INVESTIGATING THE USE OF WATER LETTUCE FOR THE TREATMENT OF WASTEWATER AT KAKOBA TREATMENT PLANT

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

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ABSTRACT

This research focuses on supplementing the wastewater treatment processes at Kakoba Waste Stabilization ponds using phytoremediation (using aquatic plants). There has been a positive response in harnessing the technology of plants to clean wastewater. Improperly treated domestic wastewater is quite harmful to the environment. Scientists are intricately studying this approach and the realization is its cost effectiveness, ecofriendly attributes and ability for it to run with no need for energy. The major aim of this specific study is to investigate how effectively Water Lettuce remove nutrients, and BOD from secondary treated wastewater. It put a test the polishing abilities of domestic wastewater. Treatment was executed in two troughs, one tub without the water lettuce was taken as the control unit and the second labeled the treatment unit that had the water lettuce. The troughs were of dimensions $0.7m \times 0.5m \times 0.3m$. The sewage samples were assessed for three pollutants, T.N, T.P and BOD. After 10 days, the results were impressive from the treatment, they showed that water lettuce removed 80.93% and 77.90% removal efficiency of T.P and T.N respectively. After 15 days. Because the effluent from the treatment unit met the discharge standards for T.N, T.P and BOD_5 it was safe to be released into the environment.

This study focused on optimizing the existing infrastructure in a to meet the present demands in a cost effective and environmentally sustainable manner.

DECLARATION

I, PRECIOUS MIREMBE, hereby declare that this is my original work, is not plagiarized and has not been submitted to any other institution for any award.

PRECIOUS MIREMBE

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Signature: ……………………………………….. Date: ………………………………………………

APPROVAL

This research project has been submitted for examination with my approval as the University supervisor.

Signature: ……………………………………….. Date: ……………………………………………….

Eng. Robert TUSIIME

ACADEMIC SUPERVISOR.

DEDICATION

This project is dedicated to my family and friends, whose love and encouragement provided a strong foundation throughout this endeavor. Their unwavering belief in me and their willingness to stand by my side were a constant source of strength, reminding me of the importance of diligence and commitment in achieving one's goals.

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GLOSSARY OF TERMS AND ACRONYMS

AP	Anaerobic Pond
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
FP	Facultative Pond
HRT	Hydraulic Retention Time
MP	Maturation Pond
NWSC	National Water and Sewerage Corporation
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
WL	Water Lettuce
WSP	Waste Stabilization Ponds
WWTP	Wastewater Treatment Plant

CHAPTER ONE: INTRODUCTION

1.1 BACKGROUND

The ideal wastewater treatment is one that delivers top-notch quality effluent while keeping costs low and operational demands minimal (Mahassen M., 2018). Wastewater treatment is important for the reduction of contaminants and pollutants of natural water sources. The quality of water in these bodies is significantly affected by the discharge of poorly treated wastewater effluent into these bodies from the different institutional wastewater treatment plants.

The high energy demands of WWTP have emerged as a significant financial burden, impacting their overall economic viability (Li, 2017). This highlights the need for exploring more energy efficient treatment processes to minimize operational costs. Large scale, conventional sewage treatment plants can have significant carbon footprint. An average carbon footprint of 0.78kg CO_2 equivalent per cubic meter was discovered by a study conducted in India (Singh et al., 2016). As a response to this predicament, many countries are embracing low cost environmentally friendly technologies. An example is using aquatic plants in the phytoremediation process for treatment of wastewater.

Wastewater Stabilization Ponds Technology is another one of the most convenient and vastly growing treatment methods for developing countries (where using the conventional method is costly) (Belay D, 2022). Because of the nature of processes this mode of treatment entails, it’s even more favorable for countries in the tropical region (regions characterized by consistently mild to warm weather throughout the year). This mode of treatment is natural, self-sufficient, possesses a straight-forward design, minimal operator responsibility to operate the system hence labour expenses are minimized.

Phytoremediation is the technology that harnesses plants in remediating soils, water, sediments and sludge. These plants are outfitted with mechanisms for adsorption and translocation of nutrients from the environment. The plants are harvested and can be deposited in various ways for example, vermicomposting done with the help of worms producing a nutrient rich compost suitable for gardening (Lumbricus rubellus and red wigglers) (The Worm Composting Company, 2023)

Meeting treatment and effluent discharge standards has proven to be a significant challenge, particularly in developing countries where there is deficiency of technology and qualified personnel (Letshwenyo W., 2018). In developing world, waste stabilization pond (WSP) has been widely used especially where land is abundant, and climate is favorable especially temperature and sunlight. Uganda is one of the countries in the tropical Region that uses Wastewater Stabilization as a treatment method for domestic waste water. However, many of these systems have been performing below the required standards (Letshwenyo W., 2018). The causes are inadequate operation and maintenance practices, and the buildup of sludge in the ponds among many other factors (Letshwenyo W., 2018). Effluent water samples were analysed for; Phosphate mean concentration levels (NEMA-5mg/l) Phosphate mean concentration levels; NO_3 was 10 mg/l; NH_4 concentration was 385.33 mg/l (NEMA -10MG/l); Colour 1627.67 TCUs (NEMA – 50 TCU); Turbidity – 186.63NTUs (NEMA).

1.2 PROBLEM STATEMENT

Mbarara Municipality's Kakoba waste stabilization ponds have been performing below the required standards due to chronic buildup of sludge in the ponds (Letshwenyo W., 2018). Limited maintenance budgets restrict proper desludging, allowing sludge to accumulate over time. This coincides with a growing population in Mbarara, placing a continuously increasing burden on the wastewater treatment system's capacity. Despite desludging efforts in June 2023, the sludge problem persists, indicating a potential need for alternative or more frequent management strategies.

The consequences of this situation are severe. They include environmental consequences; water pollution from the high organic content in the wastewater effluent, algal blooms due to increased nutrient levels in water bodies (River Rwizi where the effluent is deposited), the foul smell radiating from the waste stabilization ponds, public health concerns include disease outbreaks for example, typhoid dysentery; health risks from pollutants for example, digestive issues. Ineffectively treated wastewater poses a significant threat of environmental contamination. Untreated or inadequately treated wastewater can harbor harmful pathogens, jeopardizing public health in the surrounding communities. This situation necessitates a prompt and effective solution to safeguard public health, environmental quality, and the long-term sustainability of the wastewater treatment system.

1.3 OBJECTIVES FOR STUDY

1.3.1 MAIN OBJECTIVE

- To investigate the use of water lettuce in removal of nutrients from wastewater at Kakoba Treatment Plant.

1.3.2 SPECIFIC OBJECTIVES

1. To determine baseline conditions of removal rates of BOD, TN and TP in the existing maturation pond.
2. To determine the effectiveness of water Lettuce in removing BOD, TN And Total Phosphorous.
3. To evaluate how much water lettuce is most effective in optimizing removal of BOD, TN and TP.

1.4 RESEARCH QUESTIONS

1. What are the baseline conditions of removal rates of BOD, TN and Total Phosphorous?
2. What is the effectiveness of water Lettuce in removing BOD, TN And Total Phosphorous?
3. How much water lettuce is most effective in optimizing removal of BOD, TN and TP?

1.5 JUSTIFICATION

Nutrient removal from the wastewater generated is important to protect the receiving water bodies from eutrophication. Despite desludging of the ponds, the effluent from the ponds does not meet the discharge standards which is detrimental to the environment.

Since Water Lettuce is famous for its phytoremediation ability, it has the ability to break down pollutants like BOD and reduction of nutrients in wastewater through its different parts (roots and leaves). The cumulative effort of the invasive plant contributes enhancing the treatment process in the maturation pond. It provides an additional attribute of breaking down BOD.

Water lettuce also has the likelihood for accumulating the nutrients it takes up (Khater and Ali, 2022). This stored biomass is then harvested and prospectively employed as a fertilizer hence fulfilling the objective of sustainability through resource recovery.

Aquatic plants are simple in operation, low maintenance and low cost in operation and are self-sustaining. They are suited for the atmosphere given they thrive most in tropical climates which describes the climate of Kakoba.

They provide a technology favorable for the limited budgets given that solely depend on natural processes for nutrient uptake and BOD reduction (removal of pollutants). This is in sync with the goal of probing low-energy and conceivably low-cost alternatives for supplementing unconventional wastewater treatment processes. The systems of aquatic plants can also operate at higher loading rates.

CHAPTER TWO: LITERATURE REVIEW

2.1 INTRODUCTION

2.2 WASTEWATER

This refers to used water that contains a mixture of both organic and inorganic material that is harmful to the environment (Shah, 2017). It simply means water that is not clean because it has been used in households, factories, runoff from farms, and others. Wastewater is polluted water, and its pollutants are from both point sources and dispersed sources(R L and Mehta, 2020). It is dangerous to the environment when released without treatment.

Point sources: this simply means a single identifiable source of pollution for example drain or a pipe (usually industrial wastewater effluent being discharged by a pipe into a river)

Dispersed/ non-point sources: Also known as diffuse pollution simply mean inputs that happen over a large/ wide area and can be zeroed down to one source. They are usually attributed to a specific land use for example urban land use, Agricultural land use and factory land use and others. Diffuse pollution is executed by agents like storm water that greatly impact the water quality of the different waterways they flow into (EPA, 2021).

Wastewater from the different sources affects the quality of surface and ground water this is as a result detrimental to human health and the health of the environment at large(Madhav *et al.*, 2019). Therefore, wastewater management and treatment are a concern for the globe, and is also a key factor of the water cycle.

2.2.1 BLACK WATER

Black water refers to wastewater from toilets that contains human waste, urine, and toilet paper(Geary, 1998). It's considered highly contaminated with pathogens and bacteria that can cause illness. Black water can also contain harmful gases like methane and hydrogen sulfide, which can be dangerous in high quantities.

The various technologies for the consumption and or reuse of waste water effluent include macrophyte pond, aquaculture, irrigation, discharge for recharge to a water body or ground water (Elizabeth T., 2014). The technologies involved in generating black water include, pour flush toilets, Dry Cleansing materials, cistern flush toilets.

The blackwater generated by the users connects to the semi-centralized treatment amenity by a (gravity) simpler sewer network.

National Water and Sewerage Corporation the body incharge of treatment of wastewater in Uganda employs two major ways of treatment of wastewater. These include,

- **Conventional treatment methods:** involve a combination of both physical, chemical and biological processes to degrade and remove solid particles and other harmful substances from sewage.
- **Non-conventional methods** employ biological processes to remove harmful substances from the sewage. These mainly take place in stabilization ponds.

2.3 WASTEWATER PARAMETERS

These refer to the measurable characteristics of wastewater that help determine the quality of wastewater before it is discharged to the environment. They are classified into physical, chemical, and biological quality parameters. They sometimes depend on the source of generation.

The Physical parameters include color, odor and temperature, suspended solids with regards to the current makeup of the environment we focus on the main parameters of wastewater. These are BOD, Total Nitrogen, Total Phosphorous, Heavy metals, Total Suspended Solids, Chemical Oxygen Demand (Alumichem, 2023). These parameters must be reduced and controlled before the wastewater eluent is released into the environment. They are explained as below.

2.3.1 Colour

Colour in wastewater is mainly from municipal contamination and industrial impurities of iron and manganese and other corrosive products. Organic matter present in water is usually associated with humus, minerals and other materials which are natural impurities and corrosive products.

The variability of color within the sample for the sewage effluents in Kakoba was still very low (CV; 14.67%). The mean color of the sewage effluents was (1627.67˚C). However, the color (TCUs) of the sewage effluents were higher than the EPA (20 - 150), NWSC, 500 [16] and NEMA (300) standards. (Atwebembeire, 2019). Colour does not vary during the wet or dry season because the runoffs from the rain does not affect the effluent because the water is piped directly to the treatment plant.

2.3.2 Biochemical Oxygen Demand (BOD)

BOD refers to the amount of dissolved oxygen needed by aerobic biological organisms to break down the organic material present in the water over a period of 5 days at a temperature of 20°C (Alumichem, 2023). This specific parameter indicates the short-term impact on the oxygen levels of the receiving water body. It measures the amount of organic contamination in the water (the organics that can be biologically oxidized).

High BOD levels lead to decrease of oxygen in receiving water bodies hence death of aquatic life. physical, chemical, and biological methods are employed to cater for removal of this parameter.

2.3.3 Nitrates

Nitrates is a form of nitrogen and vital nutrient for growth, reproduction, and survival for organisms. Nitrate is a very important parameter because it estimates the organic pollution in a particular area, and it represents the highest oxidized form of nitrogen. Nitrate is one of the very common contaminants in the ground and surface waters.

Nitrates occur naturally in source water because of decaying plants. Agricultural sources of nitrates include livestock waste matter and chemical fertilizers. Nitrate concentrations exhibited extremely very high variability within samples of Kakoba (122.47%) sewage effluents and mean values of (10 mg/l) effluents. The mean NO_3 levels were higher than the NWSC maximum permissible limit (5 mg/l) but below the EPA standard (50 mg/l) (Atwebembeire, 2019).

2.3.4 Total Phosphorous (Total-P)

Total phosphorous refers to the measure of all the phosphorous in the wastewater both in particulate form and soluble form. Phosphorous translates into increased growth of algae in the stream. Causing competition with aquatic life hence chocking oxygen in the water source leading to Eutrophication changing the whole ecosystem.

2.3.5 pH

pH is the concentration of hydrogen ions and is calculated by the negative logarithm of the hydrogen ion ($H+$). pH represents an important characteristic of water and small changes in its level can disorganize the quality of water making it unsuitable for use as it influences the availability of micronutrients as well as trace metals.

High pH values also increase the toxic nature of other pollutants in the river, basing on an example of ammonia which is much more toxic in alkaline water than acid due to free ammonia NH_3. pH is also an important parameter in evaluating the acid-base balance of water.

Thus, pH of valve of 7 is neutral, a pH less than 7 is acidic, and a pH greater than 7 represents base saturation or alkaline. Kakoba sewage effluents exhibited very low values within sample variability of pH (CV; 3.3% - 5.3%) (Atwebembeire, 2019).

2.3.6 Temperature

Temperature measured in ˚C is a key factor in biological activity and microorganisms can be psychrophilic, mesophilic, and thermophilic. Aquatic organisms thrive only within specific temperature ranges. Temperature exhibited very low variability within samples of sewage effluents (CV; 18.36%) with statistically insignificant variation of mean temperature in sewage (25.05˚C) (Atwebembeire, 2019).

2.3.7 Biochemical Oxygen Demand (BOD)

- **Concept:** BOD is a broader term that refers to the amount of dissolved oxygen required by microorganisms to decompose organic matter in water over a specific period of time.

- **Timeframe:** The timeframe for BOD can be variable, but it's not typically specified unless mentioned alongside the test method.
- **Measurement:** BOD is a theoretical value and cannot be directly measured. Instead, it's estimated by measuring the remaining dissolved oxygen after a period of incubation with a sample of the water being tested.

BOD5 (5-day BOD)

Concept: BOD5 is the most common way to measure BOD. It specifically refers to the amount of dissolved oxygen consumed by microorganisms during a **5-day** incubation period at a standardized temperature (usually 20°C). It gives a snapshot of the overall consumption rate within a specific timeframe.

- **Standardized Test:** BOD5 is a standardized test with a defined methodology, ensuring consistency and allowing for comparison of results across different studies and locations.
- **Practicality:** BOD5 is a practical and widely used method because it provides a good estimate of the biodegradable organic matter present in water, which can impact oxygen levels and aquatic life. It offers a balance between accuracy and testing time.

2.4 WASTEWATER TREATMENT

These refer to infrastructure which safeguards health of the public by removing impurities from wastewater before it is re-introduced into various parts of the environment such as, aquifers, rivers, lakes and swamps (Jerry A, 2023).

The modern world relies heavily on a hidden network: wastewater systems. These critical infrastructures safeguard public health and the environment by collecting, treating, and disposing of wastewater. Untreated wastewater, also known as sewage, can contaminate water sources, spread diseases, and harm aquatic ecosystems (CHEMTECH INTERNATIONAL, 2021).

Components present in Domestic waste water and their risks.

- Microorganisms (viruses, pathogenic bacteria and worm eggs) which cause diseases like cholera typhoid and others.
- Biodegradable organic materials which cause oxygen depletion in water bodes leading to death of aquatic life.
- Other organic mateials forexample, detergents, pesticides , fat, oil and grease, colouring, solvents cyanide and phenol which cause toxic effects, aesthetic depletion and bioaccumulation in the food chain.
- Nutrients forexample, Nitrogen and Phosphorous, ammonium. These cause eutrophication leading to toxic effects from oxygen depletion.
- Metals including Hg, Pb, Cd, Ni, and Cu leading to toxic effects to human beings. Such effects include cancers and tumors, damage to the nervous sytem and others.
- Odour (and taste) from Hydrogen sulphide which leads to aesthetic inconviniences, stomach upset and toxic effects from air pollution.

2.4.1 WASTE STABILIATION PONDS

Waste stabilization ponds are colossal, shallow outdoor basins in which sunlight bacteria and algae synergize to purify raw sewage through natural processes (Kayombo S., 2018), This method of wastewater treatment is a biologically driven treatment approach that represents a natural and cost-effective technique of treatment (Green M., 2008).

It comprises of man-made ponds or basins that leverage naturally occurring biological processes mediated by microbial communities to breakdown and remove organic matter and pathogens from wastewater (Ghinea, 2020). In some instances, they could be designed to work as single units or configured in a series for enhanced treatment efficiency of the wastewater (Souza, 2019).

WSP offers a remarkable approach for treating wastewater in an environmentally friendly way. The treated wastewater, called effluent, can be reused for various purposes like irrigation, fish farming (aquaculture), and overall water conservation. This benefits the environment and public health. However, reusing the effluent isn't always possible. It can only be reused if it meets specific quality standards.

In cases where effluent is to be used for irrigation fish pond fertilization, only the Anaerobic and Facultative ponds are needed (Coldebella *et al.*, 2017). These are also only employed if weak sewage is to be purified before discharge to recharge the surface water sources (Kayombo S., 2018). Many countries have strict regulations due to the potential presence of harmful organisms (pathogens) in the treated water.

This is especially true for unrestricted irrigation of raw vegetables like cabbage and spinach. Therefore, whoever operates the system must closely monitor the biological and chemical components within the treatment process. This ensures the treated water meets the required standards and regulations.

Three distinct pond types are connected. They are categorized as, anaerobic, facultative, and maturation/ polishing pond. They are employed in the WSP system each with unique design characteristics that optimize the biological Treatment process occurring within.

2.4.1.1 Anaerobic Pond

These ponds are suited to receive and treat waste water that is highly organically loaded that is, the Volumetric loading >100G BOD/m³. day that is equivalent to >3000kg/ha. day for a 3m depth) (Kayombo S., 2018).

Volumetric loading is a very fundamental aspect of designing these ponds and is given by Equation 2.1,

$$\lambda_v = L_i \, {}^{Q}/_{V_a} \qquad \text{Equation 2.1}$$

Where;

L_i- Influent BOD (mg/l)

V_a- Pond of the anaerobic pond

Q- Flow rate (m^3/day)

For optimal treatment it is advised that the loading should range between; 100 – 400 g/ m^3. day. This helps sustain the anaerobic environment (Meiring et al., 1998) (Kayombo S., 2018).

These ponds luck dissolved oxygen and algae, this creates an environment suitable for anaerobic bacteria (Kayombo S., 2018). These bacteria break down organic matter into simpler compounds while releasing methane and Carbon dioxide (Kadlec, 2009). This done by sedimentation of solids and as a result anaerobic digestion (most pronounced at 15°C). This then is the birth of sludge in the anaerobic pond (Kayombo S., 2018).

It is important to neutralize acidic wastewater since the anaerobic bacteria is affected by a pH <6.2. An efficiently designed anaerobic pond can remove 40% of Organic Matter at 10°C but this efficiently jumps to 60% at 20°C (McCarty, 2011; Lettinga, 1995).

This pond typically functions as a deep (2-5 meters) entirely anaerobic environment that reduces solids and BOD. The residence time of the waste water within this pond is quite short, ranging from 1 to 7 days. HRT is calculated on the formular given in Equation 2.2 below;

$$t_a = \frac{V_a}{Q} \qquad \text{Equation 2.2}$$

The specific design parameters which include depth and detention time are determined based on the characteristics of the influent wastewater, specifically the organic loading.

Anaerobic bacteria thrive in this pond and this process effectively removes up to 60% of the BOD from wastewater. Due to their ability to handle high organic loads, anaerobic ponds are well suited for treating strong wastewaters (Elizabeth T., 2014). A summary of the percentage reductions at different temperatures compared to the initial Influent loadings is given in **Table 2-1.**

Table 2.1: Influent Loading BOD and Percentage Removal at Respective Temperatures

TEMPERATURE (˚C)	λ_v **(g/m³. day)**	**BOD removal (%)**
<10	100	40
10 – 20	20T – 100	2T+20
20 – 30	10T+100	2T+20
>25	350	70

2.4.1.2 Facultative Pond

These ponds are shallower than anaerobic ponds, 1m- 2m deep with the aim of optimizing these processes (enabling sufficient oxygen mixing to the upper layer). There are two types of Facultative ponds. These include;

- **Primary facultative**

These are ponds which take in raw wastewater. These types of units are very commonly used and studied. First models are the basis for their designs (F. J. A. da Silva, 2010).

$$L = {}^{L_0}/_{1 + k.HRT} \qquad \text{Equation 2.3}$$

$$L = L_0 e^{-k.HRT} \qquad \text{Equation 2.4}$$

Where L_0 and L are the influent and effluent BOD (mg/l)

HRT- Mean hydraulic retention time (days)

k- is the first order removal rate (day^{-}). This depends on temperature (F. J. A. da Silva, 2010).

- **Secondary facultative**

These are ponds whose sources include, anaerobic ponds, septic tanks, primary facultative ponds.

They exhibit both aerobic and anaerobic zones mainly because of the presence of surface layer that has DO. The bacteria in this pond find this zone ideal because they can take advantage of both aerobic and fermentation pathways to further decompose the organic material (Vymazal, 2015).

The Synergistic relationship between aerobic and anaerobic communities within the facultative pond facilitates significant reductions in BOD- up to 75%. Detention times within the FP are strategically controlled falling between 5 – 30 days ensuring time for wastewater treatment by both aerobic and anaerobic conditions.

2.4.1.3 Maturation Pond

They are commonly known as Finishing or Polishing Ponds (Elizabeth T., 2014). It is the final step in the treatment process of WSP systems. these ponds are designed to be ultimately aerobic. They promote the growth of aerobic bacteria that further degrade organic matter and eliminate pathogens through different mechanisms (Arias, 2014).

These ponds are the shallowest component within the WSP constructed with depths ranging from 0.5 – 1.5 meters (Vymazal, 2009). This strategic design ensures that sunlight penetrates the full depth of the pond, maximizing the photic zone for algal photosynthesis (Arias, 2014). As algae undergo photosynthesis during daylight hours, they produce DO a crucial resource for aerobic bacteria residing within the pond. However, DO levels naturally fluctuate throughout the day, reaching peak concentrations during sunlight-driven photosynthesis and declining at night due to the absence of this process (Vymazal, 2015).

On top of this, they also remove nitrogen and phosphorous and this can be amplified by strategic practices (Elizabeth T., 2014). When combined with algae and fish harvesting techniques, these ponds demonstrate remarkable capacity to remove significant portion of remaining nitrogen and phosphorous hence minimized discharge of these pollutants into the environment (Vymazal, 2015).MP are majorly designed for Removal of Pathogens.

These ponds have a liner which bar leaching. The line could be compacted earth asphalt, clay, or any other material. A protective bar is constructed around the pond's perimeter to using the excavated material during pond construction (Vymazal, 2009). This term physically bars, effectively intercepts and diverts runoff away from the pond, hence minimizing potential for erosion along the shoreline (Arias, 2014). The use of the excavated material for berm construction offers cost-effective and sustainable approach to pond protection (Kadlec, 2009).

2.4.2 IMPORTANT TERMS

2.4.2.1 Drogue

A drogue is a device or instrument used in wastewater treatment systems to measure the velocity, flow direction, and turbulence of water within ponds or tanks. It typically consists of a weighted object or float attached to a line, which is submerged into the water and allowed to move freely. By tracking the movement of the drogue over a period, operators can assess the flow patterns and hydraulic characteristics of the wastewater within the treatment system.

2.4.2.2 Pond Geometry

Pond geometry refers to the physical shape and dimensions of a wastewater treatment pond. This includes parameters such as length, width, depth, and surface area. The geometry of a pond plays a crucial role in determining its hydraulic efficiency, retention time, and treatment performance. Different geometrical configurations, such as rectangular, circular, or irregular shapes, can impact factors such as flow patterns, sedimentation efficiency, and mixing characteristics within the pond.

2.4.2.3 Sludge Accumulation Assessment

Sludge accumulation assessment involves the measurement and evaluation of the buildup of organic and inorganic solids (sludge) within wastewater treatment ponds over time (Mahassen M., 2018). This process typically includes regular monitoring of sludge depth, volume, and characteristics to assess the efficiency of sedimentation, solids removal, and overall treatment performance.

Techniques for sludge accumulation assessment may include manual sampling and analysis, sedimentation tests, sludge blanket measurement, and use of sedimentation cones or settling velocity meters. Evaluating sludge accumulation is essential for determining the need for desludging or maintenance activities to prevent operational issues and maintain treatment efficiency in the pond.

2.4.3 Factors affecting the Efficiency of Waste Stabilization Ponds

Several factors significantly influence the efficiency of wastewater treatment in stabilization ponds (WSPs). Below is a breakdown of some key factors:

2.4.3.1 Wastewater Characteristics

- **Strength:** The concentration of organic matter (measured by Biological Oxygen Demand (BOD) or Chemical Oxygen Demand (COD)) in the influent wastewater can significantly affect treatment efficiency(Singh, Singh and Singh, 2021). Higher organic loads require larger ponds or longer retention times for proper treatment by the microorganisms within the ponds (Mara M., 2004).

- **Nutrients:** The presence of nitrogen and phosphorus can impact treatment. While some bacteria in the ponds utilize these for growth, excessive concentrations cause algal blooms, potentially hindering treatment by reducing sunlight penetration and oxygen levels needed for aerobic digestion of organic matter to take place (Chen J., 2013).

- **Toxic substances:** Industrial wastewater may contain toxic chemicals that can inhibit the growth and multiplication of beneficial microorganisms in the ponds, reducing treatment efficiency (Eddy, 2014). These chemicals include, dyes, acids and others. Some of these could drastically affect the physiochemical properties of the water making it dangerous for the microbes.

2.4.3.2 Operational Factors

- **Hydraulic Retention Time (HRT):** The amount of time wastewater spends in the pond system is crucial (Anggarini *et al.*, 2015). A longer HRT allows for more complete treatment by providing more time for natural processes to occur. Factors like pond depth and flow rate influence HRT.

- **Organic Loading Rate:** This simply means the amount of organic matter entering the pond system per unit of surface area (Orhorhoro and Sadjere, 2018). Overloading the ponds with organic matter can overwhelm the natural treatment processes, leading to inefficient removal of pollutants (Mahapatra, Samal and Dash, 2022).

- **Pond Design:** Factors like depth of the ponds, configuration (series of ponds can be more efficient), and the presence of baffles (flow directors) can all influence treatment efficiency. For instance, proper depth allows for stratification, where settlement and biological processes occur at different zones within the pond. For the deeper layers, Anaerobic digestion of organic matter and aerobic digestion for the shallower zones that have oxygen from diffusion in the water column (US Environmental Protection Agency, 1983).

$$HRT = \frac{V}{Q} \qquad \text{Equation 2.5}$$

Where;

HRT – Hydraulic Retention Time (Days)

V – Volume of the wastewater treatment pond (cubic meters)

Q – Influent inflow entering the pond (cubic meters per day)

2.4.3.3 Environmental Factors

- **Temperature:**

Warmer temperatures generally promote faster biological activity by microorganisms, leading to improved treatment efficiency (Sharaf A., 2014).

- **Sunlight:** Sunlight is essential for algal growth, which plays a role in oxygen production through photosynthesis and nutrient uptake within the ponds (Chen J., 2013).
- **Wind:** Wind can help mix the pond contents and promote oxygen transfer, but excessive wind can also disrupt the settled sludge layer, potentially impacting treatment (Orr S. J., 2019).
- **pH:** The optimal pH range for the microorganisms in WSPs is slightly alkaline (pH 7-8). Deviations from this range can affect treatment efficiency by impacting microbial growth and multiplication (Hanif M. A., 2016). Hence digestion of organic matter present in the wastewater is affected.

2.4.3.4 Monitoring and Maintenance

- **Regular monitoring** of factors like influent and effluent quality, pond depth, and sludge accumulation is essential to maintain optimal performance. Early detection of issues allows for timely adjustments to operational parameters (Hanif M. A., 2016).
- **Periodic desludging** to remove excess settled solids is crucial to prevent pond capacity reduction and potential short-circuiting of flow within the system, where wastewater bypasses treatment stages (Orr S. J., 2019).

By understanding and managing these factors, operator's optimization of the efficiency of wastewater treatment in stabilization ponds, ensuring proper effluent quality and environmental protection is possible.

Table 2.2: Characteristics of the Main Pond System.

CHARACTERISTICS OF MAIN POND SYTEM				
General Criteria	Specific Parameter	AP - FP	FP - MP	AP - MP - FP
% Removal Efficiency	BOD	75-85	75-85	80-85
	COD	65-80	65-85	70-83
	T. N	<60	<60	50-65
	T. P	<35	<35	>50
Requirements	Area (sqm/in hab)	1.2 - 3.0	2.0 - 4.0	3.0 - 5.0
	Power (W/in hab)	0	0	0

2.5 FLOATING MICROPHYTES

Floating macrophytes, also known as free-floating macrophytes or aquatic macrophytes, are a fascinating group of macroscopic plants which are invasive to the water surface of freshwater ecosystems like ponds, lakes, and slow-moving rivers (Khurshid, Ali and Hameed, 2020). Unlike their submerged relatives, these plants are not rooted in the sediment but possess unique adaptations that allow them to thrive on the water's surface (Bornette and Puijalon, 2009).

2.5.1 Buoyancy Adaptations for Light Capture

To maintain their floating position at the water-air interface, these unique plants have evolved various ingenious mechanisms. Some species, like water hyacinth (Eichhornia crassipes), boast air-filled bladders on their petioles (leaf stalks) that provide exceptional buoyancy (Sánchez, 2001).

Water Lettuce has tiny hairs underneath its leaves that hold bubbles of air forming a basket-like structure that keeps the plants floating on the water surface. Others, such as certain duckweed species (Lemna spp.), have developed lightweight and spongy tissues that keep them afloat (Xu, 2016).

These adaptations are crucial for maximizing sunlight access, a critical factor for photosynthesis since light intensity diminishes rapidly as it penetrates the water column (Duarte, 2016).

2.5.2 Nutrient Acquisition Strategies

Since they lack a connection to bottom sediments, floating macrophytes have developed alternative strategies for nutrient uptake. Many species possess specialized structures on their leaves or stems, like trichomes, that efficiently absorb dissolved nutrients directly from the water column (Lesiv, Polishchuk and Antonyak, 2020). This allows them capitalize on the nutrient-rich surface water layer, ensuring their growth and survival (Duarte, 2016).

2.5.3 Ecological Importance and Services Provided

Floating macrophytes are vital components of healthy freshwater ecosystems, playing a multifaceted role in maintaining their ecological balance. They provide a crucial food source and refuge for a diverse range of aquatic organisms, including fish, invertebrates, and amphibians (Duarte, 2016).

Additionally, these plants act as natural biofilters, filtering out pollutants and excess nutrients like nitrogen and phosphorus through their tissues and associated microbial communities (Xu, 2016). Their presence at the water surface also helps regulate water temperature by providing shade, which can be particularly important for maintaining suitable habitat conditions for temperature-sensitive species (Boyce, 2010). Such species include;

- Salmonoids; these are fish that belong to the salmonoid family for example trout, salmon and char. Even minor temperature increase beyond their optimum range could disrupt their growth rates and spawning cycles.
- Macroinvertebrates; Specifically, mayflies (Ephemeroptera). These are aquatic insects which are sensitive water indicators of water quality and some of them have very specific water temperature requirements for their different stages of life (Lenat, 1986).
- Amphibians; They depend on external sources for body heat regulation and are vulnerable in extreme temperatures (Blaustein A., 2010). They include frogs and toads.

Furthermore, the complex structures formed by floating macrophytes create habitat heterogeneity, promoting a wider range of species and enhancing overall biodiversity within the ecosystem (Gopal, 2005).

2.5.4 Potential Challenges and Management Considerations

While undoubtedly beneficial, the uncontrolled growth of some floating macrophytes can pose challenges. Dense mats of these plants can significantly block sunlight penetration, potentially leading to oxygen depletion in the water body (Les D., 2012). This significantly disrupt the delicate balance of the ecosystem and harms other aquatic organisms.

Additionally, excessive growth can obstruct navigation and recreational activities on the waterbody (Gopal, 2005). Effective management strategies are crucial to maintain a healthy balance of floating macrophytes in aquatic ecosystems (Les D., 2012). Techniques include;

- mechanical harvesting.
- Controlled introduction of herbivorous fish
- Manipulation of water levels

2.6 Sustainable Management and Research

As the focus on ecosystem preservation and sustainable freshwater management intensifies, the ecological roles and functions of floating macrophytes are garnering increasing attention (Duarte, 2016). Recent research delves deeper into the potential of these plants to mitigate climate change impacts, particularly their capacity of carbon sequestration and nutrient recycling within fresh water ecosystems (Hanson P., 2023).

With an increased understanding of these macrophytes, management strategies that only ensure their continued ecological merits but also address the challenges associated with their unlimited growth are addressed (Xu X., 2021).

2.7 PHYTOREMEDIATION

Phytoremediation is a process that harnesses the natural ability of plants to directly absorb nutrients and accumulate pollutants within their biomass during growth (Feng, 2014). It is a general terminology for the various technologies that plants employ to treat soils, water and sludge contaminated with organic and inorganic contaminants (Nivetha C., 2016). Unconventional wastewater treatment systems in this integrate floating microphytes have emerged as a promising approach to wastewater treatment and resource recovery, promoting sustainability and cost-effectiveness (Arias, 2014).

These systems mimic natural processes, achieving waste stabilization and nutrient removal through mechanisms similar to conventional methods like activated sludge and trickling filters (Vymazal, 2009). While physical sedimentation and bacterial activity are crucial aspects, aquatic plants offer an additional treatment pathway through phytoremediation (Vymazal, 2015). Following harvest, this biomass can be further utilized or disposed of responsibly.

2.7.1 Characteristics of aquatic plants;

- Higher tolerance to a large range of temperatures
- High rate of growth in wetlands.

2.7.2 Macrophytes

Are species which grow in water. These plants are extensively distributed with some exhibiting cosmopolitan distribution (found globally) while others demonstrate regional patterns of closely related species. They have diverse habitat preferences within macrophytes. Some species thrive in deep water, while others prefer shallow zones.

Notably, some exhibit emergent growth forms, remaining partially above the water surface. Floating and amphibious growth strategies are also mentioned, showcasing the adaptability of these plants to varying water levels and durations.

Morphological and Physiological Diversity: Macrophytes exhibit a high degree of morphological plasticity, meaning their physical form can vary depending on environmental conditions. Additionally, their physiological and metabolic processes demonstrate adaptability in response to environmental changes.

2.7.2.1 Water Lettuce

Water lettuce (Pistia stratiotes), a native of tropical and subtropical regions, graces the water's surface with its floating, lettuce-like fronds. Its lush mat- like leaves grow and create a shady haven for aquatic life, enhancing the overall beauty of the water body. Additionally, water lettuce is valued for its contribution to improved water quality. Its is attributed for Nutrient removal and reduction of organic matter from wastewater.

2.7.3 General uses of water Lettuce

Nutrient Bioremediation: This plant possesses a remarkable capacity for nutrient sequestration. Its root structure facilitates the uptake of excess nitrogen (as nitrates) and phosphorus (as phosphates), both of which can contribute to eutrophication and undesirable algal blooms. The specific mechanisms underlying this nutrient uptake likely involve a combination of active transport processes mediated by membrane proteins and passive diffusion driven by concentration gradients. The precise genes and enzymes responsible for nutrient transport in water lettuce remain uncharacterized, but plant families like Araceae (to which water lettuce belongs) might possess specific transporter proteins facilitating nitrogen and phosphate uptake.

Aesthetic Enhancement: Water lettuce, with its distinctive lettuce-like foliage, adds a visually appealing element to ponds, lakes, and other water features.

Habitat Formation and Biodiversity Enhancement: The dense root matrix creates a complex bio-architecture that serves as a refuge and breeding ground for diverse aquatic fauna. Fish species utilize these underwater havens for spawning and hiding from predators. Invertebrates like insects and amphibians also benefit from the structural complexity offered by the roots.

Light Attenuation and Thermal Regulation: By forming a dense surface cover, water lettuce acts as a natural shade provider. This shading effect reduces light penetration into the water column, mitigating excessive solar radiation for sensitive aquatic organisms. Additionally, the shade helps regulate water temperature, potentially creating cooler microclimates within the water body.

Sediment Stabilization and Erosion Control: The extensive root network of water lettuce functions as a biological anchor (up-to 24 inches deep), binding and stabilizing bottom sediments. This root matrix also dampens wave action near shorelines, reducing erosion and protecting the integrity of the aquatic environment.

2.7.4 Growing water lettuce happens best under three conditions

- ❖ Suitable Environment:

The water body, pond or container should be positioned in a way that it is constantly exposed to sufficient sunlight exposure and a warm temperature exceeding 15°C

(60°F). the water should be maintained at nutrient-rich water composition to promote optimal photosynthesis processes leading to heathy plant growth. Water Lettuce requires at least six hours of direct sunlight daily.

- Gentle Introduction:

The plants thrive most on water surfaces that have little agitation. This is because they are floating plants whose roots grow up to 24 inches deep. Therefore, intense surface agitation is a stumbling block for their proper growth and optimal multiplication. It is important to Carefully place the water lettuce on the water surface. The plants naturally float, with their roots dangling freely in the water.

2.7.4.1 Water lettuce in pond

To ensure water lettuce thrives and flourishes, several key factors require attention: they are as follows

- Abundant sunshine is essential for water lettuce. When positioning the pond, aim for 6-8 hours of direct sunlight per day.
- This tropical plant thrives in warmth. Ideal water temperatures range from 20-30°C (68-86°F). During colder months or climates, the plants might need to be moved indoors or a pond heater might be necessary.
- Water lettuce prefers nutrient-rich water. In ponds without fish, supplementing with a water-soluble fertilizer could be beneficial.

- The water lettuce should be regularly inspected for signs of pests or diseases. Yellowing or browning leaves can indicate problems. Early detection allows for prompt intervention and maintenance of healthy plants.
- Water lettuce reproduces rapidly and can quickly cover the water surface. Regular pruning is crucial to ensure sufficient light reaches other plants and pond life.

2.7.4.2 Potential uses of water Lettuce

While traditionally considered a management concern, harvested water lettuce (Pistia stratiotes) presents an opportunity for resource recovery within wastewater treatment facilities. Here's an exploration of its potential applications:

Composting: A straightforward approach, water lettuce can be composted alone or co-composted with other organic substrates to generate nutrient-rich soil amendments(HASSAN *et al.*, 2023).

Anaerobic Digestion: In large-scale operations, water lettuce can be utilized as a feedstock for biogas production through anaerobic digestion. This process yields methane, a renewable energy source, along with digestate, a nutrient-rich byproduct with fertilizer potential.

Livestock Feedstock (with Caution): Water lettuce offers some nutritional value and can be incorporated as a supplementary feed for swine, rabbits, or aquaculture(Shi *et al.*, 2022). However, its low protein content and presence of oxalic acid necessitate careful dietary management and consultation with animal nutritionists to avoid potential health risks.

Vermicomposting: Water lettuce can be employed as a substrate for vermicomposting systems(Cong *et al.*, 2022). Earthworms readily consume it, ultimately producing high-quality vermicompost rich in both macro and micronutrients, as well as beneficial microbial populations.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter highlights the systematic steps taken during the study. The study investigated the potential of water lettuce (Pistia stratiotes L.) to enhance treatment efficiency in the maturation pond at Kakoba Waste stabilization Ponds. Baseline conditions were established by both assessing secondary and collection and analysis of primary data. Water lettuce was introduced and monitored. By comparing post-implementation effluent quality to baseline data, treatment performance was assessed. Finally, Cost effectiveness of this approach was assessed.

3.2 Determining baseline conditions of removal rates of BOD, TN and TP in the existing maturation pond.

3.2.1 Assessment of Secondary data.

This study benefited from data provided by National Water and Sewage Corporation (NWSC) about the design considerations, treatment methods currently used, historical problems and anomalies or occurrences and operational challenges, Pond dimensions (depth, area and size) of Kakoba WSP, **Appendix B-3** and **Appendix B-4**. This information gave a valuable foundation for understanding the existing treatment system and its limitations.

3.2.2 Design adopted for the Kakoba Waste Stabilization Ponds

1. **Primary Facultative Pond:** Length: 128 m, Width: 68 meters, Depth: 7 feet and Retention Time: 7 days

2. **Maturation Pond:** Length: 74 m, Width: 31meters, Depth: 8 feet, and Retention Time: 3 days

3. **Maturation Pond (MP):**

Length: 68 meters, Width: 31meters, Depth: 9 feet, Retention Time: 3 days.

The characteristics of Kakoba Waste Stabilization Ponds are shown in Table 3.1

Table 3.1: Characteristics of Kakoba Waste Stabilization Ponds.

	Particular Details	Kakoba WSP
1.	Year of Commission	1991
2.	Wastewater influent to the ponds	200 m^3/day
4.	Number of sewer connections (total)	967
5.	Number of cesspool truck disposal trips per day	Approx. 4/day; 4000L each
4	Portions of wastewater	• Domestic 404 • Commercial 526 • Institutional 27 • Ministry 10
5.	Wastewater lost through leaks	Approx. 1%

Three full scale ponds which include Primary Facultative Pond, the First Maturation Pond and the Last Maturation Pond connected in series were investigated during a period 28 weeks from September 2023 to March 2024 by the staff of NWSC. This was done by analysis of secondary data obtained from The Quality Control Offices NWSC

Mbarara Ruhuro Works Located opposite Nile Breweries Plant. The Data clearly stated the Quality of raw sewage and the final effluent over a period of 25 moths, **Appendix B-6** and **Appendix B-7**.

This data covered the tests that had been carried out period before during and after de-sludging was done. Before that the ponds had not been de-slugged in over 9 years.

From this data it was observed that station Infleunt and effluent caliber were assessed and the study was inclined more to organic traits of the wastewater. These were mainly portrayed by BOD. Among others, parameters like T.P and T.N were assessed.

3.3 Primary Data

To ascertain the existing removal efficiency of Kakoba Waste Stabilization Ponds, a study was conducted to determine the current removal rates of BOD, TN and Total Phosphorous.

3.3.1 Sample Collection

Clean plastic samples were labelled and rinsed with distilled water and then used for the sampling process. They were labelled Raw Sewage, Anaerobic Pond, Facultative Pond and maturation pond. Grab samples of waste water were collected from 4 key sampling points to say, inlet to the primary the inlet and out let of the primary facultative pond, the outlet of the first maturation pond and the outlet of the second maturation/polishing pond, **Figure A-4**. This ascertained obtaining of the characteristics of the influent and effluent waste water existing in each pond of the treatment system and that of the effluent exiting the ponds.

The samples were collected in January and in March. In January, the samples were collected twice a day, in the morning and at noon. Thrice a day on 30th March, 2024.

Figure 3.1: Sampling from the inlet of the anaerobic pond

3.3.2 Sample Preservation

Some of the samples were assessed on site for Temperature and pH using **Palin test pH** pocket meter. The samples were carefully stored in a cooler box at a temperature of 26°C To minimize any alterations of the concentrations of the samples in each container. They were then transported to the NWSC laboratory, Ruhuro for analysis of BOD, TN and TP. The methods used are summarized in Table 3.2.

Table 3.2: Parameters and the Methods of Analysis.

PARAMETER	METHOD
BOD	APHA-5210-B
TP	APHA-4500-P-E
TN	In house method (Diazotization Method)

BOD analysis

- **Sample collection:** 4 samples from the inlet of the Primary facultative pond, its outlet and from the inlets and outlets of the two maturation ponds; were collected using clean BOD bottles (300ml). The bottles were filled completely to minimize air bubbles. Sample collection was done in the morning, at noon day and in the evening.
- The samples collected in the morning and in the afternoon were stored at a temperature of 4^0C while waiting to collect the evening samples.
- **Sample preparation:** To ensure the final DO level remained above a minimum threshold after incubation, dilution water free of oxygen and with similar pH to the sample was used. The dilution water was seeded with the microbiological population responsible for degrading organic matter.
- **Initial DO Measurement:** using a properly calibrated DO meter the concentration of DO was quantified for both the diluted samples and the blank sample (dilution water only).
- **Incubation:** BOD bottles were filled with diluted samples and one with blank ensuring no air bubbles remained. The bottles were then sealed tightly to

prevent exchange of oxygen with the atmosphere. The bottles were incubated for 5 days in an oven at 20^0C.

- **Final DO measurement:** After incubation, the DO concentrations of the incubated samples and blanks was measured using the method.
- **Calculations:** BOD was calculated using the difference between the initial DO value and the Final DO together multiply by the dilution factor.

TP analysis

- **Sample preparation:** to determine the total phosphorous content of the sample (both dissolved and particulate fractions) the samples were acidified with HCl to a pH of 2. This was done to preserve the integrity of the sample and ensure accurate measurement.
- **Chemical reactions:** Ammonium molybdate and potassium antimonyl tartrate reacted with orthophosphate in an acidic medium forming hetropoly acid known as phosphomolybdic acid.

$$(NH_4)_6Mo_7O_{24(aq)} + Sb\big(C_4H_4O_6K\big)_{2(aq)} + H_3PO_{4(aq)} + H^+_{(aq)} \rightarrow H_3(PMo_{12}O_4O) + other\ products.$$

$\boldsymbol{H_3(PMo_{12}O_4O)}$ - Phosphomolybdic acid (simplified formula for the heteropoly acid product)

- Ascorbic acid was used to reduce phosphomolybdic acid to an intensely coloured blue complex.

- **Spectrophotometric Measurement:** 10ml of the blue complex were placed in the spectrophotometer to measure the absorbance of the solution and compared to the calibration curve. This was done to quantify the concentration of Phosphorous.

TN analysis

- Nitrates in the samples were converted to Nitrite by passing the samples through a column packed with granulated cadmium to facilitate Nitrate reduction to nitrite.

$$NO^-_{3\,(aq)} + H^+_{(aq)} + Cd_{(s)} \rightarrow NO^{2-}_{(aq)} + \frac{1}{2}H_2O_{(l)} + Cd_{(s)}$$

- **Diazotization Reaction:** The converted Nitrite then passed through a diazotization reaction with a primary aromatic amine (sulfanilamide) under acidic conditions forming a diazonium salt which is an unstable intermediate compound.

- **Coupling reaction:** This salt wasn't colored and to generate a measurable coloured compound, the diazonium salt was coloured with N-(1-naphthyl)ethylenediamine dihydrochloride. This reaction produced a stable coloured azo dye.

- **Spectrophotometric measurement:** the intensity of the coloured azo dye solution was directly proportional to the concentration of nitrite present in the sample. The absorbance of the solution at a specific wavelength using a spectrophotometer enabled quantifying the concentration of nitrite in the sample. Done using a calibration curve.

3.4 Determining the effectiveness of water Lettuce in removing BOD, TN And Total Phosphorous

The choice plant, Water Lettuce was Picked from Namanve swamp along the Kampala Jinja Highway. The area's average annual temperature is 21 and it experiences a lot of precipitation (Climate Data, 2022).

The plants were observed in a controlled environment for one week to monitor their foliage the length of the roots and their mass. The plants were kept in water in an open warmer out side in order to receive sunlight.

Pilot study, comprised of two troughs, one known as the treatment Unit (orange) the second known as the control unit (blue)

Figure 3.2: Pilot study of the treatment unit with water Lettuce VS the Control Unit (blue)

Water lettuce was then transferred to trough named **Treatment Unit** and the other trough was kept as the **Control unit**. 20 g of water Lettuce were cultivated in the treatment unit filled with treated wastewater from the first maturation pond (secondary treatment) from the WSP.

Samples were picked from both effluent collection units thrice everyday (in the morning at noon day and in the evening) respectively. This was done every two days for 10 days

Analysis was done for Total Nitrogen and Total Phosphates concentrations. Analysis for BOD was done once every five days for 15 days.

BOD ANALYSIS

Initial DO analysis: Materials:

Dilution water: Prepared beforehand according to specific guidelines in the standard method to ensure consistent microbial populations, leading to accurate results.

Wastewater samples to be tested

Dissolved oxygen (DO) meter was properly calibrated for precise and accurate measurement before commencing the test.

Suitable airtight BOD bottles with a capacity of 300 mL or more were utilized.

Pipettes for precise sample and dilution water measurement were employed.

Dilution Preparation:

A series of dilutions were prepared using dilution water and the collected wastewater samples. The specific dilution ratios were chosen based on the anticipated BOD of the samples. The standard method was referenced for guidance on dilution preparation (APHA-5210 B)

Filling BOD Bottles:

The BOD bottles were carefully filled with the prepared dilutions, ensuring no air bubbles were trapped. The bottles were filled completely to minimize headspace.

Initial Dissolved Oxygen (DO) Measurement:

The initial dissolved oxygen (DO) concentration in each BOD bottle was measured using the pre-calibrated DO meter. This value represented the starting point for oxygen depletion by microorganisms.

The BOD bottles were sealed tightly to ensure they were airtight. The bottles were then incubated at a constant temperature of 20°C (± 0.5°C) in the dark for 5 days.

Final Dissolved Oxygen (DO) Measurement:

After 5 days, the final dissolved oxygen (DO) concentration in each BOD bottle was measured using the DO meter.

Calculations:

Dissolved Oxygen Depletion:

The difference between the initial and final DO values for each BOD bottle was calculated to determine the amount of oxygen consumed by microorganisms during the incubation.

Blank Correction:

A blank bottle filled only with dilution water was included to account for any oxygen depletion due to factors apart from sample biodegradation. The DO depletion value of the blank was subtracted from the DO depletion values of the samples to obtain corrected values.

BOD Calculation:

The corrected DO depletion values and the corresponding dilution factors were used to calculate the BOD of the samples, in milligrams per liter (mg/L). The specific calculation formula was referenced from the standard method, Standard APHA-5210-B.

3.5 Evaluating how much water lettuce is most effective in optimizing removal of BOD, TN and TP

This section examined the feasibility of using water lettuce (Pistia stratiotes) on a large scale within the existing treatment units of Kakoba's wastewater stabilization ponds, the maturation pond. Here Factors like maintenance requi Incubation:

Other key aspects included the labour required for planting the water Lettuce on a large scale, prevailing monitoring systems and management of Biomass. Potential challenges were pointed out.

A literature review was conducted on water lettuce cultivation, wastewater treatment applications, and maintenance requirements. Assumptions for the cost of labour and the planting rate of the labourers was at Kakoba WSP were made.

Some of the data concerning the area of the maturation pond, the depth of the maturation pond was provided by NWSC.

Pond surface area: $3150m^2$.

Depth of the Pond:$1.2m$

Water lettuce cost: 1,000 Ugandan shillings (UGX) per plant.

Labor cost: 5,000 UGX/hour.

Planting density: 4 plants per square meter (moderate density, requiring further research for optimal value).

Planting rate: 100 plants per person-hour.

Basic monitoring program with equipment and supplies costing 200,000 UGX.

3.6 Determining how much Phosphorous is taken up by Water Lettuce

Sample Collection

Two water lettuce samples approximately 20 grams each from the treatment unit. The first set was collected at the beginning of the experiment (pre-treatment), and the second set of Lettuce plants was collected after 10 days (post-treatment).

Sample Preparation

Each of the samples was thoroughly washed with distilled water to remove any present debris or contaminants. The samples were the oven dried at a low temperature of 60°C For 48 hours to remove any prevailing moisture.

After the drying process, the samples were weighed to attain their dry weight. Both samples from the pre-treatment and post treatment were ground and crushed into fine powder using a small mortar and pestle for even distribution analysis.

Phosphorous Analysis

An ICP-OES was used to determine the Phosphorous composition in Water Lettuce Samples from pr-treatment and post-treatment.

CHAPTER FOUR: RESULTS AND DISSCUSSIONS

4.1 INTRODUCTION

This chapter delved deeply into the current state of the Kakoba Waste Stabilization Ponds and deep evaluation of the different processes there. It focused on the limitations of the pond system and analyzed the effectiveness of water Lettuce as a potential treatment enhancement strategy based on the BOD_5 reduction data.

By incorporating these findings, this section establishes water lettuce as a potentially cost-effective and environmentally beneficial solution for the Kakoba WSP. Its ability to remove pollutants and generate valuable biomass adds weight to its potential as a viable treatment strategy. An Evaluation of all this information from this chapter identified opportunities for improving the overall performance of the Kakoba Waste Stabilization Ponds. Current state of the Kakoba WSP.

4.2 OBSERVATIONS FROM ANALYSIS OF SECONDARY DATA ON KAKOBA WASTE STABILIZATION POND

- It was observed that the design adopted consists of majorly surface ponds. Emphasis on the first pond whose design is of a primary facultative pond. It is not deep enough compared to normal anaerobic ponds hence limited anaerobic microbial activity to work on the organic loading of the influent wastewater
- The Facility doesn't have a sludge treatment plant hence Sludge is deposited directly into the first pond which is the primary facultative pond. All the Cesspool trucks from around Mbarara deposit the sludge at Kakoba WSP.

- Poor Dumping Tactics as the trucks dump fecal sludge from all around Mbarara municipality and the neighboring districts into the Primary Facultative Pond; close to the outlet of the pond instead of before the pond so that the raw wastewater could go through screening; see **Figure A-3**. This is done by averagely 3 cesspool trucks a day.
- The effluent discharged into the environment doesn't meet the discharge standards even after desludging the Primary Facultative Pond in June 2023.
- The population which the ponds serve has tripled over the past 8 years characterized by expansion of universities and hospitals in Mbarara Municipality.
- The wetland around the pond responsible for further treatment of effluent has been encroached upon and hence limited effective treatment of the wastewater.

The results of the physiochemical parameterof the wastewater are summarized in Table 4.1.

Table 4.1: Results showing the Physiochemical parameters of wastewater in Kakoba Wastewater Stabilization ponds.

Parameters	**Units**	**Raw Sewage**	**Facultative Pond**	**Maturation Pond**	**Maturation Pond**	**Discharge Standard**
pH (Physical Chemical)	--	8.5	8.5	9.1	8.8	6.0-8.0

Parameters	Units	Raw Sewage	Facultative Pond	Maturation Pond	Maturation Pond	Discharge Standard
Bio-Chemical Oxygen Demand (BOD)	mg/L	553	559	511	474	50
Chemical Oxygen Demand (COD)	mg/L	1202	928	908	947	100
Total Suspended Solids (TSS)	mg/L	678	778	688	622	100
T. Nitrogen	mg/L	34.9	30.0	41.8	39.6	10
Temperature	°C	25.7	24.4	24.7	24.5	20-35°C

The laboratory results were compiled and the removal efficiencies for each was calculated by the formular;

$$Removal\ Efficiency\ (\%) = \frac{(C_i - C_e)}{C_i} \times 100$$ Equation 4.1

$$Where\ C_i - Is\ the\ influent\ concentration$$

$$C_e - Is\ the\ effluent\ concentration$$

Emphasis was rendered to the maturation pond.

The removal efficiency was;

$$\%Removal\ Efficiency = \frac{511-474}{511} \times 100 \quad \text{... ()}$$

$\%Removal\ Efficiency = 7.2\%$ of BOD was removed from the Maturation Pond.

$\%Removal\ Efficiency = 5.2\%$ of Total Nitrogen.

The Laboratory results for pH, Temperature, BOD, TP and TN concentrations in both the influent and effluent samples of each pond were compiled and tabulated as shown below.

4.3 BOD

Table 4.2: Influent, control unit and treatment unit values of BOD

	BOD_5			
Day	influent value (mg/l)	Treatment unit (mg/l)	Control unit(mg/l)	Discharge standard (mg/l)
	477			
5		344	412	50
10		199	378	50
15		86	300	50

Table 4.3: Percentage removal Efficiency of BOD from the Control Unit, Treatment Unit and Acceptable reduction.

Parameter	Day of Experiment	%Removal Efficiency		
BOD		Treatment Unit	Control Unit	Acceptable reduction
	5	27.88	13.63	85
	10	58.28	20.75	85
	15	86.16	37.11	85

Table 4.2, and **Table 4.3** on BOD_5 (Biochemical Oxygen Demand, 5-day) reduction highlighted the clear advantage of using water lettuce in wastewater treatment compared to a control unit without it. Here's a breakdown of the trends observed and how they related to achieving a target BOD_5 reduction of 85%, considering an initial BOD_5 concentration of 477 mg/l.

Control Unit: Limited BOD_5 Reduction fell short of target

The control unit exhibited a gradual increase in BOD_5 reduction, up to 37.11% by day 15. This indicated some level of organic matter removal, possibly due to settlement of solids and natural aerobic microbial activity within the control unit (Michael A., 2003) (Franklin L., 2003). However, these processes were slow and limited, which led to an in a significant gap between the achieved reduction and the desired target of 85%.

Treatment Unit: Water Lettuce Meets and Exceeds Target

The treatment lettuce showed a significantly higher and faster rise in BOD_5 reduction. By day 15, it reached 86.15%. The treatment unit not only achieved the allowable removal efficiency but slightly surpassed the target of 85% reduction by 1.16%. This highlighted the effectiveness of water lettuce in reduction of BOD under the mechanisms shown below;

- **Aerobic conditions:** Photosynthesis after direct uptake of nutrients from the water by the water Lettuce increased dissolved oxygen in the water column suitable for aerobic digestion of organic matter by aerobic microbes (Vymazal, 2015).
- **Enhanced Settling:** The presence of water lettuce root structures aided the settling of organic matter as the wastewater moved through the treatment unit.
- **Microbial Boost:** The root zone of water lettuce provided a home for beneficial microbes that break down organic matter, further reducing BOD_5 (Vymazal, 2015). The roots also acted as a floating biofilter which treated wastewater as it moved through the treatment unit

Reaching and surpassing the 85% Target

With a target BOD_5 reduction of 85%, the treatment unit achieved and even slightly exceeded the allowable percentage reduction by day 15. This signified its potential to achieve the desired level of organic matter removal within a reasonable timeframe.

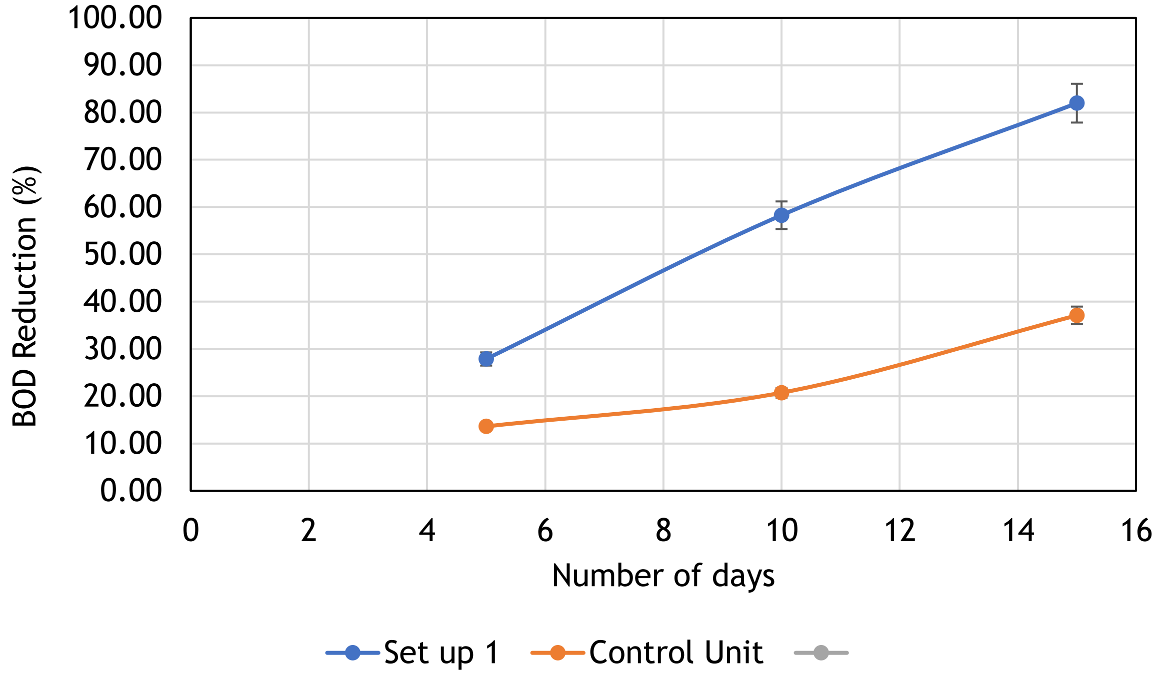

Figure 4.1: A graph of BOD Reduction (%) against Number of Days

Figure 4.1 shows Line graphs the represent the trends of BOD reduction in the Treatment unit versus the Control Unit according to the acceptable percentage reduction. The line graph for the control unit depicted a gradually increasing slope, which reflected the slow and limited BOD_5 removal without introduction of Water Lettuce. The treatment unit's line graph exhibited steeper slope, particularly in the initial days, indicating a rapid rise in BOD_5 reduction due to water lettuce's efficiency.

4.4 TOTAL PHOSPHOROUS.

Table 4.4 shows the progressive reduction of Total Phosphorous Concentration in the wastewater in the in the treatment unit versus the control unit.

Table 4.4: A table influent loading of T.P, Treatment values in the Control nit and the Treatment Unit

	TOTAL PHOSPHOROUS			Discharge standard
Day	influent value	Treatment Unit	Control unit	
	80.23			
2		70.8	78.44	10
4		65.7	73.61	10
6		44.98	70.36	10
8		31.56	63.47	10
10		15.3	50.27	10

As expected, the effluent value decreases throughout the 10-day experiment, mirroring the increasing percentage reduction observed in the treatment unit. This reinforces the effectiveness of water lettuce in removing phosphorus from wastewater.

Water Lettuce was shown to be capable of removing 80.93% of Phosphates by the end of the 10th day shown in **Table 4.5**. The concentration of Phosphorous gradually decreased day by day.

Table 4.5: T.P Removal in the Control Unit, Treatment Unit Against the Allowable reduction over 10 Days.

Parameter	**Day of Experiment**	% Removal Efficiency		
Phosphorous		Treatment unit.	Control Unit	Standard
	2	11.75	2.23	50
	4	18.11	8.25	50
	6	43.94	12.30	50
	8	60.66	20.89	50
	10	80.93	37.34	50

The percentage removal of phosphorous was compared between the control unit and the treatment unit. The values were tabulated. It showed that the percentage reduction in the treatment unit was more progressive and faster over the period of 10 days.

Graphical representation of Phosphorous removal is shown Figure 4.2 below.

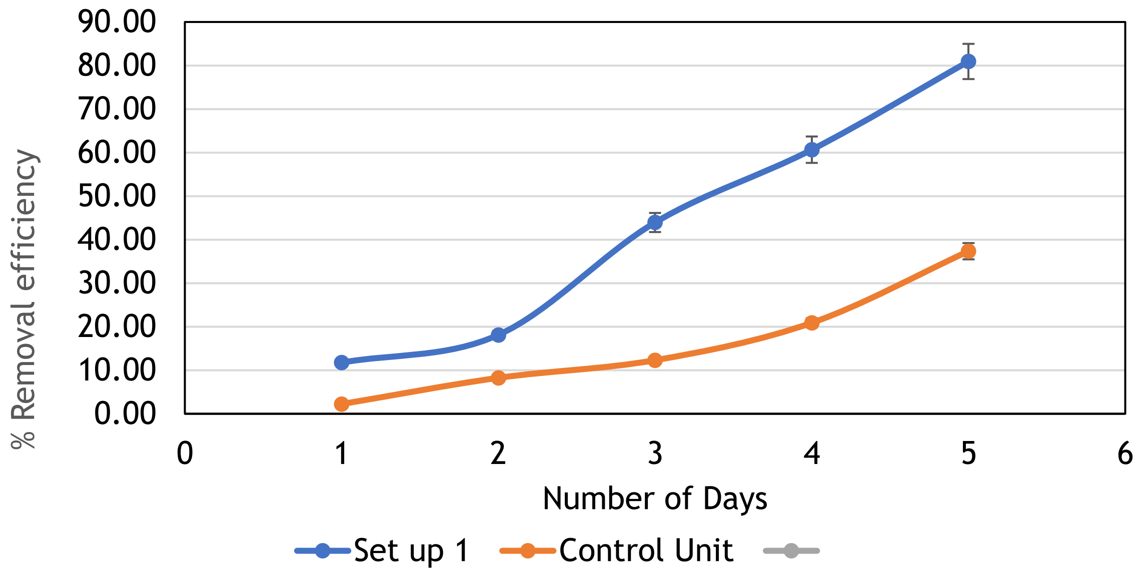

Figure 4.2: A graph of T.P Reduction (%) against number of days

Control Unit:

The control unit, lacking water lettuce, exhibited a gradual increase in phosphorus removal, with percentage reduction ranging from **2.23%** on day 2 to **37.34%** by day 10. This illustrated some level of phosphorus removal following mechanisms like:

- **Sedimentation:** Some of the phosphorous bound to suspended particles and settled down at the bottom of the control unit over time.
- **Adsorption:** Some phosphorus could have adsorbed onto existing surfaces within the control unit, such as tank walls or residual organic matter.
- **Presence of algae:** Some of the reduction of Phosphorous was attributed to the presence of algae in the Control Unit which require phosphorous for photosynthesis.

However, the limited removal efficiency indicates the need for a more active treatment method, such as the one employed in the treatment unit.

Treatment Unit:

The inclusion of water lettuce in the treatment unit led to a significantly higher removal efficiency for phosphorus compared to the control. The percentage reduction steadily increases throughout the experiment, reaching a remarkable 80.93% by day 10. This aligns with research highlighting the ability of water lettuce to remove phosphorus through:

- **Plant Uptake:** Water lettuce can directly absorb and utilize phosphorus for its growth processes.
- **Rhizosphere Microbes:** Microorganisms thriving in the root zone of water lettuce can facilitate phosphorus removal through various mechanisms like precipitation and assimilation.
- **Sedimentation Enhancement:** The presence of water lettuce can promote the settling of phosphorus-laden particles. This was done with the help of the roots.

Comparison and Significance

The stark difference between the control and treatment units highlighted the effectiveness of water lettuce in enhancing phosphorus removal from wastewater. Water lettuce acted as a biofilter with a web of roots that accumulatively absorb Phosphorous from the waste water, employing a combination of biological and physical processes to achieve this significant improvement.

4.5 TOTAL NITROGEN

The concentration of Nitrate Nitrogen in the sewage during treatment without water lettuce and after treatment using water lettuce is delineated in the table below.

Table 4.7 shows the comparison between the percentage removal efficiencies Nitrate Ammonia of the Control Unit and the Treatment Unit every 2 days for 10 days.

Table 4.6: A table influent loading of T.N, Treatment values in the Control Unit and the Treatment Unit

	TOTAL NITROGEN			
Day	influent value (mg/l)	Treatment Unit (mg/l)	Control unit (mg/l)	**Discharge Standard (**mg/l)
	62			
2		55.8	58.2	10
4		43.2	51.3	10
6		36.4	46.9	10
8		22.5	41.3	10
10		13.7	39	10

Table 4.7: % Reduction in the Control Unit, Treatment Unit Against the Allowable reduction over 10 Days.

Parameter	**Day of Experiment**	**%Reduction Efficiency**		
T. N		Treatment Unit	Control Unit	Acceptable reduction
	2	10.00	6.13	50
	4	30.32	17.26	50
	6	41.29	24.35	50
	8	63.71	33.39	50
	10	77.90	37.10	50

Water Lettuce removed 77.9% of Nitrate Ammonia by the 10th day. The concentration of nitrate Ammonia gradually reduced day by day.

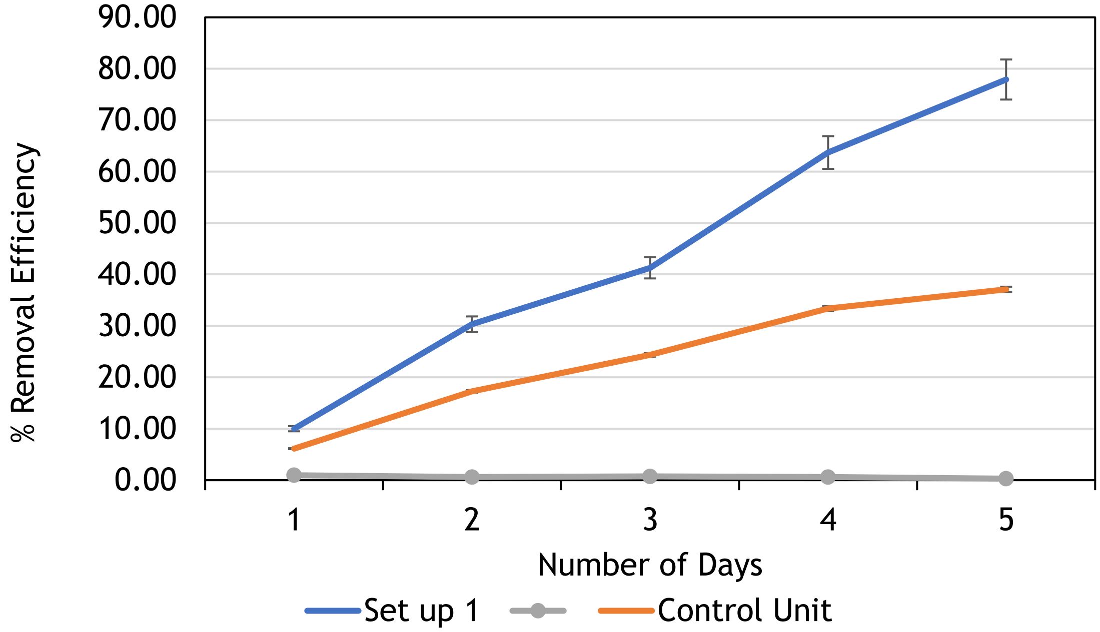

Figure 4.3: A graph of T.N Reduction (%) against number of days

Control unit

The specific removal efficiency in the control unit (ranged from 6.13% to 37.10%). Despite the presence of algae in the waste water and the specific microbial activity present, the removal efficiency did not even come close to the acceptable removal efficiency of >50% that should happen under ideal conditions at a retention time of 10 days. This slow reduction was attributed to the initial concentration of the influent entering the Control unit.

However, it's generally understood that natural settling and limited microbial activity typically lead to lower and slower nitrogen removal rates compared to systems employing biofilters or other active treatment methods.

However, the limited removal efficiency suggests the need for a more active treatment method, such as the one employed in the treatment unit.

Treatment Unit

As expected, the effluent value decreased progressively throughout the 10-day experiment, mirroring the increasing percentage reduction observed in the control unit. However, the trend in the treatment unit highlighted the effectiveness of water lettuce in removing nitrogen from wastewater. By day 10, the effluent concentration had dropped to 13.70 mg/l, representing a significant reduction of nearly 78% from the initial influent value of 67mg/l.

This trend was attributed to the natural ability to operate in moderately high loading rates as shown by the influent loading of 67mg/l. They are equipped with absorption and transportation capabilities that take up the nutrients from the water column. As they thrived, they took up the Nutrients from the matrix.

These findings provided promising evidence for the potential of water lettuce as a biological treatment method for nitrogen reduction in wastewater treatment systems.

FINDINGS

Maintenance Requirements

Planting water lettuce is relatively simple, it involved gently placing the water lettuce of a calm water surface full of nutrients. but ongoing maintenance for harvesting and potential weed control is needed.

Cost-Effectiveness:

Initial water lettuce implementation cost is estimated at

12,600 plants 50 UGX each plant = 630,000 UGX

Add 200,000UGX = Estimated for labour and transportation.

The total Initial Cost of = 830,000 UGX

Long-term cost-effectiveness depends on:

Frequency of harvesting and biomass management; done once every 8 months-100,000UGX. Amounting to 200,000UGX every two years.

Potential cost reductions in existing treatment due to water lettuce supplementation.

Current costs of removing weeds

= 300,000 every two months. Amounting to 1800,000 every month.

Difference in Costs from both treatment alternatives over a period of two years.

=1,800,000-200,0000= 1,500,000UGX is saved every two years.

Biomass Management

Harvested water lettuce can be composted or explored for alternative including;

Vermicomposting; To enhance Farming industry.

Phosphorous content of Water Lettuce

Wet weight of Water Lettuce Pre- treatment = 40 gm

Dry weight of water Lettuce post treatment = 25g

Wet wight of Water Lettuce Samples Post treatment= 65g

Dry weight of Water Lettuce Samples post treatment = 40g

Results from the analysis:

Pre-treatment Samples = Phosphorous concentration of 1.2mg/g of dry weight

Post treatment samples = Phosphorous concentration of 3.0mg/g of dry weight.

Calculations:

Difference in dry weight between Pre-treatment and Post-treatment Water lettuce samples.

$$Change\ in\ dry\ weight = 40g - 25g = 15g$$

Change in Phosphorous Concentration mg/g in dry weight samples pretreatment and post treatment.

$Change\ in\ concentration\ \left(\frac{mg}{g}\right) = Post\ treatment\ \left(\frac{mg}{g}\right) - Pre\ treatment\ \left(\frac{mg}{g}\right)$	**Equation 4.2**

$= 3.0 - 1.2 = 1.8\ mg/g$

Phosphorous uptake by water lettuce after 10 days

$$= change\ in\ phosphorous\ Concentration\ \times Dry\ \ weight\ of\ Water\ Lettuce$$

$= 1.8 \times 15$= 27mg of Phosphorous.

These results show that the Water Lettuce blooms as a result of the nutrients it takes in for growth combined with the daily sunlight it received. Hence in a space of 10 days it doubled in mass. This showed water Lettuce's ability to remove pollutants like phosphorous from waste water in a short time.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The initial cost of water lettuce (around 830,000 UGX) seems feasible. However, a definitive conclusion on cost-effectiveness requires further investigation into:

- Optimal water lettuce planting density for Kakoba's specific conditions.
- Frequency of harvesting and associated labor costs.
- Potential cost savings on the existing treatment method due to water lettuce.

5.2 Recommendations

- Research optimal planting density and harvesting frequency for Kakoba's specific conditions.
- Explore potential revenue streams from harvested water lettuce biomass.
- Effective management of harvested water lettuce is crucial. While composting remains a viable option, exploring alternative approaches like anaerobic digestion, biochar production, vermicomposting, and bioremediation are quite promising for converting this biomass into valuable resources. Further research is necessary to optimize these techniques and unlock the full potential of water lettuce as a renewable resource within wastewater treatment strategies.

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APPENDIX

APPENDIX A

Figure A-1:Satellite Image of Kakoba Waste Stabilization Ponds

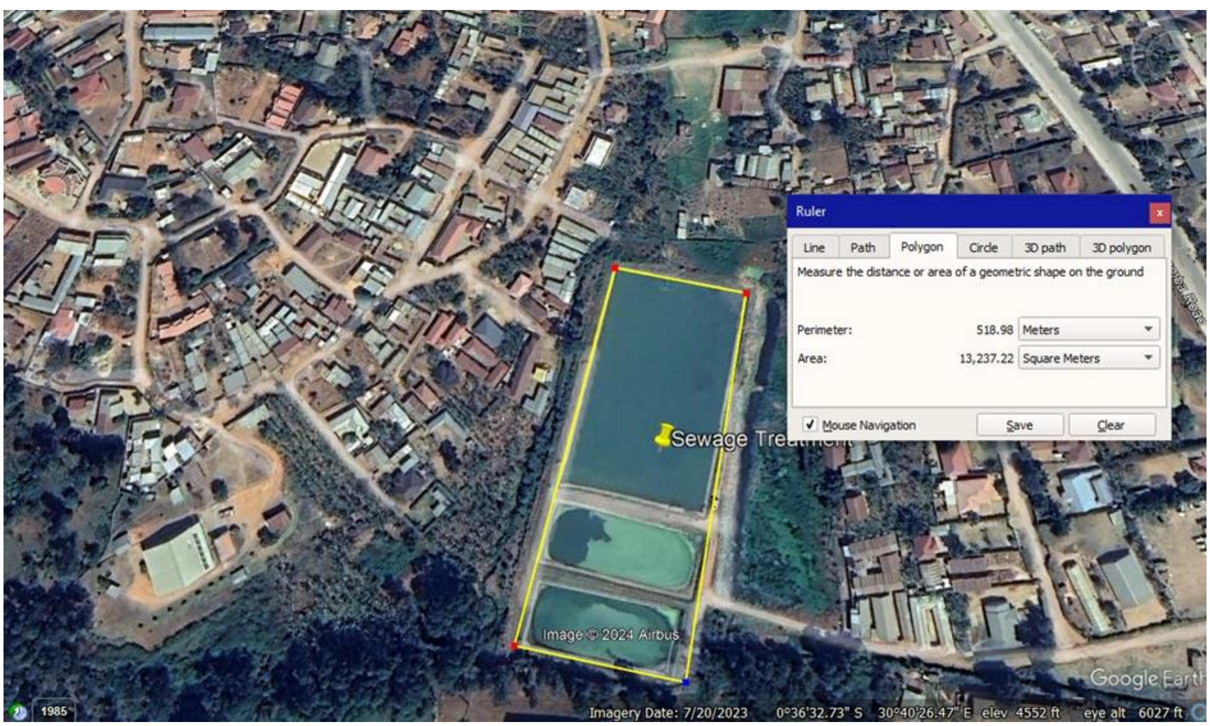


Figure A-2: Satellite Image of Kakoba Waste Stabilization Ponds

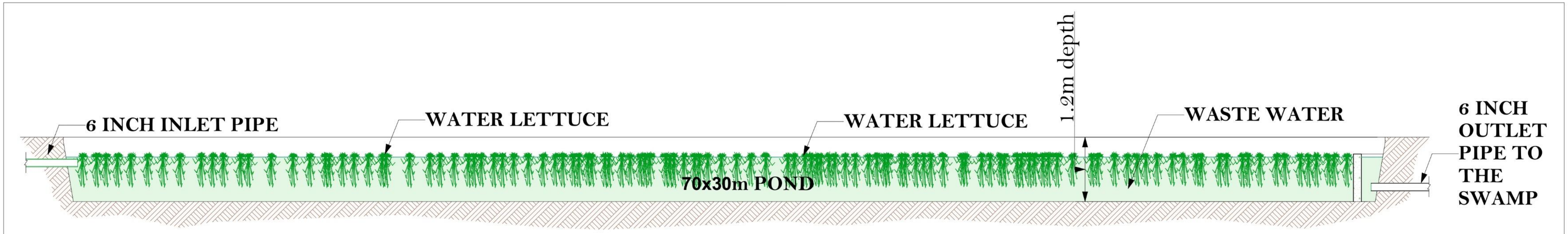
Figure A-3: Cesspool truck pouring waste water into the facultative pond.

Figure A-4: Samples from the different treat treatment stages in the laboratory.

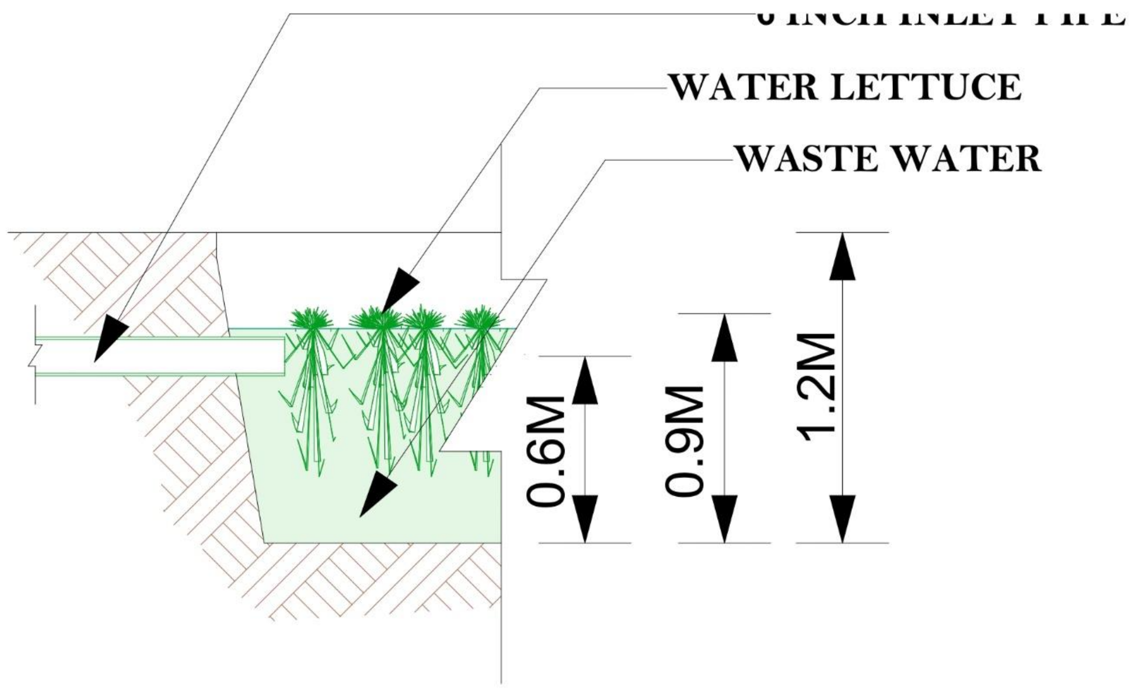
Figure A-5: Water Lettuce day1 vs Water Lettuce at day 10.

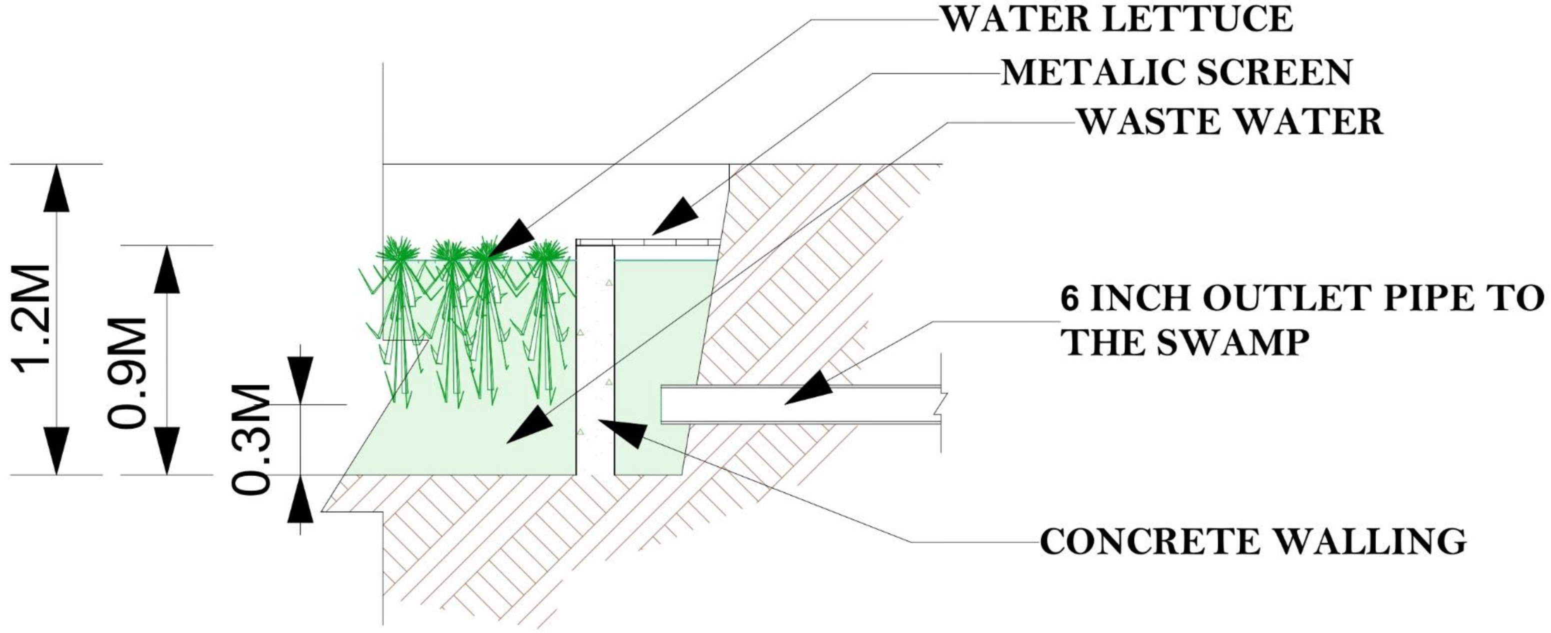
Figure A-6: Sample from treatment Unit with Lettuce Vs Sample from Control unit.

Figure A-7: Roor system of Water Lettuce plant.



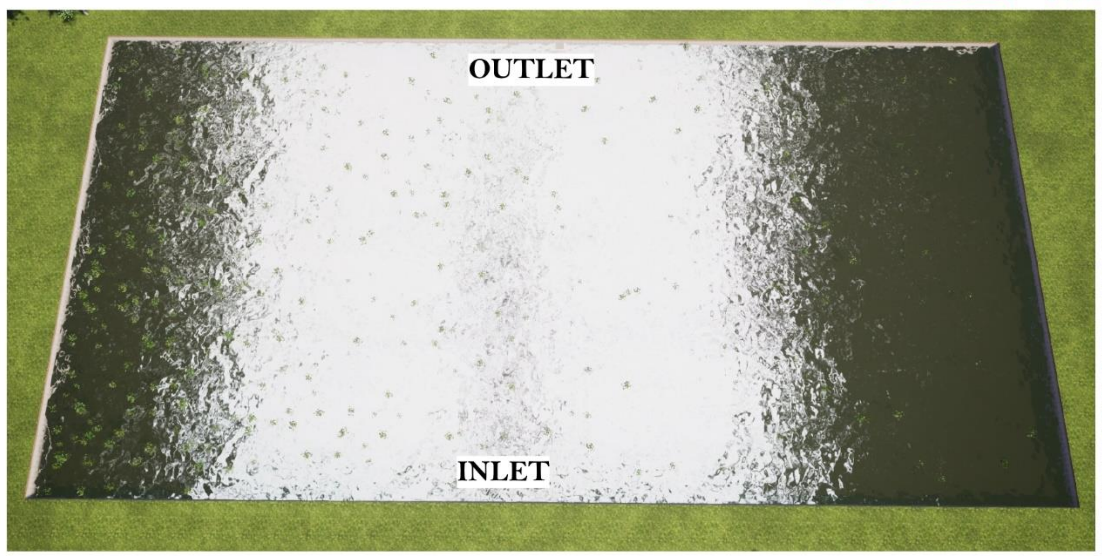
CROSS- SECTION THROUGH POND DESIGN
SCALE: 1:75



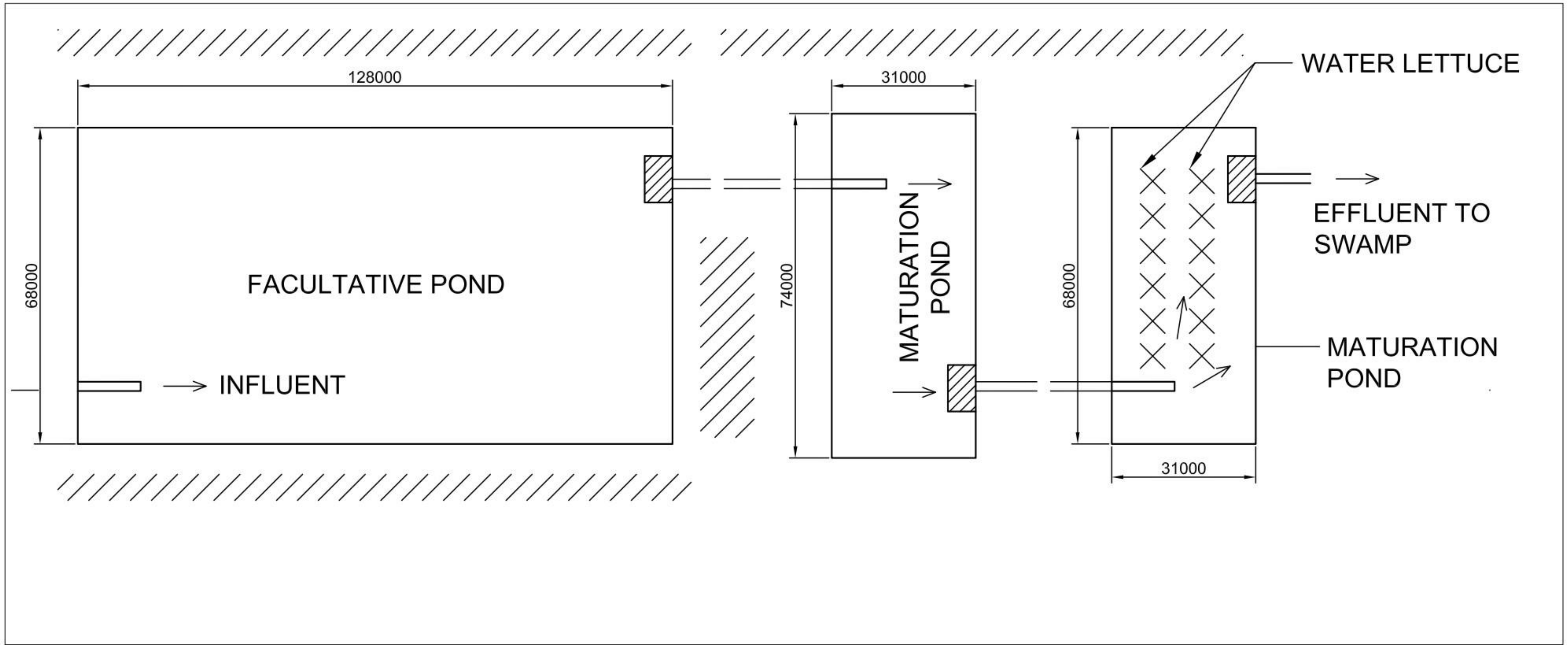


DETAIL AT INLET
SCALE: 1:75

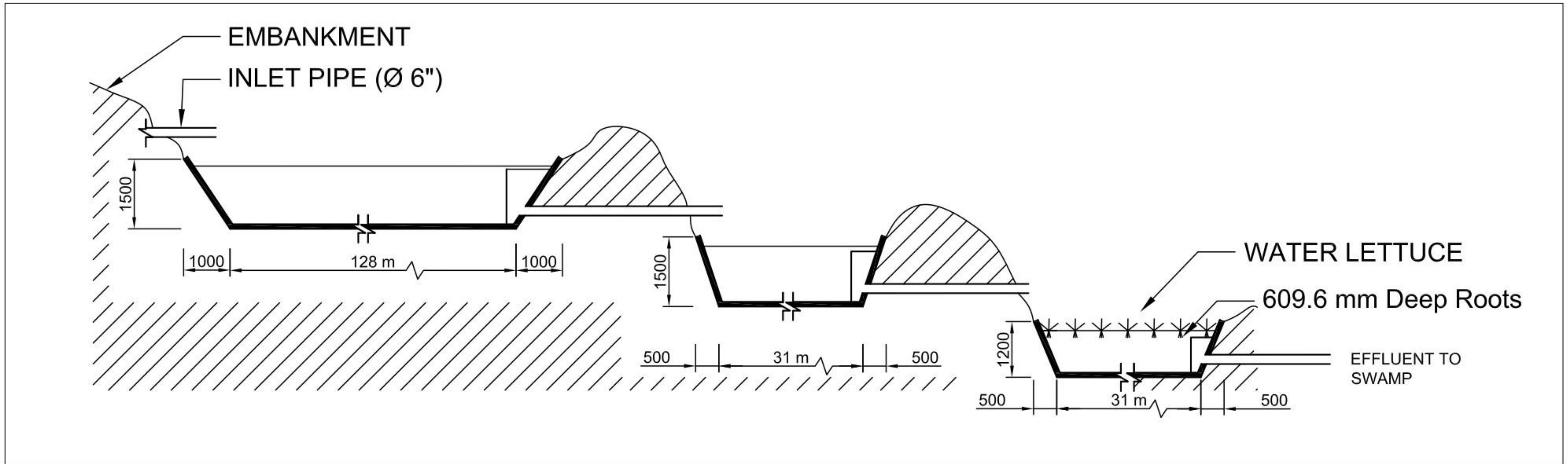
DETAIL AT OUTLET
SCALE: 1:75



DESIGN DRAWINGS: WATER TREATMENT IN MATURATION POND USING WATER LETTUCE AUTHOR: MIREMBE PRECIOUS



PLAN VIEW 1:1000



CROSS-SECTION VIEW 1:100

Drawing Title:

KAKOBA WASTE STABILIZATION PONDS-INTEGRATING WATER LETTUCE INTO THE MATURATION POND

PRECIOUS MIREMBE

Scale 1:1000 & 1:100

Page 1 of 1

APPENDIX B:

NATIONAL WATER AND SEWERAGE CORPORATION

TELEGRAMS WATERS KAMPALA
Telephone: +256–414–315 000
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Fax:0414 – 258 299/345531/346447
Email: info@nwsc.co.ug

HEAD OFFICE

P. O. BOX 7053
PLOT 3, Nakasero,
KAMPALA

Ref.: BSS/R&D/19-08

Date: 04th March 2024

GENERAL MANAGER, MBARARA AREA

Re: PERMISSION TO CONDUCT RESEARCH IN NWSC

This is to introduce to you Ms. **Wakoka Denis and Ms Mirembe Precious**, students of Bachelor of Science in Civil and Environmental Engineering at Uganda Christian University. They have been granted permission to conduct their research in NWSC. The title of their research is;

"Improving the Treatment Process at Kakoba Wastewater Treatment Plant"

The students would like to collect on the Kakoba Wastewater Treatment Plant including design parameters of the ponds, loading on the ponds from Sewerage Records at the ponds to help with their study. It is expected that the findings from this research will be made available to NWSC and key recommendations beneficial to the corporation will be adopted. In this regard, you are kindly requested to provide them with the necessary support to successfully accomplish this research project.

This admission is valid up to end of April, 2024.

Anticipating your usual cooperation.

Allan Kaford
Ag. Manager, Research and Development

Appendix B- 1: Permission from t to Conduct Research at NWSC Mbarara

NATIONAL WATER AND SEWERAGE CORPORATION

CUSTOMER COUNT REPORT

AREA: Mbarara **BRANCH:**

4/3/2024 **AS AT:** 202403

	Count	In Use	Not In Use	Closed	ActiveSewer	InactiveSewer
Classifications						
Commercial	5,696	4,133	1,321	242	425	128
Domestic	29,185	24,225	4,525	435	353	75
Institutional	604	470	102	32	19	9
Industrial	7	7	0	0	0	0
Local Authority	46	0	0	46	0	0
Ministry	114	21	6	87	6	3
Public Stand Post	592	458	104	30	1	0
Total	36,244	29,314	6,058	872	804	215

NATIONAL WATER & SEWERAGE CORP.
MBARARA REGIONAL LABORATORY

1

Appendix B- 2: Number of accounts Connected to NWSC Sewer sytem from January to March.

KAKOBA WASTE STABILISATION PONDS.

The number of total sewer connections in Mbarara is 967, mainly comprising schools, hospitals, universities, Referral hospital, hotels and a few domestic accounts. This service coverage is only about 6% of the total population of Mbarara. The following table details information for Kakoba ponds.

Table 1: Status of Kakoba Waste Stabilisation Ponds in Mbarara (31st Dec 2023)

Particular details		Kizungu WSP	Kakoba WSP	Katete WSP
01	Wastewater influent to the ponds		200 m^3/day	
02	Number of water connections		34,000	
03	Number of sewer connections (Total)		967	
04	Quantities discharged per month on average		4,800 m^3/month (sewage) 120m^3/month (Feacal sludge)	
05	Percentage proportion of wastewater	Domestic 404, Commercial 526, Institutional 27, Ministry 10.		
06	Waste water lost through leaks	Approx.1%		
Year of commission			1991	
Treatment technology			**F-M-M**	
Pond depth and dimensions			**Facultative:** Depth 1.5m **Maturation:** Depth 1.5m **Maturation:** Depth 1.2m	
Surface area of ponds			**F:** 6620m^2 **M:**3150m^2 **M:**3150m^2	
Presence of lift station			Yes: Kiswahilli	
Length of sewer lines (Total)			33km	
Presence of encroachers			Yes: Settlements around ponds	
Number of cesspool truck disposal trips per day			Approx. 4/day (4,000L each)	

Appendix B- 3: Secondary data concerningsppecifications of the Kakoba Waste Stabilization Ponds.

Kakoba Ponds

Temperature and wind direction in relation to flow direction.		A lot of smell realised in the surrounding before desludge	-
Water weeds, estimate percentage cover and on which ponds.		10% Always manually skimmed off by attendants.	
Sludge depth in the facultative pond (**where possible**)		No anaerobic pond	
Embankment (concrete slab or soil)		Concrete slab	
Presence of constructed wetland		No	
Are there gullies entering the ponds?		No	
Effluent is discharged to		Wetland	
Is there a grit channel		Yes	
Are screens installed		Yes	
Is there a flow meter or weir		V-notch	
Is the outlet appropriate?		Yes	
Outlets clogged		Not clogged	
Risk of toxic influent shocks i.e., oil discharge, hospital discharge, industries etc		Students hostels	
When was the pond last desludged		June 2023	
Was desludging appropriate		Yes	
Does scum form on the pond?		Yes	
Challenges		Kakoba receives all feacal (cesspool) sludge around Mbarara city as the area has no Fecal Sludge Treatment Plant yet. On average, the ponds receive 4 trucks of cesspool sludge (4000L) per day	

Appendix B- 4: Specifications and current situation of Kakoba Waste stabilization ponds

Mbarara Kakoba wastestabilisation Ponds Jan 2022-Feb 2024

	Raw sewage											
Date	STATION	pH	EC	TSS Influent (mg/L)	BOD- Influent (mg/L)	(COD) 100	Alk-T	O-PO_4)	(TP) 10	(NH4-N) 10	pH	EC
Jan-22	Mbarara-Kakoba	5.8	814	512	294	810	300	9.42	22.70	41.3	7.2	1600
Feb-22	Mbarara-Kakoba	5.5	788	310	270	800	262	29.58	88.75	142.1	7.2	1,624
Mar-22	Mbarara-Kakoba	5.5	801	521	280	808	259	30.84	89.60	145.0	7.2	1674
Apr-22	Mbarara-Kakoba	5.6	740	632	380	912	316	32.60	74.20	130.6	7.2	1609
May-22	Mbarara-Kakoba	5.6	920	480	276	544	300	26.60	41.20	104.2	7.0	1711
Jun-22	Mbarara-Kakoba	7.1	1698	688	209	628	428	10.41	23.80	140.0	6.7	1728
Aug-22	Mbarara-Kakoba	7.6	1687	678	218	602	442	11.31	23.02	138.0	6.9	1749
Sep-22	Mbarara-Kakoba	6.0	1794	1050	468	916	800	79.14	27.40	55.1	7.1	1736
Oct-22	Mbarara-Kakoba	8.0	1745	817	380	765	797	48.19	71.24	40.3	7.8	1553
Nov-22	Mbarara-Kakoba	7.0	1120	480	284	512	440	22.30	43.50	103.7	6.8	1711
Dec-22	Mbarara-Kakoba	6.2	1134	154	250	474	680	155.00	235.00	94.4	6.1	1082
Jan-23	Mbarara-Kakoba	8.4	1908	529	145	283	480	39.00	49.00	82.0	8.3	2510
Feb-23	Mbarara-Kakoba	7.5	1968	702	300	610	604	32.23	42.32	168.0	7.1	1526
Mar-23	Mbarara-Kakoba	5.4	3600	1400	948	1048	260	15.60	28.70	144.0	6.0	2026
Apr-23	Mbarara-Kakoba	7.1	1290	935	796	933	680	50.25	59.21	100.3	7.7	2170
May-23	Mbarara-Kakoba	7.2	1420	759	340	679	690	60.18	68.13	154.6	7.4	1414
Jun-23	Mbarara-Kakoba					Pond desludge						
Jul-23	Mbarara-Kakoba					Pond desludge						
Aug-23	Mbarara-Kakoba	7.2	1800	721	743	1027	500	21.50	53.60	155.2	7.5	1403
Sep-23	Mbarara-Kakoba	7.3	1753	821	787	1391	640	20.60	49.75	136.2	7.6	1297
Oct-23	Mbarara-Kakoba	7.5	1625	667	262	680	620	34.60	91.25	149	7.2	900
Nov-23	Mbarara-Kakoba	7.4	1540	634	366	742	690	22.25	74.21	100.41	7.3	820
Dec-23	Mbarara-Kakoba	7.5	1654	590	210	623	550	28.52	80.25	128.3	7.2	967
*Jan-24	Mbarara-Kakoba	7.5	1580	625	315	752	648	27.20	63.20	119.6	7.5	1000
Feb-24	Mbarara-Kakoba	6.9	1548	704	354	824	674	78.36	66.80	135.64	7.2	989

Appendix B- 5: Secondary Data fro NWSC Laboratory of Influent and Effluent was qualities for NWSC from Jan 2022 to feb 2024

Final Effluent											
TSS Effluent (mg/L)	TSS standard (100mg/)	BOD-Effluent (mg/L)	BOD standard: 50mg/L	(COD) 100	Alk-T	O-PO$_4$)	(TP) 10	(NH4-N) 10	BOD % Reduction	TSS % Reduction
390	100	90	50	264	540	10.22	30.60	68.2	69%	80%
160	100	86	50	252	524	12.23	36.70	70.3	68%	48%
139	100	93	50	251	494	12.63	35.80	69.1	67%	73%
148	100	100	50	263	538	13.01	37.80	70.9	74%	77%
112	100	86	50	222	360	10.60	28.90	62.7	69%	77%
92	100	53	50	189	524	10.38	30.18	53.1	75%	87%
489	100	60	50	162	534	9.83	28.21	62.1	72%	28%
275	100	77	50	142	514	1.83	20.21	54.1	84%	74%
191	100	96	50	217	581	36.72	60.98	17.5	75%	77%
150	100	90	50	222	360	10.60	28.90	70.9	68%	69%
138	100	80	50	158	640	129.00	169.00	13.5	68%	10%
156	100	92	50	181	680	25.00	34.00	51.0	37%	71%
139	100	65	50	190	438	20.86	25.80	75.2	78%	80%
600	100	440	50	860	272	10.40	20.80	58.0	54%	57%
475	100	270	50	467	820	36.30	44.80	46.1	66%	49%
182	100	76	50	122	480	28.14	35.18	46.3	78%	76%
Pond stabilisation following desludge									–	
Pond stabilisation following desludge									–	
98	100	64	50	110	440	15.65	31.50	16.8	91%	86%
170	100	145	50	214	420	14.65	30.22	59.1	82%	79%
146	100	81	50	173	410	12.23	16.25	33.2	90%	82%
124	100	68	50	125	376	18.95	33.64	28.3	81%	80%
138	100	70	50	156	380	15.88	35.34	30.2	67%	77%
122	100	66	50	123	500	38.40	122.21	31.8	79%	80%
184	100	56	50	148	482	33.44	99.80	25.3	84%	74%

NATIONAL WATER & SEWERAGE CORP. MBARARA REGIONAL LABORATORY

Appendix B- 6: Continuation of Secondary Data fro NWSC Laboratory of Influent and Effluent was qualities for NWSC from Jan 2022 to feb 2024

NATIONAL WATER AND SEWERAGE CORPORATION
MBARARA REGIONAL LABORATORY
Email:nwscmbarara@utlonline.co.ug
http://www.nwsc.co.ug/
ISO CERTIFIED 9001: 2008

Telephone: 04854 - 21547
Fax: 04854 – 21520
E-mail:

P.O. Box 1371,
Plot 3 Galt Road,
MBARARA

Raw Data

Client Name: MIREMBE PRECIOUS

Sampling analysis: 13/03/2024

No.	No. of Days	Parameter	Results		
			Influent	**Control Unit (set-up 1)**	**Treatment Unit (set-up 2)**
01		Total Phosphorous	80.26 80.18 80.02		
	02			79.74 78.11 77.30	70.50 71.10 70.20
	04			75.50 72.70 72.80	65.80 65.60 65.30
	06			71.74 69.30 70.11	45.00 44.90 44.88
	08			64.74 62.30 63.11	31.57 31.55 31.44
	10			51.85 48.663 50.47	15.45 15.35 15.30
02		Total Nitrogen	63.00 61.00 58.00		
	02			59.8 57.0 57.4	52.37 59.51 52.57
	04			53.22 50.10 50.68	43.69 42.05 41.56
	06			47.91 46.41 46.65	39.20 38.30 38.50
	08			44.07 42.38 42.65	27.41 15.39 27.70
	10			39.70 38.50 38.80	18.00 10.73 12.37

18th March 2024

NATIONAL WATER & SEWERAGE CORP.
18 MAR 2024
MBARARA REGIONAL LABORATORY

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Appendix B- 7: Raw data for Tests carried out for the Treatment Unit Vs the control Unit.

NATIONAL WATER AND SEWERAGE CORPORATION
MBARARA REGIONAL LABORATORY
ISO CERTIFIED 9001: 2008

Telephone: 04854 - 21547
Fax: 04854 – 21520
E-mail:

P.O. Box 1371,
Plot 3 Galt Road,
MBARARA.

MBARARA-RUHURO BRANCH

CLIENT: PRECIOUS MIREMBE
Tel: 0743135223
Email: doxaprecious@gmail.com
Date Sample received: 30/03/2024

Ref No:
Sampled by: Client
Type of container: Plastic
Sample source: Wastewater
Date of report: 04/04/2024

Table of Analytical Results

Parameters	Units	Raw Sewage	Anearobic Pond	Facultative Pond	Maturation Pond	National stds for effluent discharge
pH (Physical Chemical)	--	8.5	8.5	9.1	8.8	6.0-8.0
Bio-Chemical Oxygen Demand (BOD)	mg/L	553	559	511	474	50
Chemical Oxygen Demand (COD)	mg/L	1202	928	908	947	100
Total Suspended Solids (TSS)	mg/L	678	778	688	622	100
Electrical Conductivity (EC)	µs/cm	1232	1955	1679	1599	1500
Ammonia	mg/L	34.9	30.0	41.8	39.6	10
Temperature	°C	25.7	24.4	24.7	24.5	20-35°C

Analysis carried out by:

NATIONAL WATER & SEWERAGE CORP. MBARARA REGIONAL LABORATORY 04 APR 2024

Naboth Mwebaze
Senior quality control Officer

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Appendix B- 8: Raw Data for the quality of waste water at the inlets and outlets of each pond of the treatment sytem

NATIONAL WATER AND SEWERAGE CORPORATION
MBARARA REGIONAL LABORATORY
Email: nwscmbarara@utlonline.co.ug
http://www.nwsc.co.ug/

ISO CERTIFIED 9001: 2008

Telephone: 04854 - 21547
Fax: 04854 – 21520
E-mail:

P.O. Box 1371,
Plot 3 Galt Road,
MBARARA.

Raw Data

Client Name: MIREMBE PRECIOUS

Sampling and analysis: 01/04/2024

No.	No. of days	Parameter	Results		
			Influent	Control Unit (set-up 1)	Treatment Unit (set-up 2)
01		Biological Oxygen Demand	479 477 476		
	05			411 413 410	348 345 343
	10			380 376 376	198 200 198
	15			301 299 298	85 87 84

Date 7th April

NATIONAL WATER & SEWERAGE CORP. MBARARA REGIONAL LABORATORY 07 APR 2024

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Appendix B- 9: Raw data for Tests carried out for the Treatment Unit Vs the control Unit for BOD.

B.E.L

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SYSTEMS UNBS CERTIFIED

TEST REPORT

Certificate Number:	**BEL/002/01/2024**		
Client Name: WAKOKA DENIS ERIYA & MIREMBE PRECEOUS		**Sample Receipt Date** 11/01/2024	**Analysis Start Date:** 11/01/2024
Client Address and contact: UGANDA CHRISTIAN UNIVERSITY 0751974441			
Lab Sample ID: A002/2024,A003/2024 and A004/2024		**Date of analysis completion** 16/01/2024	**Date of issue of the certificate** 17/01/2024
Client Sample ID: Anaerobic pond, Facultative pond, Maturation pond			
Sample type and Location: Wastewater from ponds in Mbarara			
State of sample on delivery Water in 500ml bottles		**Testing conditions:**	Relative humidity: 69.3% Temperature: 24.7

Test Results

Parameter(s)	Units	Anaerobic pond (1)	Facultative pond (2)	Maturation pond (3)	Test Method(s) Used	East African standard for portable water EAS 12:2014
pH	-	7.37	7.37	7.80	APHA 4500-H B	5.0- 8.5
Color	PtCo	6860	5580	5160	HACH DR/890 Method 8025	50
Total phosphorous	mg/l	5.5	3.15	3.7	HACH DR/890 Method 10127	05
Temperature	degrees	23.7	23.2	23.9	ELECTROMETRIC METHOD	25
Total Nitrogen	mg/l	30.1	15.6	18.04	HACH DR/890 Method 10072	10
Chemical Oxygen Demand	mg/l	8135	1417	1115	HACH DR/890 Method 8000	70
Biochemical Oxygen Demand	mg/l	1091	611.4	177.4	BOD-5	50
E-Coli	CFU/100ml	68000	5400	3600	ISO 9308-1 (SB)	400

REMARKS:

Results do apply only for the sample as it was received and analysed. The client bears sampling responsibility as the representative characters of the sample delivered.
mg/L- stands for miligrams per liter.
SB- Subcontracted

Tested By:
Quality Analyst

BIOCORE ENTERPRISES LIMITED
17 JAN 2024
P.O. BOX 892, Kampala
0393 228012
Email: biocorenter@gmail.com

Approved By:
Laboratory Manager

This Certificate of analysis is only valid if it bears an authorised signature and an official stamp. It may not be reproduced other than in full, exept with written approval from the Laboratory Manager Biocore Laboratory.

BEL/LMS/F/44, Ver 01 page 1 of 1

BIOCORE laboratory, Namanve Industrial Park – Ssempala Road, P.O. Box 892, Kampala, Uganda. Tel: 0393 228 012, E-mail: info@biocorenterprises.com

Appendix B- 10: Raw Data for the quality of waste water of each pond of the WSSP treatment sytem

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"Environment Conservation Is Our Responsibility"

Namanve Industrial Park - Ssempala Road
P.O. Box 892, Kampala. Tel: 0393 228 012, Email: biocorenter@gmai.com

Raw data

Client Name: WAKOKA DENIS ERIYA & MIREMBE PRECEOUS

No	Parameter	Results		
		Anaerobic pond (pond 1)	Facultative pond (Pond 2)	Maturation pond (pond 3)
01	pH	7.06 7.43 7.62	7.56 7.54 7.40	7.95 7.86 7.61
02	Color	6820 6900	5640 5520	5180 5140
03	Total phosphorous	06 4.9	2.3 4.0	3.3 4.1
04	Temperature	23.6 23.6 23.9	23.3 23.0 23.4	24.5 23.7 23.4
05	Total Nitrogen	27.0 33.2	17.2 14.1	16.89 19.2
06	Chemical Oxygen Demand	8438 7831	1448 1385	1093 1137
07	Biochemical Oxygen Demand	1030 1152	599.2 23.5	189.49 165.32
08	*E-coli*	68000	5400	3600

Signed by ------------------------

BIOCORE ENTERPRISES LIMITED
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Appendix B- 11: Raw Data for the quality of waste water of each pond of the WSSP treatment sytem