has garnered global interest since its generation in terms of source, volume, quality, treatment, disposal, or reuse. It has an impact on human life and other natural resources, most notably fragile ecosystems. The study was carried out at the Savannah Research Institute (SARI) in the Tolon District of the Northern Region of Ghana. The main objective was to design, construct and test the performance of a filter for the treatment of wastewater sludge for irrigation. The filter design consisted of two poly tanks, with one labeled as a sedimentation tank and the other one as a filtration tank. Both tanks' specifications were; the flow rate of the sedimentation tank was 0.18 L/s, the height of the tank was 1.52 m, the diameter was 1.23 m, the surface area of the tank was 0.19 m^2 and the volume was 1.81 m^3. The sedimentation tank was installed to accommodate the wastewater sludge for pretreatment. HDPE pipe of 100 m was connected to a 35 m^3/h gasoline pump to lift the wastewater sludge from a 100 m distance from the source to the sedimentation tank. The filtration tank was filled with local geologic materials such as crushed stones, chipping stones, and river sand. Each layer had a height of 0.4 m and the total bed height was 1.2 m. The order of the arrangement of roughing filter materials was crushed stones as the first layer at the bottom of the tank with sizes ranging from 18-24 mm, chippings at the second layer with sizes of 8-12 mm, and the third layer river sand with sizes of 4-8 mm. The filtration velocity and up-flow velocity were 1.5 m/h. The most porous material among the three (3) filter materials used are crushed stones, which had a porosity of 44.7 %. However, river sand was almost non-porous, recording a value of 5.9 %. After the wastewater sludge from the sedimentation tanks which contain alumium salts, suspended solids and sediments had been filtered with the constructed roughing filter, desirable levels of physical, chemical, nutrient, and microbiological parameters were obtained, and they were within the acceptable limits of FAO or WHO, or EPA. The pH level moved from 6.20 before filtration to 6.61 after filtration; from 102.67 to 0 mg/L after filtration for TDS, and 8198.67 to 19.0 NTU after treatment for turbidity. The salinity level dropped significantly from 201 to 0.002 mg/L representing 99.99 % removal efficiency. Dissolved oxygen (DO) also improved as well as the other parameters. The total coliform, faecal coliform, and E.coli count reduced drastically from 200 to 100 cfu/100 ml, 60 to 8 cfu/100 ml, and 25 to 4 cfu/100 ml respectively. It is recommended that the filtered and unfiltered wastewater sludge generated at SARI water treatment plants can be used to irrigate various kinds of vegetables to monitor the impact of the filtered and unfiltered wastewater sludge on the growth and yield of these vegetables. Also, there is a need to establish infrastructure and rehabilitation of broken structures at already existing plants to accommodate wastewater sludge at water treatment plants across the country to further treat this wastewater for irrigation purposes especially in water-scarce areas to help feed the ever-growing population.

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DEDICATION

I dedicate this work to my family.

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LIST OF ACRONYMS AND ABBREVIATIONS

APHA	American Public Health Association
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CSIR	Council for Scientific and Industrial Research
DWTS	Drinking Water Treatment Sludge
E. coli	Escherichia coli
EC	Electrical Conductivity
EPA	Environmental Protection Agency
FAO	Food and Agricultural Organisation
HDPE	High-Density Polyethylene
HRT	Hydraulic Retention Time
MoFA	Ministry of Food and Agriculture
NRV	Non-return Valve
NTU	Nephelometric Turbidity Units
PVC	Polyvinyl Chloride
SARI	Savannah Agricultural Research Institute
GSA	Ghana Standard Authority
SDG	Sustainable Development Goals
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
WHO	World Health Organisation
WWT	Wastewater Treatment

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CHAPTER ONE

INTRODUCTION

1.1 Background

The globe is progressively confronting a water scarcity crisis as a result of a variety of factors such as climate change, rising global population, increased urbanization, and water pollution (Chitonge *et al.*, 2020). To mitigate this, reusing wastewater can be a viable solution, especially for irrigation (Maryam and Büyükgüngör, 2019a). According to Winpenny *et al.* (2010), wastewater reuse initiatives have the potential to provide a double or even triple reward to urban consumers, farmers, and the environment. Using wastewater for irrigation has a lot of potentials, especially in locations where water is limited (Almuktar *et al.*, 2018). Using wastewater subject to some sort of treatment in irrigated agriculture since the readily accessible freshwater source is limited could assist with the creation of jobs and advance food and nutritional security, reduce hunger, eradicate poverty, and assure human welfare and advance development in a sustainable manner (Mugagga and Nabaasa, 2016). The fulfillment of several of the Sustainable Development Goals (SDGs) of the United Nations may also be aided by the reuse of wastewater for irrigation (Jeong *et al.*, 2016).

Wastewater reuse could perhaps support the UN's 2030 Sustainable Development Initiative, particularly addresses (SDG 1, 2 and 6) its sub-target to improve water quality by eliminating dumping, reducing contamination, and minimizing the share of untreated water by 2030, substantially increase water-use efficiency across all sectors, and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from it. As a potential source of irrigation water, the treatment of wastewater offers a

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variety of potential benefits, such as dependable water availability, a reduced need for chemical fertilizers, and improved soil conditioning that boosts crop output (Gao *et al*., 2021).

Important factors to take into account include the treated wastewater quality, the source of the raw wastewater, the trust in the treatment process, and the safety of the crops being irrigated with wastewater for human consumption or potential health risks. Sludge is frequently rich in organic matter and contains high concentrations of valuable micronutrients including Fe, Mn, Cu, Zn, Mo, and Cl as well as the essential plant nutrients nitrogen, phosphorus, and potassium (Kalbar *et al*., 2013).

According to Jafarinejad (2019), sludge is defined as the waste product existing out of the water, suspended solids, and flocculant chemicals. Sludge is the most common byproduct of wastewater treatment plants, and its disposal is one of the most difficult environmental issues in wastewater treatment operations (Demirbas *et al*., 2017). A conventional treatment technique is used to treat surface water for drinking/domestic purposes at the Savannah Agricultural Research Institute (SARI) drinking water plant in the Tamale-Northern Region of Ghana (Kreijen 2020). The wastewater sludge from drinking water plants is a reliable and all-year-round water resource for irrigation purposes. To maximize the value of this water and minimize water losses, a wastewater treatment scheme can be developed to utilize the water for different irrigation methods such as sprinkler or drip irrigation.

1.2 Problem Statement and Justification

The world's population is predicted to rise further, while water resources are expected to dwindle further, and the situation is expected to worsen as a result of global warming and other environmental issues (Puplampu and Boafo, 2021).

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Cities in emerging countries such as Ghana are witnessing unprecedented population expansion (Puplampu and Boafo, 2021). Large amounts of wastewater are created as water distribution and sanitation coverage expand quickly, and this wastewater is routinely deposited untreated into the environment in streams, drains, etc. (Sagoe *et al*., 2019). Since its formation in volumetric terms, composition regarding quality and source, treatment, reuse, or disposal has an impact on human existence and other natural assets, most importantly fragile ecosystems, wastewater/sludge has attracted attention on a global scale (Eggen *et al*., 2014). The coverage of Ghana's effluents treatment system was disturbingly little, at 4.5 %, according to UNICEF (2016). Tema, a significant industry-centered city in Ghana, is the only municipality having a functional sewerage/sludge treatment setup for the handling, treatment, and disposal of wastewater, according to the research. The Waste Management Department of the Metropolitan, Municipal, and District Assemblies is in charge of managing wastewater in Ghana, Eugene *et al.* (2019). Only 4.5 % of Ghana's population is served by the sewage network, and the majority of metropolitan areas need facilities for wastewater treatment (Sagoe *et al*., 2019).

The recycling and reuse of wastewater from Ghana's numerous water treatment plants, however, depends on several conditions (Kalbar *et al*., 2013). These factors include a lack of infrastructure, technology, technical expertise, and lack of knowledge or lack of financial capacity (Mendes *et al.*, 2014; Sixt *et al.*, 2018).

The Savannah Agriculture Research Institute (SARI), Nyankpala water treatment plant has some wastewater generated that is not in use now, instead, the wastewater is discharged into the same source (dugout) that supplies the research station with potable water without any knowledge of the amount of chemicals the wastewater contains. That is because the SARI water treatment station has no infrastructure to accommodate the wastewater sludge which compels them to discharge the

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wastewater back to the dugout. While the need for infrastructure to transfer and/or store treated water arises, wastewater is identified as a barrier to; a key issue limiting its use is public concern over potential impacts on human and environmental health (Liu *et al.*, 2016; Maryam and Büyükgüngör, 2019a). Diarrhoea was one of the leading causes of death among children, accounting for 19 % of all child fatalities in 2015, with 78 % (1.46 million) happening in Africa and Southeast Asia. These fatalities were linked to the reuse of wastewater in irrigation systems (mostly untreated) and other competing water uses (Kalbar *et al*., 2013).

Voulvoulis (2018) asserted that concerns with the quality of treated wastewater may result in actual or perceived challenges in agriculture. To evaluate the quality of the treated wastewater, pathogenic contamination levels and presence are considered (Osunmakinde *et al*., 2019). Nutrient loads, dissolved oxygen content, detectable metal concentrations, pH, suspended material, microbial load (i.e., bacteria and protozoa), and the presence and levels of pathogenic contamination are examples of quality indicators or criteria (Edokpayi *et al*., 2017). Several guidelines have been produced to assist the safe use of treated wastewater in agriculture (Jaramillo and Restrepo, 2017a). Because the wastewater from the drinking water treatment plant cannot be utilized directly for drip irrigation, a filtration stage in the irrigation system is required. Before it may be used for drip irrigation, some components in the wastewater must be eliminated. In this scenario, the most relevant water considerations are:

(a) The amount and size of suspended particles - a key concern is that sludge water would clog/block the irrigation system.

(b) The biological composition - the number of biological contaminants contained in irrigation water must not be hazardous to the crops that are irrigated, and the chemical composition; and

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(c) Irrigation water should have a chemical composition that does not cause the crop or the ground to deteriorate. If the water is overly saline, for example, the irrigated land for agricultural purposes will be destroyed.

Therefore, this study focused on the design of a sludge treatment system and a water filter for the SARI drinking water treatment plant to make it appropriate for irrigation purposes.

1.3 Objectives of the Study

The main objective of the study was to to design, construct and carry out performance test of a filter for the treatment of wastewater sludge for irrigation in the Tolon District in the Northern Region of Ghana.

1.3.1 Specific Objectives

The specific objectives of the study were;

1. To design and construct a roughing filter for the filtration of wastewater sludge at the SARI drinking water treatment plant for irrigation purposes.
2. To monitor the operation and the performance of the water filtration system.
3. To determine the physicochemical quality of the wastewater sludge before filtration.
4. To determine the physicochemical quality of the water after filtration before it is used for irrigation.

1.4 Research Question

1. Which filter would be the best design for the filtration of wastewater sludge from the SARI drinking water treatment plant for irrigation purposes?

2. What is the operation and performance of the filtration system?

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3. What is the physicochemical quality of the wastewater sludge before filtration?

4. What is the quality of the filtered water for irrigation?

1.5 Thesis Structure

Five (5) major chapters make up the thesis. The background of the study, problem statement, rationale, objectives, research questions, and thesis structure are presented in Chapter One (1). In Chapter Two (2), the pertinent empirical literature is reviewed concerning the treatment of wastewater sludge, the physical, chemical, microbial, and nutrient properties of wastewater sludge, the risks associated with wastewater usage, the various types of roughing filters, the various types of sludge and their various forms, the filtration and filtering methods, etc. The study's materials and methods are described in Chapter Three (3), including the study regions, how the various properties of the wastewater sludge were determined before and after filtering, data collection techniques, and performance evaluation indicators. The results and discussions, as well as the study's conclusions and recommendations, are presented in the fourth (4^{th}) and fifth (5^{th}) Chapters, respectively.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of Wastewater and Treatment Processes

On the subject of SDG 6 i.e., clean water and sanitation, wastewater is still a hot topic with global concerns. According to Eggen *et al*. (2014), the volumes generated, their composition as it relates to the quality and source, and the mode of treatment, reuse, and/or disposal have an impact on mankind and the environment, and these make it a more sensitive topic. The reason for improved wastewater treatment in high-income countries is either to maintain the quality of the environment or to give an alternate water supply when dealing with water scarcity (Ondrasek, 2014). However, due to a lack of infrastructure, finance, and technical and institutional competence, the use of untreated wastewater remains a common practice, particularly in developing nations (Ravina *et al.*, 2021).

Approximately, 70 % of urban and factory-made wastewater in developed countries is treated, according to Connor *et al*. (2017). However, in upper to middle-income economies, only 38 % of municipal and industrial wastewater undergoes treatment, and 28 % volume of wastewater is in nations with lower-middle-class incomes. In Ghana (a lower-income country), only 8 % of wastewater produced is treated for reuse (Kwabla, T. A. 2017) . Thus, it is no surprising that about 80 % of total wastewater produced globally ends up in its final destinations untreated (Kwabla, T. A. 2017). Wastewater can be defined as domestic, industrial, agricultural, and manufacturing wastes that are liquid-borne – water that has its quality negatively impacted by human activities such as domestic, industrial, and commercial use (Chen *et al.*, 2020). It is typically composed of 99 % of water and 1 % of suspended, colloidal, and dissolved particles (Hanjra *et al*., 2012).

With the numerous importance that comes with wastewater treatment, it has become a necessity since it aids in human and environmental health promotion and protection, and reuse options in industrial and agricultural production (Kalbar *et al.*, 2013). The prime focus of wastewater treatment (WWT) is to remove contaminants that render water unwholesome for use. The various contaminant removal processes could be biological, chemical, or physical. In the treatment process, primary treatment is used in the removal of large solids and pollutants such as sand and grit from wastewater by screen usage, settling tanks, and/or skimming equipment (Wang *et al.*, 2021). The primary treatment process becomes necessary when the speed of solid contaminants ought to be reduced to settle and floating materials to subside. In secondary wastewater treatment, organics and solids from wastewater are removed biologically (Gunatilake, 2015).

Flocculation and coagulation are essential techniques for separating liquid-solid in industrial wastewater treatment. To destabilize particles and enable floc formation and removal via clarifying (buoyancy or centrifugation) and/or filtration, chemicals (aluminum sulfate or iron salts) are introduced to water during the coagulation process (Wong *et al*., 2021). In water coagulants, chemicals are employed to weaken the charges of suspended and colloidal particles (Hayder *et al*., 2017; Jiang, 2015). As a result of the coagulation process, collections of smaller particles agglomerate into bigger, better-separated floatable, or settleable particles (Wang *et al.*, 2021).

In the treatment process of wastewater, the wastewater output is termed sludge; a slurry or semi-solid by-product. This by-product has to be subjected to another treatment operation for reuse (Demirbas *et al.*, 2017).

Sludge is a byproduct of several industrial operations, such as water treatment, wastewater treatment, and on-site sanitation systems (Tun *et al*., 2021). It can also be produced as a settled suspension during conventional drinking water treatment (Ma *et al.*, 2019).

2.2 Physical Properties of Wastewater

2.2.1 Total Suspended Solids (TSS)

Total suspended solids are watery particles larger than 2 microns in size. Any particle smaller than 2 microns, on the other hand, are referred to as Total Dissolved Solids (TDS). According to Mohammadi *et al.* (2021), the majority of total suspended solids are made of inorganic components. However, algae and bacteria can also be classified as total suspended solids (TSS). Silt, plankton, sand, and other floating or suspending aquatic organisms are all examples of total suspended solids. When certain water sources are contaminated with rotting plants or animals, typically suspended solids, the organic particles are released into the water (Amakiri *et al.,* 2022). While some sediment settles at the bottom of water sources, suspended solids float on the surface or remain suspended somewhere in the middle. Total suspended solids affect water clarity, hence the higher the total suspended solids content of a water resource, the less clear it will be (Alimohammadi *et al.,* 2020).

Concerning agricultural water usage, the number of suspended solids in treated wastewater can have a significant impact on the efficacy of a drip irrigation system. Li *et al*. (2012) reported that a high quantity of suspended solids might cause an irrigation system to clog quickly. Suspended solids can also harm soil's hydraulic conductivity, since particles can build and form a less permeable top layer, resulting in a less effective irrigation system (Viviani and Iovino, 2004). Another unpleasant consequence of high suspended solids levels is that viruses and bacteria can adhere to the particles, causing crop damage and disease.

2.2.2 Total Dissolved Solids (TDS)

Rusydi (2018) indicated that the total amount of organic and inorganic substances dissolved in water is referred to as the dissolved solids concentration. In general, most of the dissolved solids in water are composed of magnesium, calcium, sodium, potassium, bicarbonate, sulfate, chloride, nitrate, and silica. Salinity is another term frequently used to describe the number of dissolved solids in water (Corwin *et al*., 2020). Combinations of these ions, such as sodium and chloride result in salts (Alipour *et al*., 2016). The concentration of dissolved solids in water is caused by human activities (e.g farming at the upstream of the dugout, burning of bushes chemicals application), the geology of the area most especially in arid regions where we have high evaporation rates and low precipitation, and climate.

The best and most efficient method for removing TDS from water and its harmful effects is typically through a water filtration system (Chaukura *et al*., 2020; Thibault *et al*., 2021). If the water source is known to contain a lot of calcium or sulfate ions, a constant of 0.8 may be utilized, however, the standard method for the examination of wastewater and water allows a TDS constant of 0.55 - 0.7 mg/L (Thibault *et al*., 2021).

2.2.3 pH

An essential quality indicator for both natural water and wastewater is the hydrogen ion concentration. The intensity level required for most biological life to exist is relatively small and crucial. Nyiyongu and Ndububa (2019), wastewater with an unfavorable hydrogen-ion concentration such high or low pH reduces biodiversity, decrease growth, respiratory inhibition and reproduction of living organisms which makes it difficult for biological processes to handle, and if the concentration is not adjusted before release, the wastewater effluent may alter the concentration in natural waters. The alkalinity in wastewater aids in the resistance to pH fluctuations produced by acid addition. Alkalinity comes from the water source, groundwater, and compounds added during residential usage; hence wastewater is generally alkaline (Warsinger *et al*., 2018; Victoria-Salinas *et al.*, 2019).

2.2.4 Turbidity

Kahle *et al*. (2021) stated that turbidity is an optical quality parameter that describes how clear or cloudy water is in general. It has to do with colour, although it is more about the loss of transparency caused by suspended particles and colloidal materials. Turbidity has an impact on the aquatic environment by scattering sunlight and lowering oxygen levels (Kjelland *et al*., 2015). It also has an impact on photosynthesis, respiration, and reproduction. The adherence of many heavy metals and other hazardous substances is also aided by suspended particles. Turbidity is a metric for water quality; the more turbid the water is, the poorer its quality (Teh *et al*., 2016).

The issue that occurs from turbid irrigated water is comparable to suspended solids and must thus be measured and regulated (Jeong *et al*., 2016). The current turbidity standards have maximum values ranging from 2 to 10 NTU and 10 NTU and above the water is considerd turbid (Al Mamun *et al.,* 2019). These statistics, known as suspended solids are utilized as an indicator of water quality.

2.2.5 Electrical Conductivity (EC)

Rahmanian *et al*. (2015) reveal that the conductivity of water is crucial because it can inform you about the concentrations of dissolved compounds, minerals, and chemicals in the water. The conductivity will increase with a higher concentration of these contaminants (Falizi *et al*., 2018). Water conductivity will increase by a tiny amount of dissolved salts and compounds (Bhateria *et* *al*., 2016). If you oversee a wastewater treatment facility, sudden changes in water conductivity above the 3.0 mS/cm may be an indication that pollutants have gotten into the system (Akoto *et al*., 2017; Kalbar *et al*., 2013). Negative and positively charged ions are created when different chemicals and salts dissolve in water (Falizi *et al*., 2018). Potassium, sodium and magnesium are examples of positively charged ions that can have an impact on water. In contrast, carbonate, sulfate, and chlorine are examples of negatively charged ions (Falizi *et al*., 2018). Electrical conductivity ought to be between 0.7 - 3.0 mS/cm for irrigation purposes (Falizi *et al*., 2018). The temperature of the water is the main component that can influence the EC of water out of a wide range of different parameters. Higher temperatures will typically result in greater electrical conductivity (Hassan, 2020). Mao (2016) reported that filtration or root eradication is the two methods for reducing conductivity. Maheshwari *et al*. (2020) said depending on the use and resources available, many technologies including reverse osmosis, deionization, carbon, filtering, and distillation are available to filter water for dissolved solids. In a generation, as filtering levels increase and the number of dissolved solids decreases, conductivity will also decrease (Rodriguez *et al*., 2020).

2.2.6 Temperature

The average annual temperature of wastewater varies by geographical area and ranges from 10 to 21 °C (Bhargava, 2016). Because of its impact on chemical reaction rates and aquatic life, wastewater temperature is an essential characteristic (Arora and Kazmi, 2015). Similarly, oxygen is less soluble in warm wastewater, and as the population of some aquatic species grows, so does the oxygen demand, resulting in dissolved oxygen depletion (Arora and Kazmi, 2015). Similarly, living organisms die because of rapid temperature changes (Baird *et al.*, 2009).

2.2.7 Salinity

Water that is too saline can have a significant impact on crop growth. Because of the difference in osmotic pressure, crops have a harder time absorbing water, resulting in fewer green leaves and a decrease in growth. The consequence of salt stress on plants are the same as those induced by water stress. The sensitivity of a plant to saltwater varies significantly amongst crops (Niu and Cabrera, 2010). Irrigation water salinity is measured in EC (electronic conductivity), and water with an EC less than 0.7 dS/m does not influence crop growth, whereas water with an EC of more than 3 dS/m is considered too saline and can causes significant damage to crops (Jeong *et al.*, 2016).

2.3 Macro-nutrient in Wastewater

Nitrogen and phosphorus are necessary for plant growth, although other elements such as iron are required in trace amounts for biological growth (Kumar *et al.*, 2015). It has been discovered that wastewater contains a range of nutrients required for agriculture production (Chiu *et al*., 2015). Even though nutrient content in wastewater plays a crucial role in plant growth, it might have negative consequences if it exceeds the recommended amounts. This involves, among other things, plant toxicity and the stimulation of excessive vegetation growth (Erel *et al*., 2019).

2.3.1 Nitrogen

Wastewater contains nitrate, ammonia, organic nitrogen, and nitrite, which are all macronutrients needed by plants (WHO, 2000; Taziki *et al*., 2015). Only 50 % of ammonia and 30 % of nitrogen may be absorbed by plants; the remainder is lost via transformation through several mechanisms such as evaporation, precipitation, adsorption denitification and chemical oxidation etc (Yuan *et al*., 2018). The main problem with nitrogen is that nitrates are heavily soluble in water, thus the

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majority of them are employed to irrigate crops (Abalos *et al*., 2014). Because many crops require enormous amounts of water to develop effectively, this often is impossible to control (Qadir *et al*., 2010). Excessive nitrogen levels in wastewater can induce over-fertilization, resulting in high vegetative growth, crop maturity delays or unevenness, and poor quality. Nitrogen levels in wastewater have been observed to range from 20 to >100 mg/L, depending on local people's in-house water use and food, as well as sewage effluent treatment before Soil Aquifer Treatment (SAT**)** (Qadir *et al*., 2010; Reta *et al*., 2021).

2.3.2 Phosphorus

According to An *et al*. (2016), wastewater can contain 5 to 50 mg/L phosphorus, depending on the local populations' diet and water use. Organic phosphorus is biologically transformed into phosphate during wastewater pre-treatment and passing through the soil of the SAT system. Phosphate precipitates with calcium in calcareous soils with an alkaline pH to generate calcium phosphate (Taalab *et al*., 2019). Phosphate combines with iron and aluminum oxides in the soil to generate insoluble compounds in acidic soils.

WHO (2006) states that fertilizer is nearly always recommended since soil phosphorus is frequently scarce in a form that is organic to plants. In soils, phosphorus is comparatively stable and may have an impact, especially close to the soil surface. Because wastewater has a low phosphorus content, it can be used for irrigation without harming the environment. However, because phosphorus accumulates near the soil surface, it has the potential to pollute surface water through soil erosion and runoff (Elgallal *et al.*, 2016).

2.3.3 Potassium

These are macronutrients found in high amount in the soil, 3 % of the lithosphere, but is not bioavailable because it is bonded to other substances. As a result, fertilizer must be used to supply potassium to the soil. Potassium is needed at a rate of around 185 kg/ha. Potassium levels in wastewater are too low to meet the theoretical demand (Kolb *et al.,* 2017).

2.4 Chemical Properties of Wastewater

2.4.1 Biological Oxygen Demand

The term Biological Oxygen Demand (BOD) refers to the quantity of dissolved oxygen that aerobic organisms in water need to consume to decompose organic material that is present in a water sample at a particular temperature and for a particular period. Oxygen depletion is very likely in water with a high BOD concentration, resulting in a decreased ability of crops to absorb nutrients (Jeong *et al*., 2016). As a result, BOD concentration in irrigation water must be measured. The average BOD guideline restricts its content to about 15 mg/L (Agoro *et al*., 2018).

Studies conducted globally have shown that wastewater has high levels of organic matter's ability to fertilize, indicating that it can be used to enrich and recondition agricultural soils to boost crop yields (Birleys and Kock, 1999). This was supported by investigations of institutions charged with wastewater management in senegel and Ghana, which revealed BOD levels (Cornish *et al*., 1999). This revealed the existence of organic matter as well as high phosphorus and nitrogen concentration, both of which are critical nutrients for plant development (N'tchougan-Sonou, 2001).

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2.4.2 Chemical Oxygen Demand

Chemical oxygen demand matter is expected to be less prevalent in drinking water sludge. The water treatment plants use surface water from a river that does not typically contain high levels of COD. Chemical oxygen demand concentration in irrigation water is not required by international reporting. As a result, the COD concentration will be limited to a maximum of 30 mg/L (Jia *et al.*, 2017).

2.5 Biological Properties of Wastewater

2.5.1 *Escherichia Coli*

The greatest indicator of the presence of faecal bacteria in the water is to test for *Escherichia coli* (*E. coli*) bacteria. In the faeces of mammals, *E. coli* is found in extremely large concentrations. Water containing high levels of *E. coli* is likely to have high levels of other dangerous bacteria (Edberg *et al*., 2000). Irrigating with bacterial-infested water can be exceedingly dangerous to people's health, hence there must be regulations and limits on the maximum bacterial contamination that can be used. In the categorization of irrigation water, vegetables likely to be eaten raw (category A), and vegetables to be cooked, processed, or fruits not directly irrigated (Category B) should have an average *E. coli* content of 1 cfu mL^{-1} and 1 cfu mL^{-1} respectively (Allende *et al.*, 2015).

2.5 Threats of Wastewater Usage

The usage of wastewater in agriculture offers numerous advantages, but poses significant health dangers, particularly when untreated wastewater is utilized for crop irrigation. Farmers regularly have no alternative but to utilize untreated sewage because there is no wastewater treatment and freshwater is either inadequate or just too costly (World Bank, 2010). Although urban vegetable production increase access to jobs, and food, improve nutrition, and reduces poverty, it poses risk to human health and the environment. This makes it challenging to receive the necessary support from authorities, especially in sub-Saharan Africa, where there are significant problems with sanitation (Drechsel *et al*., 2006: Obuobie *et al.,* 2006).

Microorganisms in untreated or inadequately treated wastewater have been shown by Bintsis (2018) and Ungureanu *et al*. (2020) to hang around long enough in the environment to cause parasitic, bacterial, and viral infections in humans when inhaled as aerosols. Ungureanu *et al*. (2020) reported that people are exposed to pathogens when wastewater is reused in irrigated agriculture through a straight link with the polluted water, inhalation, and accidental ingestion before, consumption of irrigated vegetables either during or after irrigation, and consumption of an animal product that has been contaminated by the use of wastewater.

If irrigation wastewater's physicochemical quality is poor, for instance, because it is too salty or includes excessive levels of boron, heavy metals, or other industrial toxicants, nitrogen, and/or sodium, reduced crop yields are the greatest risk to plants. When there is less industrial effluent in the wastewater, there are fewer threats to plant health, but five criteria should always be evaluated during the irrigation season: sodium, electrical conductivity, pH, total nitrogen, absorption ratio, and boron (World Bank, 2010).

2.5.1 Microbial Threat to Public Health

If pathogens in wastewater go through the food chain, they can result in deadly illnesses and even lead to death. Diarrhoea is the second leading cause of death for 800,000 young children in developing countries, where there are frequently insufficient drinking water and sanitation systems (Cisneros, 2021). Consuming untreated wastewater and consuming unprocessed or fresh vegetables from wastewater-irrigated crops can result in epidemics of cholera, shigellosis, typhoid fever, as well as seropositive reactions to helicobacter pylori that can cause chronic infections and even cancer (Kamizoulis, 2008).

Microbial pathogens such as protozoa, bacteria, viruses, and helminths are the principal health risks in low- and middle-income nations because they are present in domestic wastewater and water treatment facilities. The unregulated use of untreated or only partially treated wastewater for edible crop irrigation has been linked by epidemiology studies over the past four decades to the spread of endemic and pandemic diseases to farmers and crop consumers (World Bank, 2010).

2.5.2 Chemical Threat to Public Health

Chemical dangers are higher in middle and high-income countries, where industrial wastewater is dumped into public sewers and contaminates municipal wastewater. Several organic compounds and heavy metals, including cadmium, lead, mercury, and others, can be hazardous to human health (such as pesticides). Although their long-term health effects are less clear, pharmaceuticals, hormones, endocrine disruptors, antibiotics, and personal care products are among the growing class of anthropogenic chemical compounds that are worrying high-income countries (World Bank, 2010).

2.5.3 Wastewater Threat to the Soil

Salinization is the biggest and most typical issue brought on by wastewater use in soils, according to Singh (2021). If thorough soil washing and land drainage are not carried out, problems occur even with freshwater. Because of its higher salt concentration, wastewater can hasten the process of salinization, and this causes soil structure to collapse resulting in the loss of pores and interconnections that allow water and air movement in the soil (Drechsel *et al*., 2010). Because

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wastewater contains more salts than freshwater, the salinity of the soil and groundwater will constantly rise in long run, as a result, it is vital to integrate wastewater utilization with salinization management techniques (Drechsel *et al*., 2010). Controlling numerous chemical-related risks to plants and the environment requires putting in place robust industrial wastewater pre-treatment and control procedures. Effective programs are not the norm in developing nations, thus chemical dangers must be addressed with great care in such cases (Drechsel *et al*., 2010).

2.6 Wastewater Treatment – An Outlook on Sludge

Sludge comes from several stages of the wastewater treatment process and contains a varied amount of inorganic and organic components in both the liquid and solids phases (Świątczak and Cydzik-Kwiatkowska, 2018). It is generated through domestic, industrial, and wastewater plant which consequently produces solid materials in its treatment process (Puplampu and Boafo, 2021). Based on the source, sludge can be classified as drinking water sludge, faecal sludge, industrial wastewater sludge, and sewage sludge. The amount and characteristics of sludge produced in a wastewater treatment facility are determined by the wastewater composition, wastewater treatment method, and sludge treatment method (Świątczak and Cydzik-Kwiatkowska, 2018). Sludge is a good source of nutrients and trace minerals for plant growth, and it can help enhance soil chemical and physical quantities (Świątczak and Cydzik-Kwiatkowska, 2018). Despite the advantages and practical value of sludge, it usually contains organic, inorganic, and biological pollutants from domestic, commercial, and industrial wastewater, as well as a substance added or generated during various wastewater treatment processes (Świątczak and Cydzik-Kwiatkowska, 2018). Inorganic contaminants, for example, are metals and trace elements, and organic contaminants are polychlorinated biphenyls dioxins, medicines, and surfactants, and pathogens such as bacteria, viruses, and parasites are examples of pollutants (Świątczak and Cydzik-Kwiatkowska, 2018).

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According to Gerba and Pepper (2019), the composition of sludge is determined by wastewater content and treatment methods, and the quality indices obtained to define the application technique, rate, and level of regulatory control are necessary. Aside the materials that enter the treatment plant, some of which will sediment immediately in the mechanical treatment, the chemicals are supplied during the chemical treatment step (Englande *et al.*, 2015). However, materials that end up in sludge are pharmaceutical drugs such as antibiotics and hormones in the influent wastewater (Englande *et al*., 2015). According to Alvarenga *et al*. (2015), metals, biological organisms, organic materials, and nutrients are all mingled together since modern wastewater treatment plants use a variety of physical, chemical, and biological treatment techniques.

2.6.1 Forms of Sludge

According to Jung *et al*. (2016), drinking water treatment sludge (DWTS) is a waste by-product of the drinking water treatment process that contains significant levels of aluminum or iron species due to the usage of various coagulants. Furthermore, DWTS is made up of suspended and colloidal contaminants such as silt, sand, humic particles, and clay, all of which are related to the quality of the raw water (Ahmad *et al.*, 2016). The environment and human health are both harmed when drinking water treatment sludge (DWTS) is discharged directly from a water treatment plant (WTP).

From pit latrines septic tanks, and onsite sanitation systems which contain solid waste, human excreta, water, and other materials, faecal sludge is also produced (Lindberg and Rost, 2018). In most developed countries, faecal sludge is moved into a vacuum truck for treatment before the sludge can be used as a soil conditioner, irrigation, and production of biogas, biodiesel, and charcoal (Strande, 2014).

Awuchi *et al*. (2020) defined industrial wastewater sludge as a slurry substance that is produced from manufacturing industries and warehouses, and this wastewater by-product contains a huge number of pathogens, metals, and chemicals that can cause harm if not properly managed. Seleiman *et al*. (2020) also reported that the harmful contaminants in the sludge can adversely result in pollution of the environment and human health. For this reason, proper caution and management are required before it is discharged on land.

Sludge produced by municipals is also known as sewage sludge. It is a blend of organic (faecal matter from humans) and inorganic matter, microorganisms, food particles, and trace chemicals in a watery or semi-watery state (Gan and Shuit, 2020). After treatment, the sludge can be used as fertilizer for horticulture and landscaping purposes, and its anaerobic treatment could result in methane production, used in cooking and heating (Awuchi *et al*., 2020). Desiccated sewage sludge burning can kill pathogens to minimize the volume of sludge and decomposing of organic chemicals (Gan and Shuit, 2020). However, greenhouse gases and pollutants into the atmosphere through the burning of the desiccated sewage sludge result in the production of inert and inorganic ash which has fewer uses (Chanaka Udayanga *et al*., 2018).

2.6.2 Sludge Treatment

According to Bhargava (2016), sludge is treated by various processes that can be used in several forms. Primary sludge is generated from the primary settling tank through chemical precipitation, sedimentation, and some other primary processes. Sedimentation, though not mostly factored into the sludge processing stages, begins the whole wastewater treatment process, and in some instances, primary storages are used to trap and thicken sludge (Abarca, 2021). In the processing stages, unwanted contaminants are removed whilst the remnants are channeled for further treatment (Demirbas *et al*., 2017). At this stage, secondary sludge; an activated bio-based

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substance from biological sludge treatment is used to remove raw biodegradable wastewater solids found in the raw plant influent which are trapped and removed in the primary sedimentation process (Demirbas *et al*., 2017). The third stage of wastewater treatment involves the removal of nitrates and phosphates found in the wastewater, materials such as sand and activated carbon are predominantly used at this stage (Englande *et al.*, 2015).

In the treatment process, trickling filters are used together in wastewater treatment (Garg, 2009; Qasim, 2017). Garg (2009) and Saravanan *et al.* (2021) reported that gravity separation of drinking water treatment sludge can effectively compress wastewater sludge treatment resulting from sedimentation and filter backwashing. Garg (2009) and Shrestha *et al.* (2020) reported that during the process a slight increase in solids content might reduce overall sludge volume, necessitating larger treatment units. Gravity settling, floatation, centrifugation, and gravity belts are some of the physical sludge treatment methods (Wu *et al.*, 2017). Slow-speed stirring in a tank with a picket fence type mechanism fosters more flocculation and can greatly enhance the solids content and settle ability with a lot of flocculent sludge, especially extra activated sludge which allows the removal of the supernatant. Expounded below are some major sludge treatment processes;

a. According to Garg (2009) and Yesil and Tugtas (2019), thickening is the process of removing a portion of the liquid content from sludge to increase the solid content. However, consolidating waste sludge by gravity thickening is the most straightforward and cost-effective method. In the thickening method, the flocculants aid in a more rapid phase higher solids contents, separation, and a great level of capture (Eckhoff, 2016).
b. Stabilization of sludge reduces pathogen content, eliminates objectionable odours, and reduces or eliminates the potential for putrefaction (Demirbas *et al.*, 2017). Lime stabilization, heat treatment, aerobic digestion, anaerobic digestion, and compositing are all methods of

stabilization. At this stage, lime is added to untreated sludge during this process to raise the pH to 12 or higher because a high pH environment restricts the life of microorganisms (Abdulsada *et al.*, 2021). The risk of sludge putrefaction and odour generation is reduced. The most popular lime-stabilizing materials are hydrated lime and quick lime (CaO) which can be introduced either before or after the dewatering process (Eckhoff, 2016). Lime used before primary clarity precipitates phosphates and hardness cation as well as organic debris that will aid in scale formation, and phosphorus can be eliminated up to 95 % (Fisher *et al*., 2019). The problem with this process is the creation of scale on tanks, pipes, and other equipment as well as the disposal of the vast amount of lime because of the process. According to Lee *et al*. (2018) the main disadvantage of lime stabilization is that it is just temporary only the operation of a full-scale installation will show the severity of these potential issues. The quantity of sludge produced is roughly 1.5 to 2 times that of the conventional approach. Lee *et al*. (2018) also reported that lime stabilization, unlike biological stabilization, does not lower the amount of sludge produced but the downside is that it can only halt biological activity for a brief period and that it does not reduce solids.

c. According to Gurjar and Tyagi (2017), sludge conditioning is the preliminary treatment of sludge to aid in the removal of water in a thickening or dewatering process. The methods involved in this treatment process are chemical (inorganic and organic), elutriation, and heat treatments (Ondrasek, 2014). Elutriation is the method of cleaning the alkalinity out of an anaerobic sludge digester to reduce the acidic chemical conditioner's demand to ameliorate the dewatering and settling characteristics. It is used in plants where there is a combination of excess activated and primary sludge for digestion (Gurjar and Tyagi, 2017).

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d. Antar *et al.* (2021) reported that the chemical method is the process that involves the application of organic and inorganic flocculants to improve the process of making a porous, freely draining cake layer. The flocculants improve solids collection, sludge blanket characteristics, and sludge dewaterability in this approach (Antar *et al.,* 2021).

e. Dewatering is a physical unit action that reduces sludge's moisture content. If sludge is not burnt or applied to the land, it must be dewatered or dried (Eckhoff, 2016). This can be accomplished by employing sand beds or mechanical dewatering devices. The method used in dewatering are accurately described by the devices used, some of the major types are drying beds, filter presses, horizontal belt filters, centrifuges, rotary vacuum filters, and rotating cylindrical devices (Elbaz *et al*., 2020). The characteristics of the sludge to be dewatered, available space, and moisture content requirements of the sludge cake for ultimate disposal all influence the sludge dewatering technique chosen (Eckhoff, 2016). In dewatering, flocculants raise the level of solids capture for both agglomeration and destabilization of finer particles in cake formation (Eckhoff, 2016). The final cake becomes the right filter media.

f. Final disposal techniques; final or ultimate disposal refers to the release of sludge into the environment as a residue in any form, including liquid, cake, dry, or ash. The principal methods are cropland application, land reclamation, sanitary landfill, and ocean disposal (Ondrasek, 2014). The first three methods are also utilization procedures. In an instance where a sanitary landfill is used for purposes of topographic modification, this also could construe as utilization.

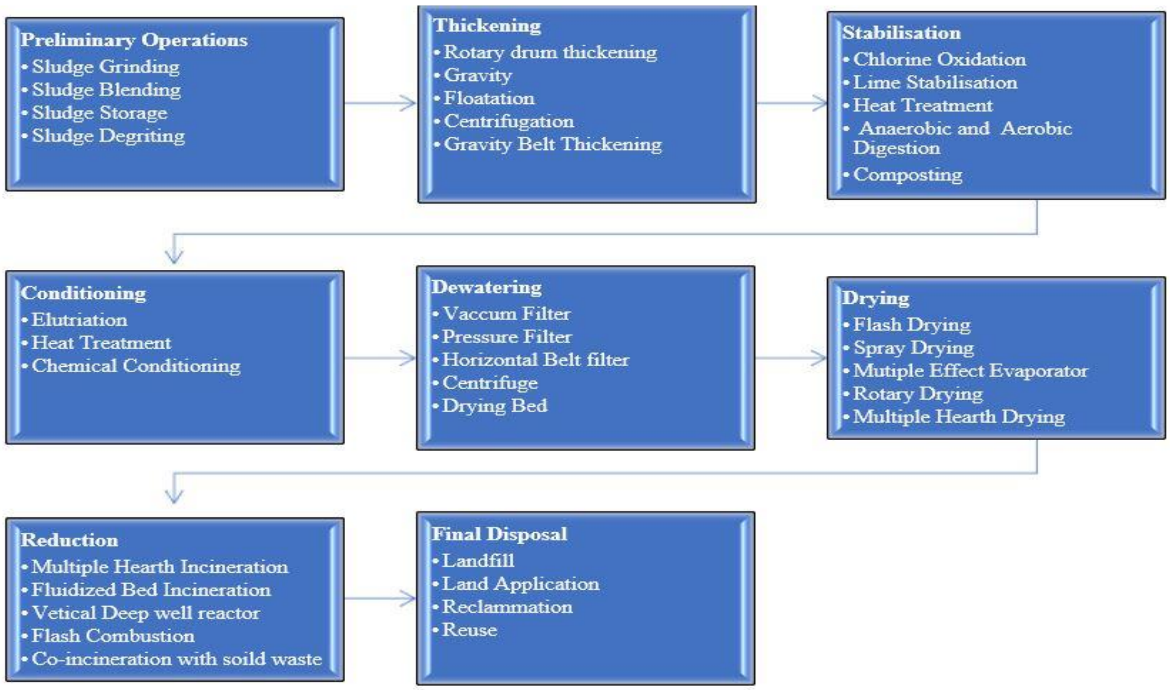

Figure 2.1: Sludge Treatment Flowchart

Source: Adapted from Ngo *et al.* (2017)

2.7 Filtration and Filtering Methods

The inhibition or expulsion of disease-causing pathogens like dangerous viruses, bacteria, cysts, and worm eggs is the primary goal of water treatment (Bultman *et al.*, 2013). Sterilization (usually with chlorine) and slow sand filters act as two predominantly used techniques for improving the bacteriological aspect of water quality (Palansooriya *et al.*, 2020). Roughing filters have become known in the last decade because of their role in pre-treating surface water before applying SSF (Jayalath *et al.*, 2016).

Because of the broad filter surface area for adsorption, sedimentation, and biological, and chemical activities, filtration is a more effective solid expulsion process (Saravanan *et al.*, 2021). Good water treatment begins with the isolation of coarse matter and ends with the inactivation or removal of tiny particles and microbes, which are typically quite challenging to separate (Xiao *al et.*, 2019).

Water that contains contaminants of varying sizes must be treated in stages (Jiménez *et al*., 2018). Firstly, screens act as a removal platform for the coarse matter that may be prevalent in surface water, and sedimentation tanks retain settleable solids (Jiménez *et al*., 2018). In a subsequent stage, roughing filters isolate the light and fine particles known as suspended solids (Cescon *et al.*, 2020).

Roughing filters are typically made up of adsorbents that gradually shrink in magnitude (Street *et al*., 2015). The rough filtration medium isolates most solids, whereas the successive intermediate and fine filter media give a polishing effect (Affam *et al.*, 2020). Roughing filters also have a turbidity-reduction effect, bringing it to an acceptable level for an efficient and safe SSF process. Roughing filters, serve primarily as physical filter media and are used to retain solid materials. SSF are biological filters that are employed to enhance the bacterial quality of water (Hashimoto *et al.,* 2019). All these filter forms are of similar technical quality, and their functionality is distinguished by high process stability (Boller, 1993). They solely rely on natural filtration that does not necessitate the usage of chemical compounds to facilitate or augment the treatment method (Francisco *et al.,* 2017). As a result, roughing filters in conjunction with SSF exemplify a suitable treatment scheme for water treatment in developing countries.

2.7.1 Roughing Filter

Roughing filter is a typology of deep-bed filters, which means that an appropriate filter design enhances particulate matter removal all through the depth of the filter medium, optimizing the filter's ability to store the separated solids (Al-Baidhani and Khadafy, 2016). The effectiveness of particle separation in roughing filters is affected by filter design, water quality, and filter materials parameters (Wegelin, 1993; Boller, 1993: Al-Baidhani and Khadafy, 2016). Roughing filter medium usually is made up of coarse (rough) particles varying in size from 25 mm to 4 mm, which are installed in different fraction layers. Gravel is commonly used as a filtering material. Roughing filters differ greatly in terms of application and design (Hashimoto *et al.,* 2019).

The various filter kinds can be categorized based on their position within the water treatment and supply scheme and flow direction. As a result, dynamic and intake filters, as part of the water intake structure, are distinguished from actual roughing filters, which are incorporated into the water-treatment plant (Francisco *et al.*, 2017; Wegelin, 1993). Al-Baidhani and Khadafy, (2016) reported roughing filters are further classified as down-flow, horizontal-flow, and up-flow filters. To protect the SSF from unexpected siltation, these two filters ought to be employed in clear river systems with short peaks of turbidity during rainfall (Nkwonta *et al.,* 2010). They may also be used during the initial pre-treatment phase with roughing filters to decrease the solid load of highly turbid water (Wegelin, 1996; Francisco *et al.*, 2017).

Roughing filters are made for treating highly turbid surface water for extended periods (Affam *et al.*, 2020; SKAT, 1996). The water is cleaned through a trio of filter fractions. Roughing filters, serve as space filters, contrary to intake and dynamic filters because of the deep solids infiltration into the porous material and thus have a vast silt storage space (Karki *et al.,* 2020). Because of structural barriers, the usable filter medium height in vertical-flow roughing filters is limited to around 1.0 to 1.5 m. Similar to vertical-flow roughing filters, the span is theoretically limitless but is commonly between 5 and 9 meters. Roughing filters have filtering rates that range from 0.3 to 1.5 m/h (SKAT, 1996). Up- and down-flow roughing filters may readily handle raw water turbidities of 50 to 150 NTU due to their longer filter length, whereas lateral roughing filters may be able to handle transient turbidity crests of 500 to 1000 NTU (Al-(Baidhani and Khadafy, 2016). The filters are washed regularly using a quick filter drainage system and, if necessary, a manual

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process by washing, removing, and reinstalling the filter material. The filter index can be used to demonstrate the filter efficiency as per Fick's law.

$$dc/dx = -\lambda c \qquad \text{Equation 2.1}$$

Where:

c - Solid concentration,

x - Filter depth

λ – Filter coefficient or the coefficient of proportionality.

2.7.2 Classification of Roughing Filters

Cescon *et al.* (2020) indicated that filters are classified into roughing filters, rock filters, and rapid and slow sand filters based on their filtration rate and material size. Roughing filters primarily use gravel as a filter medium and do not require the use of chemical compounds or any special complex mechanical device to function (Francisco *et al.*, 2017). Nevertheless, the architecture, setup, and operation differ tremendously. Roughing filters are grouped primarily according to:

i. The key reason for the application.

ii. Flow direction.

iii. Flow design.

iv. Filter cleaning technique.

Roughing filters are typically installed at treatment plants and are used as the final stage of the pretreatment process before channeling the water to a slow sand filtrating system (Khan *et al.*, 2011). Roughing filters can be operated as down-flow, up-flow, or horizontal-flow filters, with different gravel proportions installed in a separate containment and operated in series, or the different gravel sizes are placed one layer after another in the same compartment (Hashimoto *et al.*, 2019).

2.7.3 Types of Roughing Filter

2.7.3.1 Vertical Roughing Filter

Daigger *et al.* (2011) reported that the flow of effluent in vertical-flow roughing filters can be either downward or upward. The effluent is thus introduced at either the bottom or the top of the filter installation. When compared to horizontal flow roughing filters, vertical flow roughing filters have a simple self-cleaning method and take up less floor space (Nkwonta, 2010). Vertical-flow roughing filters have their filter media fully immersed. A 10 cm depth of water tends to cover the chippings and other locally available materials such as broken burnt bricks and coconut fiber. A sheet of coarse stones must be placed on top to tint the water and thus inhibit algal growth, which is common in pretreated water exposed to the sun (Nkwonta, 2010; SKAT, 1996).

2.7.3.2 Horizontal Roughing Filter

Horizontal roughing filters have a high capacity for silt storage. With increasing filtration time, solids stick to the filtration medium surface and grow into small heaps of soft granules (Ngo *et al.*, 2017). When the small heaps are becoming unsteady, they would then veer toward the bottom of the filter medium. This drift improves filter efficiency at the top while gradually silting the filter bottom upwards (Daee *et al.*, 2019). Horizontal-flow roughing filters are thus less vulnerable to solid breakthroughs caused by flow rate changes than vertical-flow roughing filters (Nkwonta, 2010). They could, nevertheless, be more vulnerable to short circuits caused by the varying temperature of raw water.

2.7.4 Components and Design Considerations of Roughing Filter

Six components make up a filter: raw water distribution, entrance flow control, real filter, collected treated water, exit flow control, and drainage system (Mwabi *et al*., 2012). The filter inflow must be sized to a specific flow rate and then sustained at that rate because steady flow conditions are required for effective filter operation (Oyanedel *et al.*, 2008). The adjusted steady flow rate can stay intact even during filter washing to optimize flow control all through the operation (Doherty *et al.*, 2015). Intake filters, on the other hand, necessitate a controlled rise in the flow rate to provide enough wash water to rinse the suspended particles out of the filter surface (Watson *et al*., 2017).

The raw water distribution on a filter needs to be equal to provide a constant flow rate in the filter bed (Karki *et al*., 2020). As a result, the flow arising from a channel or a pipe should be distributed evenly across the whole surface of the membrane (Tang *et al*., 2014). For this purpose, immersed filter beds, inlet weirs covering the whole full filter size, or vented walls providing the entire filter cross-sections are being used (Mwabi *et al*., 2012). To prevent the filter material from scouring, the hydraulic energy of fast-flowing water must be reduced by baffles located in the inlet zone (Lee *et al.*, 1998). Large flat stones or concrete slabs must be positioned on the surface of the material near overflows for the same intent (Nkwonta, 2010).

The real filter is made up of a watertight structure filled with filter material. The filter box is typically rectangular, with vertical walls (Watson *et al*., 2017). Nevertheless, based on local building techniques, spherical tanks, and inclined walls can also be constructed. Roundly shaped river bed stones or broken boulders with sharp edges are commonly employed as filter material, but any unreactive material that can resist mechanical forces, is non-soluble, and does not affect water quality in terms of odour or colour is acceptable (Ngo *et al.*, 2017).

The accumulation of treated water must also be homogeneous across the whole filter bed. Irregular water withdrawal would lower the entire filter performance and cause dangerous fluid short circuits (Chernicharo *et al.*, 2015). The excellent choice for achieving equal collection of treated water to up-flow filter media is the availability of an unrestricted water table on top of the filter bed, or the building of a pseudo-filter bottom for downward flow filters (Cescon *et al.*, 2020). A second, albeit least desirable, approach is to set in place a vented wall in the exit chamber to allow for equal withdrawal of the treated water.

The filter bed is kept moist by the outer valve (Nkwonta, 2010). Hydraulic washing of a parched roughing filter clogged with solid particles is a challenging, if not impractical, mission (Wegelin, 1996). As a result, it is ideal to operate roughing filters in wet conditions. The water is kept at the top of the filtration bed level by a sluice gate or an elevated and vented sludge hose (Wegelin, 1996). A V-notch weir may also be set up to enable the flow rate metrics at the filtration exit.

Roughing filter drainage systems serve dual functions: complete draining in times of repair or servicing works and hydraulic filtering (Nkwonta, 2010). Hydraulic filter bed washing necessitates high flow rates, necessitating the use of somewhat more big fittings and pipes (SKAT, 1996). The extra and yet tinier drainage systems in the outlets and inlet containers can be set up for the thorough removal of water.

2.7.5 Operation and Maintenance of Roughing Filters

This needs to be done once the culture medium water has exceeded the highest allowable level, i.e. when the maximum filter resistance of about 1 meter for the planned filtration flow velocity is reached (Marsidi *et al*., 2018). The very first step in filter washing is to drain the supernatant liquid and dewater the upper portion of the sand bed (Semiyaga *et al.*, 2017). The biological membrane and 1 to 2 cm of sand are then eliminated from the sand bed. Re-sanding may be done after the top sand layer has been removed (Kiky, 2018). The filter is then instantly restarted to prevent interrupting biological filter action any longer than necessary (Nkwonta, 2010). The filter bed is replenished with water from the under-drain system. This forces air from the sand pores and overwhelms the filter bed (Wegelin, 1996).

By starting the intake valve and modifying the filtration rate, the operation is restored (Liu *et al*., 2015). Which method of cleaning the filter physical or hydraulic is used depends on the pattern of residual solids in the filter. Surface filters, such as intake and dynamic filters, separate materials in the inlet zone of the filter (Kiky, 2018). These filters' fine gravel is physically cleaned by flashing the top of the filter with a spade or rake and rinsing the suspended solids from the filter bed (Xiao *et al.*, 2019). Roughing filters with varying filter material sizes function as packed bed filters, allowing solids to penetrate deeply into the filter medium (Nkwonta, 2010).

Periodic filter flushing is used to remove built-up solids. If the maintained solids are not fully separated by hydraulic filter washing, roughing filters may slowly become silted (Wegelin, 1996). Filter blocking up necessitates time-consuming manual washing, which should be prevented anytime possible by performing regular and efficient filter drainages (Solé-Torres *et al.*, 2019). The use of shallow beds in up-flow roughing filters reduces maintenance and construction work, as well as manual washing. Nevertheless, these shallow upward-flow types of roughing filters ought to be used with moderately turbid raw water (Kiky, 2018).

2.8 Benefits of Recycling and Reuse of Wastewater for Irrigation

In our daily activities, a massive amount of wastewater is produced in water treatment plants, factories, homes, and farms (Świątczak and Cydzik-Kwiatkowska, 2018). According to Gabr *et*

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al. (2021), wastewater accounts for 50 - 80 % of residential household water usage, and global wastewater discharge is estimated to be 400 billion m^3/year, contaminating around 5500 billion m^3 of water/year.

The practice of using treated wastewater for irrigation is gaining popularity in many regions of the world as a result of its numerous advantages (Świątczak and Cydzik-Kwiatkowska, 2018). Whereas the younger generation has a positive attitude toward the benefits of recycling wastewater for irrigation purposes, the older population is still cautious to ingest food cultivated using wastewater irrigation (Kihila *et al.,* 2014). Some of the advantages of using wastewater (treated, partially treated, or diluted) in irrigated agriculture are as follows: a large amount of water available all year without being affected by weather conditions, a high nutrient content that can reduce the use of inorganic fertilizers, increasing production on less fertile soils, and reducing the harm caused by eutrophication to freshwater (Świątczak and Cydzik-Kwiatkowska, 2018).

The resulting reduction in pressure on freshwater sources is one of the most well-known advantages of wastewater usage in irrigated agriculture. Ungureanu *et al*. (2020) reported that wastewater from water treatment plants can be used as an alternative irrigation source, particularly for crop production which is the world's largest water user, consuming 70 % of all available water. The use of treated wastewater from water treatment plants (WTP) for irrigation benefits society, the environment, and the economy (Jaramillo and Restrepo, 2017a). This method is being applied in various places facing water shortages and a growing population with increasing water needs especially given the loss in surface and groundwater supplies induced by climatic variability (CV) and climate change (CC) (Becerra-Castro *et al*., 2015).

Wastewater from water treatment plants has a significant nutritional content and therefore has a great potential for irrigated agriculture since it provides organic carbon, macronutrients (N, P, and K), and inorganic micronutrients (Ca, Mg, B, Fe, Mn, or Zn) to crop production (Jaramillo and Restrepo, 2017b). Several studies have highlighted the utility of wastewater, particularly treated water for the irrigation of crops, citing the benefits of enhanced crop yield as a result of the high nutritional content of these effluents (Barreto *et al.*, 2013; Jaramillo and Restrepo, 2017). However, eutrophication conditions in water bodies would be lowered as a result, as would farmer pesticide costs (Victor *et al*., 2008).

Another opportunity for wastewater reuse in irrigated agriculture would be the reduction of water contamination (Victor *et al*., 2008). The quality of receiving water bodies improves when wastewater discharge is reduced (Victor *et al.*, 2008). Furthermore, groundwater reserves are protected because they will be replenished with higher-quality water from agriculture (Victor *et al*., 2008). Furthermore, increased water recycling may help with the construction and optimization of treatment facilities to generate effluent of the desired grade for irrigation purposes, resulting in economic benefits for sanitation projects (Victor *et al*., 2008). Reducing the cost of wastewater treatment systems, obtained through a certain technological alternative that fulfills the goal of wastewater reuse for irrigated agriculture, may potentially be a viable option in regions where climatic and geographic features permit (Jaramillo and Restrepo, 2017; Ungureanu *et al.*, 2020).

2.9 Guidelines for the Safe Reuse of Wastewater for Irrigated Agriculture

Although governments and other official bodies around the world support the reuse of treated wastewater for crop irrigation, only a small number of wealthy nations have adopted new guidelines or standards regarding the physicochemical and biological characteristics of treated wastewater to safeguard public health and the environment when used in irrigated agriculture (Ungureanu *et al*., 2020). Low-income countries lack the funding for wastewater treatment plants and the capacity to adequately treat their wastewater, therefore they frequently utilize it as such, with little alternative but to accept the hazards associated with these practices (Cisneros, 2021). In three out of four cities in developing countries, farmers are currently required to use untreated or partially treated wastewater to irrigate their crops and meet their food needs (Bahri *et al*., 2016). More than 5.5 billion people are predicted to live in places without wastewater treatment plants by 2035 and if we tie that to the water shortage, we can expect an increase in the occurrence of diseases caused by eating vegetables and fruits grown on wastewater-irrigated land in those areas (Ratna *et al*., 2021).

Ungureanu *et al*. (2020) and Ratna *et al*. (2021) have stated that the guidelines for wastewater capitalization typically specify physicochemical parameters such as biological oxygen demand (BOD), chemical oxygen demand (COD), nutrients, turbidity, pH, electrical conductivity, and sodium absorption rate (salinity), suspended solids, heavy metals, and microbiological parameters (*Escherichia coli, salmonella, shigella),* depending on the quality of the crops and/or soils, regulations in different nations impose varied limitations for total coliforms, faecal coliforms, *Escherichia coli,* and nematode eggs. They also specify which kinds of crops and/or soils can be irrigated with wastewater (Becerra-Castro *et al*., 2015; Ungureanu *et al*., 2020). In 2006, the World Health Organization produced a set of guidelines for the safe reuse of wastewater in agriculture, including treatment and non-treatment recommendations that encompassed the entire food chain. Bacterial pathogens (*Shigella spp., Salmonella spp., Legionella spp., Escherichia coli,* and *Vibrio cholerae*), helminths (*Ascaris* and *Tenia spp.),* and intestinal protozoans (*Giardia* and *Cryptosporidium*) are a worldwide public health concern. Waterborne viruses such as adenovirus, and rotavirus are the most likely to spread via wastewater reuse (Świątczak and Cydzik-Kwiatkowska, 2018). Thus, health and environmental authorities consider the use of microbiological markers of faecal contamination to be the most reliable approach to assessing the effectiveness of water treatment facilities and the quality of the water they produce (Świątczak and Cydzik-Kwiatkowska, 2018).

The poor adoption of water reuse practices can be explained by the fact that, until recently, there were no unitary laws at the European level governing wastewater recovery (Świątczak and Cydzik-Kwiatkowska, 2018). Nevertheless, the value of reclaimed water needs to be uniform across the member states to meet national environmental and health standards for food hygiene for items used to irrigate agricultural land using treated wastewater (Ungureanu *et al*., 2020).

The European Commission published a new regulation on the minimum requirement for water reuse for irrigated agriculture on May 25, 2020, which has now entered into force; however, the new guidelines will be implemented beginning on June 26, 2023, and are anticipated to encourage and make it easier for the European Union to reuse water.

Table 2.1: FAO Guideline for Wastewater Quality Parameters for Irrigated Agriculture

Water Parameters	Symbols	Units	Maximum Range
Salt Content			
Electrical Conductivity	EC	dS/m	0 – 07
Total Dissolved Solid	TDS	mg/L	0 – 2000
Cations and Anions			
Calcium	Ca^{++}	me/l	0 – 20
Magnesium	Mg^{++}	me/l	0 – 05
Sodium	Na^{+}	me/l	0 – 40
Carbonate	CO_3^{--}	me/l	0 – 01
Chloride	Cl^{-}	me/l	0 – 30
Sulphate	SO_4^{--}	me/l	0 – 20
Bicarbonate	HCO_3^{-}	me/l	0 – 10
Nutrients			
Nitrate – Nitrogen	NO_3 – N	mg/L	0 – 10
Ammonium – Nitrogen	NH_4 -N	mg/L	0 – 05
Phosphate – Phosphorus	PO_4 -N	mg/L	0 – 02
Potassium	K^{+}	mg/L	0 – 01
Miscellaneous			
Acids/Basicity	pH		6.0 – 8.5
Boron	B	mg/L	0 – 15
Sodium Absorption Ratio	SAR	me/l	

Source: Adapted from FAO (2015)

2.9 Wastewater and Sustainable Development Goals (SDGs 6)

This study is in line with the Sustainable Development Goal (SDG) 6 of the United Nations, which calls for the provision of water, sanitation, and healthy living for all people, as well as their sustainable management. Andersson *et al*. (2016) assert that SDG 6's objective is to improve water quality through reduced pollution, a ban on dumping, and a restriction on the release of hazardous substances. By 2030, the percentage of untreated wastewater must be cut in half while recycling and safe reuse are both increased internationally. The achievement of this predetermined target would promote the achievement of succeeding Sustainable Development Goals (SDGs) that are related to water, such as SDGs 1, 2, and 3 correspondingly.

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According to Mabhaudhi *et al*. (2016), wastewater treatment creates a favourable condition for alternative water resources necessary for irrigated agriculture. Capturing this resource would help solve water security, food security, and agriculture productivity challenges. It would also have an added advantage to the environment derived from good wastewater treatment and management by lowering nutrient pollution in our water bodies. Additionally, deaths have been caused by inadequate sanitation and hygiene, typically in children under the age of five in impoverished nations (Alemu, 2017). However, wastewater management, together with sanitation, when given urgent attention will promote healthy living (Andersson *et al*., 2016).

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CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the Study Area

The study was carried out at the Water Treatment Plant (WTP) of the Council for Scientific and Industrial Research-Savannah Agricultural Research Institute (CSIR – SARI) in Nyankpala in the Tolon District of Ghana. It is located at latitude 9.407532 N and longitude 0.9871 W. The area experiences both dry and wet seasons with unimodal rainfall of approximately 1026 mm from May to October with a peak period between August and September. The distribution of temperature is uniform with an average yearly temperature of 28.3 °C (MoFA, 2000).

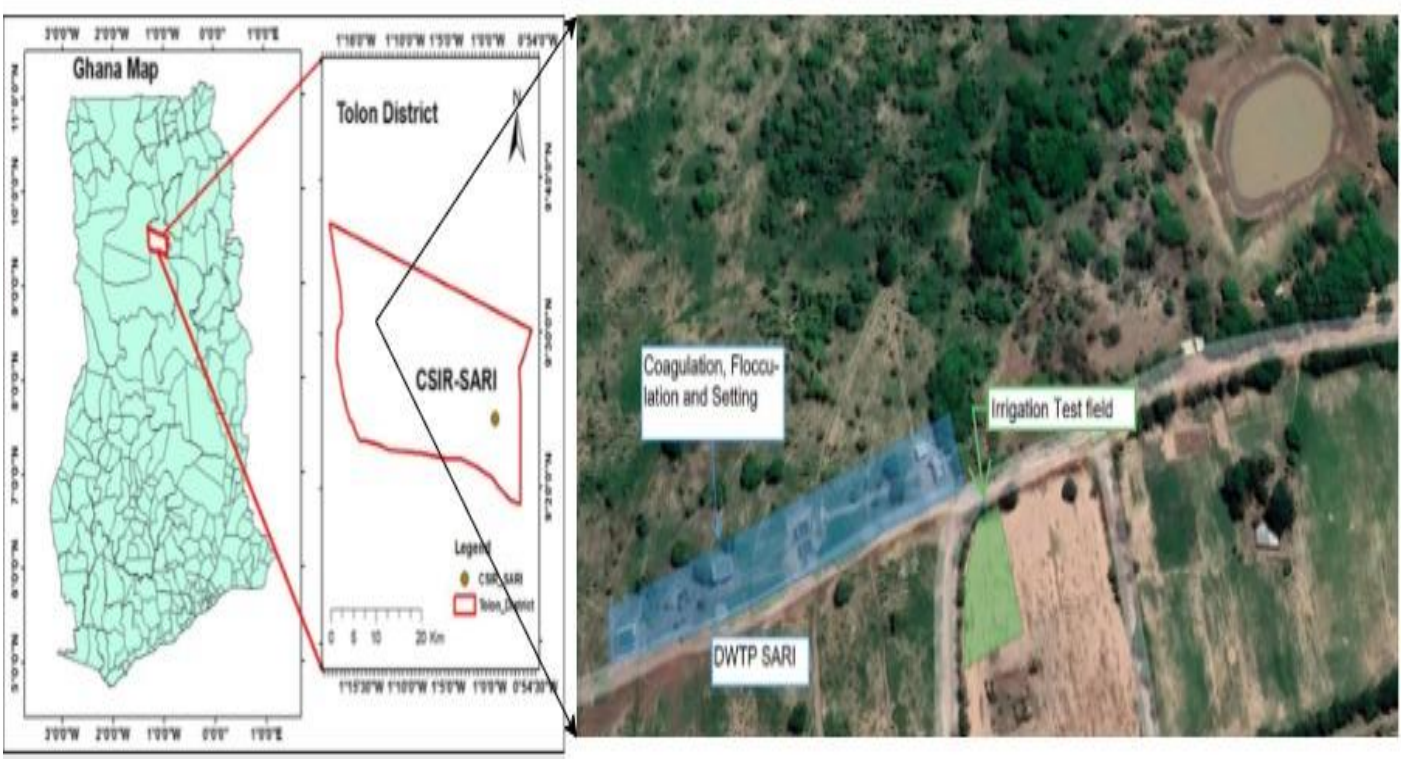

Figure 3.1: Map of Ghana Showing Tolon District and CSIR-SARI

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The drinking water treatment plant at the Council for Scientific and Industrial Research – Savannah Agricultural Research Institute (CSIR – SARI) in Tamale, Ghana has a standard treatment scheme that is used to treat surface water from a constructed dugout for domestic purposes. The water treatment plant setup at CSIR-SARI has two sedimentation tanks with capacities between 45 and 53 cubic meters respectively and two filtration tanks with an equal capacity of 23 cubic meters on each tank; the final stage is the clear well tank with a capacity of 4.5 cubic meters before the clean water goes to the distribution tank with 91 cubic meters capacity. The treatment process at CSIR – SARI exists out of coagulation; flocculation occurs at the sedimentation and filtration tanks with the use of alum sulphide. At the coagulation and flocculation stage, 3 kg per 750 ml cup or more of alum sulphide is used in the water treatment to trap suspended soils and other materials in the raw water, depending on the turbidity of the water, especially in the rainy season where the raw water becomes more turbid followed by settling and granular filtration. During this process, wastewater sludge is generated. Wastewater sludge is the waste product existing out of the water, suspended solids, and flocculants chemicals. The last stage is the disinfection of the filtered water from bad odour and taste with the use of 3 kg of chlorine before distributing the clean water for domestic purposes. The wastewater sludge at the (CSIR – SARI) drinking water treatment plant is a reliable and all-year-round water resource that can be treated and reused for irrigation and non-critical purposes (Bauer *et al*., 2021).

3.2 Materials and Equipment Used for the Study

The river sand was gotten from Nyankpala town, the chipping stones were fetched at UDS Nyankpala at the green people project site and the crush stones were collected at kukuo community under sagnarigu municipal. This material was considered because their locally available and can easily be gotten from anywhere. The purpose of the these materials were key in the design of a

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roughing filter because it improves the physical and the chemical properties of the wastewater sludge. The materials and equipment used for the study are presented in Table 3.1, 3.2, 3.3, and Figure 2.2.

Table 3.1: Material for Sedimentation Tank

Item	Quantity	Size
Poly Tank	1	1800 L
PVC pipe	5	63 mm
Valves	2	110 mm
PVC T-joint	2	110 mm
PVC Elbow	6	63-110 mm
End cap	4	63 mm

Source: Adapted from Kreijen (2020)

Table 1.2: Materials for Filtration Tank

Item	Quantity	Size
Poly Tank	1	1800 L
PVC Elbow	4	63-110 mm
End Cap	6	63 mm
Valves	3	110 mm
PVC T-joint	1	110 mm
Reducing Bend	5	
PVC Glue	3	
Tape Measure	1	
Saw	1	
HDPE Pipes	1	100 m
Pump	1	35 m^3/hr
PVC Cutter	1	
PVC Union	5	
Electric Flow Meter	1	
PVC Pipes	10	

Source: Adapted from Kreijen (2020)

Table 3.3: Materials for Roughing Filter Setup

Layer	Depth of the Layer (cm)	Filter Type	Size of Filter Material (mm)
1	40	Crushed stones	18 - 24
2	40	Chippings	12 - 18
3	40	River Sand	4 – 8

Source: Adapted from Kreijen (2020)

a. River sand b. Crushed Stones c. Chippings

Figure 2.2: Materials for Roughing Filter Setup

3.3 Setup of the Sedimentation Tank

There are a few commonly used sedimentation tank types, but this research focused on the vertical settling tank. The inlet valve was placed at the bottom of the tank and the outlet flow valve was placed at the top of the tank where the inlet valve is connected to a 35 m^3/hr gasoline pump to lift the wastewater sludge through a HDPE pipe for treatment. This is so because particles with a higher velocity will settle faster. The vertical sedimentation tank was designed to have a low flow velocity, to be used for flocculants settling which has lower efficiency for discrete settling than a horizontal flow setting tank.

To avoid rapid clogging of the filter, a sedimentation tank was installed to accommodate the wastewater sludge for pretreatment. The sedimentation tank was placed on an overhead metal stand of 1.88 m in length by 1.25 m in width with 2.45 m in height. An HDPE pipe of 100 m was connected to a 35 m^3/hr gasoline pump to lift the wastewater sludge from a 100 m distance from the source (dugout) to the sedimentation tank. An L-shaped (60 x 40 cm) pipe network with the longest side being 60 cm and a height of 40 cm is laid at the base of the sedimentation tank. The sedimentation tank was designed in that manner to avoid the disturbance of the settled sludge at the bottom of the tank anytime the wastewater is pumped from the source before the wastewater starts moving through the filtration process. The flow of pretreated sludge is by gravity which will remove the suspended solids (SS) such as flocs, sand, clay, etc. The principle of sedimentation is based on the difference in the densities between suspended solids and water. However, the wastewater sludge could settle within 10 days to avoid clogging the roughing filter before the filtration process begins. Due to stable and non-turbulent flow in the sedimentation tank, heavier particles settled in the settling zone during the 10 days. Subsequently, sludge accumulated at the bottom of the sedimentation tank and moved through the outlet flow after which the pretreated wastewater was released into the roughing filter in the filtration tank. The up-flow velocity depends on the dimension of the tank and the flow rate. Retention time (HRT) in the settling tank is the most important variable. The sedimentation tank HRT was within an hour, which ensured better settling efficiency.

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Figure 3.3: Inner View of the Inlet Pipe (Left) and Inlet Pipe Network (right)

Figure 3: Inner View of the Inlet Pipe (Left) and Inlet Pipe Network (right)

3.4 Design Parameters of Vertical Sedimentation Tank

The key parameters taken into consideration whilst designing the vertical sedimentation tank were:

1. Volume (V) of the tank [m^3]
2. Height (h) of the tank [m]
3. Diameter (d) [m] / surface (A) of the tank [m^2]
4. Inlet/outlet flow [m^3/hr]
5. Up-flow velocity [m/h]
6. Hydraulic retention time (HRT) [hr]

3.5 Setup of Filtration Tank

After mounting the sedimentation tank, the filtration tank together with its drain system was connected inside the tank. The filtration tank was filled with local materials such as crushed stones, chippings, and river sand. These materials were arranged and filled in three uniform layers with different grain sizes. Each layer had a height of 40 cm and the total bed height was 120 cm. The order of the arrangement of roughing filter materials was crushed stones as the first layer at the bottom of the tank with sizes ranging from 18 - 24 mm, chippings at the second layer with sizes of 8 - 12 mm, and the third layer river sand with sizes of 4 - 8 mm. The pretreated wastewater was filtered into the filtration tank through the base of the roughing filter to the top of the filter bed for collection. Both tanks were connected, with the sedimentation tank connected to the main source. Both tanks were installed with a T-section valve at the water inflow pipe. This T-section joint has two valves; one for shutting off the water inlet and the other for releasing water through the outlet pipe.

A multiple PVC pipe distribution network system or drain was designed and installed at the base of the filtration tank to divide the in-flowing pretreated wastewater. This PVC network system was connected to control valve s to reduce the hydraulic water energy. The outlet openings in the distribution pipes network were no larger than the filtration grains to prevent filter materials from being washed during back-washing.

The technical design of this system is shown in Figure 3.3

Figure 3.3: Inner View of the Inlet Pipe (Left) and Inlet Pipe Network (right)

3.6 Design Parameters of a Roughing Filter

The design parameters of the roughing filter are presented in Table 3.4.

Table 3.4: Design Parameters of the Roughing Filter

1. The volume of the tank (m^3)	7. Up-flow velocity (m/hr)
2. Height of the tank (m)	8. Hydraulic retention time (hr)
3. Height of the filters bed (m)	9. Height of the layers (m)
4. Diameter of the tank (m)	10. Grain size layer (m)
5. The surface area of the Tank (m^2)	11. Filtration velocity (m/hr)

6. Inlet/outlet flow (m^3/hr)	

3.7 Calculating the Necessary Parameters of the Sedimentation and Filtration Tanks

The formulae for estimating the parameters of sedimentation and filtration tanks are presented in Equations 3.1 to 3.7 as given by Wegelin (1996) and Kreijen (2020).

Volume of the tank, [m^3] = $0.25\times\pi\times D^2\times h = A\times h$……………….…………………Equation 3.1

Area of the tank, A = $0.25\times\pi\times D^2$..……….…………………………………….Equation 3.2

The up-flow velocity of the tank = Q/A……………………………………………Equation 3.3

Hydraulic Retention Time (HRT) of the Tank = $\frac{V}{t}$ ………………………………..Equation 3.4

The flow rate of the Tank, $m^3/s = \frac{V}{t}$………………………………………………Equation 3.5

Filtration Velocity of the Tank (m/hr) = $\frac{Q}{A}$……………………….........................Equation 3.6

Discharge of the Tank (Q) = AV……………………………………………….... Equation 3.7

Where;

A – Surface area,

D – Diameter,

h – height,

t – time,

Q – discharge, and

v – volume.

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3.8 Washing of Filter Materials

Filter materials were carefully washed two times before they were arranged into the filtration tank. The crushed stones chippings and river sand were washed from organic materials, silts, and clay particles. This was done because the biodegradables could degrade and affect the odour and the particles tardily moved out of the filter could heighten the treated water's turbidity.

3.9 Physical Properties of Filter Media

The following methods were used to determine the physical properties of the filtering media and different microbial, chemical, and major nutrient parameters. The filter material comprised crushed stones, chippings, and river sand. The bulk densities of the different filter materials were found by measuring their volume with a graduated cylinder and recording its weight with a scale. The association among the volume and weight, as given by Rühlmann *et al.* (2006) was employed in determining the bulk density using the following formulae.

$$\rho = {}^{m_{fm}}/_{V_{fm}} \quad \text{.......... Equation 3.8}$$

Where;

ρ –bulk density (gcm^{-3}),

V_{fm} – the volume of the filter media (cm^3), and

m_{fm} – the mass of the dried filter media (g).

The mean filter media particle density was computed using the liquid immersion approach as elaborated by Ruhlmanna *et al.* (2006). Particle density (Equation 3.9) as given by Rühlmann *et al.* (2006) was determined using the formula.

$$\rho_p = {}^{m_{fm}}/_{V_{fp}} \quad \text{.......... Equation 3.9}$$

Where;

ρ_p – the density of the particles (gcm^{-3}),

V_{fp} – the volume of the filter media excluding pore space (cm^3), and

m_{fm} – the mass of the dried filter (g).

The porosity of the filter media, as developed by Rühlmann *et al.* (2006) was calculated by finding the ratio between the average particle density and bulk density of the different media used

$n = {}^{\rho_b}/_{\rho_p} \times 100\ \%$...Equation 3.10

Where:

n – the porosity of the filter media (%),s

ρ_b – the bulk density (gcm^{-3}), and

ρ_p – the density of the particles (gcm^{-3}).

a. River Sand b. Crushed Stones c. Chippings

Figure 3.4: Determination of Physical Properties of Filter Materials

3.10 Sample Collection

Separate water samples were collected for both physic-chemical and microbiological/ bacteriological analyses. All samples for the physic-chemical analyses were collected directly into pre-cleaned 1000 ml plastic sample bottles from the wastewater sludge, pretreated, and filtered.

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For bacteriological assessment, samples were collected into sterilized 1000 ml sample bottles from these same sites. The samples were stored in an insulated box with ice and transported to the WRI water quality laboratory for analysis.

A total number of twelve (12) wastewater sludge samples were collected for analysis which included three (3) samples each of untreated water, sludge, pretreated water, and filtered water collected from the water treatment plant. Pretreated wastewater from the sedimentation tank, allowed to settle after 10 days was collected for analysis.

3.11 Laboratory Analysis of Wastewater Sludge Parameters

The physicochemical and bacteriological analyses were undertaken according to procedures outlined in the Standard Methods for the Examination of Water and Wastewater, 23rd Edition (APHA, 2012).

The physical parameters of wastewater sludge which include; Temperature, pH, Electrical Conductivity (EC), Odour, Total Suspended Solids (TSS), and Turbidity were evaluated and the chemical parameters that were examined are Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Salinity, Total Dissolved Solids (TDS). However, the nutrients that were taken into consideration were Nitrate-Nitrogen, Ammonium-Nitrogen, Phosphate-Phosphorus, and Potassium.

Escherichia coli, Total Coliform, and Faecal Coliform are among the microbiological characteristics that were determined. The following lists common approaches used to establish appropriate parameters.

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3.11.1 Determination of Ammonia

Ammonia in the wastewater sludge was determined using the Nessler method as given by American Public Health Association (APHA, 2012).

Each wastewater sample contained 5 ml, which was combined with 1 ml Roscheil salt and 25 ml of distilled water to make a total volume of 25 ml.

1. After adding 1 ml of Nessler regent to the solution, the spectrophotometer measurement was taken after 1 minute of reaction time.
2. The DR 2800 spectrophotometer was zeroed with distilled water, and the prepared sample was utilized to take the real reading.

3.11.2 Determination of Phosphate Phosphorus

Phosphate phosphorus in the wastewater sludge was determined using the stannous method as given by American Public Health Association (APHA 2012).

One drop of Phenolphthalein indicator was applied to a determined volume of 100 ml of the clear, colorless wastewater sample in a flask.

1. The Molybdate reagent was re-added in a volume of 4 ml, and then 10 drops of Stannous Chlorine reagent were added, all of which were thoroughly mixed by shaking.
2. First, 2.0 ml of the standard phosphate solution was placed into a volumetric flask and diluted to 100 ml to create a blank solution for the spectrophotometer.
3. The sample was put into the spectrophotometer after 10 minutes, but before 12 minutes, and the absorbance at a wavelength of 690 nm was measured.
4. The concentration of the wastewater samples was calculated from a calibration curve using their measured absorbance, mg/L.

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3.11.3 Determination of Total Phosphorous

Total phosphorus in the wastewater sludge was determined using the Acid Persulfate Digestion Method as given by American Public Health Association (APHA, 2012).

1. The potassium Persulfate pillows content was put into the Total Phosphorous test tube vial along with 5.0 ml of the wastewater sample, and the vial was then sealed.
2. After shaking the container to dissolve the powder, it was put into the reactor.
3. A 30 minutes reaction time was set on the instrument timer.
4. After the allotted time had passed, the vial was carefully taken out of the reactor and put in a test tube rack to cool to ambient temperature.
5. 2 ml of 1.5N sodium hydroxide standard solution was added to the vial that was at room temperature.
6. To mix, the vial was covered and flipped over.
7. After cleaning, the vial was put into a 16 mm cell holder.
8. After being tarred, the instrument displayed 0.00 mg/L $PO_4{}^{3-}$.
9. One phosver 3 powder pillows worth of powder was put into the vial containing the test sample.
10. For around 30 seconds, the vial was covered and shaken to mix, causing the powder partially dissolve.
11. The instrument was set for a 2-minute response time after which the vial was cleaned and put into 16 cell holders.
12. After two minutes of reaction time had passed the read bottom was pressed, and the sample was measured within 2 to 8 minutes.
13. The outcome was displayed as mg/L of PO_4^{3-}.

3.11.4 Determination of Nitrate-Nitrogen

Nitrate-Nitrogen in the wastewater sludge was determined using the hydrazine Reduction Method as given by American Public Health Association (APHA 2012).

1. The aliquot or a 10 ml sample of the wastewater effluent was put into a clean test tube.
2. Then, 1.0 ml of a reduction mixture consisting of 20.0 ml of copper sulphate working solution and 16.0 ml of hydrazine sulphate was added, and the mixture was gently mixed before being heated at 600 ^{o}C for 10 minutes in a water bath.
3. After the mixture had cooled to room temperature, 1.0 ml of colour development solution (consisting of roughly 150 ml of distilled water and 2.5 ml concentrated phosphoric acid) was added.
4. After the sulphanilamide had completely dissolved, 0.19g N-(1- naphthyl)- ethylenediamine dihydrochlorine was added, and 250 ml of distilled water was topped off.
5. The wastewater samples' absorbance was measured using a UV/VIS spectrophotometer at a wavelength of 520 nm after it had been agitated to mix. Before the reading, a calibration curve was created using the standards for the last use.

3.11.5 Determination of Total and Faecal Coliform

The total and faecal coliform were determined using the heterotrophic plate count method as given by American Public Health Association (APHA, 2012).

1. A tiny pipette was used to transfer 1 ml of the samples into a 100 ml test tube.
2. After diluting the 1 ml samples in the test tube to 100 ml, they were vigorously shaken to achieve homogeneity.
3. The material was then diluted, and 1 ml was then added to the placed Petri dishes.

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4. In boiling water, solids McConkey agar medium was melted, then allowed to cool to 42 ^{O}C.
5. The melted McConkey agar medium was then added to the diluted sample in a quantity of 10 ml.
6. After being shaken for even mixing, the Petri dish was placed upside down in the incubator.
7. The inspection took 24 hours to complete.
8. The Coliform Forming Unit (CFU) per 100 ml was then measured using the coliform counter.
9. To calculate the ideal count of faecal and total coliform, the final results were multiplied by the dilution factor of 100.
10. Faecal coliform was identified by a cream color, while total coliform was identified by pink color

3.11.6 Determination of Nitrate

Nitrate in the wastewater sludge was determined using the Spectrophotometric Method as given by American Public Health Association (APHA, 2012).

1. Nitrate 1 and Nitrate 2 tablets were each broken and dropped in 10 ml of the sample wastewater.
2. The reaction time for the mixture was then given 6 minutes before the spectrophotometer reading.
3. Before taking the reading, one original sample was utilized to zero the DR 2800 spectrophotometer.

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3.11.7 Determination of Nitrite

Nitrite in the wastewater sludge was determined using the colorimetric method as given by American Public Health Association (APHA, 2012).

1. A clean Erlenmeyer flask was used to measure 50 ml of each wastewater sample, and 2 ml of solution 1 and 2 Gricess-were IIosvay's added concurrently.
2. Following a gentle swirling of the samples, the mixture was given 15 minutes for a reaction.
3. The sample was then put into nesseler's tube, and the DR 2800 spectrophotometer was zeroed with it before the nitrite level was read.

3.11.8 Determination of Phosphorus

Phosphorus in the wastewater sludge was determined using the spectrophotometric method as given by American Public Health Association (APHA, 2012).

The DR 2800 Spectrophotometer had program number 490 inserted.

1. One puff of phosvate 3 powder was added after 25 ml of the sample cell had been filled.
2. There was a two-minute grace period for reactions.
3. To calibrate the DR 2800 spectrophotometer, the second 25 ml cell with the sample was filled with the blank.
4. To calculate the amount of phosphorus in milligrams per liter (mg/L) the observed value was first divided by 3.

3.11.9 Determination of Electrical Conductivity

Electrical conductivity in the wastewater sludge was determined using the bench conductivity meter method as given by American Public Health Association (APHA, 2012).

1. At the time of sample collection, a reading was taken.

2. The conductivity cell and the beaker or vessel into which a part of the sample is to be tested were both carefully cleaned and rinsed.
3. Before the analysis, the device was calibrated using standard solutions.
4. The sample had been poured into the beaker entirely.
5. The sample-containing beaker was filled with the cell.
6. The suggested value was read off in either S/cm depending on the magnitude of the value when the wastewater sample and the cell reached the same temperature.

3.11.10 Determination of Turbidity

Turbidity in the wastewater sludge was determined using the turbidimeter and nephelometric method as given by American Public Health Association (APHA 2012).

1. The turbidity of wastewater samples was measured.
2. A sample cell was filled at least two-thirds full after the 1500 ml samples were violently shaken.
3. Using the range knob on the turbidimeter (HACH 2100P), the proper range was chosen.
4. Upon the appearance of red light, the next range was chosen, and the stable turbidity reading was obtained directly from the turbidimeter.

3.11.11 Determination of pH

pH in the wastewater sludge was determined using the suntex pH meter as given by American Public Health Association (APHA, 2012). The hydrogen ion concentration or pH values of the wastewater were measured (in situ) APHA, 2005.

1. The electrode was connected to the meter, and pH 4, pH 7, and pH 10 buffer solutions were used to calibrate the instrument.

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2. The temperature of each buffer solution and the effluent samples for analysis were matched.
3. The pH buffer solution was then added to a beaker after it had been washed.
4. A steady reading was taken after the electrode was immersed, agitated twice, and suspended in the solution for one to two minutes
5. The electrode was taken out, cleaned with deionized water, and gently shaken to shake off the extra water.
6. The pH calibration was tested after the electrode was removed and cleaned with deionized water once more.
7. The samples' pH was assessed as so, and the results were recorded.

3.11.12 Determination of Dissolved Oxygen

The amount of dissolved oxygen in a specific amount of wastewater serves as a proxy for the wastewater's ability to support life. It was determined using the winkler method (APHA, 2005) as given by American Public Health Association (APHA, 2012).

1. ml of concentrated H_2 SO_4 was added to the already–fixed wastewater sample in the DO bottle before the bottle was stoppered and stirred by repeatedly tilting it until complete dissolving took place.
2. A 0.025M $Na_2S_2O_3$ solution was used to titrate the dissolved sample to a light straw color.
3. A few drops of the starch solution were added, and the titration was continued until the blue color first vanished.
4. It takes 1 ml of 0.025M $Na_2S_2O_3$ to titrate a 200 ml sample to 1 mg of DO per liter

3.11.13 Determination of Biochemical Oxygen Demand

The level of dissolved oxygen (DO) was assessed both before and after incubation.

The difference between the first and final measurements of the first and final measurements of the dissolved oxygen concentration was used to compute the BOD concentration. BOD in the wastewater sludge was determined using the dilution method as given by American Public Health Association (APHA 2012).

$MnSO_2$ and dissolved oxygen alkali-iodide-Azide solution totaling 2.0 ml each were added to the wastewater sample in the BOD bottle.

1. The bottle was meticulously corked to eliminate air bubbles and thoroughly shaken by repeatedly inverting it.
2. After allowing the precipitates to settle, 2.0 ml of concentration $H_2S_2O_4$ was added.
3. To dissolve the precipitate, which resulted in a vivid yellow coloration, the bottle was corked once again and repeatedly turned upside down.
4. The solution was next titrated with $Na_2S_2O_3$ to a pale-yellow color in 100 ml.
5. As an indication, 1.0 ml of starch was added.
6. The titration was carried out until the blue color first started to fade.
7. These steps were used to calculate the BOD levels; (D1-D2)/P = BOD5, (mg/L) Where P = decimal volumetric fraction of sample used, D1=DO of the sample immediately following preparation, mg/1, D2=DO of the sample after 5 days of incubation at 200C, mg/L.

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3.12 Data Analysis

The laboratory analysis of wastewater sludge results which include physicochemical parameters as well as microbial and biological parameters was done using Microsoft excel which include; tables and graphs were used to interpret the results.

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CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Design and Installation of Roughing Filter for Sludge Filtration

4.1.1 Design of Roughing Filter

The sedimentation tank was designed and placed on an overhead metallic stand above the filtration tank. The overhead metallic stand has a height of 300 cm whilst the surface area of the platform of the overhead stand was 28,800 cm^2 (180 cm by 160 cm). as illustrated in Figure 4.1.

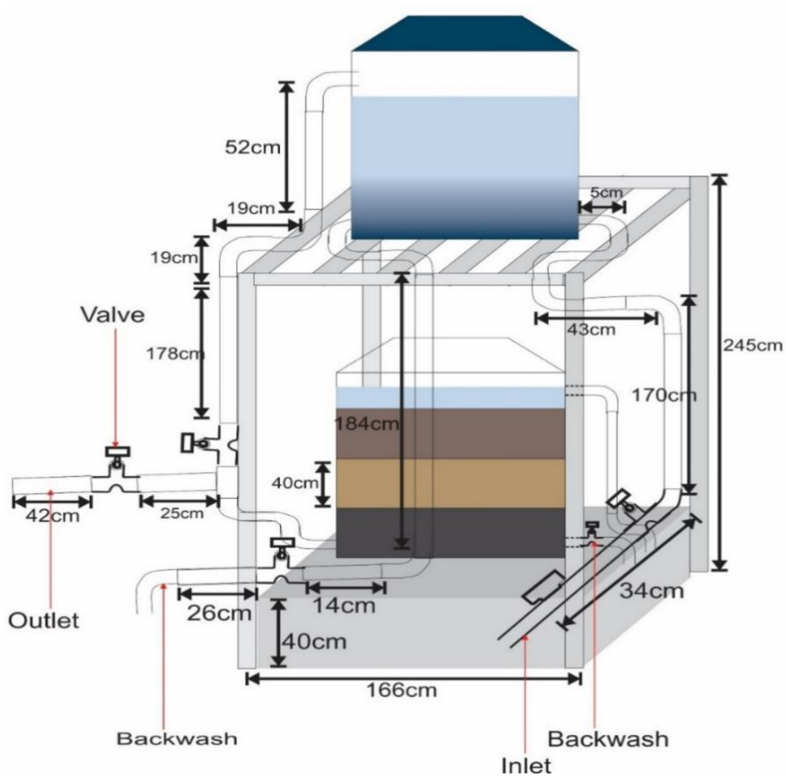

Figure 4.1: Design of a Filter System for Wastewater Sludge Treatment

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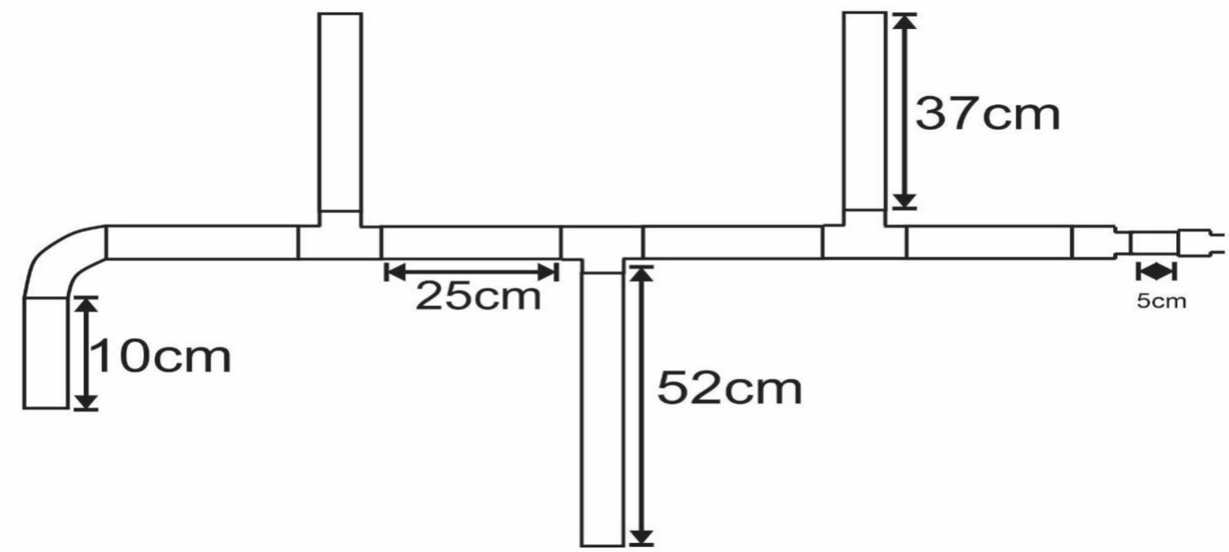

Figure 4.2: Design of a Filter Distribution and Drainage System Installed in the Filtration Tank

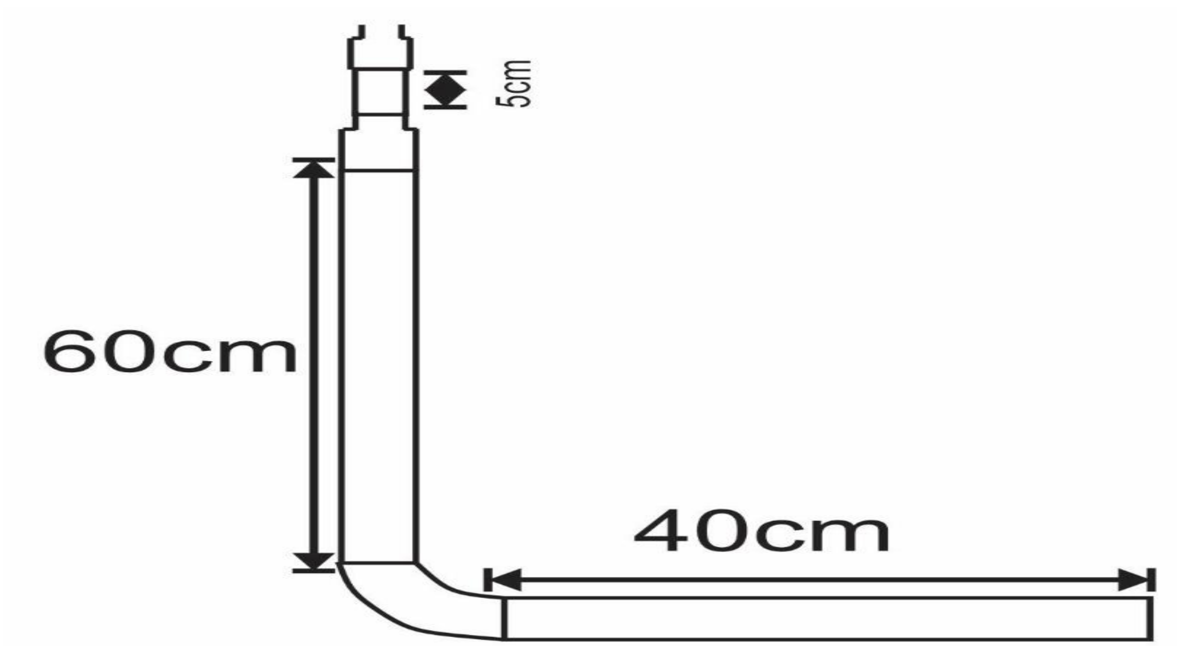

Figure 4.3: Design of Filter Inlet Flow Installed in the Sedimentation Tank

The holes where the metal stand poles were placed were hardened with concrete to keep them very firm to the ground. The filter tank which is under the metal stand was also placed on a concrete platform at a height of 40 cm as presented in Figure 4.1. Both tanks were connected i.e. the

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sedimentation tank to the source (dugout) of sludge and the filtration to the outlet. The sedimentation tank has a non-return valve (NRV) inlet which enables the wastewater sludge to flow exclusively in one direction and was inserted to ensure the wastewater sludge travel through the pipe in the right direction when pressure circumstance may otherwise result in the reserved flow. A flow meter was installed on a 1-inch pipe to determine the amount of wastewater sludge that passes through the inlet pipe into the sedimentation tank. PVC T-section were installed at the water inflow pipes which contain two control valves. One of the valves is for shutting the wastewater sludge inlet and the other one which is the fast drainage valve allows wastewater sludge to pass through the drainage pipe when the valve is open or when back-washing the sedimentation tank.

The inlet flow pipes for both the sedimentation and filtration tank were positioned 5 cm above the bottom of the tanks. The wastewater sludge outflow pipe was 5 cm below the water level of the in-flowing wastewater sludge for the sedimentation tank and 20 cm at the upper part of the filter bed below the wastewater sludge level of the in-flowing sludge for the filtration tank. Poly tank connectors such of 50.8 (mm) and 25.4 (mm) pipes, reducers, elbows, reunions, valves, and T-joints were installed at their proper positions. These materials were glued to prevent leakage occurrence in the system.

The sedimentation tank was connected to an L-shape inlet valve (60 cm x 40 cm) as it is shown in Figure 4.3 with the longest part placed inside the bottom of the tank and the shorter part vertically positioned. This ensures that after the wastewater sludge goes through the pre-treatment or the settling stage, most of the suspended particles settle at bottom of the tank; and anytime wastewater is pumped from the source, it does not disturb the settled sludge and cause the pretreated wastewater to flow through the inlet valve to the filtration tank. Wastewater sludge went through

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the settling or the pretreated stage for seven days after it was pumped into the sedimentation tank to allow all the suspended particles to settle before filtration. The pre-treatment stage is very important because if the wastewater sludge is not allowed to settle before filtration, it will clog the filter easily, rendering it inefficient due to the presence of suspended particles in the wastewater. It is for this reason that the wastewater must go through the settling stage before filtration and that is why the L-shape inlet valve is necessary to prevent sludge from entering the filter tank during the filtration process.

a. Filter Tank

Pretreated wastewater in the sedimentation tank flowed out through the wastewater distribution system under gravitational force as the pump continued to lift wastewater sludge from the source to the sedimentation tank. The pretreated wastewater has been distributed homogeneously over the filter surface to avoid souring of the filter media. The pretreated wastewater hydraulic energy was reduced by installing T-sections at the wastewater inflow with a length of 1 m multiple PVC pipes at the bottom of the filtration tank to divide the inflow of the pretreated wastewater. This T-section contains two (2) valves: one is for shutting off the inlet valve and the other is the drainage valve for letting the wastewater flow through the drainage pipe when opened. The technical design of this system is shown in Figure 4.2 with its dimensions. The design was in such a way that the outlets opening in distribution pipes diameter are not larger than the filtering grains to prevent the filtered materials from being washed out during back-washing. This was then placed 5 cm above the filter bottom in the filter bed. After back-washing, when the filter is emptied of water, the drainage valve must be shut and the inflow valve can be reopened.

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4.1.2 Physical Properties of Filter Materials Used

The physical properties of materials used in setting-up the roughing filter Table 4.1 presents . The filter comprised three (3) layers, and every layer was made up of different materials. The top layer is comprised of river sand with particle diameters in the range of 4 – 8 mm. The middle layer was chipping stones with particle diameters ranging from 8 – 12 mm, and crushed stones were used for the bottom layer with a particle diameter of 18 and above. The dry bulk density of the river sand recorded the highest value (2.50 g/cm^3), followed by the chipping stones which had a value of 1.50 g/cm^3, and the crushing stones recorded a value of 1,45 g/cm^3. The particle density for the river sand, chippings???, and crushed stones were 2.65 g/cm^3, 2.57 $g/cm^{3,}$ and 2.62 g/cm^3 respectively. The most porous material among the three (3) filter materials used is the crushed stones which had a porosity of 44.7 %. However, river sand was almost non-porous, recording a value of 5.9 %.

Table 4.1: Physical Properties of Filter Materials used in Roughing Filter Layers

Filter material	Diameter (mm)	Dry Bulk Density (g/cm^3)	Particle Density (g/cm^3)	Porosity (%)
River sand	4 -8	2.50	2.65	5.9
Chippings	8 - 12	1.50	2.57	41.6
Crushed stones	18 +	1.45	2.62	44.7

The various filter materials' particle diameter was considered due to the nature of wastewater sludge generated at the study site. With bigger particle sizes, more suspended particles escape in the process of filtration and are trapped by the smaller particles. Hatt *et al*. (2006) reported that, smaller particle size tends to trap more suspended solids and/or contaminants. Some materials are more porous than others, and this is a design check to ensure that whilst some particles escape from more porous layers, they are trapped in a less porous media layer. This is because varying pore spaces translate into varying efficiencies in removing different suspended solids and/or contaminants in wastewater (Abagale, 2014).

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4.2 Operation and Maintenance of the Filtration System

After testing the system, suspended solids accumulated in the filter bed were back-washed. This was done by closing the inlet valve and opening the drainage valve at the other end of the T-section joint valve. The wastewater present in the sedimentation tank flowed out by gravity with high velocity. Due to the high flow velocity, sediments contained in both tanks were flushed out and the sedimentation and filtration tanks were cleaned again. The valves were turned to the default setting so that the filtration system can operate again.

The filtration rate (FR) for this study was 1.5 m/h which means that it took the pre-filtered wastewater sludge contained in the filter tank for one and a half hours before it was collected as filtered water. The value obtained is similar to that of SKAT (1996) who conducted research and discovered that the rate of filtration of roughing filters ranges between 0.3 m/h and 1.5 m/h.

Hydraulic retention time (HRT) of the pre-filtered wastewater sludge was retained in the filtration tank for over an hour which agreed with the results of other researchers such as Jeong *et al*. (2016). Jeong *et al.* (2016) reported that, if wastewater takes less than an hour to go through the filtration process in the filter tank it may not achieve a good result. The reason is that the wastewater rushes through the filter without the regulation of the flow during the filtration process which does not give better results. The flow velocity (FV) of the system where wastewater sludge is pumped from the source into the sedimentation tank was 0.8 l/s.

4.3 Properties of Wastewater Sludge Before and After Filtration

Table 4.2 presents the summary statistics of the physical and chemical properties, and nutrient and microbiological levels of wastewater sludge from the Savannah Agriculture Research Institute

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(SARI) water treatment site. The levels of these properties were compared with the FAO 2015, WHO 2006, or EPA 2008 standard limits.

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Table 4.2: Summary Statistics of Wastewater Sludge Properties Before and After Filtration

Parameter		Mean ±SD		% Increment or Removal	FAO 2015/WHO 2006/EPA 2008 Guideline
Name	**Abbreviation**				
Physical		**Before Filtration**	**After Filtration**		
Power of Hydrogen	pH	6.20 ± 0.26	6.61 ± 0.01	29.89	6.0 – 8.5[f]
Temperature	T (°C)	22.71 ± 0.15	29.50 ± 0.10	23.02	< 30[f]
Total Dissolved Solids	TDS (mg/L)	102.67 ± 4.93	0.00 ± 0.00	100	0 – 2000[f]
Total Suspended Solids	TSS (mg/L)	3191.67 ± 541.30	105.00 ± 1.00	96.71	0 – 50. 0[e]
Turbidity	-	8198.67 ± 1123	19.00 ± 0.50	99.77	0 – 75[e]
Salinity	Salinity (ppt)	201.00 ± 021	0.002 ± 0.00	99.99	0.7 – 3[f]
Chemical					
Chemical Oxygen Demand	COD (mg/L)	16.00 ± 0.2	102.67 ± 4.93	98.2	0 – 1[e]
Dissolved Oxygen	DO (mg/L)	1.85 ± 0.05	24.67 ± 13.58	54.19	0 – 250[e]
Biological Oxygen Demand	BOD (mg/L)	0.95 ± 0.01	6.74 ± 3.75	85.91	0 – 50.0[e]
Nutrient					
Nitrate Nitrogen	NO_3-N (mg/L)	1.03 ± 0.12	8.19 ± 0.00	87.42	0 – 10.0[f]
Nitrite Nitrogen	NO_2-N (mg/L)	0E-7 ± 0E-8	-	-	0 – 5.0[f]
Ammonium Nitrogen	NH_4-N (mg/L)	1.43 ± 0.098	0.74 ± 0.00	48.39	0 – 2.0[f]
Phosphate Phosphorus	PO_4 -N (mg/L)	0.096 ± 0.06	0.02 ± 0.00	77	0 – 1[f]
Potassium	K^+ (mg/L)	0.47 ± 0.13	0.40 ± 0.01	14.89	
Microbiological					
Total Coliform	(cfu/100ml)	200 ± 0.00	100 ± 0.00	50	0-400[w]
Faecal Coliform	(cfu/100ml)	60 ± 0.00	8 ± 0.00	86.67	0 – 10[w]
E. coli	(cfu/100ml)	25 ± 0.00	4 ± 0.00	84	0 – 10[w]
Salmonella spp	(cfu/100ml)	0 ± 0.00	0 ± 0.00	0	-

f - FAO 2015 Guidelines for Wastewater Quality Parameters for Irrigated Agriculture
w - WHO 2006 Guidelines for wastewater quality parameters for Irrigated Agriculture
e - EPA 2008 Guidelines for wastewater quality parameters

4.3.1 Physical Properties of Wastewater Sludge Before and After Filtration

The results of the physical properties of the wastewater sludge generated from the Savannah Agriculture Research Institute (SARI) recorded before and after filtration as presented in Table 4.2 showed that the pH level of the wastewater sludge before and after filtration was 6.20± 0.26 and 6.61±0.01 respectively. The pH levels for both the wastewater sludge before filtration and after filtration were compared to the Food and Agriculture Organization (2015) standard guidelines limits of 6.0 - 8.5 for irrigated agriculture. The filtered wastewater sludge was within Ghana Standard guidelines 2011 and World Health Organization 2006 guidelines ranging from 6.0 – 8.5 for irrigation purposes. The World Health Organization (2006) report found that irrigation water with pH levels outside of this range has a higher propensity to affect the mobility of heavy metals in the soils, leading to the mobile metals being absorbed by crops and further contaminating water sources/bodies during runoff. Nyiyongu *et al*. (2019) found that wastewater with an unfavourable pH concentration is difficult to treat biologically and that if the concentration is not changed before discharge, the wastewater effluent may change the concentration in natural waters. The mean electrical conductivity (EC) indicating the levels of salinity in the wastewater sludge before and after filtration were 202.67 µS/cm and 157 µS/cm respectively. The values recorded for wastewater sludge before and after filtration did not meet FAO, 2015 standard guidelines ranging from 0.7 – 3 µS/cm, despite the reduced levels in the EC after the filtration process has taken place, this maybe affected by temperature because the warmer the wastewater sludge the higher the electrical conductivity during the filtration process and for this reason, EC recorded 157 µS/cm after filtration or inorganic dissolved solids such as chloride, nitrate, phosphate may also have an impact on the EC of the wastewater sludge hence, could not meet the FAO, 2015 standard guidelines.

Total Dissolved Solids (TDS) mean values of the wastewater sludge before and after filtration ranged from 0 mg/L to 102.67 mg/L , which falls in the range of FAO, 2015 standard limits of 0 -2000 mg/L for irrigation purposes. The mean Total Suspended Solids (TSS) levels for wastewater sludge before and after filtration recorded values from 3191.667 mg/L to 105 mg/L, and were compared to FAO, 2015 standard guidelines limits of 0 to 200 mg/L for irrigation purposes. Muhammad *et al*. (2011) reported that high dissolved solids water can harm crop output when used for irrigation because the dissolved salts make it more challenging for plants to absorb water from the soil. The causes of the huge value recorded in the wastewater sludge before treatment could be a result of dissolved organic and inorganic substances in the accumulated sludge due to the alum used during the flocculation and coagulation process of the raw water; hence, the need for the wastewater sludge to go through a filtration process to reduce the levels of dissolved solids in the wastewater. The best and most efficient method for removing TDS from water and its harmful effects is typically through a water filtration system (Chaukura *et al.*, 2020; Thibault *et al.*, 2021). It was also observed that, due to the multiple filter layers, the concentration of the total dissolved solids was reduced drastically to acceptable limits for reuse.

The average turbidity level of the wastewater sludge before and after filtration ranged from 8198.67 – 19 NTU, representing 99.77 % removal efficiency. The final level of turbidity falls within the acceptable limits of the FAO standard of 0 - 75 NTU for irrigated agriculture. In evaluating the removal efficiency of different roughing filters, Adel *et al*. (2014) found that the filters can remove colloids and particles in the range of 73.33 – 87.88 %. Although this range of values is lower than what was recorded in this study, it affirms the level of efficiency of the designed system, and the suitability of roughing filters to reduce the turbidity of roughing filters. However, Liu *et al*. (2019) bio slow sand filter had a better removal efficiency (> 99 %).

Before filtration, the wastewater sludge was full of suspended particles and colloids (Figure 4.4). Thus, the need for sludge to go through filtration to improve the quality of the water.

Figure 4: Visual Observation of Turbidity of Wastewater Sludge Before (left) and After (right) Filtration

The turbidity of the wastewater sludge improves significantly after filtration.. As a metric for water quality, the more turbid the water is, the poorer it's quality (Teh *et al*., 2016). The change that occurs from turbid irrigation water is comparable to suspended solids and must thus, be measured and regulated (Jeong *et al*., 2016). Kahle *et al*. (2021) stated that turbidity is an optical quality parameter that describes how clear or cloudy water is in general. It has to do with color, although it is more about the loss of transparency caused by suspended particles and colloidal materials. These statistics, known as suspended solids are utilized as an indicator of water quality.

The salinity levels before and after filtration were 201 mg/L and 0.002 mg/L respectively. This depicts a filter removal efficiency of 99.99 %. The salinity level after filtration falls within the FAO, 2015 acceptable limits of salinity of water (0.7 to 3 mg/L) for agriculture purposes. The reason for the wastewater sludge to record higher salinity levels could be a result of the presents of organic and inorganic pollutants that emanate from the water treatment station where alum is applied to raw water to trap all the suspended particles at the bottom of the tank before filtration, and as a result of the accumulated sludge, salinity increases. Therefore, it can be considered that filtration improves water salinity. Sometimes too, it could be farming activities upstreams of the dugout that washes contaminants into the dugout during raining season, making the water saline. Water that is too saline can have a significant impact on crop growth. Because of the difference in osmotic pressure, crops will find it difficult to absorb water resulting in stunted growth (Niu and Cabrera, 2010). According to Jeong *et al.* (2016), irrigation water salinity of less than 0.7 mg/L does not influence crop growth, whereas water with a salinity level of more than 3 mg/L causes significant damage. This suggests that the saline state of the filtered water makes it suitable for crop production.

4.3.2 Chemical Properties of Wastewater Sludge Before and After Filtration

The chemical parameters that were considered are Dissolved Oxygen (DO), Chemical Oxygen Demand (COD and Biological Oxygen Demand (BOD), and the results for these parameters are presented in Figure 4.5. The mean values recorded for the dissolved oxygen (DO) levels in the wastewater sludge before and after filtration were 1.85 mg/L and 102.67 mg/L respectively. The dissolved oxygen value increased after filtration because when DO is high, it means there is less organic pollutants in the filtered water because oxygen was much depleted due to the presence of some certain chemicals or organic compounds found in the media that have used up the oxygen in the filtered water and in the unfiltered water DO was low and this could be as a result of high amount of organic pollutants in the water because oxygen was not soo much depleted and this could also be enhance by the pH of the water, and this represents a filter DO improvement efficiency of 98.2 %. A similar increment was recorded in a study by Bali *et al*. (2011) who had a

97 % improvement in the DO of wastewater after it was filtered with sand filters. The removal efficiency of a filter, for a given parameter, may vary depending on the effluent to be filtered. Mensah (2017) recorded over 200 % efficiency of his bio-sand filter-designed septic effluent. The dissolved oxygen levels may not be considered an important parameter when it comes to irrigated agriculture, although it is an indispensable parameter when it comes to aquaculture, and environmental protection. The concentration of dissolved oxygen present in wastewater determines its quality and can support life on farms or aquatic life (Kalbar *et al.*, 2013). What could account for the increase in dissolved oxygen may be wastewater exposed to the open environment after filtration where the bad odour has been taken from the filtered wastewater.

The average levels of Chemical Oxygen Demand of wastewater sludge recorded were 16 mg/L before filtration and 32.33 mg/L after the wastewater sludge has gone through the filtration process, the increase in the chemical oxygen demand maybe as a result of the presence of chemicals/pollutants in the filtered water hence more oxygen is needed to to burn those chemical compounds in the filtered water. Also the pH could be a factor for the high levels of COD in the filtered water, in the study it was observed that before the filtration, the wastewater was close to be acidic with pH value of 6.2 while after filtration the pH improves to 6.6 which is close to neutral and this could be the influence of pH on the filter media which might have dissolved minerals from the filter bed which chemically influence the increased in COD in the filtered water. But nevertheless, the recorded values of the filtered wastewater sludge were within the acceptable limits of EPA 2008 standard guidelines for wastewater as presented in Table 4.1. In essence, the designed filter has a COD improvement efficiency of 54.19 %. Bali *et al*. (2011) obtained a better filter removal efficiency of 81 % for the parameter COD, and 82.8 % efficiency was obtained in Adu-Ofori (2019) study. The mean value for the Biological Oxygen Demand recorded was 0.95

mg/L before the wastewater sludge was filtered and the filtered wastewater sludge recorded 6.74 mg/L. The increased in BOD may indicate more oxygen is required to break down organic pollutants in the filtered water which also signifies lower water quality . The improvement in the BOD after filtration connotes a filter efficiency percentage of 85.91 %. A similar result was obtained by Manga *et al*. (2016) and Adu-Ofori (2017) who had removal efficiency rates of 85.6 % and 86.8 % respectively. The BOD level in the filtered wastewater sludge was employed as a gauge for estimating the amount of organic matter present, while the COD level shows the total oxygen requirement for digesting/decomposing both organic matter and inorganic matter in the filtered wastewater sludge. According to Kalbar *et al.* (2013), with the decomposition of greater COD and BOD levels, dissolved oxygen levels are depleted, resulting in anaerobic conditions and more contaminated wastewater sludge.

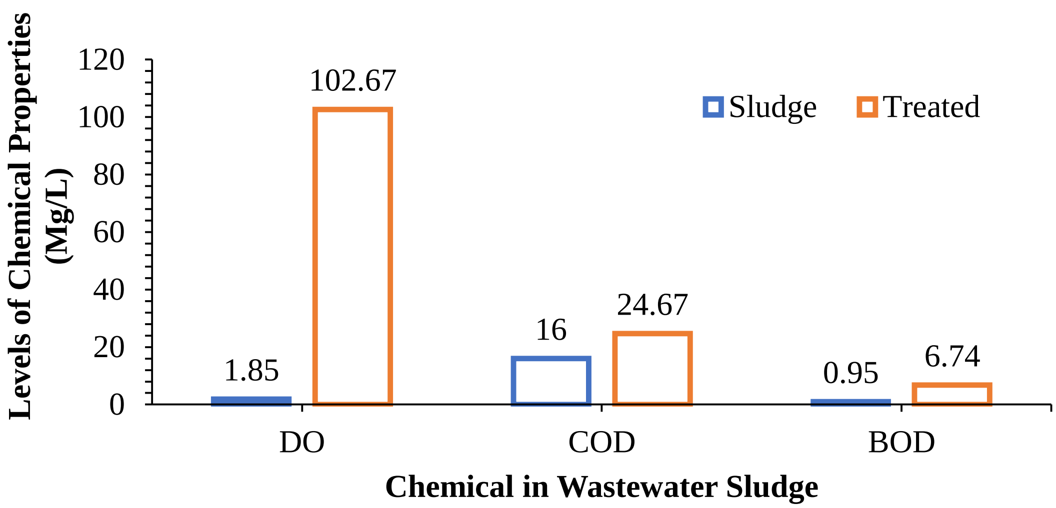

Figure 4.5: Averages of Chemical Properties of Wastewater Sludge Before and After Filtration

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4.3.3 Nutrient Concentrations Levels in Wastewater Sludge Before and After Filtration

Apart from Nitrate-Nitrogen, all the mean values of the nutrients; ammonium nitrogen, phosphorus phosphate, and potassium after filtration increased and this could be as a result of material used for the filtration process may contain minute of this nutrients in them which accounted for the increased levels of nutrients in the filtered water as presented in Figure 4.6. For Nitrate Nitrogen (NO_3-N), the wastewater sludge before filtration was 8.19 mg/L and after the filtration process, the mean value was 1.03 mg/L, indicating a percentage removal of 87.42 %. Contrary to Bali *et al*.'s (2011) study, which recorded an increase of 91.91 % in NO_3-N after filtration. The decrease in nitrate concentration might be related to the non-transformation of organic nitrogen to nitrate form during the treatment process via oxidation reactions. Ammonium Nitrate (NH_4-N) mg/L average values before wastewater sludge was filtered were 0.74 mg/L and 1.43 after filtration, representing an increment of 48.39 %. This was contrary to what was recorded by Bali *et al*. (2011) who recorded a percent removal of 86.49 %. Phosphate Phosphorus (PO_4 –N) mg/L mean values determined in the wastewater sludge before filtration was 0.02 mg/L and 0.10 mg/L after the filtration process. PO_4-N level increased by 77 % after filtration whilst it decreased by 64.61 % in a study by Bali *et al*. (2011). In a study by Adu-Ofori (2019), he also recorded a removal efficiency of 58.7 %. Instead of removing excess nutrients in the sludge after filtration, the system rather increased the level of nutrients in the sludge after filtration. Thus, the mean value of potassium in wastewater sludge before and after filtration was 0.40 mg/L and 0.47 mg/L respectively. Both the unfiltered and filtered wastewater sludge were presented in Figure 4.3 and the results are within the acceptable limits of FAO, 2015 standard guidelines.

According to Kumar *et al.* (2015), nitrogen and phosphorus are necessary for plant growth, although other elements such as iron are required in trace amounts for biological growth. It has been discovered that wastewater contains a range of nutrients required for agriculture production (Chiu *et al*., 2015). Even though nutrient content in wastewater plays a crucial role in plant growth, it might have negative consequences if it exceeds the recommended amounts (Erel *et al*., 2019). Excessive nitrogen levels in wastewater can induce over-fertilization, resulting in high vegetative growth, crop maturity delays or unevenness, and poor quality. According to An *et al*. (2016), wastewater can contain 5 to 50 mg/L of phosphorus. Organic phosphorus is biologically transformed into phosphate during wastewater pre-treatment.

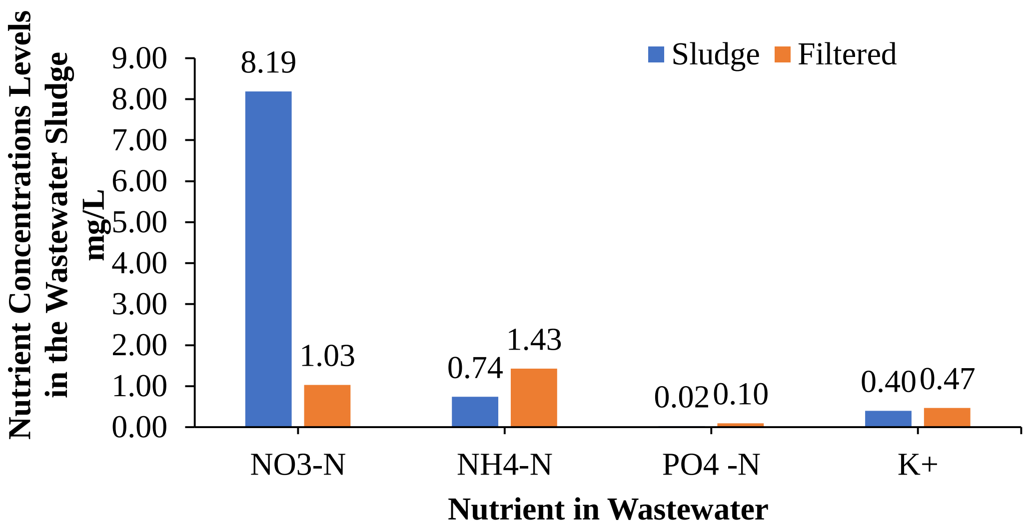

Figure 4.6: Averages of Nutrient Concentrations in Wastewater Sludge Before and After Filtration

4.3.4 Microbial Levels in Wastewater Before and After Filtration

The microbial parameters determined during the laboratory analysis include; Total coliform, Fecal coliform, *E. coli,* and *Salmonella spp,* and the results are presented in Figure 4.7, before the filtration of the wastewater sludge, the value recorded for total coliform was 200 cfu/100ml, and after filtration, the value decreased to 100 cfu/100ml, which falls in the acceptable range of FAO,

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2015 standard guideline limits of 0-400 cfu/100ml for irrigation purposes. The mean value recorded for faecal coliform for wastewater sludge before filtration was 60 cfu/100ml, which decreased to 8 cfu/100ml after filtration. *E. coli* also recorded an average value of 25 cfu/100ml before filtration, and it decreased to 4 cfu/100ml after filtration. The value of *Salmonella* for both unfiltered and filtered wastewater sludge was zero (0).

The value of total coliform recorded by Kwabla (2017) was ≤ 37.4 x 10^3 cfu/100 ml, and this is higher than what was recorded in this study before and after filtration; 200 cfu/100 ml and 100 cfu/100 ml respectively. Also, according to Adu-Ofori (2019), the recorded value was 14x10^7 to 53x10^7 counts/100 ml with an average count of 296 X 10^6 counts/100 ml which is higher than that of this study before and after filtration. Concerning the contaminant removal efficiency of the system, the designed roughing filter had a total coliform removal efficiency of 50 % system which is far lower than what was recorded by Adu-Ofori (2019) and Mensah (2017); 99.93 % and 99.99 % respectively. Ostad-Ali-Askari *et al.* (2019) also found a drastic decrease in total coliform when they employed a sand filter for water filtration. Close to the rate of total coliform removal in the filtered sludge is the value found by Bali *et al*. (2011). They recorded a 53.29 % reduction in total coliform after filtration. This value agrees with what is recorded in this study (50 %) and further affirms the level of effectiveness of the filter. The fecal coliform value in the sludge from the study site was as high as 60 cfu/100 ml before filtration. However, after filtration, the faecal coliform count was reduced to 8 cfu/100 ml, representing a removal efficiency of 86.67 %. Although Bali *et al*. (2011) also recorded a 58.95 % decrease in faecal coliform after the wastewater was filtered, it is lower than what was recorded in this study (86.67 %) which is also less than what was recorded by Mensah (2017) in his study. Several factors might have accounted for the variation in the rate of faecal coliform removal, although of much essence, is a system's ability to beat down the coliform count. *E. coli* count has reduced drastically; from 28 to 4 cfu/100 ml, representing 84 % filter removal efficiency. This falls in the range of removal rate of 45-99.99% for slow sand filters, as Chen *et al*. (1998). In the study carried out by Mensah (2017), a similar trend, and an even higher rate of reduction in *E. coli* count was recorded; 97.6 %. The concentration of microbial present in wastewater sludge determines whether the wastewater can be reused for irrigation purposes. Wastewater containing high levels of *E. coli* is likely to have high levels of other dangerous bacteria (Edberg *et al*., 2000). The value of *E. coli* after filtration in this study is higher than that of Allende *et al*. (2015) who found that the *E. coli* content for vegetables eaten raw and vegetables cooked, processed, or fruits not directly irrigated to have an average value of 1 cfu mL^{-1} and 1 cfu mL^{-1} respectively. Impliedly, from the perspective of Allende *et al*. (2015), due to the level of *E. coli* in the filtered water in this study, it does not fit to be used as irrigation water for vegetables. However, the results of *E. coli* level after filtration in this study aligned with the results from Kwabla (2017) who had results of < 10 cfu mL^{-1}.

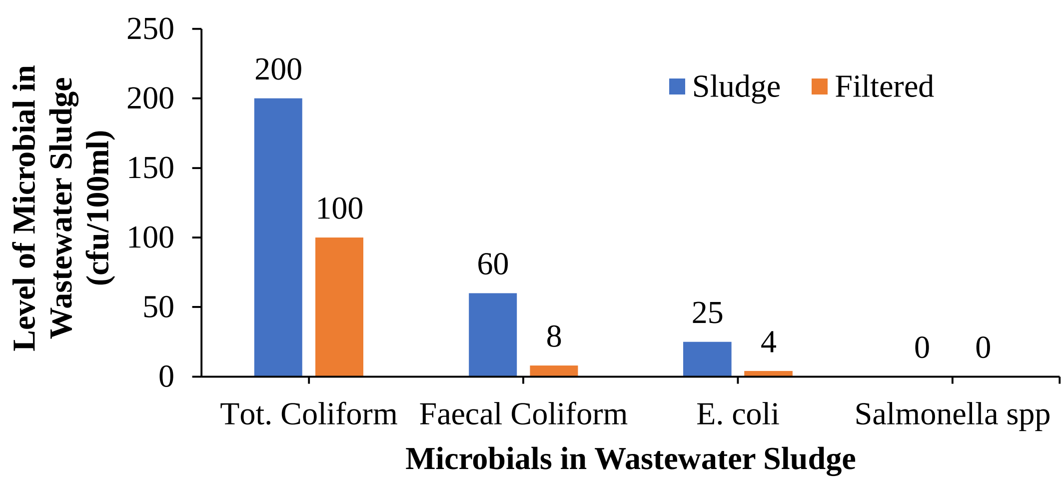

Figure 5: Levels of Microbial in Wastewater Sludge Before and After Filtration

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CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study showed that:

1. The wastewater sludge was full of contaminants or pollutants which makes it not safe for irrigation since it is not in line with the FAO, 2015/EPA, 2008 Ghana standard guidelines for irrigated agriculture
2. The design, construction, operation, and maintenance of the wastewater filtration system work satisfactorily well and are therefore technically viable at the SARI water treatment site and can be adopted in areas that generate wastewater from a similar treatment plant .
3. The filter design is robust and simple to operate and the filtration system can be constructed with locally available material (chipping stones, crushed stones, and river sand) with the help of local labor.
4. Back-washing of the filter can be done manually and no pumps are needed if there is enough elevation on the land and if the in-flowing wastewater from the source has enough filtration pressure.
5. The most porous material among the three (3) filter materials used is the crushed stones had a porosity of 44.7 %. However, river sand was almost non-porous, recording a value of 5.9 %.
6. The concentrations of the physical parameter which include turbidity suspended particles and salinity of wastewater sludge were reduced drastically and were within the FAO, 2015/EPA, 2008 Ghana standard guidelines limits for irrigation.

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7. The chemical and microbial parameters of the wastewater sludge were also reduced to the acceptable limit of FAO 2015, WHO 2006, and EPA, 2008 Ghana standard guidelines for irrigation after filtration.

5.2 Recommendations

Based on the findings of the study, the following are recommended:

1. Filtered and unfiltered wastewater sludge generated at SARI water treatment plants can be used to irrigate various kinds of vegetables to monitor the impact of the filtered and unfiltered wastewater sludge on the growth and yield of these vegetables.
2. There is a need to establish infrastructure and rehabilitation of broken structures at already existing plants to accommodate wastewater sludge at water treatment plants across the country to further treat this wastewater for irrigation purposes especially in water-scarce areas to help feed the ever-growing population.
3. There is a need for in-depth, application-based research into local, economically viable, environmentally friendly, energy-efficient technologies and applications for wastewater sludge treatment as a safe alternative water supply for competing water needs.

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APPENDICES

Appendix 1: Wastewater Sludge Properties for Before and After Filtration

Contaminant	Before Filtration	After Filtration	Removal Efficiency (%)
Physical			
pH	6.20	6.61	29.89
Temperature	22.71	29.50	23.02
EC	51.67	3.2	93.81
TDS	102.67	0	100
TSS	3191.67	105.0	96.71
Turbidity	8198.67	19.0	99.77
Chemical			
Salinity	201.00	0.002	99.99
Dissolved Oxygen	1.85	102.67	98.2
Chemical Oxygen Demand	16.00	24.67	54.19
Biochemical Oxygen Demand	0.95	6.74	85.91
Nutrient			
Nitrate Nitrogen	8.190	1.03	87.42
Ammonium Nitrogen	0.738	1.43	48.39
Phosphate Phosphorus	0.023	0.10	77
Potassium	0.400	0.47	14.89
Microbial			
Total Coliform	200	100	50
Faecal Coliform	60	8	86.67
E. coli	25	4	84
Salmonella spp	0	0	0

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Appendix 2: Summary Statistics of Water Quality Parameters Found in Dugout Water

Parameter		Mean	±SD	Minimum	Maximum	FAO, 2015/WHO, 2006/EPA, 2008 Guideline
Name	**Abbreviation**					
Physical						
Power of Hydrogen	pH (pH units)	7.74	0.09	7.65	7.82	6.0 – 8.5
Temperature	T (°C)	28.00	0.36	27.60	28.30	< 30
Electrical Conductivity	EC (µS/cm)	46.87	1.17	45.98	48.20	0 – 3
Total Dissolved Solids	TDS (mg/L)	32.19	0.32	31.92	32.54	0 – 2000
Chemical						
Calcium	Ca+	6.40	0.20	6.20	6.60	-
Magnesium	Tot. Hardness	2.07	0.12	2.00	2.20	-
Sodium	Na+	1.23	0.21	1.00	1.40	-
Chloride	Cl-	2.06	0.12	1.98	2.20	-
Bicarbonate	HCO3-	12.00	0.20	11.80	12.20	-
Calcium Carbonate	CaCO3	15.87	0.12	15.80	16.00	-
	TKN	28.13	0.12	28.00	28.20	-
Chemical Oxygen Demand	COD	6.97	0.21	6.80	7.20	0 – 1
Dissolved Oxygen	DO	7.07	0.31	6.80	7.40	0 – 250
Biological Oxygen Demand	BOD	5.80	0.40	5.40	6.20	0 – 50.0
Sulphate	SO_4	14.48	0.24	14.30	14.75	-
Nutrient						
Nitrate Nitrogen	NO_3-N (mg/L)	5.60	0.15	5.50	5.78	0 – 10.0
Nitrite Nitrogen	NO_2-N (mg/L)	0.01	0.01	0.01	0.02	0 – 5.0
Ammonium Nitrogen	NH_4-N (mg/L)	1.43	0.05	1.39	1.49	0 – 2.0
Phosphate Phosphorus	PO_4 -N (mg/L)	0.07	0.01	0.06	0.07	0 – 1
Potassium	K^+ (mg/L)	0.22	0.02	0.20	0.24	-
Microbiological						
Total Coliform	(cfu/100ml)	1.00		0.00		0-400
E. coli	(cfu/100ml)					0 – 10

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Appendix 3: Summary Statistics of Water Quality Parameters Found in Wastewater Sludge

Parameter		Mean	±SD	Minimum	Maximum	FAO, 2015/WHO, 2006/EPA, 2008 Guideline
Name	**Abbreviation**					
Physical						
Power of Hydrogen	pH (pH units)	6.20	0.26	6.04	6.50	6.0 – 8.5
Temperature	T (°C)	22.71	0.15	22.61	22.88	< 30
Electrical Conductivity	EC (µS/cm)	202.67	8.50	194.00	211.00	0 – 3
Total Dissolved Solids	TDS (mg/L)	102.67	4.93	97.00	106.00	0 – 2000
Total Suspended Solids	TSS (mg/L)	3191.67	541.30	2630.00	3710.00	0 – 50. 0
Turbidity	-	8198.67	1123.80	7208.00	9420.00	0 – 75
Chemical						
Salinity	Salinity	201.00	0.21	200.76	201.24	0.7 – 3
Chemical Oxygen Demand	COD (mg/L)	16.00	0.2	15.8	16.2	0 – 1
Dissolved Oxygen	DO (mg/L)	1.85	0.05	1.80	1.90	0 – 250
Biological Oxygen Demand	BOD (mg/L)	0.95	0.01	0.94	0.96	0 – 50.0
Nutrient						
Nitrate Nitrogen	NO_3-N (mg/L)	1.03	0.12	0.90	1.10	0 – 10.0
Nitrite Nitrogen	NO_2-N (mg/L)	0E-7	0E-8	0.00	0.00	0 – 5.0
Ammonium Nitrogen	NH_4-N (mg/L)	1.43	0.098	1.36	1.54	0 – 2.0
Phosphate Phosphorus	PO_4 -N (mg/L)	0.096	0.06	0.06	0.17	0 – 1
Potassium	K^+ (mg/L)	0.47	0.13	0.33	0.57	
Microbiological						
Total Coliform	(cfu/100ml)		1.00	1.00	1.00	0-400
Faecal Coliform	(cfu/100ml)		1.00	1.00	1.00	0 – 10
E. coli	(cfu/100ml)		1.00	1.00	1.00	0 – 10
Salmonella spp	(cfu/100ml)		0.00	0.00	0.00	-

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Appendix 4: Summary Statistics of Water Quality Parameters Found in Pre-filtered Wastewater Sludge

Parameter		Mean	±SD	Minimum	Maximum	FAO, 2015/WHO, 2006/EPA, 2008 Guideline
Name	**Abbreviation**					
Physical						
Power of Hydrogen	pH (pH units)	5.24	0.01	5.23	5.25	6.0 – 8.5
Temperature	T (°C)	29.50	0.10	29.40	29.60	< 30
Electrical Conductivity	EC (µS/cm)	205.00	1.00	204.00	206.00	0 – 5
Total Dissolved Solids	TDS (mg/L)	137.00	1.00	136.00	138.00	0 – 2000
Total Suspended Solids	TSS (mg/L)	80.01	0.01	80.00	80.01	0 – 200
Turbidity	-	116.00	1.00	115.00	117.00	0 – 75
Chemical						
Salinity	- (mg/L)	154.00	1.00	153.00	155.00	0.7 – 3
Dissolved Oxygen	DO (mg/L)	3.65	0.01	3.64	3.66	0 – 1
Chemical Oxygen Demand	COD (mg/L)	24.00	0.50	23.50	24.50	0 – 250
Biological Oxygen Demand	BOD (mg/L)	2.60	0.01	2.59	2.61	0 – 50.0
Nutrient						
Nitrate Nitrogen	NO_3-N	2.31	0.00	2.310	2.31	0 – 10.0
Ammonium Nitrogen	(mg/L)	9.34	0.00	9.337	9.34	0 – 5.0
Phosphate Phosphorus	NH_4-N	0.25	0.00	0.253	0.26	0 – 2.0
Potassium	(mg/L)	0.60	0.09	0.510	0.69	0 – 1
	PO_4 -N					
	(mg/L)					
	K^+ (mg/L)					
Microbiological						
Total Coliform	(cfu/100ml)	180	1.00	179	181	0-400
Faecal Coliform	(cfu/100ml)	30	1.00	29	31	0 – 10
E. coli	(cfu/100ml)	12	1.00	11	13	0 – 10
Salmonella spp	(cfu/100ml)	0	0.00	0	0	-

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Appendix 5: Summary Statistics of Water Quality Parameters Found in Filtered Wastewater Sludge

Parameter		**Mean**	**±SD**	**Minimum**	**Maximum**	**FAO, 2015/WHO, 2006/EPA, 2008 Guideline**
Name	**Abbreviation**					
Physical						
Power of Hydrogen	pH (pH units)	6.61	0.01	6.60	6.62	6.0 – 8.5
Temperature	T (°C)	29.50	0.10	29.40	29.60	< 30
Electrical Conductivity	EC (µS/cm)	157.00	1.00	156.00	158.00	0 – 5
Total Dissolved Solids	TDS (mg/L)	0.00	0.00	0.00	0.00	0 – 2000
Total Suspended Solids	TSS (mg/L)	105.00	1.00	104.00	106.00	0 –200
Turbidity	-	19.00	0.50	18.50	19.50	0 – 75
Chemical						
Salinity	- (mg/L)	0.002	0.00	0.00	0.00	0.7 – 3
Dissolved Oxygen	DO (mg/L)	102.67	4.93	97.74	107.6	0 – 1
Chemical Oxygen Demand	COD (mg/L)	24.67	13.58	11.09	38.25	0 – 250
Biological Oxygen Demand	BOD (mg/L)	6.74	3.75	2.99	10.49	0 – 50.0
Nutrient						
Nitrate Nitrogen	NO_3-N	8.19	0.00	8.19	8.19	0 – 10.0
Ammonium Nitrogen	(mg/L)	0.74	0.00	0.74	0.74	0 – 5.0
Phosphate Phosphorus	NH_4-N	0.02	0.00	0.02	0.03	0 – 2.0
Potassium	(mg/L)	0.40	0.01	0.39	0.41	0 – 1
	PO_4 -N					
	(mg/L)					
	K^+ (mg/L)					
Biological						
Total Coliform	(cfu/100ml)	100	1.00	99	101	0-400
Faecal Coliform	(cfu/100ml)	8	1.00	7	9	0 – 10
E. coli	(cfu/100ml)	4	1.00	3	4	0 – 10
Salmonella spp	(cfu/100ml)	0	0.00	0	0	-

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Appendix 6: Results for Sludge Analysis

Water Parameters	Symbols	Units	Sample 1	Sample 2	Sample 3	Average
Chemical						
Calcium	Ca^{++}	mg/L	0.00228	0.00198	0.0027	0.002
Magnesium	Mg^{++}	mg/L	0.003442	0.06123	0.0677	0.044
Sodium	Na^{+}	mg/L	0.02228	0.02482	0.0562	0.034
Chloride	Cl^{-}	mg/L	14.6	16.2	12.8	14.533
Bicarbonate	HCO_3^{-}	mg/L	50	70	60	60.000
SAR	SAR	mg/L	0.1323	0.13957	0.1365	0.136
Total Kjeldahl Nitrogen	TKN	mg/L	28	28.2	28	28.067
Chemical Oxygen Demand	COD	mg/L	9	32	33	24.667
Dissolved Oxygen	DO	mg/L	106	105	97	102.667
Biological Oxygen Demand	BOD	mg/L	2.42	8.61	9.21	6.747
Oxidation Reduction Potential	ORP	mV	104.4	92	102.5	99.633
Nutrients						
Nitrate Nitrogen	$NO_3 – N$	mg/L	1.1	0.9	1.0	1.000
Nitrite Nitrogen	$NO_2 – N$	mg/L	<0.001	<0.001	<0.001	<0.001
Ammonium Nitrogen	NH_4 -N	mg/L	1.36	1.54	1.38	1.427
Phosphate Phosphorus	PO_4 -N	mg/L	0.06	0.06	0.17	0.097
Potassium	K^{+}	mg/L	0.3278	0.4968	0.5742	0.466
Physical						
Power of Hydrogen	pH		6.5	6.04	6.07	6.203
Temperature	T	°C	22.61	22.88	22.65	22.713
Electrical Conductivity	EC	µs/cm	203	211	194	202.667
Total Dissolved Solids	TDS	mg/L	106	105	97	102.667
Total Suspended Solids	TSS	mg/L	2630	3235	3710	3191.667
Colour		Pt.co	102	44	103	83.000
Turbidity		NTU	7208	7968	9420	8198.667
Total Volatile Solids	TVS	Mg/L	705500	620000	709500	678333.333

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Appendix 7: Dugout Water Physic-chemical and Nutrient Composition

Water Parameters	Symbols	Units	Sample 1	Sample 2	Sample 3	Average
Chemical						
Calcium	Ca^{++}	mg/L	6.4	6.2	6.6	6.40
Total hardness		mg/L	2.0	2.0	2.2	2.07
Sodium	Na^{+}	mg/L	1.3	1.0	1.4	1.23
Chloride	Cl^{-}	mg/L	2.0	1.98	2.2	2.06
Bicarbonate	HCO_3^{-}	mg/L	12.2	11.8	12.0	12.00
Calcium hardness	$CaCO_3$	mg/L	16	15.8	15.8	15.87
Total Kjeldahl Nitrogen	TKN	mg/L	28	28.2	28	28.07
Chemical Oxygen Demand	COD	mg/L	7.2	6.8	6.9	6.97
Dissolved Oxygen	DO	mg/L	7.0	7.4	6.8	7.07
Biological Oxygen Demand	BOD	mg/L	5.8	5.4	6.2	5.80
Sulphate	SO_4	mg/L	14.75	14.50	15.30	14.85
Nutrients						
Nitrate Nitrogen	$NO_3 – N$	mg/L	5.498	5.781	5.532	5.60
Nitrite Nitrogen	$NO_2 – N$	mg/L	0.011	0.011	0.021	0.01
Ammonium Nitrogen	NH_4 -N	mg/L	1.387	1.442	1.485	1.44
Phosphate Phosphorus	PO_4 -N	mg/L	0.068	0.06	0.07	0.07
Potassium	K^{+}	mg/L	0.2	0.24	0.21	0.22
Physical						
Power of Hydrogen	pH		7.75	7.65	7.82	7.74
Temperature	T	°C	28.1	27.6	28.3	28.00
Electrical Conductivity	EC	µs/cm	48.20	46.43	45.98	46.87
Total Dissolved Solids	TDS	mg/L	31.92	32.12	32.54	32.19
Turbidity		NTU	37	36.57	37.23	36.93

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Appendix 8: Dugout Water Microbiological Composition

Microbial Parameters	Unit	Value	WHO Guideline	Ghana Standards
Total Coliform	cfu/100ml	50	0	0
Faecal Coliform	cfu/100ml	0	0	0
E. coli	cfu/100ml	0	0	0
Salmonella spp	cfu/100ml	4	0	0

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Appendix 9: Result of Pretreated Wastewater Sludge

Water Parameters	Symbols	Units	Sample 1	Sample 2	Sample 3	Average
Physical						
Power of Hydrogen	pH	mg/L	5.24	5.25	5.23	5.24
Temperature	T	mg/L	29.5	29.4	29.6	29.5
Electrical Conductivity	EC	mg/L	205	204	206	205
Total Dissolved Solids	TDS	mg/L	137	136	138	137
Total Suspended Solids	TSS	mg/L	80.0	80.01	80.01	80.0
Turbidity	NTU	mg/L	116	117	115	116
Odor		mg/L	-	-	-	
Chemical						
Salinity		mg/L	154	155	153	154
Dissolved Oxygen	DO	mg/L	3.65	3.66	3.64	3.65
Chemical Oxygen Demand	COD	mg/L	24.0	24.50	23.50	24.0
Biological Oxygen Demand	BOD	mg/L	2.60	2.61	2.59	2.60
Nutrients						
Nitrate Nitrogen	$NO_3 - N$	mg/L	2.311	2.310	2.312	2.311
Ammonium Nitrogen	NH_4 -N	mg/L	9.338	9.337	9.339	9.338
Phosphate Phosphorus	PO_4 -N	mg/L	0.254	0.255	0.253	0.254
Potassium	K^+	mg/L	0.6	0.69	0.51	0.6

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Appendix 10: Filtered Water

Water Parameters	Symbols	Units	Sample 1	Sample 2	Sample 3	Average
Physical						
Power of Hydrogen	pH	mg/L	6.61	6.62	6.60	6.61
Temperature	T	mg/L	29.5	29.4	29.6	29.5
Electrical Conductivity	EC	mg/L	157	156	158	157
Total Dissolved Solids	TDS	mg/L	< 1	< 1	< 1	< 1
Total Suspended Solids	TSS	mg/L	105	106	104	105
Turbidity	NTU	mg/L	19.0	18.5	19.5	19.0
Odor			-	-	-	
Chemical						
Salinity		mg/L	201	203	199	201
Dissolved Oxygen	DO	mg/L	1.85	1.80	1.90	1.85
Chemical Oxygen Demand	COD	mg/L	16.0	15.8	16.2	16.0
Biological Oxygen Demand	BOD	mg/L	0.95	0.96	0.94	0.95
Nutrients						
Nitrate Nitrogen	NO_3 – N	mg/L	8.190	8.189	8.191	8.190
Ammonium Nitrogen	NH_4 -N	mg/L	0.738	0.739	0.737	0.738
Phosphate Phosphorus	PO_4 -N	mg/L	0.023	0.020	0.026	0.023
Potassium	K^+	mg/L	0.4	0.39	0.41	0.4

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Appendix 11: Pretreated Wastewater Sludge

Microbial Parameters	Unit	Value	WHO Guideline	Ghana Standards
Total Coliform	cfu/100ml	180	0	0
Faecal Coliform	cfu/100ml	30	0	0
E. coli	cfu/100ml	12	0	0
Salmonella spp	cfu/100ml	0	0	0

Appendix 12: Filtered Wastewater Sludge

Microbial Parameters	Unit	Value	WHO Guideline	Ghana Standards
Total Coliform	cfu/100ml	100	0	0
Faecal Coliform	cfu/100ml	8	0	0
E. coli	cfu/100ml	4	0	0
Salmonella spp	cfu/100ml	0	0	0

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Appendix 13: Pictures of Field Work

Fixing of end caps

Washing of filter material

Tighten of poly tank connectors

Fixing of PVC pipe distribution network system in filtration tank

Fixing of PVC elbow

Cutting of a PVC pipe with a PVC cutter