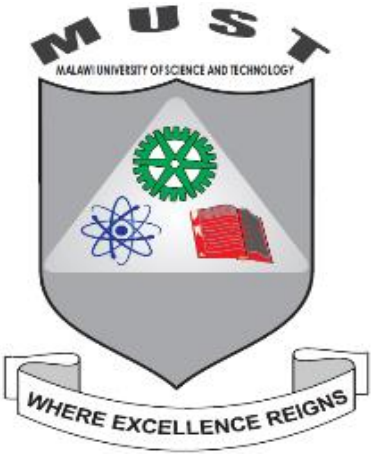


PERFORMANCE EVALUATION OF A MUNICIPAL WASTEWATER STABILISATION POND SYSTEM: CASE STUDY OF LIMBE WASTEWATER TREATMENT PLANT IN BLANTYRE, SOUTHERN MALAWI

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July, 2021

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ABSTRACT

In Malawi the need to treat wastewater is becoming more important and it has been emphasised by the existing regulatory framework institutional regulations and policy guidelines. Formalised national effluent standards also exist. Most developing countries like Malawi use waste stabilisation pond system for sewage treatment. The Limbe wastewater treatment plant was designed long time ago. The effluent from the WSPs is discharged into Limbe River. People who live near the area use the water from the river for domestic and agricultural purposes, most especially those living in the downstream. Unfortunately, there is no frequent and up to date monitoring and information providing facility on the performance of the treatment plant and the quality of the effluent being discharged into the river. The objective of this study was to evaluate the performance efficiency of Limbe WSP treatment plant. The efficiency was evaluated through periodic sampling and analysis of physicochemical and microbiological parameters of the whole system. The statistical analysis such as correlation and regression analysis were performed to assess the relationship between the parameters. The hydraulic parameters such as hydraulic loading rate (HLR) and volumetric loading rate (VLR) were also determined and it was observed that their values were below the designed values. Except for pH, temperature, dissolved oxygen (DO), Total dissolved solids (TDS), oxidation reduction potential (ORP), and nitrates (NO_3-N), the rest of the parameters were above the recommended values by MBS for effluent disposal. In terms of the removal efficiency percent, only COD, BOD and TSS were above 50%. The system was overall poor in biological parameters removal but better in some physicochemical parameters comparing to the standard limits of the country. The measured values of effluent TSS, NO_3-N and total coliform in the laboratory were very close to those predicted through regression-based tool. Therefore, the regression-based tool developed in this study can be used to estimate effluent parameters for performance monitoring.

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ACRONYMS/ABBREVIATIONS

MBS	Malawi Bureau of Standards
WSP	Wastewater Stabilisation Pond
WWTP	Wastewater Treatment Plant
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
DO	Dissolved Oxygen
EC	Electric Conductivity
PH	Power of Hydrogen
ORP	Oxidation Reduction Potential
NTU	Turbidity
CFU	Colony Forming Unit
RAS	Return Activated Sludge
OM	Organic Matter
HRT	Hydraulic Retention Time
HLR	Hydraulic Loading Rate
VLR	Volumetric Loading Rate

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CHAPTER 1: INTRODUCTION

1.1. Background information

The need for sanitation and sustainable water management is becoming more important and has led to so many countries across the world opting to construct wastewater (sewage) treatment plants. However, increased urbanization puts extra pressure on the already existing wastewater treatment plants (Beyene & Redaie, 2011). There are many methods used for sewage treatment for example activated sludge, trickling filters, biological towers and stabilization ponds. Waste stabilization ponds (WSPs) have many advantages over other methods. This is true especially for tropical and subtropical regions where the climatic conditions suit their operation (Gopolang & Letshwenyo, 2018). Waste stabilization ponds have certain disadvantages as well but these are to a great extent offset by the numerous advantages. WSPs are low-cost (usually least-cost), low maintenance, entirely natural and highly sustainable. The only energy being used is direct solar energy so it does not need any electromechanical equipment, saving expenditure on electricity and more skilled operation. It requires much more land than conventional electromechanical treatment processes such as activated sludge but land is an asset which increases in value with time, whereas money spent on electricity for the operation of electromechanical systems is gone forever. WSP systems are comprised of one or more series of different types of ponds (Oberlin, 2018). Usually the first pond in the series is an anaerobic pond, and the second is a facultative pond. These may need to be followed by a maturation pond, but this depends on the required final effluent quality which in turn depends on what is to be done with the effluent. The ponds can be arranged in series or parallel sometimes both arrangement. Treatment in ponds occur through a complex system of microbial processes that degrade organic matter (OM) (Riffat, 2013). Microbial decomposition releases oxidized compounds of carbon, sulphur and phosphorus into the wastewater matrix including nitrate (NO_3 -N) and phosphate (PO_4^{-3}). These are utilized for photosynthesis by algae in the upper regions of the

basin in the presence of sunlight to give oxygen (O_2) which help to maintain dissolved oxygen (DO) levels in the upper layers (Atefeh et al,, 2018). Prior to treatment in the WSPs, the wastewater is first subjected to preliminary treatment, screening and grit removal so as to remove large and heavy solids (Shivaraju, 2011). Malawi is a developing country in tropical Africa. The provision of adequate sewage treatment and disposal at low costs and low demand of professional manpower, while attaining the required effluent quality is very important to Malawi. This is so because there are insufficient financial resources and professionally trained manpower for the expensive and complicated sewage treatment methods. It is therefore important that waste stabilization ponds are utilized in Malawi as much as possible. Wastewater treatment is very important, mainly due to two reasons: to protect the environment for instance an overload of nutrients can lead to eutrophication of rivers and to prevent the contamination of water resources, which can lead to the spreading of diseases (Zhang & Mary, 2020).

Limbe stabilization ponds are located at Chigumula in Blantyre city with the purpose of treating domestic sewage from residential areas and industrial waste from the Limbe Central Business District (CBD) and surrounding residential areas. The wastewater treatment works was established in the 1970's and comprised an inlet works with manually raked screens, grit channels and a flow measuring flume, followed by a series of four wastewater stabilization ponds (Council, 2017). The works was extended by the construction of a further twelve ponds, which were commissioned in 1985. The waste stabilization pond system thus currently comprises the original inlet works followed by four parallel four pond series. Each of the four series of ponds is fed from a common distribution pipe running the length of the works. There are four chambers situated on the pipe, each has a weir with penstock control to allow distribution of flows between the series of the ponds. The original four ponds now form the first series, with the twelve more recently constructed lagoons providing the other three series. The configuration of the original pond series comprises two parallel primary facultative ponds independently fed with screened and de-gritted raw sewage. The combined flows from these two primary ponds enter a third pond (pond 3, primary maturation

pond), which flows to the fourth pond (pond 4, a secondary maturation pond). The original series (series 1), is therefore, from a consideration of process, a three pond series with two facultative ponds in parallel feeding a second and third pond in series. The configuration of the new series (series 2-4) are different from series 1 in that all the four ponds are in series with the first pond in the line, the facultative pond, receiving screened, de-gritted raw sewage. This primary pond feeds the primary maturation pond, the effluent of which flows to the third pond (secondary maturation pond), which in turn, feeds the final pond in series (tertiary maturation pond).The effluent from the WSPs is discharged into Limbe River. People who live near the area use the water from the river for domestic and agricultural purposes, most especially those living in the downstream. Unfortunately, there is no frequent and up to date monitoring and information providing facility on the performance of the treatment plant and the quality of the effluent being discharged into the river. Such information is very vital for the relevant authorities to take proper action in preventing pollution of the environment for the good health of the population. Before wastewater can be discharged into a water system, it has to comply with the national physical, chemical and microbiological standards for disposal in order to ensure that the environment is well cared and safe protected.

1.2. Problem statement

Waste stabilization ponds (WSP) is one of the common wastewater treatment technologies used in developing countries like Malawi and perform well in pathogen and nutrient removal. This can be achieved when the ponds are well designed and performing to the full designed capacity. The Limbe WSPs were designed to perform in reduction of pollutants entering the system from different sources in such a way that the effluent values for pH should range from 6.5-9, ORP less than or equal to 100mV, alkalinity less than or equal to 250 mg/l, temperature should be greater than or equal to 40^0C, DO greater than or equal to 5 mg/l, COD less than or equal 50 mg/l, BOD less than or equal 20 mg/l, TSS less than or equal 30 mg/l, TDS less than or equal 500 mg/l, turbidity less than or equal 5 NTU, ammonium less than or equal 10 mg/l, nitrate less than or equal 50 mg/l, EC less than or equal 500 μs/cm , faecal and total coliform should be less than or equal to 1000 CFU/100ml. Regarding the fact that Limbe WSP system was designed long time ago in 1970s to cater for a smaller population as opposed to the present time. Unfortunately, the ponds are still being used regardless of the increase in

population served. According to Malawi government, in 1970 the human population of Blantyre city was 140,000 and in 2020 it was 962,000. This becomes a major problem because the increase in population increases the amount of influent which can affect the performance of the treatment system since the volume of the pond cannot hold the whole influent for a specific period of time to enhance treatment by microorganisms as there is an increase in flow rate which reduces hydraulic retention time. Also the plant consist of sixteen ponds but apparently only four are operating which shows malfunctioning of almost twelve ponds. It is therefore pertinent to assess the performance of the system and its ability to achieve the target effluent requirements as well as provide a basis for systems improvements for enhanced sustainable water management.

1.3. Study objectives

1.3.1. Main objective

The main objective of this study was to evaluate the performance efficiency of the Limbe stabilization ponds wastewater treatment plant.

1.3.2. Specific objectives

- To assess the physicochemical and microbiological water quality characteristics for the system.
- To determine performance efficiency for selected physicochemical and microbiological parameters of the system.
- To assess the system hydraulic performance.
- To develop a simple tool for predicting system performance in terms of effluent quality.

1.4. Research questions

- What is the water quality status along the wastewater treatment trains?
- How does the operating hydraulic conditions relate to the design hydraulic parameters?
- Are there any differences in the treatment efficiencies for individual units at the plant?
- Can the system operating conditions be used together with hydraulic parameters to come up with a tool for plant management and system improvement?

1.5. Significance of the study

- To notify the relevant authorities on the performance efficiency of the WSP treatment plant so as if any improvement is required should be taken care of.
- To propose a scheme for upgrading and expanding the wastewater treatment plant if necessary.
- To serve as a reference to all who will handle similar projects in the future.

CHAPTER 2: LITERATURE REVIEW

2.1.Sewage treatment

Sewage or wastewater treatment is very essential to public health. Water supply alone cannot provide full health benefits. In some cases, owing to lack of adequate sanitary facilities, an increased water supply can cause the spread of various water related diseases (Mateo, 2012). Wastewater treatment aims at reducing the pollutants in sewage which may include biochemical oxygen demand (BOD), Total solids (TS), pathogenic bacteria, toxic compounds, nitrates and nitrites, phosphates and even some metallic compounds as well. The sewage treatment is important so that pollution of waters to which the effluent is discharged, is minimized to acceptable level (Farzadkia, & Taghi, 2014).

2.2. Sewage treatment methods

Sewage treatment is mixture of physical, chemical and biological processes. Occasionally chemical processes are additionally employed. The common physical processes are screening, comminution and removal of grit and suspended solids by sedimentation. Chemical processes involves the addition of chemicals to achieve conversion or destruction of contaminants through chemical reactions, e.g. coagulation and flocculation for solids removal, disinfection for pathogen destruction and chemical precipitation for phosphorus removal (Chavula & Mulwafu, 2007). According to Riffat et al., (2013), biological processes involves the conversion or destruction of contaminants with the help of microorganisms. In municipal wastewater treatment plants, microorganisms indigenous to wastewaters are used in biological treatment operations. Chemical processes are not commonly used in many countries owing to the high costs of materials and the high level of operation skills as such most countries have opted to use biological techniques in combination with physical techniques for sewage treatment (Kusuma & Pradesh, 2016). Examples of biological treatment include activated sludge process, membrane bioreactor, trickling filter and others. The primary purpose of biological treatment is to remove and reduce the biodegradable organic matter from wastewater to an acceptable level according to regulatory limits. Biological treatment is also used to remove nutrients such as nitrogen and phosphorus from wastewater. Biological processes constitute the most important methods of wastewater treatment since it does not require any chemicals.

2.3. Biological wastewater treatment

This refers to treatment that utilizes biochemical reactions of microorganisms in wastewater to achieve treatment objectives(Spellman, 2009). Heterotrophic and autotrophic microorganisms, including bacteria and fungi are responsible for removal of organic matter from wastewater (Miguel, Varón, & Cali, 2014). Heterotrophic microorganisms are organisms that cannot produce their own food and need an external carbon source (organic carbon) while autotrophic organisms are those that can synthesize their own food from inorganic carbon (Kusuma & Pradesh, 2016). Biological treatment is also utilized in nutrients, nitrogen and phosphorous removal from wastewater. Biological treatment can be achieved either through aerobic (oxic) processes, which are treatment processes that happen in the presence of free oxygen (O_2), or anaerobic processes, in which treatment takes place in the absence of oxygen, or anoxic processes that occur in the presence of bound oxygen such as in the biological conversion of nitrate nitrogen (NO3-N) to nitrogen gas (denitrification) (Farzadkia et al., 2014). In biological treatment, the breakdown of organic matter (OM) occurs through biological oxidation/respiration and biosynthesis. Biological oxidation/ respiration refers to OM removal that results in mineralized end products that remain in solution and discharged with the effluent. On the other hand, biosynthesis is a process for OM removal in which colloidal and soluble OM is converted into new cells (or particulate matter, PM) which are then removed through sedimentation. In the case of limited organic matter, microorganisms endogenously respire/ auto oxidize their microbial, cell tissue in order to obtain energy for body maintenance (RIFFAT, 2013). Endogenous respiration, biosynthesis and respiration all occur simultaneously in biological wastewater treatment.

2.4. Aerobic wastewater treatment

This refers to treatment processes that happen in the presence of free oxygen (O2). Two kinds of aerobic wastewater treatment processes exist: fixed film processes or suspended growth processes. Fixed film processes refer to biological treatment processes in which microorganisms are attached to an inert medium forming a biofilm such that when the wastewater gets in contact with and flows

over the biofilm, the organic matter is degraded by the microorganisms(Oberlin, 2018). On the contrary, suspended growth processes include aerated microorganisms that are suspended in a reactor with the wastewater by using a mixing technique and are in constant contact with the wastewater.

Fixed film processes

In fixed film (attached growth) systems the microorganisms are attached to an inert medium, forming a biofilm. The medium is usually an inert material with a high porosity and surface area, e.g. rock, gravel, synthetic media. The media can be wholly or partially submerged in the wastewater. As the wastewater comes in contact with and flows over the biofilm, the organic matter is removed by the microorganisms and degraded to produce an acceptable effluent. A secondary clarifier is used, but sludge recirculation to the biological reactor is not necessary. The settled sludge consisting of sloughed biofilm is usually recirculated back to the wet well or primary clarifier. Attached growth systems are characterized by a high degree of liquid recirculation (100% to 300%) to the biological reactor(George Tchobanoglous, 2019). The system can be operated as an aerobic or anaerobic process. Advantages of fixed film processes include among others; simplicity of operation, low maintenance required, ability to handle shock loads, Low energy requirement and low sludge production. Typical biological treatment technologies based on fixed film processes are trickling filters and biological towers (Hayati, Doosti, & Sayadi, 2013).

Trickling filters

A trickling filter consists of an open bed of fist-sized rocks/ other inert material/ or plastic over which wastewater seeps. Water runs through the interstitial spaces between the stones creating opportunity for growth of a biological slime on the inert material and air circulation is either mechanical or through natural circulation due to temperature difference between the air in the bed and ambient temperature. As the water runs across the surface of the slime, the microorganism communities in the slime/ biofilm absorb nutrients from the wastewater (carbon, nitrogen, phosphorus) and use them for their metabolic growth (Wanda, Gulula, & Kushe, 2014). Removal rates for BOD for a trickling filter depend on design

parameters including the wastewater flow rate; organic loading rate; and rate of diffusion of BOD and oxygen into the biofilm (Riffat, 2013).

Biological tower

Bio towers are deep bed trickling filters in which plastic or synthetic media are randomly packed in a loose accumulation of variously shaped beads, balls and amorphous beads. Biological growth occurs on these media with the hydraulic loading rates proportional to the void ratio which is the ratio of the amount of interstitial spaces between the beads/ balls to the number of beads/ balls in the reactor. Treatment occurs in the same way as the trickling filter where the substrate/ OM is removed by the biofilm on the filter media as the wastewater passes through the reactor (Fard, Reyahi-khoram, & Sobhan-ardakani, 2015).

Suspended growth processes

In a suspended growth process, the microorganisms are kept in suspension in a biological reactor by using a suitable mixing technique. The microorganisms use the organic matter as food and convert it to new biological cells, energy, and waste matter. Municipal wastewater contains a wide variety of organics, consisting of proteins, fats, and carbohydrates, among others. As a result, a variety of organisms or a mixed culture is required for complete treatment (Riffat, 2013). Each type of organism in the mixed culture uses the food that is most suitable to its metabolism. The larger species, in turn, feed on the smaller species. For example, the rotifers and crustaceans feed on the protozoa, the protozoa feed on the bacteria, and so on. The microorganisms used in the biological treatment processes are essentially the same as those found in surface waters, performing degradation of organic matter during natural purification processes. Natural purification processes take place over an extended period of time, ranging from days to weeks, depending on the strength of the wastewater and availability of a suitable microbial population. Typical biological treatment technologies based on suspended growth processes include activated sludge reactors (AS) and stabilization ponds/ lagoons (Nikoonahad et al, 2016).

Activated sludge (AS) reactors

For most of the developed world, the activated sludge (AS) process is the widely utilized suspended growth process. AS processes are used in biological treatment of

municipal and industrial wastewaters. In an AS process, microorganisms are suspended and aerated in a biological reactor, after which the suspended mass goes to the secondary sedimentation tank/ clarifier where the solids are separated from the liquid part of the wastewater. An AS system also contains a recycle unit that returns some of the settled solids to the reactor from the clarifier (return activated sludge, RAS). Treatment occurs through degradation of OM by the microbes and subsequent conversion to cell mass and waste products (Obenne Pearl Gopolang & Letshwenyo, 2019). The RAS help to maintain a high concentration of active biomass in the bio reactor. In AS processes, treatment is affected by several factors such as TSS and BOD loadings as well as the aeration regime. The aeration duration for an AS system is referred to as the amount of time that microorganisms in the biological reactor are exposed to oxygen needed for their respiration. Since microbes are aerated for as long as they are in the reactor, the aeration duration is the same as the Hydraulic retention time. Hydraulic retention time (HRT) refers to the time a fluid particle spends in the reactor before being discharged and it is expressed as;

HRT (day) = V/ Q

Where, Q = volumetric flow rate (m3/ day); and V = reactor volume (m3).

Stabilization ponds and lagoons

Waste stabilization ponds are large shallow basins enclosed by earthen embankments in which wastewater is treated by natural processes involving algae and bacteria. The basic principles of sewage treatment in all ponds is the same. The reduction of pollutants is accomplished by bacteria and algae and proceeds slowly in ponds without artificial or mechanical aeration and circulation (Aghalari, Dahms, Sillanpää, Sosa-hernandez, & Parra-saldívar, 2020). For the reason that no artificial aeration or circulation is involved, long detention times and large basins are required. Detention times in ponds of thirty or even fifty days are common. In many, highly developed countries where land is valuable and scarce, waste stabilization ponds are no longer being built. The use of waste stabilization ponds is very important, especially in tropical and subtropical regions, because there is favourable climate and sufficient land is normally available at low and affordable cost (O P Gopolang & Letshwenyo, 2018). The advantages of these land-based

treatment systems are low capital cost, low operating cost, large volume to inflow ratio provides enough dilution to minimize the effects of variable organic and hydraulic loadings and the disadvantages include large land area is required, odour problems are a concern and high suspended solids concentration in the effluent. Waste stabilization ponds are in three types, namely anaerobic ponds, facultative ponds and maturation ponds (Naddafi, Hassanvand, Dehghanifard, Razi, & Mostofi, 2009). These pond types could be arranged in parallel, series or a combination of both arrangements. However, irrespective of whichever arrangement, the first ponds in series are anaerobic ponds, followed by facultative ponds and finally maturation ponds.

a) Anaerobic ponds

In anaerobic ponds, anaerobic conditions prevail throughout. These pond cells operate under heavy organic loading rates as they are the primary units in pond systems. Anaerobic ponds rely on anaerobic digestion to achieve the removal of organic wastes. Riffat et al,. (2013) report that the removal of B0D in anaerobic ponds ranges from 50% to 80%. Anaerobic pond depths range from 3 to 5m and in a series arrangement it's followed by facultative ponds and then by maturation ponds.

b) Facultative ponds

These pond cells follow to anaerobic ponds or they can be the primary ponds if organic loading to ponds is light. Facultative ponds operate under lighter organic loading rates than anaerobic ponds. They reported that the B.0.D5 removal in facultative ponds is between 70% and 95% and depending on the concentration of algae that develop in these pond cells. Facultative ponds have depths ranging from 0.9 to 2 m. Greater depths allow the following two layers to develop; an anaerobic layer near the bottom and an aerobic layer near the surface .The lower organic loading and the shallower depths enable algae to develop in the surface layer and an ox pause to form (George Tchobanoglous, 2019). Below the oxy-pause anaerobic digestion of organic wastes occurs in the absence of oxygen. Above the oxy-pause aerobic bacterial oxidation of organic wastes occurs in symbiosis with algal photosynthesis. The algal photosynthesis provides the bulk of

the oxygen while some of the oxygen is available from surface re-aeration. The oxygen is utilized by bacteria to oxidize the organic wastes and bacterial protoplasm is formed together with carbon dioxide and water. The algae in presence of sunlight uses the carbon dioxide to convert the organic wastes to algal protoplasm and produce oxygen. Thus there is symbiosis between algae and bacteria in facultative ponds for treating sewage as shown in the figure below;

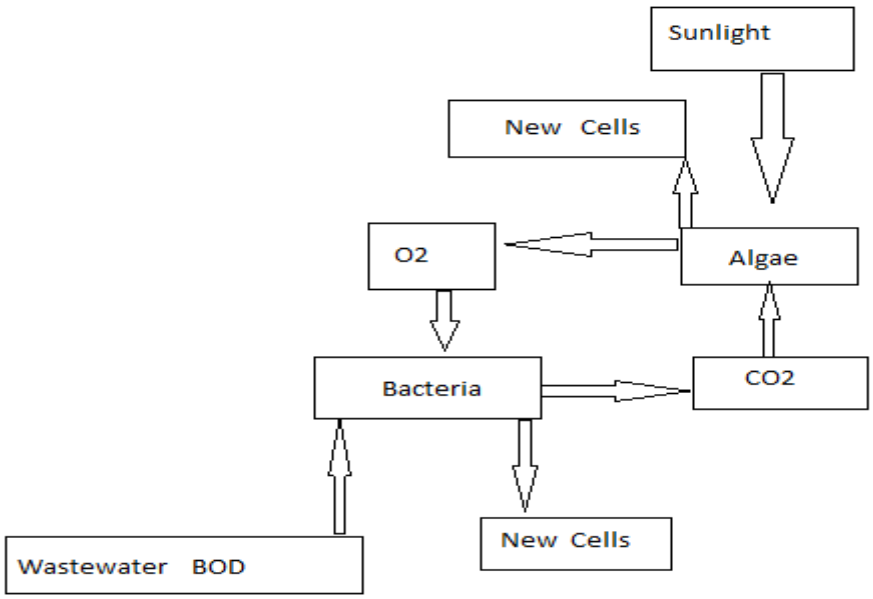


Figure 1. Symbiosis of Algae and Bacteria (Mateo et al., 2012)

C) Maturation ponds

Maturation ponds follow facultative ponds and they are largely aerobic due to low organic loading rates and shallow depths. The depths of these ponds are 1.0 to l.5m. In the maturation ponds faecal coliforms, biological oxygen demand (BOD), Total solids (TS) and ammonia are reduced further provided the ponds are well designed, constructed, operated and maintained. The total faecal coliform removal in anaerobic, facultative and maturation pond system is often above 99% (Mateo, 2012). As mentioned earlier, algal photosynthesis and surface re-aeration provide the bulk of the oxygen for the stabilization of wastewater. Maturation ponds may also be used for polishing effluent from sewage treatment plants like trickling filter plants or activated sludge plants.

2.5. Conditions necessary for wastewater stabilization ponds

Climatic conditions affect waste stabilization ponds with regards to processes involved in ponds for sewage treatment. The climatic factors which affect pond performance are temperature, solar radiation, wind speed, evaporation and rainfall. In addition to the climatic conditions, land availability and the topography of the land are factors which limit use of ponds.

Temperature

Temperature affects the biological activities which take place in ponds. The temperature has an effect on the rate of degradation of organic wastes due to its effect on the processes of microorganisms. The pond liquid temperature has a very big influence on pond performance. The optimum temperature for waste stabilization ponds is between 25°C to 32°C (Zhao et al., 2012). Temperature is important for ponds since the bacteria responsible for sewage treatment operate in the mesophilic temperature range. Higher temperatures than the mesophilic temperature range are not a problem. However lower temperatures cause's problems as they lower the treatment efficiency because of reduced bioactivity in ponds. In the case of methanogenic bacteria which are essential for anaerobic digestion, methane production almost ceases when the temperature of water in ponds is lower than 15°C (Mkude & Saria, 2014). In areas where temperature of water in ponds remains below 15°C for two months or more, Mkude et al., (2014) states that careful consideration should be given as to whether ponds are desirable or not. Temperature is also important in ponds in as far as thermal stratification is concerned. The thermal stratification can occur in ponds as a result of temperature differentials. If the stratification persists, non-motile algae below the thermocline (zone dividing darker bottom layers and surface layers where there is light) cannot enter the photic zone and they die due to lack of light. Thermal stratification can also cause short circuiting. The short circuiting results due to lack of mixing and this leads to reduced treatment efficiency of the ponds because the wastewater does not remain in the ponds for the designed detention time.

Solar radiation

Solar radiation is the energy source for photosynthesis of algae in facultative and maturation ponds. However it is stated that in tropical areas solar radiation does

not seem to play a critical role for algae growth and hence oxygen production. Periods of cloud cover in tropical regions are seldom a problem because the solar radiation in these regions during the day generally exceeds the saturation light intensity of algae in the ponds (Mkude & Saria, 2014).

Wind speed

Wind is a prominent factor affecting the performance of ponds. Wind causes surface aeration in top layers of ponds and induces mixing in the whole body of water. Mixing in the water body is essential because it over comes thermal stratification, distributes oxygen generated in the top layers to bottom layers, maintains the non-mobile algae in suspension, enhances algae growth and also increases the organic capacity of ponds. The depth to which wind induced mixing is felt is largely dependent on the distance the wind is in contact with the water. As reported by Angus (2020) an unobstructed contact length of about 100m is required for maximum mixing by wind action. Excessive wind action on the other hand may have negative effects on pond performance because the settleable solids may become suspended, thus reducing light penetration in case of facultative and maturation ponds and hence reducing the photosynthetic activity. Excessive wind may also cause erosion along the edges of ponds. To avoid short circuiting from inlet to outlet and retardation in flow, the pond layout should be planned in such a way that there is prevention of prevailing wind along the line of flow (Chu, 2020).

Evaporation and Rainfall

Evaporation and rainfall also have various effects on pond performance. Evaporation may have a big role when determining the level of water maintained in the ponds. The evaporation loss should be considered in the design of ponds because the evaporation loss in one pond results in decreased sewage flow to the ponds that follow in series. Rainfall is also important for the hydraulic design considerations of ponds. 1f the rain is heavy it can induce mixing, increase aeration, contribute high dissolved oxygen to water in ponds, and in some cases breakdown stratification in ponds. These may result in improved performance of ponds (Rahmatiyar, Salmani, Hospital, & Alidadi, 2014).

Land

According to Spellman (2009) land is one of the most important factor to be taken into account when waste stabilization ponds are to be considered as an alternative for wastewater treatment. Land should be available at a reasonable and economical distance from the community to be served. The land should be available at affordable costs. The topography and geological conditions of the sites should be suitable in order to reduce the capital costs involved during pond construction.

Mechanism of sewage treatment in waste stabilization ponds.

According to Fard et al., (2015), the major treatment processes which occur in waste stabilization ponds are:

(a) The reservoir effect which enables ponds to absorb both organic and hydraulic shock loadings,

(b) Primary sedimentation which allows the settleable solids to sink to the bottom sludge layer of anaerobic and facultative ponds and

(c) Treatment of organic waste by anaerobic digestion in sludge layers and aerobic bacterial oxidation in top layers of facultative ponds and in maturation ponds.

The efficient absorption of shock loadings and equalization of loading peaks are dependent on achieving reasonably good mixing of the influent throughout the pond contents. Mixing is also important to minimize the hydraulic short circuiting in ponds and to achieve a good vertical distribution of both oxygen and algae in facultative and maturation ponds. Non mobile algae which are the most efficient oxygen producers rely on pond mixing to bring them into the surface layers of facultative and maturation ponds where light intensity is greatest. Mixing also destroys thermal stratification as previously stated (Fard et al., 2015).

As indicated by a study done by Camille et al., (2017), settleable suspended solids settle to the benthos (at the bottom of ponds) under the quiescent conditions found in ponds. Aerobic bacteria oxidation and anaerobic digestion treat the organic wastes and BOD is reduced. The anaerobic process for treating organic wastes in anaerobic and facultative ponds is basically in two stages:

(a) Organic matter + bacteria ⟶ new bacterial cells + mixed organic acids.

(b) Mixed organic acids + bacteria ⟶ new bacterial cells + methane +carbon dioxide + water + ammonia.

The aerobic process on the other hand can be represented as a single stage process;
Organic matter + Oxygen + bacteria ⟶ new bacterial cells+ water + carbon dioxide + phosphates +ammonia.
The oxygen for the aerobic process is largely provided by algal photosynthesis which can be expressed as follows;
Carbon dioxide + water + algae + sunlight ⟶ new algal cells + water + oxygen.
The pathogenic and faecal indicator bacteria are reduced due to various pond effects. Many theories about the destruction of pathogens and faecal indicator bacteria in ponds have been suggested that detention time and settling in ponds, temperature,
bactericidal effect of solar radiation, presence of toxic substances produced by algae, high pH values found in ponds due to algae and competition for food (Adams et al., 2020). The faecal bacteria and indicator organisms die off reasonably quickly in ponds due to the unfavourable environment mentioned above.

2.6. Designing of wastewater stabilization ponds

Treatment plants should be designed on the basis of the flow and the strength of pollutants like B0D, TS and coliforms. Ogbonna et al., (2014) indicated that from previous studies by Burkhard et al., (2010), and Roland et al., (2012), it is fairly well established that pond process performance is effected by areal B0D loading and detention time (hydraulic retention time, HRT).
The studies conducted showed that pond performance can be improved by three techniques;

(a) Increased detention time will increase B0D removal and can be accomplished by deepening the pond. The most probable cause of improvement would be the increased algal sedimentation.

(b). Decreased areal B0D loading will increase the BOD removal by decreasing the carbon to be processed (and recycled to algae). This decreased loading can be accomplished by pre-treating the sewage.
(c) Decreased areal B0D loading and increased detention time can be accomplished by increasing the number of ponds in the system. This agrees with the findings by

Naddafi et al (2009), who established that for an equivalent total volume, a series of ponds is superior over a single pond. Another reason why a series of ponds is better than single pond is because short circuiting is reduced in a series of pond.

2.7. Physico-chemical parameters

pH

PH, or the "potential of hydrogen", is a measure of the concentration of hydrogen ions in the water. This measurement indicates the acidity or alkalinity of the water. On the pH scale of 0-14, a reading of 7 is considered to be "neutral". Readings below 7 indicate acidic conditions, while readings above 7 indicate that the water is alkaline, or basic. The pH of the water is important because it affects the solubility and availability of nutrients, and how they can be utilized by aquatic organisms(Miguel, Varón, & Cali, 2014). Generally a pH between 6-8 is desirable for the biological oxidation of most wastes.

Temperature

Temperature is a measure of how cold or hot the water is, expressed in degrees Celsius (°C). Temperature is a critical water quality parameter, since it directly influences the amount of dissolved oxygen that is available to aquatic organisms. The amount of oxygen that will dissolve in water increases as temperature decreases. Water at 0°C will hold up to 14.6 mg of oxygen per litre, while at 30°C it will hold only up to 7.6 mg/L. Water temperature that exceeds 18 degrees Celsius has a deleterious effect on several fish species in streams. To a certain level, increased temperature leads to an increase in biological activity (Rahmatiyar, Salmani, Alipour, & Alidadi, 2014).

Biological oxygen demand (BOD)

The BOD is used as a measure of the pollution potential of wastewater. It gives us an idea of the amount of biodegradable organic matter that is present in a wastewater. BOD is defined as the amount of oxygen utilized by a mixed population of microorganisms during aerobic oxidation of organic matter at a controlled temperature of 20°C for a specified time (RIFFAT, 2013). Theoretically it would take an infinitely long time for the microorganisms to degrade all the organic matter present in the sample. The BOD value is time dependent.

Chemical oxygen demand (COD)

Chemical oxygen demand (COD) refers to the oxygen consumption capacity of the wastewater through chemical oxidation of the organic matter in the wastewater. COD differs from BOD in that BOD is related to biochemical oxidation of organic matter completely by microorganisms while COD corresponds to chemical oxidation of organic matter via a strong oxidizing agent like potassium dichromate. COD includes non-biodegradable organic matter such as lignin (in fibres) and other such complex organic compounds(Kanda, Masamha, Gotosa, & Shepherd, 2013).

Total suspended solids (TSS)

Total Suspended Solids is the amount of material, by weight that is suspended (not dissolved) in a given volume of water and is expressed in mg/l. The solids mainly consist of living and dead phytoplankton and zooplankton, silt, human sewage, animal excrement, portions of decaying plants and animals. Suspended particles may provide a place for harmful microorganisms to lodge. Some suspended particles may provide a breeding ground for harmful bacteria (Chavula & Mulwafu, 2007).

Total dissolved solids (TDS)

Total dissolved solids (TDS) are a measure of the amount of particulate solids that are in solution. The solids can pass through the 1.5 μm filter and are then evaporated and dried at a specified temperature and comprises of colloidal and dissolved solids (Adams et al., 2020).

Turbidity (NTU).

In simple terms, turbidity answers the question, "How cloudy is the water?" Light's ability to pass through water depends on how much suspended material is present. Any substance that makes water cloudy will cause turbidity. Turbidity may be caused when light is blocked by large amounts of silt, microorganisms, plant fibres, sawdust, wood ashes, chemicals and coal dust. The units of measure for turbidity are Nephlometric Turbidity Units (NTUs). Turbidity affects fish and aquatic life by interfering with sunlight penetration. Water plants need light for photosynthesis. If suspended particles block out light, photosynthesis and the production of oxygen for fish and aquatic life will be reduced. If light levels

get too low, photosynthesis may stop altogether and algae will die. It is important to realize that reduced photosynthesis in plants result in lower oxygen concentrations and large carbon dioxide concentrations in a water body (Burkhard, Deletic, & Craig, 2012).

Electrical conductivity (EC)

Electrical Conductivity (EC) is the ability of the water to conduct an electrical current, and is an indirect measure of the ion concentration. The more ions present, the more the electricity that can be conducted by the water. Wastewater contains much higher concentrations of salts than drinking water (Ngwira & Lakudzala, 2018).

Nutrients

A nutrient is an element that is essential to organisms and plants. In domestic wastewater high levels of essential elements such as nitrogen (N), phosphorus (P), potassium (K), sulphur (S), chlorine (Cl), sodium (Na), magnesium (Mg) and calcium (Ca) are often found . This is mainly due to the high levels of nutrients in urine and faeces, but also to the use of for example detergents in households. Unless the water is purified properly there is a risk that these levels are harmful to plants and organisms when emitted into streams and rivers. In plants, this can lead to crop failure, which can have devastating consequences in a country like Malawi that is highly dependent on its agriculture. An excessive intake of nutrients in humans and other organisms can cause damage to health. In domestic wastewater both bacteria and plants can help reduce the nutrient levels in wastewater through mineralization and uptake (El-sheekh, Metwally, & Gamal, 2014).

Dissolved oxygen (DO)

This is the oxygen concentration existing in a solution (dissolved) with water. It is a variable for fish breath and aerobic microorganisms to utilize. If not present at certain levels, aquatic life cannot be sustained. Dissolved oxygen can be added to water in several ways; by aeration equipment, turbulent flow, algae or wind. Whatever the mechanism, dissolved oxygen is of major importance for good wastewater treatment.

Alkalinity

This is a measure of the capacity of water to neutralize acid. Alkalinity is due to the presence of bicarbonate, carbonate and hydroxide ions. Salts of week acids, such as borates, silicates and phosphates may also contribute. Carbonates and hydroxide may be significant when algal activity is high. In wastewater treatment, alkalinity is an important parameter in determining the amenability of wastes to the treatment process and control of processes such as anaerobic digestion, where bicarbonate alkalinity, total alkalinity and any fraction contributed by volatile acid salts become considerations(Aghalari et al., 2020).

2.8. Microbiological parameters

For example E.coli, total coliforms and faecal coliforms. Faecal coliforms are microscopic organisms that live in the intestines of all warm blooded animals, and in animal wastes or faeces eliminated from the intestinal tract. Faecal coliforms may indicate the presence of disease carrying organisms which live in the same environment as the faecal coliform bacteria. The measurement is expressed as the number of organisms per 100 ml sample of water (N/100ml) (Mkude & Saria, 2014).

CHAPTER 3: METHODOLOGY

3.1. Study Area

The study focused on the Limbe municipal wastewater treatment plant located at Chigumula in the city of Blantyre, Malawi. Blantyre is Malawi's commercial capital city, with a population of 956,898 (Malawi Government, 2019). The city of Blantyre lies within the Shire Highlands, with a topography ranging from 800 m to 1600 m, in the southern part of Malawi. Malawi lies between latitudes 9^0 and 17^0 south and between longitudes 33^0 and 36^0 East (Malawi Government, 2018).
The Limbe stabilization pond system consist of sixteen ponds as shown in figure 2 below.



Figure 2; Aerial view of Limbe sewerage works

Conventional wastewater treatment

Prior to treatment in the WSPs, the wastewater is first subjected to physical treatment (screens) to remove coarse material and suspended solids which may otherwise clog the pumps and floating materials accumulating on the surface of waste stabilization ponds and heavy solids entering the pond sludge layer. Collected wastewater is led through a grid which retains the large particles. Such a grid consists of parallel bars with a mutual distance as shown in figure 3 below.



Figure 3; Screen consists of parallel bars with a mutual distance

From screening stage wastewater flows into a grit removal longitudinal chamber with sloping bottom provided prior to the collection pipe. The purpose of inclusion of grit channels in physical treatment is to differentially remove grit. These materials are removed to allow efficient pumping of effluents and to prevent clogging of pumping system. After physical treatment the wastewater is channelled through a pipe into different ponds. During the study only the facultative pond (pond in green colour figure 2) was functioning the rest of the ponds were not functioning. The facultative pond was covered with algae and phytoplankton's showing that there was life as shown in figure 4 below. Algae and phytoplankton's help with nutrient removal from the pond. After treatment in the facultative pond the wastewater effluent is channelled to Limbe River.



Figure 4; Facultative Pond

3.2 study design

This study used experimental quantitative research design in which samples were measured before and after treatment using different analytical methods, in order to determine the relationship between independent variables and dependent variables.

3.3. Sampling

Grab samples were collected at the inlet and outlet point of the treatment system in order to find out the performance efficiency in treating the pollutants. The glass bottles used for sample collection and storage were cleaned and rinsed with deionized (DI) water before sample collection. Samples were taken directly by means of 15 litre bucket and transferred into 1 litre glass bottles. The collected samples were preserved by maintaining a temperature below 5^0C using ice blocks in order to avoid biodegradation of the chemical species in the samples. The samples were carried to MUST Environmental science laboratory for physicochemical and microbiological parameters analysis.

3.4. Materials and Methods

There were several methods that were used in determining the physicochemical and biological water quality parameters. Some of the physicochemical parameters like pH, temperature, oxidation-reduction potential (ORP), dissolved oxygen (DO), electrical conductivity (EC), and Total dissolved solids (TDS) were measured in situ, using a multi parameter probe as shown in figure 5 below. The probe was dipped into the wastewater, then it was switched on to determine the values of the parameters.



Figure 5; In situ wastewater measurement for physicochemical parameters using a multi parameter probe

Determination of ammonium

Ammonium (NH_4) was determined using photometric method (Andrew D. Eaton, 1999).Firstly, water samples were filtered to remove total suspended materials, 10ml of the water sample was added into a beaker and was diluted with 390ml distilled water. A clean vial was filled with a 10 ml of distilled water and closed with a cap, the vial was placed on the photometer chamber aligning the marks. Ammonium measurement is at number 60 in the photometer. The measurement value was selected and the zero key was pressed in order to set the photometer into ammonium measurement. The vial was removed from the sample chamber. Another viral was filled with a 10ml of diluted sample. Then AMMONIA No. 1 tablet which is colour forming reagent was added straight from the foil to the water sample in a vial. The tablet added into sample was crushed using a clean stirring rod, another tablet AMMONIA No. 2 was added straight from the foil to the same water sample and it was crushed using the same clean stirring rod. These two colour forming reagents facilitate the absorbance of light by photometer. After addition of the reagents, the vial was tightly closed with the cap and swirled several times until the tablets were dissolved, the vial was placed on the photometer aligning the marks, and then the test key was pressed. After 10 minutes

of waiting, the reaction finished and the measurement was then recorded. The filtered water samples were tested in triplicates.

Determination of nitrates

Nitrates were determined using photometric method (Andrew D. Eaton, 1999). Firstly, water samples were filtered to remove total suspended materials, a clean vial was filled with a 10 ml of distilled water and closed with a cap. The vial was placed on the photometer chamber aligning the marks. Nitrates measurement is at number 65 in the photometer. The measurement value was selected and then the zero key was pressed in order to set the photometer to Nitrate (NO3-N) measurement. The vial was removed from the sample chamber. 20ml nitrate test tube was filled with 20ml of the water sample. One level spoon of nitrate test powder was added to 20ml of the water sample in a test tube, then one nitrate test tablets was added straight from the foil to the same water sample and it was crushed using a clean stirring rod, the vial was tightly closed with the cap and swirled several times until the tablets dissolved. After that a vial was placed on the photometer aligning the marks, then the test key was pressed. After 2 minutes of waiting, the reaction finished and the measurements were then recorded. The filtered water samples were tested in triplicates.

Determination of total suspended solids

TSS were obtained using photometric method (Andrew D. Eaton, 1999) . Firstly a clean vial was filled with a 10 ml of distilled water and closed with a cap. The vial was placed on the photometer chamber aligning the marks. TSS measurement is at number 105 in the photometer. The measurement value was selected and then the zero key was pressed in order to set the photometer to TSS measurement. Then the vial was removed. Another viral was filled with a 10ml of sample. The vial was placed on the photometer aligning the marks, then the test key was pressed and the measurements were obtained immediately and recorded.

Determination of turbidity

Turbidity was also determined using photometric method(Andrew D. Eaton, 1999). Firstly a clean vial was filled with a 10 ml of distilled water and closed with a cap. The vial was placed on the photometer chamber aligning the marks. Turbidity measurement is at number 125 in the photometer. NTU measurement value was

selected and then zero key was pressed in order to set the photometer to turbidity measurement. Another viral was filled with a 10ml of sample. The vial was placed on the photometer aligning the marks, then the test key was pressed and the measurements were obtained immediately and recorded.

Determination of chemical oxygen demand (COD)

COD was determined by digestion method. (Andrew D. Eaton, 1999). Firstly, samples were digested with acid for 2 hours at 150°c. Water was used for blank determinations and preparation of control standards to show negligible interference. A pipette was used to transfer samples in mercury test tubes. The tubes were swirled to mix the contents and closed then put in a digester, a heating source. After 2 hours the test tubes containing the sample was placed on the photometer to read the value of the COD.

Determination of biological oxygen demand (BOD)

The values of BOD were obtained from secondary data, (Chipofya, Kraslawski, & Avramenko, 2010) due to failure of the BOD analyser in the lab during this period. In this paper BOD5 was determined by the Winkler method of oxygen measurement in the samples before and after incubating for five days at 20° C. This study is different from the present one since it was conducted during the dry season in a month of October ten years ago while this study was conducted in April, 2021 during spring season.

Alkalinity

This was measured using titration method (Andrew D. Eaton, 1999). Titration test was done twice for each sample. 50ml of water sample was poured into a conical flask, phenolphthalein indicator was added and it was observed that there was no colour change meaning there was no hydrocarbons. Then 2-3 drops of methyl orange was added in the flask and there was colour change into orange, after titrating with hydrochloric solution while shaking the flask, a red colour was obtained as the end-point of acid-base titration. Initial and final burette readings were recorded.

Determination of Faecal and Total coliforms

Total coliforms and faecal coliforms were determined using membrane filtration method (Andrew D. Eaton, 1999). Before sample collection, the sampling bottles

were autoclaved at 105^0 C for 25 minutes in the drying oven to kill all the present bacteria in the sampling glass bottles. After sample collection all the apparatus to be used were sterilized with ethanol to avoid contamination of the samples. A membrane filter was placed on a sterilized membrane filtration unit, then 100ml volume of water sample was drawn through a membrane filter (45 m pore size) through the use of a vacuum pump. The microorganisms present in the wastewater remained on the filter. Another membrane filter (used as a medium for growth) was placed in a petri dish and saturated with lauryl sulphate broth so that growth of desired organisms (faecal or total coliforms) is encouraged while that of other organisms is suppressed. The filter containing microorganisms was placed on top of the filter saturated with growth medium in the dish. Then the dish containing the filters was incubated for 18 hours at 44.5 ^{0}C in the incubator to allow the growth of faecal coliform. This elevated temperature heat shocks non-faecal bacteria and suppresses their growth. As the faecal coliform colonies grow they produce an acid (through fermenting of lactose) that react with the aniline dye in the agar thus giving the colonies their yellow colour. The same procedure was followed for total coliforms only that the filter was incubated for 24 hours at 37.0 ^{0}C in a different incubator and as the colonies grow they give a pink colour. Both filters after their respective incubation time, were removed and placed on the colony counter where they were counted directly. The values obtained were recorded in the lab book.

Removal efficiency calculation

After knowing the inlet and outlet concentration of the studied parameters the removal efficiency for these parameters were calculated by using the following formula;

Efficiency (%) = $[(C_{in} - C_{eff})/ C_{in}] * 100$

Where; C_{in} is the concentration of the waste material in the influent C_{eff} is the concentration of the waste material in the effluent (Riffat, 2013).

Measuring flow rate

In the absence of a flow meter at the plant, a physical flow estimation approach was used. Firstly, a glass bottle was placed against the flow direction of the raw wastewater. A stop watch was started immediately the water started filling the bottle and it was paused when the water filled to the required volume. The

volume and time taken was recorded. This was done three times for accuracy purpose. After this flow rate was calculated using a formula

Flow rate (Q) = Volume/Time.

the values of the flow rates calculated was used to calculate hydraulic loading rate and volumetric loading rates using their respective formulas as shown in table 3 and 4 below.

Statistical analysis

The data obtained from the water samples were analysed by using the software Microsoft Office Excel 2013. The statistical tools such as correlation and regression analysis were used. Different bar charts and tables were prepared for the presentation of the results.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Physicochemical and microbiological parameters

PH

PH is a measure of the amount of hydrogen ions in water. The wastewater pH in the raw wastewater (influent) was 7.5 and 7.1 in the facultative pond (effluent). It is common to find variations in pH in WSP. In this study the pH decreases in the facultative pond though it was within the MBS standard for wastewater disposal as shown in table 1 below. According to Angus at el., (2020), pH decrease in wastewater effluent indicates that the rate of photosynthesis is low by the pond algae as such consumption of carbon dioxide (CO_2) is slower than its replacement by bacterial respiration as a result carbonate and bicarbonate ions associates in the pond. This condition reduces hydroxyl ions (OH), so lowering the pH value. It is reasonable for rate of photosynthesis to be low, since the study was conducted during spring season which is mostly accompanied by cold weather.

Oxidation reduction potential (ORP)

ORP is similar to pH in that pH indicates how acidic or basic a solution is based on the hydrogen ions activity within the solution and ORP indicates the reduction oxidation status of a solution based on the collective electron activity within the solution. ORP increases with decreasing pH (Mkude & Saria, 2014) . In this study ORP in the raw wastewater (influent) was 1.37mV and 18.9mV in the facultative pond (effluent). This shows that ORP increased in the facultative pond. According to Mkude and Saria, (2014) ORP increased due to pH decrease in the facultative pond. ORP effluent value is below the MBS standards for effluent disposal as shown in table 1 below which means the system is performing well in terms of maintaining ORP.

Alkalinity

Alkalinity is a measure of carbonate and bicarbonate levels in water and it is related to pH. Regardless of the starting pH, the higher the alkalinity of water the higher the pH (Ogbonna, 2014). In this study alkalinity was decreasing from raw wastewater with a value of 646.35 mg/l $CaCO_3$ to 520.42 mg/l $CaCO_3$ in the facultative pond (effluent) since pH was also decreasing along the train though

alkalinity was higher than the Malawian standard for wastewater disposal as shown in table 1 below which means that the receiving environment is exposed to a treat.

Table 1; Results of the physicochemical and microbiological parameters with their standard deviation for each parameter plus effluent discharge limits (MBS)

Parameters	Influent	Influent std	Effluent	Effluent Std	MBS
pH	7.5	0.34297716	7.1	0.01527525	6.5-9
Alkalinity (mg/l CaCO3)	488.67	208.629656	393.33	169.213869	≤ 250
Oxidation Reduction Potential (mV)	1.37	25.1726704	18.9	2.93995465	≤ 100
Temperature (°C)	12.25	0.61441029	10.1	0.05773503	≥ 40
Dissolved Oxygen (mg/l)	0.2	0.1	0.56	0.32908965	≥ 5
Total Dissolved Solids (mg/l)	478	131.111911	405	0.57735027	≤ 500
Electric Conductivity (µs/cm)	738.33	203.160856	625	1.15470054	≤ 500
Turbidity (NTU)	461	19.055183	93	3.06050105	≤ 5
Total Suspended Solids (mg/l)	576	11.8222953	106	3.98329847	≤ 30
Nitrate (NO3 -N) (mg/l)	2.08	1.11460157	1.27	1.11789087	≤ 50
Ammonium (NH4) (mg/l)	30	10.384604	36.4	4.88906944	≤ 10
Chemical Oxygen Demand (mg/l)	278	25.6580072	72	10.40833	≤ 50
Biological oxygen demand (mg/l)	740		89		≤ 20
Fecal Coliform (CFU/100ml)	3260	984.211867	1936	719.598731	≤ 1000
Total Coliform (CFU/100ml)	3889	880.253562	2932	280.016666	≤ 1000

STD gives a range of errors when determining the values of variables. Standard deviation were calculated to help check the variations in triplicates of variables. The graphs below represents the trend analysis of different parameters.

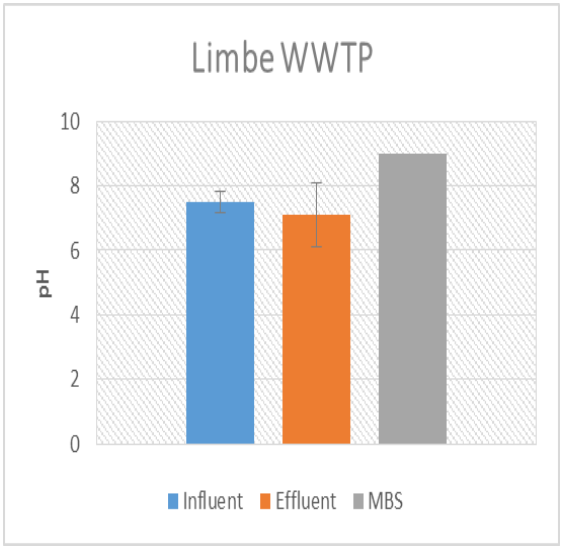


Figure 6.1. Trend analysis of pH

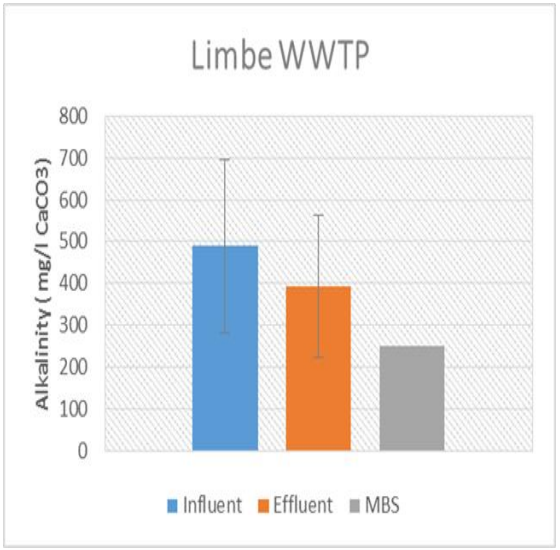


Figure 6.2.Trend analysis for Alkalinity

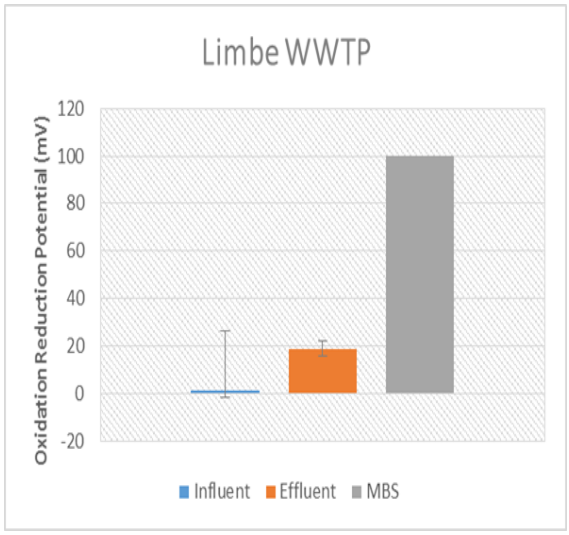


Figure 6.3.Trend analysis for ORP

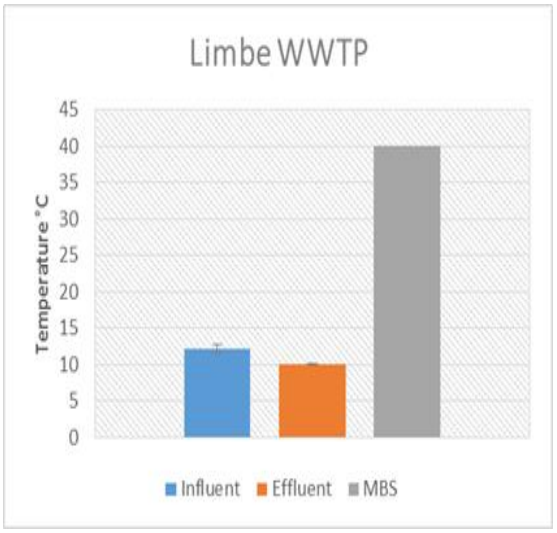


Figure 6.4.Trend analysis of temperature

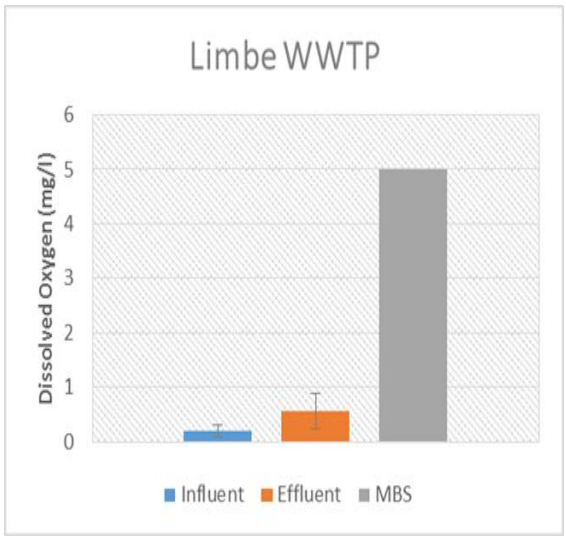


Figure 6.5. Trend analysis for DO

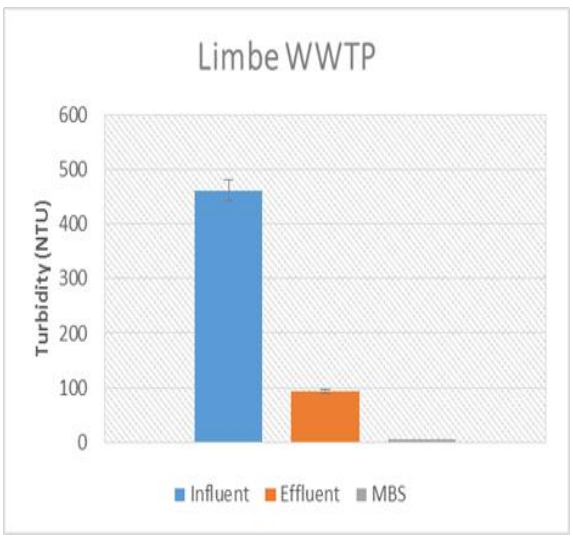


Figure 6.6. Trend analysis for turbidity

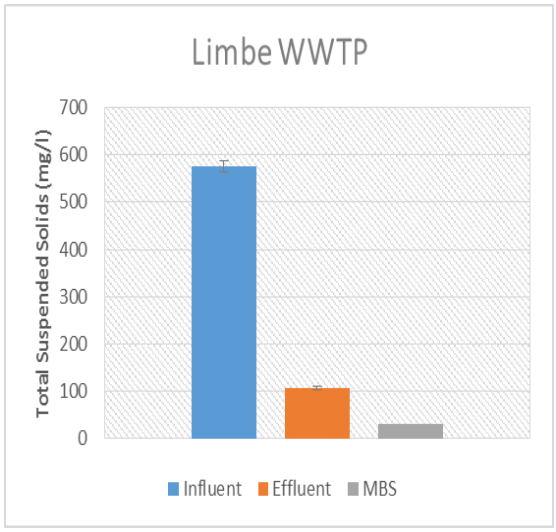


Figure 6.7. Trend analysis for TSS

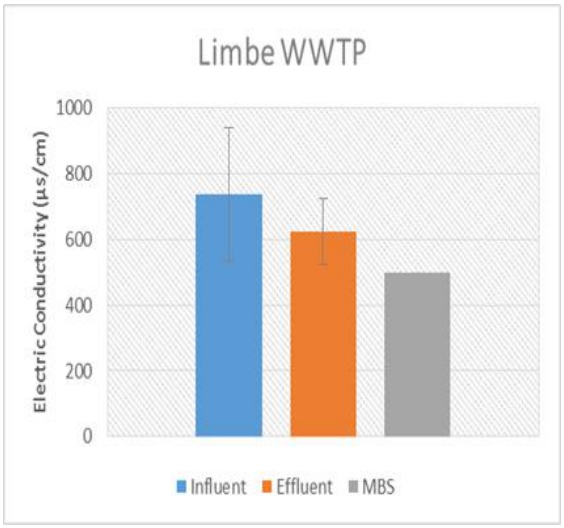


Figure 6.8. Trend analysis for EC

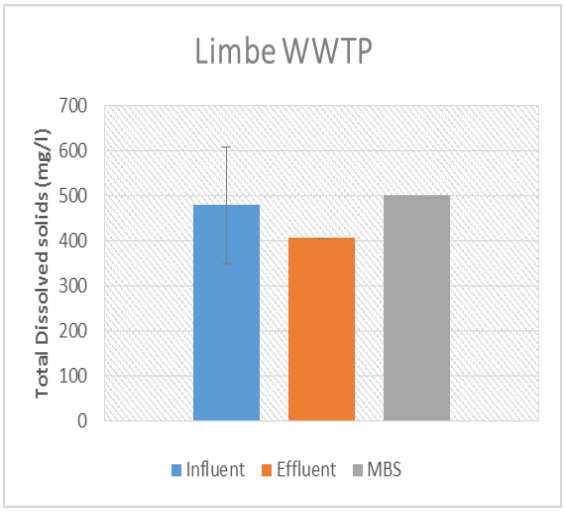


Figure 6.9. Trend analysis for TDS

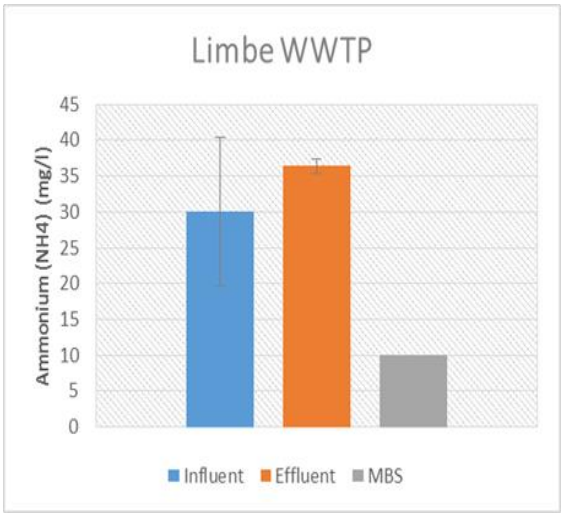


Figure 6.10. Trend analysis for NH_4

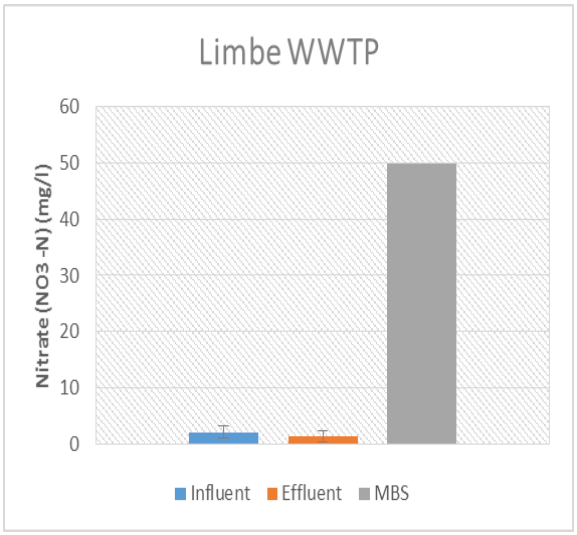


Figure 6.11. Trend analysis for NO_3-N

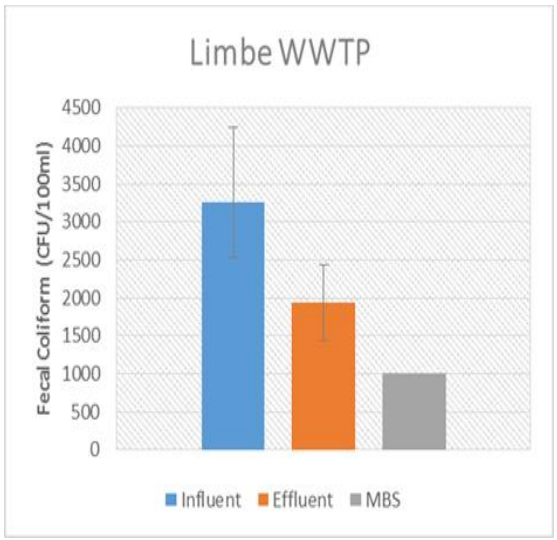


Figure 6.12.Trend analysisfor faecal coliform

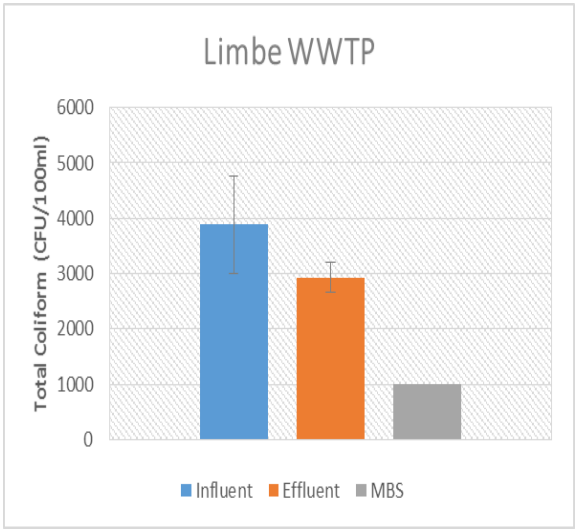


Figure 6.13. Trend analysis for total coliform;

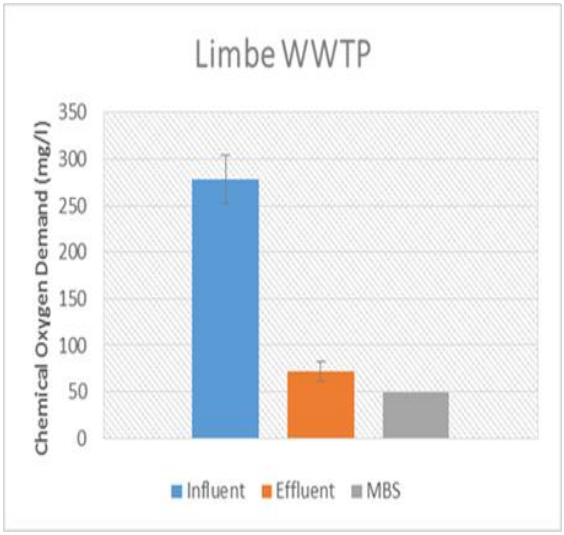


Figure 6.14. Trend analysis for COD

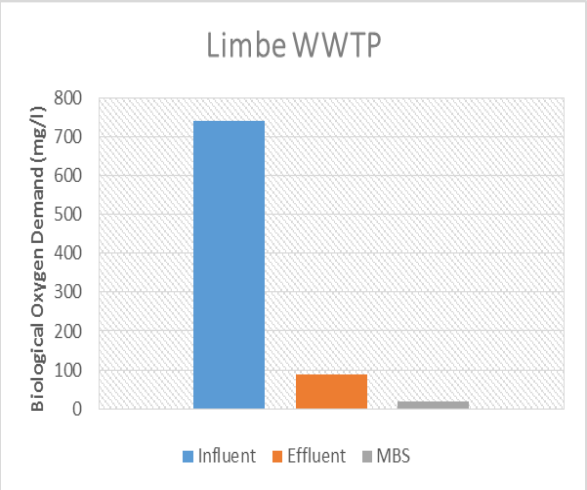


Figure 6.15. Trend analysis for BOD

Temperature

The wastewater temperature in the raw wastewater (influent) was 12.25 and 10.1 in the facultative pond (effluent). The temperature decreases in the facultative pond. This is due to the higher evaporation rate from the surface of the ponds which accomplished with higher latent heat (Mateo, 2012).. Decrease in temperature increases amount of DO since decrease in temperature decreases metabolic (respiration) reactions in water system as such lowering the consumption of oxygen by microorganisms but this reduces rate of OM degradation by microorganisms. Temperature was below the Malawian standard range for wastewater disposal as shown in table 1 above which means the system is not maintaining the required temperature.

Dissolved oxygen

For the case of dissolved oxygen (DO) the concentration was 0.2 mg/l in the influent (raw wastewater), and 0.56 mg/L in the final effluent (facultative ponds). Low values of DO in influent can be attributed to the fact that raw wastewaters are usually with high organic loads and rely totally on anaerobic digestion (absence of oxygen) to achieve organic removal. According to Arnell et al., (2016), raw wastewater normally do not contain dissolved oxygen (DO) or algae. A great enhancement in DO concentration in facultative pond can be attributed to the occurring reduction of BOD load, algal oxygen production, and transformation of oxygen from air through the ponds surface. Effluent DO concentration could be due to the process of photosynthesis in these ponds. During

this process algal cells generate oxygen which is utilized by bacteria. All these processes lead to efficient mineralization of organic matter translating into lowered BOD and inactivation of microorganisms. But values of the dissolved oxygen concentration in the effluent provide little useful information on pond performance, since they are altered substantially by oxygen exchange between the effluent and the atmosphere during the turbulent exit of the effluent from the pond (Arnell, 2016). The effluent DO amount is below the Malawian standard as shown in table 1 above.

Turbidity

This a measure of the amount of light that is absorbed and scattered by substances in the water when light shines through the water. Increased turbidity will also increase water temperature (Gopolang & Letshwenyo, 2018). This is due to presence of suspended particles which absorb heat from the solar radiation more efficiently than water. The heat is then transferred from the particles to water molecules increasing the temperature of the surrounding water. In this study turbidity in the influent was 461 NTU and 93 NTU in the effluent. This shows a decrease in turbidity though the effluent turbidity is higher than the MBS standard for wastewater disposal as shown in table 1 above. As such the receiving environment is exposed to the impact of high turbidity. As turbidity decreases, water temperature also decreases and DO levels increases which is the case in this study.

Total suspended solids

TSS is the quantitative expression of suspended particles. In this study TSS in the raw wastewater was 576 mg/l and 106 mg/l in the effluent (facultative pond). TSS was decreasing though the effluent value is above the MBS standards for wastewater disposal to safeguard the receiving environment as shown in table 1 above. This indicates that there was settling down (sedimentation) of suspended particles in the pond. Decrease in TSS, decreases turbidity and temperature as well. This is due to decreased amount of substances which can absorb and scatter heat in the water which is the case in this study.

Total dissolved solids

TDS is the measure of dissolved ions concentration in water. In this study TDS in the influent was 478mg/l and 405mg/l in the effluent. TDS was decreasing in the facultative pond and it was below the MBS standard for wastewater disposal as shown in table 1 above. This is due to the decrease in temperature in the facultative pond which decreases the solubility of substances in the water as a result there was less dissolved ions.

Electric conductivity (EC)

EC is the ability of the water to conduct an electrical current and is a direct measure of the ions concentration. The more the ions present the more the water conductivity. In this study the conductivity in the influent was 738.33μs/cm and 625μs/cm in the effluent (facultative pond). The EC was decreasing in the facultative pond though it was above the MBS standard for wastewater disposal as shown in table 1 above. This is due to decrease in the amount of dissolved ions (TDS) as discussed above and also decrease in temperature lowers the movement of ions, hence the apparent conductivity decreased.

Ammonium (NH_4)

Ammonium compounds are formed when ammonia compounds gain hydrogen ion and ammonia is produced from the decomposition of organic matter. In this study the concentration of ammonium in the raw wastewater (influent) was 30 mg/l and 36.4 mg/l in the facultative pond (effluent). Ammonium concentration increased in the facultative pond which means that there is no any removal of NH_4 in the treatment system and its concentration was above the MBS standard for wastewater disposal as shown in table 1 above. This is due to the continuous transformation of nitrogenous organic matter into ammoniacal nitrogen by the ammonification process and conversion of nitrate to ammonium under anaerobic conditions (Farzadkia et al., 2014).

Nitrates (NO_3-N)

Nitrates are formed from ammonium through nitrification process by nitrifying bacteria. In this study the concentration of nitrate in the raw wastewater was 2.08mg/l and 1.27 mg/l in the facultative pond (effluent). Nitrate concentration decreased in the effluent and it was below the MBS standard for wastewater

disposal as shown in table 1 above which means that there is removal of nitrates in the system. This is due to loss of nitrification. Loss of nitrification in biological wastewater treatment plant is caused by cold weather, which slow down the growth rate of nitrifying bacteria (Kusuma & Pradesh, 2016). Since this study was conducted during spring season which is mostly accompanied by cold weather, it is reasonable for the concentration of nitrate to be low in the effluent.

Total coliform and faecal coliform

Total coliforms include bacteria that are found in the human or animal waste whereas faecal coliforms are the group of the total coliforms that are considered to be present in the gut and faecal of warm blooded animals. In this study both total and faecal coliform decreased with a small proportion in the facultative pond and their values were far above the MBS standard for wastewater disposal as shown in table 1 above. This means that the pond is not performing efficiently in the removal of coliforms as such the receiving environment is exposed to a health risk.

Biological oxygen demand (BOD) and chemical oxygen demand (COD)

BOD is a test of the level of organic matter that can be biologically oxidized and COD is a test of the amount of organic matter that can be chemically oxidized. In this study both variables, BOD (from a study done in 2010 during the dry season) and COD decreased in the facultative pond though for the case of BOD it was above the MBS standard but COD was below the MBS recommended value as shown in table 1 above. This indicates that there was degradation of organic matter both biologically and chemically.

4.2. Removal efficiency of Physicochemical and microbiological parameters

Table 2 below shows the measured values and calculated removal percentage of ammonium (NH_4), nitrate (NO_3-N), total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD), chemical oxygen demand (COD), faecal coliform and total coliform. According to Riffat et al, (2013) a treatment plant is considered to be efficient in the removal of a particular water variable if the removal percent for the variable is equal to or above 50%.

The values obtained forNH_4 represents, -21% removal efficiency. The removal percent value was a negative number indicating no reduction in NH_4 but rather

NH_4 increased in the effluent due to the continuous transformation of nitrogenous organic matter into ammoniacal nitrogen by the ammonification process and conversion of nitrate to ammonium under anaerobic conditions as discussed above. This indicates that the plant is not efficiently removing the NH_4.

The NO_3-N concentration at the influent and facultative pond effluent represents, 39% removal efficiency in the facultative pond. The removal efficient percent observed was low due to loss of nitrification process as discussed above which indicates that the Limbe WSP systems was not efficient in treating nitrates. Nitrates can cause eutrophication of rivers if discharged in high quantity.

The TDS at the influent and facultative pond effluent represents 15% removal efficiency and this value is very low which indicates that the Limbe WSP system was not efficient in the removal of TDS, as a result the receiving water body is exposed to high amount of dissolved ions which increases the conductivity of the water making life difficult to aquatic species which are sensitive to high conductivity.

The TSS at the effluent (facultative pond) was lower than the influent value. The high TSS concentration of the influent can be attributed to the high TSS levels of the raw sewage. The reduced TSS levels at the outlet could be attributed to the removal efficiency through sedimentation of solids. TSS removal of 82% was observed in the study which implies that the WSP is efficient in removal of TSS hence ensuring that the impact of effluents in the receiving water body (Limbe River) is reduced and that the users of Limbe River are safeguarded. Discharge of effluents with high levels of suspended solids into the aquatic bodies lowers water quality and depletes dissolved oxygen available to aquatic life (Aghalari et al., 2020).

The faecal coliform level of the raw sewage was 3260 CFU/100ml while of the final effluent was 1936 CFU/100ml; representing removal efficiency of 40%. The levels of the total coliform in the raw sewage was 3889 CFU/ 100 ml while in the final effluent was 2932 CFU/ 100ml; representing removal efficiency of 24%. The concentration of the coliforms of the final effluent is very high. This indicates that the final pond effluent is not supposed to be discharged into the natural environment as it can pose a threat to humans and the ecosystem in general.

Effluents with high coliform concentration have high potential of endangering public health.

BOD at the influent was observed to be 740 mg/l and 89 mg/l in the facultative effluent. This represents 88% removal efficiency in the facultative pond. The satisfactory BOD removal performance can be attributed to the higher hydraulic retention time (HRT) applied. The COD at the influent was 278 mg/l and 72 mg/l at the effluent. This represents 74% removal efficiency. When effluents with high concentrations of BOD are discharged into the natural water body, they can cause depletion of natural oxygen resources which may lead to septic conditions. A study done by Mkunde in 2014 indicates that it is uncommon to obtain better than 80% BOD removal in waste stabilization ponds. Therefore findings in this study suggest that the WSP system at Limbe is very effective in the removal of BOD.

Table 2; Results of removal efficiency percent for physicochemical and microbiological parameter

Parameter	Influent	Effluent	Removal Efficiency %
NO3-N	2.08	1.27	38.94230769
NH4	30	36.4	-21.33333333
TDS	478	405	15.27196653
TSS	576	106	81.59722222
COD	278	72	74.10071942
BOD	740	89	87.97297297
Fecal Coliform	3260	1936	40.61349693
Total Coliform	3889	2932	24.60786835

Removal efficiency = $[(C_{influent} - C_{effluent})/C_{influent}] * 100\%$,

Where; C = concentration

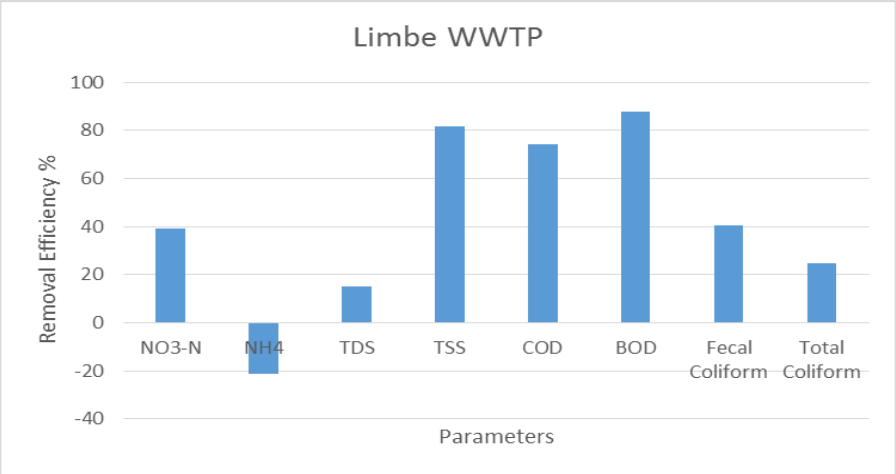


Figure 7; Graphical representation of removal efficiency percent

4.3. Hydraulic parameters

According to Kanda et al., (2013) hydraulic loading rate (HLR) and volumetric loading rate (VLR) are similar in that both indicates the volume of wastewater applied to the surface of the processing unit per unit time. Increase in flow rate increases HLR and VLR (Miguel et al., 2014). High HLR and VLR reduces treatment efficiency as severe loads affect the performance of microbes and can cause cell death of conventional microbes. In this present study it was also observed that as flow rate was increasing, hydraulic and volumetric loading rates were also increased though they were below the designed values as shown in table 3 and 4 below. This means that controlling flow rate can help to overcome the problem of HLR and VLR and improve treatment efficiency in wastewater treatment plants.

Table 3. Facultative Pond dimensions and design hydraulic parameters

Dimension	Value
Length (m)	95
Breadth (m)	45
Depth (m)	1
Area (m2)	4275
Volume (m3)	4275
Sludge Depth (m)	0.34
Flow rate (m3/day)	630
HLR (m3/m2.day)	0.147368421
VLR (kg/m3.day)	0.147368421

Table 4. Measured hydraulic parameters

Volume (mL)	Time (s)	Flow rate (m3/day)	HLR (m3/m2.day)	VLR (kg/m3.day)
1250	9	12	0.0020807	0.00161668
900	5	15.552	0.0036379	0.0020949
300	2	12.96	0.0030316	0.0017462
Average		13.504	0.002916733	0.00181926

Flow rate = Volume/Time

Hydraulic loading rate (HLR)

This is the amount of wastewater applied onto the surface of the reactor (pond) and it is expressed as

HLR = Q/As

Q- Wastewater flow rate (m3/day)

As- surface area of the pond (m2)

Volumetric loading rate (VLR)

This is mass of substrate or food applied per unit volume of reactor and is given by;

$VLR = QS_0/V$

Q- Flow rate

S_0- Substrate concentration entering the reactor)

V- Pond volume

4.4. Correlation and regression analysis for physicochemical and microbiological parameters

Correlation analysis was performed in order to determine the significance of the relationship between the variables. Results of the correlation are represented in table 5 below. Correlation value (r) ranging from 0.5 to 1 means that there is a strong relationship and values ranging from 0.4 below means that there exist a relationship but it is weaker. From table 5 it's evident that effluent TSS with influent pH (r= 0.2721), with ORP (r=-0.5721), with EC (r=0.996255), with TDS (0.9974), with temperature (T) (r=0.768958), with NTU (r=0.51951), with HLR (r=-0.97373) and with VLR (0.066125). Effluent NO_3-N with influent pH (r= 0.93178), with ORP (r=-0.700597), with T (r= -0.76532), with NH_4 (r=-0.9908), with HLR (r=0.396481) and with VLR (r= 0.066125). Effluent total coliform (TC) with influent pH (r=0.923178), ORP (r=-0.49281), TDS (r= -0.36608), EC (r=-0.352113), T (r=-0.90864), NO_3-N (r=-0.97888), HLR (r= -0.97373) and VLR (r=

-0.97888). At this stage regression equations were obtained for each of the dependent variables as shown in table 6 below. Each of the equation obtained was tested by applying the values which were obtained in the laboratory and it was observed that the values calculated were closely related to the values analysed. This means that the regression equations obtained can be used in determining their respective expensive parameters.

Table 5; Correlation results showing the strength of relationship between the variables

	Eff TSS	Eff TC	Eff NO3-N	Inf PH	Inf ORP	Inf TDS	Inf NTU	Inf EC	Inf T	Inf FC	Inf NH4	Inf DO	Inf NO3-N	HLR	VLR
Eff TSS	1														
Eff TC	-0.43174	1													
Eff NO3-N	-0.17701	0.964176	1												
Inf PH	0.214892	0.788146	0.923178	1											
Inf ORP	-0.5721	-0.49281	-0.70597	-0.92396	1										
Inf TDS	0.997436	-0.36608	-0.10612	0.284237	-0.62933	1									
Inf NTU	0.519551	-0.99501	-0.93291	-0.72283	0.403565	0.457068	1								
Inf EC	0.996255	-0.35213	-0.09124	0.298533	-0.64087	0.999888	0.443725	1							
Inf T	0.768958	-0.90864	-0.76532	-0.45912	0.084425	0.721233	0.945755	0.7108	1						
Inf FC	0.180421	0.809299	0.936122	0.999382	-0.90994	0.250352	-0.74668	0.264793	-0.49007	1					
Inf NH4	0.042207	-0.91942	-0.9908	-0.9667	0.795308	-0.0294	0.875607	-0.04434	0.671186	-0.9751	1				
Inf DO	-0.56949	-0.49556	-0.70821	-0.92517	0.999995	-0.62686	0.406463	-0.63844	0.087583	-0.91125	0.797225	1			
Inf NO3-N	-0.97888	0.607011	0.374462	-0.01071	0.392356	-0.96174	-0.68324	-0.95754	-0.88341	0.024453	-0.24555	0.389438	1		
HLR	-0.97373	0.625802	0.396481	0.013153	0.370295	-0.95493	-0.70047	-0.95039	-0.89434	0.048301	-0.26861	0.367348	0.999715	1	
VLR	-0.92857	0.066125	-0.20093	-0.56203	0.835649	-0.95275	-0.16531	-0.95719	-0.47675	-0.5326	0.33163	0.833903	0.833092	0.819656	1

Table 6. Regression equations for the relationship between dependent variables and independent variables

Dependent Variables	Independent Variables
Effluent TSS	= 274.7 - 16.54 Inf PH - 2.298 Inf ORP = 98.20 - 0.06236 Inf EC + 0.1168 Inf TDS = 70.90 + 11.33 Inf T - 0.2169 Inf NTU = 116.9 - 559.0 HLR - 3975 VLR
Effluent Total Coliforms	= -49696 + 5839 Inf PH + 481.8 Inf ORP = 4856 + 269.8 Inf EC - 420.5 Inf TDS = 34602 - 2430 Inf T - 785.9 Inf NO3-N = 9503 + 500000 HLR - 4530000 VLR
Effluent NO3-N	= -53.13 + 6.398 Inf PH + 0.4051 Inf ORP = 9.024 - 0.3521 Inf T - 0.08208 Inf NH4 = 13.05 + 660.9 HLR - 7178 VLR

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Waste stabilization ponds is cheap method for treating sewage as compared to other methods of sewage treatment. The operation and maintenance activities of ponds do not require sophisticated equipment or professional skills. Waste stabilization ponds however operate well only under particular climate which is of tropical or subtropical type and their land requirement is very high. WSPs provide effluent of high quality in terms of B0D, TSS and coliforms provided they are properly designed, constructed and maintained under required climate conditions. When designing waste stabilization ponds, just as for other sewage treatment methods, it is important to know the required effluent standards for which the ponds are designed. The performance efficiency for Limbe WSPs has been investigated. The results obtained reveals that the pond perform fairly well with regard to pH, ORP, TDS, COD and nitrates except for BOD, TSS, EC, alkalinity and turbidity with respect to Malawian standards. In terms of temperature and dissolved oxygen the effluent values obtained are lower than the standard. The two parameters affect treatment efficiency when they are below the standard as they have a great impact on aquatic species survival. Total coliform and faecal coliform reduction does not satisfy the effluent value recommended by Malawi Bureau of standards. Upon observation this has been attributed to the malfunctioning of the subsequent ponds in the treatment system since coliforms are mostly removed in maturation ponds. It was also observed that the removal efficiency percent's for NO_3-N, TDS, total and faecal coliform were below 50% with ammonium showing a negative reduction percent which means, the system is not supporting removal of NH_4. The hydraulic parameters determined in this study were below the designed values. The measured values of effluent TSS, NO_3-N and total coliform in the laboratory were very close to those predicted through regression based tool. Therefore, the Excel regression based tool developed in this study can be used to estimate effluent parameters for performance monitoring of the system.

5.2. Recommendations

The waste stabilization ponds under this study are owned by the Blantyre city council. The council has employed workers to operate and maintain the ponds. These workers are adequate for all the duties on the ponds. However, the district council should provide the workers with necessary tools and equipment for the operation and maintenance activities. These workers should also be educated so

that they know basic principles of pond operation. The authority should also monitor the ponds frequently in order to ascertain any deficiencies. In order to improve treatment efficiency of the plant, it has been suggested that the authority should make sure that at least four pond in series, anaerobic pond, primary facultative pond, secondary facultative pond and maturation pond in the treatment system should start to operate as soon as possible in order to safeguard the receiving environment. This will increase stages of coliforms reduction (since coliforms are mostly removed in maturation pond) and other pollutants reduction hence improving treatment efficiency of the treatment plant. Algae removal from the ponds should be done in order to improve TSS removal. In addition, wire fences should be provided around the premises of the waste stabilization ponds. Lastly, they should also make sure that a flow rate measuring flume is replaced for easy evaluation of the hydraulic parameters per day.

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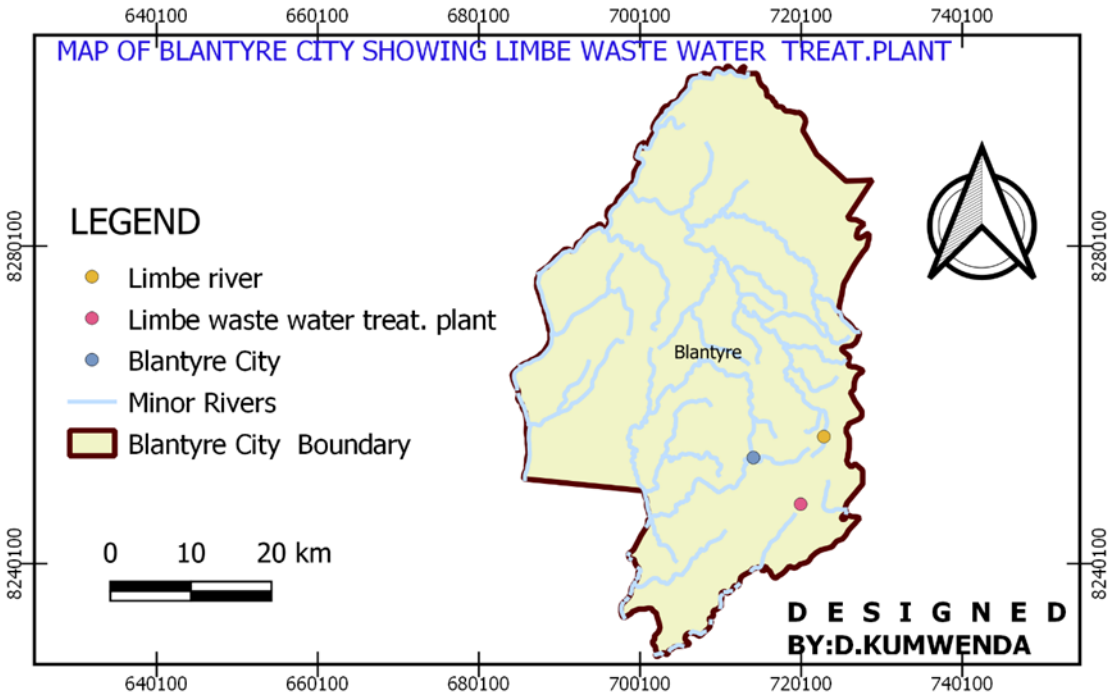
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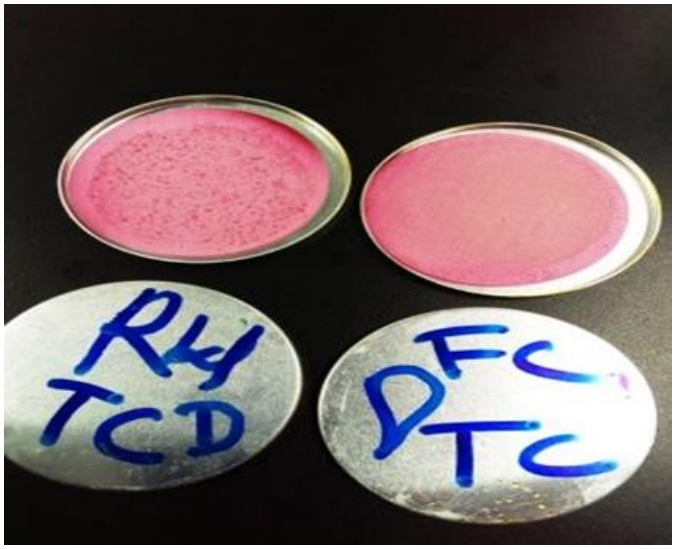
APPENDICES



Location of Limbe WWTP in Blantyre city



Limbe WWTP Preliminary raw wastewater Treatment stage



Total coliform growth after incubation



Membrane filtration unit