ASSESSING THE SUITABILITY OF A WASTEWATER EFFLUENT REUSE SYSTEM FOR NON-POTABLE APPLICATIONS

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M22B32/010

A DISSERTATION SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY

February, 2026

UGANDA CHRISTIAN UNIVERSITY
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ABSTRACT

This project addresses the problem of the high cost of using potable water to carry out low quality tasks such as flushing in toilets and urinals by offering a sustainable, yet environmentally friendly way of harnessing treated wastewater effluent for these non-potable applications. In this research, the quality of raw effluent from the UCU activated sludge treatment plant was assessed and determined. This information was then input into design calculations to design an effluent polishing system and a non-potable water distribution system.

Uganda Christian University (UCU) purchases between 6000 to 7000 m^3 of potable water from National Water and Sewerage Corporation (NWSC) on a monthly basis. This water is used to ensure smooth running university activities such as cleaning, cooking, drinking, and waste management. Studies show that about 20-40% of domestic water demand is consumed in toilet flushing and 50-70% of commercial water demand (Ilemobade *et al.*, 2012).

DECLARATION

I, **BWIRE PAUL WAFULA** with registration number **M22B32/010** hereby declare that this is my original work, is not plagiarized and has not been submitted to any other institution for any award.

Student's name: BWIRE PAUL WAFULA

Sign: …………………………………………………….   Date: ……………………………………………

APPROVAL

This research project report submitted by **BWIRE PAUL WAFULA** to the Department of Engineering and Environment at Uganda Christian University has been carried out and compiled under constant supervision.

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Academic Supervisor (Uganda Christian University)

Signature: …………………………………….

Date: …………………………………………….

DEDICATION

This report is dedicated to my loving father and mother, for your constant love and support throughout my education journey and through every season of my life thus far. This research is a testament of your loving guidance and perseverance to shape me into valuable citizen of this country. I am grateful for the sacrifices and investments you have made for my future.

ACKNOWLEDGEMENT

I give all glory and thanks to God Almighty for His boundless grace, wisdom, and strength throughout the length of my academic life. without His guidance and favors, it would have been impossible to complete this study. In times of doubt and uncertainty, His presence was my hope and strength.

I am highly grateful to my parents for their unlimited love, kindness, and sacrifices. Their guidance and belief in me have been the foundation of my quest for studies. Their encouraging words and blessings have been the driving force that has helped me get to this milestone, and I will forever be thankful for their contribution to my life.

Special thanks to the developers of ImageJ software, especially the National Institutes of Health and the University of Winsconsin Laboratory for Optical and Computational Instrumentation. I acknowledge the Autodesk, Inc., for their software AutoCAD 2026, which was instrumental in developing precise engineering designs. Gratitude to the United States Protection Agency (EPA) for developing the EPANET software, as well as the Grundfos Holding A/S for the Grundfos software.

I would also like to express my most sincere thanks to my supervisor, Eng. Prof. Eleanor Wozei, for her invaluable guidance, patience, and constructive criticism throughout the duration of this study. Her professionalism and dedication not only had an impact on the quality of this research but have compelled me to grow academically and personally too. In a special way, I thank my project partner Lokwang Dominic for his continuous contribution and support in the making of this research.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASTP………………………………... Activated Sludge Treatment Plant

BOD…………………………………… Biochemical Oxygen Demand

NWSC………………………………… National Water and Sewerage Corporation

PUB…………………………………… Public Utilities Board (in Singapore)

UCU……………………………………Uganda Christian University

US EPA……………………………… United States Environmental Protection Agency

UV……………………………………… Ultraviolet (radiation)

VOCs………………………………….. Volatile Organic Compounds

WHO………………………………….. World Health Organization

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CHAPTER ONE: GENERAL INTRODUCTION

1.1 BACKGROUND

Uganda Christian University (UCU) is increasingly subjected to pressure with its water resources due to the increasing population of students and staff. This is because clean water is being consumed on a massive scale for purposes other than drinking, such as flushing toilets and urinals. UCU Mukono treats its sewage in a decentralized system where majority wastewater generated on campus is led through a sewage transmission pipeline to the UCU activated sludge treatment plant. Being commissioned in 2006, it was the first of its kind in Uganda, treating wastewater from daily University activities such as cooking, cleaning, washing, and human waste management.

Its main purpose for commission is to promote sustainable, decentralized waste management on university premises. Sewage generated from toilets, showers, and laundry is treated. The sewage is treated in a three-stage process namely; solid removal, bacterial decomposition, and chlorination. The raw sewage from university activities (influent) is treated into effluent which is safe for environmental discharge.

1.2 PROBLEM STATEMENT

Uganda Christian University (UCU) currently uses potable water to supply non-potable applications such as toilet and urinal flushing. This practice represents a systematic misallocation of treated potable water resources and therefore an unsustainable use of potable water as high-quality resource for a low-quality task of flushing in toilets. Furthermore, this places a significant financial burden on the University due to its reliance on high quality potable water from National Water and Sewerage Corporation (NWSC) for the above non-potable applications. UCU has paid between UGX 30 million to UGX 40 million per month to NWSC to purchase potable water for the past five years. This is approximately 6000 to 7000 cubic meters of potable water purchased per month (Mangene, 2025).

A wastewater effluent reuse system will reduce the demand on potable water sources in UCU and promote environmental sustainability through the reduced effluent discharge into the environment.

1.3 **MAIN OBJECTIVES**

To assess the suitability of a wastewater effluent reuse system for non-potable applications.

1.4 **SPECIFIC OBJECTIVES**

1. To determine the physicochemical and bacteriological characteristics of UCU effluent.
2. To design a wastewater effluent treatment system.
3. To design a non-potable water distribution system.
4. To conduct a comprehensive cost benefit analysis of the wastewater effluent reuse system.

1.5 **RESEARCH QUESTIONS**

1. What are the physicochemical and bacteriological characteristics of raw UCU effluent.

2. What treatment system can polish the wastewater effluent.
3. What system can distribute non-potable water in the university.
4. What is the cost-benefit analysis of the wastewater effluent reuse system.

1.6 JUSTIFICATION

INTRODUCTION

Universities are high-density of water users (consumers). This results in large economic burdens experienced due to the way water is consumed in universities. For example, operations in UCU where there is a misallocation of high-quality drinking water sources to complete low-quality tasks like flushing in toilets and urinals. UCU purchases drinking water from NWSC at a monthly price of UGX 30M to UGX 40M, approximating to about 6000 m^3 to 7000 m^3 per month. Almost immediately, this water is used to in waste management of sanitary waste in the flushing of human waste in toilets and urinals.

UCU incurs a large expense that compounds continuously and is a financial setback for the maximization of the university's potable water resources.

The solution to this problem must implement a substitute water supply to complete the same non-potable application because purchasing and consuming drinking water at this rate is unsustainable.

Globally, this institutional problem has been approached by the reuse of wastewater. This has been done through the installation of wastewater reuse systems (PUB, 2014). This approach has been tested and proven to close the water loop through the treatment of generated wastewater to meet accepted standards for non-potable applications like toilet flushing, irrigation, and industrial use like machine cooling.

The problem of the high cost of flushing using potable water is experienced worldwide and is addressed differently in different countries. This necessitates a detailed investigation on how this problem has been addressed and solved by different researchers.

1.7 CONTENT SCOPE

This research is focused on determining the suitability of a wastewater effluent reuse system for non-potable applications in Uganda Christian University. This study strives to treat and compare effluent produced by the Uganda Christian University activated sludge treatment plant to the guidelines of treated wastewater effluent quality for non-potable use (toilet and urinal flushing).

1.8 GEOGRAPHICAL SCOPE

This study is to be carried out in Uganda Christian University in the Activated Sludge treatment plant.

1.9 TIME SCOPE

This research project commenced in June 2025 and will be completed in December 2025.

CHAPTER TWO: LITERATURE REVIEW

INTRODUCTION

This literature review gives information on the current research on the use of wastewater effluent for non-potable applications such as flushing in toilets and urinals, irrigation, and cooling of machinery in industries to mention but a few.

The treatment and reuse of wastewater effluent for non-potable applications is an admirable strategy used to conserve potable water supplies in urban areas. The initial stage is the treatment of the wastewater effluent to meet non-potable water quality standards for toilet flushing. This is to reduce the risk human contamination and user acceptance of the project. This can reduce the demand for potable water in a community (Pandey, 2022). When wastewater effluent is incorporated into waste management, there is a closed loop in which water is transformed from a discharged waste into a precious resource.

2.1 PHYSICOCHEMICAL AND BACTERIOLOGICAL CHARACTERISTICS UCU WASTEWATER EFFLUENT

2.1.1 UCU effluent quality

To discuss effluent quality, the chemical, physical, and biological characteristics of the effluent generated by the UCU activated sludge treatment plant has to be understood in regards to the intended use of the effluent. For water to be acceptable for use by the population, there must be no risk of disease contraction by the users and an aesthetically acceptable outlook of the reused water.

A total of six water quality parameters were selected for this study (PUB, 2014). They are;

a) Turbidity

The turbidity of effluent indicates the presence of suspended particles in the effluent. Filtration is type of treatment widely used to reduce turbidity of water. in this process, the wastewater effluent is passed through the porous medium to remove particulate matter (J. Shanthi Sravan, Leonidas Matsakas and Sarkar, 2024). Membrane technologies used include; microfiltration and ultrafiltration which are used for advanced wastewater treatment because they are effective in removing micron sized particles.

Another technology widely used in wastewater filtration is sand filtration. Larger suspended particles like silt are physically trapped in the spaces or pores between the sand grains as wastewater trickles through sand layers. In addition, through the process of adsorption, small colloidal particles that pass through the sand's pore spaces are trapped by adhesion on the surface of the sand grains.

b) Color

Color is an important physical parameter that informs about the wastewater effluent composition, condition, and potential contaminants therein.

In the treatment of wastewater effluent, chemical treatment methods are often employed. The coagulation and flocculation processes are widely employed because they are highly effective in the decolorization of water (Ho, Chua and Chong, 2020). This involves the addition of chemical coagulants to destabilize the suspended particles and colored compounds in the wastewater effluent.

c) pH

In the treatment of wastewater effluent, it is crucial to have a neutral pH. This is because extreme pH values are fatal to both aquatic life and cause damage to the piping and plumbing systems in place aimed towards the reuse of effluent (El-Khateeb, Nashy and Nayl, 2020).

The fundamental principal in pH correction is the addition of an acidic or basic chemical to adjust the pH of the wastewater effluent to a neutral range. For example, between 6.0 – 9.0.

d) Total coliforms

Total coliforms are a group of bacteria that are no exactly harmful, however their presence in wastewater effluent indicates the presence of certain disease-causing microorganisms. Total coliforms are found in all parts of the environment such as the soil, in vegetation, and in the guts of warm-blooded animals (Solomon Oluwaseun Akinnawo, Peter Odunayo Ayadi and Mathew Temitope Oluwalope, 2023).

Chlorine is widely used as a disinfectant because it disrupts the microbial cell membranes and inactive enzymes crucial for cell survival of the bacteria. The effectiveness of the chlorination by chlorine depends largely on the chlorine dosage, contact time, pH, and the presence of other interfering substances.

e) Escherichia coli (E. coli)

E. Coli is a bacterium very commonly found in the intestines or gut of animals classified as warm-blooded, including humans. Presence of e. coli in wastewater effluent indicates fecal contamination, and the presence of pathogenic microorganisms that are a health risk to the public and to the environment (Pallavali, Shin and Choi, 2023).

E. Coli and other pathogens can also be treated using chemical disinfection with chlorine disinfection being one of the most used methods. Another method is ozonation where ozone, a powerful oxidant and disinfectant is used to inactivate microorganisms. In some cases, ozonation is preferred because of its ability to disinfect without forming harmful disinfection byproducts (Solomon Oluwaseun Akinnawo, Peter Odunayo Ayadi and Mathew Temitope Oluwalope, 2023).

f) BOD_5

Biochemical oxygen demand over 5 days is an important parameter to determine the quality of the wastewater effluent. The concentration of BOD_5 in water is indicative of the level of organic pollution present in the water. It is used to quantify the amount of dissolved oxygen consumed in the decomposition of organic matter by microorganisms (Maddah, 2022). Presence in organic pollutants in wastewater effluent increases the risk to human health if this effluent is reused for toilet flushing.

2.2 CASE STUDIES OF IMPLEMENTED WASTEWATER EFFLUENT REUSE SYSTEMS

2.2.1 Water Factory 21, Orange County California

Water factory 21 is a large-scale ground water recharging facility located in Fountain Valley, Orange County California. It was founded by the Orange County Water District to augment and protect the scarce groundwater aquifers from seawater intrusion. The ground water aquifers in Orange County faced a problem of the drop of groundwater levels caused by the over excavation of groundwater and the intrusion of seawater into the aquifers. The solution employed is the use of municipal sewage effluent generated by approximately 2.5 million residents to recharge the groundwater aquifers. The first objective was to treat the secondary effluent to a high quality for injection in to the ground (OCWD, 2018).

A tertiary treatment train was used to treat the secondary effluent which involved lime clarification, carbon adsorption, reverse osmosis, and chlorination as a multi-barrier treatment train. This treatment was focused on meeting drinking water quality standards. Injection wells were used to deliver the highly treated water into the aquifer, which then served as a natural storage and distribution reservoir, preventing salt water (seawater) contamination and augmenting the region's drinking water supply.

Results showed that the Water Factory 21 provided a high-quality Groundwater Replenishment System, a supply system that can trace contaminants, and long-term water security in a semi-arid region.

2.2.3 Sembcorp NEWater plants, Singapore

The Sembcorp NEWater plant is the world's largest water reclamation plant operated by the Public Utilities Board of Singapore. It has a capacity of 228,000 cubic meters per day. The challenge of water scarcity and national security have been vital in the driving of Singapore's NEWater program which has been a vital initiative ever since its establishment because the country previously relied on imported water. Therefore, to diversify the nation's water supply the scheme began to treat secondary effluent generated from the comprehensive sewerage network of the Island known as the Deep Tunnel Sewerage System (PUB, 2018). The non-potable applications considered are: flushing of water closets and urinals, general washing, irrigation, and cooling-tower make-up (PUB, 2018).

Figure 9: Sembcorp NEWater Plant in Singapore (Changi Water Reclamation Plant & Sembcorp NEWater Plant, 2023)

The NEWater plants a treatment system that comprises of three stages to make the effluent reach non-potable water quality standards as per their PUB guidelines. They include:

a) Microfiltration or ultrafiltration to remove suspended solids and colloids.
b) Reverse osmosis to remove viruses and salts.
c) Ultraviolet disinfection and chemical disinfection.

NEWater facilities produce tens to hundreds of millions of gallons of water per day in aggregated capacity and significantly contribute to Singapore’s water supply. A single plant is reported to meet approximately 12% - 15% of the water demand. The reported output is was discovered to have a very high microbial and chemical quality suitable for industrial reuse and other non-potable applications.

The distribution system comprises of a ‘purple pipe’ system that is used to deliver the treated effluent to the industrial facilities and the other non-potable water applications (Opening of Singapore's Fifth and Largest NEWater Plant, The Sembcorp NEWater Plant, 2025).

The system design and selection went on as follows. After the characterization of the wastewater effluent to be reused, the data collected was used to identify worst case loads, typical loads, seasonal loads, and shock loads. This enabled PUB to clearly define the feedwater quality. Afterwards, the boards used removal performance data for the candidate treatment technologies of interest (membrane filtration, reverse osmosis, ultraviolet disinfection, and advanced oxidation) which they often obtained from pilot plants, such as the 2000 full-scale demonstration plant which would establish the suitable treatment train to achieve their desired water quality. To set the target water quality, PUB referenced WHO and the US EPA to attain high water quality standards. The board created mass balance and removal requirements for each contaminant as well as calculated log reductions that the treatment process must achieve to produce the desired water quality of the effluent.

Informed by the pilot and baseline data, PUB selected the three-stage treatment train for NEWater mentioned above.

2.2.4 Arizona State University (ASU) Tempe Campus, USA

The Tempe Campus once faced the problem of heavy reliance on municipal water sources for non-potable applications which resulted in high operational costs and the need for water independence in an arid climate. The solution employed was the establishment of a wastewater effluent reusing system to offset the cost incurred due to the use of clean water for non-potable applications. The effluent is generated by the campus community (students, faculties, and staff residents) and nearby community (Tortajada, 2014).

The wastewater is obtained from the municipal secondary treatment plant back to the wastewater effluent reclamation plant on the Tempe Campus. The treatment methods used are typically sand filtration and chlorination to meet the strict health standards for non-potable uses. The distribution system employed consists of color-coded pipe networks (purple pipes) constructed within the campus grounds to distribute the treated wastewater effluent to large landscaping irrigation systems, athletic fields and most importantly, toilet and urinal flushing in academic buildings.

2.2.5 Coastal Metropolitan Area Schemes - Catalonia Spain

A Barcelona coastal metropolitan reuse scheme was developed to address seasonal water scarcity. In addition, they were also developed to reduce pressure on surface water and groundwater sources and to prevent seawater intrusion in the LIobregat delta aquifer. The scheme sources secondary effluent from the metropolitan wastewater treatment plants. The end uses of the effluent include agricultural irrigation, wetland restoration and the prevention of seawater intrusion through a barrier.

To meet district end-use water quality standards, the schemes use a four-stage treatment system. That is to say, filtration, advanced biological and chemical treatment, and finally disinfection. For the distribution system, bulk conveyance pipelines, pumping stations, and reservoirs designed to meet seasonal peak demands as well as the need to meet the intrusion barrier (Mujeriego *et al.*, 2008).

Figure 10: A Reclaimed water pumping station for instream flow and agricultural irrigation (Mujeriego et al., 2008).

2.3 TREATMENT OF WASTEWATER EFFLUENT TO MEET NON-POTABLE WATER QUALITY

The tested parameters that did not meet the Singapore PUB guideline quality for non-potable water for toilet and urinal flushing are, turbidity, E. Coli, and Total coliforms. This necessitates the use of a sequence of treatment units to polish the effluent and disinfect it to reduce the risk of microbial contamination of the users of the effluent reuse system.

To select the appropriate treatment method, the following were taken in to careful consideration;

a) What is the current quality of the effluent?
b) What is the target effluent quality?
c) What adjustment is desired in the effluent?
d) What sequence of unit processes is most suitable to achieve the desired effluent quality?

2.3.1 Turbidity

The turbidity is caused by the way colloidal and suspended particles in wastewater effluent reflect light. To polish the effluent and remove reduce its turbidity, a filtration unit is proposed to make the effluent more aesthetically acceptable and remove the suspended particles in the effluent. A filtration process is the most suitable alternative to remove the residual suspended solids from the effluent (Metcalf & Eddy Inc. et al., 2014).

Filtration in the process of physically removing suspended particles, solids, and other fine particles from a liquid as it passes through a permeable barrier or a porous medium that retain these particles and allow the liquid filtrate to pass through the filter medium (Yogafanny et al., 2020).

To select the type of filtration to be employed, the following technologies were identified and assessed basing on their capabilities, viability, and availability in Uganda.

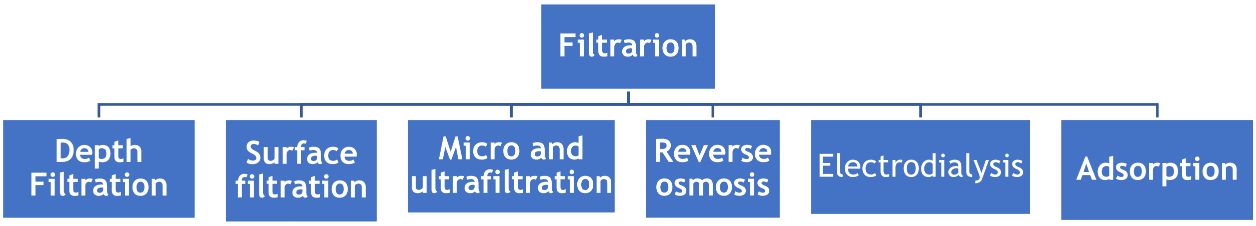


Figure 11: A flow chart showing the unit process technologies for removal of particulate matter from treated wastewater effluent (Metcalf & Eddy Inc. et al., 2014).

Depth filtration

This is a physical unit process that involves the physical removal of suspended matter and colloidal solids from liquids passed through granular filter media. Depth filters operate by straining, sedimentation, interception, impaction, and adsorption (Metcalf & Eddy Inc. et al., 2014). A depth filter is the proposed treatment unit for polishing the wastewater effluent because of the principal mechanisms by which it operates.

The principal mechanisms by which depth filters remove particulate matter include;

a) Straining: where particles larger than the pores in the medium are trapped mechanically (Metcalf & Eddy Inc. et al., 2014).
b) Sedimentation: where heavy particles in the liquid settle on the filter medium (Metcalf & Eddy Inc. et al., 2014).
c) Interception: when particulate matter in the liquid being filtered comes into contact with the surface of the filtering medium as is moves in a streamline (Metcalf & Eddy Inc. et al., 2014).
d) Adhesion: which occurs when particles become attached to the surface of the medium as they pass through the filter (Metcalf & Eddy Inc. et al., 2014).
e) Flocculation: occurs in the interstices of the filter medium where larger particles form due to the velocity gradients of the liquid as it is being filtered. Afterwards the particles are removed by any one of the above mechanisms (Metcalf & Eddy Inc. et al., 2014).

2.3.1.1 Estimating the performance of a depth filter in the reduction of the turbidity of wastewater secondary effluent.

To determine whether a depth filter will be effective in the polishing of effluent from the UCU ASTP, the following equation was employed to estimate whether the filtrate turbidity would meet the required turbidity quality of <2NTU.

Filter effluent turbidity, NTU = 0.5 NTU + 0.2 (Filter influent turbidity, NTU) (Metcalf & Eddy Inc. et al., 2014)

Table 6: Estimating the performance of a depth filter

Calculation	**Check**	**Comment**
Filter effluent turbidity, NTU = 0.5 NTU + 0.2 * 30.7 NTU = 0.5 NTU + 6.14 NTU = 6.64 NTU	Filter effluent turbidity, NTU = 0.5 NTU + 0.2 (Filter influent turbidity, NTU) (Metcalf & Eddy Inc. et al., 2014)	

From the above calculation, a depth filter cannot achieve the desired turbidity (<2NTU). This could mean that either a depth filter is not an appropriate technology for this treatment, or another treatment unit can be employed to reduce the effluent turbidity before it is fed into the depth filter.

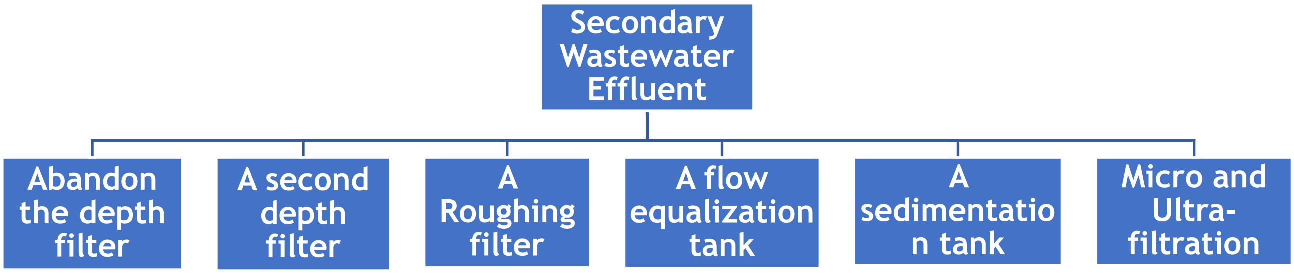


Figure 12: A flow chart showing options for the reduction of effluent turbidity (Metcalf & Eddy Inc. et al., 2014).

Theoretically, a second depth filter can reduce the effluent turbidity to a level that can be polished by a primary depth filter that meet the turbidity limit of <2NTU as shown in the calculation below.

Table 7: Estimating the performance of a second depth filter

Calculation	**Check**	**Comment**
Filter effluent turbidity, NTU = 0.5 NTU + 0.2 * 6.64 NTU = 0.5 NTU + 1.33 NTU = 1.83 NTU	Filter effluent turbidity, NTU = 0.5 NTU + 0.2 (Filter influent turbidity, NTU) (Metcalf & Eddy Inc. et al., 2014)	

2.3.2 E. COLI AND TOTAL COLIFORMS

To protect human health, the microbiological characteristics (E. Coli and total coliforms) will have to be treated to acceptable levels according to the Singapore Public Utilities Board non-potable water quality guidelines for toilet flushing.

The first step is to reduce the turbidity of the effluent because harmful pathogens can hide within the particles and suspended solids present in effluent rendering the disinfection ineffective.

Identified disinfection technologies include;

Chlorine dosing: dosing with chlorine involves the variation of dosage and contact time in order to determine the optimum dose that meets the chlorine demand in the effluent. This also entails determining the amount of residual chlorine required to continue disinfecting the non-potable water in the distribution lines.

For the purpose of disinfection, chlorine dosing will be employed in this research because it is a technology already in place at the UCU activated sludge treatment plant to disinfect wastewater effluent.

In conclusion, as it was pointed out by the already existing research that was done on this topic, specific input data for the depth filtration system and the non-potable water distribution system is required in order to come up with designs. The following chapter discusses the methods that were used to carry out the research and data collection.

CHAPTER THREE: METHODOLOGY

METHODOLOGY INTRODUCTION

The reuse of treated wastewater (effluent) for non-potable applications (toilet flushing in particular) is a sustainable water conservation and resource management strategy. This chapter serves to provide an academic and scientific rationale for selecting key parameters to determine the physical, chemical, and biological parameters for the quality assessment of UCU's effluent which is intended to be reused for toilet flushing. The selected parameters are relevant to guaranteeing the safety, aesthetic acceptability, and long-term viability of a water reusing system. The selection is justified by their impact on human health, system longevity, and user acceptance.

There is no single, universal standard for non-potable water quality for flushing toilets. Instead, the standards for water reuse vary widely from country to country and are regulated by a "fit-for-purpose" approach, i.e., water quality is managed to be safe to use and to pose no hazard to public health and the environment.

Given that this research is taking place in Uganda, a country that experiences tropical climate and tropical weather patterns, the Singapore non-potable water guidelines for toilet and urinal flushing will be used to ensure the treated effluent meets public health standards for Uganda's climatic conditions. Singapore is located near the equator which results in a tropical climate with high temperatures and high humidity all year-long (Department of Statistics Singapore, 2025).

3.1 DETERMINING THE PHYSICOCHEMICAL AND BACTERIOLOGICAL CHARACTERISTICS OF UCU EFFLUENT.

Effluent discharged into water or on land by any establishment must be treated based on the best practicable means, that is to say, environmentally sound practice and in compliance with the relevant guidelines (Standards for Discharge of Effluent into Water or on Land Regulations, 1999). National Environment Management Authority

Procedure for sample collection

1. Prepare the necessary equipment and apparatus for the field work. This includes sample collection containers and gloves. The containers are cleaned using distilled water to prevent any contamination of the raw sample.
2. The UCU ASTP (sampling location) is then accessed with clearance from the plant operator. This is to ensure all project activities are authorized and do no cause alarm to the concerned officials of the plant. A 1.5L representative sample was obtained from the effluent discharge point in the UCU ASTP. This procedure was repeated twice, once in the afternoon and once in the evening monitor any variation with in the day.
3. The sample was then transported to the UCU Environmental Quality Lab in a cooler box to protect it from sunlight.

3.1.2 LABORATORY TESTS

The collected samples were taken to the UCU Environmental Quality Lab to determine the physicochemical and bacteriological characteristics of the raw effluent from the UCU activated sludge treatment plant. The parameters were selected based on the Public Utilities Board (PUB), of Singapore because this country experience tropical climates like Uganda, with no distinct seasons like winter and summer, but rainy and sunny weather all year long with high temperatures and high humidity (Department of Statistics Singapore, 2025). The Singapore PUB guidelines are to be compared to the INTERNATIONAL STANDARD ISO 20426: Guidelines for health risk assessment and management for non-potable water reuse.

The sources of the wastewater in UCU are toilets and bathrooms in the halls of residence, staff quarters, lecture blocks, public sanitary facilities and the Janani Lowum dining hall in UCU.

3.1.2.1 Turbidity

Turbidity is a measure of the clarity of the effluent indicating the presence of suspended particles such as silt, sludge and inorganic matter. Turbidity is critical in this study because suspended solids in the effluent can create a hiding place for pathogens, protecting them from disinfection treatment methods such as ultraviolet (UV) light. The turbidity of raw effluent was measured using a turbidimeter instrument and the SI units are NTU (Nephelometric Turbidity Units).

Procedure

1. Using a standard calibration solution with known turbidity values, the turbidimeter is calibrated.
2. The raw effluent sample was collected from the effluent discharge point.
3. The sample was placed in a turbidimeter. A turbidimeter measures the degree of light scattering by suspended and colloidal particles in the wastewater effluent at
4. The displayed on the turbidimeter is read and recorded in Nephelometric Turbidity Units.

3.1.2.2 Color

The effluent color is an aesthetic parameter that quantifies color imparted into water by dissolved substances (true color) and suspended materials (apparent color), indicating potential contamination and aesthetic issues (Omer, 2019). User perception is greatly dependent on the color of the effluent. The color of the non-potable water affects the acceptability of the users (students and staff).

Procedure

1. The raw effluent sample is collected and inspected for its apparent color.
2. The effluent samples' color is determined using an optical apparatus by filling a blank with the sample until the bottom of the meniscus reaches the bottle's mark.
3. After inserting the blank into the apparatus, the read button is pressed. The data value is then read and recorded.

3.1.2.3 pH value

pH is the measure of how acidic or how basic the effluent is on a scale of 0 to 14.

The pH of the effluent is critical for the effectiveness of other treatment measures such as chemical disinfection through chlorination. pH also influences the potential for corrosion of pipes and fixtures.

Procedure

1. A standard buffer solution with established pH values was used to calibrate the pH meter.

2. The pH meter was used to determine the pH values of the raw effluent sample, then results were read and recorded.

3.1.2.4 Total coliforms

Measuring total coliform concentration in wastewater effluent is significant as they are a composite parameter of water quality and treatment efficiency. While E. coli particularly points towards fecal contamination, the total coliform group consists of bacteria from a more diverse array of environmental sources such as soil, plant material, and putrefying organic matter. Total coliforms are largely harmless, but their existence shows there is a pathway present for more dangerous pathogens to enter the system.

Procedure

1. A culture media is prepared by mixing 2.55g of violet red agar in 100ml of distilled water, and boiled for 2 minutes with continuous mixing until it completely dissolves. Sterilized petri dishes are then filled with the agar and allowed to settle so that the agar cools and solidifies.
2. The components of the membrane filtration are autoclaved to sterilize them and assembled afterwards.
3. The collected effluent sample is well shaken and 100ml of the sample is poured into the funnel.
4. After filtration, the sterilized forceps were used to place the filter paper in a violet red agar plate and then covered and labeled with the sample name.
5. The petri dishes are then incubated at 36^{o}C for 24 hours.

6. After 24 hours of incubation, the petri dishes were removed from the incubator and the number of colonies formed are counted and considered as the total coliform result.

3.1.2.5 E. Coli

1. 2.55g of MacConkey agar is mixed with 100ml of distilled water and boiled for 2 minutes with continuous mixing to ensure all the agar is dissolved into the water. 10ml of the agar is then poured into sterilized petri dishes and allowed to cool.
2. The membrane filtration apparatus are then placed into an autoclave to sterilize them and assemble them afterwards.
3. The raw effluent sample is thoroughly shaken and 100ml of the sample is measured and poured in the funnel in the membrane filter.
4. After filtration, the funnel was removed and membrane filter paper was transferred to the MacConkey agar in the petri dishes using sterilized forceps.
5. The MacConkey agar plates are then covered and labeled with sample name.
6. The petri dishes are then incubated at 36ºC for 24 hours.
7. After 24 hours had elapsed, the petri dishes were removed from the incubator and the formed colonies were counted. The number of colonies formed was then taken as the E. Coli colony count.

3.1.2.6 Biochemical Oxygen Demand (BOD_5)

BOD_5 is a measure of the amount of dissolved oxygen in water required by microorganisms to aerobically breakdown (oxidize) organic matter present in a water sample with in a given period of 5 days. BOD concentration is indicative of the extent of organic pollution of the water or effluent in the case of this research. Water with a high BOD indicates a high concentration of organic pollutants.

Procedure

1. Collect raw effluent samples in clean sterilized containers.
2. Two BOD bottles were obtained and cleaned with distilled water.
3. 300ml of the collected samples were added into 2 BOD bottles. One for afternoon sample and another for evening sample.
4. 50ml of Sodium thiosulphate solution were added into each BOD bottle. The bottles were then shaken gently to evenly mix the solution.
5. Using a syringe, 1ml of manganese solution, sodium azide solution, and concentrated sulfuric acid were each added to the two samples in the BOD bottles and they are gently shaken to create a homogeneous solution.
6. The bottles are then left to settle for about 2 minutes.
7. Using a measuring cylinder, 100ml of each sample is added into a conical flask each.
8. Place each of the conical flasks under a burette and read off the initial readings of the sodium thiosulfate solution in the burette. Titrate sodium thiosulfate into each of the conical flasks until the solutions become colorless.
9. Read and record off the final burette reading.
10. Incubate the two BOD bottles at 35^oC for 5 days.
11. After five days, repeat the procedure from step 5 to step 9.
12. The BOD_5 result is then calculated using the burette reading obtained.

Table 8: The parameters tested to determine the effluent quality (Public Utilities Board (PUB), 2014).

S/No.	Parameter	PUB guideline	Unit
1	Odor	Non offensive	
2	Color	<15	Hazen units
3	PH	6-9	
4	Turbidity	<2	NTU
5	BOD_5	<5	Mg/l
6	E. coli	Non detectable	CFU/100ml
7	Total coliform	<10	CFU/100ML

The sampling location is UCU activated sludge treatment plant in Mukono. The purpose of this sampling was to determine the characteristics of raw effluent which will inform the type of treatment required to meet the non-potable water standards for toilet flushing identified (Technical Guide for Greywater Recycling 1 st Edition: V2-Sep 2014). These guidelines were established to aid in the recycling of greywater for non-potable applications such as toilet and urinal flushing, general washing, irrigation, and cooling tower make up water.

3.2 DESIGNING A WASTEWATER EFFLUENT TREATMENT SYSTEM.

As earlier discussed, the proposed treatment system to make the secondary effluent meet the non-potable water quality standards involves two depth filters to reduce the suspended particles and disinfection to reduce the microbiological contamination risk.

Two depth filters will play the role of polishing the secondary effluent and reducing its turbidity to the required level (<2 NTU).

The proposed filtration media is sand because it has a proven effectiveness in removing suspended particles. In addition, sand is readily available at a low cost which makes it easy to use in the system when the project is implemented in the University.

3.2.1 FILTRATION SYSTEM

To determine the suitable size of sand particles to effectively reduce turbidity and suspended particles from the effluent, one has to first understand the typical size of the suspended particles present in the effluent. This is vital for the operation of the filters because if the sand particles are too small compared to the unwanted particles, then the filter will clog quickly and require frequent backwashing. And if the sand particles are too big, they will allow most of the suspended particles to pass through the pores together with the filtrate.

3.2.1.1 Considerations for the design of two depth filters (Metcalf & Eddy Inc. et al., 2014).

a) Final effluent quality
b) Influent wastewater quality
c) Filter medium characteristics (effective size d_{10}, uniformity coefficient)
d) Filter bed characteristics (bed depth, porosity)
e) Filtration rate
f) Flowrate control
g) Allowable head loss
h) Backwashing system and requirements
i) Filter appurtenances

To determine the influent wastewater quality, the suspended particles to be removed from the secondary effluent have to be characterized to know their typical size. This will help in the characterization of the sand medium particles because the pores between the grains have to be suitable that compared to influent particles, the pores effectively stain the suspended solids without clogging the filter in a short time of operation.

As earlier discussed, the required non-potable water turbidity for toilet flushing is <2 NTU.

3.2.1.2 Characterization of filter influent particles using Microscopy and Digital image analysis (Khanam *et al.*, 2016).

For this procedure, an electric microscope and a mobile phone are used to determine the typical size of filter effluent particles. A mobile phone was used to capture images with a fixed magnification of X2 to eliminate the inaccuracies brought about by the ability of a mobile phone to automatically change its camera magnification.

Procedure of filter influent characterization.

A secondary effluent sample that was collected from the UCU ASTP was brought to the Environmental Quality lab at the Faculty of Engineering Design and technology in a plastic bottle. During sample collection, the bottle and its cover was rinsed with the sample and the sample was collected.

In the lab, the sample was shaken to evenly distribute the particles that had settled and poured into a clean beaker. A pipette was used to apply 2-3 drops of the sample on a microscope slide.

The microscope was then switched on and the slide inserted into it. The microscope knobs were adjusted to clearly focus on the slide. Using a magnification lens of X4 on the microscope the particles in the sample were seen clearly. With the fixed magnification of X2 on a mobile phone, 3-5 pictures were taken. This procedure was repeated two more times for with different drops of the sample on the microscope slide.

Analysis of microscopic images (Nano, 2020)

For analysis of these images, "ImageJ" open-source software was used to determine the average size of the particles in the effluent. Having installed the ImageJ software, the microscopic images were imported from the mobile phone storage and analyzed.

Once the images were imported into the software, the following criteria were used:

a) A pixel distance of 40 pixels.

b) An image scale of 5μm.

c) A pixel aspect ratio of 1.0

d) Unit of length was μm.

In the image analysis, a total of 10 particles per image were measured using the ImageJ software. Their respective lengths were recorded in a Microsoft excel sheet and from here averages for all 3 three images were determined. Information about the calculated averages is in the appendices chapter.

Table 9: Average filter influent Particle size

Microscopic image	Average Particle Size from three images (μm)
Image 1	53.09
Image 2	48.29
Image 3	51.66

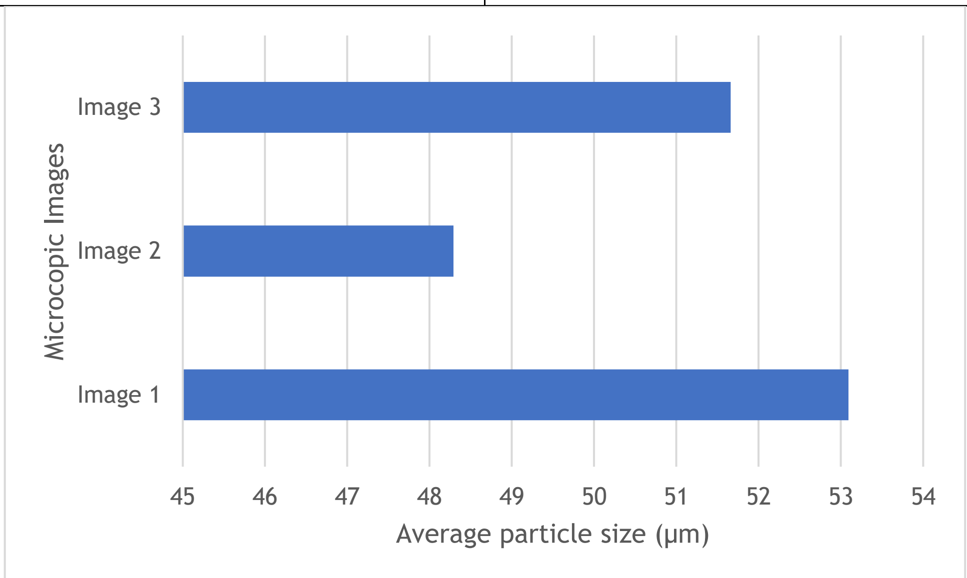


Figure 13: Trend in filtration influent particle size.

As seen from the graph, Image1 has the highest average particle size compared to Image2 and Image3. This is probably due to the differences in the efficiency of shaking the sample in the bottle which resulted in a more homogeneous mixture of the sample when Image1 was analyzed.

Average particle size = (53.09 μm + 48.29 μm + 51.66 μm) / 3

= (153.04 μm) /3

= 51.01 μm

This is the typical size of suspended particles in the secondary effluent generated in by the UCU ASTP.

Table 10: Typical design data for sand in a depth filter (Metcalf & Eddy Inc. et al., 2014).

Property	**Range**	**Typical value**
Depth (mm)	300–360	330
Effective size, d_{10} (mm)	0.45-0.65	0.45
Uniformity Coefficient (unitless)	1.2–1.6	≤1.5
Filtration rate (m^3/m^2.min)	0.08-0.24	-

3.2.1.3 Filter medium characteristics

Given the typical size of the secondary effluent suspended particles (51.01 μm), the suitable effective size, d_{10} of the sand grains will have to be appropriate to prevent quick clogging of the filter while straining out the suspended particles. The proposed sand grains are of an effective size, d_{10} of 0.45 mm and a pore size range of 20-100 μm (Eliasson, 2002). Given that the determined typical size of effluent particles is small compared to the stated pore size range, polishing the effluent to the target turbidity would require a biofilm to effectively strain suspended particles from the effluent.

The characterized suspended particles can be effectively removed in a 300-360 mm sand filter bed depth. Therefore, to achieve effective removal of these suspended solids, a bed depth of 360mm provides sufficient media depth and thickness to so with the formation of a biofilm. A biofilm also known as "schmutzdecke" is a German word that means "dirt layer" which forms in a slow sand filter between 10 to 40 mm depth (Abdiyev *et al.*, 2023).

3.2.1.4 Designing of wastewater effluent treatment unit

According to pilot scale filter studies, sand depths of 300-400 mm are effective for polishing applications. A filter bed depth of 360mm was selected for the following reasons;

a) A 360 mm depth provides sufficient space to establish a biofilm in the sand medium.
b) Adequate depth for the filtration mechanisms (straining, sedimentation, interception, adhesion, flocculation).
c) To balance the performance, head loss, and available space at the UCU activated sludge treatment plant.

3.2.1.5 Determining the influent flow rate.

Effluent Discharge pipe diameter, d = 110mm

Time taken to fill a 19-liter bucket, t.

Number	t (s)
1	8.23
2	8.24
3	8.27
4	8.90

t = (8.23 + 8.24 + 8.27) / 3

t = 8.25 s

Effluent discharge = known volume / time taken in seconds

1000L = 1m^3

19L = (19L * 1m^3) / 1000L

= 0.019m^3

Effluent flow rate = 0.019m^3 / 8.25 s

= **0.0023 m^3/s**

3.2.1.6 Designing for large scale filtration units (Metcalf & Eddy., 2014).

Table 11: Design calculations for depth filters

Parameter	Check against manual (Metcalf & Eddy Inc. et al., 2014).	Check by supervisor
Activated sludge treatment plant flow rate (Q) =**0.0023 m^3/s** **Filtration Rate** (Hydraulic Loading Rate, HLR) = 0.04 m^3/m^2.min $\text{HLR} = \frac{0.04\ \text{m}^3/\text{m}^2.\text{min}}{60\text{s}}$ $\text{HLR} = 0.0007\text{m}^3/\text{m}^2.\text{s}$	Typical filtration rate range for sand in a mono-medium depth filter: 0.08-0.40 (m^3/m^2.min)	
Total surface area required to polish effluent, TSA. $\text{TSA} = \frac{\text{Filter influent flow rate}}{\text{Filtration Rate (HLR)}}$ $\text{TSA} = \frac{0.0023\ \text{m}^3/\text{s}}{0.0007\text{m}^3/\text{m}^2.\text{s}}$ $\text{TSA} = 3.286\text{m}^2$ This is the total surface area of the filter required to polish the effluent.		
Dimensions of the Depth filter For space efficiency, the filters will be rectangular to maximize the available space in the activated sludge treatment plant.		

Parameter	Check against manual (Metcalf & Eddy Inc. et al., 2014).	Check by supervisor
Total surface area = 3.286 m^2 Number of treatment units; 2 units (2 depth filters) Surface area for a single filter $= \frac{3.286\ \mathrm{m}^2}{2\ \mathrm{units}}$ = 1.643 m^2 To maintain this surface area, taking inner width of the filter to be 1m. A = L x W; 1.643 m^2 = L x 1.0 m $L = \frac{1.643\ \mathrm{m}^2}{1.0\ \mathrm{m}}$ **L = 1.643m** Therefore, the inner dimensions of the depth filter will be 1.65m x 1.0m. As earlier mentioned, the filter depth will be 360mm to allow the formation of a biofilm and to provide sufficient contact time.	Inner dimensions of the depth filters.	

3.3 DESIGNING A NON-POTABLE WATER DISTRIBUTION SYSTEM.

INTRODUCTION

The supply of non-potable water (treated wastewater effluent) in UCU depends on the number of sanitary appliances, that is to say; toilets and urinals.

Once the effluent has been treated to meet the required non-potable water quality for toilet flushing, a non-potable water distribution pipe system will be installed to supply the toilets and urinal on campus.

To avoid potential contamination of the already existing potable water distribution system, a separate pipe system with a different color code is needed to ensure the non-potable water pipes are handled differently from the potable water pipes during connection and installation of sanitary appliances like the toilets. The treated effluent will be pumped from a clean water tank to an elevation tank placed at a high elevation at a high point on campus, possibly near the incinerator on campus premises.

Table 12: Design calculations for the non-potable water distribution system.

Calculations	Calculated Parameters	Parameters checks
Discharge (m^3/s) =volume(m^3) /time(s) Q=V/T influent discharge = $0.019m^3/15.27s$ = $0.0012m^3/s$	influent discharge =$0.0012m^3/s$ Effluent discharge =$0.0023m^3/s$	

Calculations	Calculated Parameters	Parameters checks
Volume of effluent = 19 L Time = 8.25 seconds Discharge (m^3/s) =volume(m^3) /time(s) Q=V/T **Effluent discharge** = 0.019m^3 / 8.25 s =0.0023m^3/s		
Maximum Day Demand (MDD) (90% of monthly amount 6000-7000m^3) =demand/30(90/100) =7000/30(90/100) MDD = 210 m^3/day	MDD= 210m^3/day	
Storage (tank) 30% the MDD = 30/100*MDD (m^3/day =0.3*210 Capacity =63m^3	50m^3/day (ok)	
P(Kw)= pgQH/3600η =1000kg/m^3 g(m/s^2) =9.8m/s^2 Q (m^3/day) =198.72m^3/day	Power=3KW	

Calculations	Calculated Parameters	Parameters checks
H(m) =70m $P=1000kg/m^3*9.8m/s^2*198.72m^3/day *70m/3600*0.3$ P=1947456/3600*0.3 P=1803.2kWh Number of solar Pannel= Daily power required/peak power rating*5 Number of solar Pannel=1803.2kWh/50*5 Number of solar Pannel =7.2128 =8pannels		
Battery size=required energy(W)/12*0.5 BS=3000/12*0.5 BS=500wh 160W) Voltage of 12v and lead acid battery Solar panel size=BS/hours of sunshine Solar panel size=600/5 Solar panel size=120W =120+(30/100*120) =156=160 (Get a panel of 160W) Charger controller=160/12=13.33=14A		

3.3.1 TRANMISSION NETWORK

A transmission line is the main pipe that convey treated water from either borehole or clean water tank to elevated storage distribution tank. Designing of pipeline is very important ensuring that adequate flow, stable pressure and minimal losses throughout the network. (Alemayehu et al., 2020)

Transmission lines compose of large diameter pipes design to maximize hydraulic and structural duality across long distance. design need evaluation factors of topography, projected water demand, choices of pipe material and cost effectiveness (Mays, 2019). performance of transmission is assessed using modeling software Grundfos used for simulation of flow distribution, pressure variation and energy consumption within the network (Rossman, 2000).

The data was collected using Handy GPS, hand book and pen, elevation differences were determined from the clean water tank to the elevated tank is (1276.51-1217.27) m 59.24m

70m in which the elevated tanked will be placed. The discharged of effluent was determined to be 0.0023m^3/online software called Grundfos was used for determining the power that will pump the water through the transmission to the elevated tank and later distribute the water to the appliances by gravity.

The source of water supply is from the UCU activated sludge treatment plant effluent that will be treated to supply water from the design clean water tank or contact time tank which lies with 470959.276 Eastings,38852.802 Northings and Altitudes 1217.27m above mean seal level. The total length to the reservoir is 437m along the Ankirah small gate from the source to the reservoir.

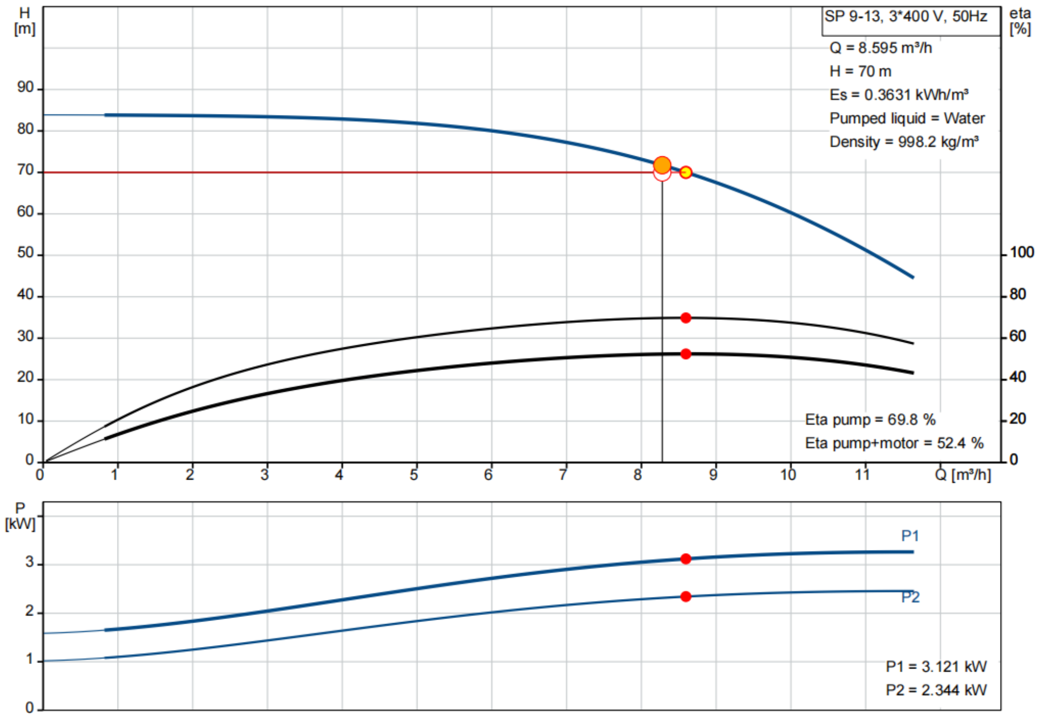


Figure 14: power variation needed to pump non-potable water

3.3.2 DISTRIBUTION NETWORK

The distribution of water is by gravity through which elevated tank/reservoir, highest point is known to determine the pressure that equalizes the system, using Epanet to simulate the system using Hazen William formular. The pressure differences will be known, diameter and the lengths of the pipes will equally be determined using the formular (Hazen William).

Dataset of elevation point were picked using Handy GPS such that the highest point within the distribution line must not be higher than that of elevated tank for pressure operation.

The layout of a water supply system illustrates both the physical arrangement and hydraulic features of the network, detailing how water is transported from the source, to the appliances through the elements of reservoir, pipes, and fittings.

Hydraulic and water quality were performed using EPANET, a widely modelling software, to evaluate flow distribution, pressure variation and overall operational performance of the system (Rossman, 2000).

This layout offers a clear visual depiction of network connectivity, showing pipe sizes, nodes elevations. It is an essential tool for detecting potential hydraulic challenges, like low pressure, excessive velocities, or areas with inadequate supply. It facilitates performance assessment under varying demand conditions. Supporting effective planning, design optimization and potential future expansions of the water distribution network.

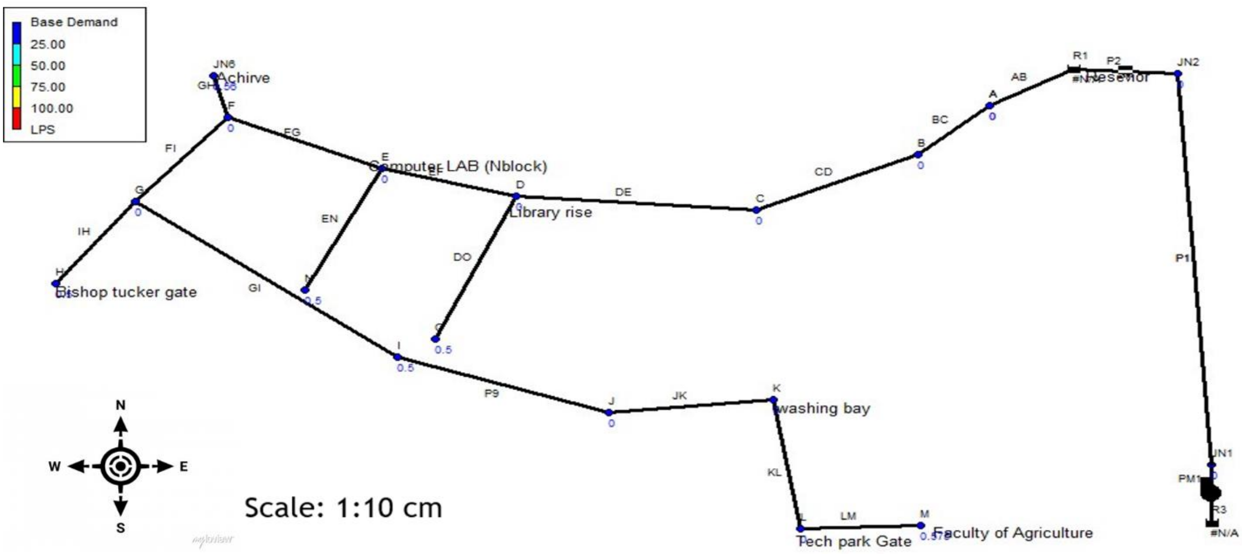


Figure 15: Non-potable water distribution system Layout (EPANET 2.2)

Table 13: Showing node variations

Node ID	Elevation (m)	Base demand (Lps)	Demand (Lps)	Head (m)	Pressure (m)
Node B	1259	0	0	1278.68	19.68
Node A	1279	0	0	1278.84	-0.16
Node C	1256	0	0	1278.23	22.23
Node D	1248	0	0	1277.04	29.04
Node F	1252	0	0	1275.95	23.95
Node JN6	1257	0.56	0.56	1275.9	18.9
Node H	1228	0.5	0.5	1275.66	47.66
Node I	1227	0.5	0.5	1275.64	48.64
Node J	1226	0	0	1275.57	49.57
Node K	1239	0	0	1275.42	36.42
Node L	1225	0	0	1275.07	50.07
Node M	1223	0.575	0.57	1274.73	51.73
Node N	1226	0.5	0.5	1276	50
Node O	1255	0.5	0.5	1276.86	21.86
Node G	1229	0	0	1275.72	46.72
Node E	1247	0	0	1276.17	29.17

Node ID	Elevation (m)	Base demand (Lps)	Demand (Lps)	Head (m)	Pressure (m)
R1	1279	#N/A	-3.13	1279	0

Table 14:showing Links variations

Link ID	Length (m)	Diameter (mm)	Velocity (m/s)	Unit head loss (m/km)
Pipe BC	131	125	0.26	1.22
Pipe CD	198	110	0.33	2.27
Pipe DE	198	90	0.49	6.04
Pipe GH	75	75	0.13	0.61
Pipe FI	131	90	0.25	1.69
Pipe IH	131	75	0.11	0.49
Pipe GI	104	90	0.17	0.83
Pipe P9	105	75	0.13	0.63
Pipe JK	104	63	0.18	1.48
Pipe KL	75	50	0.29	4.57
Pipe LM	75	50	0.29	4.57
Pipe EF	198	90	0.41	4.38

Link ID	Length (m)	Diameter (mm)	Velocity (m/s)	Unit head loss (m/km)
Pipe FG	75	90	0.34	2.96
Pipe EN	150	63	0.16	1.15
Pipe DO	150	63	0.16	1.14
Pipe AB	131	125	0.26	1.22
	2031			

Pressure distribution across the various nodes within the network was simulated in EPANET. the x-axis represents the pressure at each node (meters of head) and the y-axis shows the percentage of nodes with pressure less than or equal to the specific value. indicating that nodes experience moderate to high pressure levels, typically ranging from 20 -50 meters, with the majority concentrated around 45-52m. a few nodes record pressure below 20m, likely corresponding to areas of higher elevation or greater distance from the main supply source. The smooth upward trend of the curve demonstrates generally balanced pressure distribution across the network ensuring sufficient service levels for consumers. Nevertheless, higher-pressure nodes need regulation to prevent excessive pressure and potential pipe damage in low lay areas (EPA,2020, Ministry of water of water and environment, 2021).

Figure 16:showing pressure distribution

The distribution of water demand also various with nodes within the network of water supply. The x- axis represents the demand at each node (LPS) and the y- indicates the percentage of nodes with demand less than or equal the specific value. Moderate demand levels generally between 0.10 and 0.50 LPS only a few nodes record higher demand approaching 0.58 LPS. The trend of the graph reflects a fairly uniform distribution of water demand across the service area, showing that the network design provides a well-balanced supply among the consumption points

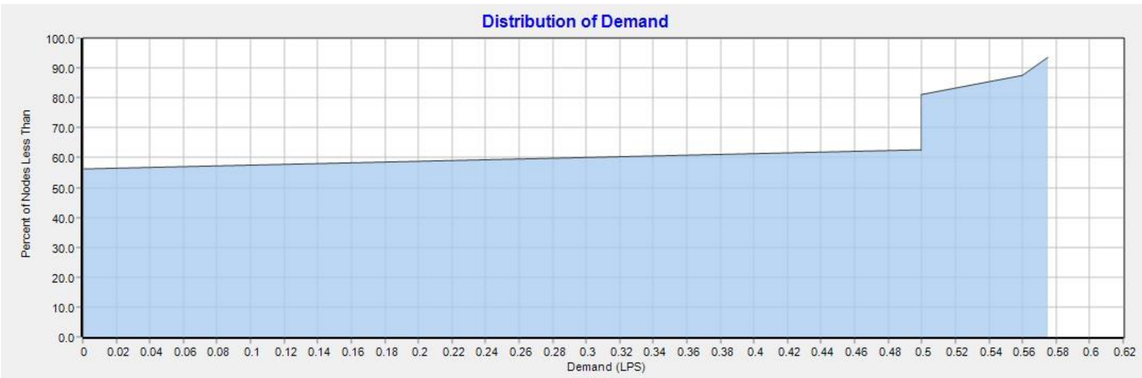


Figure 17:showing the graph of demand distribution.

The graph presents the elevation profile of the water supply system generated from Epanet hydraulic analysis each plotted point represents the variation of induvial nodes along the pipe line. The variations depict the topographical features of the project area which affect the hydraulic head and pressure distribution within the network. The graph shows that the elevation differences from the reservoir to the consumers showing that it is fed gravity. (EPANET 2.2 user manual)

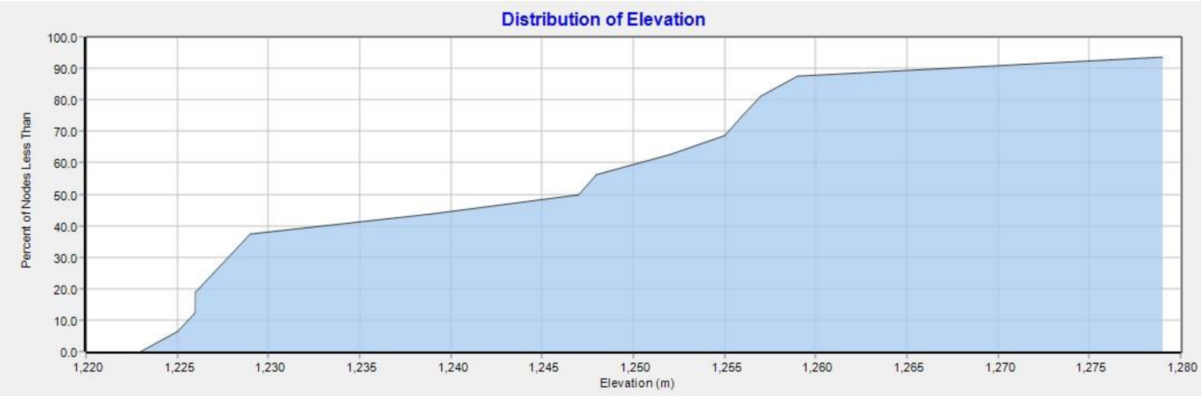


Figure 18: showing elevation differences

3.3.3 WATER TANK

Reliable water storage systems are vital for maintaining a steady and dependable water supply to institution and distribution networks. Elevated water tank is particular important in achieving this as it provides adequate storage capacity, regulate distribution pressure and supply water during period of demand during temporary shortage.

Structural arrangement and functional element of a $50m^3$/day of steel tank intended to store treated water and deliver into the distribution line,

Configuration measuring 6.03m x6.03m, with clear storage space of 5.0m x5.0m, the structure is supported by reinforce concrete columns and footings and incorporated based footing.

The accompanying plan and cross-sectional drawing illiterates the tank geometry including the element thickness, inlet and outlet pipe's location. Material requirements, service features and overall design layout of the elevated tank as depicted in the drawings.

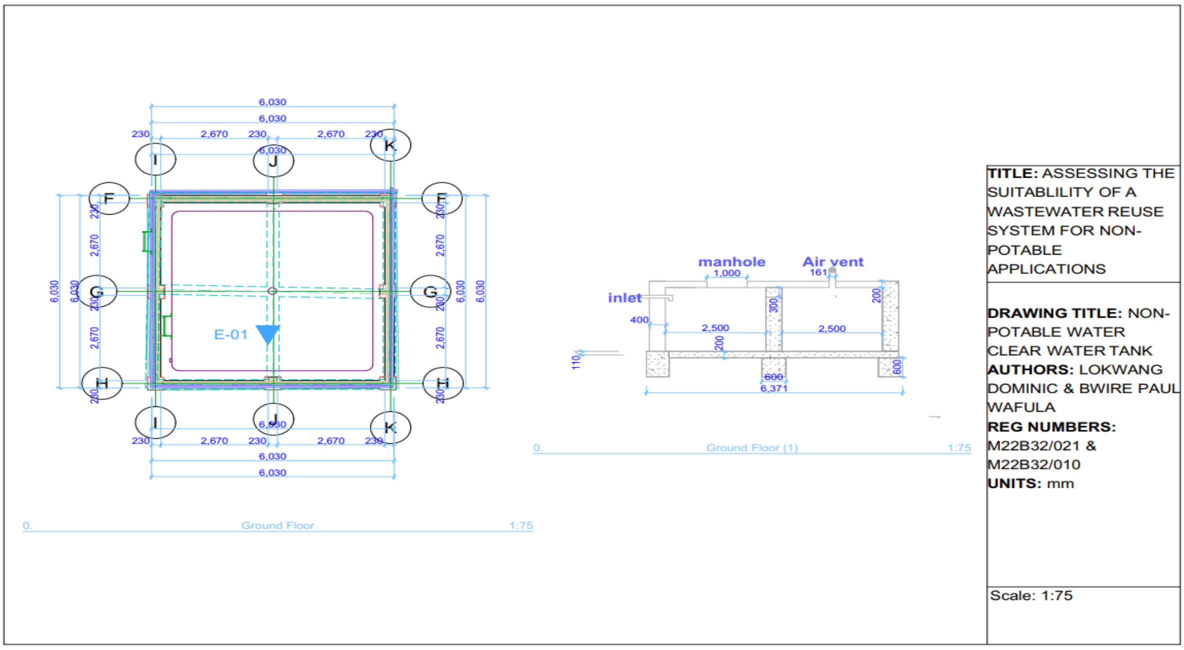


Figure 19: showing the elevation tank drawing

3.4 CONDUCTING A COMPREHENSIVE COST BENEFIT ANALYSIS OF THE WASTEWATER EFFLUENT REUSE SYSTEM.

INTRODUCTION

The third element of this study is the cost benefit analysis (CBA) in determining the financial viability of reusing effluent for non-potable use within Uganda Christian university. The estimation of the cost will begin with identification of all the capital costs, materials for construction wetland (liner, gravel, outlet and inlet pipes and plant of the wetland), a storage tank for treated water, a min-pump for water for water transfer, and transmission and distribution of non-potable water to selected sanitary facilities. Operational and maintenance cost, such as energy for pumping, regular cleaning and minor maintenance, will be estimated based on the rates used in similar studies (Ou et al., 2006; Kadlec and Wallace, 2009). Benefits will be quantified by calculating the volume of potable water saved through substitution with treated effluent for non-potable use. The water demand for sanitary use will be determined from population and per capita demand guidelines from water Supply Design M annual (Republic of Uganda, 2018). Using the current National Water and Sewerage Corporation (NWSC) tariffs, this volume will be translated into annual cost savings. Environmental benefits, such as reduced discharge of untreated effluent into environment, will be described qualitatively. Finally, the payback period and net benefits will be computed to determine whether the cost of implement the reusing system is justified by savings and environmental benefits (Kyambadde et al., 2004; WHO, 2006).

Concrete Mix Design

Batching by volume.

Concrete yield is the volume of freshly concrete different from a known quantity of ingredients. the volume of hardened concrete may be less than expected. Due to waste, spillage, over excavations, spreading forms entrained air/settlement of wet mixtures none of which are the responsibility of the producer.

It is therefore paramount to cater for the losses when producing concrete, when batching by volume note that the yield is the volume.

Volume of 1 bag of cement is 50kg as packed which is equal to 33liters

Yield of mix=2/3(loose of cement + sand +aggregate)

mix proportion by volume is 1:2:4 meaning 1 part of cement, 2 parts of sand and 4 parts of aggregate/stones and 1:3:6 where prescribed to use such mixes originated from UK and are suitable for well graded round aggregates.

The south Africa materials, proportions with equal volume of sand and stones (1:3:3 or 1:4:4) are more like to work. S.K, Suryakanta "How to estimate yield of concrete for volume batching"

Materials required.

Volume of concrete required (m^3) = LWH

Number of batches of mix=volume of concrete (L)/Yield of mixtures.

Sand trip = batches *(33*3)

Aggregate = batches *(33*3)

Table 15: Showing material acquisition

item	element	Volume(m^3) =LWH	volume 2/3(1*33:3*33:4*33)	Materials=v/y		
				cement	sand	Ag g
Filter media	slab	v=2.75*1.4*0.2 v=0.77m^3	0.176m^3	5	1	2
	slab	v=1.65*1.4*0.2 v=0.462m^3	0.176m^3	3	1	2
	wall	v=2.75*2*2.20.2 v=2.42 m^3	0.176m^3	14	2	3
	wall	v=1.49*1*0.2*2 v=0.596 m^3	0.176m^3	4	1	2
		v=1.4*2.2*0.2*4 v=2.46 m^3	0.176m^3	14	2	3
		v=1.65*2.2*2*0.2 v=1.452m^3	0.176m^3	9	1	2
Length of= (length/spacing +1) *length*sides						
		l= (1.75/0.15+1) *1.75*4				
		l=177.24m	(16*16/162) * 177.24m	280kg		
		l= (1.65/0.15+1) *1.65*4 l=158.4m	(16*16/162) * 158.4m 250.272kg	250.272kg		

		l= (1.4/0.15+1) 1.4*4 l=231.392m	(16*16/162) *231.392m 365.60kg	365.60kg		
		l= (1.49/0.15+1) *1.49*4 l=122.45m	(16*16/162) *122.45m =193.50kg	193.50kg		
		l= (2.2/0.15/0.15+1) *2.2*8 l=1103m	(16*16/162) *1103m 1743.012kg	1743.012kg		
		l= (1/0.15+1) *1*2*4 l=61.28m	(16*16/162) *61.28m =96.837kg	96.837kg		
		Total length=1731.312**m**	1731.312**m**	2735.9kg		
		BRC				
Area of the filter bed=LW A=4.4*1.4 A=5.5m^2						
Elevated tank	footing	V= (0.6*0.6*0.6) *9 V=1.944m^3	Y=2/3(1*33+3*33+4*33) =0.176m^3	12	2	3
	column	V= (0.4*0.4*2) *9 V=2.88m^3	Y=2/3(1*33+3*33+4*33) =0.176m^3	17	2	3

	slab	6.03*6.03*0.2 =7.272m^3	Y=2/3(1*33+3*33+4*33) =0.176m^3	42	5	6
	beam	V=6.03*0.3 V=3.256	Y=2/3(1*33+3*33+4*33) =0.176m^3	19	2	2
Clear water tank	footing	V= (0.6*0.6*0.6) V=1.08m^3	Y=2/3(1*33+3*33+4*33) =0.176m^3	7	1	1
	slab	V=6.03*6.03*0.2*2 V=7.2721*2 V=14.544m^3	Y=2/3(1*33+3*33+4*33) =0.176m^3	83	9	11
	column	V= (0.4*0.4*2) *9 V=2.880m^3	Y=2/3(1*33+3*33+4*33) =0.176m^3	17	2	3
	beam	V= (6.03*0.3*0.3) *2 V=3.616m^3		21	3	3
	Bars (slab wall)	Bars of steel (slab and the wall)	Weight of steel (kg) =(D^2/162) *Length			
		l= (6.03/0.15+1) *2 l=52.26m	(16*16/162) *52.26 =82.584kg	82.584kg		
		(6.03/0.15+1) *4 l=321.6m	(16*16/162) * 321.6 =508.207kg	508.207kg		

		l=*(2/0.15+1) *2*4 l=114.667m	(16*16/162) *114.667	181.202kg

Table 16: Showing estimated cost of the materials

ITEM	UNIT	QTY	RATE	AAMOUNT
UPC-pipe DN125 PN16	m	270	25316	6835500
UPVC-pipe DN110 mm PN 16	m	198	17800	3524400
HDPE pipe DN90 mm PN16	m	925	10500	9712500
HDPE pipe DN75 mm PN16	m	529	7500	3967500
HDPE pipeDN63 mm PN16	m	404	4900	1979600
HDPE pipe DN50 mm PN16	m	150	2800	420000
HDPE pipe DN20 mm PN16	m	500	2000	1000000
Couple HDPE DN90 mm PN16	pcs	19	31400	596600
Couple HDPE DN75 mm PN16	pc	6	22400	134400
Couple HDPE DN63 mm PN 16	pcs	5	10500	52500
Couple HDPE DN50 mm PN16	pcs	2	7100	14200
Tee HDPE 90*90*75 mm PN 16	pcs	5	32500	162500
Control value (Falange) DN125	pcs	1	300000	300000
Control valve (Falange) 90*75	pcs	4	250000	1000000
Washout valve DN75	pcs	4	450000	1800000
bulky meter DN 80mm	pc	1	963109	963109
Reducing socket 80*75	pcs	8	45000	360000
Power invertor	pc	1	150000	150000

Pump	pc	1	1010000	1010000
Solar panel (260W/24v monocrystalline)	pcs	8	600000	4800000
Power cable	m	30	15000	450000
Reducing socket HDPE DN63*50 mm	pcs	2	14000	28000
Reducing socket HDPE DN75*63 mm	pcs	2	21900	43800
Reducing socket HDPE DN90*75 mm	pcs	6	26200	157200
saddle clamp DN110*20 mm PN16	pcs	5	20100	100500
saddle clamp DN 90*20 mm PN16	pcs	6	9000	54000
saddle clamp DN 75*20 mm PN16	pcs	5	8000	40000
saddle clamp DN 63*20 mm PN16	pcs	7	9700	67900
saddle clamp DN 50*20 mm PN16	pcs	3	6500	19500
End cap HDPE DN75 PN16	pcs	2	2300	4600
End cap HDPE DN63 mm PN16	pcs	2	8600	17200
End cap HDPE DN50 mm PN16	pcs	2	5000	10000
Adaptors HDPE DN75 mm PN16	pcs	4	25100	100400

Adaptors HDPE DN20 PN16	pcs	150	1500	225000
GI pipe DN75 mm	m	9	150000	900000
Tank (elevated)	m^3	1	3000000	3000000
Expansion storage	m^3	15	813300	12199500
Ball valve	pcs	2	8000	16000
GI elbows 75	pcs	4	32000	128000
GI elbows DN90	PCs	4	41000	164000
HDPE adaptors DN90	pcs	3	31500	94500
cement	bags	184	35000	6440000
sand	tone	42	500000	21000000
aggregate	tone	58	500000	29000000
y16	PCS	185	36000	6660000
strips	pcs	57	8500	484500
BRC	pcs	10	15000	150000
labour 30% of the material cost	slum	1	36101227	36101227
contingencies 10%	slum	1	1564863.6	1564863.6
profit 15%	slum	1	2370052.94	2370052.94
TOTAL AMOUNT				**160,373,552.5**

Cost benefit analysis for reusing wastewater effluent for non-potable applications.

Rising utility costs are significant challenges for institutions in Uganda, including universities. Uganda Christians university consume large volume of freshwater for non-potable applications such as irrigation, toilet flushing, and cleaning.

Dependence on National water and sewerage corporation (NWSC) expose the university to high water bills and potential disruption in supply (NWSC, 2023; Nsubuga et at., 2014).

Reusing the treated wastewater effluent for non-potable application creates sustainable solution to reduce fresh water consumption and operational cost in promoting environmental conservation. Cost benefit analysis is and essential tool for carrying out economic viability of the projects by comparing the cost of implementation and operation with the financial benefits arising from reduced water purchases (Boardman et al., 2018; World Bank, 2020).

This study evaluates the feasibility of investing Ugx160373552.5 in wastewater reuse at UCU to assesses potential cost saving, payback period Profitability index and Net present value (NPV) over a ten-year period.

Assess the economic feasibility of the project to inform sustainable management

equation $DF = 1/(1+r)^{t}$ (Brigham, E. F., & Ehrhardt, M.C. (2017)

Table 17: Payback period

Parameter	**Description**	**Value**
Capital expenditure (CAPEX)	Total amount of the wastewater reuse system	UGX. 160,373,552.5
Annual operation and maintenance (O&M)	8% of capital expenditure (assumed)	12827004.2

Unit water price (NWSC institutional tariff)		UGX. 4358
Project lifetime		10 years
Discount rate		11%
Daily effluent reuse		50m^3/day
Annual volume=Daily*365	Small=50*365	18250
Annual benefit (Avoided water cost) =Volume annual *unit price	18250*4358	79533500
Net annual benefit= Annual benefit-O&M	79,533,500-12,827,004.2	66,706,495.8
Payback period=initial investment/annual cash inflow	160373552.5/66,706,495.8	2years,4months ,24days.

Table 18:showing present value using volume of $50m^3$/day

YEAR	DF= 1/(1+r) ^{t}	PV	NPV
1	0.901	66,706,495.80	60,102,552.72
2	0.812	66,706,495.80	54,165,674.59
3	0.731	66,706,495.80	48,762,448.43
4	0.659	66,706,495.80	43,959,580.73
5	0.593	66,706,495.80	39,556,952.01
6	0.5535	66,706,495.80	36,922,045.43
7	0.482	66,706,495.80	32,152,530.98
8	0.434	66,706,495.80	28,950,619.18
9	0.391	66,706,495.80	26,082,239.86
10	0.352	66,706,495.80	23,480,686.52
			394,135,330.4

NPV=TPV-Cash inflow.

NPV=394,135,330.4-160,373,552.5

NPV=Ugx 233,761,777.9 (using 11% rate for a period of 10 years)

Profitability index (PI)=TPV/initial investment

Pi = 394,135,330.4/160373552.5

Pi = 2.5

Conclusion

The methods discussed above were conducted to collect accurate and precise information or data needed to fill the gap of input data highlighted at the end of the previous chapter. The information collected from carrying out this methodology is an input for the design calculations for the filtration system and the non-potable water system.

CHAPTER FOUR: RESULTS AND DISCUSSION

INTRODUCTION

Effluent samples were collected at two different times: afternoon (2pm), and evening (4pm). The pH, turbidity, color, E. coli, total coliform, and BOD_5 of the two samples were examined. The findings were contrasted with the Singapore's Public Utilities Board's Technical Guide for Greywater Recycling (PUB, 2014), which was selected because it gives the non-potable water quality requirements for toilet and urinal flushing. In addition, this guideline is relevant to tropical climates similar to Uganda.

In addition, secondary data was obtained from the UCU activated sludge treatment plant to help determine the typical quality of the wastewater effluent generated from in UCU. This information consisted of data collected on several parameters to determine the compliance of the plant to the National Standards for Wastewater effluent discharge into the environment from 2014 to 2023. However, only three parameters (BOD_5, E. Coli, and pH) in the secondary data are considered in this study and not all months of the years in that period are accounted for. This chapter strives to compare the primary data to the available secondary data obtained from the plant.

4.1 PHYSICOCHEMICAL AND BACTERIOLOGICAL CHARACTERISTICS OF RAW EFFLUENT FROM THE UCU WASTEWATER TREATMENT PLANT.

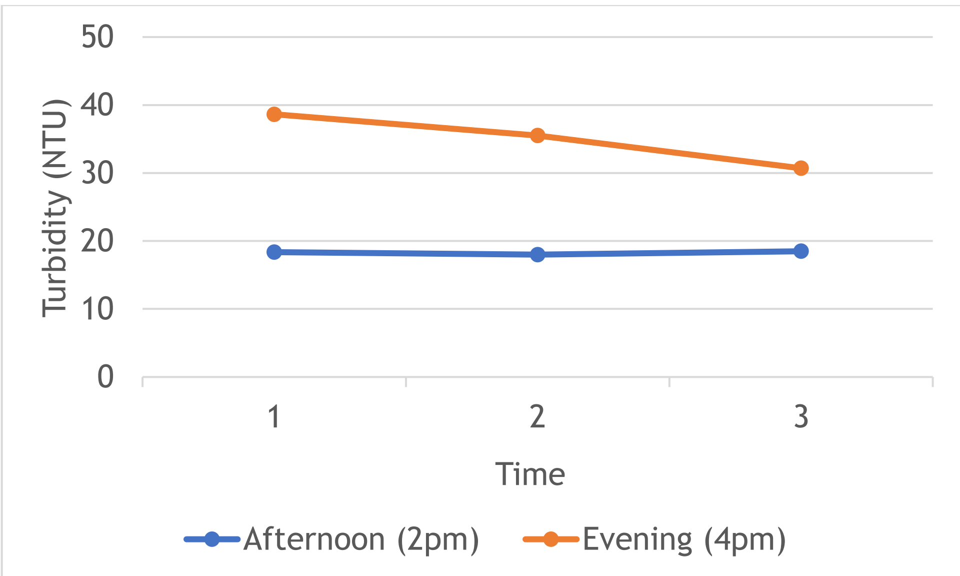
The purpose of this chapter is to discuss the quality of effluent generated from the UCU Activated sludge treatment plant

The parameters of interest are turbidity, pH, color, E. coli, total coliforms, and BOD_5. These parameters will be monitored before treatment, after treatment and during distribution of the effluent.

The standards and guidelines considered for this study are the National Environment Standards-for Discharge of Effluent into Water or Land and the Singapore Public Utilities Board (PUB) guidelines. They are contrasted with the obtained lab results as follows.

4.1.1 TURBIDITY

Turbidity is the measure of the cloudiness or haziness of the effluent caused by the presence of suspended particles like silt, clay, and organic matter. It is measured in Nephelometric Turbidity units (NTU).



For the atmospheric conditions, there was a rain storm before the evening sample was collected which might have resulted in disturbance of the wastewater in the activated sludge treatment plant, resulting raising of any settled particles in the de-sludging chamber. This therefore explains why the evening turbidity range is higher than the turbidity in the afternoon.

The turbidity results support the necessity for filtration, specifically sand filtration given the high levels of turbidity. Reducing the turbidity of the effluent will prevent suspended particles from shielding pathogens from applied disinfectants such as chlorine.

4.1.2 COLOR

Color is the water quality parameter which refers to the presence of dissolved or suspended substances that cause water to appear discolored.

The color results were 8 PtCo in the afternoon and 2.3 PtCo in the evening. These both complied with the PUB guidelines of <15 PtCo. A low color indicates a low concentration of organic compounds that may make water or effluent visually unappealing, affecting public acceptance.

4.1.3 pH VALUE

pH is the measure the acidity or alkalinity of the effluent based on the concentration of hydrogen ions (H^+). A pH range scales from 0 to 14, with 7 being the neutral pH. Any pH below 7 is acidic and any value above it is alkaline.

The effluent pH values for the afternoon (9.1) and evening (9.2). Both do not comply with the Singapore PUB guidelines, (6.0 – 9.0). To make the effluent reach the required pH range, sulfuric acid will be dosed into the effluent to help lower its pH slightly. It is likely that the pH of the effluent exceeds the neutral range because of the cleaning products used by the cleaners in the halls of residence and the staff residence such as soaps and detergents, as well as food waste from kitchens.

Secondary data shows that the pH of the effluent over seven years has varied within the acceptable range that complies with the Singapore PUB water quality limits for toilet flushing using non-potable water (6.0 -9.0).

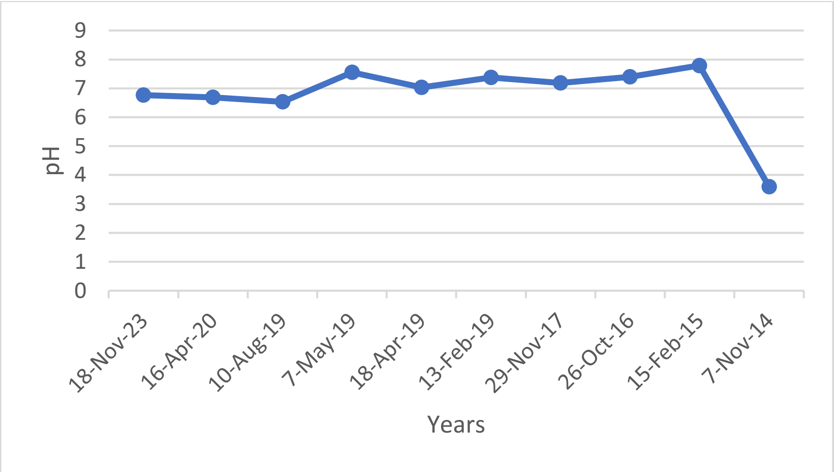


Figure 20: pH trend over seven-year period

From 18th November, 2023 to 15th February, 2015 the pH of the effluent remains in a neutral range, that is to say, between 6 and 8.

Results from the year 2014 indicate that the effluent was more acidic at the time and suggests the possible use of acidic cleaning agents and disinfectants in the toilets, and bathrooms on the campus for example the use of hydrochloric acid (HCl) based cleaning agents.

In comparison, the primary data shows that the effluent pH is slightly alkaline suggests that there might be more use of alkaline compounds such as sodium carbonate also known as washing soda, which can raise the pH.

4.1.4 ESCHERICHIA. COLI (E. Coli)

Escherichia coli (E. coli) is a parameter used to quantify the microbiological quality of wastewater effluent because its detection indicates fecal contamination. The Public Utilities Board (PUB) policy states that treated wastewater should have zero E. coli in one 100 ml sample (Public Utilities Board (PUB), 2014). This is a strict requirement because E. coli is not a pathogen in its natural state, but it is a reliable indicator organism for the potential presence of potentially more virulent disease-causing organisms that originate from feces, such as Salmonella and Giardia. The occurrence of E. coli is an instant warning that the treatment process has not removed or destroyed a source of fecal contamination.

The high microbial count in the effluent is an indication of the presence of human waste. The E. Coli colony counts are less than the raw sewage colony counts, indicating primary pathogen reduction occurred during the wastewater treatment process. The afternoon sample gave an E. Coli colony count of 385 CFU/100ml, and the evening sample result was 334 CFU/100ml which failed to comply with the considered PUB guideline of Zero colony counts. The reduction of the colony counts from afternoon to evening is most likely due to the dilution effect caused by the rain storm that occurred before the evening sample was collected.

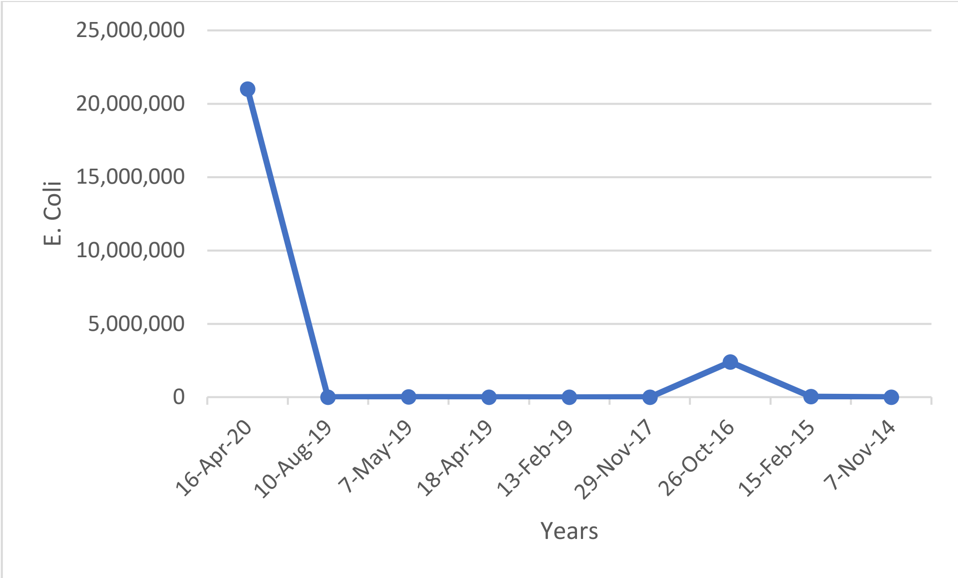


Figure 21: E. Coli trend over seven-year period

In the secondary data, the E. Coli levels were significantly higher on 16th April, 2020. In this period, the world was struck by the COVID-19 virus. The President of the Republic of Uganda initiated a lockdown in the country from 30th March to 30th June (Katana *et al.*, 2024). The very high level of E. coli detected in the effluent on 16th April, 2020 could be a result of the scaling down of the activated sludge treatment plant operations because the operators were either at home or had limited access to the premises.

4.1.5 TOTAL COLIFORMS (TC)

Total coliforms are a group of bacteria used as indicator of the overall microbiological quality of a water sample. They are rod-shaped in nature and are found throughout the environment including soil, vegetation, and the intestinal tract of warm-blooded animals.

Similar to E. Coli, the colony count for the afternoon (276 CFU/100ml) and in the evening (95 CFU/100ml) exceeded the water quality limit of the Singapore PUB guideline of <10 CFU/100ml. The evening sample result was less than the afternoon sample result possibly because of the dilution effect caused by the rain.

4.1.6 BIOCHEMICAL OXYGEN DEMAND (BOD_5)

BOD_5 refers to the amount of dissolved oxygen on the effluent than aerobic microorganisms need to break down biodegradable organic material in a water sample over a period of five days.

The BOD_5 result for the afternoon and evening was 4.269 mg/l which was below the Singapore PUB guideline limit of <5mg/l and also complied with the National Environment (Standards-for Discharge of Effluent into Water or Land) Regulations which was also <5mg/l. This compliance indicated that the UCU activated sludge treatment plant process effectively removes most of the soluble organic pollutants in the wastewater.

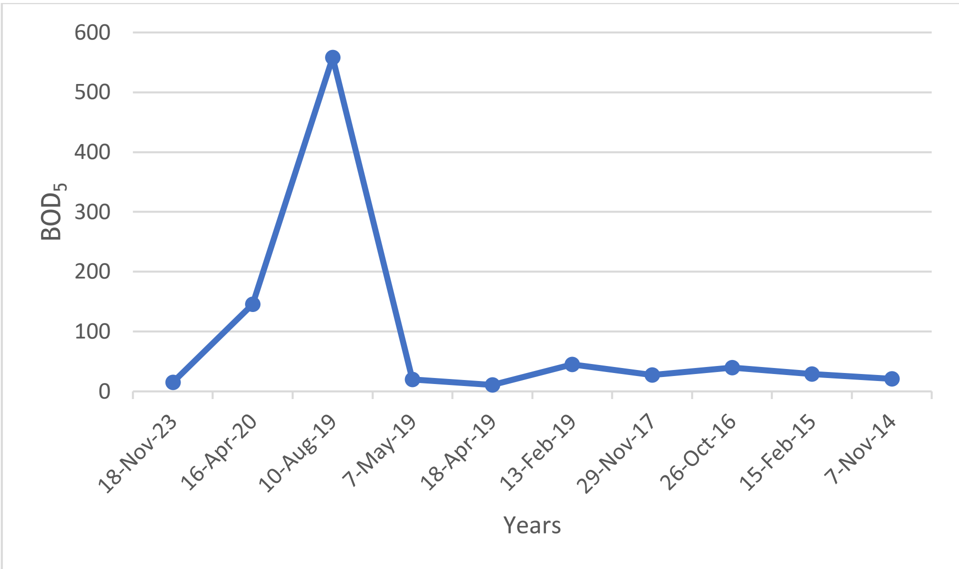


Figure 22: trend over seven-year period

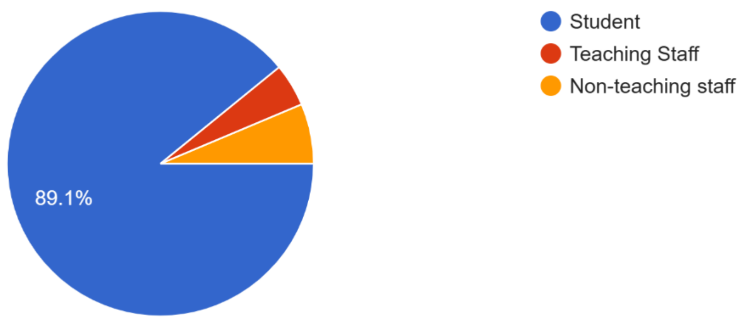
As earlier mentioned, the concentration of BOD_5 is indicative of the level of organic pollution in water. The high level of BOD_5 in effluent samples tested on 10^{th} August, 2019 suggest a high percentage or organic particles in the wastewater effluent. This is also an indicator of the efficiency of the treatment process in the elimination of organic particles from the wastewater. Organics in the wastewater are treated through the process of aeration where blowers are used to introduce are into the wastewater to facilitate the aerobic breakdown of the organic matter by microorganisms.

The organic particles in the wastewater effluent potentially originate from the halls of residence, the staff and guest quarters, the dining hall, and the offices on campus where there is disposal of organic waste into toilets and washing away of food particles.

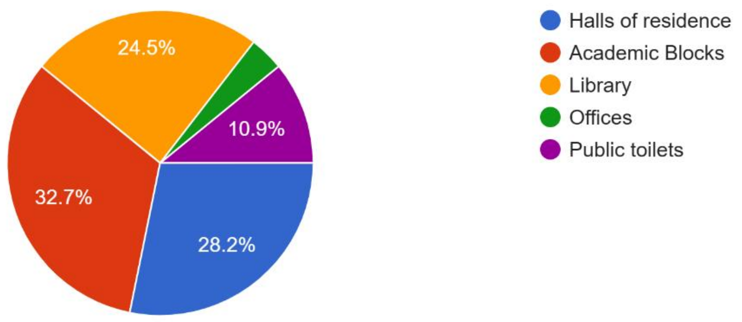
4.2 STUDENT AND STAFF SURVEY

A total of 110 students and staff participated in this survey. The main objective was to determine the UCU toilet user behavior through a questionnaire with simple targeted questions. Another objective was to estimate the average number of flushes per person per day.

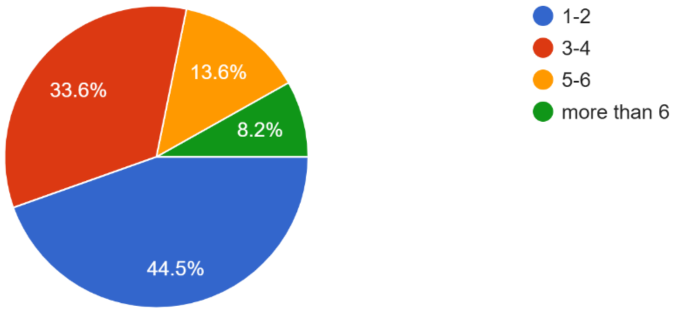
Question 1: The graph below shows the responses obtained for question one in the survey. Participants identified themselves as one of three categories; Student, Teaching staff, or as a non-teaching staff. The majority of the participants were student with a percentage of 89.1%. Teaching and non-teaching staff were



Question 2: The second question of the survey was aimed to determine the type of sanitary facilities in the university that are most used by students and staff. According to the survey, majority of users access sanitary facilities in the lecture block (32.7%). For example, lecture blocks such as N Block, and Nkoyoyo are lecture blocks that have sanitary facilities.



Question 3: This question is focused on determining the average number of flushes per person per day. Majority of participants (44.5%) flush one-to-two-times a day. To determine the average number of flushes per person per day, the following calculation was carried out.



Because Question 3 does not have exact number of flushes in it responses, an average response was determined as shown below;

Number of Flushes	Number of flushes Midpoint	Percentage Number of Responses
1 - 2	1.5	44.5%
3 -4	3.5	33.6%
5 - 6	5.5	13.6%
>6	7.5 (assumed)	0.08%

Average number of flushes = ∑ [Number of flushes Midpoint * Percentage Number of Responses]

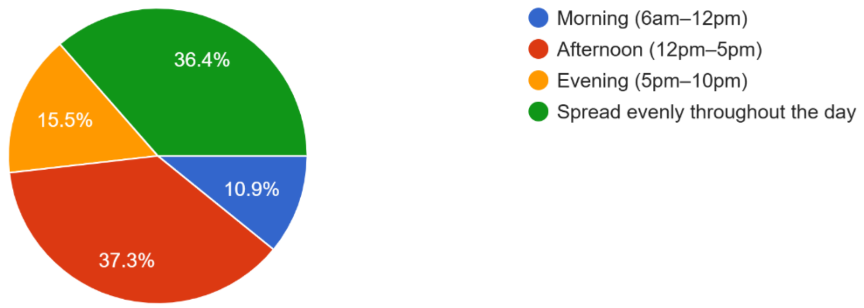
Average number of flushes = (1.5 * 0.445) + (3.5 * 0.336) + (5.5 * 0.136) + (7.5 * 0.08%)

= 0.6675 + 1.176 + 0.748 + 0.615

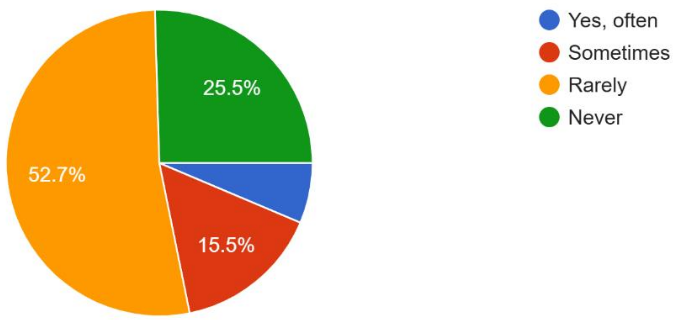
= 3.2065

≈ 3 flushes/ person/ day

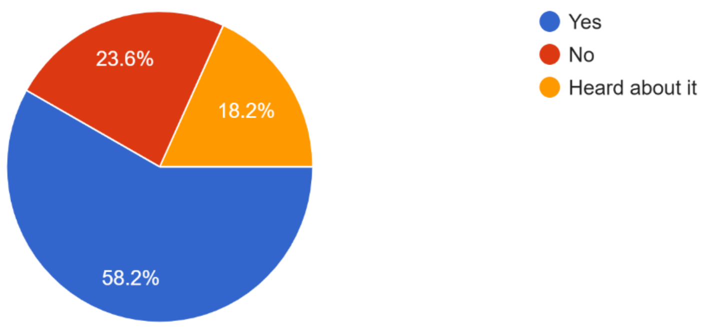
Question 4: This was aimed to determine the time that participants most frequently use sanitary facilities on campus. The data collected showed that most individuals visit sanitary facilities in the afternoon, that is to say, from 12 noon to 5pm with a percentage of 37.2%. This might be because of the lunch break during the day, when morning lectures have ended and students use these facilities before they go for their lunch.



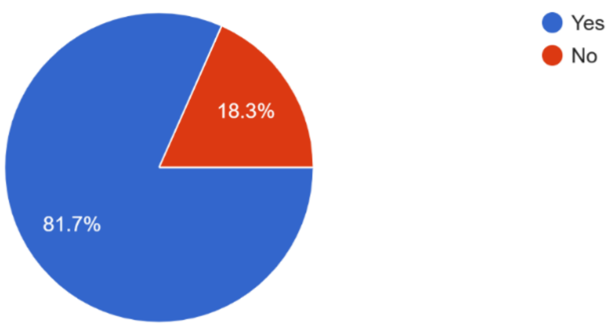
Question 5: This question focused on determining the frequency inconveniences due to water shortages while using the sanitary facilities. Majority of the participants responded by saying they rarely experience water shortages with a percentage of 52.7%. 25.5% of the participants never experience water shortages. This is mostly due to the reliable water supply system in UCU. 15% and 21.8% of the participants experience water shortages.



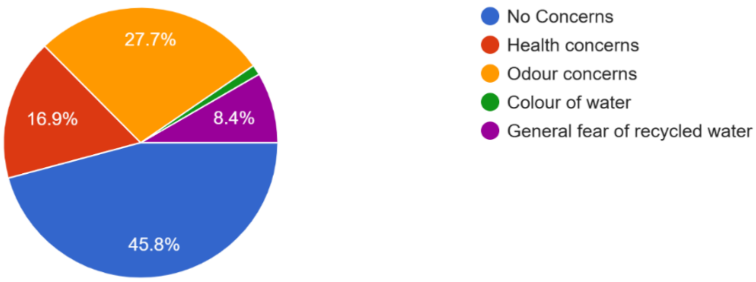
Question 6: was aimed at determining the toilet user awareness of the UCU activated sludge treatmetn plant. Majority of the participants were aware of the existance of the activated sludge treatment plant in UCU. This is largely because of the fact that the plant is located on campus grounds and is visible to all users of the Tech Park gate.



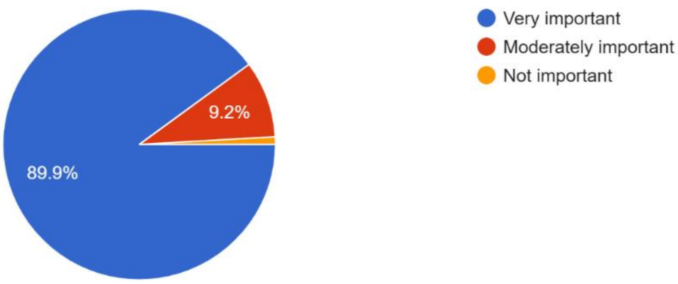
Question 7: Here, the participants were engaged to determine their perception on the use of treated wastewater effluent (non-potable water) for non-potable applications, more specifically flushing in toilets and urinals. Out of the 109 responses, 81% were in support of the use non-potable water to flush in toilets, in the University. 18.3% of the participants were not in support. The next question is to find out why they might not accept to use non-potable water to flush in toilets.



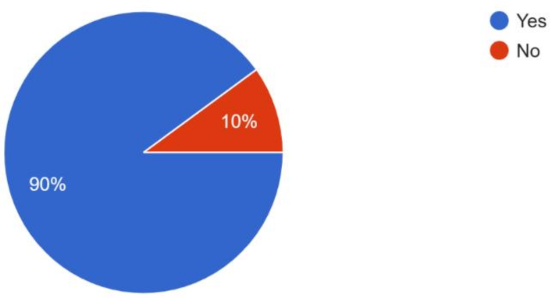
Question 8: this question focused on determining the possible concerns of toilet users in UCU about the use of reclaimed wastewater effluent to flush in toilets.



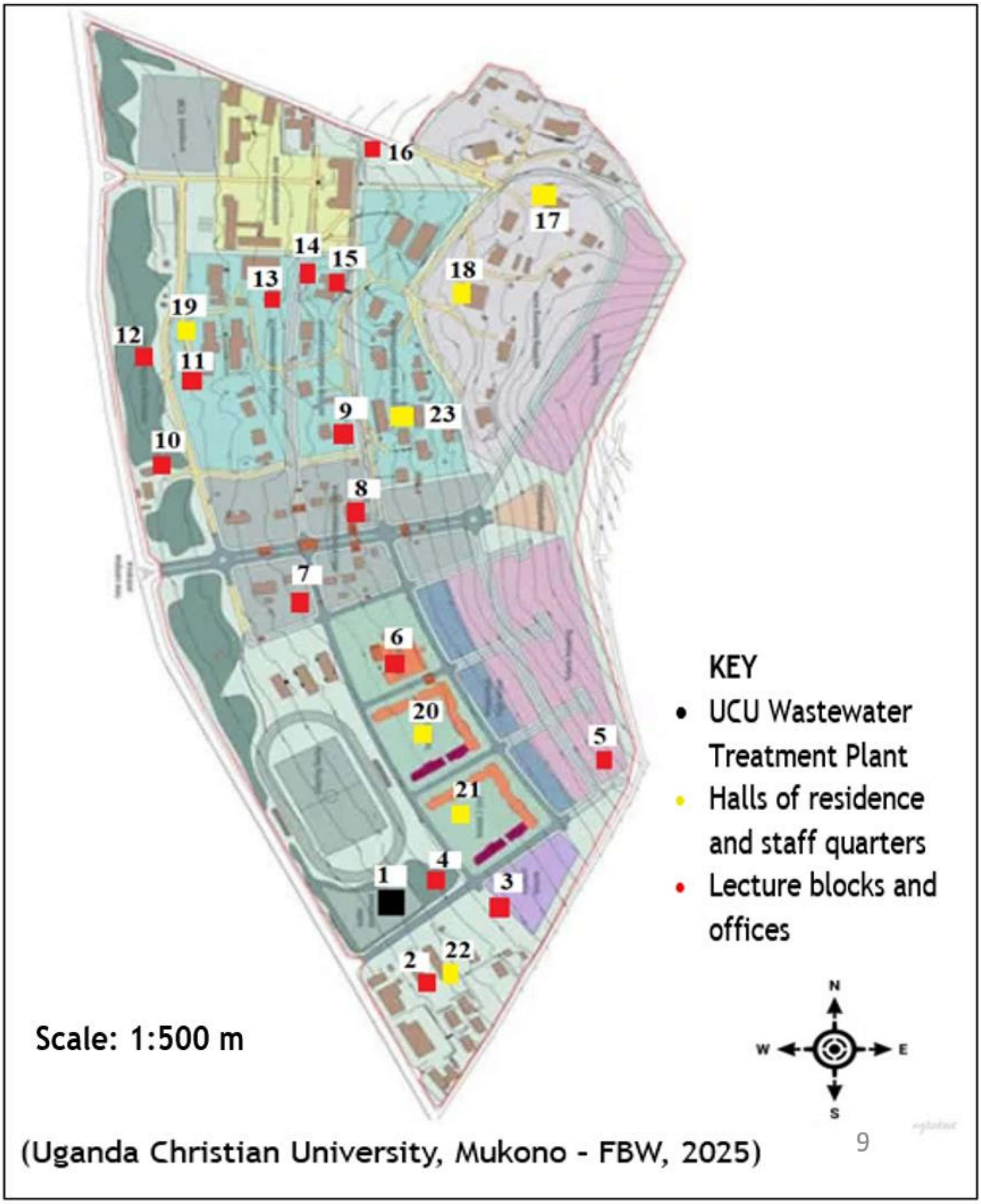
Question 9: this question asked the participants about their opinions on the reliability and imporance of the current flushing systems in UCU



Question 10: From the survey, it was determined that 90% of the total 110 participants are in support of a wastewater recycling system.



A Map of Uganda Christian University showing the positions of the different washrooms with respect to the activated sludge treatment plant.



4.3 POPULATION PROJECTIONS

Year	Number	Population Growth rate
2019	6605	0
2020	5951	-0.110
2021	6774	0.121
2022	6789	0.002
2023	6981	0.028

(Omonya, 2025)

Population growth rate = $\frac{\text{Current population} - \text{Previous population}}{\text{Current population}}$

Say, 2019

Population growth rate = $\frac{5951 - 6605}{5951}$

Population growth rate = -0.110 (the population growth from 2019 to 2020 is -0.110)

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The findings from testing the secondary wastewater effluent show that out of the total six parameter tested, that is to say, turbidity, pH, color, E. coli, total coliforms, and BOD_5, three parameters (turbidity, E. coli, and total coliforms) were found non-compliant with the required quality for non-potable water for toilet and urinal flushing.

Data collected from the first objective was used to input into design calculations. The particles to be polished out from the effluent were characterized and this led to the determination of the subsequent design inputs such as the effective size of sand particles, the filter bed depth, and filtration rate to mention a few. It was determined that two depth filter were required to polish the effluent using a design calculation from the Wastewater Engineering: treatment and resource recovery design manual.

A non-potable water distribution and transmission system was designed using EPANET software and Grundfos software. The input data for the design of the non-potable water distribution system was collected using trilateration method where Handy GPS app was used to collect data of the layout of the conduits used to distribute potable water in the University.

A cost benefit analysis was conducted which concluded that the entire wastewater reuse system (effluent filtration system and non-potable water distribution system) will cost a sum of UGX. 160,373,552.5. considering a discount factor of 11%, the project will have a payback period of 2 years,4 months, and 24 days.

5.2 Recommendations

Recommend that a chemical treatment be incorporated into the already existing activated sludge treatment system units to ease polishing the wastewater effluent and reduce suspended matter.

Further research should be conducted on the UCU secondary effluent to determine the seasonal variations of the effluent in the dry and wet season. Also to determine the effect of weather changes on the quality of the effluent.

Further research should also focus on the hydraulic aspects of the non-potable water distribution system. This will aid in the cost benefit analysis by reducing the potential number of system components like pipes and joints that contribute to the high cost of the project.

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APPENDICES

UGANDA CHRISTIAN UNIVERSITY

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FACULTY OF ENGINEERING, DESIGN, AND TECHNOLOGY
Department of Engineering and Environment

ENVIRONMENTAL QUALITY LABORATORY

CERTIFICATE OF ANALYSIS

Certificate Number: EQL25012SE1	
Sample: Water Sample	**Sample ID No.:** EQL/23/09/1008, 1543
Sample Description: Said to be "Effluent from UCU Waste Water Treatment Plant"	
Party's Ref No: Nil	**Certificate Issue Date: 26th September 2025**
Client Name & Address: 1. Paul and Dominic **Physical Address:** UCU, Mukono **Client's Contact** **Phone No.:** +256 785 195565	Job Code: : Effluent Test Sample Received On : 23rd September 2025 Date of Testing : 23rd September 2025 Completion Date : 24th September 2025
Sample Condition:	Liquid sample packed in a 1.5 Liter plastic bottle

SN	Test Parameter	Units	Test Results		Specification as per: *The National Environment (Standards-for Discharge-of Effluent into Water or Land) Regulations 2020*	Test Methods
			Morning	Afternoon		
1	Turbidity	NTU	18.2	34.9	N/A	HACH 8195
2	pH value	-	9.1	9.2	5.0 - 8.5	US ISO 10523
3	E. Coli	CFU/100ml	>400	>400	<400	Colilert-18/APHA-9222B
4	Total Coliform	CFU/100ml	>400	>400	<400	APHA Method 9222
5	Color	PtCo	8	2.3	≤50	HACH 8025
6	BOD_5	mg/l	4.269	4.269	<5	APHA 5210B

Remarks: The tested sample is in compliance with only ONE parameter (color), All the other physio-chemical and bacterial parameters are above recommended values for effluent discharge.

Reviewed & Authorized by:

Eddie Ojara
Laboratory Instructor

Head of Department's Stamp

UGANDA CHRISTIAN UNIVERSITY
H.O.D
26 SEP 2025
DEPARTMENT OF ENGINEERING AND ENVIRONMENT

Figure 23: Raw effluent quality results

Figure 24: Figure 8: shows student 1 collecting an effluent sample

Figure 25: shows student 2 collecting an effluent sample

Figure 26: shows effluent samples mixed with reagents in BOD bottles

Figure 27: A student collecting effluent in a bucket to determine the flowrate.

Figure 28: The UCU activated sludge treatment plant effluent discharge point.

Table 19: UCU effluent quality primary data

SN	Test parameter	Units	Afternoon data	Evening data	The National Environment (Standards-for Discharge of Effluent into Water or Land) Regulations 2020	PUB guidelines	Test Method
1	Turbidity	NTU	18.2	34.9	N/A	<2	HACH 8195
2	pH value	-	9.1	9.2	5.0 - 8.5	6.0 -9.0	US ISO 10523
3	E. Coli	CFU/100ml	>400	>400	<400	Non detectable	Colilert-18/APHA9222B
4	Total Coliform	CFU/100ml	>400	>400	<400	<10	APHA Method 9222
5	Color	PtCo	8	2.3	≤50	<15	HACH 8025
6	BOD_5	mg/l	4.269	4.269	<5	<5	APHA 52108

Table 20: Secondary data obtained from the UCU activated sludge treatment plant.

Date	Turbidity (NTU)	Color (PtCo)	pH	E. Coli (CFU/100mL)	Total coliforms (CFU/100mL)	BOD_5 (mg/L)
18-Nov-23	…	…	6.76	…	0	15.26
16-Apr-20	…	…	6.69	21,000,000	…	145.5
10-Aug-19	…	…	6.53	0	…	558
7-May-19	…	…	7.55	7,700	…	19.8
18-Apr-19	…	…	7.03	0	…	10.8
13-Feb-19	…	…	7.37	180	…	45
29-Nov-17	…	…	7.19	2	…	27.6
26-Oct-16	…	…	7.4	2,400,000	…	39.9
15-Feb-15	…	…	7.79	35,000	…	29.1
7-Nov-14	…	…	3.6	0	…	20.9

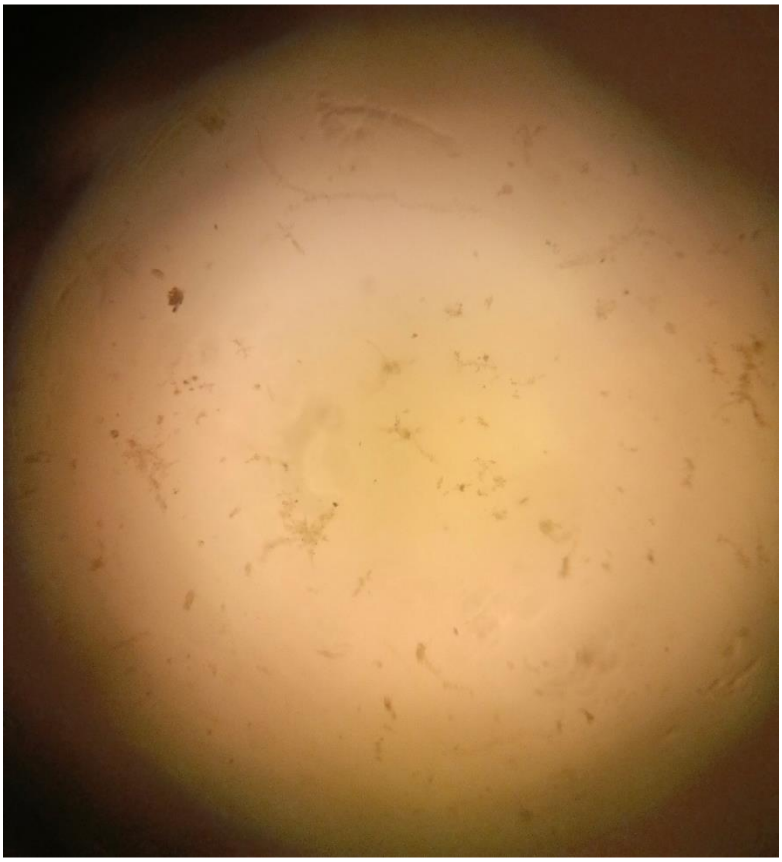

Figure 29: A microscopic image of effluent particles

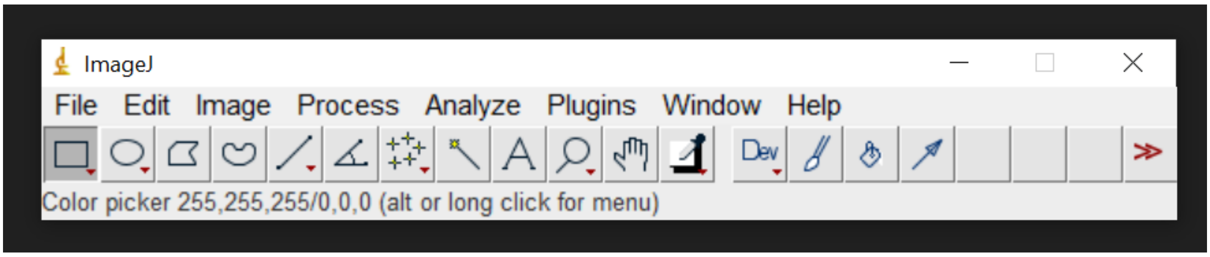

Figure 30: A screenshot of the Image J software user interface

Table 21: Filter influent Particle sizes for Image 1

No.	Area (μm^2)	Mean (μm)	Min (μm)	Max (μm)	Angle (°)	Length (μm)
1	5.719	137.244	113.808	164.354	116.495	46.672
2	7.312	178.092	116.096	191.111	37.164	68.351
3	9.281	112.908	90.494	128.416	164.745	74.111
4	5.75	118.909	101.382	131.31	96.892	45.831
5	4.531	175.094	153.809	187.011	-48.086	36.115
6	6.75	144.39	121.442	170.667	158.791	53.901
7	6.078	133.852	124.309	140.43	12.208	48.471
8	4.75	101.082	93.646	106.95	149.036	37.901
9	5.953	135.441	106.927	154	-34.485	47.466
10	9.031	155.491	143.225	162.958	173.331	72.113

Average particle size for Image 1

= (46.672 + 68.351 + 74.111 + 45.831 + 36.115 + 53.901 + 48.471 + 37.901 + 47.466 + 72.113)/10

= 53.0932 μm

Table 22: Filter influent Particle sizes for Image 2

No.	Area (μm^2)	Mean (μm)	Min (μm)	Max (μm)	Angle (°)	Length (μm)
1	7.828	108.128	91.705	119.23	-53.451	62.551
2	7.984	110.365	93.311	135.07	143.287	63.775

No.	Area (μm^2)	Mean (µm)	Min (µm)	Max (µm)	Angle (°)	Length (µm)
3	5.688	92.819	63.364	121.667	151.881	45.353
4	5.156	141.929	125.983	153.973	176.163	41.092
5	4.078	93.096	75.76	106.603	-23.604	32.466
6	7.406	148.714	117.256	161.476	163.672	59.135
7	6.156	107.11	85.139	124.333	100.996	49.152
8	5.406	59.111	40.551	75.85	172.504	43.118
9	3.938	76.024	63.145	84.89	108.795	31.426
10	6.875	85.783	72.3	108.958	165.203	54.818

Average particle size for Image 2

= (62.551 + 63.775 + 45.353 + 41.092 + 32.466 + 59.135 + 49.152 + 43.118 + 31.426 + 54.818)/10

= 48.2886 µm

Table 23: Filter influent Particle sizes for Image 3

No.	Area (μm^2)	Mean (µm)	Min (µm)	Max (µm)	Angle (°)	Length (µm)
1	9.438	100.606	48.389	135.681	-67.475	75.375
2	11.844	144.124	123.719	160.544	135.802	94.673
3	5.094	145.005	129.495	158.914	163.909	40.59
4	5.438	109.225	73.094	134.818	9.788	43.381
5	4.609	150.439	138.075	171.763	105.972	36.795
6	4.984	138.643	124.315	146.071	127.338	39.776
7	5	108.218	89.213	123.242	-167.88	39.889
8	3.656	157.501	140.443	174.949	-16.723	29.106
9	8.062	68.941	57.4	79.468	153.485	64.399
10	6.594	60.473	36.158	77.431	144.383	52.588

Average particle size for Image 2

= (75.375 + 94.673 + 40.59 + 43.381 + 36.795 + 39.776 + 39.889 + 29.106 + 64.399 + 52.588)/10

= 51.6572 µm

Table 24: GPS data for the transmission pipe system

	Eastings (m)	Northings (m)	Altitude (m)	Length (m)	remarks
1	471280.993	39037.346	1276.51	0	Reservoir
2	471240.667	38890.804	1259.12	153	School of Business Road
3	471146	38882	1243	95	End road to Anykira gate
5	470959.276	38852.802	1217.27	189	Source (WWP)
				437	

Table 25: GPS data for distribution system

Location	Easting(m)	Northing (m)	$L=\sqrt{((E_2-E_1)^2+(N2-N_1)^2)}$ (m)	Elevation (m)
Source WWP	470959	38852	0	1217.27
WWP Gate	470988	38870	34	1230
Opposite eng Faculty	471044	38870	56	1231
Opposite Foot Path	471097	38876	54	1236
End Road	471146	38882	50	1243

Location	Easting(m)	Northing (m)	$L=\sqrt{(E_2-E_1)^2+(N_2-N_1)^2}$ (m)	Elevation (m)
Ben Bella Studios	471178	38865	37	1254
Ben Bella	471213	38885	41	1261
Incinerator	471241	38923	48	1264
Next to school of business road	471240	38890	33	1259
Reservoir/tank	471280	39037	152	1276
Total length			**443**	
From Ankira small gate to Archives				
End road	471146	38882	0	1243
Opposite Nsibambi	471137	38931	50	1245
Opposite Green House	471136	38980	49	1241
Opposite Sabiti	471140	39028	49	1246
Opposite DH	471142	39075	47	1246
Opposite Firewood	471150	39124	50	1242

Location	Easting(m)	Northing (m)	$L=\sqrt{(E_2-E_1)^2+(N2-N_1)^2}$ (m)	Elevation (m)
Opposite Guild	471158	39173	50	1243
Opposite Library	471175	39218	49	1244
Opposite Library	471196	39264	51	1243
Opposite N block	471213	39309	49	1247
Opposite Comp Lab	471227	39354	48	1248
Near Allan	471246	39398	47	1252
Opposite. Archives	471298	39410	54	1257
Total length			**441**	
Through Bishop tucker to old pitch				
Opposite. Bishop Tucker	471296	39459	0	1248
Near Bishop Tucker	471279	39439	27	1239
Opposite. Bishop tucker Entrance	471274	39536	98	1237

Location	Easting(m)	Northing (m)	$L=\sqrt{(E_2-E_1)^2+(N2-N_1)^2}$ (m)	Elevation (m)
Opposite George	471232	39564	51	1235
Opp. Old pitch	471189	39593	52	1229
Gate(W)	471161	39613	35	1226
Total length			263	
Along Canteen area				
Opposite. Nkoyoyo parking	471173	39543	0	1231
Opposite Law faculty	471147	39501	50	1228
Opposite Save the mothers	471104	39474	51	1229
Opp. Canteen toilet	471085	39428	50	1227
Opposite ICMI	471073	39380	50	1233
Lib Rise	471060	39329	53	1230
Opposite main gate	471044	39279	53	1231

Location	Easting(m)	Northing (m)	$L=\sqrt{(E_2-E_1)^2+(N2-N_1)^2}$ (m)	Elevation (m)
Opposite Basket court	471027	39223	59	1230
Opposite Sport toilet	471017	39180	45	1233
Opposite power station	471065	39159	53	1239
Total length			**419**	
Road to Engineering faculty				
Opposite DH	471065	39113	0	1235
Beginning of sabiti	471051	39059	56	1236
end of sabiti	471044	39008	53	1236
Opp. Nsibambi	471073	38956	60	1234
Opp. Wash Bay	471073	38907	49	1233
Opp. Faculty	471042	38872	47	1233
Total length			265	
To faculty of Agriculture				
Opp. WWP	470993	38859	0	1226
Tech gate	470948	38849	47	1225
Carpentry	470936	38800	51	1224

Location	Easting(m)	Northing (m)	$L=\surd((E_2-E_1)^2+(N2-N_1)^2)$ (m)	Elevation (m)
Faculty agricultural sciences	470932	38750	51	1223
Total length			149	
Along library rise opposite computing Library	471150	39315	0	1234
End of the road between library and N block	471198	39270	150	1247
Total length			**150**	
Road from Computer lab (N block) to canteen area				
Computer lab	471227	39354	0	1248
Near K block	471183	39382	53	1237
Opp Academic`s offices	471081	39407	105	1228
			158	

Source: Handy GPS

UGANDA CHRISTIAN UNIVERSITY
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FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY
Department of Engineering and Environment

Date: 11th July 2025

TO WHOM IT MAY CONCERN

Dear Sir/Madam,

RE: INTRODUCTORY LETTER FOR LOKWANG AND BWIRE PAUL WAFULA

This is to introduce the above-named students of Uganda Christian University, pursuing a ***Bachelor of Science Degree in Civil and Environmental Engineering,*** currently in Fourth Year Semester One.

Mr. Lokwang and Bwire PAUL are working on a research project of assessing the use of effluent for water reuse for the provision of flushing water for sanitary appliance

The information obtained is entirely for educational purposes, not shared for public consumption, and will be treated with the highest level of confidentiality.

Any help rendered to them will be highly appreciated as they go through their learning process.

In case of any questions, contact the undersigned.

Thank You

Yours sincerely,

UGANDA CHRISTIAN UNIVERSITY
H.O.D
11 JUL 2025
DEPARTMENT OF ENGINEERING AND ENVIRONMENT

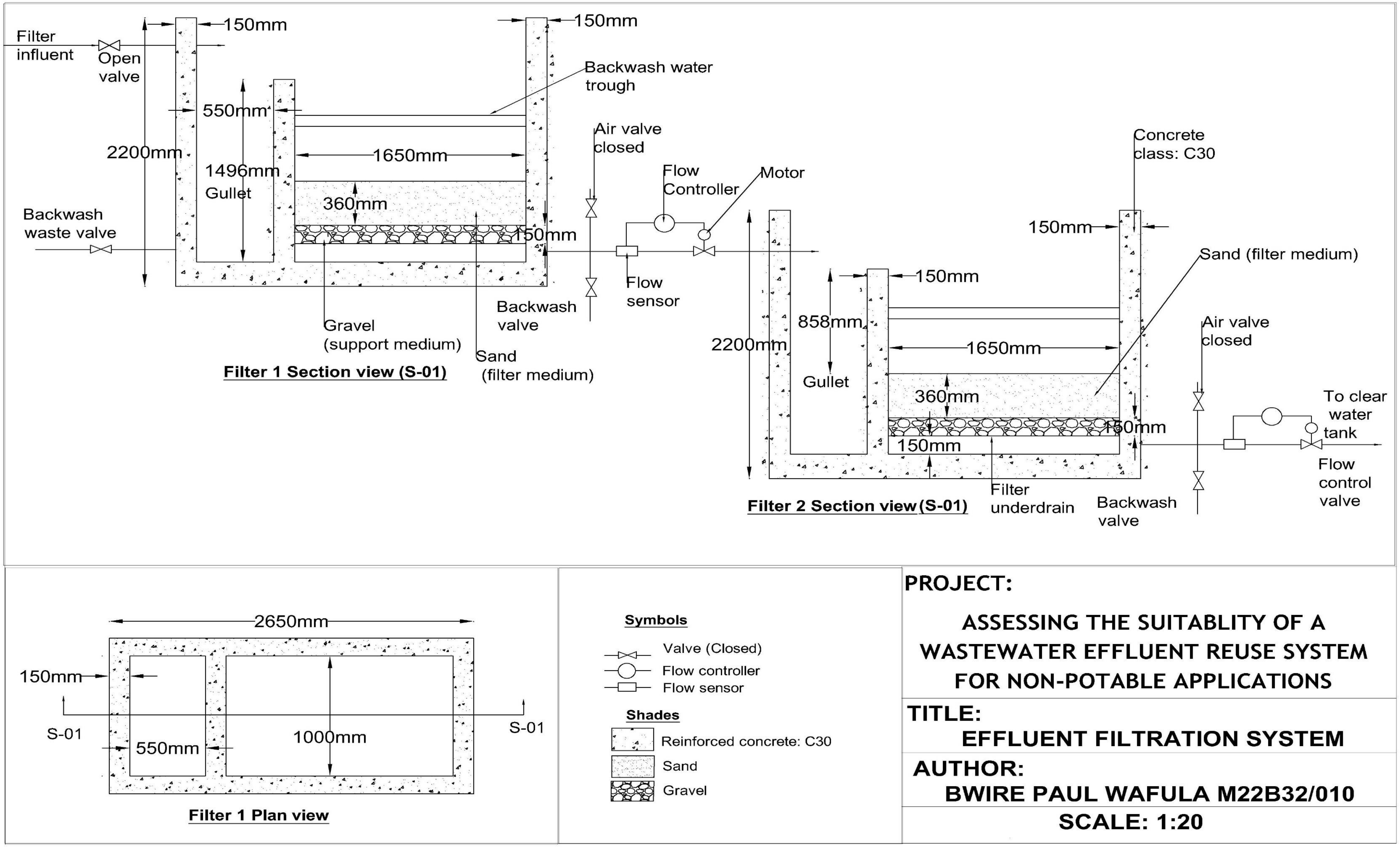
Mwanje

Mr. Tom More Mwanje
Head of Department, Engineering and Environment
Uganda Christian University
email : tmwanje@ucu.ac.ug or ***contact***: 0785-057593

A Complete Education for A Complete Person P. O. Box 4, Mukono, Uganda Tel: (+256) 312 350 830, (+256) 312 350 837
Email: technology@ucu.ac.ug Web: www.ucu.ac.ug Founded by the Province of the Church of Uganda. Chartered by the Government of Uganda

Figure 31: An introductory letter used to request for information.

APPENDIX


Filter influent
Open valve
150mm
150mm
Backwash water trough
550mm
2200mm
1650mm
1496mm
Gullet
360mm
Backwash waste valve
150mm
Air valve closed
Flow Controller
Motor
Flow sensor
Backwash valve
Gravel (support medium)
Sand (filter medium)
Filter 1 Section view (S-01)
Concrete class: C30
150mm
Sand (filter medium)
150mm
858mm
2200mm
1650mm
Gullet
360mm
Air valve closed
150mm
150mm
To clear water tank
Flow control valve
Filter underdrain
Backwash valve
Filter 2 Section view (S-01)
2650mm
150mm
S-01
S-01
550mm
1000mm
Filter 1 Plan view
Symbols
Valve (Closed)
Flow controller
Flow sensor
Shades
Reinforced concrete: C30
Sand
Gravel
PROJECT:
ASSESSING THE SUITABLITY OF A WASTEWATER EFFLUENT REUSE SYSTEM FOR NON-POTABLE APPLICATIONS
TITLE:
EFFLUENT FILTRATION SYSTEM
AUTHOR:
BWIRE PAUL WAFULA M22B32/010
SCALE: 1:20