PERFORMANCE EVALUATION AND REDESIGN OF WASTE STABILIZATION PONDS FOR THE TREATMENT OF WASTEWATER IN ONGWEDIVA

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ABSTRACT

The existing Ongwediva Waste Stabilization Ponds have had several problems in their operations over the past years. Thus, the treatment performance of the waste stabilization ponds was assessed in terms of the reduction efficiency of some physical, chemical and biological pollutants of importance. Data were collected daily from May to June 2017 and analyzed for both raw and treated wastewater. Results of these investigation showed that the average effluent concentrations of BOD, DO, TSS FC, nitrate, nitrite, ammonia, pH, EC and turbidity taken at the secondary facultative pond were 22.07mg/l, 1.91 mg/l, 21.73 mg/l, 2×10^5 counts/100 ml, 2.33 mg/l, 0.39 mg/l, 0.74 mg/l, 7.64, 16.67 NTU and 98.52 mS/m respectively. The results also indicated that the average effluent concentrations of BOD, nitrate, nitrite, ammonia, TSS and pH complied with the Namibian treated wastewater standards for disposal. However, FC, EC, TDS and turbidity exceeded their maximum permissible limits. The lowest overall efficiencies were for EC, TDS and FC of 5.05%, 5.12% and 20% respectively. Hence the addition of two maturation ponds of size 5408m^2 as a final stage of OWSPs. The design of facultative ponds can also be modified by adding additional entrances of wastewater to the ponds to make complete mix in the ponds.

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LIST OF ABBREVIATIONS

BOD	Biological oxygen demand
DO	Dissolved oxygen
EC	Electrical conductivity
N	Nitrogen
OTC	Ongwediva Town Council
pH	Potential of hydrogen ions
TDS	Total dissolved solids
TFC	Total fecal coliforms
TSS	Total suspended solids
UNAM	University of Namibia
WHO	World Health Organization
WSPs	Waste Stabilization Ponds
OWSPS	Ongwediva Waste Stabilization Ponds
DWA	Department of Water Affairs

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DEDICATION

Firstly, I thank the Almighty God, for giving me strength, courage and patience throughout my research. Most importantly I thank Ricardo, for his unique combination of patience and encouragement. Lastly, I thank my beautiful and most precious family: my wonderful Mom, and Sisters and friends who helped and motivated me throughout my research project. God bless you all.

DECLARATIONS

I, Oriri Rukoro, hereby declare that this study is my own work and is a true reflection of my research, and that this work, or any part thereof has not been submitted for a degree at any other institution.

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1. INTRODUCTION

1.1. Background of the study

Ongwediva is one of the fastest growing towns in Namibia and is growing faster than most of the resources can accommodate. The increasing demand for water in Ongwediva due to population growth, improvements in living standards and the growing industrial sector increased the total amount of wastewater to be treated. According to the 2011 national census, the population of Ongwediva was 34 065 with an annual growth rate of 2.8% [1] compared to 4.0% for the capital city Windhoek and 1.4% for the entire country Namibia [2].

The current wastewater treatment technology employed in Ongwediva is oxidation ponds which are located on the southern part of Ongwediva in a flood prone area. The ponds treat wastewater from the town entire sewer system and also from emptied septic tanks. The ponds are currently designed to operate on no surface effluent discharge and the final ponds are large evaporation ponds. There are no maturation ponds which are essential for pathogen removal. Thus, the currently used Ongwediva Waste Stabilization Ponds (WSPs) for treating wastewater has caused major issues.

The prevailing status of most Ongwediva Waste Stabilization Ponds is that they are overgrown with reeds and water hyacinth and filled with sludge as shown in Figure 1 and Figure 2, thus reducing the maximum designed holding capacity of the ponds and causing unnecessary overflowing. During the year 2015 alone, several complaints were raised by the residents from the nearby villages outside town on the possible health risks posed by the overflowing of the wastewater [3]. The situation was viewed as seriously hazardous and would result in an outbreak of a waterborne disease such as cholera and skin infections [4].

Figure 1: Ongwediva facultative and anaerobic ponds filled with sludge and overgrown reeds

Figure 2: Hyacinth growing in the Ongwediva anaerobic ponds

1.2.Statement of the problem

WSPs that receive wastewater of Ongwediva Town were designed years back based on Ongwediva population at that time. Unfortunately, the ponds are still being used despite the increase in population from that used during the initial design. A reconnaissance survey undertaken prior to the start of this research showed that the ponds are filled with sludge and are overgrown with reeds. The effluents from WSPs have normally been discharged into the evaporation ponds for evaporation. However, due to the sludge and reeds growing in the ponds, the wastewater is overflowing into the nearby villages, thereby affecting residents [3]. Furthermore, there has not been a thorough investigation carried out on the performance of Ongwediva WSPs. This study will therefore evaluate the performance of the existing WSP at Ongwediva by assessing the quality of wastewater influent and effluent into and out of the WSPs in terms of physical, chemical and microbiological performance indicators including assessing the efficiency of WSPs in reducing the pollutant loads.

1.3.Objectives of the study

The main objective of this study is to assess the performance of Ongwediva waste stabilization ponds in reducing the pollutant loads in the ponds. In order to fulfill the main objective, the following specific objectives were achieved;

i. Assess the performance of the treatment steps of the Ongwediva Waste Stabilization Ponds in relation to the removal of biological and physical-chemical parameter loads.

ii. Identify performance limiting factors in the treatment steps along the pond system by comparing with NAMWATER standards.

iii. Produce a new design for the ponds.

iv. Propose proper operational and maintenance procedures for improving pond performance.

1.4.Hypothesis of the study

H_o: There is no significant differences in the mean parameter values at the different sampling points.

H_a: There is a significant difference in the mean parameter values at the different sampling points.

Confidence level = 95%

1.5.Significance of the study

The wastewater in the Ongwediva Waste stabilization ponds (WSPs) is treated to ensure that the levels of certain contaminants are brought below acceptable limits before discharging the effluents into the natural environment. To avoid polluting soils, receiving water bodies and endangering human health, flora and fauna lives from the points of discharge, it is necessary to monitor some water quality parameters in the treated domestic wastewater before it is discharged. This also provide a means for evaluating the performance of the treatment mechanism and makes data available for trend analysis and regulation evaluation.

The results from this study showed the performance of OWSPs in terms of the removal efficiencies of wastewater parameters. The recommendations strategies given in this study will help optimize the performance of the pond system. Thus, most importantly, the findings of this study contributes to knowledge.

1.6.Limitations of the study

Due to the unavailability of analytical instruments such as the mass spectrophotometer and others at the University of Namibia premises, samples were sent to Namwater Laboratory in Windhoek for test results. This delayed the availability of the results of the study. Also, the samples were collected for determining FC was reduced from 25 to 15 due to the constant breakdown of the incubator.

1.7.Delimitations of the study

The scope of the study only focused on waste stabilization ponds of Ongwediva. To increase the validation of the findings, the samples taken for each parameter was 15. This was to make the data series statistically stronger.

2. LITERATURE REVIEW

2.1. Historic background on wastewater treatment

The production of wastewater and the need for wastewater treatment is not a new problem, and knowledge on wastewater treatment has evolved and advanced throughout human history. Every person produces human excreta as a natural part of human life, thus there has been a history of treating wastewater as long as mankind existence. Together with the increase in population growth, improvements in living standards and wastewater collection, problems related to large accumulation of wastewater has risen. The liquid waste referred to as wastewater is essentially the water of the community after it has been used in a variety of applications [5]. Wastewater can therefore be defined as a combination of the water-carried wastes removed from residences, institutions and commercial and industrial establishments, together with such groundwater, surface water and storm water as may be present [6].

Generally, wastewater is perceived as a negative resource due to the fact that its main component is human excreta and its characteristic of bad odor. When untreated wastewater is collected and is allowed to go septic, the decomposition of organic matter it contains will lead to difficult conditions including production of gases [5]. Also, wastewater contain pathogenic microorganisms and nutrients, which can stimulate the growth of aquatic plants. Additionally, wastewater may contain toxic compounds that potentially may be mutagenic or carcinogenic [6]. Therefore, it is of greater importance to remove wastewater from its source of generation, followed by treatment, reuse or dispose it into the environment to protect public health and the environment. The environmental risks is mainly due to overloading of physical and chemical constituents contained in the wastewater and the public risks are due to the result of pathogenic contamination.

The reuse of untreated municipal wastewater for disposal, irrigation and fertilization purposes has been practiced for many centuries since the Bronze Age (ca. 3200–1100 BC), with the aim of diverting wastewater outside the urban settlements. Thereafter, the use of the land treatment systems followed into the twentieth century in central Europe, USA, and other locations all over the world, but not without causing serious public health concerns and negative environmental impacts. However, by the end of the first half of the twentieth century, these systems were not easily accepted, due to drawbacks such as large area requirements, field operation problems, and the inability to achieve the higher hygiene criteria requirements required [7].

Modern sewage systems were first built in the mid-nineteenth century as a reaction to the exacerbation of unsanitary conditions brought on by heavy industrialization and urbanization. Due to the contaminated water supply, cholera outbreaks occurred in 1832, 1849, and 1855 in London, killing tens of thousands of people. In addition, the Great Stink of 1858 occurred when the smell of untreated human waste in the River Thames became overpowering [7]. During the late 19th and the early 20th century, there was an awakening in the development of centralized wastewater treatment systems, mainly in the United Kingdom and the United States. In addition to collection and discharge of wastewater, physical, biological and chemical processes for the wastewater treatment were introduced, for the removal of pollutants. In 1853, the first comprehensive sewerage system was completed in Hamburg, Germany. The system was designed by William Lindley and served as a model for US and European cities.

In 1890 the first true biological filter was constructed at Lawrence Experimental Station, in the United States. In 1916 the first full-scale activated sludge plant was constructed at Worcester. In the 1990's, membrane biological reactors were developed in Japan [8]. In the 1970s, a move started to raise standards and improve environmental protection, to some extent driven by public opinion and greater public awareness. The first step in this direction was the Clean Water Act in the US in 1972 [8]. Today, most countries have their own national regulations for maximum allowable discharge values of different constituents, determining the scope of treatment necessary.

Waste Stabilization Ponds (WSPs) are used in all parts of the world, from Alaska to New Zealand. The US has more than 7000 WSP systems (one-third of all wastewater treatment plants). In Europe for example, WSPs are widely used for small rural communities (up to populations of about 2000, but large systems exist in Mediterranean France, and also in Spain and Portugal) [9]. France has over 2500 and Germany (mainly in what was West Germany) has more than 1100. In New Zealand, WSP are the most common form of wastewater treatment, with 100 of the 160 plants. There are many WSP systems in Australia, including those at the Western Treatment Plant in Melbourne [5].

2.2.Wastewater treatment in developing countries

Sanitation coverage varies widely in developing countries. Countries with the lowest sanitation coverage are now concentrated in sub-Saharan Africa and Southern Asia with 24% and 22% respectively [10]. The Figure 3 below gives a visual presentation of improved sanitation coverage in countries of the world by 2015 and shows that low sanitation coverage is experienced in southern parts of the world.

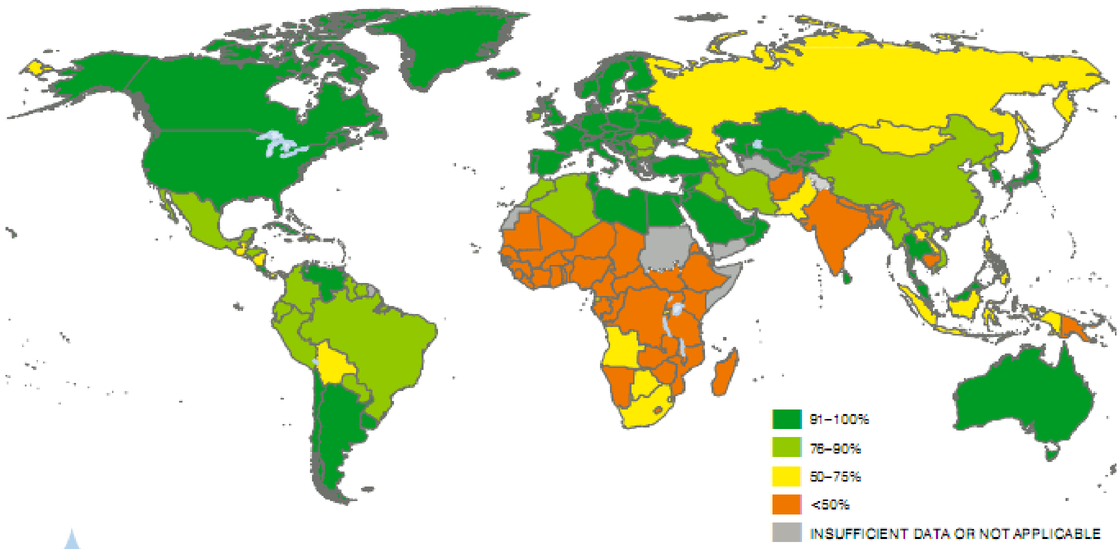

Figure 3: World Sanitation coverage [11]

According to a survey conducted by Raschid-Sally and Jayakody, wastewater is used for irrigation purposes without any significant treatment in most cities in developing countries [11]. In most sub-Saharan cities, greywater is mixed with storm water, solid waste and excreta before it enters water bodies. Furthermore, in some regions of India, partially treated greywater is used for kitchen-garden irrigation and sanitation [11]. Many cities in developing countries use conventional sewer systems to collect wastewater. However, it is expensive. Only a small proportion of the wastewater produced by sewered communities in developing countries is treated. For example in Latin America, less than 15 percent of the wastewater collected in towns connected to sewer and cities is treated before discharged [5]. It is often due to financial reasons that wastewater is not treated prior to discharge. Also, in some areas of developing countries, collected wastewater is disposed into water bodies without any treatments at all.

Waste Stabilization Ponds (WSPs) are common in all parts of the developing world, where they can serve large populations, for example, the Dandora WSP near Nairobi, Kenya serve a sewered population of 1 million, and the Al Samra WSP near Amman, Jordan serve a population of 2.6 million [12]. Furthermore, WSP are so common due to its cost effectiveness and high potential of removing different pollutants [13], [14]. They are the most important method of wastewater treatment in developing countries where there is sufficient land available and where the temperature is most favorable for their operation [15], [16].

2.2.1. Wastewater treatment in Namibia

Although Namibia has achieved the Millennium Development Goal targets for drinking water, sanitation still remain a major concern. With a sanitation coverage of 35%, Namibia has the lowest levels of sanitation coverage in southern Africa [10]. The situation has not improved since 2006 as only 13% of the rural population and 61% of the urban population had access to improved sanitation facilities by 2009 [17]. In 2009, Raili Hasheela conducted a study on Municipal Waste Management in Namibia and found that the treatment of wastewater as a waste management principle was the common waste treatment being practiced. He also reported that majority of the towns in Namibia, if not all, treated sewage [18]. The Namibia's Greenhouse Gas Inventory for the year 2000 confirmed that all towns of Namibia practice sewage treatment and that the most common wastewater treatment method used in the country is the pond system. The capital city Windhoek generates an average of about 12, 8 Mm^3/year of domestic wastewater, while the second largest city of Walvisbay produces an average of about 0.66Mm^3/year [19]. In Windhoek, wastewater is treated to potable water by advanced treatment methods i.e. anaerobic digesters, activated sludge plants and bio-filters which produce high quality water. About 30% of the reclaimed wastewater is blended with raw water and supplied to consumers [19]. Treated wastewater is also used for irrigation of parks and sport fields [18]. The wastewater treated by the rest of the towns using WSPs can only be used for irrigation purposes.

2.3.Characteristics of domestic wastewater

Domestic wastewater is discharged from commercial, institutional and residential buildings. The wastewater is characterized by physical, chemical and biological constituents.

2.4.Physical parameters

2.4.1. Total Solids

Total solids are dissolved solids plus suspended and settleable solids in wastewater. Dissolved solids may consist of calcium, phosphorus, nitrates, iron, chlorides Sulphur and other ions particles that will pass through a filter of pores of around 0.002cm in size. Suspended solids include clay and silt particles, algae, plankton, fine organic debris, and other particulate matter. This are particles that will not pass through 0.002cm filter. Typically, 60 percent of suspended solids in wastewater are settleable. Suspended solids are widely used to determine treatment efficiency for conventional treatment processes [6]. Although, waste stabilization ponds are effective methods of wastewater treatment, high concentrations suspended solids exceeding 100mg/l in their effluent can be a major disadvantage [14].

2.4.2. Turbidity

Turbidity is a measure of the light transmitting properties of wastewater and is a test used to indicate the quality of wastewater with respect to colloidal and residual suspended matter [6]. The results of turbidity measurements are reported as nephelometric turbidity units (NTU).

2.4.3. Colour

Colour is a qualitative characteristic giving general condition of the wastewater. Fresh wastewater is usually a light brownish-grey colour. However, as the time in the collection system increases, and more anaerobic conditions develop, the colour of the wastewater changes sequentially from grey to dark grey, and ultimately to black [6]. When the colour of the wastewater is black, the wastewater is often described as septic [20].

2.4.4. Temperature

The temperature of wastewater is commonly higher than that of the local water supply, because of the addition of warm water from households and industrial activities [20]. Depending on the location and the time of the year, the effluent temperatures can be either higher or lower than the corresponding influent values [6]. The temperature of wastewater is a very significant parameter because of its effects on chemical reactions and reaction rates. In addition, oxygen is less soluble in warm wastewater than in cold wastewater. Moreover, abnormally high temperatures can promote the growth of undesirable water plants and wastewater fungus. Also, optimum temperatures for bacterial activity are in the range from 25 to 35°C [6]. It is important to take note that as the temperature of wastewater rises, its ability to hold dissolved oxygen decreases [20].

2.4.5. Conductivity

The electrical conductivity (EC) of a wastewater is a measure of the ability of a solution to conduct an electrical current. Because the electrical current is transported by the ions in the wastewater, the conductivity increases as the concentration of ions increases [6]. Wastewater effluents often contain high amounts of dissolved salts from domestic sewage. EC is therefore a useful indicator of its salinity or total salt content [21]. The electrical conductivity in SI units is expressed as millisiemens per meter (mS/m) [6].

2.4.6. Odor

Odor in wastewater are caused by gases produced by the decomposition of organic matter. Odor or smell is another test measure which is an indicative of dissolved oxygen level present in wastewater. The most characteristic odor of stale or septic wastewater is that of hydrogen sulfide, which is produced by anaerobic microorganisms that reduce sulfate to sulfide.

2.5.Chemical parameters

2.5.1. Organic chemical parameters

2.5.1.1. Biochemical Oxygen Demand

The most widely used parameter of organic pollution applied to wastewater is the 5-day BOD (BOD_5). Biochemical oxygen demand (BOD) measures the amount of oxygen required by bacteria for breaking down to simpler substances the decomposable organic matter present in the wastewater under aerobic conditions [21]. BOD can be used as a measure of the concentration of organic matter present in that water. The greater the organic matter present, the greater the oxygen demand and the greater the BOD value. The BOD test results can also be used to measure the efficiency of treatment processes and to determine compliance with wastewater discharge permits [6], [21]. BOD is based on the principle that if sufficient oxygen is available, aerobic biological decomposition (i.e. stabilization of organic waste) by microorganisms will continue until all waste is consumed. For these reasons, BOD was used as an independent variable in this research. BOD is a determining factor of wastewater character based on the BOD amount. Normal domestic wastewater contains about 250-300 mg/L of BOD [22]. Wastewater character can fall into four groups according to its BOD_5 amount; weak (< 200 mg/l), medium (350mg/l), strong (500 mg/l) and very strong (>750 mg/l) [5], [23]. The BOD test is conducted for a period of five days in an incubator at 20°C. The higher the BOD, the more the organic and inorganic pollutants present in the sample and the more oxygen needed by the bacteria to decompose the organic material [6], [20].

2.5.1.2. Chemical Oxygen Demand

The chemical oxygen demand (COD) test is used to measure the oxygen equivalent of the organic material in wastewater that can be oxidized chemically using dichromate in an acid solution. The COD value for raw domestic wastewater can range from 250-800 mg/L. Even though it would be expected that the value of BOD would be the same as COD, COD values are usually higher. Some of the reasons for the observed differences are as follows: (1) many organic substances such as lignin which are difficult to oxidize biologically, can be oxidized chemically, (2) inorganic substances that are oxidized by the dichromate increase the apparent organic content, (3) some organic substances might be toxic to microorganisms used in the BOD test, and (4) because of the presence of inorganic substances with which the dichromate can react [6].

2.5.1.3. Dissolved Oxygen

Dissolved oxygen (DO) is oxygen that is dissolved in wastewater. DO is necessary for the respiration of all aerobic life forms as well as aerobic microorganisms [20]. However, oxygen is only slightly soluble in water. The amount of oxygen present in wastewater is determined by the following factors: (1) the solubility of the gas, (2) the partial pressure of oxygen in the air, (3) the temperature, and (4) the concentration of impurities such as salinity, suspended solids [6]. As the temperature of wastewater rises, the amount dissolved oxygen decreases. At 0°C and at sea level, the most oxygen that will dissolve in wastewater is 14.6mg/L. At 20°C, the most oxygen is about 9mg/L. However, because of excessive algal activity, stabilization ponds have been known to hold more than 14.6mg/L (often as high as 25-30 mg/L) [20].

2.5.2. Inorganic chemical parameters

2.5.2.1. pH

The hydrogen-ion concentration is an important quality parameter of wastewater indicating how acidic or alkaline the wastewater is. It is measured on a scale from zero to 14, and 7 being neutral meaning neither acidic nor alkaline. The concentration suitable for the existence of biological life is pH 6 to 9 [20]. Wastewater with a high pH is difficult to treat by biological means. Both anaerobic and facultative ponds operate most efficiently under slightly alkaline conditions [16].

2.5.2.2. Nitrite Nitrogen

Nitrite nitrogen is relatively unstable and is readily oxidized to the nitrate form. This form of nitrogen is an indicator of past pollution in the process of stabilization and it rarely exceeds 1 mg/l in wastewater [6]. However, in low concentrations, nitrite is significant in wastewater because it is severely toxic to most fish and other aquatic species.

2.5.2.3. Nitrate Nitrogen

Nitrate nitrogen is the most oxidized form of nitrogen found in wastewater. In wastewater effluents, nitrate as N concentration varies from 0 to 20 mg/l [6].

2.5.2.4.Ammonia Nitrogen

Ammonia nitrogen exists in aqueous solution as either the ammonium ion or ammonia gas, depending in the pH of the wastewater [6]. About 60 - 75% of total nitrogen in raw wastewater is in the form of ammonia, whilst the rest is organic nitrogen [24]. [25] suggest that ammonia removal in WSP can be high as 95%, while total nitrogen removal can reach 80%.

2.6. Biological parameters

The biological characteristics of wastewater are of fundamental importance in the control of diseases caused by pathogenic organisms of human origin, and because of the broad and significant role played by bacteria and other microorganisms in the breaking down and stabilization of organic matter in wastewater.

2.6.1. Bacteria

Many types of harmless bacteria colonize the human intestinal tract and are routinely shed in the feces. One of the most commonly contained bacteria in intestinal tract of humans is the large population of rod-shaped bacteria collectively known as coliform bacteria [6]. Each person can discharge 100-400 billion coliform daily. Domestic wastewater contains a wide variety and concentration of nonpathogenic and pathogenic bacteria. Thus, the presence of coliform bacteria in wastewater over the years has been taken as an indication of the presence of pathogenic organisms [6]. The principal mechanism for faecal bacteria removal in facultative and maturation ponds are retention time, temperature, high pH (>9) and high light intensity together with high dissolved oxygen concentration [16], [20], [24].

2.7.Critical effluent parameters

Urban wastewater contains pathogens, organic pollutants, suspended solids, nitrogen and compounds. Their disposal into the environment without treatment causes pollution of surface and groundwater sources, stench and also health hazards.

The maximum permitted discharge values of critical parameters in wastewater are normally given by National Regulations. The Department of Water Affairs from Namibia’s Ministry of Agriculture, Water and Forestry has given the guidelines for Namibia in Table 1 [26], [27]

Table 1: Water quality standards for effluent from the Department of Water Affairs *[26]*, *[27]*

Effluent to be discharged or disposed of in areas with potential for drinking water source contamination; international rivers and dams and in water management and other areas				
			Special Standard	**General Standard**
DETERMINANTS	**UNIT**	**FORMAT**	**95 percentile requirements**	
PHYSICAL REQUIREMENTS				
Temperature	° C		Not more than 10^0C higher than the recipient water body	
Turbidity	NTU		< 5	< 12
pH			6.5-9.5	6.5-9.5
Colour	mg/litre Pt		< 10	< 15
Smell			No offensive smell	
Electric conductivity 25 °C	mS/m		< 75 mS/m above the intake potable water quality	
Total Dissolved Solids	mg/litre		< 500 mg/litre above the intake potable water quality	
Total Suspended Solids	mg/litre		< 40	< 100
Dissolved oxygen	% saturation		>75	>75
ORGANIC REQUIREMENTS				
Biological Oxygen Demand	mg/litre	BOD	< 10	< 30
Chemical Oxygen Demand	mg/litre	COD	< 55	< 100
INORGANIC MACRO DETERMINANTS				
Ammonia (NH_4 – N)	mg/litre	N	< 1	< 10
Nitrate (NO_3 - N)	mg/litre	N	< 15	< 20
Nitrite (NO_2 - N)	mg/litre	N	< 2	< 3

Note: Total coliforms counts must be (MPN/100ml) < 1000 counts/100ml

2.8.Wastewater treatment processes

Wastewater effluents treated effectively can efficiently contribute to water conservation, expansion of irrigated agriculture, environmental and public health protection [28]. Wastewater must always be treated before disposed. The adverse environmental impact of allowing untreated wastewater to be discharged in groundwater or surface water bodies and/ or land is that the decomposition of the organic materials contained in wastewater can lead to the production of large quantities of malodorous gases [11]. Untreated wastewater (sewage) containing a large amount of organic matter, if discharged into a river/stream, will consume the dissolved oxygen for satisfying the biochemical oxygen demand (BOD) of wastewater and thus, deplete the dissolved oxygen of the stream; thereby, causing fish kills and other undesirable effects [11], [29]. Wastewater may also contain nutrients, which can stimulate the growth of aquatic plants and algal blooms; thus, leading to eutrophication of the lakes and streams [21]. Untreated wastewater usually contains numerous pathogenic, or disease causing microorganisms and toxic compounds, that dwell in the human intestinal tract or may be present in certain industrial waste [28]. These may contaminate the land or the water body, where such sewage is disposed. For the above-mentioned reasons, the treatment and disposal of wastewater, is not only desirable but also necessary.

A conventional sewage treatment plant has the requisite operating units arranged one after another for treatment and final disposal of sewage. Figure 4 shows a diagrammatic representation of a flow chart of a conventional sewage treatment plant.

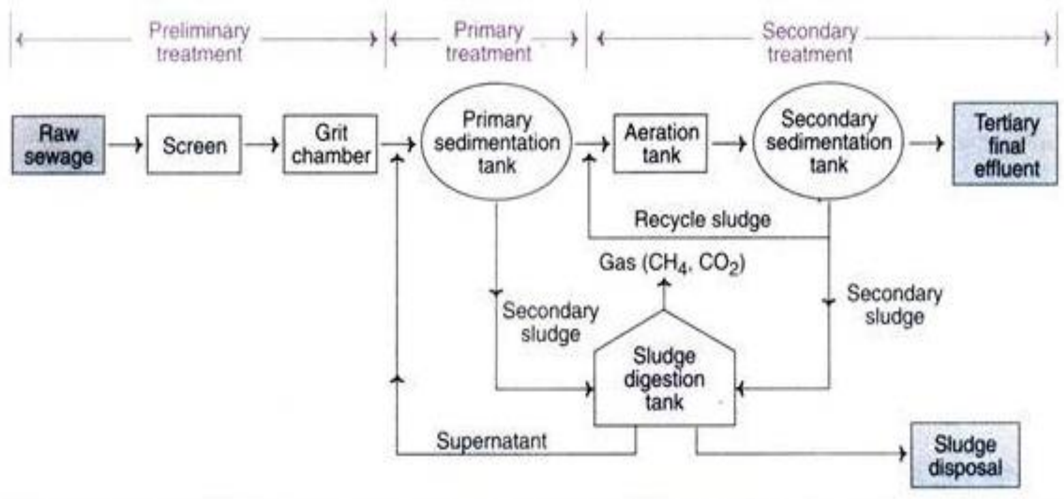

Figure 4: A diagrammatic representation of a flow chart of a conventional sewage treatment plant

2.8.1. Preliminary treatment

Preliminary treatment involves the removal of floating materials such as leaves, papers, rags and settleable inorganic solids such as sand and grit that may cause maintenance or operational problems in the treatment operations, processes and ancillary systems [29]. Methods of removing these materials prior to primary and subsequent treatment are part of a pretreatment or preliminary treatment. The treatment process reduces the BOD of the wastewater, by about 15-30%.The three major types of equipment employed in preliminary treatment are namely; screeners, grit chambers, and skimming tanks. The most commonly used in stabilization ponds is a screener. A screener is a device with openings (usually uniform in size) to remove the floating materials and suspended particles. The process of screening can be carried out by passing sewage through different types of screeners (with different pore sizes). The screeners are classified as coarse, medium or fine, depending on the size of the openings. The coarse screen has larger openings (75-150 mm). The openings for medium and fine screens respectively are 20-50 mm and less than 20 mm [30].

2.8.2. Primary treatment

Primary treatment process involves the removal of a portion of the suspended solids and organic matter from the wastewater. This removal is usually accomplished by physical operations such as sedimentation or settling [29]. The principle of sedimentation is that solid particle of the sewage tend to settle down due to gravity. In this process, settleable solids and most suspended solids settle to the bottom of the basin. The process of sedimentation is influenced by several factors. These include the size, shape and specific gravity of particles, besides viscosity and flow velocity of sewage. Removals from domestic wastewaters undergoing plain sedimentation will range from about 30 to 40 percent for BOD and in the range of 40 to 70 percent for suspended solids [12], [25]. There are four major types of settling namely; discrete settling, flocculent settling, hindered or zone settling and compression. Settlement of particles in the lower layers can occur by compression of the weight of the particles on the upper layers. This process facilitates sludge thickening at the bottom. Primary treatment processes occurs mainly in anaerobic ponds [28]. The principal function of primary treatment is to act as a precursor to secondary treatment.

2.8.3. Secondary treatment

This process is also referred to as biological treatment and it involves the use of microorganisms (bacteria, algae, fungi, protozoa, rotifers, nematodes) that decompose the unstable organic matter to stable inorganic forms [29]. In secondary treatment process, biodegradable organic matter (in solution or suspension) and suspended solids are removed. In Ghana for example, the commonest secondary treatment technologies adopted for domestic sewage treatment are trickling filters, activated sludge and waste stabilization ponds [28]. Secondary treatment processes occurs mainly in facultative ponds as shown in Figure 5 [28].

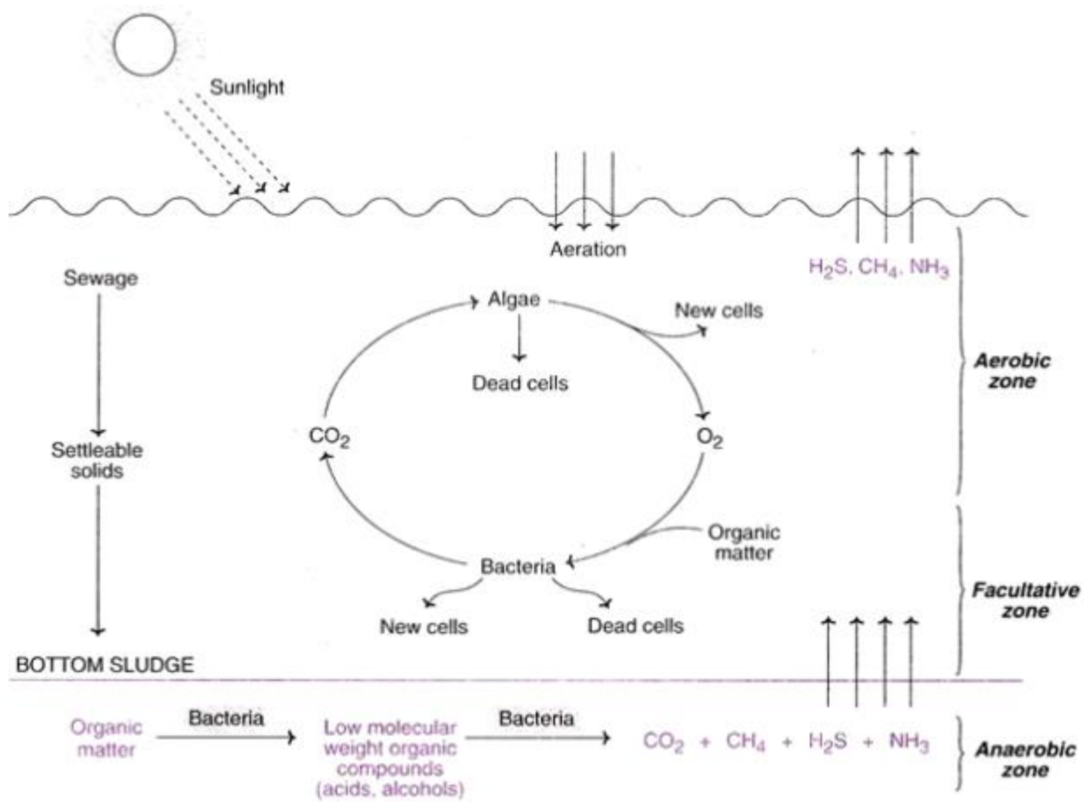

Figure 5: A diagrammatic representation of a facultative pond [6]

2.8.4. Tertiary treatment

Tertiary treatment process involves the removal of residual suspended solids (after secondary treatment). Typically, disinfection is also part of tertiary treatment. Often, nutrient removal is included in this process. Tertiary treatment processes mainly occurs in maturation ponds [28].

However, tertiary treatment is needed under the following circumstances:

- When the quality of the effluent to be discharged does not meet the standard requirements.
- When there is a necessary to reuse the sewage/ waste water.
- For the removal of nitrogen and phosphorus compounds.

Tertiary treatment process broadly involves the removal of suspended and dissolved solids, nutrients such as nitrogen, phosphorus and pathogenic organisms [30].

2.9. Waste Stabilization Ponds

Waste stabilization ponds (WSPs) are large, shallow, normally rectangular basins in which there is a continuous inflow and outflow of wastewater [15]. In WSPs, the biological treatment that occurs is an entirely natural process achieved primarily by bacteria and microalgae [14], [28]. Bacteria and microalgae in WSPs stabilize the organic matter and lower the effluent pathogen levels.

WSPs are normally the most appropriate method of domestic or municipal wastewater treatment all over the world that could be applied before effluent discharge [12], [5], [16]. This wastewater treatment method can produce effluent meeting the recommended microbiological and chemical quality guidelines both at low cost and with minimal operational and maintenance requirements [9], [28]. They are well suited for tropical and subtropical countries since temperatures and intensity of the sunlight are most favorable for the efficiency of the removal process [9]. Also in developing countries, they are the most important method of wastewater treatment where sufficient land is readily available and temperature is also favorable for their operation [5], [12],

[31], [25], [16]. If properly designed and operated, WSPs can attain a 99.9% faecal coliform reduction [16]. Factors like temperature and solar radiation favor microbial growth because wastewater consists of organic matter whose degradation largely depends upon microbial activity as shown in Figure 6 [20]. Development activities in WSPs are mostly based on loading rate; retention time, pond depth, solar radiation, total sunshine hours, wind velocity and rainfall [23], [25], [32].

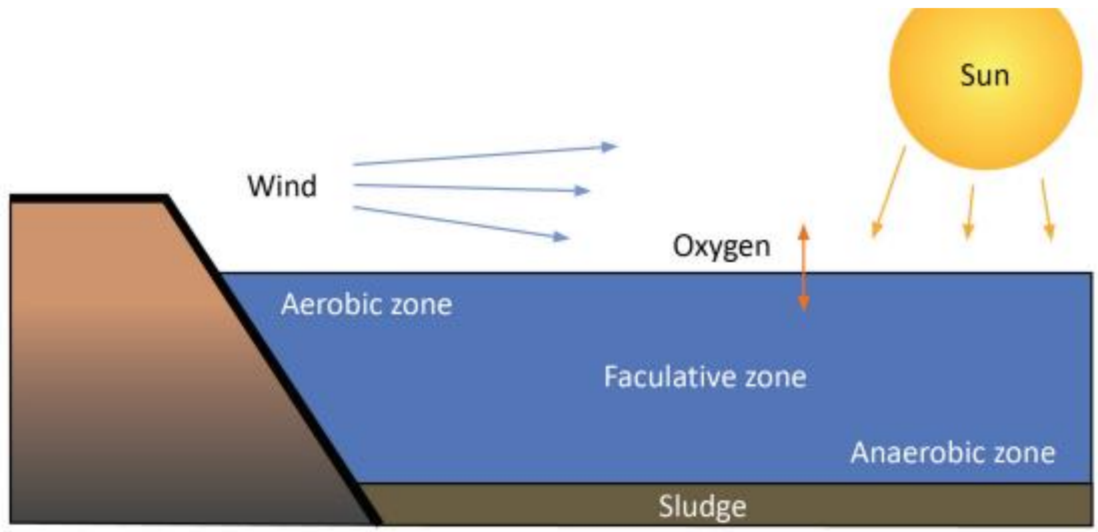

Figure 6: Climatic conditions affecting pond activity *[20]*

There are three main types of waste stabilization ponds: anaerobic, facultative and maturation ponds [23], [28], [25], [33]. These ponds differ in terms of their function in the overall wastewater treatment system. The anaerobic and facultative ponds are designed for the removal of BOD whereas maturation ponds are primarily designed for fecal bacteria removal [5], [16], [25]. Although WSPs are easily constructed, their effectiveness depends on a complex interaction of physical, chemical and biological processes. Several different single ponds are normally used together in series or several series in parallel to provide a complete treatment system. It is commonly concluded that the effluent from a series of ponds is of better quality than that of a single pond of the same size. Furthermore, the pond system can be used alone but usually they are used in combination with each other. Figure 7 below shows different pond configurations [31], [34].

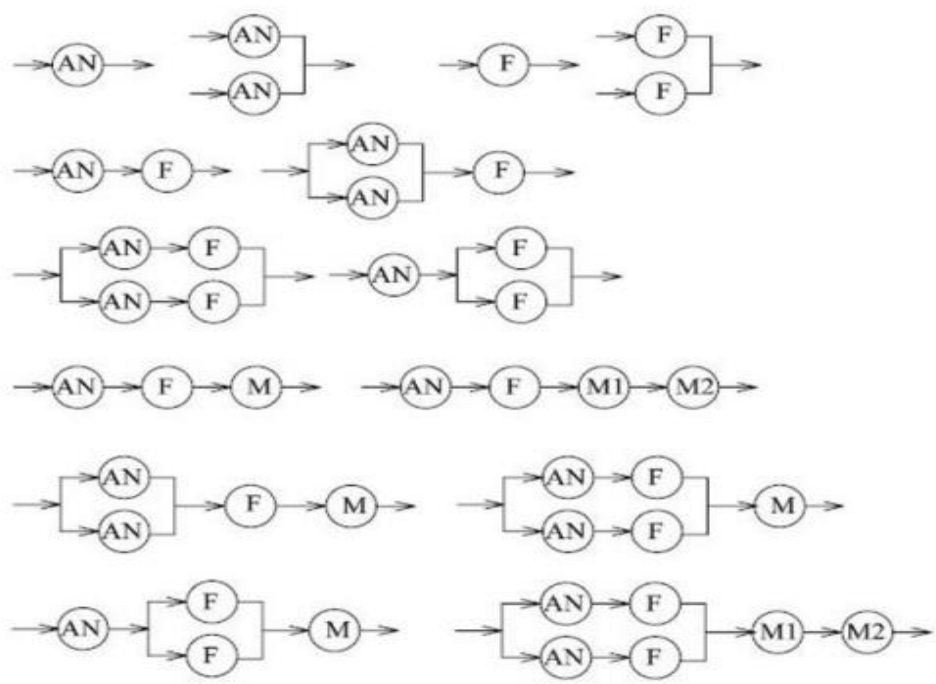

Figure 7: Different Configurations for Waste Stabilization Ponds [Source: *[31]*, *[34]*]

2.9.1. Anaerobic ponds

Anaerobic ponds, as their name implies, are devoid of dissolved oxygen or contain no or very few algae. The settleable solids in the raw wastewater settle to form a sludge layer, where they are digested by bacteria at temperature above 15°C. The primary function of anaerobic ponds is BOD removal [28]. Total BOD removal is high, ranging from 40% at 10°C or below to over 60% at 20°C and above. A scum layer often forms on the surface, and this need to be removed. Odour release is commonly seen as a major disadvantage of anaerobic ponds. However if designed to receive a volumetric loading >400g BOD per m^3 per day, odour nuisance does not occur with domestic wastewater containing <500mg SO_4/l. A depth of 4 m is about optimal from the point of view of treatment efficiency. However, depth of less than 2.5 m should not be used if possible [35].

2.9.2. Facultative ponds

Facultative have large algal population which play an essential role in waste stabilization, thus they are sometimes referred to as photosynthetic or natural ponds. Facultative ponds are sometimes divided into primary and secondary facultative ponds, which receive raw and settled sewage (effluent anaerobic ponds) respectively. Facultative ponds which are properly designed and maintained can give a BOD reduction ranging from 75% - 90% for domestic wastewater [22]. The depth of facultative pond is usually 1.5 - 3 m, although depths between 1m and 2m are used. Depths less than 0.9m are not recommended, as rooted plants may grow in the pond and provide shaded habitat suitable for mosquito breeding.

The wind has a significant on the performance of facultative pond, as it induces vertical mixing of the pond liquid. Good mixing ensures a more uniform distribution of BOD, DO, bacteria and algae, and hence a better degree of waste stabilization. Poor mixing, therefore, causes large fluctuations in effluent quality (BOD, COD, TSS).

2.9.3. Maturation ponds

A maturation pond receives effluent from a facultative pond, and the size and the number of maturation ponds is determined mainly by the required bacteriological quality of the final effluent. The depth of up to 3m have been used, but more commonly, maturation ponds are the shallowest with depths ≤1.5 m. Maturation ponds are principally designed for fecal bacterial removal [13], [16]. The main parameter that affect the removal of fecal bacteria in these ponds are temperature, high pH (>9), retention time and high light intensity together with high concentrations of DO [16], [36]. Fecal bacterial removal increases with increasing temperature and retention time. However, nutrient removal, such as nitrogen is quite slow [5], [20]. According to Metcalf & Eddy, maturation ponds are designed to remove 50-80 % of COD and BOD [13].

2.10. Reviews on the Performance of WSPs

This chapter has presented major concerns associated with wastewater when not properly treated, how wastewater has serious environmental and health implications. It has also shown the widespread use of WSPs all over the world. Many reviews had been published on the performance of WSP. For instance, in 2003, Lloyd et al. were reported to have studied fourteen WSP system in Mexico and found that all produced poor quality effluents [12]. The causes of the underperformance was gross under-design, adverse environmental conditions, a very high degree of hydraulic short-circuiting, and very poor operation and maintenance. Secondly, another study carried in 2005 showed that the WSPs in New Borg Al-Arab city in Egypt had final effluents that had levels of COD, TSS and BOD higher than the standards proposed by the WHO and the Egyptian regulations [37]. The higher TSS in the effluents might have been attributed to the growth of microalgae and other photosynthetic bacteria followed by their release in the effluents. Concerning BOD and COD, this might have been caused by the prevailing anaerobic conditions that reduced the rate of organic degradation within the ponds.

Another study done in Kumasi, Ghana also reported effluent concentrations of BOD and FC all exceeded the benchmark concentration levels acceptable to the Environmental Protection Agency (EPA) of Ghana. The poor performance was traced to a combination of technical and operational factors. The main causes were overloading of the plant beyond its design capacity and poor maintenance practices.

Furthermore, [13] carried out a study on the performance of WSPs and reported that the performance of these ponds attained a lower efficiency. However, the final effluent complied with WHO guidelines for restricted irrigation. Also, [14] carried out a study in Iran and concluded that the variation of organic load, pH, EC and seasonal variation had no effects on organic matter removal, and the removal of BOD was approximately constant. In [15] study, the wastewater temperatures of the WSPs were decreased along the ponds series whereas wastewater pH and DO increased along the ponds. Due to the high pH values that occurred in the ponds, there was a high efficiency removal of heavy metals. The maximum overall removal efficiency of measured TSS was 70% in summer season and reported 48% as minimum values in winter season. The maximum overall removal efficiency of BOD was in summer with 88% and minimum efficiency was 73% in winter season. In addition, [23] also carried a study in Dodoma, Tanzania, and reported that the major problem of the WSPs was the very low overall removal efficiencies of all analyzed parameters (BOD, pH, TDS, EC), ranging from 0% to 27%.

3. RESEARCH METHODOLOGY

3.1.Research design

The methodology employed for this research was comprised of; literature survey, use of questionnaire, personal interview, on-site data collection, data analysis and redesign of the ponds. Thus, the researcher conducted an empirical research that was both qualitative and quantitative, presenting original research findings. A questionnaire was prepared and answered by the senior manager for planning and technical services from Ongwediva Town Council (OTC) to evaluate the ponds' performance. A personal interview was carried with the technical officer also from OTC to get an idea on how the ponds are operated and maintained. On-site data collected was done by observation, taking flow and weather records. In terms of quantitative data, samples were also collected for physical, chemical and biological analysis, thus primary data was collected for this research. However, secondary data from the past studies was also used for the purpose of understanding the history of the ponds. Samples were collected at inlets and outlets of Ongwediva ponds to characterize the parameters of wastewater. Also, a desktop design was used for the design of the new Ongwediva WSPs.

3.2. Analysis of wastewater samples

Sampling was done manually. Using grab sampling method, samples of the raw wastewater and of the effluent of anaerobic and facultative ponds were collected daily from May to June 2017. So as to take into account the daily variation in influent and effluent quality, samples were collected from 09H00 to 11H00 every day. Overall standard deviation was 0.5mg/L, acceptable level of uncertainty is ± 0.25 mg/L, and a 95% confidence level is desired, thus, 15 samples were taken at each sample point.

Values of parameters such as color, temperature, EC and pH were measured on site, while TDS, TSS, BOD, nitrate as N, nitrite as N, DO, turbidity, FC and ammonia were determined in the laboratory.

3.2.1. Sampling and data collection

The following procedures describes how grab samples were taken and stored for analyses by Namwater laboratory:

- ❖ Samples were collected at the inlet (as inflow) or outlet (as outflow) of a specific unit process;
- ❖ A sealed, clean 2 ℓ plastic bottle was then filled and rinsed three times with the wastewater that was to be sampled;
- ❖ Sampling bottle was filled completely and sealed while still under water/while bottle overflows;
- ❖ Each bottle was marked or labelled immediately.
- ❖ Sample bottles were then stored at or below 4°C and delivered to the laboratory for analysis.

The samples were sent to Namwater lab within 24hours after sampling. Results of the measured samples were analyzed and the final effluent quality were compared to the effluent quality standard according to the General Standards for Waste Water Discharge into the Environment. Analysis for all parameters were done according to the standard method for the examination of wastewater.

3.2.2. Laboratory methods/instruments

Samples were collected at both inlet and outlet position of each pond in series for the analysis of EC, temperature, fecal coliform, TSS, turbidity, Nitrite, Nitrate, BOD, DO, Total Dissolved Solids, Conductivity and pH.

3.2.2.1. Electrical Conductivity (EC)

An AD3000 EC meter was used to measure the electrical conductivity.

3.2.2.2. Temperature

A thermometer was used to measure temperature and the results were reported to the nearest 0.1°C.

3.2.2.3. Turbidity

A HACH spectrophotometer DR/2010 was used to measure turbidity using the nephelometric method.

3.2.2.4. pH

The electrometric method was used to measure pH. A pH meter, beakers and stirrers were used to carry out the measurements.

3.2.2.5. Colour

For measuring color, the visual comparison method was used. Nessler tubes are required for this measurement.

3.2.2.6. Nitrate, Ammonia and Nitrite as N

The Cadmium Reduction Method was used to measure nitrate, ammonia and nitrite as nitrogen. A HACH DR/2010 spectrophotometer and a reduction column were needed to perform this procedure.

3.2.2.7. Dissolved Oxygen (DO)

The membrane electrode method was used to carry out the measurements of the dissolved oxygen. A sensitive-oxygen membrane electrode was required to perform the procedure. A DO meter AD610 was used to measure DO.

3.2.2.8. Total Suspended Solids (TSS)

Total suspended solids dried at 103-105 °C method was used to determine the total suspended solids in the samples. Hence, evaporating dishes, 180°C drying oven and steam bath were required to determine TSS. The HACH Spectrophotometer DR/2010 was used to carry out the experiment.

3.2.2.9. Fecal Coliforms

The fecal coliform membrane filter procedure was used to measure the fecal coliforms present in the samples. A M-FC medium, culture dishes and an incubator were required to perform this measurement.

3.2.2.10. Biochemical Oxygen Demand (BOD)

To perform a BOD measurement, the following procedures were followed using the Oxi Top system:

i. The measuring range of the sample to be analyzed was estimated.
ii. Before filling the overflow measuring flask, all the additional solutions were added.
iii. The nitrification inhibitor was.
iv. The sample was seeded.
v. Nutrient solutions, mineral solutions and buffer solutions was then added.

vi. The selected volume of homogenized sample with the aid of the overflow measuring flask.

vii. By means of a funnel, the measurement solution was transferred into the graduated measuring flask.

viii. A magnetic stirrer bar was inserted into the bottle.

ix. Two sodium hydroxide pellets were placed in the rubber sleeve.

x. The rubber sleeve were inserted onto the bottle.

xi. It was then screwed on the OxiTop C measuring head tightly. The rubber sleeve ensured the necessary sealing of the system.

xii. The measurement on the OxiTop C head was started, on the controller.

xiii. The graduated measuring flask was then placed in the incubator for five days at 20°C.

xiv. The results were read after five days.

The required instruments and tools used were:

- OxiTop C measuring system
- Inductive stirring system
- Incubator thermostatic box (temperature 20°C ± 1K)
- Sample bottles (nominal volume 510 ml)
- Stirring rods
- Stirring rod remover
- suitable overflow measuring beakers
- Rubber quivers
- Sodium hydroxide tablets

3.3. Design of the new Ongwediva waste stabilization ponds

3.3.1. Design guidelines for Ongwediva Waste Stabilization Ponds

In order to design for waste stabilization pond for Ongwediva, the following guidelines were used;

- Guidelines for Human Settlement and Design Volume 2 from the Red Book,
- Sewage Treatment in Hot Climate by Wiley and
- General Sewage Guidelines for Design and Operation from the Department of Water Affairs of the Republic of Namibia.

3.3.2. Design criteria for Ongwediva Waste Stabilization Ponds

The design criteria that were considered included temperature, population, wastewater generation, design period and other factors that will be discussed in sections below.

3.3.2.1. Temperature

Following the Namibian guidelines, a temperature of 20°C is chosen as the design temperature.

3.3.2.2. Population

According to the [1], the population of Ongwediva was estimated to be 20 260 people. Since, waste stabilization pond system is usually designed for 15 years period; the expected population for the next fifteen years with a growth rate of 2.8% will be 23 911 people. This is to cover for all the developments that have been proposed to take place in the future.

3.3.2.3. Wastewater generation, Q, and design for 15 years period

The daily water requirement was found to be 120 L/C/day.

Therefore, the total water consumption for the design period of 15 years was:

120 L/C/day × 23 911 persons = 2 869 320 L/day = 2 869.32 m^3/day

Since 80% of the water consumed is given as the wastewater flow, therefore, Q, which is the daily wastewater flow = 2 295 m^3/day.

3.3.2.4. BOD contribution per capita per day

The values of BOD, usually, vary between 54 and 60 gm per person per day [38]. For this particular study, the average was used: BOD (b) = 57 g/capital/day based on the standard of living.

3.3.2.5. Total Organic Loading

This was calculated as B = b × population

$$= 57 \times 23\,911/1000$$

$$= 1\,363 \text{ kg/day}$$

3.3.2.6. Total Influent BOD Concentration (Li)

The total influent BOD concentration (Li) was calculated from the equation below [30], [25], [9].

$$Li = b/q \times 10^3 \quad \text{.....................Equation 1}$$

$$= 60/\ 67.2 \times 10^3$$

$$= 893 \text{ mg/l}$$

Where q is the effluent flow per capita per day.

3.3.2.7. Influent Bacteria Concentration (Ni)

Bacteria concentration in an influent ranges between 10^7 to 10^9 fecal coliform per 100 ml. A Ni value was chosen as 4×10^7 fecal coliform per 100 ml, which is within the above range.

3.3.2.8. Required effluent standards

It is assumed that the effluent will be discharged. Therefore, the following effluent standards are required:

i. Faecal coliform in effluent; $Ne \leq 100$FC/100 ml

ii. Effluent BOD; $Le \leq 25$ mg/l

3.4. Data analysis

For Statistical Analysis, Minitab 17 software was used to for analyzing statistical values; average, range and their standard deviations. Minitab 17 was also used to carry out statistical regression analysis. The regression technique was used to determine the relationships between dependent and independent variables based on statistical data. The mean effluent results were then compared to the Department of Water Affairs wastewater effluent quality standards.

To evaluate the performance of each pond removal efficiencies for all the parameters monitored were computed on the basis of concentration. The concentration-based efficiency E was computed according to the equation below:

$E_T (\%) = [(Ci-Ce)/Ci] \times 100$ ……………………………………………...Equation 2

Where: E_T is the total efficiency of the pond. Ci is influent concentration to the ponds and Ce is the effluent concentration from the pond [26], [28].

4. RESEARCH ETHICS

In order to avoid violation of copyright principles and intellectual property rights, works of other authors stated in full or part, are clearly acknowledged. Also, test procedures and results were correctly reported to reflect true findings of the study. Lastly, all other relevant ethical policies of the University of Namibia were strictly adhered to.

5. RESULTS

5.1. Description of the study area

Ongwediva is a town located in the northern part of Namibia. The town was declared one of the fastest growing towns in the country due to urbanization [2]. The town urban population rapidly increased between 2001 and 2011 from 26 700 to 34 065 [1]. The current wastewater treatment technology employed in Ongwediva is a pond system that serves the whole town. It is situated in the southern part of the town as indicated in red in Figure 8.

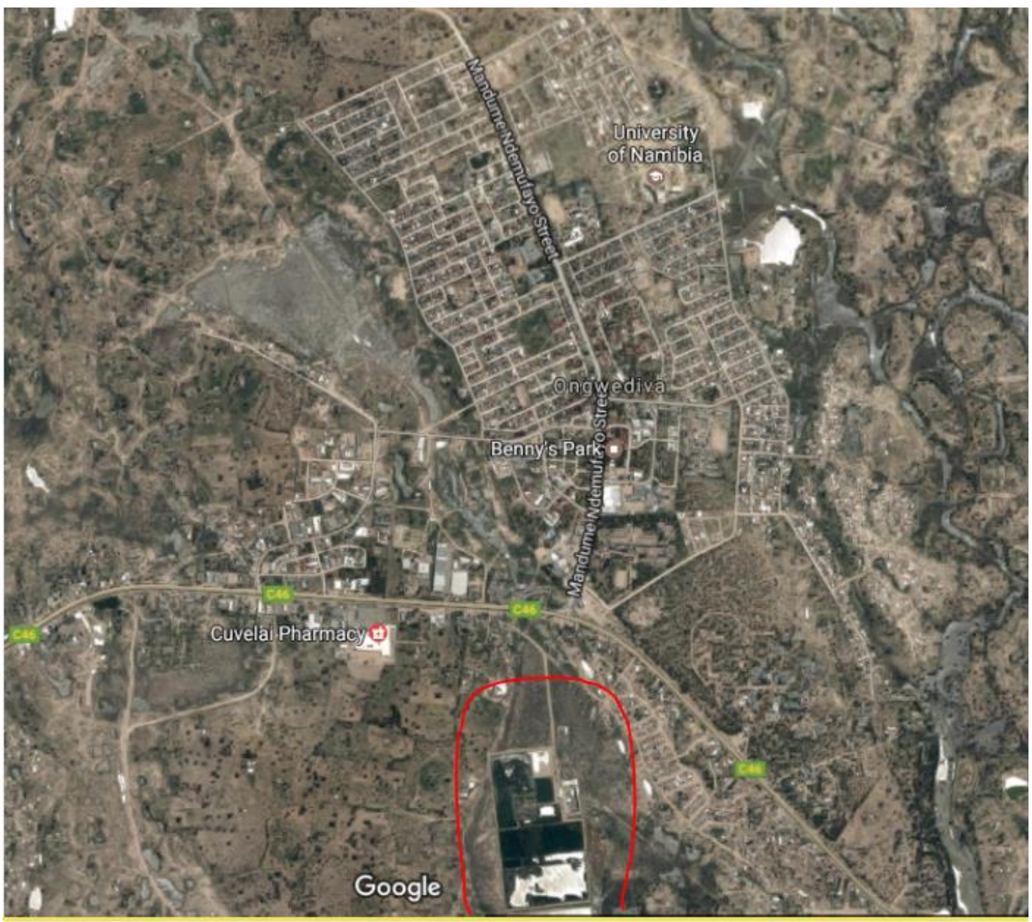

Figure 8: Location of Waste Stabilization Ponds in Ongwediva Town

5.2. Climate

The climate in Ongwediva can be described as hot to very hot, with relatively constant temperature throughout the year. The average minimum temperature ranges from 13°C (July) to 27°C (November – December). The average maximum temperatures ranges from 30°C (June – July) to 36°C (November). Ongwediva receives an average 777mm of precipitation annually, during the rainy season from November to April. The mean relative humidity annually is 36.4%.The maximum wind speed that occur in Ongwediva is 15.9mph in October and there is a total of 1557.7hours of sunshine annually.

5.3. Study of the existing wastewater treatment system

The Ongwediva Waste Stabilization Ponds have been reported to be in operation since before Namibia's independence in March 1990. However, there is no record of the exact date the ponds were constructed. Data about the ponds' design capacity is also not available. The wastewater treated by the waste stabilization ponds is mainly domestic wastewater. All wastewater from the town is conveyed to the ponds through sewers under gravity and there are manholes along the channels to change the direction of the sewers. There are 12 pump stations in Ongwediva used to pump sewerage into the ponds from the plots connected to the sewer system. At each pump station, there is a meter which records the amount of wastewater that is pumped to the ponds. For the plots not connected to the sewer system, hired trucks and mechanical pumps are used to pump wastewater from their septic tanks and transport it to the ponds at a fee.

There is a newly constructed inlet structure at the OWSPs where the wastewater goes through a screening chamber for large objects and particles to be removed. At this inlet structure, this is also where scum is removed as part of maintenance. From this point, raw wastewater flow by gravity through a pipe into the first anaerobic ponds. During the time of this study, some ponds were not being utilized and were being maintained (disludged) i.e. Pond D, J, k, L, M and N. Thus caused overflowing of ponds. Therefore, two new anaerobic ponds were constructed to prevent the overflow. From the anaerobic ponds, the wastewater then enters into the primary facultative ponds and then flow into the secondary facultative ponds for further treatment. There are no maturation ponds. The final pond is a large evaporation that was constructed after the secondary facultative ponds to contain the treated effluent and prevent it from being discharged into the adjacent drainage water courses. The ponds are partially overgrown with reeds, therefore it is not easy to determine the flow path through the ponds. Some of the ponds are filled with sludge. From the survey that was carried by Ongwediva Consulting Engineers in 2014, and inspection on site, Figure 9 shows the schematic layout of the Ongwediva Waste Stabilization Ponds.

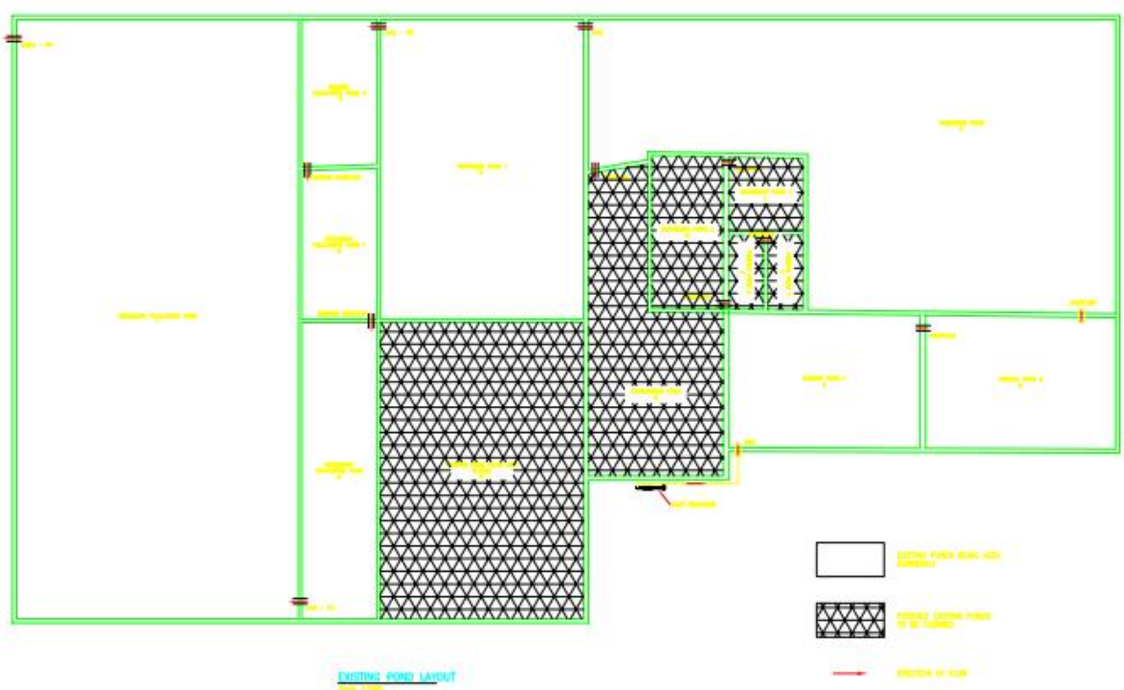

Figure 9: Schematic layout of Ongwediva Waste Stabilization Ponds

5.4. Geometry of the Existing Ponds

The layout of the Ongwediva Waste Stabilization Ponds (OWSPs) including flow direction appear in Appendix 2. It is important to point out that some of the ponds are completely filled with reeds and sludge such as Pond D, J, K, L, M and N. At Ongwediva, anaerobic ponds are shallower (1.3m deep) than those at Obuasi in Ghana (4-5 m deep). However, the facultative and maturation ponds at Ongwediva have the same depth (1-2 m and 1-1.5 m deep respectively) as those at Obuasi in Ghana [28].

Table 2: Geometry of the existing Ongwediva WSPs [Source: *[39]*]

POND	AREA (m^2)	DEPTH (m)	VOLUME (m^3)	TYPE
A	12 900	1.3	16 770	Anaerobic
B	12 800	1.3	16 640	Anaerobic
C	59 700	1.3	77 610	Anaerobic
D	30 700	1.3	39 910	Reed bed/sludge
E	30 600	1.3	39 780	Anaerobic
F	5 200	1.3	6 760	Facultative
G	5 300	1.3	6 890	Facultative
H	11 400	1.3	14 820	Facultative
I	83 800	1.3	108 940	Facultative
J	1 250	1.3	1 625	Reed bed/sludge
K	1 400	1.3	1 820	Reed bed/sludge
L	2 800	1.3	3 640	Reed bed/sludge
M	5 700	1.3	7 410	Reed bed/sludge
N	15 400	1.3	20 020	Reed bed/sludge

5.5. Flow

No data could be found on wastewater quality and few data exist on wastewater quantity. There are meters installed at every pump to record wastewater pumped to the ponds. Readings of the wastewater quantities at the pump station are only recorded on a monthly basis. Thus, if there was a breakdown of a pump at any pump station, no reading will be taken and that will be recorded as a defect as shown in Appendix 3.

The average flow throughout the month was calculated to be 2 512.98 m^2/d based on the records provided by Ongwediva Town Council. The observed flow at the inlet of the pond system shows a tendency of being the highest in the morning around 7-8 AM and in the afternoon around 7PM in the weekdays. This is expected since early morning hours is the time most people prepare to go to work or to school and 7PM is the time when most working people are at home.

5.6. Evaluation of the Pre-treatment Units

As a result of poor maintenance, the pre-treatment units are not frequently cleaned leading sometimes to an increase in pollution load of the wastewater reaching the ponds. Figure 10 shows scums accumulating at the inlet structure which is a symptom of delay in the removal of scum at the inlet structure. Also, due to poor operation of ponds, the result is growing reeds and increase of sludge production in the ponds. Table 3 show the mean concentration values of the wastewater parameters following screening and grit removal:

Figure 10: Scum accumulating at the inlet structure

Table 3: Mean parameter concentration values after screening and grit removal

Parameter	Unit	Mean Value
pH		6.98
EC	S/m	103.87
TDS	mg/l	695.9
Nitrate	mg/l	0.57
Turbidity	NTU	274.7
Ammonia	mg/l	110.9
Nitrite	mg/l	0.1
DO	mg/l	0.71
TSS	mg/l	400.2
BOD	mg/l	247.6
Temperature	°C	22.57
Feacal Coliforms	Counts/100ml	$>1\times10^6$

5.7. Physical, chemical and biological characteristics of the wastewater along the pond system

5.7.1. Temperature

The variation in temperature of the Ongwediva stabilization ponds is shown in the Table 4 below. The influent to the pond treatment held an average of 22.57°C during the sampling period. A gradual increase in temperature was observed from the inlet until at the effluent of the primary facultative pond, before the temperature decreased at the outlet to 22.8°C. The effluent held an only slightly higher temperature than the influent.

Table 4: Temperature values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE	
				MIN.	MAX.
Influent	15	22.57	± 0.50	22.00	23.30
Anaerobic effluent	8	22.96	± 0.14	22.70	23.20
Facultative Effluent	8	23.41	± 0.13	23.30	23.70
Effluent	15	22.80	± 0.33	22.20	23.20

After running a one-way ANOVA in Minitab 17 for temperature, the following were found; One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	$\alpha = 0.05$

Equal variances were assumed for the analysis.

Factor Information

Factor Levels Values

Factor 4: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	4.752	1.58417	33.04	0.000
Error	28	1.343	0.04795		
Total	31	6.095			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.218967	77.97%	75.61%	71.23%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	22.350	0.355	(22.191, 22.509)
Anaerobic Ponds	8	22.9625	0.1408	(22.8039, 23.1211)
Facultative Ponds	8	23.4125	0.1246	(23.2539, 23.5711)
Effluent	8	22.7250	0.1753	(22.5664, 22.8836)

Since the P- Value is 0.000, the null hypothesis was rejected.

5.7.2. Color

The variation in color along the ponds are shown in Table 5 below. The wastewater was observed to be yellow green as shown in Figure 11. The mean color of the influent was 423.7 mg/l Pt. and 139.47 mg/l Pt at the effluent.

Table 5: Color values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE MIN.	MAX.
Influent	15	423.70	± 107.80	152.00	500.00
Anaerobic effluent	8	300.90	± 33.80	224.00	327.00
Facultative Effluent	8	209.63	± 12.44	192.00	232.00
Effluent	15	139.47	± 24.52	115.00	195.00

After running a one-way ANOVA in Minitab 17 for color, the following were found;

One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent
Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	$\alpha = 0.05$

Equal variances were assumed for the analysis.

Factor Information
Factor Levels Values
Factor 4: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance

Source	DF Adj	SS Adj	MS	F-Value	P-Value
Factor	3	461290	153763	81.49	0.000
Error	28	52832	1887		
Total	31	514122			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
43.4381	89.72%	88.62%	86.58%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	465.3	74.2	(433.8, 496.7)
Anaerobic Ponds	8	300.9	33.8	(269.4, 332.3)
Facultative Ponds	8	209.63	12.44	(178.17, 241.08)
Effluent	8	146.00	27.38	(114.54, 177.46)

Since the P-Value is 0.000, the Null hypothesis was rejected.

Figure 11: Color of the wastewater from observation

5.7.3. pH

The variation in pH are described in Table 6 below. The influent to the pond system held an average of 6.98. A slight increase in pH was observed along the pond system. The final effluent held an average value of 7.64. The pH values of the pond treatment ranged between 6.3 and 8.1 as the maximum at the final effluent.

Table 6: pH values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE	
				MIN.	MAX.
Influent	15	6.98	± 0.30	6.30	7.50
Anaerobic effluent	8	7.16	± 0.28	6.90	7.50
Facultative Effluent	8	7.43	± 0.19	7.2	7.80
Effluent	15	7.64	± 0.19	7.40	8.10

After running a one-way ANOVA in Minitab 17 for pH, the following were found;

One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent
Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.
Factor Information:
Factor Levels Values
Factor 4: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance

Source	DF Adj	SS	Adj MS	F-Value	P-Value
Factor	3	2.403	0.80115	9.88	0.000
Error	28	2.271	0.08112		
Total	31	4.675			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.284809	51.41%	46.21%	36.54%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	6.988	0.394	(6.781, 7.194)
Anaerobic Ponds	8	7.1625	0.2825	(6.9562, 7.3688)
Facultative Ponds	8	7.4250	0.1909	(7.2187, 7.6313)
Effluent	8	7.7125	0.2295	(7.5062, 7.9188)

Since the P-Value is 0.000, the Null hypothesis was rejected.

5.7.4. Turbidity

The variation in turbidity of the pond treatment system is shown in Table 7 below. The raw wastewater held a mean value of 274.7 NTU while the final effluent went as low as 16.67 NTU. A sudden decreased was observed between the influent of the raw wastewater and effluent at the anaerobic pond. A slight increase was later seen at the effluent of the anaerobic pond and primary facultative ponds followed by a decrease again at the final effluent.

Table 7: Turbidity values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE	
				MIN.	MAX.
Influent	15	274.70	± 122.40	65.70	515.0
Anaerobic effluent	8	40.00	± 10.17	26.90	51.50
Facultative Effluent	8	49.31	± 11.70	38.10	71.80
Effluent	15	16.67	± 4.72	9.00	26.70

After running a one-way ANOVA in Minitab 17 for turbidity, the following were found;

One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	$\alpha = 0.05$

Equal variances were assumed for the analysis.
Factor Information
Factor Levels Values
Factor 4: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance

Source	DF Adj	SS Adj	MS	F-Value	P-Value
Factor	3	471218	157073	35.33	0.000
Error	28	124501	4446		
Total 31 595719					

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
66.6818	79.10%	76.86%	72.70%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	314.2	132.4	(265.9, 362.5)
Anaerobic Ponds	8	40.00	10.17	(-8.29, 88.29)
Facultative Ponds	8	49.31	11.70	(1.02, 97.60)
Effluent	8	16.59	5.38	(-31.70, 64.88)

Since the P-Value is 0.000, the Null hypothesis was rejected.

5.7.5. Electrical Conductivity (EC)

The variation in EC of the ponds is shown it Table 8 below. It was observed that EC decreased all along the pond system from the inlet (103.87 S/m) to the outlet (98.53 S/m. The values for EC ranged from 67.3 to 100.1 S/m.

Table 8: EC values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE	
				MIN.	MAX.
Influent	15	103.87	± 16.96	67.30	128.20
Anaerobic effluent	8	111.59	± 1.42	109.50	113.60
Facultative Effluent	8	102.21	± 1.91	99.70	105.30
Effluent	15	98.53	± 1.04	97.20	100.10

After running a one-way ANOVA in Minitab 17 for EC, the following were found;

One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	$\alpha = 0.05$

Equal variances were assumed for the analysis.
Factor Information

Factor Levels Values
Factor 4: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	789.5	263.15	4.24	0.014
Error	28	1737.5	62.05		
Total	31	2527.0			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
7.87748	31.24%	23.87%	10.19%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	105.72	15.56	(100.02, 111.43)
Anaerobic Ponds	8	111.587	1.420	(105.882, 117.293)
Facultative Ponds	8	102.213	1.911	(96.507, 107.918)
Effluent	8	98.038	0.769	(92.332, 103.743)

Since the P-Value is 0.014, the Null hypothesis was rejected.

5.7.6. Total Suspended Solids (TSS)

The variation of TSS are shown in Table 9 below. A gradual decrease was observed between the inlet and effluent of the anaerobic ponds, from 400.2 mg/l to 48 mg/l respectively. A continuous slight decrease in TSS followed from the effluent of the anaerobic ponds until at the outlet to 21.73 mg/l. The TSS values ranged between 3 mg/l and 820 mg/l along the pond treatment system. There was 88% removal efficiency in the anaerobic ponds.

Table 9: TSS values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE	
				MIN.	MAX.
Influent	15	400.20	± 183.80	100.00	820.00
Anaerobic effluent	8	48.00	± 1.93	44.00	50.00

Facultative Effluent	8	24.00	± 3.00	19.00	27.00
Effluent	15	21.73	± 12.78	3.00	41.00

After running a one-way ANOVA in Minitab 17 for TSS, the following were found;

One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent
Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	$\alpha = 0.05$

Equal variances were assumed for the analysis.
Factor Information
Factor Levels Values
Factor 4: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	1280540	426847	65.33	0.000
Error	28	182954	6534		
Total	31	1463494			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
80.8337	87.50%	86.16%	83.67%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	490.0	161.4	(431.5, 548.5)
Anaerobic Ponds	8	48.000	1.927	(-10.541, 106.541)
Facultative Ponds	8	23.875	2.800	(-34.666, 82.416)
Effluent	8	14.75	8.22	(-43.79, 73.29)

Since the P-Value is 0.000, the Null hypothesis was rejected.

5.7.7. Total Dissolved Solids (TDS)

The variation in TDS are shown in Table 10 below. The inlet TDS value was 695.9 mg/l which increased to 747.75 mg/l at the anaerobic ponds effluent and gradually decreased up to 660.27 mg/l at the outlet.

Table 10: TDS values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE	
				MIN.	MAX.
Influent	15	695.90	± 113.6	451.00	859.00
Anaerobic effluent	8	747.75	± 9.35	734.00	761.00
Facultative Effluent	8	684.75	± 12.89	668.00	706.00
Effluent	15	660.27	± 7.01	651.00	671.00

After running a one-way ANOVA in Minitab 17 for TDS, the following were found;

One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent
Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	$\alpha = 0.05$

Equal variances were assumed for the analysis.
Factor Information
Factor Levels Values
Factor 4: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	35445	11815	4.24	0.014
Error	28	78033	2787		
Total	31	113478			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
52.7910	31.24%	23.87%	10.18%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	708.4	104.2	(670.1, 746.6)
Anaerobic Ponds	8	747.75	9.35	(709.52, 785.98)
Facultative Ponds	8	684.75	12.89	(646.52, 722.98)
Effluent	8	657.00	5.21	(618.77, 695.23)

Since the P-Value is 0.014, the Null hypothesis was rejected.

5.7.8. Ammonia as N

The variation in ammonia concentration is shown in Table 11 below. The inlet held a concentration of 110.9 mg/l which was suddenly reduced to 1.7 mg/l at the anaerobic effluent before increased to 5.38 mg/l and increased at the effluent of the primary ponds. It was finally decreased again to 0.74 mg/l at the outlet. However, the ammonia values along the pond system ranged between 0.1 mg/l and 480 mg/l. A 95% removal efficiency in the facultative pond was achieved when [40] reported a general value of <50 in facultative ponds.

Table 11: Ammonia values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE MIN.	RANGE MAX.
Influent	15	110.90	± 168.5	0.1	480.00
Anaerobic effluent	8	1.70	± 1.53	0.330	4.00
Facultative Effluent	8	5.38	± 1.27	3.20	7.00
Effluent	15	0.74	± 0.94	0.07	3.2

After running a one-way ANOVA in Minitab 17 for Ammonia N, the following were found;

One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent
Method
Null hypothesis All means are equal
Alternative hypothesis At least one mean is different
Significance level $\alpha = 0.05$

Equal variances were assumed for the analysis.
Factor Information
Factor Levels Values
Factor 4: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance
Source DF Adj SS Adj MS F-Value P-Value

Factor	3	6840	2280.1	9.03	0.000
Error	28	7069	252.5		
Total	31	13910			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
15.8896	49.18%	43.73%	33.62%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	36.2	31.7	(24.7, 47.7)
Anaerobic Ponds	8	1.698	1.526	(-9.810, 13.205)
Facultative Ponds	8	5.375	1.265	(-6.133, 16.883)
Effluent	8	0.897	1.060	(-10.610, 12.405)

Since the P-Value is 0.000, the Null hypothesis was rejected.

5.7.9. Nitrate

The variation in nitrate concentration of the pond system is shown in Table 12 below. The average nitrate value for the raw wastewater was 0.57 mg/l which decreased to 0.5 mg/l and then increased to the value of 2.33 mg/l at the final effluent. There was a small nitrate removed in the anaerobic ponds, otherwise the nitrate increased along the ponds series.

Table 12: Nitrate values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE	
				MIN.	MAX.
Influent	15	0.57	± 0.28	0.50	1.60
Anaerobic effluent	8	0.50	± 0.00	0.50	0.50
Facultative Effluent	8	1.68	± 1.36	0.50	4.10
Effluent	15	2.33	± 1.11	0.30	3.30

After running a one-way ANOVA in Minitab 17 for Nitrate N, the following were found;

One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent
Method
Null hypothesis All means are equal

Alternative hypothesis	At least one mean is different
Significance level	α = 0.05

Equal variances were assumed for the analysis.
Factor Information
Factor Levels Values
Factor 4: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	17.05	5.6845	6.27	0.002
Error	28	25.37	0.9062		
Total	31	42.43			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.951948	40.19%	33.79%	21.89%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	0.5000	0.0000	(-0.1894, 1.1894)
Anaerobic Ponds	8	0.5000	0.0000	(-0.1894, 1.1894)
Facultative Ponds	8	1.675	1.357	(0.986, 2.364)
Effluent	8	2.163	1.335	(1.473, 2.852)

Since the P-Value is 0.000, the Null hypothesis was rejected.

5.7.10. Nitrite

There was no significant variation in the concentration of nitrite along the pond series as shown in Table 13 below. The nitrite values of the ponds varied between 0.1 mg/l and 2 mg/l. The average nitrite of raw wastewater was 0.1mg/l and the average final effluent was 1.2mg/l.

Table 13: Nitrite values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE	
				MIN.	MAX.
Influent	15	0.10	± 0.00	0.10	0.10
Anaerobic effluent	8	0.10	± 0.00	0.10	0.10

Facultative Effluent	8	1.2	± 1.07	0.10	3.10
Effluent	15	0.39	± 0.57	0.10	2.00

After running a one-way ANOVA in Minitab 17 for Nitrite, the following were found;

One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent
Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	$\alpha = 0.05$

Equal variances were assumed for the analysis.
Factor Information
Factor Levels Values
Factor 4: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	6.480	2.1600	6.43	0.002
Error	28	9.400	0.3357		
Total	31	15.880			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.579409	40.81%	34.46%	22.69%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	0.1000	0.0000	(-0.3196, 0.5196)
Anaerobic Ponds	8	0.1000	0.0000	(-0.3196, 0.5196)
Facultative Ponds	8	1.200	1.065	(0.780, 1.620)
Effluent	8	0.400	0.457	(-0.020, 0.820)

Since the P-Value is 0.002, the Null hypothesis was rejected.

5.7.11. Dissolved Oxygen (DO)

The variation of the DO concentration is shown in Table 14 below. The average raw wastewater DO concentration was 0.71 mg/l and the final effluent concentration was 1.91

mg/l. The minimum recorded DO concentration was 0.47 and maximum concentration was 2.9 mg/l.

Table 14: DO values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE	
				MIN.	MAX.
Influent	15	0.71	± 0.13	0.47	0.98
Anaerobic effluent	8	0.96	± 0.32	0.56	1.60
Facultative Effluent	8	0.65	± 0.08	0.55	0.81
Effluent	15	1.91	± 0.56	0.71	2.90

After running a one-way ANOVA in Minitab 17 for DO, the following were found;

One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Method

Null hypothesis	All means are equal
Alternative hypothesis	At least one mean is different
Significance level	$\alpha = 0.05$

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Factor	4:	Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Factor	3	9.368	3.12266	36.79	0.000
Error	28	2.376	0.08487		
Total	31	11.744			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.291326	79.77%	77.60%	73.57%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	0.7225	0.1341	(0.5115, 0.9335)
Anaerobic Ponds	8	0.961	0.321	(0.750, 1.172)
Facultative Ponds	8	0.6525	0.0819	(0.4415, 0.8635)
Effluent	8	2.000	0.460	(1.789, 2.211)

Since the P-Value is 0.000, the Null hypothesis was rejected.

5.7.12. Biochemical Oxygen Demand (BOD)

The variations in BOD concentration of the ponds during the study period are shown in Table 15 below. The mean BOD concentration of the raw wastewater was 247.6mg/l which can be categorized as strong since BOD > 150mg/l [5], [25]. The anaerobic ponds removal efficiency was excellent, of about 91.3%. The outlet BOD concentration was 22.07 mg/l. Only 70% removal efficiency was achieved in the facultative ponds compared to 75-85 % that is generally achieved by facultative ponds [40].

Table 15: BOD values observed along the pond system

SAMPLING POINT	N	MEAN	STANDARD DEVIATION	RANGE	
				MIN.	MAX.
Influent	15	247.60	± 140.80	40.00	550.00
Anaerobic effluent	8	21.50	± 3.02	17.00	26.00
Facultative Effluent	8	81.75	± 24.61	52.00	130.00
Effluent	15	22.07	± 9.21	12.00	38.00

After running a one-way ANOVA in Minitab 17 for BOD, the following were found;

One-way ANOVA: Influent, Anaerobic Ponds, Facultative Ponds, Effluent
Method
Null hypothesis All means are equal
Alternative hypothesis At least one mean is different
Significance level $\alpha = 0.05$

Equal variances were assumed for the analysis.
Factor Information
Factor Levels Values
Factor 4: Influent, Anaerobic Ponds, Facultative Ponds, Effluent

Analysis of Variance
Source DF Adj SS Adj MS F-Value P-Value

Factor	3	477322	159107	26.34	0.000
Error	28	169133	6040		
Total	31	646455			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
77.7205	73.84%	71.03%	65.83%

Means

Factor	N	Mean	StDev	95% CI
Influent	8	318.1	153.1	(261.8, 374.4)
Anaerobic Ponds	8	21.50	3.02	(-34.79, 77.79)
Facultative Ponds	8	81.75	24.61	(25.46, 138.04)
Effluent	8	22.13	10.88	(-34.16, 78.41)

Since the P-Value is 0.000, the Null hypothesis was rejected.

5.7.13. Fecal Coliform (FC)

The variation of the FC values along the ponds system are shown in Table 16 below. The inlet held a value of $>1 \times 10^6$ counts/100ml and the outlet held a value of 2.0×10^5.

Table 16: FC values observed along the pond system

SAMPLING POINT	N	MEAN	RANGE	
			MIN.	MAX.
Influent	6	$>1\times10^6$	$>1\times10^6$	$>1\times10^6$
Anaerobic effluent	4	5.87×10^5	142080	$>1\times10^6$
Facultative Effluent	4	1.0×10^4	360	21333
Effluent	6	2.0×10^5	900	$>1\times10^6$

5.8. Overall Pond Performance and Removal Efficiency

The overall removal efficiency of the parameters measured in this study of OWSPs is shown in Table 16 below. EC and TDS showed the lowest removal efficiencies with 5.05% and 5.12% respectively. FC removal efficiency was only 20%. The removal efficiencies of ammonia, turbidity, BOD and TSS were significantly high, 99.33%, 93.93%, 91.09 and 94.57% respectively.

Table 17: Overall Removal Efficiency of the OWSPs

Parameters Analyzed	**Inlet …………… mean±SD**	**Outlet …………… mean±SD**	**Removal Efficiency (%)**
pH	6.98±0.30	7.64±0.19	
EC (mS/m)	103.87±16.96	98.52±1.04	5.05
TDS (mg/l)	695.90±113.60	660.27±7.01	5.12
Nitrate (mg/l)	0.57±0.28	2.33±1.11	-308.77
Nitrite (mg/l)	0.10±0.00	0.39±0.57	-290
Ammonia (mg/l)	110.90±138.50	0.74±0.94	99.33
Turbidity (NTU)	274.70±122.40	16.67±4.72	93.93
Colour (mg/l Pt.)	423.7±107.80	139.47±24.52	67.08
DO (mg/l)	0.71±0.13	1.91±0.56	-169.01
BOD (mg/l)	247.60±140.80	22.07±9.21	91.09
TSS (mg/l)	400.20±183.80	21.73±12.78	94.57
Temperature	22.57±0.50	22.8±0.33	
FC counts/100ml	$>1\times10^6$	2.0×10^5	20

5.9. Disposal of Final Effluent

The concentrations and values of the final effluent disposed and general standards from the Department of Water Affairs are shown in Table 17 below. The table showed that parameters such as EC, TDS, turbidity and fecal coliforms all exceeded the maximum permissible levels. Despite those parameter that did not comply with the standards, other parameters such as pH, nitrate, nitrite, ammonia, BOD, TSS and temperature are within the limits. The final stage of the ponds is the earthly evaporation ponds that receives final effluent and is allowed to evaporate. OTC assured that there are no boreholes near the OWSPs.

Table 18: Effluent values observed compared to DWA effluent quality standards

Parameter	Effluent	General DWA guideline
pH	7.64	6.5-9.5
EC (mS/m)	98.52	< 75
TDS (mg/l)	660.27	< 500
Nitrate (mg/l)	2.33	< 20
Nitrite (mg/l)	0.39	< 3
Ammonia (mg/l)	0.74	< 10
Turbidity (NTU)	16.67	< 12
Colour (mg/l Pt.)	139.47	< 15
DO (mg/l)	1.91	>75
BOD (mg/l)	22.07	< 30
TSS (mg/l)	21.73	< 100
Temperature (°C)	22.8	< 10°C of recipient body
FC	2.0×10^5	< 1000

5.10. Statistical Analysis

A statistical regression analysis was performed to evaluate if any of the measured parameters affected the concentration of BOD at the inlet and outlet. Thus, BOD was used as the dependent variable and temperature, pH, TSS, DO, ammonia, turbidity, EC, TDS, nitrate and nitrate was used as independent variables.

For this analysis, confidence interval was 95%, therefore a p-value < 0.05 indicates a strong statistical relation of the findings. The correlation between the variables at the inlet is shown in Table 18, Figure 33 and Figure 34 below. As shown in table, the analysis showed that there was a significant relationship between BOD and only two parameters, i.e. turbidity and TSS ($p<0.05$). The table also showed that there was no significant relationship between the other parameters and BOD ($p>0.05$).

Table 19: Relationship between BOD and physical-chemical parameters at the inlet

Parameter	R^2	Coefficient	P-Value	Constant
pH	3.5	-0.187	0.505	-0.000396
EC	0	0.015	0.958	0.00180
TDS	0	0.015	0.958	0.0120
Nitrate	1	-0.101	0.719	-0.000204
Turbidity	54.7	0.740	0.002	0.6423
Ammonia	11.7	-0.341	0.213	-0.4085
DO	0	0.017	0.951	0.0000160
TSS	57.4	0.757	0.001	0.9883
Temperature	3	-0.172	0.540	-0.000609

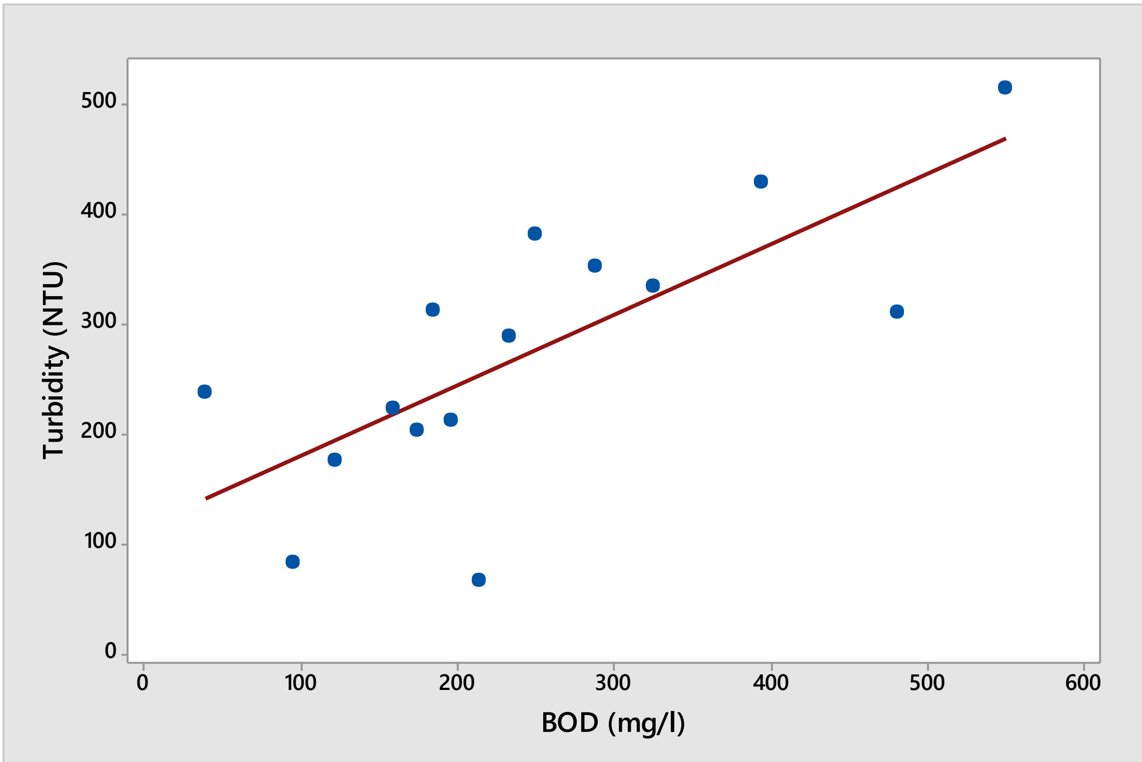

Figure 12: Linear correlation between BOD and turbidity at the inlet

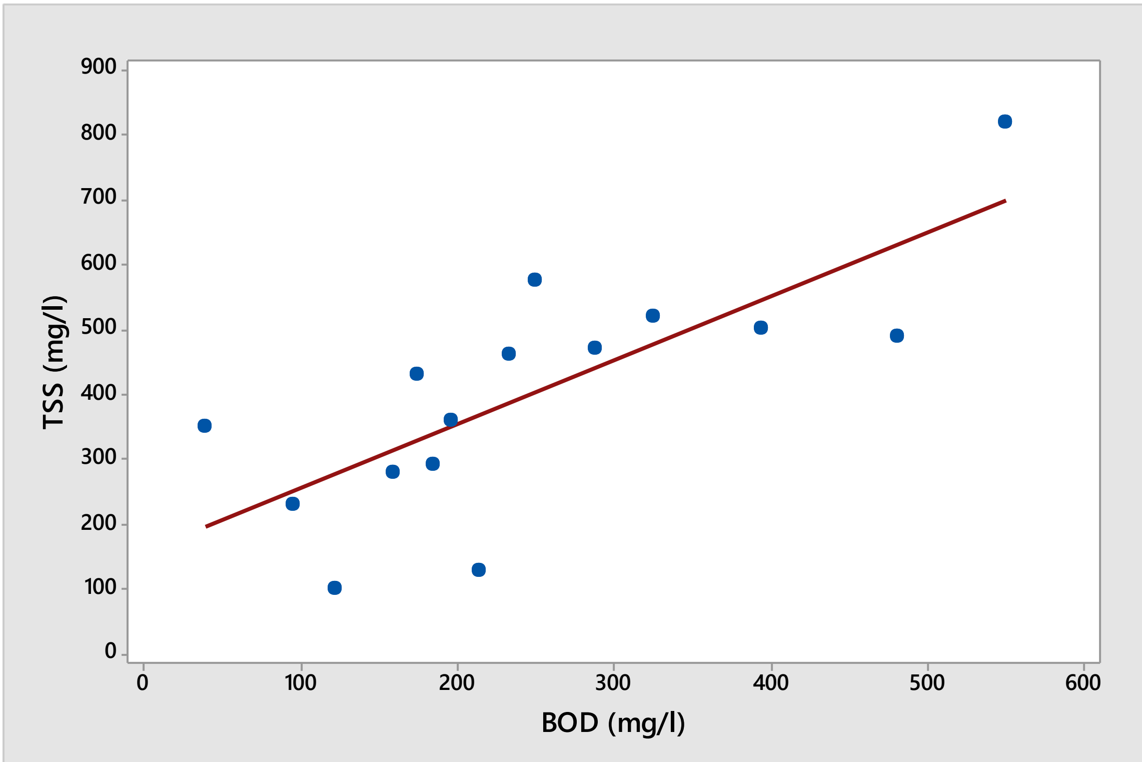

Figure 13: Linear correlation between BOD and TSS at the inlet

The correlation between the variables at the outlet is shown in Table 19, Figure 35 and Figure 36 below. As shown in table, the analysis showed that there was a significant relationship between BOD and only these parameters, i.e. pH, turbidity and nitrate ($p<0.05$). The table also showed that there was no significant relationship between the other parameters and BOD ($p>0.05$).

Table 20: Correlation between BOD and physical-chemical parameters at the outlet

Parameter	**R^2**	**Coefficient**	**P-Value**	**Constant**
pH	50.3	0.710	0.003	0.0148
EC	0.2	0.044	0.877	0.00495
TDS	0.2	0.040	0.889	0.0301
Nitrate	35.6	-0.597	0.019	-0.0716
Nitrite	5.9	0.244	0.382	0.0151
Turbidity	29.8	0.546	0.035	0.280
Ammonia	12.2	0.350	0.201	0.0357
DO	0.1	-0.032	0.911	-0.00193
TSS	6.3	0.252	0.366	0.349
Temperature	0.3	0.052	0.853	0.00185

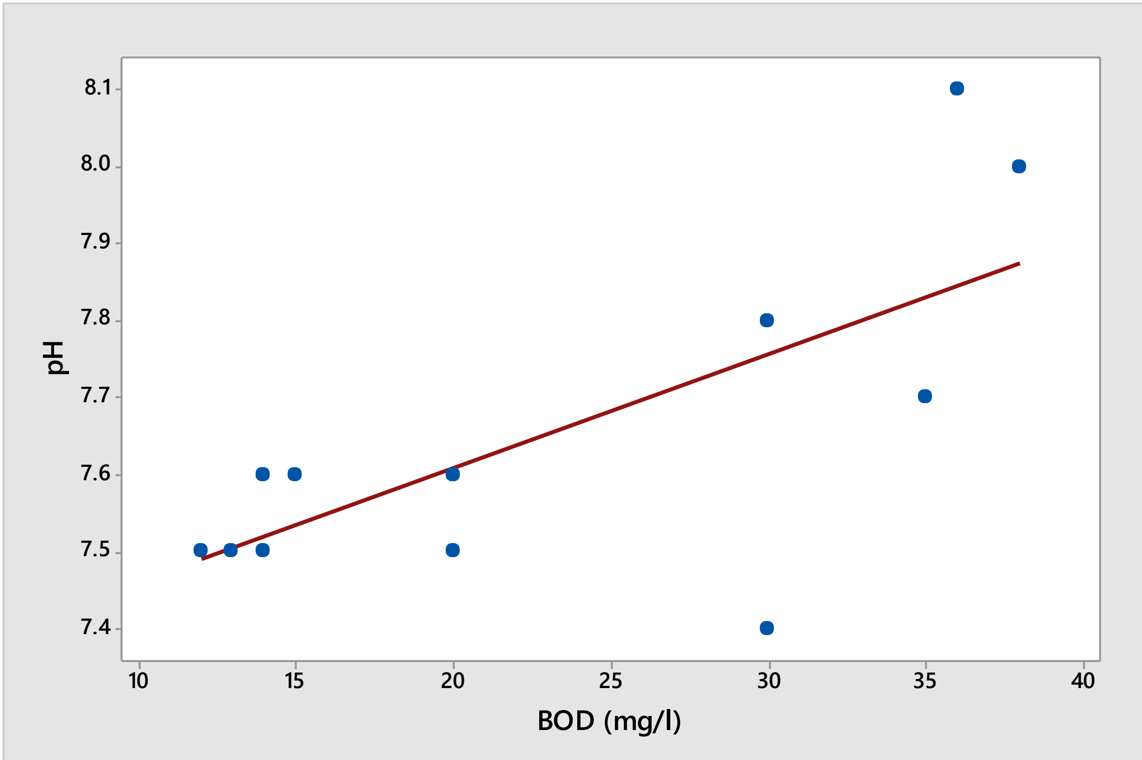

Figure 14: Linear correlation between BOD and pH at the outlet

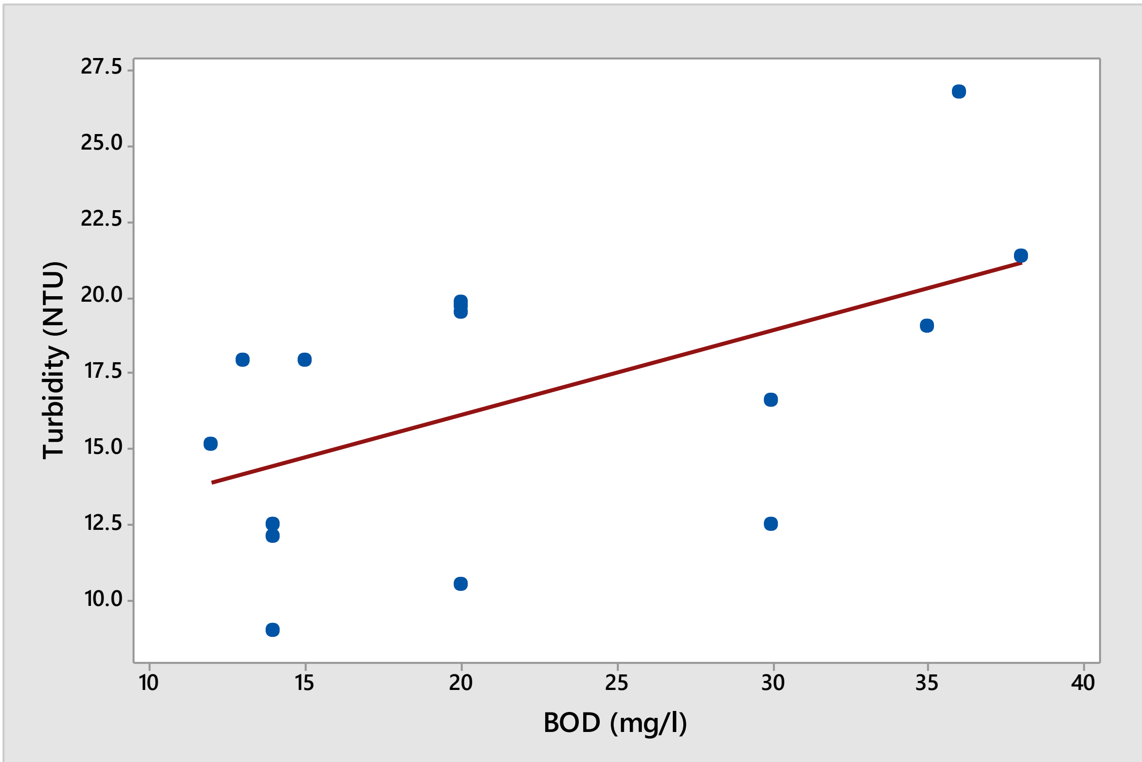

Figure 15: Linear correlation between BOD and turbidity at the outlet

6. WASTE STABILIZATION PONDS DESIGN

6.1. Design of Anaerobic Ponds

Temperature (T) = 20°C

Chosen retention time (t) = 5 days and Depth (D) = 2.5m

$A = Q \times t / D$ ………………………………….………………………Equation 3

$= (2\,295 \times 5) / 2.5$

$= 4\,590\ m^2$

L: B = 2:1

$2B \times B = 4\,590\ m^2$

L = 96 m, B = 48 m

Thus, Area = 96×48

$= 4\,608\ m^2$

Anaerobic achieve 60% BOD reduction:

BOD effluent = $(1- 0.6) \times 848 = 339.2$ mg/l

Check:

$\lambda v = Li \times Q / A \times D$ ……………………………………………………Equation 4

$= (848 \times 2\,295) / (4\,608 \times 2.5)$

$= 168.9\ g/m^3d$

OK since $100 < 168.9 < 400\ g/m^3d$ for odour control

6.2. Design of Facultative Ponds

$L_i = 339.2$ mg/l

Choose: $L_e = 60$ mg/l and $D = 1.5$ m

$A_f = Q (Li – Le) / 18 D (1.05) T\text{-}20$ ………………………………………Equation 5

$= 2\,295 \times (339.2 – 60) / (18 \times 1.5 \times 1)$

$= 23\,732 m^2$

L:B = 2:1

2B: B = 23 732 m^2

Two ponds: L = 156 m, B = 78 m

$A_f = 24\,336$ m^2

$t = A \times D / Q$

$= 24\,336 \times 1.5 / 2\,295$

= 16 d

Checking for volumetric loading: $\lambda v = Li \times Q / A \times D$

$= 339.2 \times 2\,295 / (24\,336 \times 1.5)$

$= 21.33$ g/m^3d

OK since $15 < 21.33 < 30$ g/m^3d

Checking for surface loading: $\lambda s = 20T\text{-} 120$

$= (20 \times 20) – 120$

$= 280$ kg/ha.d

Thus, the design can be considered satisfactory.

Check:

$k_1 = 0.3\ (1.05)^{T-20}$ ……………………………..………………………….Equation 6

$= 0.3\ (1.05)^{(20-20)}$

$= 0.3$

$Le = Li / 1 + k_1 \times tf$ ……………………………………………………….Equation 7

$= 339.2 / (1 + 0.3 \times 16)$

$= 58.5$mg/l

OK since $58.5 < 60$ mg/l

6.3. Design of Maturation Ponds

Objectives: To reduce BOD from 60 mg/l to ≤ 25 mg/l

To have an effluent with FC ≤ 1000 counts/100ml

Choose: $D = 1.5$ and $t = 7d$

$A = Q \times t / D$

$= 2\ 295 \times 7 / 1.5$

$= 10\ 710\ m^2$

L:B = 2:1

$2B \times B = 10\ 710\ m^2$

2 Ponds: L = 104 m, B = 52 m

$Kb\ (T) = 2.6\ (1.19)^{T-20}$ …………………………………………………..Equation 8

$= 2.6\ (1.19)^{(20-20)}$

$= 2.6$

Check FC with two ponds in series

$Ne = Ni / (1+ ka\times ta)\ (1+ kf\times tf)\ (1+ km\times tm)^{2}$ ………………………….Equation 9

$= 4 \times 107 / [1 + 2.6 \times (5)]\ [1 + 2.6(16)]\ [1 + 2.6\ (7)]^{2}$

= 181.9 FC / 100 ml < 1000 FC/100 ml OK

Checking for BOD effluent:

$Le = 2\ Li / 1+ k1 \times tm \times n$ ……………………………………………Equation 10

$= 2\ (60) / (1 + 0.3 \times 7 \times 2)$

= 23 mg/l < 25 mg/l OK

7. DISCUSSIONS

Although the Ongwediva Waste Stabilization Ponds has been recently rehabilitated to increase its capacity to accommodate the whole town, this study questions the investments made. As a result of reeds growing and sludge accumulating in the ponds, the capacity of the ponds has been reduced. This study has indicated the constant overflowing of the wastewater in the ponds due to low capacity. Despite the new constructed anaerobic ponds to increase capacity, the retention period in the ponds are significantly reduced. As a result, the performance of the ponds were also reduced since ponds operate best after a specific number of days. The tall reeds does not allow the wind to blow freely. For this reason, there is poor mixing in the ponds, causing large fluctuations in the effluent quality (BOD, ammonia, nitrate and DO). Apart from the overflowing wastewater in ponds, there is only one inlet and outlet for every pond.

The average faecal coliforms removal efficiency was determined to be 20% which was significantly lower than the removal efficiency obtained in other areas [16], [28], [21]. The removal efficiency of Ongwediva Waste Stabilization Pond system for FC was lower than the removal efficiency of another study conducted in Obuasi, as 40% [28]. The final effluent was 2×10^5counts/100ml which is >>>1000 counts/100ml compared to the recommended guideline from the Namibian standards [27]. This indicate that the final pond effluent cannot be discharged into the natural environment as it poses threats to humans and the ecosystem in general. Waste stabilization ponds usually give high micro-organism removal efficiency. According to [28] effluents with high concentrations of faecal coliforms have high potential of endangering public health. Thus, the Ongwediva Waste Stabilization Ponds might cause public health problems such as cholera [4]. The system has currently showed different problems on performance such as the absence of maturation ponds, which is a third process on WSP system to remove nutrients and reduce fecal coliform [6], [25], [40].

The average variation of measured pH of Ongwediva Waste Stabilization Ponds was increased along the pond series from 6.3 (minimum value occurred in raw wastewater) to 8.1 as a maximum value in the final effluent, so faecal bacterial die very quickly and the photosynthesis activity of the algae becomes less. The pH values in the ponds ranged from 6.3-8.1 which is the essential range for the desirable bacteria [5], [6], and were close to neutrality, which means that most of the sulphide present was in the form of the bisulphide ion (HS^-), which is odorless [40], [6], [25]. The final effluent pH value was 7.65 which was acceptable as it was within the Namibian standard value (6.5-9.5) [26]. According to Kayombo et al [41] , it was reported that it is common to find variations for pH in WSP system. The average temperature was observed to be above 20°C. The wind speed recorded was 15.9 mph and the annual sunshine hours were 1557.7 hours. This conditions are reported to be the good conditions for the WSP functioning [25].

Effluents with high concentrations of nitrates can cause unwanted phytoplankton growth in the receiving bodies [28]. According to Metcalf and Eddy [6], nitrate is typically absent in domestic wastewater. The nitrate and nitrite of the raw sewage was 0.57mg/l and 0.1mg/l respectively. The amount of nitrate and nitrite allowed by the Namibian standards to be discharged is <20mg/l and <3mg/l respectively [26]. The effluent contains 2.33mg/l of nitrate and 0.39mg/l of nitrite, regardless the increment, the ponds fall within the allowable limit. This is similar to a study conducted in Nigeria, where the nitrate level of the final effluent increased from 2.24mg/l to 2.53mg/l. However, other studies carried out showed a reduction (the opposite) in nitrate final effluent concentrations from the raw wastewater concentrations [21], [16], [23].

The ammonia concentration of the raw wastewater was 110.9mg/l and that of the final effluent was 0.74mg/l, giving a reduction efficiency of 99.33%. This reduction efficiency was higher than the reduction efficiency of another study conducted in Ethiopia, as -204.85% [16]. The high ammonia reduction efficiency demonstrates that the Waste Stabilization Ponds at Ongwediva are efficient in reducing ammonia.

When effluents with high concentrations of BOD are discharged into the natural drains, they can cause depletion of natural oxygen resources which may lead to septic conditions. The BOD of the strong raw wastewater was 247.6mg/l and that of the final pond effluent was 22.07 mg/l. The results showed that the BOD level was lower than the recommended guideline value (30 mg/l). The average BOD removal efficiency of the ponds was calculated to be 91.09%. A study by Gloyna [28] indicated that it is uncommon to obtain removal efficiency better than 90% BOD removal in waste stabilization ponds. Therefore the finding of these research suggests that the WSPs system at Ongwediva are very effective in the removal of BOD.

The turbidity of the raw wastewater was 274.7NTU. The removal efficiency of the ponds for turbidity was calculated to be 93.93%, which is higher than the removal efficiency obtained in other areas [16], [22]. Although the WSPs at Ongwediva achieved such a high percentage removal efficiency for turbidity, the effluent value was 16.67 NTU which exceeded the maximum permissible value of 12 NTU [26].

The lowest efficiencies were recorded for EC and TDS with 5.05% and 5.12% respectively. The amount of EC and TDS allowed by the Namibian standards to be discharged is <75mS/m and <500mg/l respectively [26]. The average effluent contains 98.52mS/m of EC which exceed the maximum allowable limit. The average effluent contains 660.27mg/l of TDS which also exceed the permissible level.

The DO concentration of the raw wastewater was 0.71mg/l and that of the final effluent was 1.91mg/l, giving an increment of 37.17%. The mean DO concentration of the raw wastewater of Ongwediva Waste Stabilization Ponds were higher than values obtained in other areas [16]. The final effluent value for DO was less than the allowable limit, <75 [26]. The TSS concentration of the raw sewage was 400.2mg/l and that of the final effluent was 21.73mg/l, giving a removal efficiency of 94.57%. The removal efficiency of OWSP system for TSS was higher than the removal efficiency obtained in other areas [14], [15] [13], [21].

Lastly, the study showed that there is a correlation at confidence interval of 95% between BOD and turbidity & TSS at the inlet. Whereas, there is no correlation between BOD and all the other wastewater parameters. Also, a correlation exists at the outlet between the effluent BOD and parameters such as pH, nitrate and turbidity. However, there is no relationship between effluent BOD and other wastewater parameters.

8. CONCLUSIONS

The Waste Stabilization Ponds at Ongwediva was assessed to achieve high removal efficiencies of raw wastewater contaminants. The ponds demonstrated high reduction efficiencies in the physicochemical contaminants, however low reduction in microbiological contaminants levels of the effluents. The high BOD (91.09%), turbidity (93.93%) and TSS (94.57%) removal efficiencies demonstrated that the WSPs at Ongwediva are efficient in reducing BOD, turbidity and TSS. The present study also indicates that wastewater plant is useful to enhance DO and reduction of BOD, but there is no reasonable change in FC after treatment.

The wastewater treatment system is ineffective and does not comply with all standard wastewater management practices (EC, TDS, FC & turbidity). Significant pollution of the environment was indicated for turbidity, EC, and TDS. The high levels of FC and TDS obtained in this study may in addition be affecting the health of the ecosystem. Although the concentrations of FC did not conform to a definite pattern in the influent and effluent, the high FC level and high levels of some parameters in the evaporation ponds give cause for concern because the health of the ecosystem are at state and consequently the health of people's health also.

One of the most important problem of the OWSPs is the very low overall removal efficiencies for EC and TDS, ranging from 5.05% to 5.12%. The OWSPs do not have maturation ponds which are the final stage of WSP and where the highest pathogens are removed. There are limited entrances and exits for facultative ponds and they are poorly maintained. The ponds are filled with sludge and tall reeds reducing the designed capacity of the ponds. The sewage treatment oxidation pond is still in a chaotic state and seems to do little in the way of treatment. It therefore needs to be upgraded to improve its treatment performance since the oxidation pond in its present state is obviously not efficient enough.

9. RECOMMENDATIONS

The upgrading of the Ongwediva Waste Stabilization Ponds requires a new design to improve the treated effluent in terms of FC reduction. Therefore, for a new design, there can be two parallel anaerobic ponds, followed by two parallel facultative ponds and finally two parallel maturation ponds to achieve a BOD effluent below 25mg/l and FC < 1000 counts/100ml as per the new design under Chapter 6.

In order to improve the performance of the Ongwediva Waste Stabilization Ponds (OWSPs), the OWSPs needs upgrading for better removal of wastewater parameters. This can be done by:

i. Modifying the design of the facultative ponds by adding more additional points for entrance of wastewater to the ponds to make complete mix in the ponds.
ii. Frequently desludging the present ponds where necessary.
iii. Additional of a third stage (maturation) especially for nutrients and pathogen removal.
iv. Frequently maintaining the present ponds to make sure they are performing to the required designed level.

If the wastewater is well treated by the OWSPs, there is an opportunity of wastewater reuse especially to the uses that do not need drinking water quality, like gardening, irrigation agriculture, spraying gravel roads for dust control and for compaction in road construction. Most importantly, effective treated effluents can efficiently contribute to environmental and public health protection. Also, if WSPs are correctly designed, properly operated and well maintained, the ponds provide a useful method of wastewater treatment and disposal for growing communities such as Ongwediva, and therefore should be regarded as a method of choice for treating wastewater in Namibia

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APPENDICES

Appendix 1: Pictures

Figure 16: Entrance of Ongwediva facultative pond

Figure 17: Ongwediva pond filled with sludge and overgrown reeds

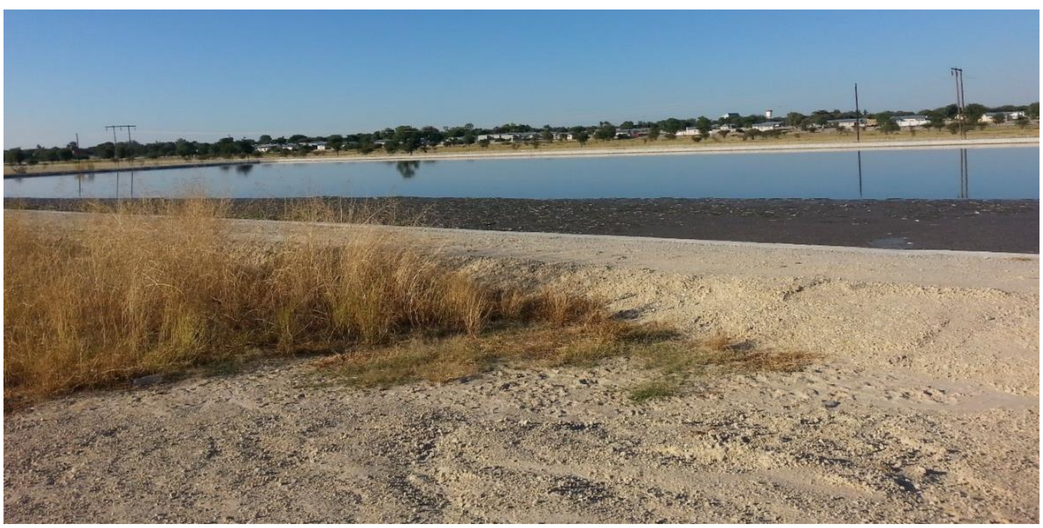


Figure 18: Ongwediva Evaporation pond

Figure 19: Exit of an Ongwediva facultative pond

Figure 20: An unskilled laborer from OTC removing scum from the inlet structure

Figure 21: Inlet structure of the Ongwediva pond system

Figure 22: Scum that has accumulated at the inlet structure of Ongwediva WSP

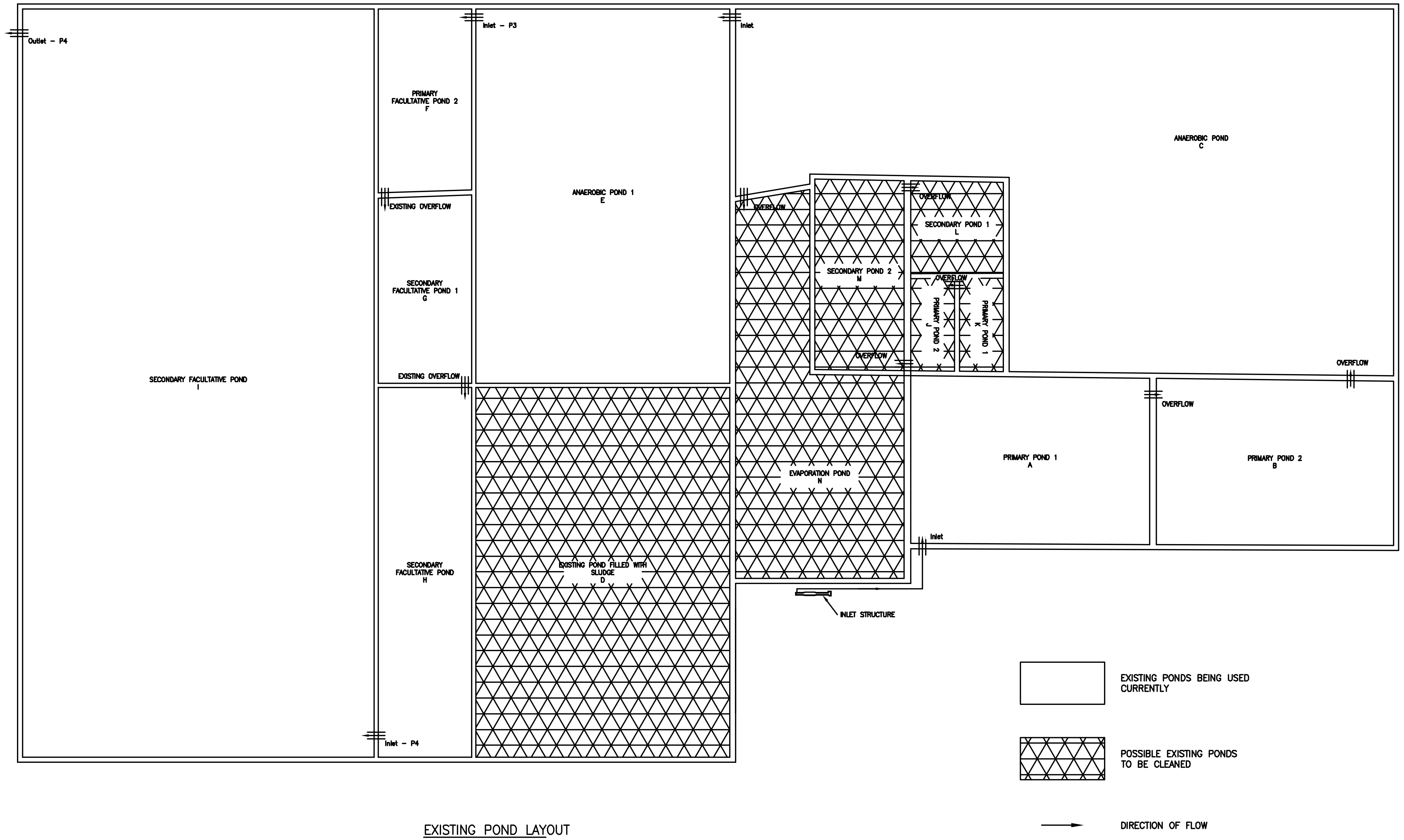
Figure 23: Ongwediva Ponds overflowing

Figure 24: Trucks hired to pump wastewater from households' septic tanks into ponds

Figure 25: Exit from an Ongwediva anaerobic pond

Figure 26: Incubator and refrigerator used for storing samples in the laboratory

Appendix 2: Layout of the Existing Ongwediva Waste Stabilization Ponds showing wastewater flow direction.



EXISTING POND LAYOUT

Scale: 1:1500