# EVALUATING THE PERFORMANCE OF LIVINGSTONIA WASTEWATER STABILIZATION PONDS AND THEIR EFFECTS ON MPOPI STREAM IN RUMPHI, MALAWI

MSc THESIS (SANITATION)

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MZUZU UNIVERSITY

JULY, 2024

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A THESIS SUBMITTED TO THE FACULTY OF ENVIRONMENTAL SCIENCES, DEPARTMENT OF WATER AND SANITATION IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF

MASTER OF SCIENCE DEGREE IN SANITATION

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## DECLARATION

I hereby declare that this thesis titled, ‘*Evaluating The Performance Of Livingstonia Wastewater Stabilization Ponds And Their Effects On Mpopi Stream In Rumphi, Malawi’* has been written by me and is a record of my research work. All citations, references, and borrowed ideas have been duly acknowledged. It is being submitted in fulfillment of the requirements for the award of the Master of Science Degree in Sanitation at Mzuzu University. None of the present work has been submitted previously for any degree or examination in any other University.

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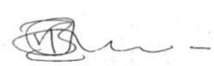

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## CERTIFICATE OF COMPLETION

The undersigned, certify that this thesis is a result of the author's own work, and that to the best of our knowledge, it has not been submitted for any other academic qualification within the Mzuzu University or elsewhere. The thesis is acceptable in form and content, and that satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate through an oral examination held on 30 /05 /2024.

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# DEDICATION

This study is dedicated to my mother, Mrs. Tryness Jere for her inspiration and charismatic personality that changed my life. It is my sincere hope that my family and friends will get motivated to pursue their education further and lead successful lives.

## ACKNOWLEDGEMENT

I express my sincere gratitude to my research supervisors, Engineer Eddie Mtonga and Dr Russel Chidya for the valuable support, coaching, advice, suggestions and commitment throughout the duration of this study. Special vote of thanks is extended to the University of Livingstonia for permitting the researcher access to collection of the test samples; Northern Region Water Laboratory staff in Mzuzu for their support and technical input; Mzuzu University Staff members and my classmates. Above all, I would like to thank God for the good health, guidance, support and for allowing me to complete this work.

## ABSTRACT

Partially treated effluent contributes to water quality degradation of water bodies in Malawi. This study was aimed at evaluating the overall performance of Livingstonia Wastewater Stabilization Ponds and their effects on Mpopi stream in Rumphi, Malawi. Representative duplicate grab samples ($n$ = 40) were collected from five sampling points from the treatment ponds (inlet and outlet), effluent discharge point (experiment), upstream (control) and downstream in four sampling campaigns executed from October 2022 to January 2023. Physico-chemical and microbiological parameter were analyzed and then the effluent was compared with the Malawi Effluent Standards (MS 539:2013). Data was analyzed using IBM SPSS version 23. The results showed that effluent does not meet the Malawi Effluent Standard (MS 539:2013). High levels of 5-day Biochemical Oxygen Demand (40.80 mg/L), E. Coli (253 cfu/100 mL), Total Phosphorus (1.67 mg/L), Total Suspended Solids (746.00 mg/L), Turbidity (42.65 mg/L) above Malawi Standards specifications for industrial effluents tolerance limits in the effluent (20 mg/L) proved poor performance of the plant. Similarly, high levels 5-day Biochemical Oxygen Demand (3.38 mg/L), E. Coli (65.00 cfu/100 mL), Turbidity (1.65 mg/L), $NO_3^-$ (6.00mg/L), $NH_3$ (2.50 mg/L), Total Dissolved Solids (26.50 mg/L), Dissolved Oxygen (5.10mg/L), temperature (26.48 $^oC$), Total Suspended Solids (7.48 mg/L) and pH (6.25) on discharge point than upstream point in the stream, were indicative of water pollution resulting from the effluent. Also the study expressed lack of professional ponds maintenance, stream monitoring and inadequate laboratory equipment's as factors that contribute to poor performance of the wastewater stabilization ponds. Therefore, there is a need for regular maintenance, specialized staff and adequate laboratory services for monitoring of the ponds' performance and their effects on water quality.

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| | |
|---|---|
| ANOVA | Analysis of Variance |
| APHA | American Public Health Association |
| $BOD_5$ | 5Day Biochemical Oxygen Demand |
| COD | Chemical Oxygen Demand |
| DO | Dissolved Oxygen |
| EC | Electrical Conductivity |
| E. Coli | Escherichia Coli |
| EPA | Environmental Protection Agency |
| FC | Fecal Coliform |
| IWA | International Water Association |
| MBS | Malawi Bureau of Standards |
| MS | Malawi Effluent Standards |
| SDG | Sustainable Development Goal |
| SPSS | Statistical Package for Social Sciences |
| SRWSIHL | Sustainable Rural Water infrastructure for improved Health and Livelihood |
| TSS | Total Suspended Solids |
| UWSPs | University of Livingstonia Wastewater Stabilization Ponds |
| WHO | World Health Organisation |

# CHAPTER ONE: INTRODUCTION

## 1.1 Background information

Wastewater stabilization ponds are a commonly used low cost wastewater treatment method worldwide, especially in areas with limited resources (Miller *et al*., 2017). In the pursuit of sustainable development and environmental stewardship, the management of wastewater is of paramount importance **(**Mogha, 2018). Wastewater stabilization ponds, particularly in regions where infrastructure and resources are limited, presents a significant challenge and opportunity **(**Miller *et al*., 2017**)**. Globally, inadequate wastewater treatment practices and improper storage of drinking water commonly lead to waterborne illnesses such as Cholera (Baloyi *et al*., 2014; Teklehaimanot *et al*., 2015). Even though, the purposive discharge of organic wastes for disposal has been practiced since early times; different systems are used worldwide for wastewater treatment such as activated sludge, trickling filter and wastewater stabilization pond systems (United Nation, 2017). Emptying of onsite facilities is often neglected and wastewater overflows from the pits to the roads or gardens presenting a health risk to the population (Roberto, 2012; Malik, 2015). However; if treated properly wastewater can be reused as resources. This is why natural technologies for wastewater treatment such as wastewater stabilization ponds are paid much attention due to low cost, easy maintenance, long life and desirable ability for effluent reuse (Kayira and Wanda, 2021; Ngoma *et al.*, 2020; Mogha,2018; Mdolo, 2017; Morro, 2012; Shahmahdi, 2020).

In African countries like Zimbabwe and Malawi partially treated or untreated wastewater is discharged into surface water bodies resulting in pollution (Miller *et al*., 2017; Mogha, 2018).

Most of the times it is the rising population, rapid urbanization, growing industrialization combined with pollution from sewage and untreated effluents that have put a major strain on water availability and water quality in rivers and streams (Kayira and Wanda, 2021; Ngoma *et al*., 2020; Msilimba, 2014). For example, a study conducted in Harare (Zimbabwe's capital city), revealed that the city's water management challenges were caused by the discharge of poorly treated effluent into Lake Chivero, which is the city's raw water source (Muserere *et al.*, 2014; Chirisa, 2017). The future scenario that water resources will be further depleted by a growing world population will be coupled increasingly with environmental degradation due to poor pollution control, particularly in most of the developing countries (Jacobsen *et al*., 2013; Okello, 2015). It is important to treat and reuse wastewater as it contains concentrated amounts of waste such as toxins, pathogens, nutrients and many others that may be harmful to the environment if left untreated (Kayira and Wanda, 2021; Ngoma *et al*., 2020; Lundgren, 2013). This makes Wastewater stabilization ponds very crucial in the effluent reuse, Malawi 2063 Implementation plan, provision of sanitation and safe water for all as per sustainable development goal number 6 and the vision of the National Sanitation Policy (2008).

Similarly; in Malawi, partially and untreated effluent is discharged into water bodies (Mogha, 2018). The researcher believes that lack of adequate wastewater treatment causes increase in water bodies pollution and outbreaks of waterborne diseases among communities as it is with Cholera outbreaks in Malawi including Rumphi district. However proper treatment of wastewater could have helped in provision of safe water. The discharge of partially or untreated wastewater into the environment especially water bodies is against National Sanitation Policy (2008), National Water policy (2023) and Environmental Management Act (2008).

Thus, water pollution control approaches which focus on proper treatment of effluent for reuse and reducing the discharge of wastewater into water bodies at the point of wastewater treatment plant should be prioritized (Kayira and Wanda, 2021; Ngoma *et al* 2020; Mogha,2018; Capodaglio, 2017).

University of Livingstonia Wastewater Stabilization Ponds (UWSPs) comprises of four wastewater stabilization ponds by design. There is one primary facultative pond, two secondary facultative ponds and one maturation pond. All these are arranged in a treatment series with each pond performing its specific duty. Facultative ponds are designed for the removal of BOD with relatively low surface loading (100-400 kg BOD/ha day) to make a conducive environment for the growth of algal, since the photosynthetic algal population is responsible for generation of oxygen for BOD removal by the pond bacteria (Beyerlin & Bodansky, 2015). However; due to blockages and non-specialized maintenance wastewater by-passes 3 ponds and discharged directly into the stream after passing the primary facultative pond only. The key argument is that one facultative pond cannot perform the duties of all the by-passed ponds as each pond is designed to perform a specific task. The sewage from the University and the surrounding community is treated in the pond and discharged into Mpopi stream for reuse, in form of domestic purposes, fish farming and irrigating crops, which may be eaten raw (Kumwenda *et al*., 2012; Malawi Government, 1995; Nyirenda, 2017).

On the other hand, the efficient functioning of the wastewater stabilization ponds can be compromised by various factors leading to suboptimal performance and potential environmental performance and environmental hazards (Ngoma *et al*, 2020).

It is questionable if the primary facultative pond reduces physico-chemical and microbiological parameters to meet the Malawi Effluent Standard (MS 539:2013). On a similar note, the effluent from the treatment plant is suspected of containing high levels physico-chemical and microbiological parameters that contaminates the stream as shown by other researchers (Msilimba *et al*., 2014, Palamuleni, 2015). It is thus imperative to assess the extent of effluent quality as compared to the Malawi Effluent Standard (MS 539:2013), effects of the effluent on water quality in the receiving water and identify factors that compromise functionality of the wastewater stabilization ponds. Nevertheless, there is lack of information regarding the efficiency of the plant and its effects. Despite all this, there is continued discharge of partially treated effluent into Mpopi stream for reuse which demonstrates lack of knowledge regarding the consequences of this practice. Therefore, the aim of the present study was to evaluate the overall performance of Livingstonia wastewater stabilization ponds and their effects on water quality in Mpopi stream.

## 1.2 Problem statement

Despite an outcry by previous researchers on poor wastewater management and it effects (Ngoma *et al*., 2020; Mdolo., 2017; Mogha 2018., Musa and Chidiokonkwo 2017), University of Livingstonia is still using wastewater stabilization ponds that have visible blockages due to limited maintenance, lack of specialized staff for the operation and under equipped laboratory for monitoring of its performance and effects. The study was done because there is an accidental wastewater by-pass way that leads partially treated effluent into the stream. This may compromise the efficiency of the treatment plant because by design the influent was supposed to go through four ponds in a series before being discharged into the stream (Nyirenda, 2016).

Each pond is designed to reduce a specific percentage of physico-chemical and microbiological parameters to meet a minimum level that is allowed to be discharged into the stream to avoid water pollution based on the Malawi Effluent Standard (MS 539:2013). However, due to blockages and non-specialized maintenances at UWSPs, the influent passes into the primary facultative pond only before taking its own bypass way into the stream. This is likely to hinder its efficiency and cause downstream water pollution as it was described by other researchers (Kayira and Wanda, 2021; Ngoma *et al*., 2020; Mogha,2018; Mdolo, 2017). This is against the National Sanitation Policy (2008), National Water policy (2023) and Environmental Management Act (2008).

It is unknown if the effluent meets the minimum MS 539: 2013 in order to be discharged into the stream. The stream contamination may lead to communicable diseases like Cholera and diarrhea which is already a health burden in Livingstonia especially affecting children under five years of age (Malawi Demographic Health Survey, 2022; 2023; Malawi Government Health Information Management System 2016; 2017; 2018 & 2019). Despite the continued deterioration of water quality in surface water bodies, there is lack of comprehensive and regular monitoring of UWSPs and receiving stream by the responsible authorities (Msilimba *et al*., 2014, Palamuleni, 2015).

## 1.3 Study objectives

### 1.3.1 Main objective

The main objective of this study was to evaluate the overall performance of University of Livingstonia wastewater stabilization ponds and their effects on Mpopi stream in Rumphi, Malawi.

### 1.3.2 Specific Objectives

a) To determine the physico-chemical and microbiological parameters at University of Livingstonia Wastewater Stabilization Ponds and compare the effluent with the Malawi effluent standards.

b) To determine the effect of University of Livingstonia Wastewater Stabilization Ponds effluent on water quality in Mpopi stream.

c) To establish factors that contributes to inadequate performance of the University of Livingstonia Wastewater Stabilization Ponds.

## 1.4 Research questions

a) Does effluent from University of Livingstonia Wastewater Stabilization Ponds meet the Malawi Effluent Standards?

b) Does effluent from University of Livingstonia Wastewater Stabilization Ponds contaminates Mpopi stream?

c) What are the factors that contributes to inadequate performance of the University of Livingstonia Wastewater Stabilization Ponds?

## 1.5 Justification

This study provided empirical evidence regarding the performance of Livingstonia wastewater stabilization ponds and their effects on water quality in Mpopi stream. This will promote good health by triggering change through technical, behavioral, managerial and operational actions toward improvement in sanitation and water polices and services in Livingstonia and beyond. This will help in meeting the Malawi 2063 National Implementation Plan aspirations.

It will help to provide clean water, safe sanitation and hygiene services to Malawians while promoting environmentally friendly practices. This will help to achieve the Sustainable Development Goal number six (Water and Sanitation for all by 2030). Also, the dissemination of research result will provide knowledge to water users and relevant stakeholders (University of Livingstonia, Rumphi District Council) and the community at large the risk of using water from Mpopi stream. This will help the community to avoid using the water for drinking hence reducing water born diarrhea diseases which kills a lot of under five children in Livingstonia (Malawi Government Health Information Management System, 2016; 2017; 2018 & 2019).

# CHAPTER TWO: LITERATURE REVIEW

Pollution is causing widespread concern and has become an important area of interest in the field of modern research (Mishra, 2012; Prashant, 2020). Water pollution has increased in both developed and developing countries, threatening the physical and environmental health of billions of people (Javier *et al*., 2017) About 3.4 million people die worldwide each year from water-related diseases like cholera, typhoid, polio, ascariasis, cryptosporidiosis and diarrheal diseases that are transmitted due to poor sanitation (United Nation Environmental Protection, 2016). Therefore, poor sanitation practices and improper storage of drinking water commonly lead to waterborne illnesses (WHO, 2018). Appropriate operation and maintenance of Wastewater Treatment Plants (WWTPs) is essential in producing effluent, which meet quality requirements of regulatory agencies and minimizes detrimental effects on the environment as well as public health (Kayia and Wanda, 2021; Ngoma *et al*., 2020; Mogha,2018; Mdolo, 2017).

## 2.1 Wastewater treatment plants

The purposive discharge of organic wastes for disposal has been practiced since early times; different systems are used worldwide for wastewater treatment such as activated sludge, trickling filter and waste stabilization ponds (United Nation, 2017). Existing traditional onsite wastewater systems, are usually overloaded thereby presenting a major pollution source that threatens the scarce water resources and the immediate environment. Emptying of onsite facilities is often neglected and wastewater overflows from the pits to the roads or gardens presenting a health risk to the population (Roberto, 2012; Malik, 2015). This is against National Sanitation Policy (2008), National Water policy (2005) and Environmental Management Act (2008).

This is why natural technologies for wastewater treatment such as stabilization ponds are paid much attention due to low cost, easy maintenance, long life and desirable ability for effluent recycling (Morro, 2012; Shahmahdi, 2020). Additionally, wastewater stabilization ponds are becoming more popular in tropical and subtropical regions because of the abundant sunlight and high ambient temperatures (Zhao, 2018) which are some of the requirements for effective treatment of wastewater in natural treatment processes as compared to conventional mechanical technology (Lam, 2015). They are common in all parts of the developing world, where they can serve large populations (Zhao, 2018). A wastewater stabilization pond is a relatively shallow body of wastewater contained in an earthen basin which is designed to treat wastewater (Zhao, 2018). Wastewater stabilization ponds are used to treat a variety of wastewaters, from domestic wastewater to complex industrial wastewaters, and they function under a wide range of weather conditions, i.e., tropical to arctic.

The ponds are designed to achieve different forms of treatment up to three stages in series, depending on the organic strength of the input waste and effluent quality objectives (Geothals, 2017). Usually, classical Wastewater Stabilization Ponds consist of an anaerobic pond, followed by primary or secondary facultative pond. If further pathogen reduction is necessary, maturation ponds will be introduced to provide tertiary treatment. They are very widely used for small rural communities but in warmer climates (the Middle East, Africa, Asia and Latin America) ponds are commonly used for large populations (Hon, 2017). Pond systems are commonly employed for municipal sewage purification, especially in developing countries, due to its cost-effectiveness and high potential of removing different pollutants. In addition, their operation is easy and their maintenance requirements are minimal.

They are usually the most preferred system in hot climate zones (Hon, 2017). Wastewater stabilization pond technology has advanced greatly in recent years. This system has been proven to be reliable, economic, flexible and adaptable, and able to meet the most stringent effluent standards (Almasi, 2018).

### 2.1.1 Types of wastewater stabilization ponds

Wastewater stabilization ponds are the final stage of liquid waste treatment before effluent is either reused or released into the environment. It is important to treat liquid waste to prevent water contamination with toxins, pathogens, nutrients and many others that may be harmful to the environment if left untreated (Paulshus, 2019). Rising population, rapid urbanization, growing industrialization combined with pollution from sewage and untreated effluents have put a major strain on water quality in many countries including Malawi (Msilimba, 2016). This makes Wastewater Treatment Plants very crucial in provision of sanitation and safe water for all as per sustainable development goal number 6 and the vision of the national water policy (Giorgis, 2015). Stabilization ponds or lagoons, also called oxidation ponds, are operated as aerobic ponds, aerobic–anaerobic (facultative) ponds (which are most common), aerated ponds or anaerobic ponds/lagoons (Piras, 2020).

#### a) *Anaerobic pond*

Anaerobic ponds are the smallest units in the series. They are sized according to their volumetric organic loading, which means the quantity of organic matter, expressed in grams of BOD per day, applied to each cubic meter of pond volume. Ponds may receive volumetric organic loadings in the range of 100 to 350 g BOD/$m^3$ day, depending on the design (Khan, 2020).

The primary treatment usually takes place in the anaerobic pond which is mainly designed for removal of suspended solids, and some of the soluble organic matter (Khan, 2019). They reduce N, P, K and pathogenic microorganisms by sludge formation and the release of ammonia into the air (Daud, 2018).

The high loadings produce a strict anaerobic environment throughout the pond volume (i.e., there is no dissolved Oxygen present). The depth of anaerobic ponds is in the range 2−5 m; the precise value depends on the ground conditions and local excavation costs − depths are often 3−4 m **(**Giorgis, 2015). The biochemical reactions which take place in anaerobic ponds are the same as those occurring in anaerobic digesters, with a first phase of acidogenesis and a second slower-rate of methanogenesis. Ambient temperatures in hot-climate countries are conducive to these anaerobic reactions **(**Wang, 2018). Anaerobic ponds work extremely well in warm climates: for example, a properly designed pond will achieve around 60 % $BOD_5$ removal at 20 °C and over 70 % at 25 °C and above. Organic matter removal in anaerobic ponds is governed by the same mechanisms that occur in all other anaerobic reactors (Talvitie, 2017). Odor nuisance from anaerobic ponds, typically due to hydrogen sulfide, has always been a concern. However, odor is not a problem provided that the anaerobic pond is properly designed and the sulphate ($SO_4^{2-}$) concentration in the raw wastewater is less than 500 mg/L **(**Giorgis, 2015**).** Removal of bacterial pathogens in anaerobic ponds is poor, due to the absence of detrimental environmental factors to enhance decay. Bacterial pathogens are therefore only removed by adsorption to solids and subsequent sedimentation. Helminths eggs are removed fairly effective (up to 90 %) in anaerobic ponds by plain sedimentation (Thalla, 2019).

b) ***Facultative Pond***

Facultative ponds (1.5-2 m deep) could either be primary or secondary. Primary facultative ponds receive raw wastewater, whereas secondary facultative ponds receive effluent from anaerobic ponds (Ragush *et al*., 2015). Facultative ponds are designed for the removal of BOD with relatively low surface loading (100-400 kg BOD/ha day) to make a conducive environment for the growth of algal, since the photosynthetic algal population is responsible for generation of oxygen for BOD removal by the pond bacteria (Beyerlin & Bodansky, 2015). Facultative ponds are colored dark green due to the presence algae (Hong *et al*., 2018). The algae concentration in a healthy facultative pond is usually dependent on surface loading and temperature (Akbari, 2016).

The photosynthetic activities of the pond algae, results in a diurnal variation in the concentration of dissolved oxygen (DO) and power of Hydrogen (pH). DO usually starts rising after sunrise rises to a maximum in the mid-afternoon, and is lowest during the night (Joel *et al*., 2017). Similarly, at peak algal activity carbonate and bicarbonate ions react to provide more carbon dioxide for the algae, thereby raising the pH to above 9, (which kills fecal bacteria) (Kamali, 2017). The wind action aids in good mixing and ensures a more uniform distribution of BOD, DO, bacteria and algae; and hence a better degree of waste stabilization. If wind is blocked, the algal population concentrates in a narrow band, during daylight hours, and causes fluctuations in effluent quality (especially BOD and suspended solids) (Ragush *et al*., 2015). As a result of these algal-bacterial activities, about 30 % of the influent BOD leaves the primary facultative pond in the form of methane, the remaining BOD ends up in algal cells (Khodabakhshi & Heidari, 2015). The Hydraulic Retention Time for ponds treating anaerobic effluent varies between 5 and 30 days.

Facultative ponds are most widely used for treatment of municipal wastewater following aerated or anaerobic ponds. Filtered effluent BOD values range from 20 to 60 mg/L, while total suspended solids (TSS) levels vary from 30 to 150 mg/L **(**Gunatilake, 2015). A facultative pond is built with a smaller depth and with a larger surface area than an aerobic pond of the same volume. The aerobic condition in the upper layer is produced by the dissolved oxygen; this is primarily generated as a result of photosynthesis caused by the incidence of solar radiation upon the algal population of the pond. In facultative ponds, waste conversion is performed by a combination of aerobic, anaerobic, and facultative bacteria **(**Ebrahim, 2019**).** Waste treatment in oxidation ponds is the result of natural biological processes carried out mainly by bacteria and algae.

Waste treatment is carried out by a mixture of aerobic, anaerobic, as well as facultative microorganisms. These ponds allow the accumulation of solids, which are degraded anaerobically at the bottom of the pond. Many categories of organisms play a role in the treatment process **(**Yung, 2015). Aerobic and facultative bacteria in the upper and middle layers metabolize the dissolved, colloidal and suspended organic matter, consuming dissolved oxygen and producing carbon dioxide; this is transformed into algal cell material (organic carbon) **(**Pretel, 2016**).** Respiration occurs in the presence of sunlight; however, the net effect is oxygen production, i.e. photosynthesis. During photosynthesis algae uses carbon dioxide, resulting in high pH levels in low alkalinity wastewater. In facultative ponds, algae can use bicarbonate as a carbon source for cell growth; when this occurs; there is a diurnal fluctuation in pH **(**Pretel, 2016).

### *c)* **Maturation *ponds***

Maturation ponds are about 1-1.5m deep and receives the effluent from a facultative pond, the size and number of maturation ponds present on a wastewater treatment plant is dependent on the bacteriological quality of the final effluent (Khodabakhshi & Heidari, 2015). Maturation ponds usually show less vertical biological and physicochemical stratification and are well oxygenated throughout the day (Sharma *et al*., 2017). Maturation ponds have a much more diverse algal population when compared to that of facultative ponds. A properly designed maturation pond will remove excreted pathogens, a significant amount of nutrients and a small amount of BOD (Hlongwane, 2019). A small amount of BOD is removed in maturation ponds, due to the lower algal concentrations (and hence lower "algal BOD") which, is as a result of a decreased nutrients supply and predation by protozoa and micro-invertebrates such as *Daphnia* or by fish (Miller-Robbie *et al*., 2017).

Maturation ponds are used mainly for reduction of pathogenic organisms like fecal bacteria, viruses, protozoa and other pathogens maturation ponds may also remove some algae and some nutrients. Occasionally however, algal blooms do occur in maturation ponds (Kalbar, 2015). The effluent from facultative ponds treating municipal sewage or equivalent input wastewater will normally contain at least 50 mg/L $BOD_5$ and if an effluent with lower $BOD_5$ concentration is required it will be necessary to use maturation ponds (Elena, 2020). Although the longer retention in anaerobic and facultative pond systems will make them more efficient than conventional wastewater treatment processes in removing pathogens, the effluent from a facultative pond treating municipal sewage will generally require further treatment in maturation ponds to reach effluent standards imposed for reuse in unrestricted irrigation (Elena, 2020).

Fecal coliform (FC) bacteria are commonly used as indicators of excreted pathogens and maturation ponds can be designed to achieve a given reduction of FC. Protozoan cysts and helminths ova are removed by sedimentation in stabilization ponds and a series of ponds with overall retention of 20 days or more will produce an effluent totally free of cysts and ova (Water Sanitation and Hygien, 2017). The bactericidal effect of maturation ponds is due to several natural factors, including sedimentation, lack of food and nutrients, solar ultraviolet radiation, high temperatures, high pH values, predators, the toxins and antibiotics excreted by some organisms as well as natural die off **(**Mitchell, 2016). In this way, shading by phytoplankton growth reduces the bacterial removal efficiencies. Nevertheless, high pH values produced during photosynthesis is also an important parameter for bacterial death (Gehrke, 2015).

d) ***Aerated Ponds***

In the aerated pond, oxygen is provided through the use of mechanical or diffused air systems. When aeration is used, the depth of the pond and the acceptable loading levels may increase. Aerated ponds are 2–6 m deep with a detention time of 10 days. They are used to treat high-strength domestic wastewater. Mechanical or diffused aeration is often used to supplement natural oxygen production or to replace it (Myroslav, 2016)**.**

### 2.1.2 Performance of wastewater stabilization ponds

In wastewater treatment, the pollutants of most concern are $BOD_5$, chemical oxygen demand (COD), TSS, total nitrogen (TN), ammonia ($NH_3^-$), nitrate ($NO_3$), orthophosphate ($PO_4^{3-}$), total phosphorus (TP), sulfate ($SO_4^{2-}$), sulfide ($S^{2-}$), Total Coliforms (TC) or FC (Ngoma, 2020).

In the European Union, pond effluents have to meet the same BOD requirement as other effluents (<25 mg/L) but with one very important difference: filtered samples are used to determine the BOD. Furthermore; in the EU pond effluents can contain up to 150 mg per liter, whereas effluents from other treatment processes can contain only 35 mg/L (Ngoma, 2020). But in India the standards for the discharge of treated wastewaters into inland surface waters are: 30 mg/L for BOD, 100 mg/L for TSS, 100 mg/L for TN, 2 mg/L for $S^{2-}$ and 5.5 – 9.0 for pH (Ngoma, 2020). Whereas the MS 539: 2013 recommend 20 mg/L for BOD, 70 mg/L COD, 100 mg/L for TSS, 50 mg/L for Nitrate nitrogen, 0.15 mg/L for TP, > 5mg/L for DO, 40 for temperature and 6.5 – 9.0 for pH.

Specification of the wastewater components measured or the form of pollution evaluated is essential for describing the efficiency of wastewater treatment plant. Most often, removal efficiency is expressed as a percentage and these values are used to compare different treatment processes and to determine if a particular treatment plant has accomplished the purpose for which it was developed (Mdolo, 2017). For example; a waste stabilization pond system in Egypt was evaluated for its performance for the removal of $BOD_5$, COD and TSS and showed that the pond system removal efficiency was 50.65 %, 48.95 % and 44.3 % respectively (Mahassen *et al*, 2008). In another study conducted in Ghana to assess the performance of waste stabilization ponds in treating domestic wastewater showed that the removal of $BOD_5$, TSS, COD, and $NH_3$ were effective with the removal of 77.1 %, 83.5 %, 70.6 %, 93.2 %, respectively (Hodgson, 2017). Similarly, Oke *et al*, (2016) found that waste water treatment ponds in Nigeria were able to achieve mean SS, $BOD_5$, COD, ammonia organic nitrogen and phosphate removal efficiency of 66.1 %, 93.58 %, 96.45 %, 87.58 %, 50.04 % and 80.8 %, respectively.

In a similar study, the average $BOD_5$ removal by wastewater stabilization ponds was found to be 69 % and the percentage removal for COD and TSS by the pond system was 76 % and 39 %, respectively (Naddafi *et al.*, 2008). This shows that removal efficiency is a powerful tool used in showing performance efficiency of wastewater stabilization ponds.

### 2.2 Pollution of water bodies that receive effluent

Most aquatic ecosystems around the world, have been polluted by untreated or partially treated wastewater, and other pollutants (Edokpayi *et al*., 2017). The major causes of this are; industrialization, increasing population density and high urbanization (Liu *et al*., 2016). The disposal of untreated or poorly treated sewage into surface water bodies in urban areas is common in most developing countries, including Malawi (Muserere *et al*., 2018). Discharge of untreated or partially treated sewage water in surface water bodies can lead to contamination of upper soil surfaces, sewage drainage facilities, surface water, and groundwater (Egwuonwu *et al*., 2017). The nutrients, nitrogen and phosphorous, are dominant in these municipal discharges, posing a great risk of eutrophication-related problems to the receiving waterbodies (Juma *et al*., 2019).

Water bodies with large algal blooms, may smother the lake bottom with organic material due to the death of the blooms. The decay of this dead algal material can reduce dissolved Oxygen in the surrounding water, thereby threatening the survival of many species of fish and other aquatic life (Nhapi *et al*., 2019). In addition, sewage effluent not only increases water treatment costs extensively, but also introduces a wide range of pollutants and contaminants to water sources (Hong *et al*., 2018).

All these effects of improper discharge of sewage effluent into surface waters will ultimately reduce the potential of concerned water bodies becoming water resources (Norah *et al*., 2015).

Anthropogenic nutrient enrichment of freshwater resources is now a global water resource problem (Liu *et al*., 2011). It is most evident in highly populated areas, where waterborne sewage system and agricultural practices contribute large amounts of nutrients into the receiving natural water systems (Tendaupenyu *et al*., 2016). The nutrients promote the growth of algae in receiving systems, causing a wide array of water quality problems (Li and Mitch, 2017). For example; a study carried out in South Africa, found out that Malamulele sewage plant was contributing to the deterioration of water quality of Mandzoro River downstream of the discharge point (Baloyi *et al*., 2014). In urban areas, "the indiscriminate disposal of industrial effluents and other wastes may contribute greatly to the poor quality of the water" (Mogha, 2018). Since people make use of untreated or partially treated waters from these sources, there is continuous outbreaks of waterborne / water related diseases such as cholera and diarrhea just to mention a few (Hanif *et al.*, 2012).

Like many other African countries, Malawi is experiencing rapid growth of industries resulting in difficulties in environmental conservation (Mogha, 2018). Specifically; sewage systems have been reported to be facing a wide range of challenges such as blocked sewer lines due to poor maintenance, improper design of some sections as well as lack of public awareness on use of the sewerage systems (Kayira and Wanda, 2021). The lack of political will is hindering the effective implementation of environmental conservation and natural resources management policies that the government has put in place (Kosamu *et al*., 2018).

A study on Likangala River revealed elevated levels of several pollutants in the effluent from Zomba wastewater treatment plant, making the water unfit for various uses (Lundgren, 2013). It could therefore be concluded that poorly functioning wastewater treatment plants contributes to the deterioration of our water bodies.

**2.3 Wastewater and water quality parameters**

Water quality is a term usually used to describe the physical, chemical and biological characteristics of water (Baird *et al*., 2017). Physical water quality parameters include temperature, turbidity, odor, salinity, solids, taste and conductivity. The chemical water quality comprises the inorganic constituents (i.e. metallic elements: Na, K, Mg, Ca, Fe, Pb and Zn as well as the nonmetallic: $F^-$, $Cl^-$, $SO_4^{2+}$, hardness and organic constituents such as pesticides and biological oxygen demand (BOD). In contrast, microbiological water quality parameters comprise various groups of biological organisms such as bacteria, viruses and algae (Udhayakumar, 2016).

A study done by Al-Mayah & Al-Azzawi (2013) about the monthly changes that occurred on some chemical and physical properties of Al-Gharraf River in Al-Haay city, concluded that values of air temperature, water temperature, pH, DO, total hardness, EC, chlorides and $NO_3$ have been within permitted limits, while values of $BOD_5$, turbidity, dissolved solid substances, suspended solid substances and phosphates ($PO_4^{-3}$**)** have been exceeded permitted limits due to discharge of domestic sewage directly into the river. Also, a study done by Kumwenda *et al.*, 2011 showed that most water parameters in the river were higher than European Commission Standards of 1994 for maintenance of aquatic life, irrigation and domestic use.

### 2.3.1 Temperature

Generally, wastewater has a higher temperature than the local water supply, as a result of a high content of warm water from households or industries and microbial activity (Mccardle, 2015). The mean temperature values vary with the local air temperatures, but the optimum temperature for biological treatment of wastewater is in the range of 25 to 35 °C. For lower temperatures the microbial reactions will occur more slowly, and at very high temperatures, aerobic digestion and nitrification cease completely (Li & Lu, 2017). Effluent water with higher temperatures than that naturally found in the recipient waters could affect the conditions required by aquatic life and can thus cause a change in the species of fish that live therein (Helen, 2018).

Previous studies in Europe and United States of America have shown that the nutrient removal efficiency by ponds is higher in summer where temperatures are higher than in winter where temperatures are lower (Abed, 2020). In a similar study the highest removal of nitrogen (92 %) and phosphorus (89 %) was achieved at a temperature of 30 °C and removal efficiencies were observed to be decreasing at temperatures higher than 30 °C (Toutian, 2020). It could be observed that at temperature higher than 30 °C the removal efficiency decreases because the activity of microorganism becomes lower after this temperature which means ability to remove pollutants decreases (Wenger, 2011; Khanifan, 2017). This result is in a good agreement with the conditions detected by environmental protection agency (Eric,2011; Abed, 2020).

### 2.3.2 Electrical conductivity

Electrical Conductivity (EC) arises from the presence of dissolved ions in water. Primarily, as the concentration of dissolved salts in water increases, the conductivity also increases.

EC is usually used to estimate the Total Dissolved Solids (TDS) in water (Geng, 2018).

### 2.3.3 The pH

The pH refers to the negative logarithm of the hydrogen-ion concentration, expressed as pH = -log10 [H+]. Since most microbial life thrives within narrow pH ranges (typically 6-9), the hydrogen-ion concentration is of great concern in relation to biological treatment (Sharma *et al.*, 2017, Edjere *et al.*, 2016). Influent water with exceptional high or low pH-values (typically industrial wastewater) can be hard to treat biologically (Zalihat & Kamaludeen, 2019). Effluent water may also affect the pH of the natural waters in the recipient waters. As a chemical component of the wastewater, pH has direct influence on wastewater treatability regardless of whether treatment is physical/chemical or biological. Because it is such a critical component of the makeup of the wastewater, it is therefore critically important to treatment (Noori *et al.*, 2019).

Abnormal or irregular pH in biological treatment processes can result in a significant decrease in the rate of removal of organic compounds from the environment. It takes residence or contact time during wastewater treatment for the pH to adjust appropriately (Ba *et al.*, 2018). A very narrow pH range (i.e., 7.0 to 8.0) requires less contact or residence time as compared to a wider pH range (i.e., 7.0 to 10.0), so the procedure is affected by the required pH adjustment range (X Du, 2018). At an acidic pH; the excess hydrogen ions begin to form bonds with and break down the cell, slowing their growth or killing them outright (Mkude & Saria, 2014; Eze, 2018). After a wastewater treatment cycle the pH must be raised back to neutral by use of additional chemicals or it will continue to damage any living cell it comes into contact (Sabeen *et al.*, 2018).

### 2.3.4 Dissolved Oxygen

DO is essential for all kinds of aerobic life forms. In aerobic biological wastewater treatment, dissolved oxygen in the water is required for bacterial respiration (Mkude & Saria, 2014; Razzak, 2017). Environmental conditions, such as temperature, partial pressure of the gas in the atmosphere, the solubility of the gas and the concentration of impurities such as salts and suspended solids, all affect the quantity of oxygen that can be present in a solution (Huang, 2017). The comparison of the DO-concentration before and after biological treatment steps are thus of great interest, since this indicates the rate of biological activity within the treatment unit (Goncalves, 2017). Thus, dissolved–oxygen measurement is vital for maintaining aerobic treatment processes which aids in wastewater treatment. Another study done in Zimbabwe found that "a rapid fall in the DO indicates a high organic pollution in the river" (Monica, 2020). The optimum DO value for healthy aquatic life in a water body is 4 to 6 mg/L (Makori, 2017) and > 5 mg/L (MS 691:2005).

### 2.3.5 Nitrates and Ammonia

Raw domestic wastewater normally holds a large fraction of organically bound nitrogen, and a low fraction of inorganic forms such as $NH_3$, nitrite ($NO_2^-$) or $NO_3^-$ (Hdjimichael *et al*., 2015). The term *total nitrogen* refers to the sum of the organic and inorganic compounds of nitrogen (Ragush *et al*., 2015). When the term *Kjeldahl nitrogen* is used, it refers to the sum of organic and inorganic nitrogen from ammonium (Berth, 2020). Nitrogen is an essential nutrient for the growth of microorganisms, plants and animals (Tazkiaturrizki *et al*., 2018). The content of nitrogen in the effluent of wastewater cause an environmental concern, as it contributes to eutrophication (Hanson, 2018).

Decomposition by bacteria changes the organic form of nitrogen to ammonia, and the relative amount of ammonia present in the wastewater is thus an indicator of the age of the wastewater. In aerobic environments, bacteria oxidize the ammonia nitrogen to nitrites and nitrates (Ragush *et al*., 2015). Thus, predominance of nitrate nitrogen in wastewater indicates that the wastewater has been stabilized with respect to oxygen demand (Feng, 2017). The excessive release of nutrients ($NO_3^-$ and $PO_4^{-3}$) into water bodies increases turbidity, plant and animals' biomass which in the long run increases species diversity resulting in change of dominant species of the aquatic biota (Nayla, 2019).

### 2.3.6 Phosphates and Phosphorus

Just like nitrogen, phosphorus is an essential nutrient for growth of biological life (Sukacova, 2015). Raw wastewater normally contains a large fraction of phosphate, and as it makes a significant contribution to eutrophication when led untreated into a natural water body, it should be removed during treatment (Carrillo, 2020). Phosphorus is, just like nitrogen, of great interest in relation to reuse purposes, since it constitutes a resource that can be utilized for irrigation means (Qadir *et al*., 2010). Studies on water quality in Blantyre and Zomba indicated phosphate ranges of 0.63 to 5.5 mg/L in some streams and effluent from various wastewater treatment plants (Lundgren, 2013).

### 2.3.7 Total suspended solids

The TSS gives an indication of the content of solid matter in the wastewater. In general, raw wastewater contains solids of variable types and sizes (Chipofya *et al.*, 2013). Larger objects and course materials are normally removed in the first stage of the treatment process.

TSS values are widely used to determine treatment efficiency for conventional treatment processes and to assess the need for effluent filtration in the case of reuse applications (Ngoma *et al*., 2020).

### 2.3.8 Microbiological water quality indicators

Water contaminated with pathogenic bacteria such as *Escherichia Coli* (*E. Coli*) can make people suffer from water-borne illness. Although some *E. Coli* infections are self-limiting in nature, resulting in full recovery after a few days of mild to moderate illness, certain species are considered more virulent because they can easily cause aggressive symptoms, particularly those belonging to the group 0157: H7 (Barrios, 2018). The presence of *E. Coli* in water is strongly suggestive of contamination by fecal waste since the organism can only be traced in human intestines and other mammals (Kirsten, 2017).

Coliform bacteria are rod-shaped Gram-negative non-spore forming bacteria and are mostly used as a measure of the sanitary quality of water and food. They are capable of fermenting lactose to produce acid and gas when incubated at a temperature range of between 35–37 °C (Joshua, 2014). Coliform bacteria are abundantly found in the feces of humans and other mammals and do not normally cause harm. However, their presence can be indicative of a higher probability of other highly infective pathogenic agents of fecal origin such as *E. coli* (Subodh, 2017). Total coliforms are a large collection of different kinds of bacteria whereas fecal coliforms are a type of total coliform bacteria that are mostly found in feces; *E. Coli* is a sub-group of FC (Kirsten, 2017). The relationship between total coliforms (TC), FC, and *E. Coli* is illustrated in the Figure 1 below.

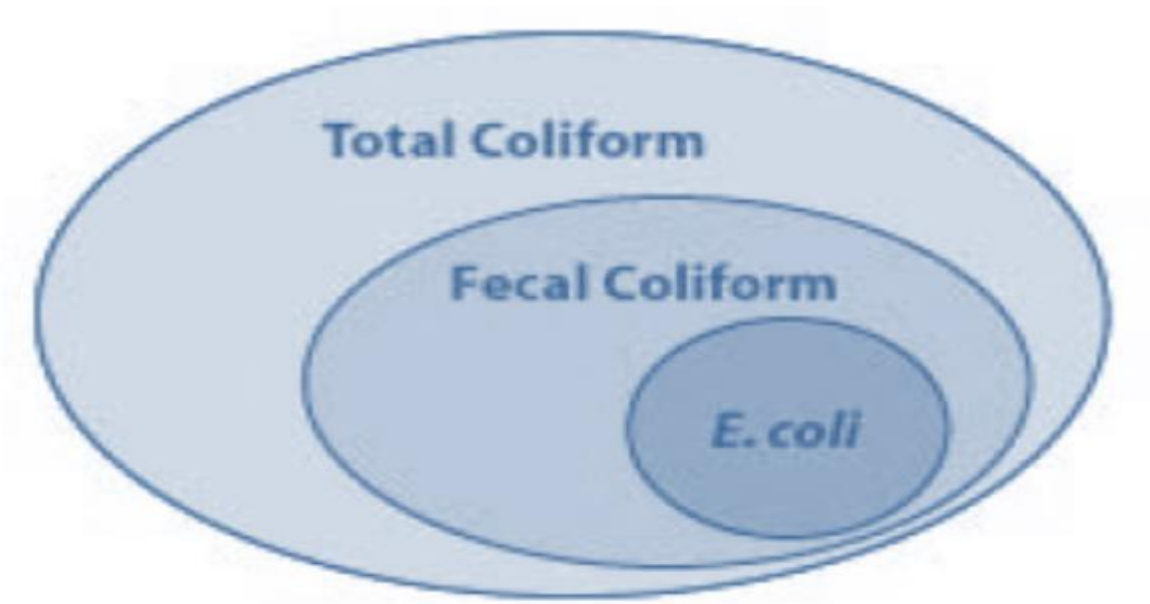


**Figure 1:** Relationship between Total Coliform, Fecal Coliform and Escherichia Coli

Matlob (2016) studied some bacteriological characteristics in Bany-Hassan river and one of its branches in Karbala city, The results showed that water in this study was not matching to the Iraqi and the international standards for drinking water and some other indicators according to the levels of the total number of bacteria and coliform bacteria and fecal coliform bacteria, recorded between 55-2438 cell/mL and 42-1522 cell/100 mL and 25-788 cell/100 mL, respectively for all mentioned bacterial groups. A study done by Chidya *et al*., 2011 showed that high coliform counts above WHO (2008) and MS (2005) limits of (0 cfu/100 mL) were measured at sites S15 and S16 where Zomba and Chancellor College sewage effluent is discharged. On the same way the use of untreated or partially treated waters from sewage contaminated rivers is associated with continuous outbreaks of waterborne / water related diseases such as cholera and diarrhea just to mention a few (Hanif *et al*., 2012).

# CHAPTER THREE: MATERIALS AND METHODS

## 3.1 Description of the study area

### 3.1.1 Geographical location

University of Livingstonia is found in the northern region of Malawi at Latitude 10º 36´S and Longitude 34º 06´E. Malawi is one of the least developed countries found in the sub-Saharan Africa with an estimated population of about 17,563,749 (National Statistical Office, 2019). It is a land locked country and has an area of about 118,484 square kilometers, one third of which is made up by Lake Malawi. The country is divided in three regions; North, Central and South (Malawi Government, 2020).

### 3.1.2 Demography and settlement pattern

The rapid population growth, weak institutional governance, legal framework and inadequate physical planning are leading to environmental degradation, pollution, deforestation and uncontrolled development on fragile lands (Malawi Demographic Health Survey, 2018). Only 20 % of Malawi's population is classified as urban, making the country one of the least urbanized countries in Africa. However, Malawi is one of the most urbanizing countries in Africa at 6.3 % per annum, three times the global rate and nearly twice the Africa rate of 3.5 % Rumphi district covers an area of 4769 $km^2$ and has a population of 128,360 (National Statistical Office, 2019). The opening of the University has caused rapid population growth in the surrounding villages. This has caused pressure in accessing clean water, solid waste collection and disposal, sanitary and sewage facilities.

### 3.1.3 Water and sanitation

About one third of the population use piped water however, two third use streams and rivers as sources of water for irrigation, fish farming and domestic use (DHS, 2020). Similarly, on campus most people use flash toilets while others use traditional pit latrines. University of Livingstonia wastewater stabilization ponds are suspected of contaminating Mpopi stream as wastewater by-passes other middle ponds and discharged directly into the stream.

Rumphi District benefited from Sanitation business project called Sanitation Business Model, which aimed at equipping poor households to have sustainable sanitation facilities so that they attain an open defecation free status (Gondwe, 2020). Livingstonia area also benefited from Sustainable Rural Water infrastructure for improved Health and Livelihood (SRWSIHL) project which spur socioeconomic growth in Malawi by improving health and livelihoods of the marginalized rural population through provision of sustainable water supply and improved sanitation. SRWSIHL helped in maintaining the old water channels by putting new pipes and expand the water system (Sandwell, 2015).

### 3.1.4 Socio-economic activities

Many people in Rumphi cultivate in rainy season, they mainly grow maize, tobacco and groundnuts since in most parts the soil pH>6.5 suitable for maize and groundnuts (Nyirenda, 2017). Villages in Livingstonia like Nthunda, Vunguvungu, Mpopi and Matchewe do practice irrigation and fish farming using Mpopi stream which ends up in Matchewe river. They plant different crops like vegetables, tomatoes and maize for food and for sale. Since it is done on a small scale, they use water canes and buckets to irrigate their crops in dry season (Chirwa, 2016).

### 3.1.5 Geology and soils

Rumphi is a large igneous complex of approximately 60 x 15 km which includes granite, syenite, diorite and nepheline syenite (MG, 2019). Rumphi loam soil has a combination of silt, sand and clay which is suitable for many crops. Landslides are a common phenomenon in Rumphi district, it is mainly covered with highlands and slopes for instance, Chiweta, Ntchenachena, and Livingstonia (Chirwa, 2016).

### 3.1.6 Weather and climate

In most part of Rumphi the wet season is humid and overcast, the dry season is windy and mostly clear and it is warm year-round. However; Livingstonia area in particular is cloudy and cold all year round. Over the course of the year, the temperature typically varies from 5 $^{o}$C to 25 $^{o}$C and rarely below 4 $^{o}$C. It is very cold in June and July then hot in September and October (Sandwell, 2015, Munthali, 2016). The rainy season of the year lasts for 7.8 months from October 11 to June 3, with sliding 31days rainfall of at least 0.5 inches. The most rainfalls during the 31 days centered on January 19 with an average total accumulation of 9.1 inches. The dry season of the year lasts for 4.2 months from June 3 to October11 (Sandwell, 2015; Munthali, 2016).

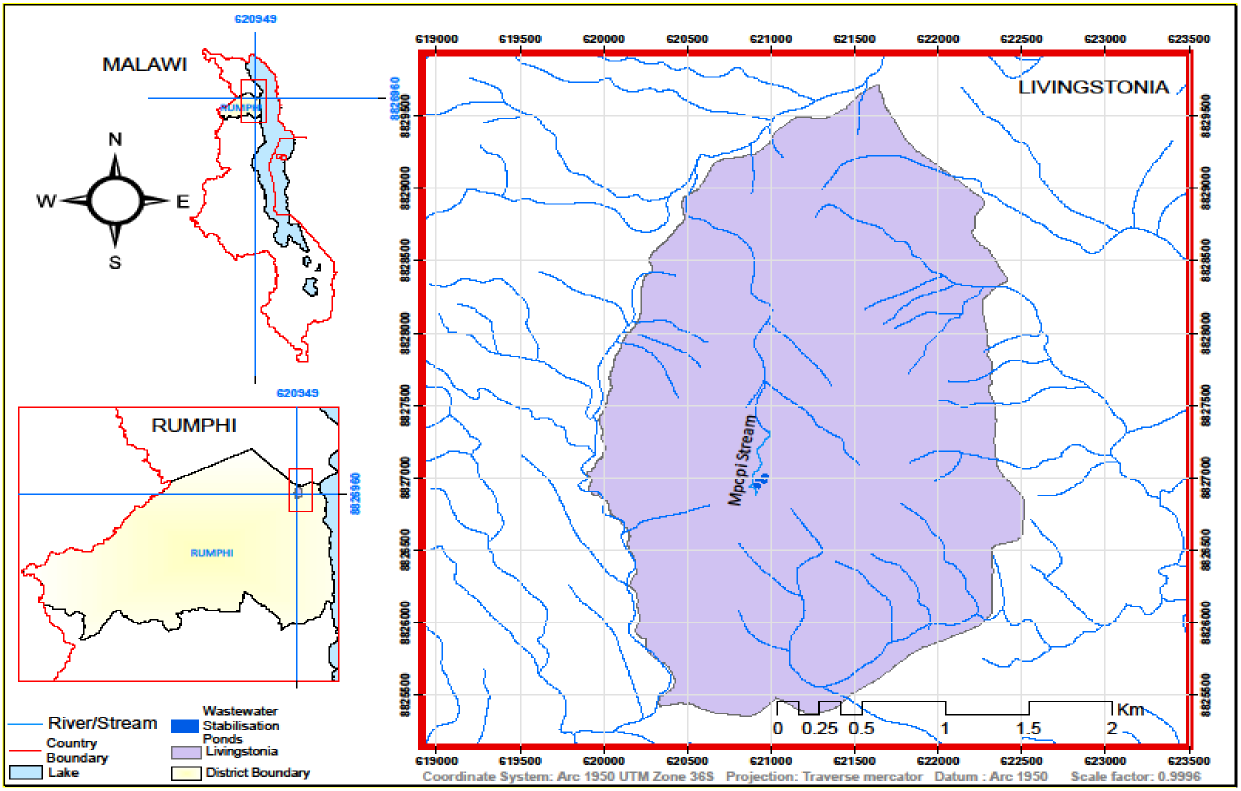


Figure 2: **Map of Livingstonia showing study area**

### 3.2 Study design

The research was a quantitative experimental design. Quantitative experimental study design is where one or more dependent variables are randomly assigned to different treatment and the results are observed to make conclusion. It can be carried out with or without a pretest on at least two randomly assigned dependent variables. It is a way of doing impact evaluation in which the sample receiving the intervention is chosen at random from the eligible sample and a control group is also chosen at random from the same eligible sample. It tests the extent to which specific impacts are being achieved. In this case, this design was chosen because of its strength in providing a very powerful response to questions of causality, helping researchers to know that the situation was as a result of the intervention and not anything else.

Similarly, it achieved clear, measurable impacts that was attributed to a distinct intervention and which lend themselves to causal pathway analysis. It was an experimental form of impact evaluation. It had three intervention groups (S2, S4, S5) and two control groups (S1, S3). It measured the effect of an intervention (sewage effluent disposal) on a particular outcome (stream water quality).

This design was employed to explain and understand the efficiency of the UWSPs and its effects on water quality in the stream. The researcher objectively observed phenomena which occurred in different samples at a strictly controlled situation. The researcher was interested in determining cause and effect and then come up with the solution to the problem. The study involved primary data collection through laboratory and field measurements of key selected parameters in water samples (pH, Temperature, $BOD_5$, TSS, EC, $NH_3$, $NO_3^-$, TP, DO and E. Coli). Secondary data emanated from desk literature reviews.

On the other hand, the researcher collected data from eight key informants who were purposively chosen (1 Principal Environmental Officer, 1 Principal of the University, 1 plumber of the University, 1 Head of Public Health Department at the University, 2 Environmental Management Lecturers at the University, 1 Health Surveillance Assistant of the area and 1 Laboratory Technician at University). These enabled the development of understanding of the meaning that people ascribe to their experiences (Israel, 2009). This involved the use of key informant interviews. Observatory approach was used to collect data through observing practices at the treatment plant.

### 3.2.1 Selection of study representative sampling sites

The selection of representative sampling points throughout the treatment plant was designed to achieve a better understanding of the plant's performance (Ngoma, 2020). Sampling points S1 and S2 were at different stages of the treatment plant while S3 to S5 were on the Mpopi stream. S1 was at the inlet of the treatment plant for baseline data and influent strength. S2 was the outlet of the treatment plant which showed the effluent quality that was compared with the Malawi Effluent Standard. S3 was located upstream of the point of discharge as a control point in the stream. S4 was located at the discharge point as an experiment site in the stream and S5 was downstream of the discharge point as an additional backup control site (Figure 3). Sampling point S3 served as a control as it was before the discharge point with no interaction with the discharged effluents. Sampling in three sites in the stream aimed at determining the effects of the effluent on water quality in the stream. Sampling points in the stream were at 30 m interval based on accessibility, mixing zone, depth and stream width as suggested by Zhao, 2012 & Vinod, 2017.

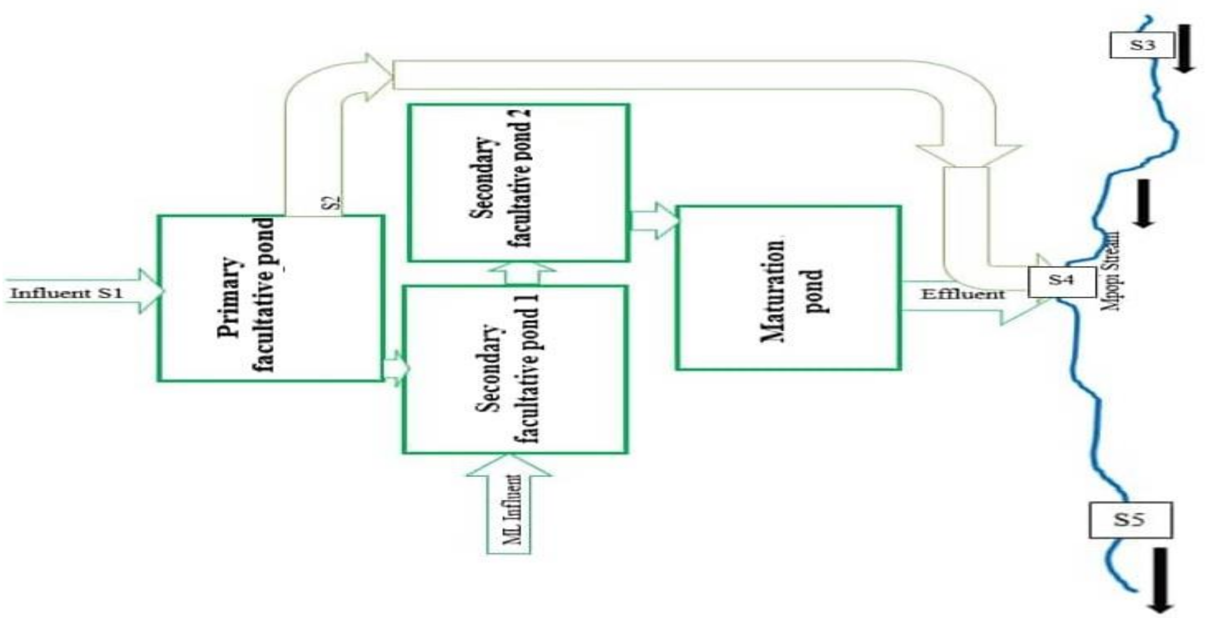


**Figure 3:** Schematic layout of the treatment plant showing sampling points

S1 is raw wastewater inlet (influent),

S2 is where facultative pond overflows through a natural channel to the stream instead of going in maturation pond 1,

S3 is a point in Mpopi stream upstream the discharge point,

S4 is a point in Mpopi stream where effluent is discharged into Mpopi stream,

S5 is a point downstream after S4.

### 3.2.2 Selection of key parameters for analysis

The parameters were selected according to the specific objectives (Table 1). The constituents of the domestic wastewater can be divided into physical, chemical and biological parameters which are in many ways interrelated and are all important in the matter of treatment performance, environmental impact, re-use potential and health aspects (Bayo, 2020).

### 3.2.3 Methods of sampling and frequency

The grab sampling method was used for all sampling sites S1 to S5 (Figure 3) (Liu *et al*., 2016). Samples were collected in duplicate on 25$^{th}$ October, 29$^{th}$ November, 27$^{th}$ December, 2021 and 31$^{st}$ January, 2022 (4 campaigns) in order to maintain reliability of the results which helped to assess the overall performance of UWSPs (Joel *et al*., 2017). Sample collection was done every fourth week of the month mentioned above. The aim of sampling was to collect a small portion that is portable yet sufficient for analytical purposes and which accurately represents the material on the ground (Garcha, 2016).

**Table 1**: Key parameters measured and the method or instrument used.

| PARAMETER | METHOD | INSTRUMENT | REASON FOR DETERMING IT |
|---|---|---|---|
| Biochemical Oxygen Demand (mg/L) | Conventional standard method | BOD Incubator (OXITOP.BOX990409) | Reduce or increase metabolism resulting in loss of aquatic life |
| Escherichia Coli (counts/L) | Membrane filtration | Millipore kit | Causes diseases |
| Total Phosphorus (mg/L) | Spectrophotometric method | 2092PLUS UV/VIS Spectrophotometer | Causes eutrophication resulting in loss of aquatic life |
| Nitrates (mg/L) | Spectrophotometric method | 2092PLUS UV/VIS Spectrophotometer | Causes eutrophication resulting in loss of aquatic life |
| Ammonia (mg/L) | Spectrophotometric method | 2092PLUS UV/VIS Spectrophotometer | Causes eutrophication resulting in loss of aquatic life |
| Temperature (°C) | Not Applicable | Portable Multi-meter HANNA.HI1991400 | Reduce or increase metabolism resulting in loss of aquatic life |
| Electrical Conductivity ($\mu S.cm^{-1}$) | Not Applicable | Portable Multi-meter HANNA.HI1991400 | Reduce or increase metabolism resulting in loss of aquatic life |
| pH (N/A) | Not Applicable | Portable Multi-meter HANNA.HI1991400 | Reduce or increase metabolism resulting in loss of aquatic life |
| Total Suspended Solids (mg/L) | Gravimetric analysis method | Lab Oven NWDP.ADF.OFFQ.0410.BL UEFIC | Reduces Oxygen and sunlight in water resulting in loss of aquatic life |
| Dissolved Oxygen (mg/L) | Not Applicable | DO meter (Model HI.9146) | Reduce respiration resulting in loss of aquatic life |

### 3.2.4 Sample treatment and preservation

The samples were collected at each sampling site during each sampling campaign. The representative water sample were collected from each selected site in clean well dried 1 L plastic bottles (Lares, 2019). The bottles were washed with dish soap then soaked in a 10 % bleach water solution and rinsed with distilled water. Prior to filling the sample bottles; they were rinsed three times on site with wastewater or water from the sources in order to maintain the integrity of the samples.

Wastewater and water samples were collected, preserved and transported in cooler box at a temperature of 3 to 4 °C. This is according to the guidelines and recommended procedures set by Malawi Bureau of Standards (MS 214:2021) (Appendix 2).

## 3.3 Sample analysis methods

These were done in line with standard procedures and protocols performed by previous researchers (APHA 2017; Ngoma, 2020). Onsite tests were carried out for pH, temperature, EC and DO whereas E. Coli, TSS, $BOD_5$, $NO_3^-$, $NH_3$ and TP were analyzed at the Northern Region Water Laboratory in accordance with APHA 2017 Standards presented in Table 1.

### 3.3.1 Field measurements

#### *3.3.1.1 Temperature*

Temperature was measured in the field with a portable multimeter (0-50 ºC) graduated up to 0.1 intervals, at the depth 20 cm. The measurement was taken after temperature stabilizing for a few minutes. The results were expressed in ºC.

#### *3.3.1.2 Electrical conductivity*

Electrical conductivity of water was measured directly in the field by using a portable multimeter. The instrument was supplied with an automatic temperature corrector. The results were measured and recorded.

#### 3.3.1.3 The pH

A portable multimeter powered by rechargeable batteries was used.

The sensing electrodes were immersed sufficiently in a water sample. The amplified voltage was then displayed on a graduated meter (APHA, 2017).

#### 3.3.1.4 Dissolved Oxygen

Dissolved Oxygen was determined by using azide modification of Winkler method as described by (APHA 2017), which was summarized by fixing oxygen in field, 2 ml of $H_2SO_4$ were added and the bottle was shacked thoroughly to dissolve the precipitate. Then was titrated against (0.0125 N) $Na_2S_2O_3.5H_2O$ (sodium thiosulphate solution) using 2 drops of starch solution as an indicator. The results were expressed as mg/L. DO values were calculated according to the equation:

$$DO\left(\frac{mg}{L}\right) = \frac{(V_2 \text{ x } 8000 \text{ x } 0.0125)}{(V_1 - 1.3)} \qquad Equation\ 1$$

where:

$V_2$: volume of titrate (mL)

$V_1$: volume of sample (mL)

### 3.3.2 Laboratory measurement

#### *3.3.2.1 BOD₅*

$BOD_5$ was determined as recommended by EPA (2006), after 5days incubation at 20 ºC in dark bottle then measured using Conventional standard method. The results were expressed as mg/L. $BOD_5$ values were calculated according to the equation:

$$BOD_5 = \frac{D0_1 - DO_2}{P} \qquad Equation\ 2$$

where:

$DO_1$ = dissolved oxygen (mg/L) on the first day

$DO_2$ = dissolved oxygen (mg/L) of sample after 5days incubation

P = Volume of sample used (mL)

**3.3.2.2 Nitrate**

$NO_3^-$ ions were measured using Spectrophotometric method (APHA, 2017) by using 2ml HCl (1 N) added to the diluted sample (5 ml of sample to 50 ml deionized water), then measured by UV-spectrophotometer at wave length 220 nm. Results were recorded in mg/L.

***Preparation of standard and buffer solutions***

***Standard solutions (1.00 mg/L, 10 mg/L, 10 mg/L and 100 mg/L and 1000 mg/L $NO3^-$)***

Sodium nitrate, $NaNO_3$ (1.3710 g) were weighed accurately in a 100 mL beaker. The content was then dissolved in distilled water, transferred qualitatively into a 1.00 L volumetric flask and made up to the mark. The resulting standard solution (1000 mg/L $NO_3^-$) was finally stored in 1.00 L polythene bottle. Intermediate solutions (1.00 mg/L, 10.00 mg/L and 100.00 mg/L $NO_3^-$) were prepared by serial dilution of the 1000mg/L $NO_3^-$ standard solution (APHA, 2017).

***Ionic Strength Adjustment Buffer (ISAB) solution; 2 M $(NH4)_2SO4$***

Ammonium sulphate crystals (134.1400 g) were accurately measured and dissolved in a 500 mL volumetric flask using distilled water. The resulting buffer solution was then transferred and stored in a 1.00 L polythene bottle (APHA, 2017).

***Treatment of standard solution with ISAB and measurements***

Series of standard solutions were prepared from the intermediate and stock solutions and treated with ISAB. This was done by transferring exactly 25, 50, 50 and 10 ml of the 1, 10, 100, 1000 mg/L $NO_3^-$ solutions respectively into four corresponding 100 mL volumetric flasks. To each flask, 2 mL of ISAB (2 % v/v) was added and diluted to the mark with distilled water to make final solutions of 0.25, 5.00, 50.00 and 100.00 mg/L $NO_3^-$. For meter calibration, first 10 mL of each of the four smaller treated standard solutions was transferred into respective 100 mL beakers. Starting with smaller standard solutions, the electrode potentials (mV) that developed in each of the calibration standard solution was observed (APHA, 2017).

***Treatment of the samples with ISAB and measurements***

Exactly 10 mL of each of the triplicate samples was separately transferred into corresponding 100 mL beakers. In each of the beakers, 0.20 mL of the ISAB (2 % v/v) was added and swirled to mix (APHA, 2017). Reading of the electrode potential developed in each water sample was done similar to that of the standards. Consequently, nitrate concentrations (C) in the water samples were computed from the calibration curve whilst taking into consideration the dilution factor of 1.02.

***3.3.2.3 Phosphates***

The $PO_4^{-3}$ in water samples were determined by vanadomolybdo phosphoric acid Ascorbic Acid method (APHA, 2017). Measurements were carried out with the aid of UV/Vs spectrophotometer (Appendix 2).

***Preparation of reagents and standard solutions***

***Vanadate- molybdate reagent:***

To prepare solution **X**, ammonium molybdate, $(NH_4)_6Mo_7O_{24}.4H_2O$ (25.0000 g) was accurately weighed and dissolved in 400 mL distilled water in an 800 mL beaker. Solution **Y** was prepared by weighing ammonium metavanadate, $NH_4VO_3$ (1.2500 g) and dissolved it by heating to boiling in 300 mL distilled water in a 1.00 L Pyrex glass beaker (APHA, 2017). The solution was then cooled and added in 330 mL of concentrated hydrochloric acid. Next, the solution was further cooled to room temperature, followed by addition of solution **X** and dilution of the contents to the mark with distilled water in a 1.00 L volumetric flask (APHA, 2017).

***Standard solution (0, 2.0, 3.0, 5.0, 7.0, 10, 15 and 50 mg/L $PO_4^{3-}$)***

Dried potassium dihydrogen phosphate, ($KH_2PO_4$) (219.5000 mg) was weighed in a 250 mL beaker and dissolved in distilled water. The solution was then transferred into a 1.00 L volumetric flask and diluted to the mark with distilled water to produce a stock solution (50 mg/L $PO_4^{3-}$). To prepare phosphate calibration standard solution series, exactly 0, 4, 6, 10, 14, 20 and 30 mL of stock solution (50 mg/L $PO_4^{3-}$) was separately transferred into respective 100 mL volumetric flasks. The solutions were then diluted to the mark with distilled water to get final standard solutions of concentrations 0, 2.0, 3.0, 5.0, 7.0, 10 and 15 mg/ L $PO_4^{3-}$, respectively (APHA, 2017).

***Treatment of standard solutions and water samples: color development***

Exactly 70 mL of the calibration standard solution of concentration 0 mg/L $PO_4^{3-}$ previously prepared was transferred into a 100 mL volumetric flask.

Into the flask, 20 mL of vanadate-molybdate reagent was added, diluted to the mark with distilled water and waited for 10 minutes. The same procedure was followed for the rest of the calibration standard solutions and the water samples (APHA, 2017).

***Phosphate measurement and preparation of calibration curve***

Subsequent to addition of the vanadate-molybdate reagent, the absorbance of the standard solutions and water samples versus the blank were determined. This was carried out by carefully pouring 0 mg/L $PO_4^{3-}$ standard solution into the absorption cell of the photometer and measured using UV/V spectrophotometer at 470 nm wavelength (APHA, 2017). The same procedure was followed to measure phosphate in the rest of the standard solutions (2, 3, 5, 7, 10 and 15 mg/L $PO_4^{3-}$**)** and water samples. The phosphate concentration in each of the water samples was finally determined directly by referring to the calibration curves prepared (APHA, 2017).

**3.3.2.4 Total suspended solids**

Gravimetric analysis method was used to determine the suspended particulate matter by washing millipore filter paper 0.45 μm then oven dried at 105 $^{o}$C for one hour, then cooled and weight. Filter 100 mL of sample and returned again to the oven and cooled then weight and used the following equation:

$$TSS\left(\frac{mg}{L}\right) = \frac{(A-B)\times 1000}{C} \qquad Equation\ 3$$

where:

A: weight of filter paper with residue (mg)

B: weight of filter paper (mg)

C: volume of sample (mL)

#### *3.3.2.5 Escherichia Coli*

MPN procedure was used as described by Baird *et al*., (2017)), using EC-MUG broth as cultivated medium. Tubes were incubated in the water path at 44.5±0.25 ºC for 24 hrs. The results were expressed as counts/L (APHA, 2017).

### 3.4. Data management and statistical analysis

Water quality parameters were used to characterize influent and effluent of UWSPs. The water quality data was entered in Microsoft Excel (2021). The data were further subjected to statistical analysis using IBM SPSS (Statistical Package for Social Scientists) Version 23.0. The means, standard deviations and range were calculated. One-way Analysis of variance (ANOVA) was used to test for significant variation of water quality parameters within sampling points and sampling campaigns. Independent samples t-test was used to compare influent and effluent quality in SPSS. Statistical significance was assessed at 95 % confidence interval ($p<0.05$). Tables and graphs were used to depict the main findings. Data was further analyzed by comparing the results to available Malawi Effluent Standards (MS 539: 2013) and comparing with expected removal efficiency achieved by similar plants.

# CHAPTER FOUR: RESULTS

## 4.1. Descriptive Statistics of the selected parameters

A summary of descriptive statistics showing standard deviation and mean levels of the biochemical oxygen demand in influent and effluent from the wastewater stabilization pond, discharge point into Mpopi Stream, upstream of the discharge point and downstream of the discharge point are presented in Table 2. Table 2 also presents corresponding permissible levels of the physico-chemical and microbiological parameters based on the MS 539 (2013) guidelines.

## 4.2. Spatial variations in levels of physico-chemical and microbiological parameters

### 4.2.1. Spatial variations in the levels of pH

The mean levels of pH ranged from 4.78 to 7.55 with an overall mean pH = 6.21 (Table 2 and Fig. 4). The highest mean pH value was observed at the inlet of the facultative pond (i.e. mean pH = 7.55 ± 0.49). On the other hand, upstream of the discharge point registered the lowest mean pH value (4.78 ± 0.83).

### 4.2.2. Spatial variations in the levels of Nitrates

The mean levels of nitrates ranged from 3.25 to 13.00 mg/L with an overall mean = 7.57 mg/L (Table 2 and Fig.5). It was observed that the inlet of the facultative pond registered the highest mean levels of nitrates (13 ± 0.37 mg/L) while the upstream point registered lowest levels of nitrates (3.25 ± 2.63 mg/L).

## Table 2: Descriptive Statistics of the selected parameters

| Sample ID | Sample name | pH | Temp (° C) | EC | TDS (mg/L) | TURB (mg/L) | DO (mg/L) | TSS (mg/L) | TP (mg/L) | $NH_3$ (mg/L) | $NO_3^-$ (mg/L) | BOD (mg/L) | FS | FC (Counts/100mL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *MS 539 (2013)* | *6.5-9.0* | *40* | *800* | *500* | *25* | *5* | *30* | *0.15* | *10* | *50* | *20* | *0* | *50* |
| | ***COMMENT*** | *Within* | Below | Below | Below | Exceeded | Below | Exceeded | Exceeded | Below | Below | Exceeded | Exceeded | Exceeded |
| A | Inlet | 7.55± 0.48 | 27.38± 1.90 | 686.75± 40.16 | 454.75± 63.36 | 44.60± 2.50 | 1.27± 0.37 | 748.50± 66.38 | 1.87± 0.34 | 4.00± 0.82 | 13.00± 3.37 | 42.50± 8.72 | 31± 3 | 262± 8 |
| B | Outlet | 7.47± 0.44 | 26.23± 2.15 | 683.50± 36.49 | 446.75± 63.47 | 42.65± 3.73 | 1.39± 0.52 | 746.00± 66.70 | 1.67± 0.46 | 3.63± 1.07 | 12.00± 3.16 | 40.80± 7.49 | 29± 2.38 | 253± 10 |
| C | Upstream | 4.78± 0.83 | 20.77± 1.21 | 32.75± 4.65 | 17.75± 2.22 | 1.86± 0.71 | 4.58± 1.35 | 8.85± 5.11 | 0.04± 0.02 | 1.43± 0.56 | 3.25± 2.63 | 3.13± 0.28 | 7± 2 | 21± 4 |
| D | Discharge | 6.26± 1.41 | 26.48± 1.18 | 44.25± 11.95 | 26.50± 3.70 | 1.65± 0.42 | 5.10± 0.64 | 7.48± 4.09 | 0.04± 0.03 | 2.50± 0.58 | 6.00± 2.94 | 3.38± 0.25 | 29± 17 | 65± 5 |
| E | Downstream | 5.01± 0.72 | 25.00± 1.96 | 37.00± 9.41 | 20.75± 4.86 | 5.17± 4.20 | 4.84± 0.57 | 5.00± 1.38 | 0.03± 0.01 | 1.88± 1.03 | 3.60± 1.70 | 3.18± 0.17 | 15± 11 | 35± 6 |
| **Minimum** | | **3.70** | **19.70** | **28.00** | **15.00** | **1.07** | **0.94** | **1.90** | **0.01** | **0.50** | **1.00** | **2.78** | **4** | **17** |
| **Maximum** | | **8.01** | **29.00** | **722.00** | **532.00** | **48.10** | **6.19** | **837.00** | **2.35** | **5.00** | **17.00** | **50.10** | **48** | **268** |
| **Overall mean** | | **6.21** | **25.17** | **296.85** | **193.30** | **19.18** | **3.43** | **303.17** | **0.72** | **2.69** | **7.57** | **18.60** | **22** | **127** |
| **Pooled Std Dev** | | **1.42** | **2.83** | **326.05** | **218.64** | **20.67** | **1.90** | **373.90** | **0.90** | **1.26** | **4.94** | **19.85** | **13** | **111** |

KEY:
pH: power of hydrogen; Temp: Temperature; EC: Electrical Conductivity; TDS: Total Dissolved Solids, TURB: Turbidity; DO: Dissolved Oxygen; TSS: Total Suspended Solids; TP: Total Phosphorus; $NH_3$: Ammonia; $NO^{3-}$: Nitrate; $BOD_5$: 5 Day Biochemical Oxygen Demand; FS: Fecal Streptococci; FC: Fecal Coliforms; MS: Malawi Standard Effluent.

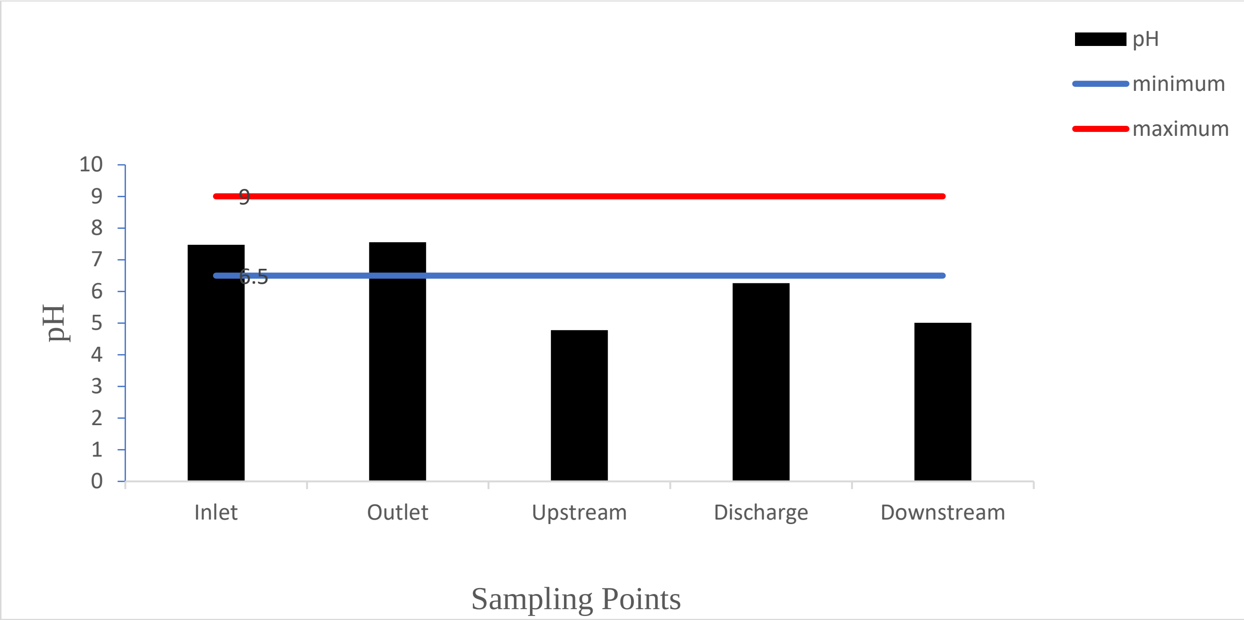


**Figure 4:** Spatial variations in levels of pH

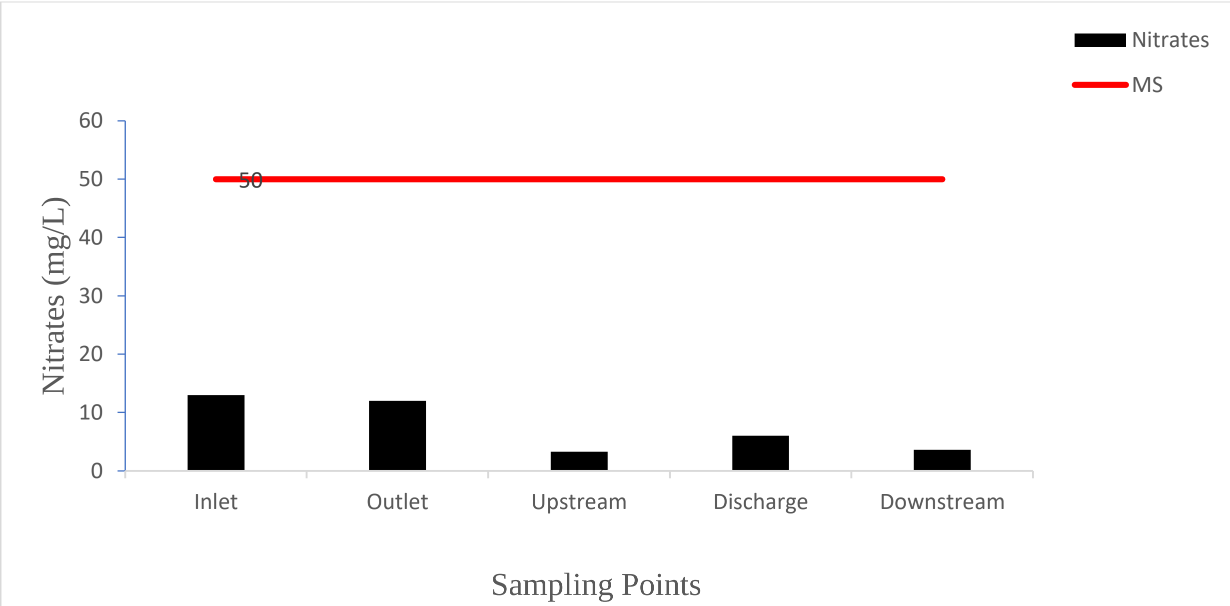


**Figure 5:** Spatial variations in levels of Nitrates

### 4.2.3. Spatial variation in the levels of total Phosphorus

In this study, the mean levels of TP ranged from 0.025 to 1.88 mg/L with an overall mean = 0.73 mg/L (Table 2 and Fig.6).

It was observed that the inlet of the facultative pond registered the highest mean levels of TP (1.88± 0.35 mg/L), whereas the downstream of the discharge point registered low mean levels of TP (0.02± 0.01 mg/L).

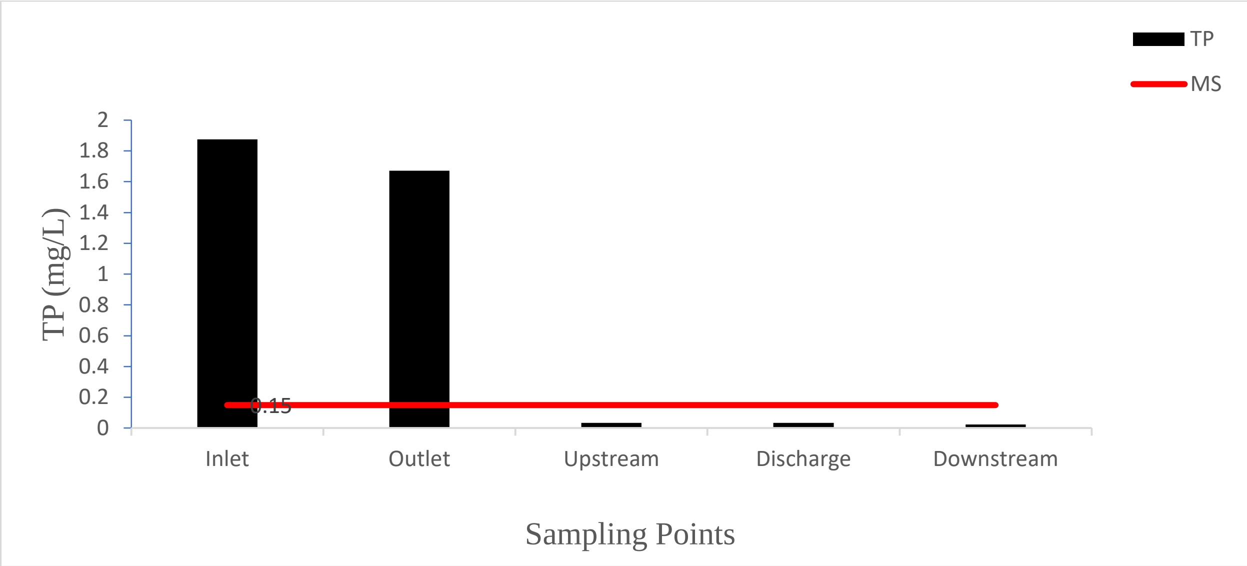


**Figure 6:** Spatial Variations in levels of TP

#### 4.2.4. Spatial variations in the levels of total suspended solids

The mean levels of TSS ranged from 5.00 to 748.50 mg/L with an overall mean of TSS = 303.17 mg/L. The highest mean levels of TSS (i.e. 748.50 ± 66.38 mg/L) were registered in the inlet and the outlet (Table 2 and Fig 7) with the lowest mean levels (5.00 ± 1.38 mg/L).

#### 4.2.5. Spatial variations in the levels of Temperature

The mean average levels of temperature ranged from 20.78 to 27.38 $^{o}$C with an overall mean of 25.174 $^{o}$C. The inlet of the facultative pond registered the highest mean levels of temperature (27.38 $^{o}$C) while the upstream registered lowest mean levels of temperature (20.78 $^{o}$C). Statistically significant spatial variations in levels of temperature were apparent (Table 2).

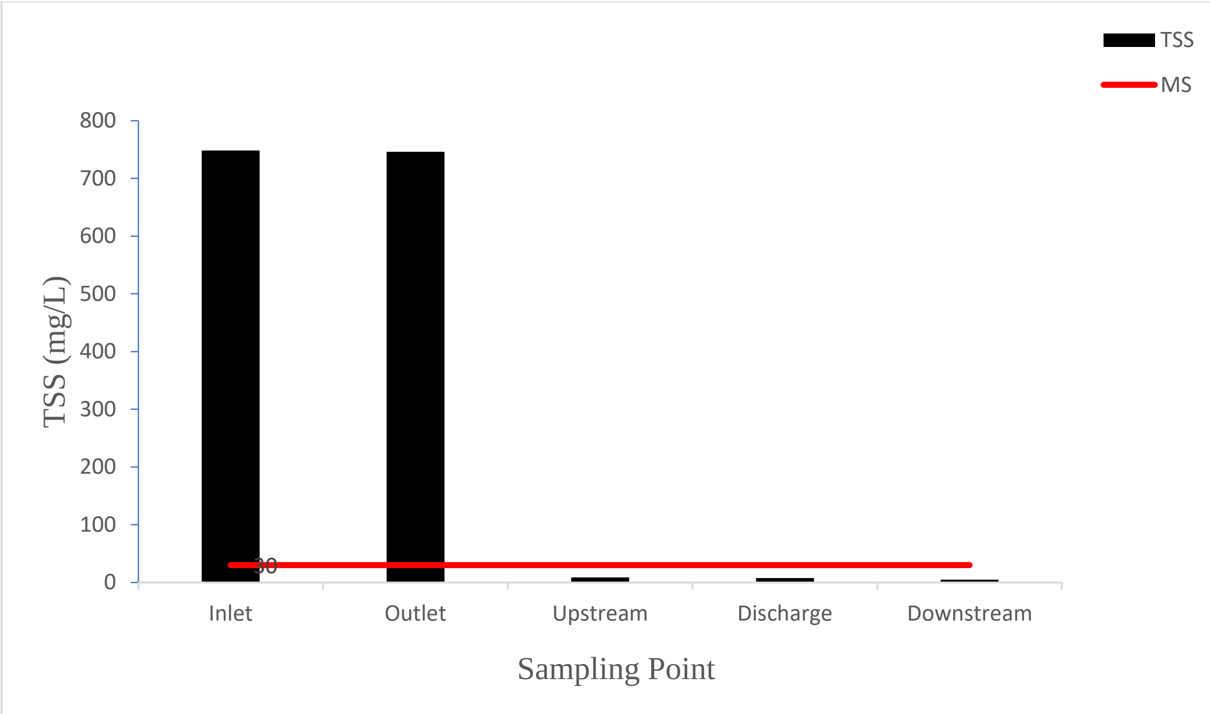


**Figure 7:** Spatial Variations in levels of TSS

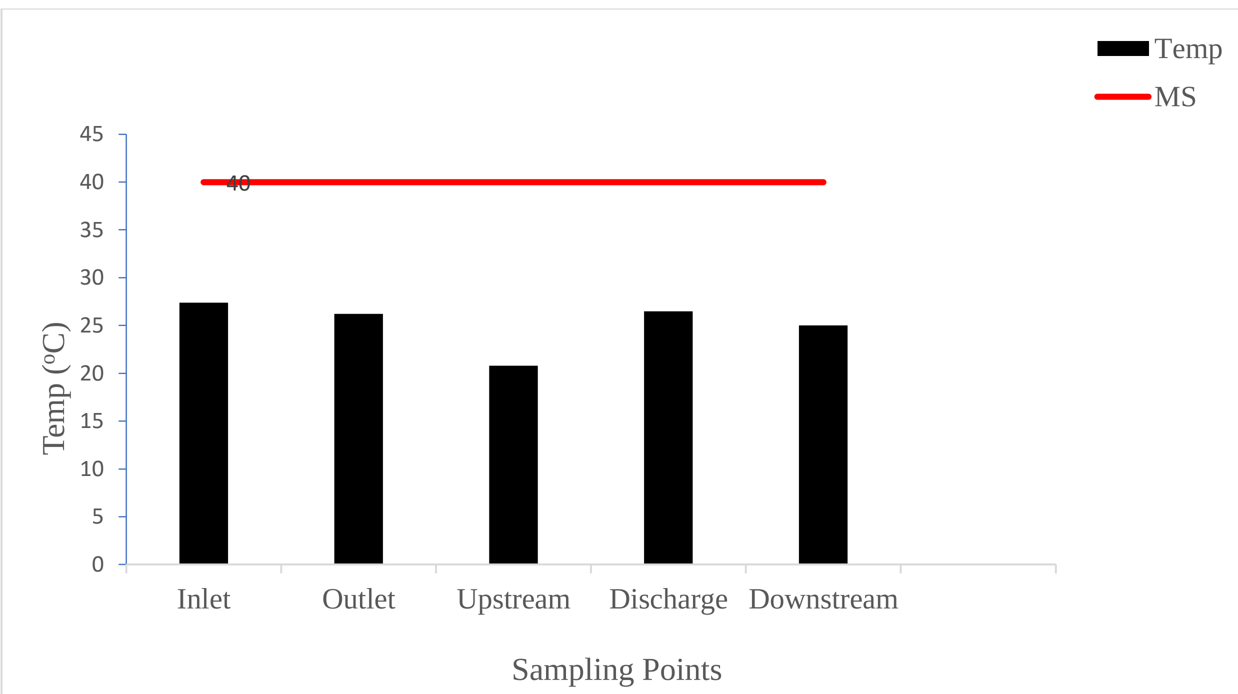


**Figure 8:** Spatial Variation in levels of Temperature

### 4.2.6. Spatial variations in the levels of Escherichia Coli

The mean levels of *E. Coli* ranged from 21 to 268 cfu/100 mL with an overall mean of 126 cfu/100 mL. The inlet of the facultative pond registered the highest mean levels of *E. Coli* (268 ± 8 cfu/100 mL) whereas the upstream of the discharge point registered the lowest mean levels of *E. Coli* (21 ± 4 cfu/100 mL) (Table 2 and Fig. 9).

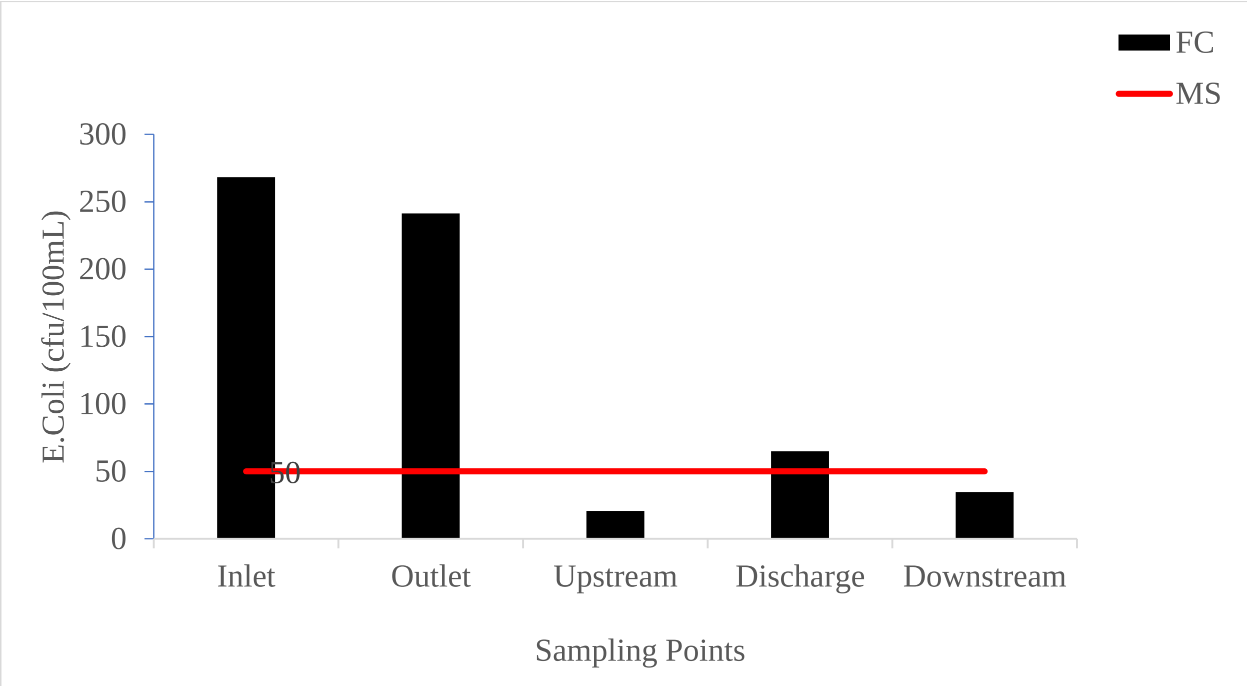


**Figure 9:** Spatial Variation in levels of *E. Coli*

### 4.2.7 Spatial variations in levels of dissolved Oxygen

In the present study, DO showed a large variation for sampling site S1 ($p < 0.05$) (inlet) as opposed to all other sampling points (Figure 10). Higher DO values were observed in the outlet, upstream, discharge and downstream points (S2; 1.39 ± mg/L, S3; 4.58 ± 2.38 mg/L, S4; 5.10 ± 1.52 mg/L and S5; 4.8425± 1.84 mg/L), respectively.

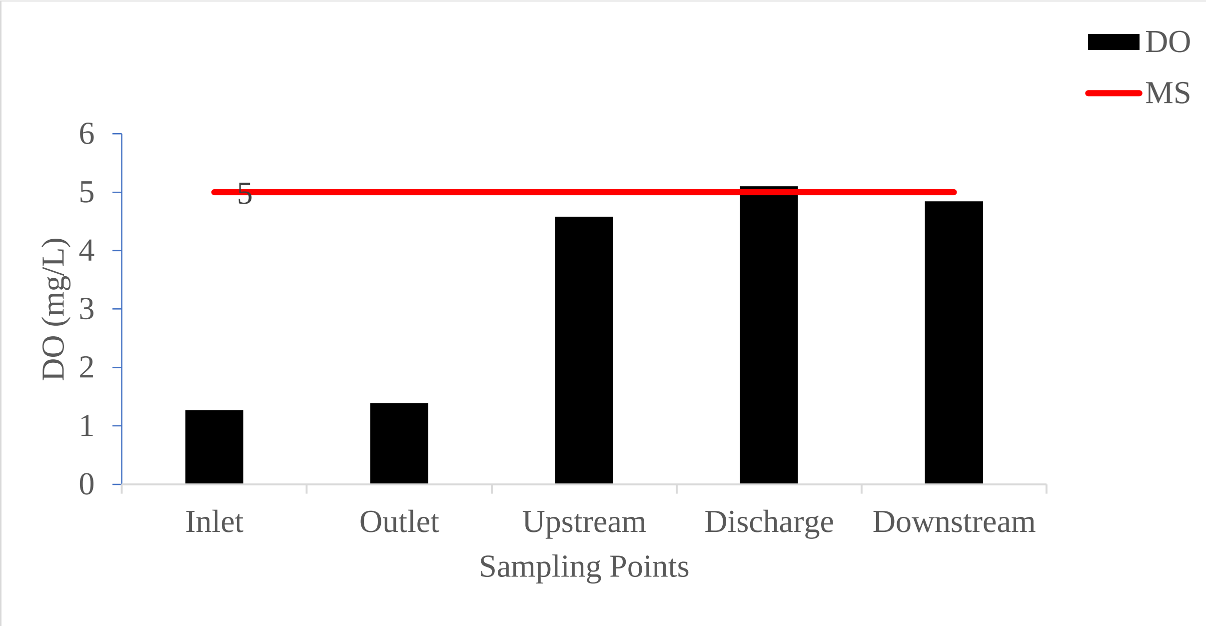

**Figure 10:** Spatial Variations in levels of DO

#### 4.2.8. Spatial variations in the levels of $BOD_5$

The levels of BOD represent the amount of oxygen required for the biological decomposition of either organic matter under aerobic conditions at a standardized temperature in surface water (e.g. lakes and rivers) or leachate (WHO, 2006). In this study, the mean levels of $BOD_5$ ranged from 3.13 to 42.5 mg/L with an overall mean of 18.60 mg/L (Table 2 and Fig.11). It was generally observed that the inlet of the facultative pond registered the highest mean levels of $BOD_5$ (42.5 ± 8.72 mg/L), whereas upstream of the discharge point registered lowest mean levels of $BOD_5$ (3.13 ± 0.28 mg/L).

#### 4.2.9. Spatial variations in the levels of total dissolved solids

The mean values of TDS ranged from 17.75 to 454.75 mg/L with an overall mean = 193.3 mg/L (Table 2). The inlet registered the highest mean of (454.75 ± 63.36 mg/L), whereas the upstream of the discharge point registered the lowest mean of TDS (17.75 ± 2.22 mg/L) (Fig. 12).

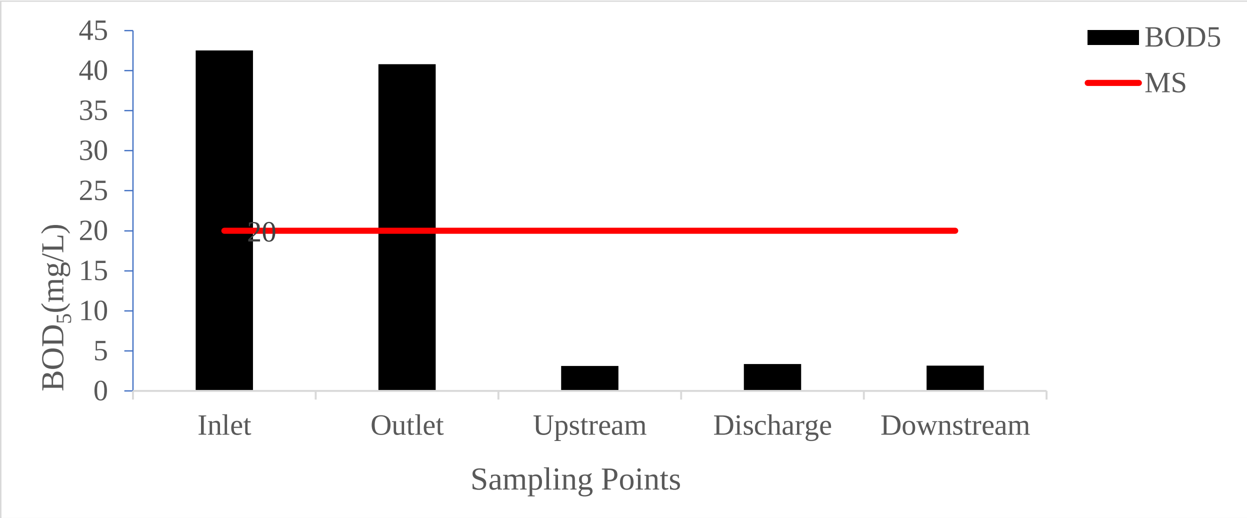


**Figure 11:** Spatial variations in levels of $BOD_5$

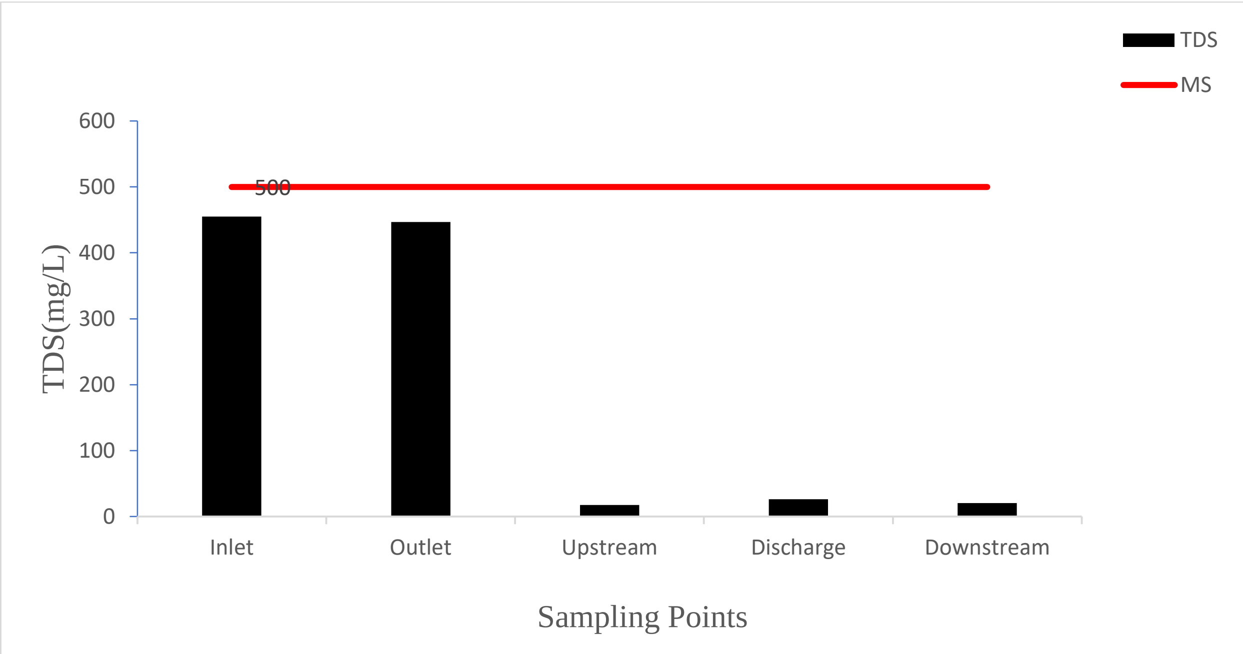


**Figure 12:** Spatial variations in levels of TDS

#### 4.2.10. Spatial variations in the levels of electrical conductivity

The mean values of EC ranged from 32.75 to 686.75 $\mu S.cm^{-1}$ with an overall mean = 296.85 $\mu S.cm^{-1}$ (Table 2).

It was observed that the inlet registered the highest mean levels of EC (686.75 ± 40.16 µS.cm$^{-1}$), whereas the upstream of the discharge point registered lowest mean levels of EC (32.75± 4.65 µS.cm$^{-1}$) (Table 2, Fig. 13).

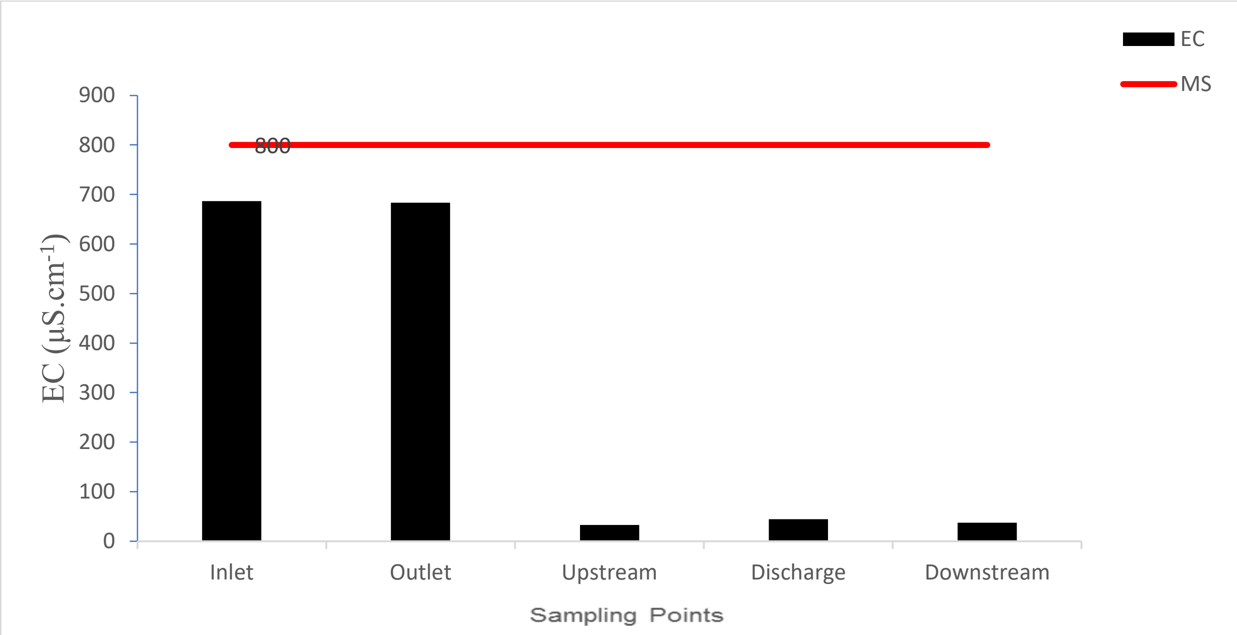


**Figure 13:** Spatial variations in levels of EC

### 4.3. Factors contributing to inadequate performance of University of Livingstonia wastewater stabilization ponds

The study results showed that performance of University of Livingstonia wastewater stabilization ponds are not monitored, not maintained regularly and that there is no professional staff to manage them at the time of the study representing 100% (Table: 3).

### 4.4. Removal efficiency of the University of Livingstonia wastewater stabilization ponds

Generally, it was observed that the University of Livingstonia wastewater stabilization ponds were able to reduce parameters in very low performances of less than 11 % efficiency for all parameters (Table 4).

**Table 3: Factors contributing to inadequate performance of University of Livingstonia wastewater stabilization ponds**

| Variable | Frequency (percentage%) | Standard Error |
|---|---|---|
| 1. Do they do regular specialized maintenance of the wastewater stabilization ponds? | | 0.136 |
| Yes | 0/8 (0%) | |
| No | 8/8 (100%) | |
| 2. Why is the wastewater stabilization ponds performance and their effects not monitored regularly? | | 0.136 |
| Inadequate staff | 4/8 (50%) | |
| Inadequate equipment | 2/8 (25%) | |
| Lack of knowledge | 2/8 (25%) | |
| Lack of motivation, | 0/8 (0%) | |
| Lack of financial support | 0/8 (0%) | |
| Other | 0/8 | |
| 3. Do they have adequate laboratory services for the monitoring of wastewater stabilization ponds performance and their effects? | | 0.136 |
| Yes | 0/8 (0%) | |
| No | 8/8 (100%) | |
| 4. Does University of Livingstonia have professional staff to monitor the wastewater stabilization ponds performance and their effects? | | 0.136 |
| Yes | 0/8 (0%) | |
| No | 8/8 (100%) | |
| Variable is significant at (p-value < 0.05) 95% confidence level | | |

**Table 4: Percentage removal efficiency of the University of Livingstonia wastewater stabilizations ponds**

| Parameter | Mean Influent | Mean Effluent | Removal percentage (%) | Expected % removal |
|---|---|---|---|---|
| pH | 7.47 | 7.55 | -1.07 | - |
| Temp (◦C) | 27.38 | 26.23 | 4.20 | - |
| DO (mg/L) | 1.27 | 1.39 | -9.45 | - |
| EC (µS.cm$^{-1}$) | 686.75 | 683.50 | 0.47 | - |
| TDS (mg/L) | 454.75 | 446.75 | 1.76 | - |
| TSS (mg/L) | 748.50 | 746.00 | 0.33 | 90 (Alexiou and Mara, 2003) |
| $NO_3^-$ (mg/L) | 13.00 | 12.00 | 7.69 | 60 (Alexiou and Mara, 2003) |
| TP (mg/L) | 1.88 | 1.67 | 10.87 | Less than 35 (IWA, 2007) |
| $BOD_5$ (mg/L) | 42.50 | 40.80 | 4.00 | 70-90 (Alexiou and Mara, 2003) |
| FC (cfu / 100ml) | 268 | 242 | 10 | 90 – 99 (IWA, 2007) |

# CHAPTER FIVE: DISCUSSION

## 5.1. Determining the physico-chemical and microbiological parameters at University of Livingstonia Wastewater Stabilization Ponds and comparing the effluent with the Malawi effluent standards (MS539:2013).

### 5.1.1. Levels of pH

Compared to the MS 539 (2013) specifications, all samples in the treatment pond, except for the samples in the stream, registered pH values within permissible levels set by the MS (Table 2; Fig. 6). It is worth noting that pH outside the permissible MS 539 (2013) ranges can inhibit aerobic and anaerobic treatment and might lead to sludge buildup (Sharma *et al.,* 2017). Moreover, elevated levels of pH in facultative ponds indicate septic conditions. Interestingly, elevated levels of pH in facultative ponds is beneficial since above pH = 9.0, the hydrogen sulphide molecule pulls apart, transforming from rotten-egg smelling H2S into benign hydrogen and hydrosulphide. It should be pointed out that higher levels of pH lead to a bitter taste of the water, water pipe distribution lines and water using appliances could become entrusted with deposits (Edjere *et al*., 2016). Higher levels of pH also depress the effectiveness of the disinfection of chlorine, thereby generating the need for additional chlorine (Edjere *et al*., 2016).

The increased pH value in the pond could be attributed to rapid photosynthesis by the pond algae, which consumes carbon dioxide ($CO_2$) faster than it can be replaced by bacterial respiration; as a result; carbonate and bicarbonate ions dissociate. Algae fix the resulting $CO_2$ from the dissociation while hydroxyl ions (OH) accumulate so raising the pH value (Mumbai *et al*., 2018).

Independent samples t-test revealed statistically significant differences between the pH means at S1 and S2 ($p < 0.05$). Similar results were found by (Joel *et al*., 2017). UWSPs releases effluents that could impact the environment as far as pH is concerned. The results of this study are in agreement with those of a similar study conducted in Mzuzu where pH mean value was slightly higher in effluent than in influent (Kayira and Wanda, 2021). This could be due to the higher rate of photosynthesis in the facultative pond. Because during photosynthesis algae uses carbon dioxide, resulting in high pH levels in low alkalinity wastewater **(**Liu, 2017).

### 5.1.2. Levels of Nitrates

The mean levels of nitrates were observed to be within the recommended MS 539 (2013) specifications (Fig. 7). In terms of spatial variability, independent samples t-test revealed that the mean levels of nitrates significantly vary spatially (p-value < 0.05) at 95 % confidence level. The whole trend of levels of nitrates reported in this study is in agreement with the findings of Kayira and Wanda (2021) who also reported increased nitrate concentration in Lunyangwa river as a result of effluent inflow. On the other hand, Ngoma *et al*., (2020) reported no statistical significance difference ($p > 0.05$). Inferring that influent and effluent values of nitrate were almost the same.

### 5.1.3. Levels of Phosphates

All the sampled sites registered phosphate below permissible levels of the MS 539 (2013) specifications except for inlet and outlet of the pond (Fig. 8). The observed trends in the levels of phosphate registered in the pond could be attributed to the effect of urine, detergents and chemicals discharged from the hostels and houses to sewers and ending up in the treatment pond.

Despite the upstream of the discharge point registering lower levels of phosphates than downstream of the discharge point, there was a general decrease in levels of phosphates in the effluent, point of discharge and downstream of the discharge point. In terms of spatial variability, independent samples t-test revealed that the mean levels of phosphates significantly vary spatially (p-value < 0.05) at 95 % confidence level. The trend is similar to a study done by Ngoma *et al*., (2020), who attributed the trend to what is known as self-purification of the river as the river passes through less disturbed areas leading to lower levels of phosphorus downstream of the discharge point. Also, the decrease in phosphorus values could be due to some being transferred into sludge and some being taken up by plants and algae (Egle *et al.*, 2016).

#### 5.1.4. Levels of total suspended solids

Generally, levels of TSS were uniformly higher and above the acceptable limit standards set by MS 539 (2013) in samples drawn from inlet and outlet sampling points (Figure.9). Independent samples t-test revealed that the levels of TSS vary spatially (p-value < 0.05) at 95 % confidence level. The greater the suspended solids in the water, the murkier is the appearance of the water. Alabaster and Lloyd (2015) reported that excessive concentration of TSS might be harmful to aquatic life, inhibit photosynthetic processes and eventually lead to increase of bottom sediments. In addition, higher levels of TSS may cause increase in sediment load into the river plus the function of the microbes is also affected as reported by Lintern *et al*. (2017).

#### 5.1.5. Levels of temperature

The levels of temperature were observed to be within the recommended limits of MS 539 (2013).

However; sampling points at the inlet (27.38±1.90 $^{o}$C) and at the outlet (26.23±2.15 $^{o}$C) registered high temperatures (Figure.10). Independent samples t-test revealed that the mean levels of temperature significantly vary spatially (p-value $< 0.05$) at 95 % confidence level. Elevated levels of temperatures in the facultative pond suggest increase in $BOD_5$ loadings in the ponds. Elevated levels of temperature in the facultative pond was also attributed to elevated TDS values, which are believed to reduce water clarity, hinder photosynthesis, and lead to increased water temperatures. It is worth noting that higher levels of temperatures could increase speed of metabolic reaction as well as reduce the solubility of DO in the water column, which is detrimental to aquatic life (Edjere *et al*., 2016).

### 5.1.6. Levels of Escherichia Coli

It is worth noting that the primary constituent of concern for community consumption is *E. Coli.* In this study, all the samples registered *E. Coli* levels above MS 539 (2013) except for the upstream and downstream. This is because the availability of nutrients such as carbon, nitrogen and phosphorus influence *E. Coli* survival and growth in the environment (Figure.11). Independent samples t-test revealed that levels of *E. Coli* significantly vary spatially (p-value $<0.05$) at 95 % confidence level (Table 2 and Fig. 9). The elevated levels of *E. Coli* in water is a strong indication of recent sewage or animal waste contamination which can cause disease outbreak as was also noted by Kayira and Wanda (2021).

### 5.1.7. Levels of dissolved Oxygen

The ideal DO value for the survival of aquatic life in a water body is 5 mg/L (MS 539:2013) (Figure.12).

Thus; UWSPs treats the wastewater and releases effluent that meets the standards as far as DO is concerned (Figure 12). Independent samples *t*-test performed on DO revealed that S1 (1.27 ± 0.74 mg/L) values were significantly different from S2 (1.39 ± 1.84 mg/L) with $p < 0.05$. The drop in DO at S1 to as low as 1.27 ± 0.37 mg/L suggests that raw influent had high organic load at the time of study. This therefore, infer that water quality improved along the treatment steps as far as DO is concerned. The DO concentration present in surface waters depends on many factors such as water temperature, turbulence, salinity, and altitude among other factors (Rathore, 2011). The DO concentration present in water reflects atmospheric dissolution, as well as autotrophic and heterotrophic processes, respectively, that are responsible for the production and consumption of oxygen (Parmar *et al*., 2010).

A great enhancement in DO concentration in the stream (Figure 12) can be attributed to the reduction of $BOD_5$ load, algal oxygen production, and transformation of Oxygen from air through the ponds surface observed elsewhere (Hayati *et al*., 2013). Similarly; high DO could be due to higher rate of photosynthesis in these ponds. During this process algal cells generate oxygen which is utilized by bacteria. These processes all lead to the efficient mineralization of organic matter translating into lowered $BOD_5$ and inactivation of microorganisms.

### 5.1.8. Levels of $BOD_5$

It was observed that the mean levels of $BOD_5$ in the pond were above the permissible levels of MS 539 (2013) specifications (Table 2 and Figure 13). Independent samples *t*-test revealed that the mean levels of $BOD_5$ significantly differ spatially (p-value < 0.05) at 95 % confidence level.

It should be pointed out that raw wastewater can be categorized into four groups of weak, medium, strong and very strong using amount of $BOD_5$ in its typical compositions. Raw wastewater from University of Livingstonia falls into the weak group based on $BOD_5$ amount, which is < 100 mg/L (Washington State Department of Health, 2002). The low mean levels of $BOD_5$ observed in this study could possibly be attributed to smaller organic matter loadings broken down by bacteria, which leads to lower levels of DO being consumed in the process. It should be noted that levels of $BOD_5$ in the influent were observed to be higher than that in the effluent. This indicates that the University of Livingstonia Wastewater stabilization ponds partially treats the wastewater. Racault and Boutin (2004) suggest that when $BOD_5$ concentration in the influent exceeds 300 mg/L, dysfunction risks become high.

The findings of this study are not in agreement with those of Birjand Wastewater which had higher inlet $BOD_5$ (463.5 mg/L) as opposed to the low inlet $BOD_5$ at UWSPs (42.5 mg/L). The higher influent $BOD_5$ at Birjand Wastewater treatment plant was attributed to low average water use. Thus; we would infer that the low influent $BOD_5$ from UWSP could be attributed to the highwater usage which reduces the concentration of the wastewater. Additionally, in the same study 201.58 mg/L higher than the provisional standards where as in the present study very low $BOD_5$ was observed which was below the Malawi effluent standards. (Council of European Union, 1991; MS 539:2013).

**5.1.9. Levels of total dissolved solids**

The levels of TDS were above standards MS 539 (2013) in the pond (Figure 14). Higher in the influent and started decreasing toward the discharge point. Thistrend was attributed to the reduction in fecal sludge.

TDS which was attributed by the settling down of solids and eventual formation of a sludge layer at the bottom of the ponds. Nevertheless, Independent samples *t*-test revealed that the levels of TDS significantly vary spatially (p-value $< 0.05$) at 95 % confidence level. The results are in agreement with the findings of Edjere *et al*., (2016) who observed a general decrease in levels of TDS downstream of the discharge point possibly due to the self-river purification.

#### 5.1.10. Levels of electrical conductivity

All samples registered EC values within the recommended MS 539 (2013) specifications. Independent samples *t*-test revealed that there were statistically significant spatial variations in the mean levels of EC ($p < 0.05$) at 95 % confidence level (Table 2 and Figure 15). Higher levels of EC downstream of the discharge point than upstream of the discharge point could be attributed to the effluent inflow containing higher concentration of dissolved constituents in the effluent. Electrical conductivity is a useful indicator of mineralization and salinity in wastewater samples. Similar trend has also been reported by Imoobe and Okoye (2020) when they reported higher conductivity value at the effluent discharge point of a river receiving effluent.

### 5.2. Removal efficiency of the University of Livingstonia wastewater stabilization ponds

The University of Livingstonia wastewater stabilization ponds registered very low removal Efficiency. The levels of some parameters in the effluent were still below permissible levels of MS 539 (2013) specifications. Nevertheless, the mean levels of all parameters except DO and pH decreased from influent to effluent levels with removal efficiency of below 10 % (Table 3). It was noted that the removal efficiency of these parameters especially TSS is very low compared to the general design performance of facultative ponds according to MS539 (2013).

It should also be pointed out that mean levels of DO and pH showed an increase from influent to effluent levels with removal efficiencies of -9.45 and -1.07 respectively (Table 3). This suggested that regardless of the weak wastewater ($BOD_5 < 100$ mg/L) of a raw University of Livingstonia wastewater collected, the stabilization ponds fail to reduce levels of different parameters to meet the MS539 (2013) and International Water Association required standards. The MS539 (2013) suggested that general removal efficiency characteristic for the facultative (in this case is the last step) should remove 60 % of the influent $BOD_5$ at 20 $^oC$. This is much higher than the $BOD_5$ removal efficiency registered in this study. With respect to pH, although the removal efficiency was low, an increase in mean levels of pH from 7.47 in the influent to 7.55 in the effluent is not worrisome and this is essential range for desirable bacterial performance.

## 5.3. Effects of University of Livingstonia wastewater stabilization ponds' effluent on water quality in Mpopi stream

### 5.3.1. Effect on levels of pH

The pH is a measure of the acidity or alkalinity of a substance and is one of the stable measurements. The pH is extremely important, since most of the chemical reactions in aquatic environment are controlled by changes in its value (Himmel *et al*., 2010). In the stream, the fact that S4 recorded higher values than S3 and S5 would suggest that this elevated pH is as a result of the wastewater stabilization ponds effluent discharge in the stream. This therefore infer that effluent from University of Livingstonia Wastewater Stabilization Ponds pollutes the stream.

It was observed that there were statistically significant spatial variations in the mean levels of pH ($p < 0.05$) among the five sampling sites at 95 % confidence level (Table 2). The results of this study are not in agreement with a study conducted by Ngoma, 2020.

### 5.3.2. Effect on levels of temperature

In the stream the measured mean temperature was below the effluent discharge standards (< 40 °C) on all sampling points S3 (20.77±1.21 °C), S4 (26.48±1.18 °C) and S5 (25.00±1.96 °C) as outlined in table 2. In the stream, the fact that S4 (effluent discharge point) recorded higher values than S3 (upstream before the discharge point) and S5 (downstream after the discharge point) it would show that this elevated temperature is as a result of the wastewater stabilization ponds effluent discharged in the stream. This would therefore infer that the effluents at the time of study could pose minimal threat to the stream. One-way ANOVA revealed a statistically significant difference among all sampling points for temperature ($p < 0.05$). A similar study by Musa and Chidiokonkwo (2017) on assessment of brewery wastewater on self-purification of the river revealed similar results, in which temperature decreased again downstream of the discharge point due to self-purification.

### 5.3.3. Effect on levels of Escherichia Coli

The discharge point of the stream registered the high mean levels of *E. Coli* 44 ± 12 whereas the upstream of the discharge point registered the low mean levels of *E. Coli* (21 ± 4 cfu/100 mL).
One-way ANOVA revealed a statistically significant difference among all sampling points for temperature ($p < 0.05$). Elevated levels of *E. Coli* in the stream may lead to incidences of typhoid fever, hepatitis, gastroenteritis and dysentery in animals and humans (Gaffied and Walker, 2008). Furthermore, elevated levels of *E. Coli* may contaminate meat and vegetables in addition to greatly affecting the downstream users in the sense of causing hemorrhagic diarrhea and can have long term effect if not fatal complications. The results of this study are in agreement with a study conducted by Kayira and Wanda 2021.

### 5.3.4. Effect on levels of Nitrates and phosphates

High levels of nitrates and phosphates have the same effect on aquatic plant growth leading to eutrophication hence reducing oxygen levels and fish dies. Nitrates are relatively short-lived form of nitrogen that quickly become converted to nitrites by bacteria. However high levels of nitrites produce a serious illness called brown blood disease in fish. Nitrites also react directly with hemoglobin in the blood of people to produce met hemoglobin, which destroys the ability of blood cells to transport oxygen. This condition is especially serious in babies under three months of age as it causes a condition known as methemoglobinemia or blue baby disease. Urea and proteins are normally the main contributors to the nitrogen content in raw wastewater (Dong, 2015). Significant differences ($p > 0.05$) were observed for nitrates (S3: 3.25±2.63 mg/L, S4: 6.00±2.94 mg/L and S5: 3.60±1.70 mg/L) and total phosphorus (S3: 0.04±0.02 mg/L, S4: 0.04±0.03 mg/L and S5: 0.03±0.01 mg/L) among all sampling points as shown by table 2. This would infer that nitrates and phosphates from University of Livingstonia Wastewater Stabilization Ponds effluents are pollution threats to Mpopi stream. The findings of this study are in agreement with studies done by Edokpayi *et al.,* 2017 who found that wastewater effluents containing nitrate, nitrogen and phosphorus induce eutrophication (Appendix 2).

### 5.3.5. Effect on levels of $BOD_5$

$BOD_5$ typically provides an approximation of organic contamination in water and wastewater. They are vital wastewater quality factors as they are used to measure the efficiency of most wastewater treatment facilities. Surface water is expected to have low $BOD_5$ values to sustain aquatic life. High levels of $BOD_5$ are an indicator of bad water quality and can harm the aquatic life, whereas low levels of $BOD_5$ in a water body shows that the water is of good water quality.

There is an inverse relationship between the $BOD_5$ levels and DO concentrations.

In the presence of high $BOD_5$ in water as it is the case with most wastewater, DO is consumed by bacteria. This causes DO level to drop below a threshold and has negative impacts on aquatic life as they are unable to continue their normal life sustaining processes such as growth and reproduction. One- way ANOVA revealed statistical significance ($p > 0.05$) in all sampling points for $BOD_5$. This would therefore infer that the levels of $BOD_5$ from University of Livingstonia Wastewater Stabilization Ponds pose threat to Mpopi stream. Higher S4 (3.38±0.25 mg/L) values than S3 (3.13±0.28 mg/L) values for $BOD_5$ suggests that the stream is being subjected to pollutants from the effluent. The results of this study are not in agreement with a study conducted in Mzuzu City by Ngoma *et.al.*, 2020 but is in agreement with a study done at Mzuzu Central Hospital Wastewater Stabilization ponds by Kayira and Wanda.

### 5.4. Factors contributing to inadequate performance of University of Livingstonia wastewater stabilization ponds

The study results showed that University of Livingstonia does not have regular specialized maintenance of wastewater stabilization ponds (Table 4). This option is statistically significant because it reveals that all respondents (100%) reported the absence of regular specialized maintenance activities for wastewater stabilization ponds. Regular maintenance is crucial for the proper functioning and longevity of pond systems, and the absence of such maintenance can lead to deterioration in performance and potential environmental hazards. This is in agreement with a study done in Mzuzu by Ngoma *et al.,* 2020.

On the other hand; the results showed that University of Livingstonia does not have adequate laboratory services for the monitoring of wastewater stabilization ponds performance and their effects (Table 4). This option is statistically significant because all of the respondents (100%) indicated the absence of adequate laboratory services for monitoring wastewater stabilization ponds performance and their effects. Adequate laboratory services are essential for accurate monitoring and analysis of wastewater quality, ensuring effective wastewater treatment practices. This was in agreement with a study done by Kayira and Wanda 2021. Also; the results showed that University of Livingstonia does not have professional staff for the regular monitoring of the performance of the wastewater stabilization ponds and their effects (Table 4). This option is statistically significant because it indicates a complete absence of professional staff managing the wastewater stabilization ponds, with all respondents (100%) selecting this option. The absence of professional staff could significantly impact the efficiency and effectiveness of pond management, making it a crucial factor to consider. This was in agreement with a study done by Kayira and Wanda 2021.

# CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

There are three main conclusions based on specific objectives. These are:

### 6.1.1 Determining the physico-chemical and microbiological parameters at University of Livingstonia Wastewater Stabilization Ponds and comparing the effluent with the Malawi effluent standards.

It was observed that UWSPs effluent are not meeting the MS539 (2013) standards before being discharged into the stream for public health reuse. This study noted that the stabilization ponds failed to substantially reduce the levels of $BOD_5$ to the recommended standards. The presence of *E. Coli* in levels above the MS539 (2013) permissible levels does not give a good picture of the efficiency of the stabilization ponds, despite registering some substantial reduction in levels of the *E. Coli.* Although levels of phosphates and nitrates were generally lower and within the permissible levels in both the influent and effluent, the presence of phosphates and nitrates in the effluent does not give a good picture of the efficiency of the facultative ponds.

### 6.1.2 The effect of University of Livingstonia wastewater stabilization ponds' effluent on water quality in Mpopi stream

The study observed that the effluent from UWSPs contaminates Mpopi stream which may cause disease outbreak. It is worth noting that the elevated levels of $BOD_5$, coupled with the presence of *E. Coli*, nitrates and phosphates on the discharge point of the stream (experiment) than on the upper stream (control point) and downward stream confirmed that the University of Livingstonia wastewater treatment effluent is negatively affecting quality of water in Mpopi stream.

### 6.1.3 The factors that contribute to inadequate performance of University of Livingstonia wastewater stabilization ponds

It was observed that UWSPs do not have professional expertise to run the operation assessment of the ponds, do not have advanced laboratory equipments that could help to monitor the performance of the ponds and their effects and there is limited maintenances of the ponds.

## 6.2 Recommendations

### 6.2.1 Determining the physico-chemical and microbiological parameters at University of Livingstonia Wastewater Stabilization Ponds and comparing the effluent with the Malawi effluent standards.

The study recommends a need for outsourcing specialized maintenance tasks or professional service providers for the professional maintenance of the wastewater stabilization ponds to improve effluent quality that meets the MS539 (2013) prior to be discharge into Mpopi stream for public health reuse. Also there is need for encouraging community participation in monitoring efforts and reporting any irregularities related to the pond operation.

### 6.2.2 The effect of University of Livingstonia Wastewater Stabilization Ponds' effluent on water quality in Mpopi stream

The study also recommended that authorities and stakeholders should embark on a risk communication and public sensitization. This is specifically to the need to boil and filter the water prior to consumption for communities that rely on downstream of the discharge point as their drinking water sources as well as in agriculture, especially for the food and vegetables that are eaten in raw.

### 6.2.3 The factors that contribute to inadequate performance of University of Livingstonia wastewater stabilization ponds

The study recommends authorities and stakeholders to develop a comprehensive maintenance schedule of the UWSPs outlining routine tasks such as vegetation control. Similarly; they should consider collaboration opportunities with nearby municipalities or organizations to share expertize, laboratory resources and benefits. On the other hand; they should consider employing their own professional staff.

### 6.2.4 Research recommendations

i. It was also observed that Mpopi stream is still capable of self-purification as shown by the decreases in the levels of most parameters as water flowed further downstream from the discharge points. There is need for a further study to investigate the self-purification capacity of Mpopi stream.

ii. Due to blockage of the sewer system (one part), it may lead to pollution of the groundwater, hence likely to cause serious problems to the surrounding ground and surface water resources. The study recommends an in-depth study to look at the extent of groundwater pollution and some mitigation measures.

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# APPENDICES

## Appendix 1: Consent letter from MZUNIREC

**MZUZU UNIVERSITY**

DIRECTORATE OF RESEARCH

Mzuzu University
Private Bag 201
Luwinga
Mzuzu 2
MALAWI
TEL: 01 320 722
FAX: 01 320 648

**MZUZU UNIVERSITY RESEARCH ETHICS COMMITTEE (MZUNIREC)**

**Ref No: MZUNIREC/DOR/24/01** **22/01/2024.**

Immaculate Jere,
Mzuzu University,
P/Bag 201,
Luwinga,
Mzuzu 2.

Mzuzu University

Email: immaculatejere@gmail.com

Dear Immaculate,

**RESEARCH ETHICS AND REGULATORY APPROVAL AND PERMIT FOR PROTOCOL REF NO: MZUNIREC/DOR/24/01: INVESTIGATION ON THE EFFECTS OF POOR SANITATION ON SURFACE WATER: A CASE STUDY OF LIVINGSTONIA WASTEWATER STABILIZATION PONDS.**

Having satisfied all the relevant ethical and regulatory requirements, I am pleased to inform you that the above referred research protocol has officially been approved. You are now permitted to proceed with its implementation. Should there be any amendments to the approved protocol in the course of implementing it, you shall be required to seek approval of such amendments before implementation of the same.

This approval is valid for one year from the date of issuance of this approval. If the study goes beyond one year, an annual approval for continuation shall be required to be sought from the Mzuzu University Research Ethics Committee (MZUNIREC) in a format that is available at the Secretariat. Once the study is finalised, you are required to furnish the Committee with a final report of the study. The Committee reserves the right to carry out compliance inspection of this approved protocol at any time as may be deemed by it. As such, you are expected to properly maintain all study documents including consent forms.

Wishing you a successful implementation of your study.

**Committee Address:**

***Secretariat, Mzuzu University Research Ethics Committee, P/Bag 201, Luwinga, Mzuzu 2; E-mail address: mzunirec@mzuni.ac.mw***

This approval is valid for one year from the date of issuance of this approval. If the study goes

Yours Sincerely,

Gift Mbwele

**SENIOR RESEARCH ETHICS ADMINISTRATOR**

**For: CHAIRMAN OF MZUNIREC**

**Committee Address:**

***Secretariat, Mzuzu University Research Ethics Committee, P/Bag 201, Luwinga, Mzuzu 2; E-mail address: mzunirec@mzuni.ac.mw***

## Appendix 2: Some study tools and eutrophication view in the stream

Cooler Box & sample bottles


Spectrophotometer

Eutrophication in Mpopi stream