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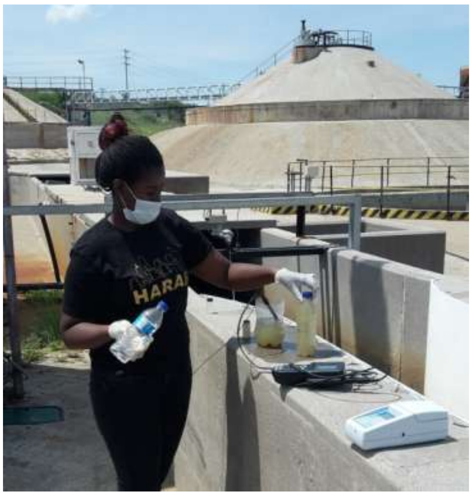

ASSESSMENT OF THE PERFORMANCE OF WASTEWATER TREATMENT PLANTS: A CASE STUDY OF GAMMAMS AND OTJOMUISE WASTEWATER TREATMENT PLANTS IN WINDHOEK, NAMIBIA

By

CHAZE SIBEYA

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In collaboration with

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A thesis submitted in partial fulfillment of the requirements of the degree of Master of Science in Integrated Water Resources Management of the University of Zimbabwe

JUNE 2016

DECLARATION

I**, Chaze Sibeya,** declare that this research report is my own work. It is being submitted for the degree of Master of Science in Integrated Water Resources Management (IWRM) of the University of Zimbabwe. It has not been submitted before, for examination of any degree in any other University.

Date: ________________________

Signature: ____________________

DISCLAIMER

This document describes work undertaken as part of the programme of study at the University of Zimbabwe, Department of Civil Engineering. All views and opinions expressed therein remain the sole responsibility of the author, and not necessarily represent those of the University.

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DEDICATION

Dedicated to the Lord Almighty and to my mom Mrs. Florencia Sibeya, for her continual support and motivation.

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LIST OF ABBREVIATIONS, ACRONYMS AND TERMS

BOD...	Biological Oxygen Demand
CML..	Centre of Environmental Science of Leiden University (Netherlands)
COD..	Chemical Oxygen Demand
CoW..	City of Windhoek
EC..	Electrical Conductivity
EP..	Eutrophication Potential
GaBi..	Ganzheitlichen Bilanzierung (German for “holistic balancing”)
GRN..	Government of the Republic of Namibia
GWP..	Global Water Partnership
GWWTP...	Gammams Wastewater Treatment Plant
IPCC..	Intergovernmental Panel on Climate Change
ISO..	International Organization for Standardization
LCIA...	Life Cycle Impact Assessment
LCA...	Life Cycle Assessment
ML/d..	Mega-litres per day
mS/l	Milli-Siemens per litre
OWWTP...	Otjomuise Wastewater Treatment Plant
PSTs..	Primary Sedimentation Tank
SST..	Secondary Settling Tank
TE..	Treatment Efficiency
TDS...	Total Dissolves Solids
TSS..	Total Suspended Solids
WHO..	World Health Organization
WWTP...	Wastewater Treatment Plant

ABSTRACT

Wastewater Treatment Plants (WWTPs), if not operated properly, may cause undesirable effects such as eutrophication. Gammams and Otjomuise are two WWTPs, treating domestic wastewater in Windhoek, the capital city of Namibia. Both plants are alleged to cause negative impacts on the environment, through nutrients in their effluent, released into the environment. However, very few scientific studies have been done on the treatment plants to estimate their contribution to eutrophication. Therefore, the objectives of this study were to assess the performance of the two WWTPs, by analysing historical and primary water quality data on the plants' performance. The variations of water quality and compliance with effluent standards were analysed using influent and effluent time series. The treatment efficiencies of the two plants were determined. The contribution to eutrophication of GWWTP was also estimated using a Life Cycle Assessment (LCA) Approach, using the Centre of Environmental Science of Leiden University (CML) method in the GaBi model. GWWTP complied with the Namibian water quality effluent standards of 2013, for total suspended solids, ammonia, Total Kjeldahl Nitrogen, Biological Oxygen Demand and Chemical Oxygen Demand, while for the same parameters; Otjomuise's effluent did not comply. Temperature, pH, and orthophosphates effluent compliance were similar for both treatment plants. There were no significant monthly average variation trends in influent and effluent concentrations between the two treatment plants. Treatment efficiencies for TKN were 94% and 80%, Orthophosphates had 37% and 87% for Gammams and Otjomuise respectively. LCA Approach had the following results, for 2004-14 data, input/influent was 15.9kg while output/effluent was 0.960kg of phosphate loading per unit volume. For 2016 data, input/influent was 18.3kg, while output/ effluent was 3.6kg of phosphate loading per unit volume. The GaBi identified Orthophosphate as the parameter that significantly contributed to eutrophication. Similarly, overall results in assessing the performance of the wastewater treatment plants indicated that orthophosphates were the parameter that significantly contributed to eutrophication. Apart from recommending that the two wastewater treatment plants constantly upgrade the plants regularly, wastewater treatment should transfer enough phosphates to sludge to avoid eutrophication of receiving waters and communities should be sensitized on the use of adding phosphate containing detergents in washing.

Key Words: Effluent Standards, Eutrophication, Life Cycle Assessment, Treatment efficiency Wastewater.

CHAPTER 1 : INTRODUCTION

1.1 Background

Wastewater treatment plants (WWTPs) are constructed, mainly with the objective of protecting societal health and the environment (Hophmayer-Tokich, 2010). Wastewater treatment systems are, designed to minimize environmental impacts of discharging untreated wastewater in natural aquatic systems (Machado *et al.*, 2007). In addition, effluent from wastewater treatment plants can be further treated to potable water standards (Safari *et al.* 2013). However, converse to their main purpose, in recent years it has been established that some WWTPs damaging the environment, posing a threat to society through the disposal of nutrient rich effluent and sludge into water bodies (Buyukkamaci, 2013). Effluent rich in nutrients especially those in nitrogen and phosphorus leads to eutrophication, which in turn exacerbate the growth of aquatic plant life such as algae and aquatic macrophytes (water weeds) *(Jones-Lee et al.*, 2005). While natural eutrophication takes place over geological time, human activities increase nutrient inputs to water bodies, which rapidly accelerate aquatic plant growth, causing cultural eutrophication (Rabalais, 2002).

Windhoek is the capital city of Namibia, a country in Southern Africa. The City of Windhoek is a dry area far from freshwater sources, and wastewater treatment was adopted as a water demand management strategy, in that is used to diversify water supply sources (Bahri, 2012). WWTPs are of outmost important in Windhoek, as treated effluent is further processed to potable drinking standards and feeds into the water supply system (Hege, 2002). Thus treated effluent contributes about 26% towards the city's water supply, while 66% is from dams and 8% from groundwater sources (Lahnsteiner and Lempert, 2007). When effluent is heavily polluted, the cost is incurred on energy and chemicals used to treat water, which might result in higher water tariffs towards the residents of the city. Treatment plants also provide treated effluent and dry sludge to municipal parks and resident's gardens (Vigneswaran and Sundaravadivel, 2009). Nutrient rich effluents lead to eutrophication in receiving water bodies, ultimately resulting in odours and fish kills

A study done in Namibia in 2012 highlighted that Gammams wastewater treatment plant's effluent had negative impacts towards the anatomy of fish species in the Goreangab Dam where the effluent is released (Kalwenya, 2012). Effluent from the Gammams treatment plant is also supposedly the cause of eutrophication in the dam (Daniel *et al.,* 2014).

The city of Windhoek has three main wastewater treatment plants, namely Gammams, Otjomuise and Ujams wastewater treatment plants. Gammams wastewater treatment plant treats about 80% of the city domestic effluent, while Otjomuise wastewater treats the remaining 20%. Industrial wastewater is treated at Ujams wastewater treatment plant (Pisani, 2006). Purposely for this study, the focus will be on Gammams and Otjomuise wastewater treatment plants, both of which exclusively treat domestic wastewater.

Several methods can be used when evaluating the performance of wastewater treatment plants. Specifically for this study evaluating water compliance to water quality effluent standards, treatment efficiency and using a life cycle assessment approach were the methods used in evaluating the performance of Gammams and Otjomuise wastewater treatment plants. Effluent standards are restrictions imposed by an environmentally related government on quantities, rates, and concentrations of materials in wastewater discharge (World Bank, 2016). Treatment efficiency refers to the effectiveness of the WWTP in removing pollutants and nutrient from the wastewater (Khanijo, 2002). A Life Cycle Assessment is an assemblage and evaluation of outputs and probable environmental impacts of a product or system throughout its life cycle (Li *et al*., 2013).

1.2 Problem statement

Gammams wastewater treatment plant is suspected to have negative impacts on the environment, through the concentration of organic nutrients in effluent released into the environment (Kalwenya, 2012). Limited scientific studies have been conducted Otjomuise wastewater treatment plant, and it appears literature may not exist on quantifying eutrophication contribution of the two wastewater treatment plants

(Cashman *et al.* 2014). Thus, this study addressed the knowledge gap on the two treatment plants, by looking at the treatment efficiencies of Gammams and Otjomuise wastewater treatment plants, and estimating Gammams wastewater treatment plant's contribution to eutrophication.

1.3 Justification

Results of the study would feed into the treatment plant's information database, for future improvement of the treatment systems. This information could also be incorporated into the city's future plans when constructing more wastewater treatment plants, so as to mitigate the release of nutrient-rich effluents into the environment. In addition, there is a lot of bacterial activity going on in eutrophic water bodies, and these can cause diseases to people that come in contact with the water.

Particularly in a dry area like Windhoek, where effluent is further treated to potable standards, treating water from eutrophic water bodies can be costly, Due to the amount of chemicals needed to purify the water. .Algae also tends to block pipes and pumps, causing damage to equipment. In addition, understanding and protecting water resources is in line with the Namibian National Development Plans, whereby the mandate is to ensure that water sources together with its fisheries are protected from pollution and exploitation, and used for the development of the country (NPC, 2016). Eutrophication's negative impacts on society and the environment, are amongst the components addressed in the world discourse of the recently phased out Millennium Development Goals (MDGs) and the newly introduced Sustainable Development Goals (SDGs) (Sachs, 2012).

1.4 Objectives of the study

1.4.1 Overall Objective

To assess the treatment efficiencies of Gammams and Otjomuise wastewater treatment plants in Windhoek, Namibia, and to quantify Gammam's contribution towards eutrophication over the last 10 years (2004-16) using a Life Cycle Assessment approach.

1.4.2 Specific objectives

i. To analyze historical and primary water quality variations for Gammams and Otjomuise wastewater treatment plants' effluent from 2004-16.

ii. To compare the treatment efficiencies of Gammams and Otjomuise wastewater treatment plants from 2004-16.

iii. To estimate the contribution to eutrophication from 2004-16, of Gammams wastewater treatment plant towards receiving waters using a Life Cycle Assessment (LCA) approach in the GaBi software.

CHAPTER 2 : LITERATURE REVIEW

2.1 Gammams and Otjomuise wastewater treatment plants

The objective of wastewater treatment systems is moving beyond the protection of human health and aquatic systems, to the enabling recycling of nutrients and the minimisation of losses of scarce resources, by reducing the use of energy and water during treatment(Lundie *et al.,* 2004).Gammams and Otjomuise wastewater treatment plants are Biological Nutrient Removal (BNR) plants that treat influent wastewater through an activated sludge process with nitrogen and phosphorus removal (Lahnsteiner and Lempert, 2005). Sewage flowing into the plants is predominantly of domestic origin, with no formal industrial effluent into the treatment systems that discharges into the treatment plants. As shown in Figure 2-3 and Figure 2-4, the two treatment plants have similar processes for preliminary, primary, secondary and tertiary treatment, with slight differences discussed as follows;

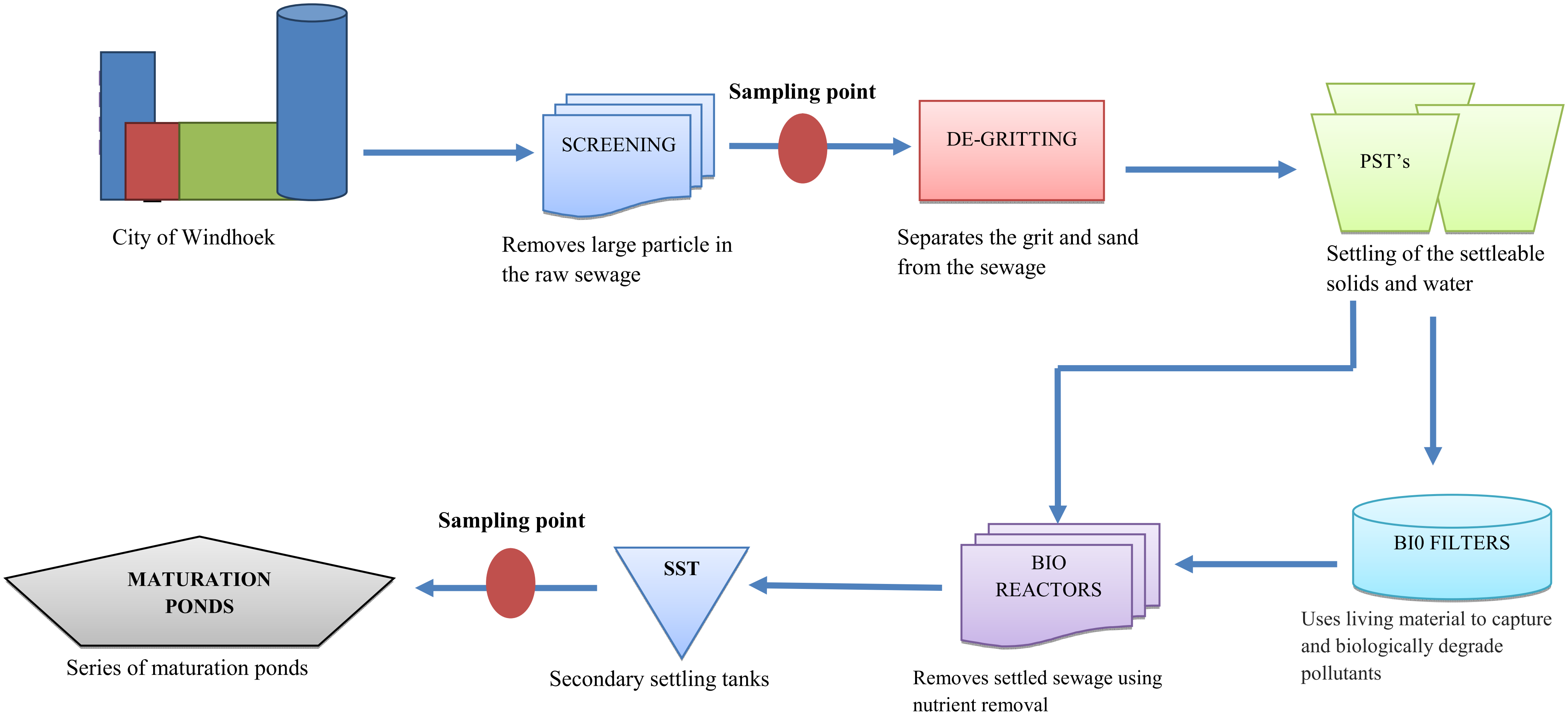

Figure 2-1: Schematic Diagramme of Gammams Wastewater Treatment Plant

Source: (City of Windhoek, 2015)

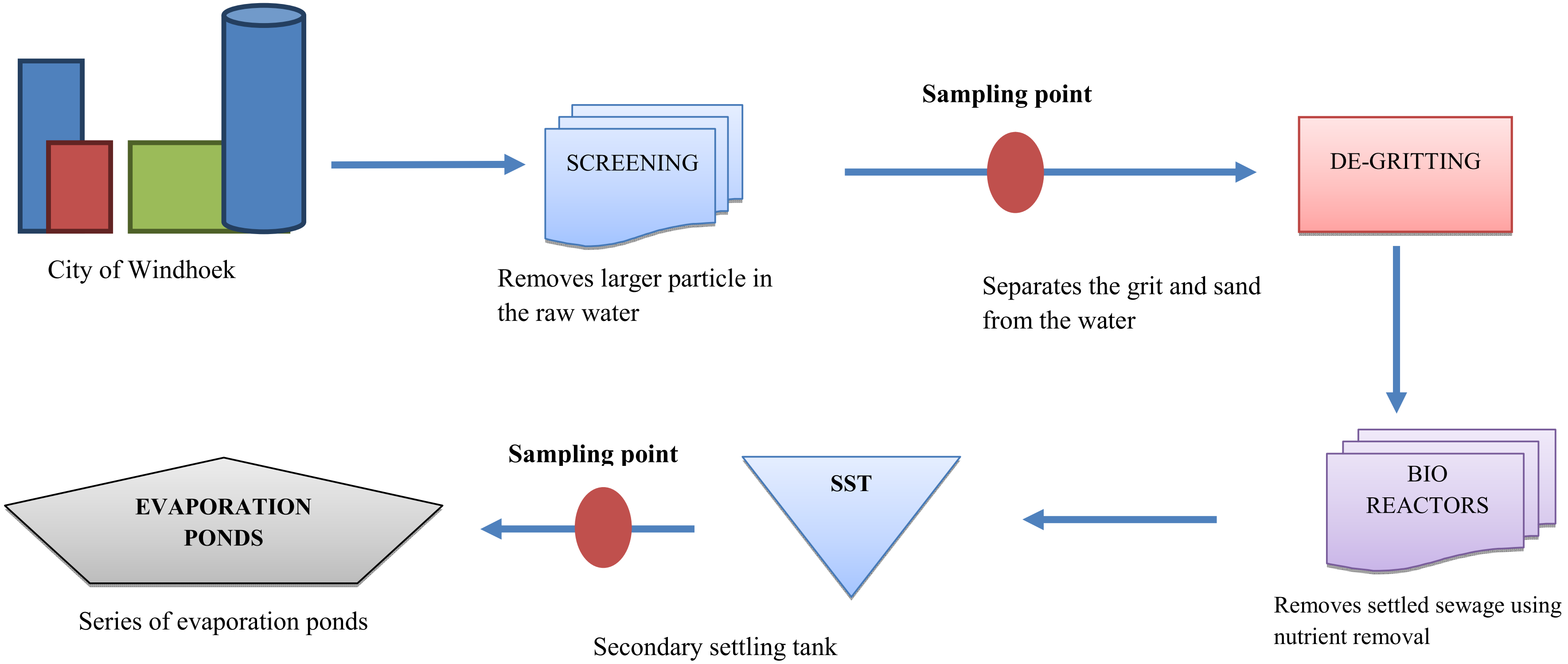

Figure 2-2: Schematic diagramme of Otjomuise Wastewater treatment Plant

Source: (City of Windhoek, 2015)

2.1.1 Preliminary treatment

Source: (CoW, 2015)

The description for the treatment process will begin at the stage where raw sewage enters the treatment plant. For both treatment plants, raw wastewater flows by gravity to the inlet works. Screening is the first process; Wastewater enters a screen/bar rack that removes large floating material such as sticks, and rags, (Figure 2-1). From screening, wastewater flows to the de-gritting chamber, also known as grit removal. This is the in wastewater treatment, where heavier inorganic material such as sand and small stones are separated and removed from the water.

Figure 2-3: Screen at Gammams wastewater treatment plant

Source: (CoW, 2015)

2.1.2 Primary treatment

Primary treatment is a process that removes about 50 percent of organic matter in sewage (World Bank, 2016). At Gammams wastewater treatment plant (GWWTP), grit removal is followed by primary settling tanks (PSTs). Here suspended solids are settled and removed from wastewater. Primary waste sludge is extracted from the bottom of the PSTs and treated separately in an anaerobic digester, before being discharged to drying beds for further treatment. It must be noted that at Otjomuise wastewater treatment plant (OWWTP), influent from grit removal flows directly towards the secondary treatment phase because the plant does not have any PSTs.

2.1.3 Secondary treatment

Secondary treatment is a biological process that removes at least 85 percent or more of the organic matter in sewage (World Bank, 2016). Secondary treatment is the treatment phase where bacteria are used to further purify the effluent by breaking down the organic matter simple compounds such as carbon dioxide and water. Half of the wastewater flows from the PSTs flows into the bioreactors (also known as aeration basins), where the air is mixed with sludge for activation.

At GWWTP half from PSTs flows into the biofilters, which consists of a basin or tower filled with support media such as stones, plastic shapes, or wooden slats. Wastewater is applied intermittently, or sometimes continuously, over the media. Microorganisms become attached to the media and form a biological layer or fixed film. Organic matter in the wastewater diffuses into the film, where it is metabolized. Oxygen is normally supplied to the film by the natural flow of air either up or down through the media, depending on the relative temperatures of the wastewater and ambient air. Forced air can also be supplied by blowers but this is rarely necessary. The thickness of the bio-film increases as new organisms grow. Periodically, portions of the film 'slough off the media. Activated, sludge provides bacteria that consumes the "food" provided by the wastewater flowing into the aeration basin (shown in figure 2-2), thus purifying it (Adonadaga, 2014). This process produces a clear effluent which is low in suspended solids and organic matter. This effluent is then settled in the secondary settling tank for the remaining suspended solids to settle, releasing clear water discharge into the environment.

Wastewater aeration is the process of adding air into wastewater to allow aerobic bio-degradation of the pollutant components. Aeration is part of the stage known as the secondary treatment process. Aeration in an activated sludge process is based on pumping air into a tank, which promotes the microbial growth in the wastewater. The microbes feed on the organic material, forming flocs which can easily settle out. After settling in a separate settling tank, bacteria forming the "activated sludge" flocs are continually recirculated back to the aeration basin to increase the rate of decomposition (Figure 2-4).

2.1.4 Tertiary treatment

Wastewater from the secondary settling tank at GWWTP is further polished in maturation ponds with a retention time of approximately three days to decrease the pathogens. Water from the ponds serves as raw water for the new Goreangab Wastewater Reclamation Plant (NGWRP) and old Goreangab Wastewater Reclamation Plant (OGWRP), the water reclamation plants purifies treated effluent to drinking standards. Water that is not channelled towards the two plants is fed into the river downstream of Goreangab Dam.

Wastewater from secondary settling tank at OWWTP is further treated in two gravity thickeners. The thickening process uses slowly rotating rake arms to separate solid particulate. A liquid feed with suspended solids is fed into a tank. As the particles settle, angled rake arms move the concentrated slurry toward the center of the tank, where it is removed. Clear liquid overflows the top of the tank and is collected in a trough. It is expected that phosphate content from the thickener is too high to be directly discharged into the natural water course. Thus, effluent is pumped into evaporation ponds, where there is significant removal because it is taken up by macrophytes (water plants) before being discharged into the Swakoppoort River.

GWWTP is required to produce an effluent which should confirm to the treated effluent requirements that eventually feeds into the reclamation plant; this makes the treatment plant an important link in the water cycle for the City of Windhoek (CoW). The Goreangab water reclamation plant treats domestic wastewater to potable standards (Menge *et al.,* 2009). Although the City of Windhoek owns the reclamation plant, the plant is operated by Windhoek Goreangab Operating Company (WINGOC) a private company (NGWRP, 2010).

The reclamation plant is designed to purify 21, 000 m^3 of water per day, although it is primarily only purifying 16, 000 m^3 of water per day· One-third of the reclaimed water is combined with surface water from dams (Menge, 2006).

The main features of both plants are shown in Figure 2-1

Table 2-1: Main features of GWWTP and OWWTP wastewater treatment plants

Plant characteristics	**GWWTP**	**OWWTP**
Sources of Wastewater	Domestic, storm water	Domestic, storm water
Water supply of the area	Established suburbs, with high-income earners	New and not so established suburbs with low-income earners
Treatment process	Activated sludge with biological nutrient removal	Activated sludge with biological nutrient removal
Design Capacity	25 ML/d	15 ML/d
Actual primary treatment	40 ML/d	8 ML/d
Number of staff	4 plant operators	2 Plant operators
Effluent users	Windhoek reclamation plant	Irrigation

Similarities and differences of Gammams and Otjomuise wastewater treatment plants are shown in Table 2-1 above. Despite the slight differences between the two treatment plants, the same set of physical and chemical water quality parameters were chosen for both treatment plants for comparison.

2.2 Physical and chemical characteristics of water

Physical and chemical water quality parameters that are of importance include temperature, turbidity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Electrical Conductivity (EC), pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrogen and Phosphates.

2.2.1 Temperature

Temperature is a measure of the average kinetic energy of water molecules. It is one of the most important water quality parameters, as it affects the chemistry and functions of aquatic organisms (Starrett, 2004). There are three temperature ranges over which microorganisms survive namely, psychrophilic (r around 15 °C), mesophilic (temperatures around 30 °C), and thermophilic (temperatures around 53 °C), (Eckenfelder and Wesley, 2000). The mesophilic range is known to be the range that most aerobic biological treatment processes operate because its ideal for microorganisms' activity (Abdelgadir *et al*. 2014). Temperature is known to affect metabolic activities of the microbial population, as well as influence activated sludge process and the sludge’s settling characteristics. Generally, high temperatures, increase biochemical reaction rates of substrate transfer processes.

On the other hand, in the mixed liquor oxygen solubility decreases as temperature increases, resulting in reduced biodegradation conditions for aerobic microbes for example. Saraswathi and Saseetharan (2010) stated that a rise in temperature sustains microbial activity which results in increased flocculation of activated sludge in the influent. In addition, the temperature has an effect on the amount of oxygen that can be dissolved in the water, photosynthetic rate by aquatic autotrophs, the organisms metabolic rate,organisms, sensitivity to toxic wastes, parasites and diseases, and timing of reproduction (Starrett, 2004).

2.2.2 Turbidity

Turbidity is the reduction of clarity in water due to the presence of suspended particles. It is measured by the amount of light reflected by suspended or colloidal particles (Oram, 2014). Suspended particles such as silt and clay contribute to turbidity, and this relates turbidity to suspended solids, in addition, turbidity includes organic matter such as plankton and other living microorganisms (Omar and MatJafri, 2009). Treatment plants and surface runoff contribute to the turbidity of receiving waters. As sewage becomes stronger, turbidity also increases making causing problems in wastewater treatment (Mandal, 2014) .

2.2.3 Total Suspended Solids

Total Suspended Solids (TSS) refers to all solids in a water sample that cannot pass through a 45µm filter (Ebeling *et. al,* 2003). This ranges from dead plant and animal matter to non-biodegradable waste such as metals. High concentrations of suspended solids compromise stream health affecting aquatic life. TSS is capable of reducing the amount of light passing through the water, thus reducing the light reaching the submerged vegetation. This slows down photosynthetic activity, which results in less dissolved oxygen being released into the water by the submerged plants. Low dissolved oxygen in water leads to fish kills.

Other effects of suspended solids include reducing clarity in the water (affecting the ability of fish species to see and catch food) and clogging of fish gills, causing morbidity and mortality. To prevent the effects of TSS , coagulation and flocculation processes with agents such as alum or ferric chloride are standard techniques in the water industry for removal of suspended solids during water treatment/ for wastewater treatment (Ebeling *et. al,* 2003).

2.2.4 Total Dissolved Solids

Total Dissolved Solids (TDS) refers to all substances dissolved in water, which includes, organic and suspended particles that are capable of passing through a 45 µm filter (Boman *et al*. 2012). TDS in laboratories is measured in milligrams per litre (mg/l). High TDS concentrations in general, indicate hard water and may result in scale build-up in pipes, reduced efficiency of water filters, and aesthetic problems. Water containing high TDS levels may point to elevated levels of ions such as nitrates, which pose a health concern. Excessive amounts of TDS also make water unsuitable for drinking, should it end up in river streams (Raddad and Jordan, 2005).

2.2.5 Electrical Conductivity

Electrical Conductivity (EC), is a measure of the ability of a water sample to transmit an electric primary (Ali *et al.,* 2012). EC is a rapid and reasonably precise determination that measures the total concentration of ionic solutes. Values are expressed for the standard temperature of 25 °C (Uwidia and Ukulu, 2012). EC measurement in a solution is an indication of the presence of organic and inorganic materials in that particular solution and direct relationships of the extent of impurities present in a specified solution can be determined by establishing the EC of the solution. Conductivity is a parameter used to monitor processes in the wastewater treatment that result in changes in total salt concentration and therefore in changes of conductivity (Levlin, 2010). Processes in many wastewater treatment plants that results in changes in conductivity include biological phosphorus and nitrogen removal.

2.2.1 Dissolved Oxygen

Dissolved Oxygen (DO) refers to the level of free, non-compound oxygen present in water or other liquids (Oram, 2014). In wastewater treatment plants, DO is important as it supports biological activity, In other words, enough oxygen is required for the microorganisms to breakdown the waste(Pigue, 2013). Continuous and reliable DO monitoring can improve plant efficiency (thus lowering operating costs) as well as decrease the risk of unwanted odour events. DO is an important parameter in assessing water quality because of its influence on sustains life underwater (Davis, 1999). Many forms of life including fish, invertebrates, bacteria and plants require DO as these organisms use oxygen in respiration, similar to organisms on land.

2.2.2 pH

pH refers to how acidic or alkaline a solution is; it is a measure of hydrogen ion activity in a solution. During the treatment process, pH allows dissolved waste to be separated from water, thus highlighting the importance of adding acidic and alkali chemicals to wastewater. Water contains positively charged hydrogen ions and a negatively charged hydroxide ions, in acidic (pH<7) water, there is a high concentration of positive hydrogen ions while in neutral water, the concentration of hydrogen and hydroxide ions is balanced, Basic water(pH>7), contains an excess of negative hydroxide ions (Brand, 2013).

Different stages of the wastewater treatment require different pH concentrations. It is, therefore, necessary to adjust the pH in the treatment process to make the wastewater neutral. This is particularly important when biological treatment, as the microbes used in biological treatment require a pH in the range of 6-8 and may be killed by highly acidic or alkali wastewater (Meenakshipriya and Saravanan, 2008)Water pH can be used to kill off bacteria in wastewater, since the most common organic matter and bacteria are best suited to a neutral or slightly basic environment. At the end of a wastewater treatment cycle, pH must be raised back to neutral, as highly acidic water may continue to damage any living cell it comes in contact with.

2.2.3 Biological Oxygen Demand

According to Lee and Coyne (2012), Biological Oxygen Demand (BOD) can be defined as the quantity of Dissolved Oxygen (DO) required by microorganisms for the oxidation (breaking down) of organic compounds in wastewater to carbon dioxide and water. The BOD test, also known as "BOD_5" as it is based on the accurate measure of DO at the beginning and end of a five-day period, during which the sample is kept in the dark and is incubated at 20°C (Kiepper, 2010). BOD_5 provides information on the extent of water pollution with organic matter and is a key indicator of water pollution. High BOD is an indicator of the heavy load of organic matter and reduces the abundant supply of dissolved oxygen in the water (Raddad and Jordan, 2005).

2.2.4 Chemical Oxygen Demand

Chemical Oxygen Demand (COD) refers to the total amount of oxygen required for the complete oxidation of organic pollutants into carbon dioxide and water (Raddad and Jordan, 2005). COD is a measure of potassium permanganate consumed, calculated in terms of oxygen equivalent. Compared to BOD, COD is the popular alternative test to the establishment of the concentration of organic matter in wastewater samples. The COD test has an advantage in that it only takes a few hours to complete as compared to the BOD test which takes 5 days. COD can also be used to test wastewater which is too toxic for the BOD test, because if water is too toxic microorganisms are not expected to survive. The COD test should be considered an independent measure of the organic matter in a wastewater sample rather than a substitute for the BOD test because the test utilizes a specific chemical oxidation, thus the result has no definite relationship to the Biochemical Oxygen Demand (BOD) of the waste (Kiepper, 2010).

2.2.5 Nitrogen

In aquatic environments, nitrogen exists in a number of different forms. The major forms which are of importance to wastewater treatment include Total Nitrogen (TN), Total Kjeldahl Nitrogen (TKN), Ammonia (NH_3), organic nitrogen, Nitrates (NO_3^-) and Nitrites (NO_2^-). For the purpose of this study, the focus was on total nitrogen and Total Kjeldahl Nitrogen. While TKN of a water sample, is obtained by adding the concentrations of NH_4^+ and organic nitrogen (TKN = NH_4^+ and Organic nitrogen). The TN of a water sample is obtained by adding the concentrations of TKN, NO_3^-, and NO_2^-

($TN = TKN + NO_3^- + NO_2^-$). A municipal wastewater treatment plant with an effluent containing more than 5mg/l TKN is not fully nitrifying, meaning converting all the ammonia to nitrites and nitrates (WPC, 2015).

Nitrogen can be removed from influent wastewater through the biochemical processes of ammonification changes complex nitrogen compounds to ammonia nitrification (oxidation of ammonia and organic nitrogen to nitrite then to nitrate within an aerobic zone) and denitrification (reduction of nitrate to gaseous nitrogen in an anoxic environment) (Carey and Migliaccio, 2009). Nitrogen, together with phosphorus, contributes to eutrophication of water bodies (Raddad and Jordan, 2005).

2.2.6 Phosphorus

Phosphorus is essential for aquatic plant and algae growth, and most waters bodies in nature have sufficient phosphorus to support aquatic life. Thus, excess phosphorus concentrations in water bodies accelerate plant and algae growth and result in water quality problems. Phosphorus is an element which, while it is essential to life as a key limiting nutrient, together with nitrogen, it contributes to the eutrophication of lakes and other bodies of water. (Raddad and Jordan, 2005).

High phosphate concentrations in wastewater are due to human activities such as the application of fertilizers, herbicides, and insecticides in agricultural activities. As a result, runoff from rainfall and over-irrigated land carry nutrient-rich effluent, including phosphates into water bodies. Another source of phosphates is detergents used in households, as well as excrements from animals and humans, which end up in domestic effluent flowing into treatment plants, resulting in an increase in phosphorus concentrations.

Wastewater treatment plants (WWTPs) which use biological nutrient removal in secondary treatment process often reduce total phosphorus concentrations to 0.3mg/l and below (Ragsdale, 2007). WWTPs designed to remove nutrients, mainly nitrogen and phosphorus are an important step of the treatment process (Abdel-Raouf *et al.,* 2012). Biological removal of phosphorus from wastewater makes use of activated sludge with specific microorganisms, categorized as phosphorus accumulating bacteria (PAB), which can assimilate surplus phosphorous such as that in the form of polyphosphates (Carey and Migliaccio, 2009).

2.3 Treatment Efficiency

Treatment Efficiency (TE) refers to the measure of effectiveness to which a treatment plant reduces concentrations of pollutants in wastewater, also known as removal efficiency (Khanijo, 2002). The performance of wastewater treatment plants is essential to be monitored as the treated effluent is discharged into water bodies that support life. The efficiency of sewage treatment plants can be shown by evaluating pollutant levels of the influent and the effluent at the treatment plant of sewage treatment plants discharging into the environment (Sukumaran *et al.* 2015).

The treatment performance of each phase is based on the efficiency of treatment and robustness of its parameters as set by design standards. Therefore, WWTP performance depends on the state of WWTP's infrastructure and the treatment performances of their treatment units (Qasem, 2011). Environmental regulations are always concerned with the characteristics of the effluent discharged from treatment plants, as these regulations are usually a set of restrictions on the quality of effluent that must be met by any WWTP. Wastewater treatment characteristics vary from one WWTP to another on a daily and seasonal basis, which makes the standardization of evaluation procedures for all plants very difficult. In this regard, special attention is necessary to assess the environmental impacts of existing wastewater treatment facilities (Kumar and Pinto, 2010).

2.4 Eutrophication

Nitrogen and phosphates are two important nutrients needed for aquatic plant growth. In a healthy water body, both nutrients occur in limited amounts, restricting plant growth. Anthropogenic (human) factors such as WWTP's effluents are capable of substantially increasing the concentrations of these nutrients in water bodies, a phenomenon known as “cultural eutrophication” (Hasler, 1947 as cited by Leng, 2009). Excessive nutrient loading of nitrogen and phosphorus is a major threat to water quality.

Even though non-point water source contributors such as urban and agricultural land uses are significant, point sources such as WWTPs’ effluent, can overwhelm receiving waters (Volterra *et al*., 2002). For example, a study done, for a Canadian lake, indicated that the input of phosphorus inputs directly controlled algae blooms. It was observed that algal blooms increased when phosphate input was kept constant while the nitrogen input was reduced (Carpenter, 2008).

The effects of eutrophication consist of increased algal biomass, decreased water transparency and low dissolved oxygen concentrations. With reduced transparency, sunlight penetrating the water is reduced, in the dark, animals, plants, aerobic microorganisms and decomposing dead organisms respire and use up the available oxygen, in addition, oxygen contained in sulphates ($SO4^{2-}$) is used by some specific bacteria. And this leads to the emission of sulphur (H_2S) which immediately captures the free oxygen in the upper layers, resulting in the water body losing all its oxygen. In turn, the aquatic life disappears, and sulphur causes the smell of rotten eggs.

The reduction in DO increases fish mortality and results in the most frequent occurrence of toxic phytoplankton. The long-term reductions in dissolved oxygen concentrations may result in changes in species composition (Akpor and Muchie, 2011). Through direct contact and consumption of contaminated water, humans may also be exposed to toxins. Animals and humans are affected by toxins at a molecular level affecting cells, tissues, and organs. Secondary effects of eutrophic water include a variety of symptoms such as fatigue, headache, diarrhoea, vomiting, sore throat, fever and skin irritations (Volterra *et al.,* 2002). Other effects of eutrophication include distorting the aesthetics of the water body. In a country like Namibia, where treated water is pumped from water bodies together with treated effluent and it is further purified to potable standards, it is costly to treat water from eutrophic sources because chemicals are expensive as well as algae tends to block pipes and pumps damaging the equipment.

2.5 Effluent standards

Soon after Namibia gained independence in 1990, the Water Act of 1956 was reviewed(GRN, 2013) . The sections of the revised Water Act of 2013 which address the discharge of industrial effluents include Section 21(1), which states that the purification of waste water shall form an integral part of water usage (Fallis, 1990). The section goes on further to specify that purified effluents shall comply with the General Standard Quality restrictions as laid out in Government Gazette 553 of 5 April 1962 (Fallis, 1990). In addition, Section 21(2) stipulates that this purified effluent be returned as close as possible to the point of abstraction of the original water (Fallis, 1990).

In 2013, Namibia reviewed the then existing Water Act of 1956, and catered for the prohibition of discharge into the sewerage system, of any industrial wastewater from an abattoir, tannery, brewery, dye-house or any other obnoxious industrial wastewater which might inhibit the biological process of the wastewater treatment facility of a local authority (GRN, 2013). This led to industries being made responsible for treating the wastewater they produced, (on their premises) before releasing effluent into the environment. However monitoring compliance to the Namibian water quality effluent standards has been cumbersome.

Effluent standards refer to restrictions imposed relating to quantities, rates, and concentrations of materials in wastewater discharge (World Bank, 2016). Regulating effluent is important as the pollution of water has a serious impact on the environment as a whole, including its effects on biotic and abiotic organisms. Polluted water affects different uses such as household water use, recreation, fishing, transportation, and commerce. In many parts of the world, health problems and diseases have often been caused by discharging untreated or inadequately treated wastewater and have resulted in the spreading of diseases, fish kills, and destruction of other forms of aquatic life (Cushman and Carlson, 2004).

Eutrophication potential which results from the presence of nutrients in the effluent has been considered to be a relatively important environmental issue when performing an environmental evaluation of WWTPs (Poch *et al.,* 2014). WWTPs discharge directly into water bodies and are therefore considered point sources of possible pollution.

2.6 Life Cycle Assessment Approach

Life Cycle Assessment (LCA) refers to the assemblage and evaluation of outputs and probable environmental impacts of a product or system throughout its life cycle (Li *et al*., 2013). Hence, the assessment of environmental impacts of a product or process in LCA is usually carried out from "cradle to grave". The "cradle to grave" approach begins with the extraction of raw materials from the earth, followed by product development and manufacturing, and ends when materials are returned to the earth. LCA is an ISO 14040 standardized method for the environmental assessment of industrial systems (Barjoveanu *et al.,* 2010).

However, even though an LCA study looks at the environmental aspects and the potential impacts throughout the life of a product or service, several studies have assessed environmental impacts of a system using a life cycle assessment approach but only looking at a specific time period for example a study by Mcnamara *et al. (*2014), used an LCA approach to assess the impacts of wastewater treatment plants from the point influent flows into the plant to the point the effluent flows out. Similarly, the LCA approach for this study will be used to assess the environmental impacts of an activated sludge, wastewater treatment plant from the wastewater inlet treatment point to the outlet point, over a period of two years which is less than the lifetime of the project. Other studies that have used a gate to gate approach in conduction an LCA include a gate to gate study of the LCA of an oil palm seedling by (Muhamad et al. 2012), and an LCA of the United States particleboard production by (Oneil, 2013).

CHAPTER 3 : DESCRIPTION OF STUDY AREA

3.1 Namibia

Namibia is situated in South West Africa, bordered by the Atlantic Ocean on the West, Angola and Zambia to the North, Botswana to the East and of South Africa to the South (Reynolds, 2002), (Figure 3-1). The country has a surface area of approximately 825 814 km², with an estimated population of 2,104,900 million inhabitants (NSA, 2012).

Figure 3-1: Southern African map indicating the location of Namibia

Source: (Small Cap Network, 2015)

3.2 City of Windhoek

Windhoek, the capital city of Namibia is about 1,540 m above mean sea level and is located at 22°33.6′ S and 17°5′ E (GPS coordinates.net, 2015). The city covers a total surface area of 5,133 km^2, with an estimated population of 322,500 during the (2011 census) (NSA, 2012).

As mentioned earlier OWWTP treats water from low-income suburbs, such as Katutura, Hakahana, Otjomuise, and Wanaheda. Since these suburbs consists of formal and informal settlements, where some people have public toilets or are do not have toilets at all, these areas only account for about 20% of the city's produced domestic wastewater

(CoW, 2015). Windhoek west and Windhoek east on the Map (Figure 3-2) consists of high-income suburbs accounting for about 80% of the city's wastewater.

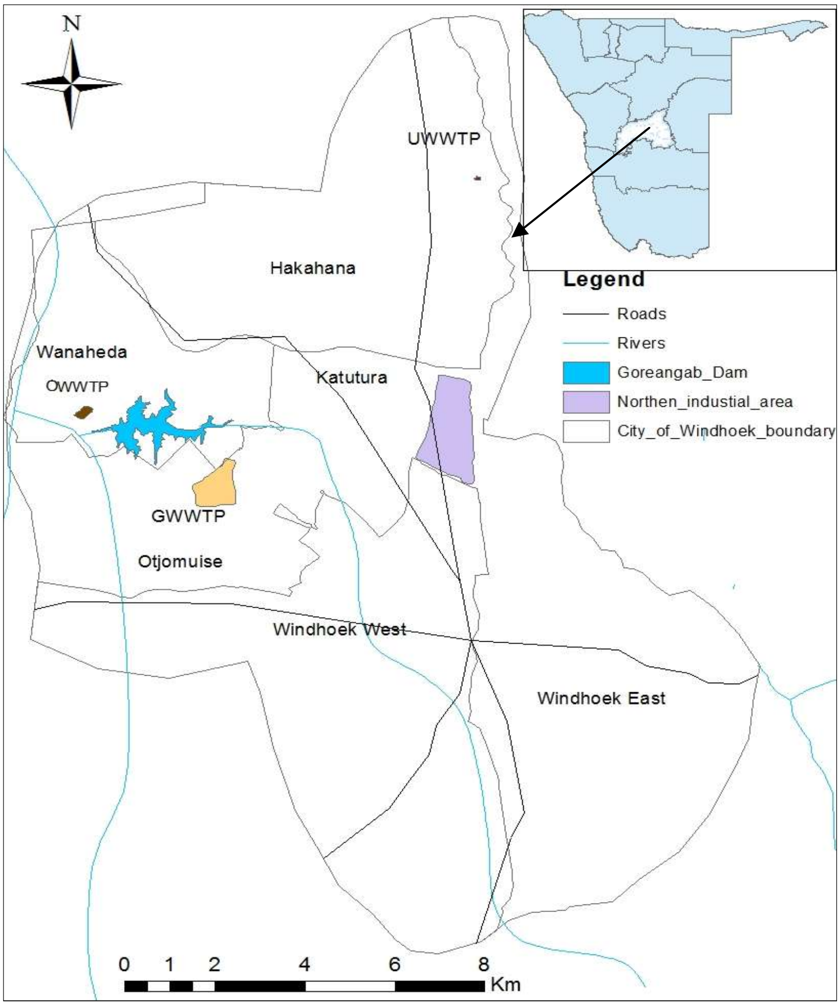

Figure 3-2: Map of Namibia showing Windhoek boundary

Gammams and OWWTPs are located within Khomasdal North and Wanaheda residential boundaries. The two treatment plants are separated by a dam. Both discharge into river streams, as indicated in Figure 3-3. Until recently treated effluent from Gammams WWTP was previously discharged into the Goreangab dam. However, the treated effluent now goes directly to the City of Windhoek's water reclamation plant which treats water for potable use.

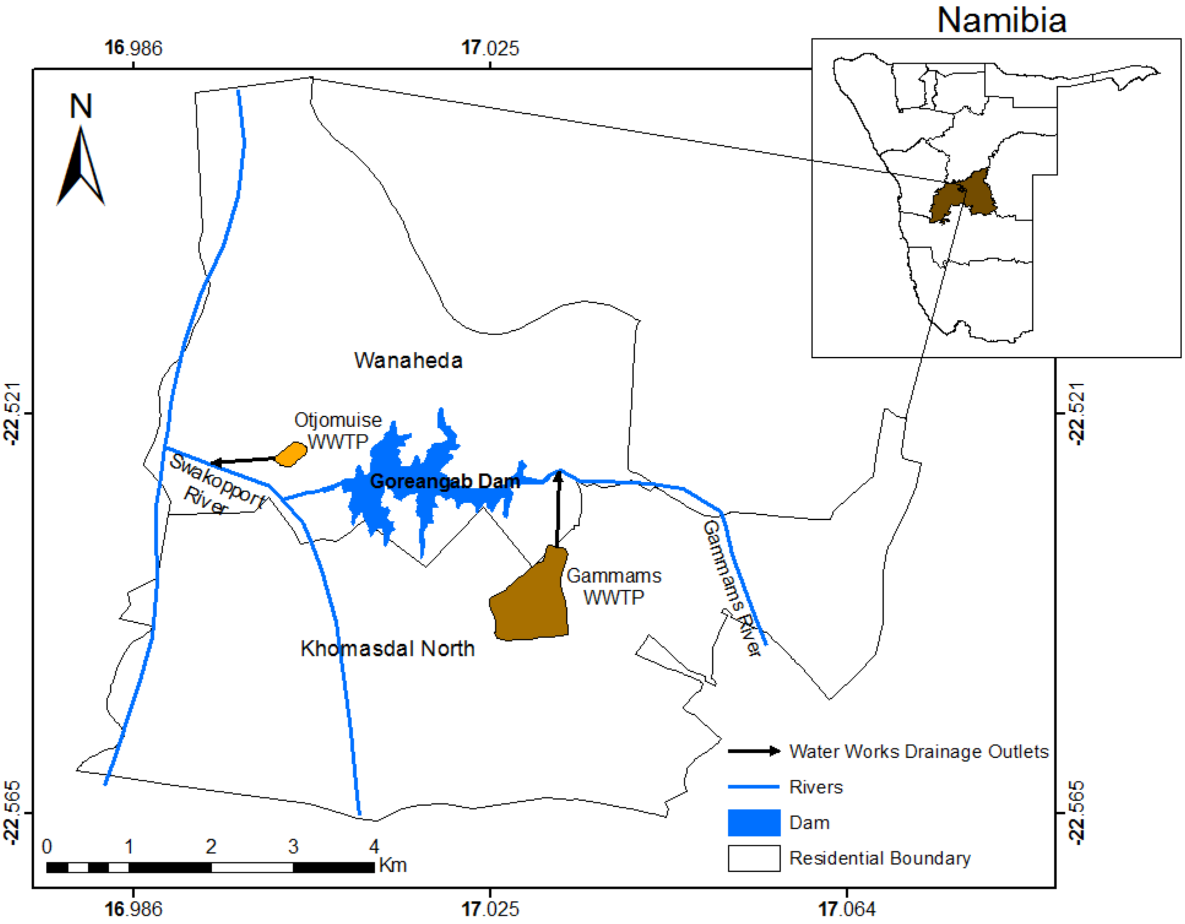

Figure 3-3: Map showing the study area and its location in Namibia

3.2.1 Geology and soils in Windhoek

The geological region around Windhoek is part of the South-West plateaux and is characterized by extreme ruggedness (Bertram and Broman, 1999). The area has the oldest rocks, namely the metamorphic inliers from the Paleoproterozoic age and is associated with intrusive rocks. A large part of Windhoek is composed of a variety of meta-sedimentary rocks, which were liable to extensive folding, faulting, and erosion before being covered by sedimentary deposits, followed by another long time of erosion (Lehmann, 2010).

Erosion produces minimal amounts of phosphorus, while the excess may come from plant and animal residues and end up in water bodies, resulting in growth of aquatic species, which leads to eutrophication (Gladh, 2002).

3.2.2 Climate

Windhoek has a semi-desert, arid climate; with very hot summers and mild winters. Temperatures tend to drop considerably at night. On average, winter temperatures between May and August range from 6 °C to 21 °C, while summer temperatures (September to February) are around 30 °C. The city has approximately 300 days of sunshine per year. Due to high temperatures and many days of sunshine, the country has high evaporation rates, reduces the dilution factor of the water resulting in highly nutrient concentrated water bodies, and this can easily result in eutrophication.

Windhoek's climate is a local steppe climate. A steppe is a dry, grassy plain. Steppes occur in temperate climates. Temperate regions have distinct seasonal temperature changes, with cold winters and warm summers (Ritter, 2003). A local steppe climate is the climate of a region that receives precipitation below potential evapotranspiration, but not extremely (Kottek *et al.* 2006)

There is not much rainfall in Windhoek all year round. December is known to be the wettest month of each year (World Bank, 2016). The driest weather is August when on average no precipitation occurs. Potential precipitation is lower than potential evaporation because the country has an arid to semiarid climate (Flod and Landquist 2010).This is not surprising as water is a scarce resource in Namibia, and is said to be the driest country south of the Sahara desert (Kgabi and Joseph, 2012).

3.2.3 Water resources

The only perennial rivers that Namibia have access to (Kunene, Orange, Okavango, and Zambezi), are located along its borders, hence are shared with other countries (Amakali, 2005). Thus, perennial rivers are about 500 km North and South of Windhoek, which is situated in the center of Namibia. The city's water supply is from reclaimed water, boreholes and three surface dams which are fed by ephemeral rivers (some 60 to 200 km away) from the city (Menge, 2006). Windhoek is located in an area with many challenges to water quality and quantity. Challenges relating to the maintenance of these reservoirs include pollution in the surrounding basin, low recharge and high evaporation (Lahnsteiner and Lempert, 2007). in addition to limited water resources, the population of the city has been increasing at a rate of five percent per year since 1990 (Lahnsteiner and Lempert, 2007).

3.2.4 Socio-economic profile of Windhoek

The City of Windhoek is the social, economic, political, and cultural centre of Namibia. Nearly every national enterprise, governmental body, educational and cultural institution in Namibia is headquartered in the city. Windhoek's population in the latest census of 2012, was 322,500 (NSA, 2012)., and Windhoek is a classically dualistic city, with clear divisions between the high-income suburbs and low-income suburbs (Melorose *et al.* 2015). The central business district is modern, with high-rise buildings and a wide range of goods and services on offer.

There are elite suburbs to the east, such as Klein Windhoek, middle-income areas to the South and South-West with suburbs like Pioneers Park, while Katutura in the North and North-West is predominantly inhabited by low-income people, as indicated in (Figure 3-3) (Gold and Muller, 2001). According to FAO (2010) water is vital for socio-economic growth and for maintaining a healthy ecosystem. In many countries, including Namibia, where water is a scarce resource, the efficient use of water is crucial. Water supply in Windhoek tends to follow the divisions between high-income suburbs and low-income suburbs. People in high-income suburbs tend to have consistent water supply at all times, while the water supply in low-income suburbs' may not be reliable at times (Cohen, 2006). This is simply because income suburbs are able to pay for the water, as compared to low-income suburbs. Due to the difference in water supply, treatment plants tend to receive more concentrated or polluted water from low-income suburbs as compared to high-income suburbs.

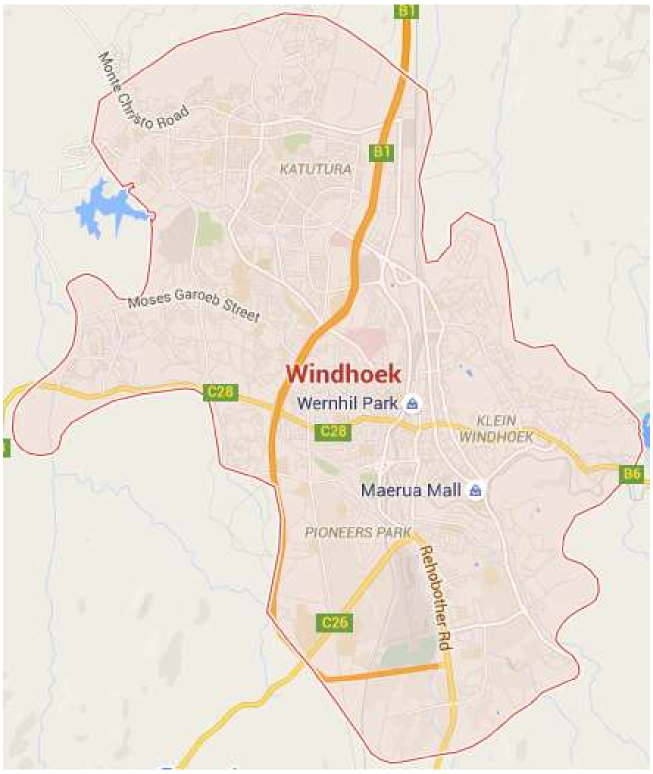

Figure: 3-4: Google earth image showing Windhoek and its suburbs

Source: (Google Earth, 2016)

CHAPTER 4 : MATERIALS AND METHODS

4.1 Study design

In the study design section, the interviews conducted the selection of study area, sampling points, water quality parameters, and sampling time and sampling frame is discussed as follows.

4.1.1 Interviews

Key informant interviews were conducted for Gammams and Otjomuise wastewater treatment plants, Goreangab dam and the Windhoek reclamation plant (See Appendix 1). In all the four organisations background information was obtained on the people's positions, experience in the position, and roles and responsibilities to establish the right people to talk to in each organisation. Information obtained from Gammams and Otjomuise wastewater treatment plant included sources of water into the treatment plants, electricity used during treatment, users of treated effluent, and whether or not there was some foam of linkage to the Goreangab dam. The interview aimed to obtain information from the Goreangab dam such as sources of water in the dam, purpose of the dam, water quality changes over the years, and relationship or linkage to wastewater treatment plants and Windhoek's reclamation plant. Then lastly information that the interview guide sought to obtain from Windhoek's reclamation plant was on whether it was in any way linked to wastewater treatment plants and the Goreangab dam.

4.1.2 Selection of study area

The study focused on GWWTP and OWWTP because, they both treat domestic sewage using an activated sludge treatment with biological nutrient removal, while Ujams WWTP treats the city's industrial effluent using oxidations ponds system (Kaimbi Lapaka, 2010). The city of Windhoek has a separate pipe network for industrial wastewater. The two domestic treatment plants are plants which have existed with sufficient historical data to be able to perform a Life Cycle Assessment on, and both directly discharge into Windhoek's ephemeral rivers. GWWTP was constructed between 1959 and 1961 and extended with the addition of an activated sludge in 1979, and upgrades have followed since then. OWWTP was constructed in the 90s. The effluent from Gammams is further purified by Windhoek's reclamation plant to potable standards, while some of the effluent flows into the Gammams River and ends up in the Goreangab Dam. Otjomuise's effluent is discharged into the Swakoppoort River leading to the Swakoppoort Dam.

4.1.3 Selection of sampling locations

Since the study aimed at evaluating the concentration of what was coming into the plants and what was being released into the environment by the plants, sampling points were strategically located at the influent and effluent points of each plant (Figure 4-1), to give insight into the quality of water coming into each plant and the quality of water discharged into the environment. The study consisted of four sampling sites in total with, two sampling points per treatment plant.

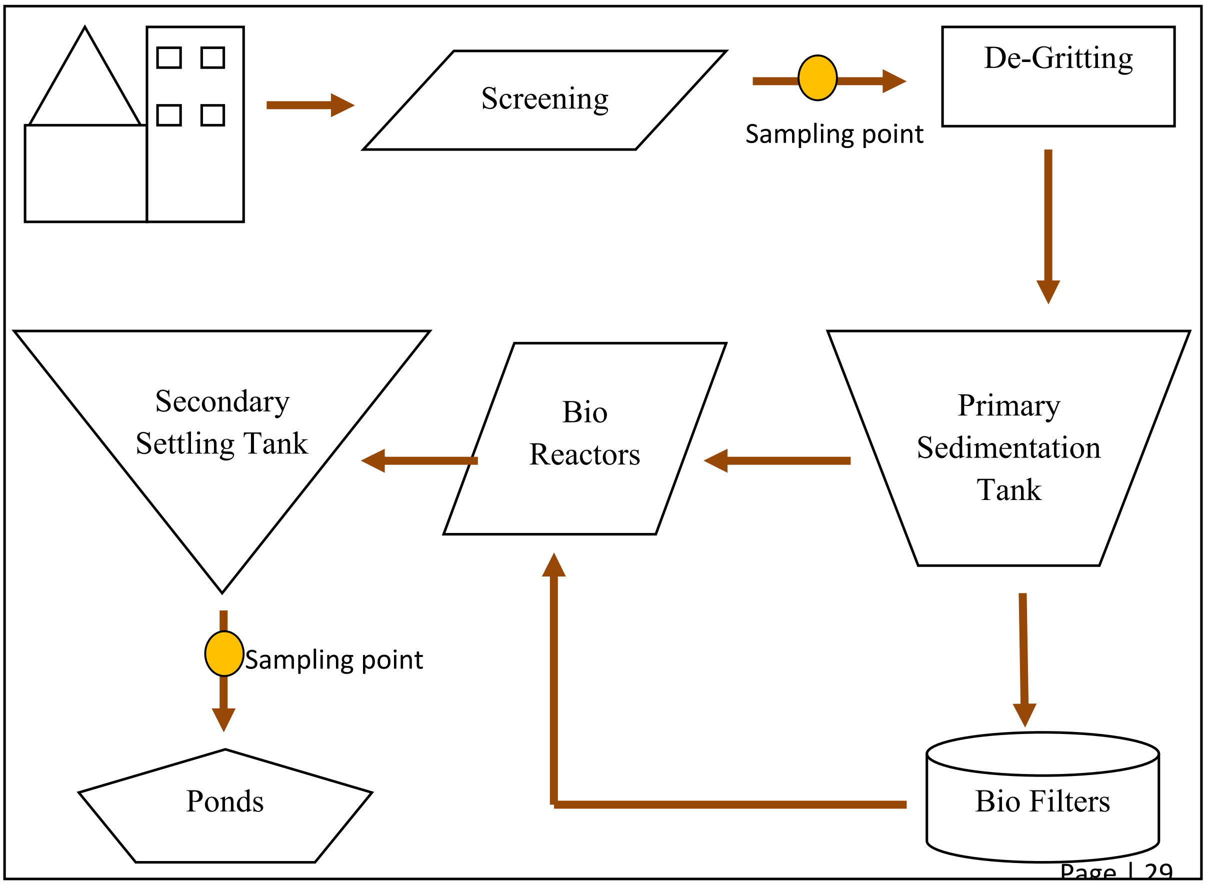

Figure 4-1: activated sludge wastewater treatment sketch indicating sampling points

4.1.4 Selection of water quality parameters

The selection of water quality parameters measured, considered roles in wastewater treatment in relation towards eutrophication parameters and possible contribution to eutrophication. Eutrophication in receiving waters was noted, as some of the main concerns of water quality (Akpor and Muchie, 2011). Therefore effluent from the treatment plants was suspected to be the cause of eutrophication in the receiving waters. This study utilised the physical and chemical water quality parameters in assessing the treatment efficiency and the contribution to eutrophication, physical and chemical water quality parameters considered included, Temperature, Turbidity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Electrical Conductivity (EC), pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Nitrogen and Phosphates. These parameters were selected because of their role in wastewater treatment and eutrophication.

4.1.5 Sampling times, and sampling frequencies

The aim of sampling is to collect a small portion that is potable, yet sufficient for analytical purposes, and which accurately represents the material on the ground (Clesceri *et.al.,* 1998). The grab sampling method was used because the analyte of interest was not expected to vary greatly (Duncan *et al.* 2007); this refers to a single sample collected at a specific spot at a specific site over a short period of time, typically seconds or minutes (Clesceri *et al*., 1998). Samples were collected once every Wednesday of every week for the months of January and February (which is a wet season) 2016, in total there were five sampling campaigns. Sampling took place from 20 January 2016 to 17 February 2016, from 7:30 to 9:30 in the morning as the laboratory requirements are that the samples have to be in by 10:00 am each sampling day. Pre-sterilised sampling bottles were bought from the water lab. All the bottles were labelled with the name of the site and date at which the sample was taken. All of the collected samples were preserved in a cooler box with ice cubes and were immediately transported in a vehicle to the laboratory after collection for further analysis. A total of 20 samples were collected within the two months from the treatment plants. There was no replication in the field, but the two litres collected per sample was enough to replicate in the lab. In-situ measurements were done for physical parameters such as temperature, turbidity, pH and electrical conductivity.

4.2 Data collection

4.2.1 Historical data

Historical data was used in order to observe the long-term temporal variations and to assess the performance of treatment plants over a 10 year period. Historical water quality data from Gammams and OWWTPs was obtained from the City of Windhoek's laboratory, for the period of January 2004 to December 2014 (10 years) and this was done weekly every Wednesday of every week. The laboratory is tasked by the City of Windhoek to monitor water quality of the WWTPs to ensure compliance with effluent standards and enable to other forms of research aimed at feeding into the database, which might be used in the development of the country. Therefore, the laboratory has been monitoring water quality for the two WWTPs for more than ten years. Complete data obtained was for both influents and effluents, for the following parameters: Temperature, Total Suspended Solids, Total Dissolved Solids, Electrical Conductivity, pH, Biological Oxygen Demand, Chemical Oxygen Demand, Total Kjeldahl Nitrogen and Orthophosphates.

4.2.2 Field measurements and laboratory tests

1. Field measurements

Field measurements refer to on-site tests, done immediately after sampling in the field during data collection (Venkatesh and Davis, 2000). Field measurements were done for the following physical and chemical parameters: temperature, turbidity, pH and electrical conductivity. The parameters, measuring instruments and units are shown in Table 4-1.

Table 4-1: Field water quality parameters, units and instrument/method of determination

Parameter	**Unit**	**Instrument/ Method of Determination**
Temperature (T)	°C	Conductivity meter 2550 WTW OXI 330
Turbidity (NTU)	mg/l	Turbidity meter 2132B HACH 2100N
Electrical Conductivity (EC)	mS/m	Conductivity meter 2550 JENWAY 4070
pH		pH meter 4500-H^+ JENWAY 370

2. **Laboratory tests**

Samples were sent to the City of Windhoek and NamWater laboratory to test for the following parameters: biological oxygen demand, chemical oxygen demand**,** orthophosphates, and total kjeldahl nitrogen. The parameters tested in the laboratory, their units and instruments/method of determination and their units are shown in Table 4-2. For parameters that required laboratory tests, samples were sent to the City of Windhoek and NamWater laboratories. City of Windhoek and NamWater laboratories are certified and use standard methods for water quality analysis presented in Table 4-2.

Table 4-2: Laboratory water quality parameters tested, their units and instrument/ method of determination

Parameter	**Units**	**Instrument/ Method of Determination**
Total Suspended Solids (TSS)	mg/l	Total suspended solids dried at 180°C 2540C
Total Dissolved Solids (TDS)	mg/l	Total dissolved solids dried at 180°C 5240C
Biological Oxygen Demand (BOD_5)	mg/l	5 Day-BOD Test 5210B
Chemical Oxygen Demand (COD)	mg/l	Titration (closed reflux 5220C method)
Total kjeldahl nitrogen (TKN)	mg/l	Spectrometer HACH 2010DR
Total Nitrogen (TN)	mg/l	Spectrometer HACH 2010DR
Orthophosphates (OP)	mg/l	Spectrometer 21D 4500-PE
Total Phosphorus (TP)	mg/l	Spectrometer 21D 4500-PE HACH 2010DR

4.3 Data analysis

During the period of 2004-2014, data was sampled every Wednesday of every week, four times a month by the City of Windhoek laboratory, and this was over a period of 10 years. To make data analysis easier when performing statistical analysis, data was averaged to monthly values for each water quality parameter.

4.3.1 Variations of water quality and effluent standards

The temporal variations were determined by plotting monthly average line graphs in Excel. Thereafter the graphs were observed to identify trends within the different months over the 10 year period. Statistical tables of means, standard deviation, range, minimum, maximum and correlation tables were also compiled for influent and effluent water quality parameters (see Appendix 3).

Compliance with the Namibian wastewater effluent standards was checked by comparing effluent from the two WWTPs with Namibian wastewater effluent standards (See Appendix 2) from the Namibian Water Act (2013). Water quality parameters whose effluent standards are not stated, South African wastewater effluent standards were used, as, they are quite similar to Namibia.

4.3.2 Treatment Efficiencies

Historical and sampled, influent and effluent data were first averaged for each parameter, in order to obtain a single value. Treatment Efficiency (TE) was then calculated according to the method proposed by Kantachote *et al.* (2009) who induced that TE or Removal Efficiency is calculated using the following equation:

$$\mathbf{TE} = \frac{(\mathbf{Input}-\mathbf{Output})}{\mathbf{Input}} \boldsymbol{X}\ \mathbf{100} \text{ ------------------------------------ } \textbf{Equation 1}$$

Where:

TE ....Treatment efficiency

Input.................Average value of the influent per parameter

Output.............Average value of the effluent per parameter

Appendix 4 shows examples of calculated treatment efficiency. The difference in treatment efficiencies between influent and effluent was used to determine the percentage difference in treatment efficiencies of the two plants.

4.3.3 Life Cycle Assessment Approach

Life Cycle Assessment (LCA) approach was conducted according to ISO 14040 and the steps set in the standards were followed. It is well documented that the construction phase of a wastewater treatment plant's life cycle is negligible compared to the operation and maintenance phase (Muhamad et al. 2012). McNamara (2014) carried out an LCA of a WWTP in Ireland, where a "Gate to Gate" approach and only the treatment phase was considered (see Figure 4-2), similarly, this study only considered the treatment phase of Gammams and Otjomuise wastewater treatment plants.

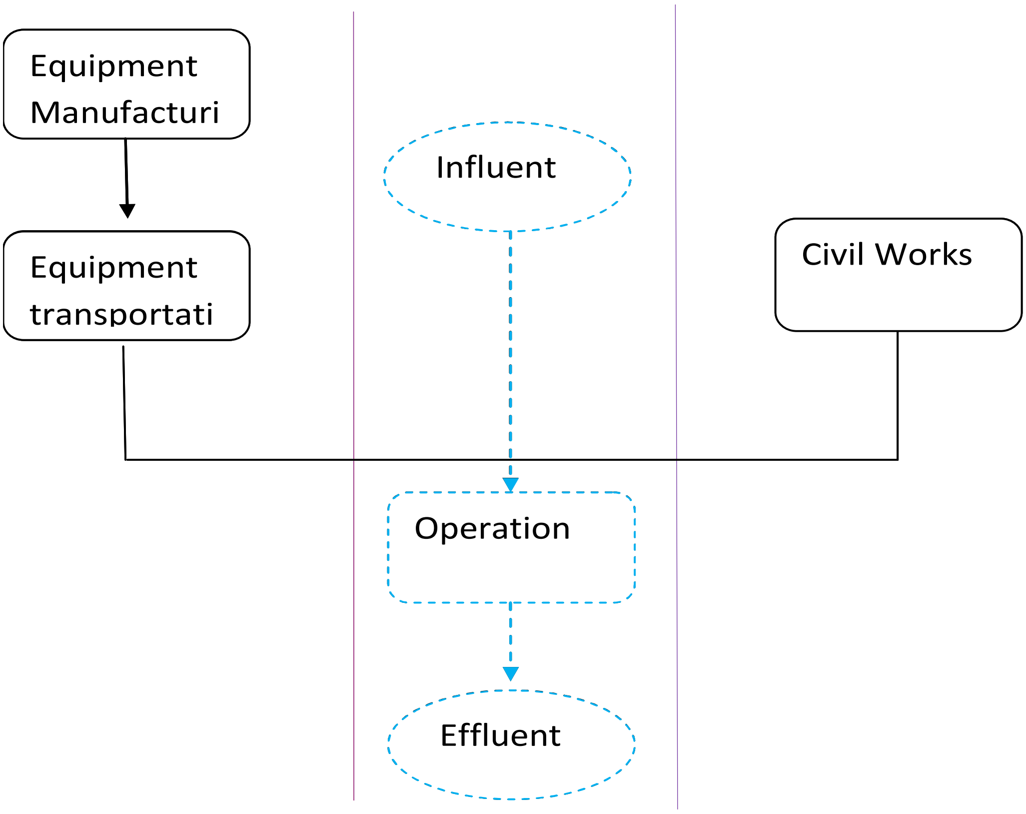

Figure 4-2: System boundary

Based on the ISO 14040 standards the LCA series uses four important steps (as shown in Table 4-3). The first step is the goal and scope definition, which identifies the LCA's purpose and the expected products of the study, as well as determining the boundaries and assumptions based upon the goal definition. The first step is followed by inventory analysis, where performing mass and energy balances to quantify all the material and energy inputs wastes and emissions from the system, such as the environmental burdens take place. This is followed by the impact assessment step, which involves aggregating the environmental burdens quantified in the inventory analysis into a limited set of recognized environmental impact category, such as global warming, ozone depletion, and acidification. Lastly, the fourth category is interpretation, which involves using the results for the reduction of associated environmental impacts, with the product or process. Normalisation of the results was done to obtain graphical representations of the results.

Table 4-3: The four stages of a Life Cycle Assessment (Williams, 2009)

Stages of LCA	**Considerations in each stage**
1. Goal and Scope definition	The study aims to the assess performance of a wastewater treatment plant Functional unit: 1kg/d per unit volume of each water quality parameter
2. Inventory analysis	Local data: (influent, effluent, chemicals and energy usage) For individual wastewater processes over a period of 10 years.
3. Impact Assessment	Impact category chosen for this study is Eutrophication At the end of the impact assessment, graphical results will be produced
4. Interpretation	GaBi Balance will be performed, which is an analysis tool for results interpretation, and produces a graph function that can be export to Excel and interpreted.

The eutrophication impact category was considered in LCA modelling, eutrophication potential impact category is a dominating factor when selecting the best wastewater treatment operating strategies, because of its relatively high share in the final normalized results of all analyzed impact categories (Hospido *et al.,* 2004). It is demonstrated that the eutrophication potential impact category of a WWTP is mostly associated with the discharge of water, mainly rich in phosphorus, nitrogen and to a lower extent, degradable organics, such as COD in wastewater effluent (Gallego *et al.,* 2008).

GaBi Product Sustainability Performance software was used to model eutrophication., GaBi is a leading product of sustainability solution, which combines modelling and reporting software data content and consulting expertise (PE International , 2012)**.** The software is established standard software for Life Cycle Assessment (LCA) in all branches and allows users to assess the potential environmental burdens of products and services in their production, use, and disposal (end of life). The GaBi software requires inputs such as water quality parameters concentrations, electricity consumption and chemicals used during the treatment process, and output is the eutrophication contribution (Figure 4-3).

Figure 4-3: Inputs and Outputs of the GaBi Software

The Centre for Environmental Science of Leiden University (CML) Method in the GaBi software was used to estimate the contribution to eutrophication. According to a study conducted by Halleux *et al*. (2006) the CML method highlights the most important environmental impact categories such as eutrophication and aquatic ecotoxicity. The method does not give a single score; rather it provides graphic results which can be easily interpreted. When evaluating environmental impacts of eutrophying substances, the CML method simultaneously considers the impacts of phosphorus and nitrogen on aquatic ecosystems.

The Sections followed in the GaBi software include plans, processes, and flows, which are defined and are added to the LCA model. Plans refer to the life cycle to be analysed, processes represent the actual steps that occur in real life. Together, plans and processes are placed on a "plan". Flows connect processes, and represent the energy and materials moving from one point to the other in the system. To be able to model a plan, a few steps in the process were followed. These included selecting the type of flow. U-So was selected, as the unit process because data modelled was only for one specific process.

Namibia was specified as the country of study in the LCA model. The random Number 1000 was used as a scaling factor and the LCA model was balanced using the CML methodology. Only the results of the eutrophication impact category were considered from all the given impact categories, as eutrophication was the only impact category under study. In terms of validation, the software comes with background info checked and validated for different specific areas, hence only the data entered into the model should be checked for consistency and results are expected to be reliable (Gabi, 2010).

CHAPTER 5 : RESULTS AND DISCUSSION

5.1 Introduction

The objective of the study was to assess the influent and effluent variations for different water quality parameters from Gammams wastewater treatment plant (GWWTP) and Otjomuise wastewater treatment plant (OWWTP). This section further assesses the two wastewater treatment plants compliance to the Namibian water quality effluent standards as stipulated in the Namibian Water Act of 1956, amended in the Water Resources Management Act of 2013. Historical data obtained from the City of Windhoek laboratory is presented and discussed in Section (5). The historical data was collected over a period of 10 years from 2004 to 2014. This was sampled by the City of Windhoek laboratory on a weekly basis, once a week. In addition, primary water quality data was sampled by the researcher and analysed, to compliment historical data, presented and discussed under Section (5). The data was collected once a week, over a period of five weeks (five sampling campaigns), from the 20 January 2016 to 17 February 2016.

Water quality parameters considered for historical data include Temperature, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Electrical Conductivity (EC), pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Orthophosphates (PO_4^{2-}). Water quality parameters considered for primary data include Temperature, Turbidity, Electrical Conductivity (EC), pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen and Total Phosphorus.

5.2 Variations of water quality and effluent standards

5.2.1 Temperature

GWWTP's influent and effluent temperatures for 2004-14 are shown in Figure 5-1. Both influent and effluent remained uniform around 20°C, except for the peaks that were above effluent temperature standard limits of 35°C, in October 2004 and September 2014. OWWTP's influent and effluent temperature for periods of 2004 to 2014 are shown in Figure 5-2. Both influent and effluent graphs remained around 20 °C, except for the visible peaks that rose above effluent standard limits of 35°C, in July 2011, October 2013, then May, April and October 2014. Effluent from both Gammams and OWWTPs complied with Namibian effluent standards, except for the mentioned peaks. Rise in influent temperatures above 35°C can result in deterioration of biological activity during the treatment process reducing nutrient removal efficiency, while high effluent temperatures might lead to disruption of aquatic organisms in receiving waters (Eckenfelder and Wesley, 2000).

Mean influent for historical data was 22°C and 23°C, while mean effluent was 22°C and 22°C for Gammams and Otjomuise in that order.

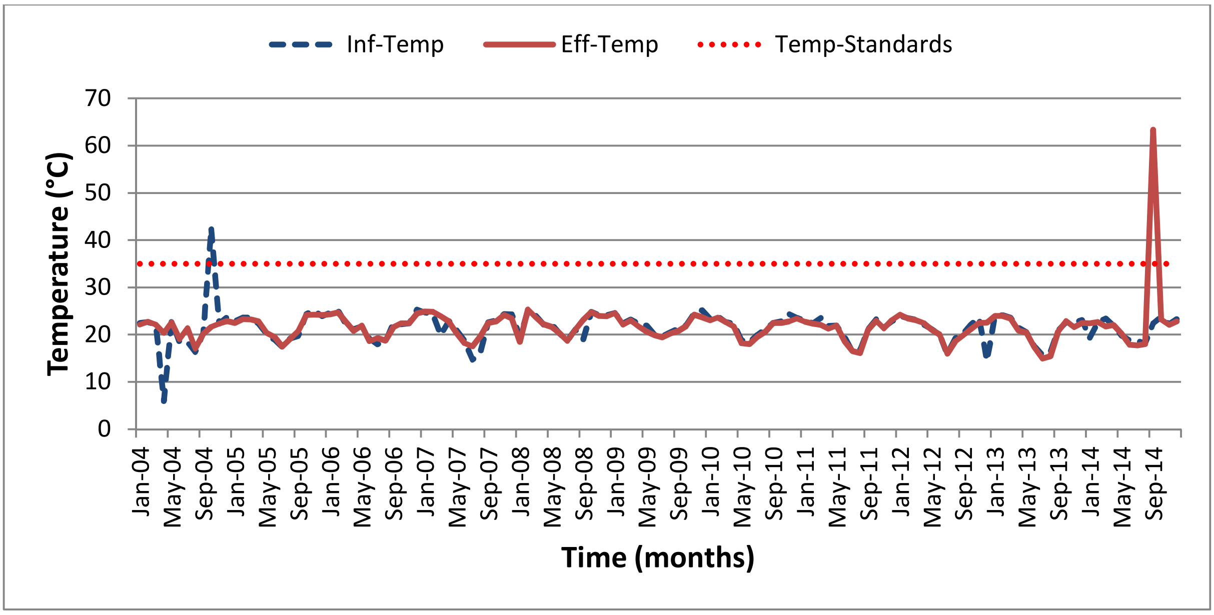

Figure 5-1: GWWTP: variations of monthly temperatures for the periods 2004-14

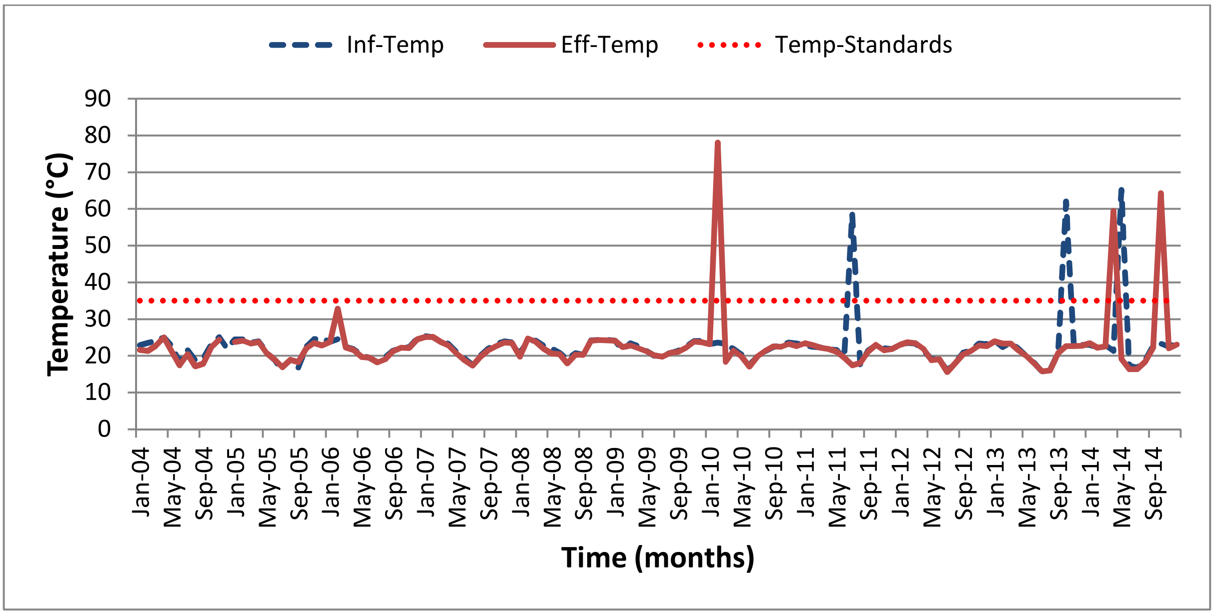

Figure 5-2 : OWWTP variations of monthly Temperatures for the periods 2004-14

The variations of weekly temperatures for the five sampling campaigns for GWWTP are shown in Figure 5-3. The influent and effluent graphs both followed a similar trend, ranging from 23 and 28°C. The variations of OWWTP weekly temperatures for the five sampling campaigns are shown in Figure 5-4. Both influent and effluent ranged from 22 to 26°C. Effluent from the two WWTPs complied with the Namibian water quality effluent standards. While mean influent for primary data at Gammams was 25°C and the effluent mean temperature was 26°C. The Otjomuise influent mean temperature was 25°C and the effluent mean temperature was 26°C.

Historical data had peaks above temperature effluent standards while primary data remained within the limits of effluent standards for all the sampling campaigns. It can be concluded that temperature of the effluent does not pose any threat to the homeostatic balance of receiving water bodies (Jaji *et al.*, 2007).

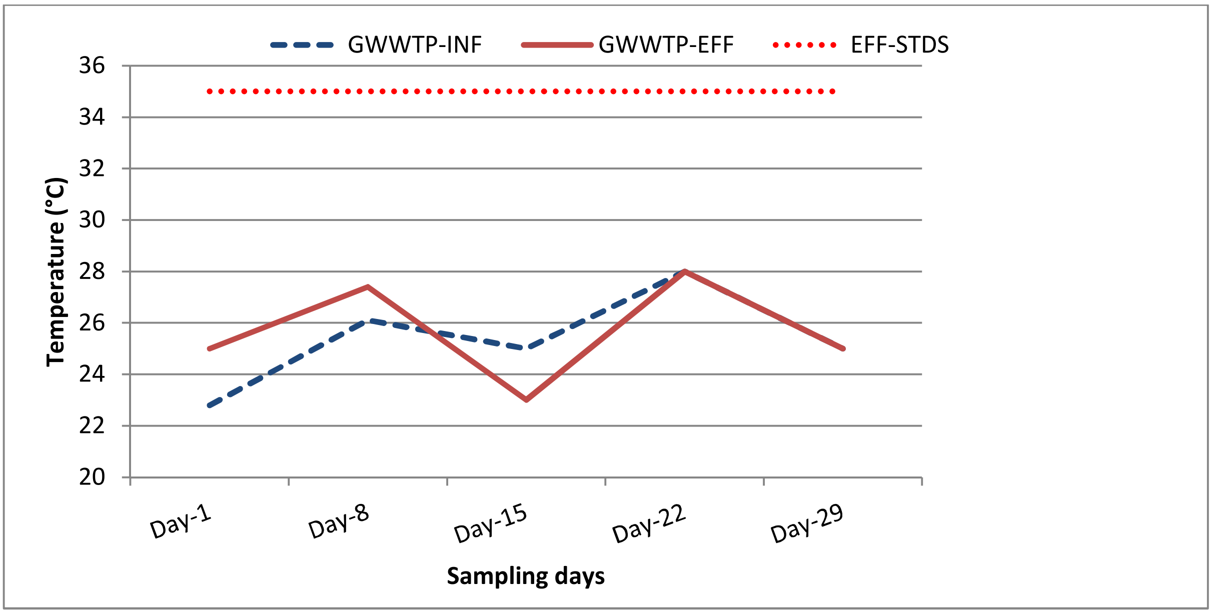

Figure 5-3: GWWTP weekly temperatures from 20 January to 17 February 2016.

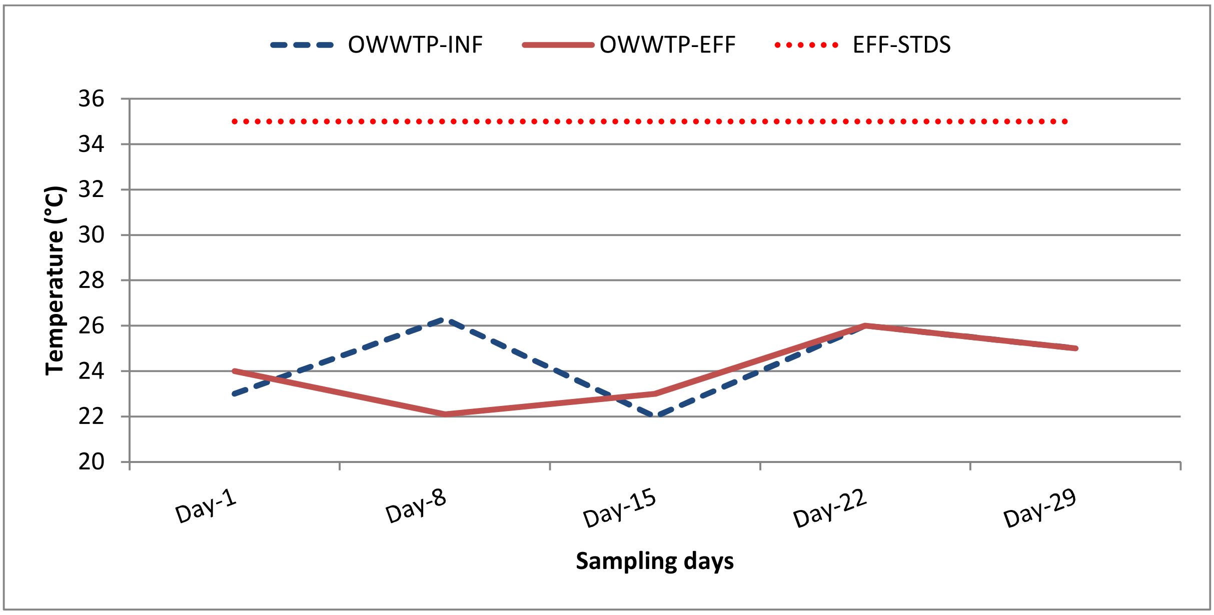

Figure 5-4: OWWTP weekly temperatures from 20 January to 17 February 2016.

5.2.2 Turbidity

For turbidity only primary data was used, as there was no secondary data available from the parameter. Weekly data from 20 January 2016 to 17 February 2016, results were as follows; turbidity levels for GWWTP ranged from 5 to271NTU for influent, while effluent ranged from 4 to 257NTU. Weekly turbidity levels for Otjomuise wastewater treatment plant ranged from 25 to 337NTU for influent, while effluent ranged from 7 to 247NTU. Gammams and Otjomuise influent means were 207 to 236NTU, while effluent means were 44 to 79NTU respectively. Turbidity effluent standards are not stipulated in the Namibian water quality effluent standards in the water Act of 1956 amended in 2013. Otjomuise has higher turbidity for both influent and effluent than Gammams, and this can be as a result of the consistency of water supply in the different suburbs feeding into the treatment plants (Kumar and Pinto, 2010). OWWTP treats domestic effluent from low-income suburbs that experience water cuts and inconsistency in water supply, while GWWTP treats domestic effluent from high-income suburbs that have a consistent water supply.

5.2.3 Total Suspended Solids

Total Suspended Solids (TSS) results were only for historical data. Gammams and Otjomuise wastewater treatment plants' results for periods of 2004-14 were as follows: GWWTP's influent fluctuated between 130 and 800mg/l, with a visible peak that reached 1843mg/l in December 2014. Effluent fluctuated around the Namibian water quality TSS effluent standards of 25mg/l, with two visible peaks of 166mg/l in August 2006 and 730mg/l in August 2008. Otjomuise wastewater treatment plant's TSS influent and effluent fluctuated greatly throughout the 10 year period. Influent fluctuated between 112mg/l and 2930mg/l, while effluent fluctuated between 10mg/l and 3050mg/l. This could have been caused by erosion from urban runoff, as the plant also receives and treat storm water (Oram, 2014).

Gammams and Otjomuise mean influent was 798mg/l and 771mg/l, while mean effluent was 41mg/l and 333mg/l in that order. OWWTP's TSS was higher than that of Gammams. This could be attributed to the difference in water supply for the areas that feed into the two treatment plants. Otjomuise treats wastewater from the southern part of the city, which consists of informal settlements and low-income class. Water supply is not consistent; hence it is expected for the water to be more concentrated with organic and inorganic nutrients. Similarly Kumar and Pinto (2010) in a study carried out in Bangalore India, attributed highly concentrated influent to heavy organic and inorganic loading with less liquid content.

5.2.4 Total Dissolved Solids

Total Dissolved Solids (TDS) results for historical data were as follows; TDS for GWWTP and OWWTP for the periods of 2004-14 were as follows; TDS influent and effluent fluctuated between 500 and 1000mg/l. GWWTP had visible peaks in May , and from April to August 2011. OWWTP had visible peaks in April, June and September 2006, and then again, in June and July of 2011 and December 2014. The mean effluent was 725 and 696mg/l for Gammams and Otjomuise respectively. Effluent concentrations for the two treatment plants were above effluent standard limits, TDS did not comply with Namibian effluent standards, as it exceeded effluent limits of 500mg/l (Fallis, 1990).

5.2.5 Electrical Conductivity

Electrical Conductivity (EC) results for historical data of GWWTP and OWWTP for periods of 2004-14 were as follows influent and effluent for GWWTP fluctuated between 100 and 200mS/m, with slight peaks above 200mS/m in May, June, July and August 2011. Influent and effluent for OWWTP fluctuated between 75 and 200mS/l, with slight peaks above 200mS/l in June 2006 and June 2011. Gammams and Otjomuise influent mean were 147 and 150mS/l, while effluent means were 120 and 119mS/l respectively. Effluent did not comply with Namibian water quality effluent standards of 70mS/m.

Weekly data for EC from 20 January 2016 to 17 February 2016 indicated the following results. EC concentration levels for GWWTP influent ranged from 135 and 205mS/l, while effluent ranged from 150 and 160mS/l. EC concentration levels for OWWTP influent ranged from 130 and 175mS/l, while effluent ranged from 130 and 145mS/l. Means were as follows, GWWTP influent mean was 159mS/l, while effluent mean was

155mS/l. The otjomuise influent mean was mean 146mS/l, while effluent mean was 139mS/l. Overall EC was for both historical data and primary data were above effluent water quality standards of 70mS/m, and this might be as a result of high concentration influent coming into and leaving the different plants. Influent from OWWTP is expected to be highly concentrated compared to GWWTP because OWWTP treats domestic effluent from low-income suburbs that experience water cuts and inconsistency in water supply, while GWWTP treats domestic effluent from high-income suburbs that have a consistent water supply.

5.2.6 pH

Influent and effluent pH, for GWWTP for periods of 2004 to 2014 is shown in Figure 5-5. Influent and effluent remained uniform from pH7 and pH9, except for the peak in May 2007 on the influent graph. OWWTP's influent and effluent monthly average pH of for periods of 2004 of 2014 is shown in Figure 5-6. Influent and effluent remained uniform from pH 7 and pH 9. Effluent from the two treatment plants complied with effluent standards except for the mentioned peaks.

Weekly pH concentrations for GWWTP and OWWTP are shown in Figure 5-7 and Figure 5-8 respectively. Influent and effluent for the two treatment plants ranged from pH 7 and pH 8. Effluent remained within the Namibian effluent standards of pH 5.5 and pH 9.5 for the entire sampling period. Monthly means for influent were 8 and 13, and mean effluent were 8 and 12, for Gammams and Otjomuise in that order. For weekly sampled data, the two treatment plants had the same influent and effluent mean of pH 7. Generally, the pH value of pH 7 for both monthly averages and weekly sampling campaigns, for the two treatment plants lie within the Namibian effluent standards (Fallis, 1990).

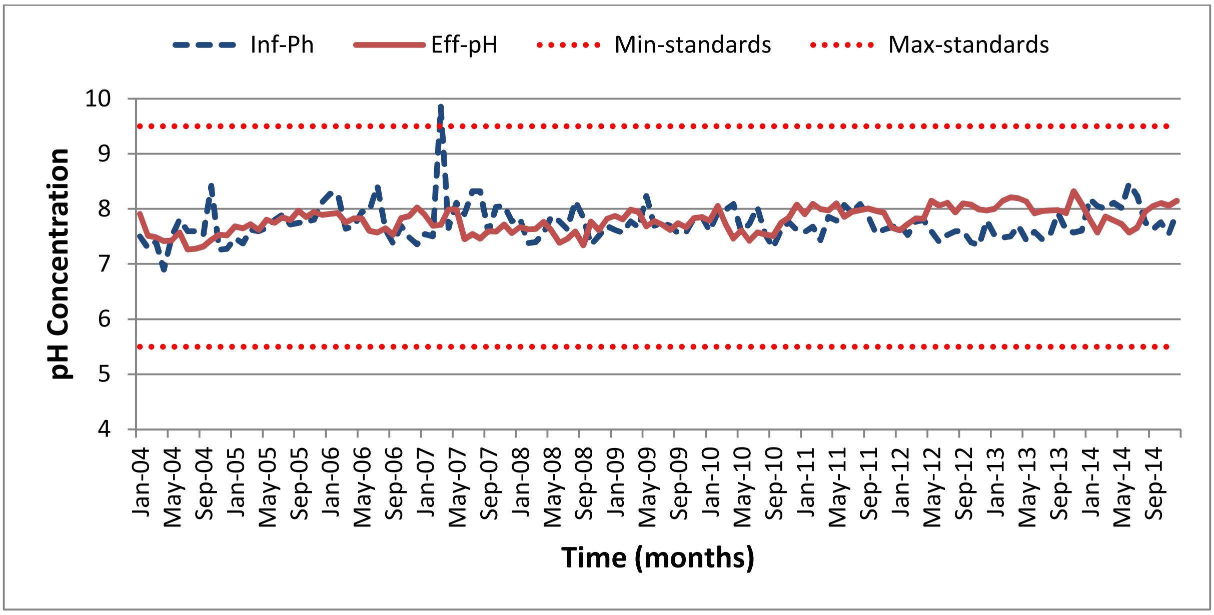

Figure 5-5: GWWTP monthly pH concentrations for periods from 2004-14

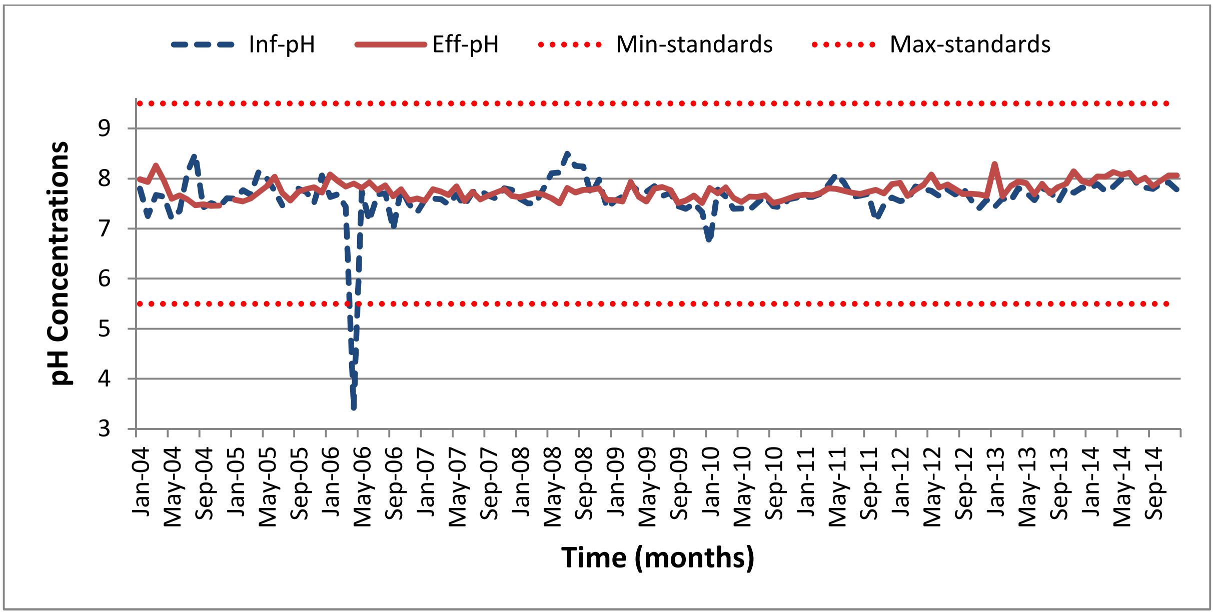

Figure 5-6: OWWTP monthly pH concentrations for periods from 2004-14

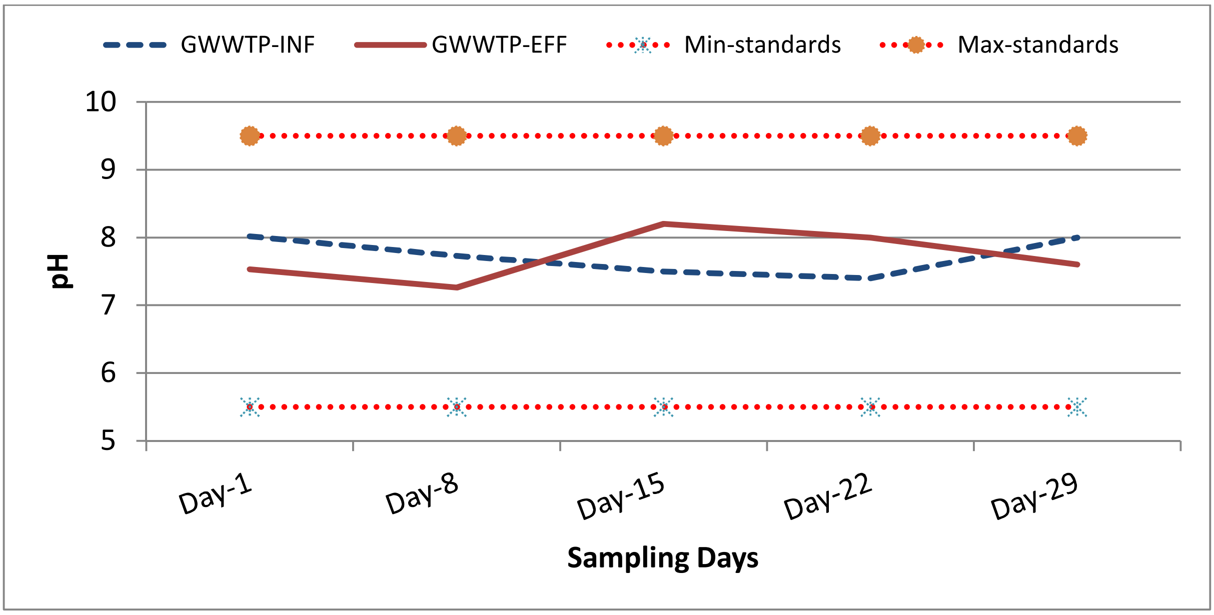

Figure 5-7: Weekly pH concentrations for GWWTP from 20 January 2016 to 17 February 2016

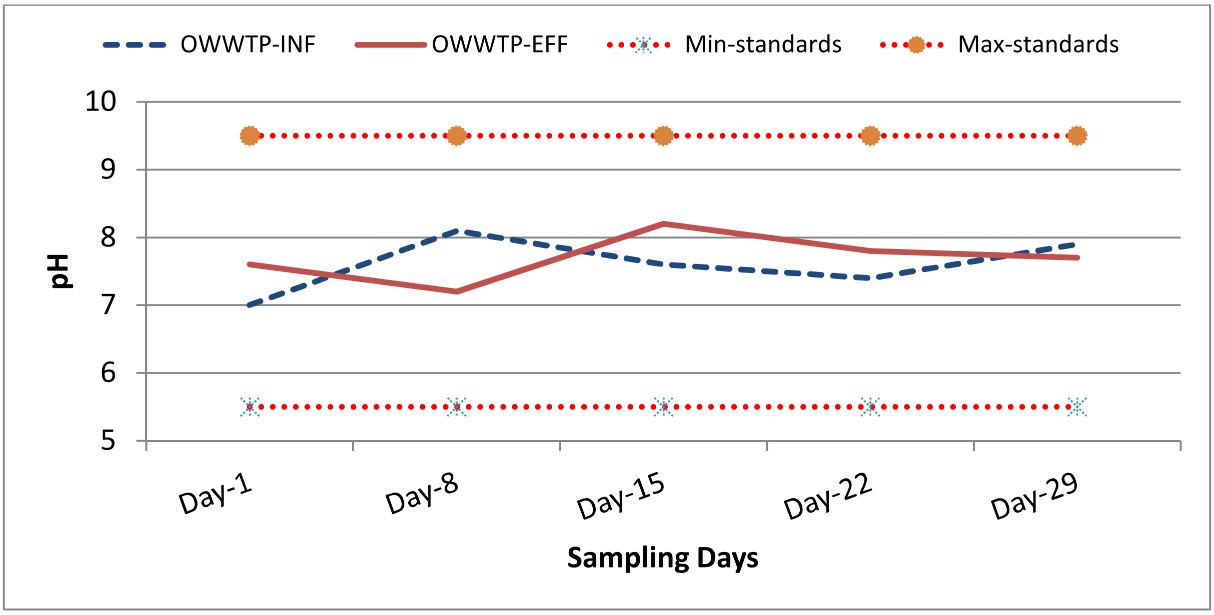

Figure 5-8: Weekly pH concentrations for OWWTP from 20 January 2016 to 17 February 2016

5.2.7 Biological oxygen demand

Biological Oxygen Demand (BOD) results for GWWTP for periods of 2004-14 indicated that influent varied throughout the 10 year period, with visible peaks in September and December 2005. Effluent complied with effluent standards throughout the 10 year period. GWWTP influent mean was 239mg/l, while effluent mean was 9.5mg/l. BOD results for OWWTP for periods of 2004-14 indicated that influent ranged between 238mg/l and 3650mg/l, with a mean of 1050mg/l and the highest peak was observed in June 2006. Effluent ranged between 21mg/l and 1441mg/l, with a mean of 246mg/l. Effluent did not comply with Namibian water quality effluent standards for BOD.

Current weekly BOD concentration levels for GWWTP (20 January to 17 February 2016), influent ranged between 90mg/l and 268mg/l, while effluent ranged between 9mg/l and 53mg/l. Effluent complied with BOD effluent standards in exception of sampling day 29 when effluent slightly rose above the standards by 3mg/l. Weekly BOD concentration levels for OWWTP influent ranged between 90mg/l and 270mg/l, while effluent ranged between 8mg/l and 81mg/l. Effluent complied with BOD effluent standards in exception of sampling day 29 when effluent slightly rose above the standards 81mg/l. Gammams wastewater treatment plant influent mean was 175mg/l and the effluent mean was 20mg/l. While Otjomuise influent mean was 175mg/l and the effluent mean of 35mg/l. Comparing historical and primary data, GWWTP complied with Namibian water quality effluent standards for historical data, as well as primary data. OWWTP's primary data complied with Namibian water quality effluent standards except for the last sampling campaign while there was non-compliance with historical data.

5.2.8 Chemical oxygen demand

Influent and effluent Chemical Oxygen Demand (COD) concentrations, of GWWTP for periods of 2004-14 are shown in (Figure 5-9). Influent ranged between 67.5 and 1240mg/l, with a mean of 708mg/l, and the highest peak was in October 2005. Effluent ranged between 6 and 149mg/l, with a mean of 40mg/l. Effluent complied with the

Namibian water quality effluent standard limit of 75mg/l, except for August 2006 and May 2013. OWWTP's influent and effluent COD concentrations for periods of 2004-14 are shown in (Figure 5-10). Influent and effluent fluctuated throughout the entire 10 year period. Effluent rarely complied with the Namibian water quality effluent standards. Influent means was 355mg/l, while effluent means was 91.5mg/l

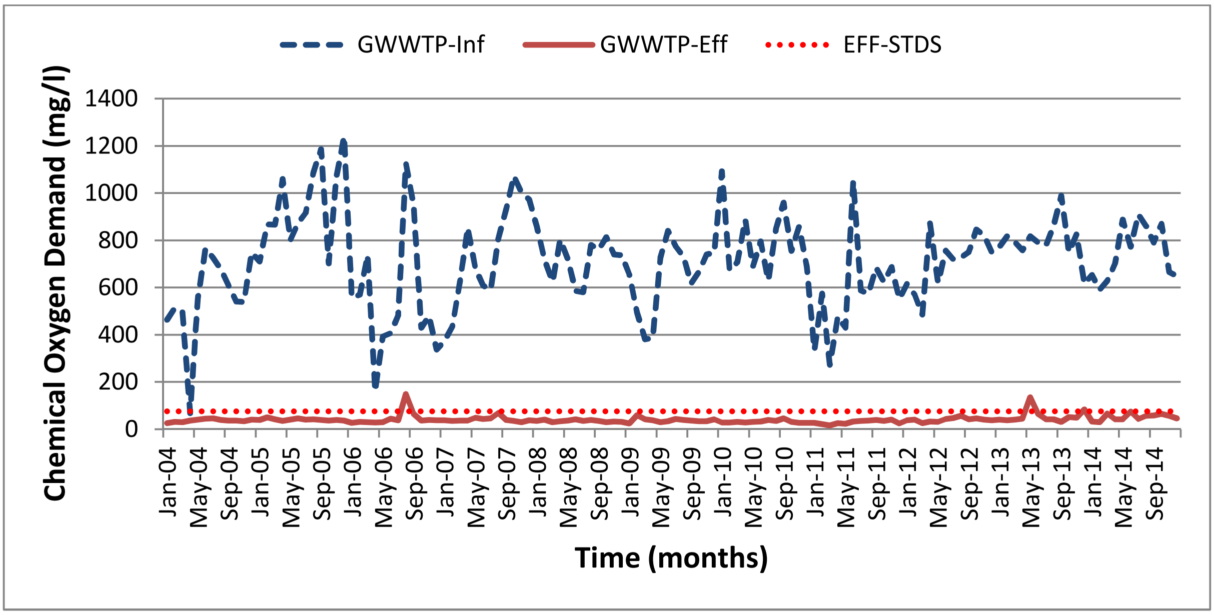

Figure 5-9: COD concentrations of GWWTP from 2004-14

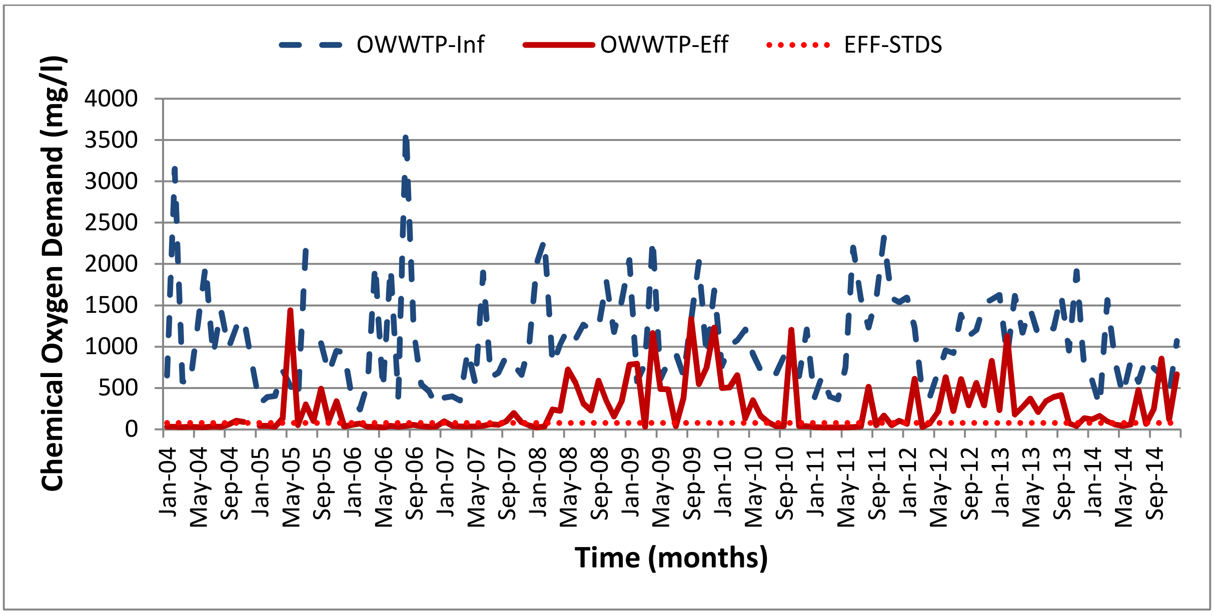

Figure 5-10: COD concentrations of OWWTP from 2004-14

GWWTPs' weekly COD concentrations for periods 20 January to 17 February 2016 are shown in (Figure 5-11). Influent ranged between 467 and 796mg/l, while effluent ranged between 27mg/l and 225mg/l. Effluent complied with Namibian water quality effluent standards in exception of sampling day 29 when effluent rose to 225mg/l and was above the Namibian effluent standards of 2013.

Weekly COD concentrations for OWWTP are indicated in (Figure 5-12). Influent ranged between 321mg/l and 819mg/l, while effluent ranged between 33mg/l and 218mg/l. Effluent complied with Namibian water effluent standards in exception of sampling day 29 when effluent rose to 218mg/l and was above the effluent standards. Gammams wastewater treatment plants mean influent was 518.4mg/l and mean effluent was 73mg/l. While Otjomuise wastewater treatment effluent was 530 and effluent was 103.

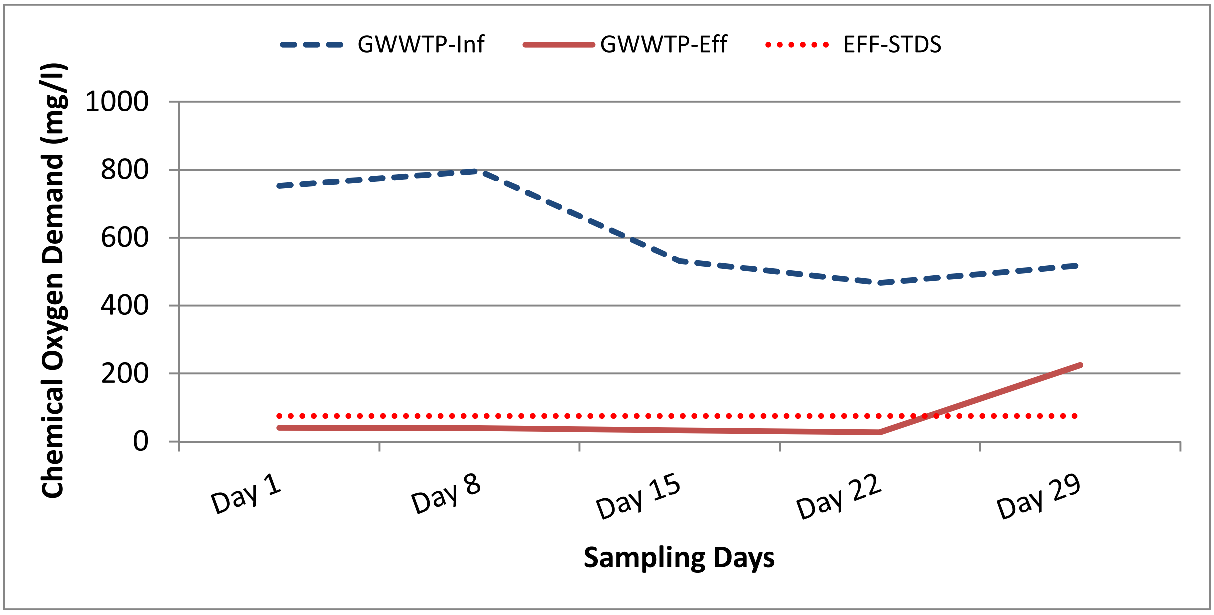

Figure 5-11: GWWTP's weekly COD concentrations from 20 January to 17 February 2016.

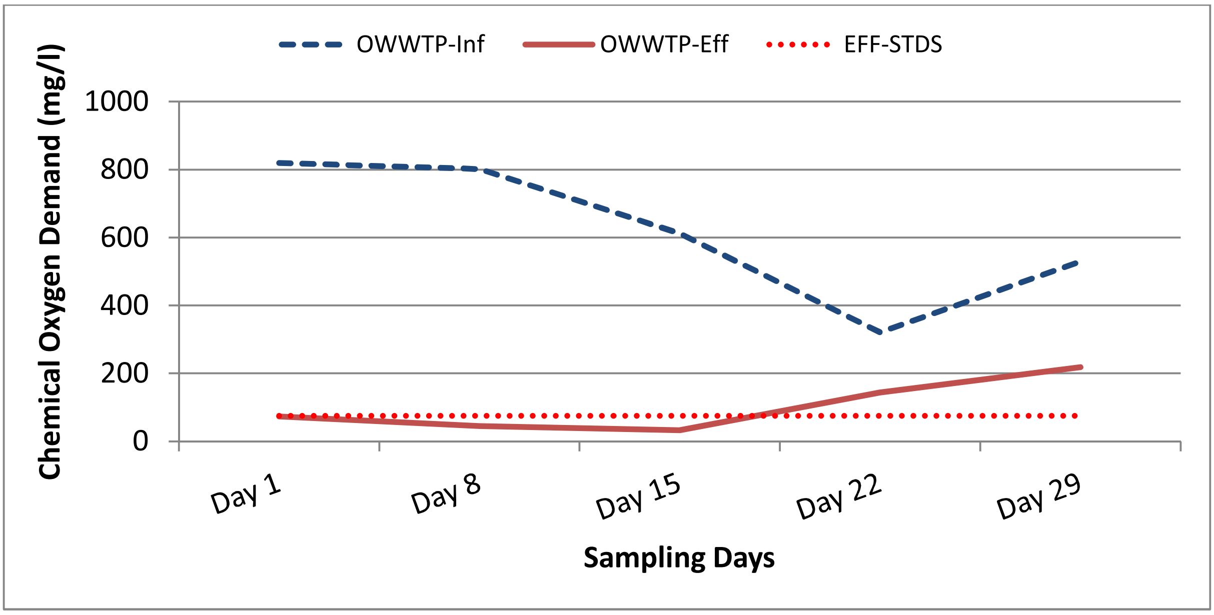

Figure 5-12: OWWTP's weekly COD concentrations from 20 January to February 2016.

GWWTP and OWWTP had a similar trend in compliance to the Namibian water quality effluent standards with primary data. Historical data showed a different trend, where

GWWTP complied and OWWTP did not comply with the Namibian water quality effluent standards.

5.2.9 Nitrogen

Total Kjeldahl Nitrogen (TKN) and Total Nitrogen (TN) were the two forms of nitrogen for this study. TKN consists of ammonia and organic nitrogen, and is a good indicator of wether a wastewater treatment plant is fully nitrifying or not. TN consists of TKN, nitrites, and nitrates and gives the total of all forms of nitrogen contributing to eutrophication of receiving waters.

Total Kjeldahl Nitrogen

Influent and effluent Total Kjeldahl Nitrogen (TKN) concentrations, of GWWTP for periods of 2004 to 2014 are shown in Figure 5-13. Gammams wastewater treatment plant's TKN influent graph depicts that of a bell-shaped (graph, starting with a rising limb, reaching a peak and then falling limb). The influent graph has peaked in July 2007, July 2009 and July 2011. Effluent graph remained rather a constant bellow the Namibian effluent standards of 33mg/l, with no significant peaks.

Influent and effluent TKN concentrations, of OWWTP for periods of 2004 to 2014 are shown in Figure 5-14. Otjomuise wastewater treatment plant's TKN influent and effluent graph depicts a similar trend to that of Gammams wastewater treatment plant, resembling a bell shape. Peaks on the influent graph correspond with peaks on the effluent graph. Influent peaks reaching 400mg/l occurred in September 2006 and April 2009. Effluent's compliance to Namibian effluent standards varied throughout the entire 10 year period.

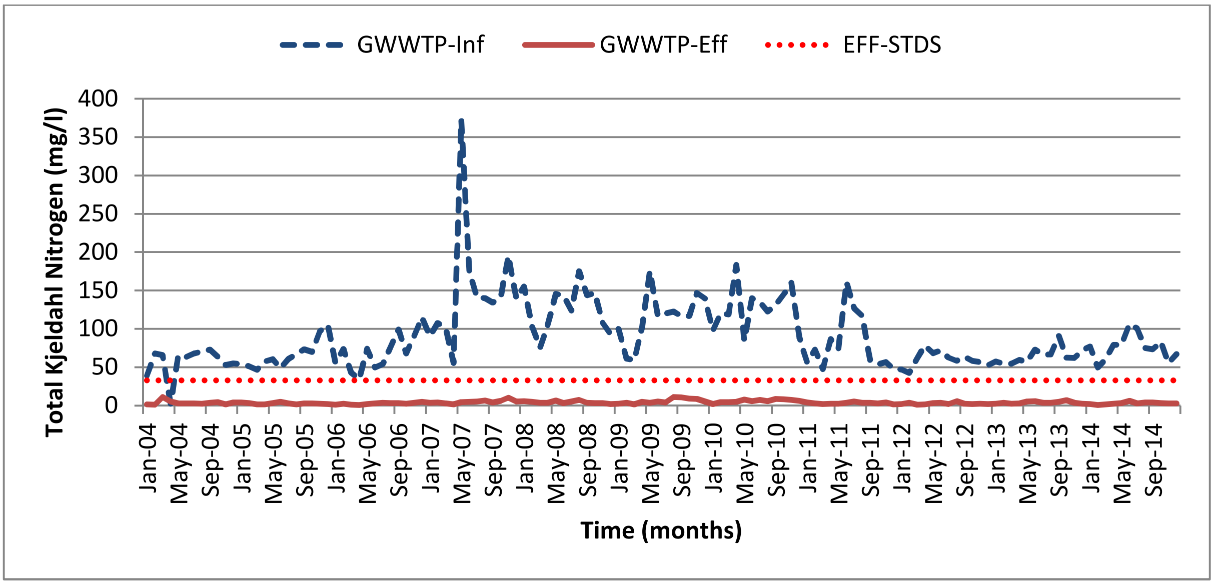

Figure 5-13: Average monthly concentrations of TKN for GWWTP for periods of 2004-14

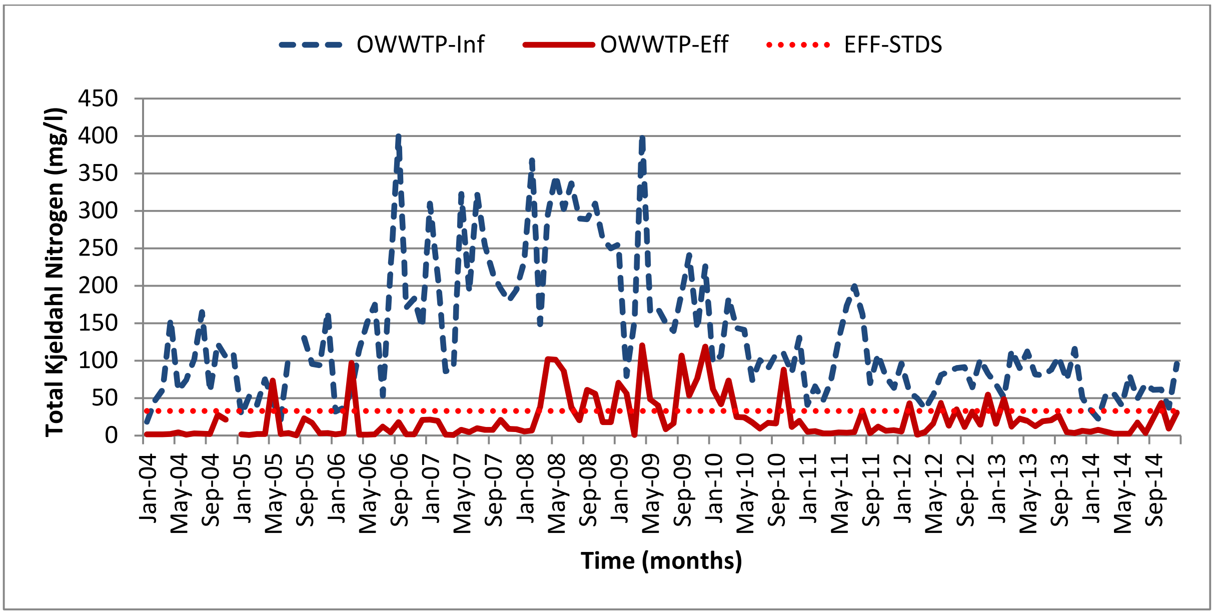

Figure 5-14: Average monthly concentrations of TKN for OWWTP from 2004-14

Averages of TKN for Gammams and Otjomuise wastewater treatment plants for influent, was 90mg/l and 132mg/l, while effluent was 4mg/l and 22mg/l respectively. The influent mean for Gammams wastewater treatment plant was 1mg/l and the effluent mean was 3mg/l, while Otjomuise influent mean was mean 0.8mg/l and the effluent mean was 0.6mg/l in that order.

Total Nitrogen

Weekly Total Nitrogen (TN) levels for GWWTP's influent ranged between 0.4mg/l and 3mg/l, while effluent ranged from 0.4mg/l and 6mg/l. Effluent complied with Namibian effluent standards for the entire sampling period. Weekly TN levels for OWWTP's influent ranged between 0.6mg/l and 1mg/l, while effluent ranged between 0.3mg/l and 0.8mg/l. Effluent Complied with Namibian effluent standards for the entire sampling period. Both TKN and TN effluent for the two plants complied with Namibian effluent standards GRN (2013), except for TKN at Otjomuise that varied throughout the 10 year period.

5.2.10 Phosphates

Orthophosphates are the inorganic forms of phosphates, which are used heavily in fertilizers and are often introduced to surface waters through runoff. Total phosphates are the sum of all forms of the phosphates; most commonly reported form of phosphate concentration.

Orthophosphates (OP)

Influent and effluent OP concentrations, of GWWTP from 200414 are shown in Figure 5-15. Influent and effluent graphs show a similar trend. As from January, both influent and effluent graphs begin to reduce. Effluent was above effluent standards graph as from February 2004, and only began to fluctuate below and above the effluents, standards graph after July 2009. Influent and effluent OP concentrations, of OWWTP for periods of 200414 are shown in Figure 5-16. There were variations with the influent graph, indicating peaks in July 2006, September 2009 and January 2013. The effluent graph's peaks followed the trend of the influent, and uniformly complied with the Namibian water quality effluent standards of 2mg/l, as from July 2010.

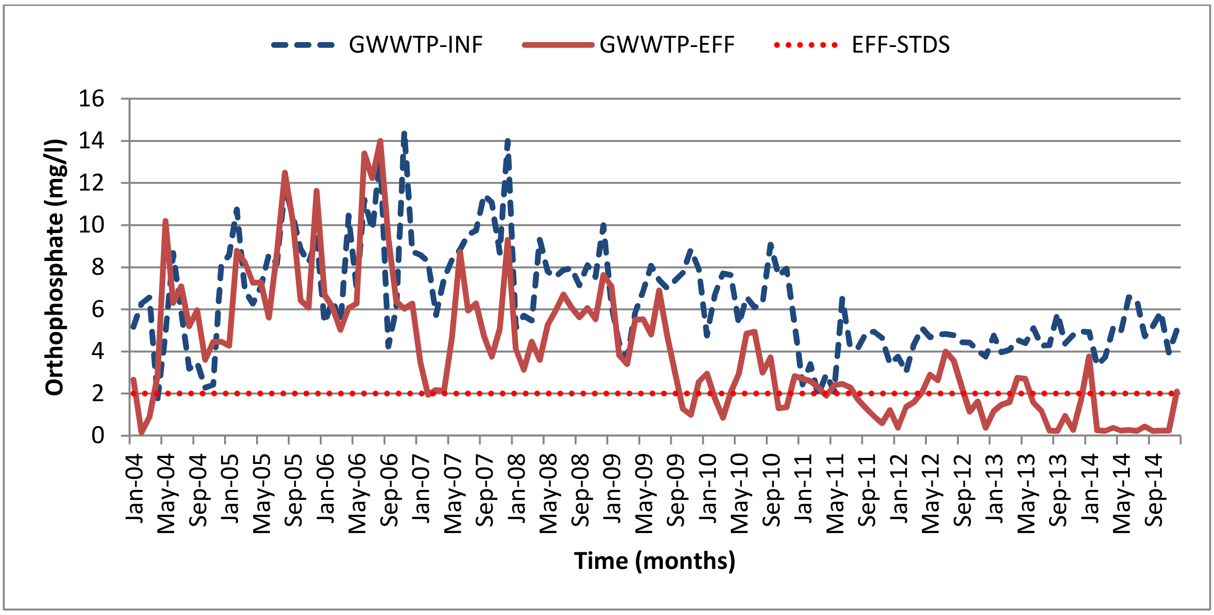

Figure 5-15: GWWTP's Orthophosphate concentrations from 2004-14

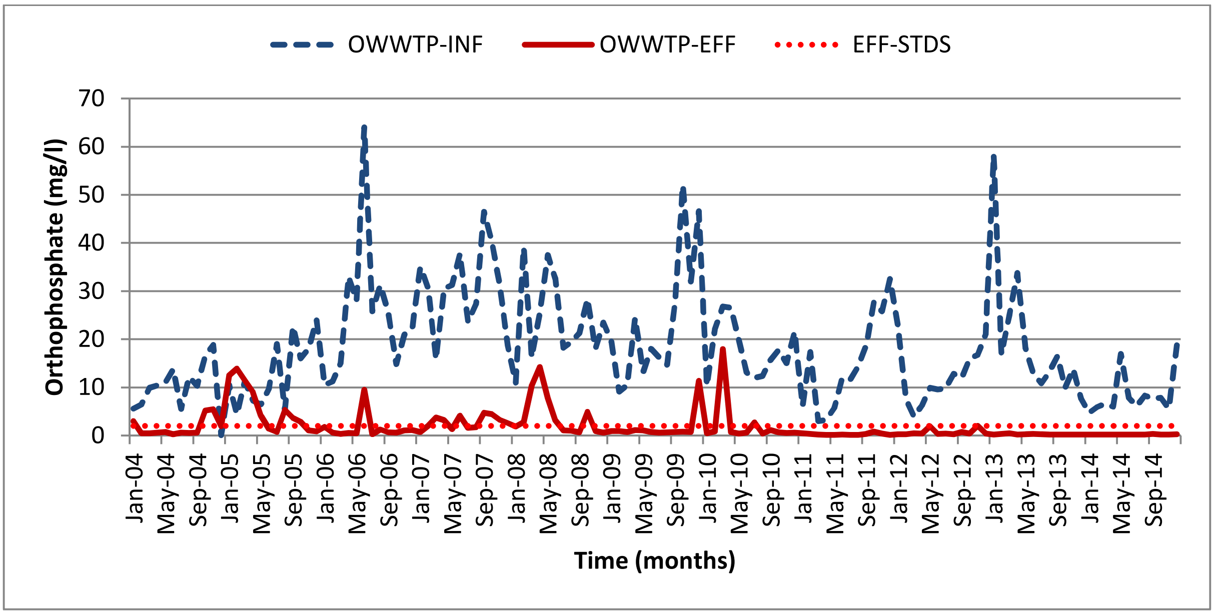

Figure 5-16: OWWTP's Orthophosphate concentrations from 2004-14

Total Phosphates

GWWTPs' weekly Total Phosphates (TP) concentrations from 20 January to 17 February 2016 are shown in Figure 5-17. Influent ranged between 0.5 and 8mg/l, while effluent ranged between 0.4 and 2mg/l. Effluent complied with the Namibian water quality effluent standards for the first four sampling campaigns, except for the last sampling campaign day 29 effluent rose to 2mg/l. OWWTPs' weekly TP concentrations for periods 20 January to 17 February 2016 are shown in Figure 5-18. Influent ranged between 0.6mg/l and 1mg/l, while effluent ranged between 0.3mg/l and 0.8mg/l.

GWWTP and OWWTP had orthophosphate influent means of 6 and 18mg/l, while effluent means were 6 and 2mg/l, respectively. The total phosphate for GWWTP influent mean was 16mg/l and the effluent mean was 2mg/l, while Otjomuise waste water treatment plant had an influent mean of 0.8mg/l and the effluent mean of 0.6mg/l. An increase in influent phosphate resulted in an increase in effluent phosphate. Both orthophosphate and total phosphate hardly complied with the Namibian water quality effluent standards. This could be attributed to phosphorus-containing detergents used in households that end up in domestic effluent (Correll, 1998 as cited by Igbinosa and Okoh, 2009).

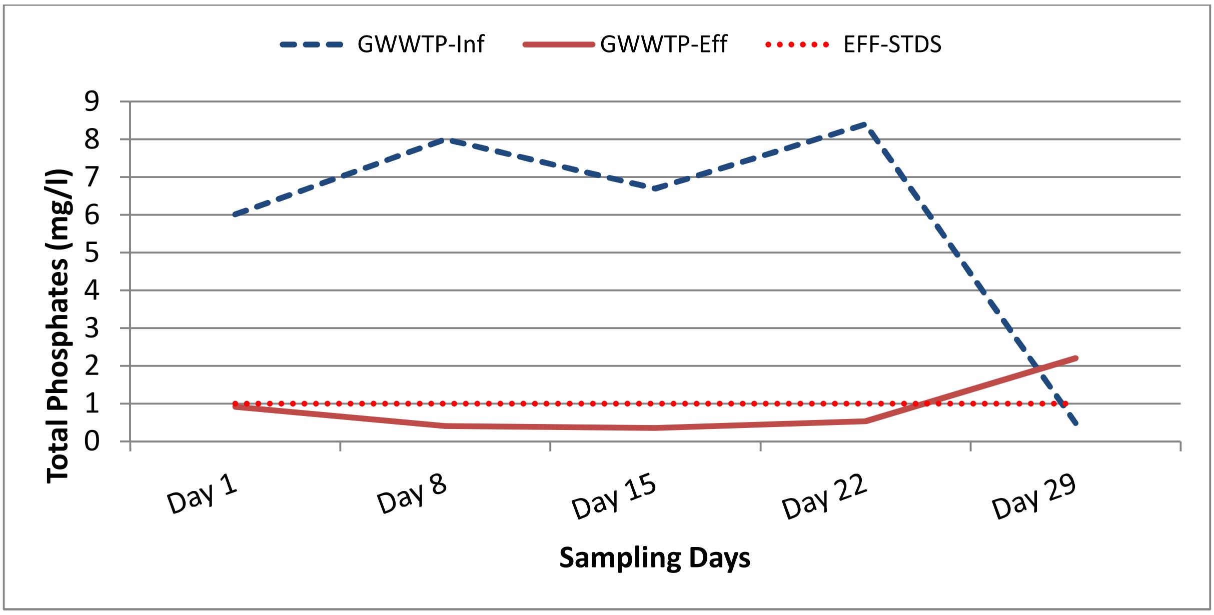

Figure 5-17: GWWTP's weekly total phosphates from 20 January to 17 February 2016

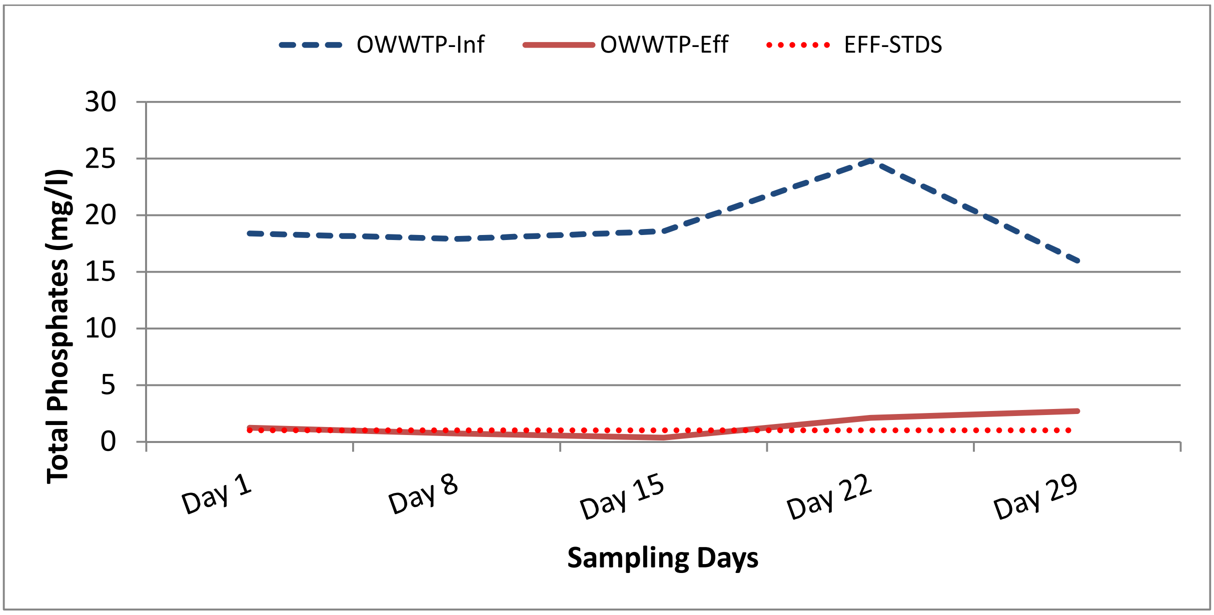

Figure 5-18: OWWTP's weekly total phosphates from 20 January to 17 February 2016.

Overall discussion

Both GWWTP and OWWTP did not comply with effluent standards for EC and TDS. GWWTP complied with the Namibian water quality effluent standards with parameters including, TSS, TKN, BOD_5 and COD, while, with similar parameters Otjomuise's effluent did not comply. Temperature, pH, and orthophosphates effluent compliance were similar for both the wastewater treatment plants.

Despite the fact that GWWTP is operating above design capacity, it is still doing fairly well compared to OWWTP, operating under design capacity, this could be attributed to the fact that GWWTP has been given much attention in terms of upgrading the different sections of the treatment plant. GWWTP is highly valued because it supplies treated effluent to the Windhoek reclamation plant that treats water to potable standards.

The month with the least compliance of influent to effluent standards and most observed influent and effluent graph variations was May for different years. Hence it can be concluded that influent and effluent concentrations were not affected by temperature changes or rainfall patterns, because it would be expected for concentrations in influent to be less concentrated around the month of December, which is Namibia's wettest month, but it was not the case, influent concentration fluctuated throughout the year for all the years. It would also be expected for influent and effluent concentrations to be similar each year between the months of June to august as that's when Namibian winter takes place, again no such trend was observed.

Influent and effluent concentrations might be affected by other factors such as the consistency in water supply in the residential areas where effluent being treated comes from. Otjomuise treats wastewater from the southern part of the city, which consists of informal settlements and low-income class, and water supply is not consisted, therefore it is expected for the water to be more concentrated with organic and inorganic nutrients. Similarly, Kumar and Pinto (2010), attributed highly concentrated influent to heavy organic and inorganic loading with less liquid content.

5.3 Treatment Efficiencies for Gammams and Otjomuise wastewater treatment plant

The objective was to assess the treatment efficiencies of GWWTP and OWWTP, using historical and primary data. Research by Ramadan *et al.* (2016) evaluated the performance of different wastewater treatments, and this included assessing water quality parameters such as nitrogen and phosphates. Kumar and Pinto (2010), determined treatment efficiencies by evaluating suspended solids, BOD_5 and COD.

Treatment efficiencies for Gammams and OWWTPs, for historical data (2004 to 2014) is shown in Figure 5-19. TSS was 89% and 47%, while for TDS, was 0% and 9% for Gammams and Otjomuise respectively. The COD/ BOD_5 effluent ratio for both Gammams and Otjomuise was 3.0, indicating that there is a relationship Ramadan *et al.* (2016) reported that the typical COD/ BOD_5 ratio of domestic wastewater is usually in the range 1.25 to 2.5. This means that the influent wastewater consists of human waste and is not contaminated with industrial waste. The two WWTP's COD/ BOD_5 ratio is slightly higher than 2.5, this indicates that the treatment plant's influents contained traces of industrial waste.

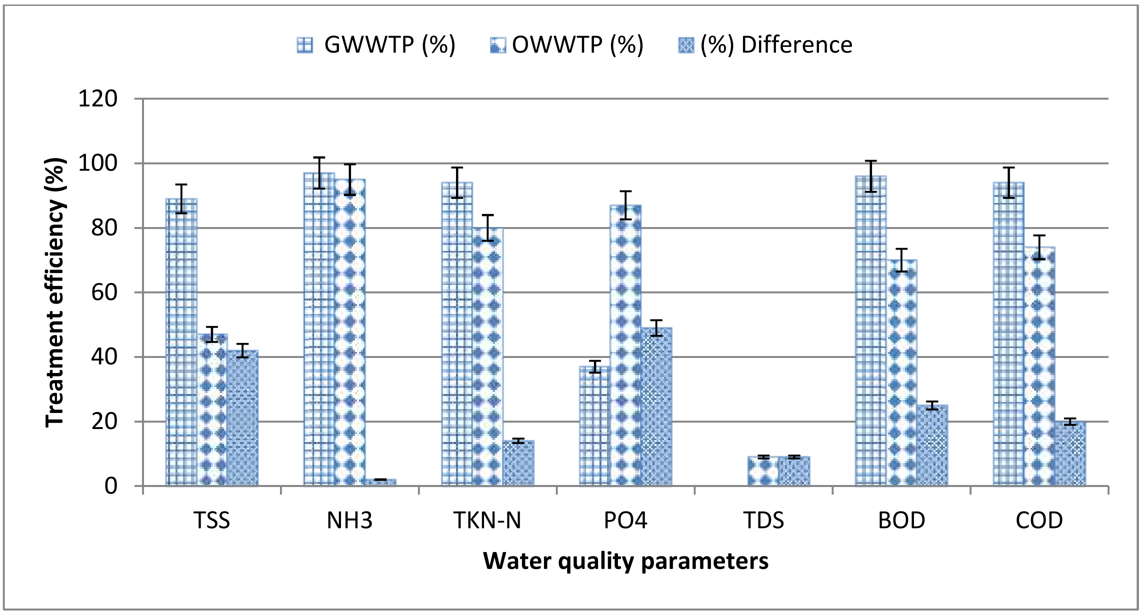

Figure 5-19: GWWTP and OWWTP treatment efficiencies from 2004-14

Kumar and Pinto (2010) stated that expected removal efficiency of TSS is from 85-90%, with this expectation Gammams performed quite well in removing TSS as compared to Otjomuise, which performed poorly. Expected removal efficiency in TDS is 70-80%, compared to this both Gammams and OWWTPs performed poorly in the removal of TDS.

Gammams and Otjomuise wastewater treatment plants had the following treatment efficiencies for ammonia, 97%, and 95%, TKN had 94% and 80 and orthophosphates had 37% and 87% respectively. Low TKN removal at Otjomuise wastewater treatment plant could be attributed to the process being fully aerated, therefore, not allowing for denitrification which is more effective at nitrogen removal (Adonadaga, 2014). Increasing the influent organic load concentration decreases the COD, ammonia and phosphorous removal efficiency (Ibrahim, 2013). This is not the case for the low removal efficiency of Orthophosphates, as Gammams has less organic load than Otjomuise, high COD, and Ammonia removal efficiencies, thus this can only be attributed to the fact that other forms of phosphates were converted to orthophosphates. Treatment efficiency for BOD_5 was 96% and 70% for Gammams and Otjomuise in that order and COD was 94% and 74% in that order.

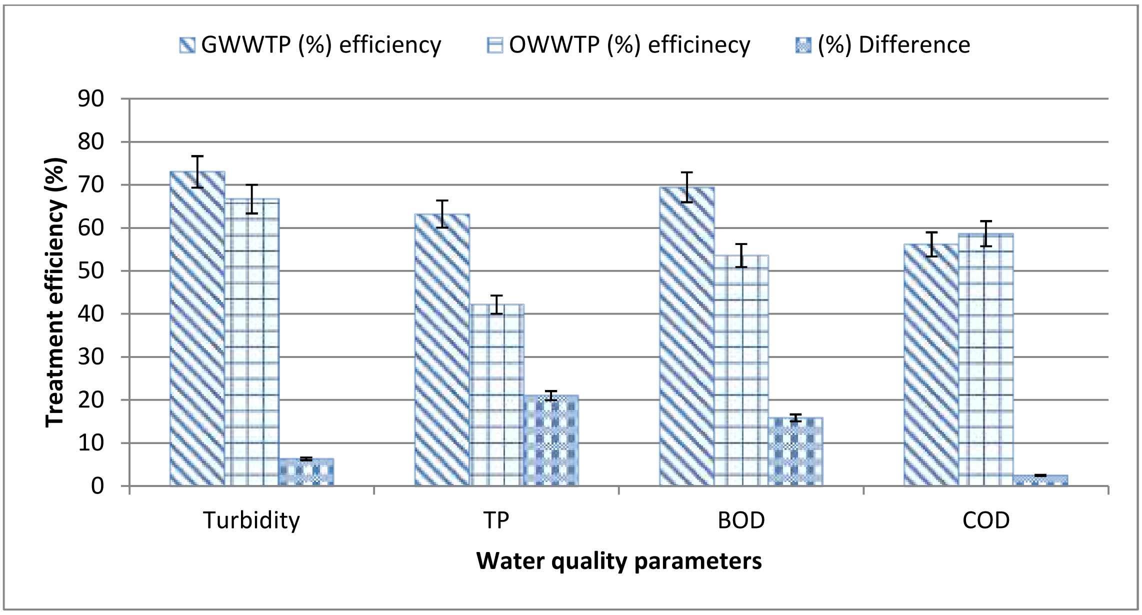

Figure 5-20: GWWTP and OWWTP treatment efficiencies for 20 Jan 2016 to 17 Feb 2016

Gammams and OWWTPs treatment efficiency for primary (20 January 2016 to 17 February 2016) data is shown in Figure 5-20. Treatment efficiency for turbidity was 73% and 67%, for Gammams and Otjomuise in that order. They are no effluent standards for turbidity in the Namibian Water Act of 1956 amended in the Water Resources Management Act of 2013. There is also no specified effluent standard discharge for turbidity in South Africa (Igbinosa and Okoh, 2009).

Total phosphates' treatment efficiency was 63% and 42% for Gammams and Otjomuise respectively. Otjomuise's influent total phosphates were almost twice as Gammams influent total phosphates, and this could be the reason for the above average treatment efficiency at Gammams and below average treatment efficiency for Otjomuise.

Gammams and Otjomuise had following treatment efficiencies, for BOD 69°C and 54%, and for COD 56% and 59% in that order. The influent and effluent ratio for COD/BOD ranged between 3.0 and 3.7, again this could be attributed to the fact that they are traces of industrial effluent coming into the two wastewater treatment plants (Ramadan et al. 2016).

5.4 Assessment of the contribution to eutrophication using a Life Cycle Assessment approach

This section aimed at to assess Gammams wastewater treatment plant's eutrophication contribution using a Life Cycle Assessment (LCA) approach. This was done by using CML methodology modelled in software called GaBi, with inputs into the model consisting of GWWTP water quality parameters and electricity consumption. Electricity consumption for both historical and primary water quality data was reduced to kWh.ML/d as shown in Table 5-1.

5.4.1 Electricity Consumption

Average electricity consumption for 100ML Activated sludge treatment process is 294.33 kWh/d (Scheepers et al. 2009).

Gammams treats about 40ML per day: (0.4 x 294.3kWh/d) = 117.732kWh/d

Gammams used 117. 732kWh/d.

Per 1ML/d : (117.732kWh/d/40) = 2.943kWh/d

Table 5-1: Estimated electricity consumption used in the GaBi Software

Life Cycle Stage	Percent Plant Electricity (%)	Sum of flows	kWh/kg (10^{-7})
Screening and grit removal	0.14	0.14	4.12
Pumping	17.69		
Primary sedimentation	1.95	19.64	577
Aeration	62.86		
Secondary clarifiers	2.22	65.08	1910
Primary disinfection	0		
Sludge thickening and dewatering	13.64		
Sludge incineration	1.5	15.14	445
Sum	100	100	2940

Water quality parameters were also reduced to a single unit of kg/d required when using GaBi, indicated in Table 5-2, for historical data and Table 5-3, for primary data.

Water quality parameters

The plant is treating 40ML/d

Orthophosphate loading was 6.4ML/d

To get orthophosphate loading per unit volume

$$= \frac{6.4\frac{ML}{d}}{40\frac{ML}{d}} = 0.17\frac{\mathrm{ML}}{\mathrm{d}}$$

$$= \frac{0.17\frac{ML}{d}}{1000} = 0.00017\frac{\mathrm{m}^3}{\mathrm{d}}$$

$$= \frac{0.00017\frac{m^3}{d}}{1000} = 0.00000017\ \frac{\mathrm{kg}}{\mathrm{d}}$$

Gammams wastewater treatment plant's eutrophication contribution for historical and primary data is shown in Figure 5-21 and Figure 5-22 respectively. Figure 5-21 indicated an input/influent value of 15.9kg orthophosphate loading per unit volume of water treated per day, while the output/effluent value for historical data was 0.906kg orthophosphate loading per unit volume of water treated per day, over a period of 10 years. Similarly, Figure 5-22 indicated input/influent value of 18.3kg orthophosphate loading per unit volume of water treated per day while, the output for primary data was 3.6kg orthophosphate loading per unit volume of water treated per day, over a two months period.

Table 5-2: GWWTP water quality data reduced to kilograms per day (2004-14)

Parameter	Influent		Effluent	
	Average loading per 40ML/d	kg/d (10^{-7})	Average loading per 40ML/d	kg/d (10^{-7})
Temp (°C)	21.6	5.4	21.8	5.45
Total suspended solids TS:105°C-TDS:1)(mg/l)	393	98.3		0.243
Ammonia (NH3-N)	44.7	11.2	0.97	0.928
Total Kjeldahl nitrogen (TKN) (mg/l)	90	22.5	3.71	1.55
Orthophosphate (mg/l)	6.8	1.7	6.21	2.03
pH	7.77	1.9	8.1	295
Conductivity (mS/m 25°C)	146.3	36.6	118	180
Total Dissolved Solids (TDS:180°C) (mg/l)	797	199	721.8	10.3
Chemical Oxygen Demand (mg/l)	723	181	41.2	5.45

Table 5-3: GWWTP water quality data reduced to kilograms per day (20 Jan 2016 to 17 Feb 2016)

Parameter	Influent		Effluent	
	Average loading per 40ML/d	kg/d (10^{-7})	Average loading per 40ML/d	kg/d (10^{-7})
Temperature (°C)	25.4	6.35	25.7	6.42
Turbidity (NTU)	207.5	51.9	56.0	14
Total nitrogen (mg/l)	1.2	0.29	2.5	0.62
Total phosphorus (mg/l)	5.9	1.48	2.2	0.55
pH	7.7	1.93	7.7	1.93
Conductivity (mS/m 25°C)	159.0	398	155.0	38.8
Chemical Oxygen Demand (mg/l)	518.4	130	227.2	56.8

Orthophosphate loading was reduced by 14.9kg (94%) for historical data over a period of 10 years, while the reduction for primary data was 14.7kg (80%). For both historical and primary data sets, there were significant reductions in the orthophosphate released into the environment. Thus it can be concluded that the treatment plant significantly reduces eutrophication in the environment, when comparing the reduction in eutrophication contribution during the treatment process, using both historical and primary data.

Nitrogen and phosphates in various forms are the significant contributors to eutrophication. However, the LCA results did not include nitrogen in all its different forms. Eutrophication estimating contribution was solely based on phosphates. This could be attributed to the fact that nitrogen in all its various forms was not significant enough to be modelled in the software, as phosphates were. for example, a study by Svanstrom (2016), stated that nitrogen in wastewater is typically diverted either to air as nitrogen gas (increasingly, as biological nitrogen removal is commonly being installed in WWTPs today) or to sludge.

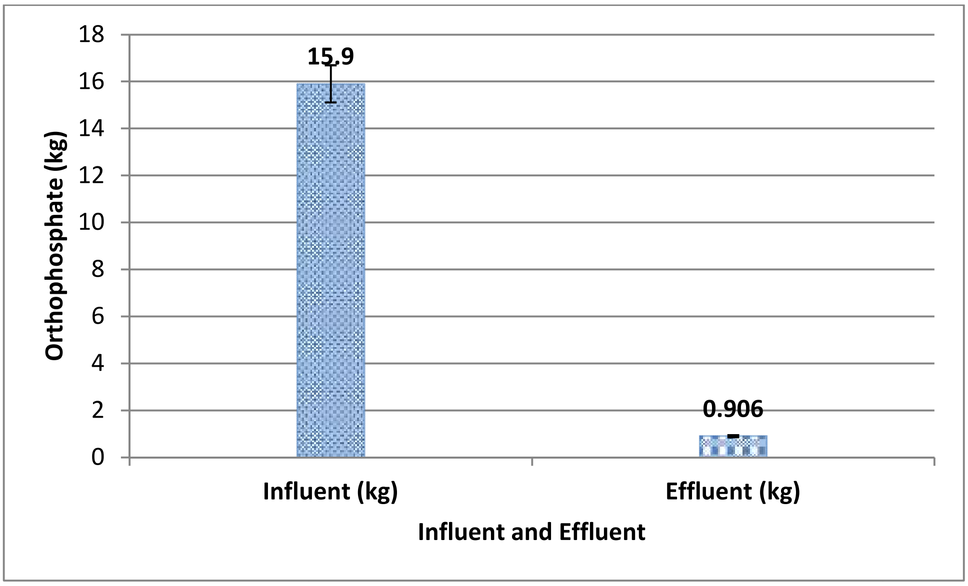

Figure 5-21: GWWTP and OWWTP LCA results for 2004-14

During wastewater treatment nitrogen is capable of escaping as Ammonia gas, and in this form, an LCA model will evaluate the ammonia gas in a different impact category of acidification instead of eutrophication. Phosphates are easier to manage and to model the as compared to nitrogen since it does not notably transfer into air-borne forms in wastewater treatment and sludge management (Svanstrom, 2016). As a result, the goal of wastewater should treatment when it comes to phosphates should be to transfer enough phosphates to sludge to avoid eutrophication of receiving waters.

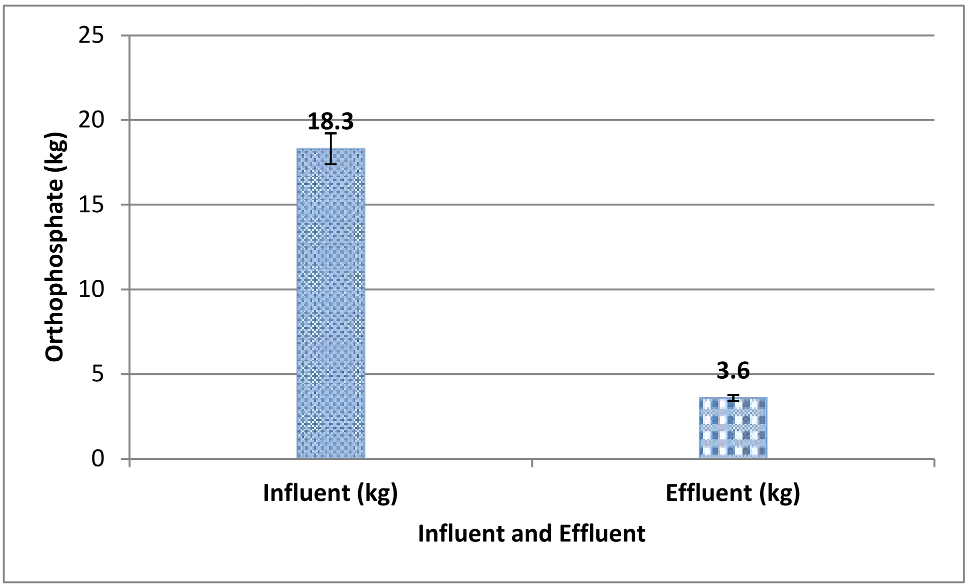

Figure: 5-22: GWWTP and OWWTP LCA results for 20 January 2016 to 17 February 2016

CHAPTER 6 : CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions were made from this study:

1. Total kjeldahl nitrogen and total nitrogen from Gammams complied with effluent standards, while with the same parameters Otjomuise compliance was not stable throughout the entire period.
2. Both treatment plants' orthophosphates fluctuated throughout the entire period. The fluctuations in phosphates concentration in the influent pose as a threat to ecosystem health as it can result in eutrophication of receiving waters.
3. Gammams is operating almost double its treatment capacity but is still able to treat effluent to Namibian water quality effluent acceptable standards, significantly reducing eutrophication contribution as compared to the trance amount being released

4. Gammams's orthophosphates removal efficiency was quite poor (37%), compared to Otjomuise's orthophosphate removal, posing as a threat to receiving waters, as this can result in eutrophication. OWWTP significantly removed orthophosphate (80%).

5. Both total phosphates and orthophosphates for the two treatment plants were high for influent and effluent flow, this could be attributed to the detergents that are used in homes and end up in domestic effluent.

6. A Life Cycle Assessment approach was conducted for Gammams wastewater treatment plant. This was modelled in the in the GaBi software to determine the contribution of Gammams wastewater treatment plant towards eutrophication of receiving waters. Results indicated that of all the water quality parameters modelled in the software, orthophosphate contributed significantly towards eutrophication of receiving waters

7. In assessing the overall performance of the two wastewater treatment plants, all the water quality parameters orthophosphate seemed to be the one that notably pose a threat towards eutrophying receiving waters

6.2 Recommendations

The following recommendations were compiled from this study:

1. Monitor effluent closely to ensure that effluent complies with the Namibian effluent standards stipulated in the Namibian Water Act of 1956, and amended in the Water Resources Management Act of 2013.

2. Constant upgrading of the Gammams wastewater treatment plant should also be applied to Otjomuise wastewater treatment plant, as Gammams is already operation above design capacity, thus Otjomuise is most likely to bear the responsibility of treating wastewater from the suburbs being established. Should Otjomuise start treating water to acceptable standards eater quality standards it might also feed Windhoek reclamation plant, securing water supply.

3. Gammams and Otjomuise wastewater treatment plants should pay attention to phosphates released into the environment, mechanisms to ensure efficient removal of phosphates should be adopted as it the parameter that seems to significantly contribute to receiving waters.

6.3 Recommendations for further research

1. More research is needed on Otjomuise wastewater treatment plant, as little to no literature exists on the plant. And it is only by researching that faults can be detected and repaired for the plant to function properly. Treated effluent can be safely discharged into the environment, streams, rivers and can be reused for irrigation of public and private gardens

2. Further research could be done on the purification capacity of receiving waters. As well as Research on the final effluent compared receiving waters.

3. Research can also be done on comparing water quality after primary treatment, secondary treatment and after tertiary treatment, on both treatment plants, as this could provide more detailed information on the operation of the treatment plants.

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APPENDICES

Appendix 1: Interview Guide

Section A: Background information on the organisations

1. What is your position?
2. Roles and responsibilities within the organisation?
3. Years of experience in the current position?

Section B: Questions for the Goreangab Dam Manager

1. What are the purposes of the dam (activities)?
2. What are the sources of water into the dam (Name of the river(s)
3. Water level changes over the years
4. Water quality changes over the years (from 2005) (clearness and weeds visibility)
5. Who are the different uses of water in the dam (activities)
6. Challenges faced in maintaining and operations of the dam
7. How are the challenges addressed (Mitigation and adaptation measures in place)
8. Any Annual reports and publications available to the public
9. Was an EIA conducted in the establishment of the Dam
10. Is your organisation in any way linked to Gammams/Otjomuise Wastewater Treatment Plant? How?

Section C: Questions for the Gammams/ Otjomuise wastewater treatment Manager

1. Sources of the wastewater received
2. What are the different chemicals added during the process (different stages?) and the different demand for this chemicals thought the year
3. What is the amount of chemicals used and how frequent
4. Who are the different stakeholders/users for the final products (effluent and sludge)
5. Average electricity used
6. Challenges faced with regards to the wastewater treatment plant
7. Mitigation and adaptation measures in place to address challenges.
8. Any annual reports and publications available to the public
9. What is your organisation’s role towards Goreangab dam

Section D: Questions for the WINGOC Manager

1. Does your organisation use water from the Goreangab dam (explain answer… if yes/no why?)
   if not why did they stop?
2. Challenges faced compared to other water sources
3. Mitigation and adaptation measures in place

Appendix 2: Effluent Standards

Wastewater effluent standards

Parameter	**Units**	**Maximum allowable levels**
Temperature	°C	35
Total Suspended Solids	mg/l	25
Total Dissolved Solids (TDS)	mg/l	Not more than 500 mg/l >influent
pH	Units	5.5-9.5
Biological Oxygen Demand (BOD)	mg/l	50
Chemical Oxygen Demand (COD)	mg/l	75
Total Kjeldahl Nitrogen	mg/l	33
Orthophosphate	mg/l	2
Total Phosphate	mg/l	1

Appendix 3: Statistical tables

Gammams wastewater treatment plant

		Temp_Inf	Turbidity_Inf	TN_Inf	TP_Inf	pH_Inf	EC_Inf	BOD_Inf	COD_Inf	Temp_Eff	Turbidity_Eff	TN_Eff	TP_Eff	pH_Eff	EC_Eff	BOD_Eff	COD_Eff
N	Valid	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Missing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean		25.4	207.5	1.2	5.9	7.7	159.0	174.5	518.4	25.7	56.0	2.5	2.2	7.7	155.0	53.3	227.2
Std. Error of Mean		0.8	51.1	0.5	1.4	0.1	12.4	53.4	134.0	0.9	50.3	1.2	1.6	0.2	1.6	44.2	192.5
Median		25.0	260.0	0.9	6.7	7.7	155.0	253.4	531.0	25.0	6.4	1.1	0.5	7.6	155.0	9.4	39.0
Std. Deviation		1.9	114.3	1.1	3.2	0.3	27.7	119.3	299.6	2.0	112.4	2.7	3.7	0.4	3.5	98.8	430.4
Range		5.2	266.3	2.6	7.9	0.6	70.0	261.9	751.0	5.0	252.6	6.0	8.4	0.9	10.0	222.0	970.1
Minimum		22.8	4.7	0.4	0.5	7.4	135.0	6.0	45.0	23.0	4.4	0.4	0.4	7.3	150.0	8.0	26.9
Maximum		28.0	271.0	3.0	8.4	8.0	205.0	267.9	796.0	28.0	257.0	6.4	8.7	8.2	160.0	230.0	997.0

Otjomuise wastewater treatment plant

		Temp_Inf	Turbidity_Inf	pH_Inf	Conductivity_Inf	Nitrates_Inf	Total Phosphates_Inf	BOD_Inf	COD_Inf	Temp_Eff	Turbidity_Eff	pH_Eff	Conductivity_Eff	Nitrates_Eff	Total Phosphates_Eff	BOD_Eff	COD_Eff
N	Valid	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
	Missing	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mean		24.5	236.0	7.6	146.0	0.8	16.2	174.5	529.2	24.0	78.6	7.7	139.0	0.6	9.4	81.0	218.8
Std. Error of Mean		0.8	57.8	0.2	7.8	0.1	3.9	50.8	141.4	0.7	43.9	0.2	2.9	0.1	8.3	55.3	146.3
Median		25.0	264.0	7.6	145.0	0.8	18.4	230.0	612.0	24.0	45.0	7.7	140.0	0.7	1.2	27.0	73.0
Std. Deviation		1.9	129.3	0.4	17.5	0.2	8.8	113.6	316.1	1.5	98.1	0.4	6.5	0.2	18.5	123.6	327.2
Range		4.3	351.9	1.1	45.0	0.4	23.4	250.1	727.0	3.9	239.9	1.0	15.0	0.5	42.2	292.0	766.0
Minimum		22.0	25.1	7.0	130.0	0.6	1.4	20.0	92.0	22.1	7.1	7.2	130.0	0.3	0.4	8.0	33.0
Maximum		26.3	377.0	8.1	175.0	1.0	24.8	270.1	819.0	26.0	247.0	8.2	145.0	0.8	42.5	300.0	799.0

Appendix 4: An example of Treatment efficiency calculations

An example of calculated treatment efficiencies for Orthophosphates and chemical oxygen demand

$$\mathbf{TE} = \frac{(\mathbf{Input}-\mathbf{Output})}{\mathbf{Input}} \boldsymbol{X}\ \mathbf{100} \qquad \textbf{Equation 2}$$

Orthophosphates

$$\mathbf{TE} = \frac{\left(5.2\frac{mg}{l}-2.7\frac{mg}{l}\right)}{5.2\frac{mg}{l}} \boldsymbol{X}\ \mathbf{100} \qquad = \mathbf{96.1\%}$$

Total kjeldahl nitrogen

$$\mathbf{TE} = \frac{\left(39.0\frac{mg}{l}-1.5\frac{mg}{l}\right)}{39.0\frac{mg}{l}} \boldsymbol{X}\ \mathbf{100} \qquad = \mathbf{96.2\%}$$

Chemical xygen demand

$$\mathbf{TE} = \frac{\left(163.8\frac{mg}{l}-26.0\frac{mg}{l}\right)}{163.8\frac{mg}{l}} \boldsymbol{X}\ \mathbf{100} \qquad = \mathbf{94.4\%}$$

Appendix 5: Fieldwork Plan

Data description	Period	Sampling time	Sampling Frequency	Place/location of sampling	Parameters to be tested	Number of data sets
Background information of the WWTPs	14 Dec2015 to 22 Jan 2016	8:00 – 13:00		MAWF City of Windhoek GWWTP and OWWTP		
Historical Waste quality data	14 Dec2015 To 29 Jan 2016	8:00 – 13:00		City of Windhoek Laboratory		Data from 2004 - 2014
Water Sampling and quality Analysis	20 Jan 2016	07:30 – 10:00	Grab sampling	Influent and effluent point of GWWTP and OWWTP	• Biological Oxygen Demand (BOD) • Chemical Oxygen	4

Water Sampling quality and Analysis	27 Jan 2016	07:30 – 10:00		Influent and effluent point of GWWTP and OWWTP		4
Water Sampling quality and Analysis	3 Feb 2016	07:30 – 10:00		Influent and effluent point of GWWTP and OWWTP		4
Water Sampling quality and Analysis	10 Feb 2016	07:30 – 10:00		Influent and effluent point of GWWTP and OWWTP		4
Water Sampling quality and Analysis	17 Feb 2016	07:30 – 10:00		Influent and effluent point of GWWTP and OWWTP		4
20 samples will be collected, from 4 sampling points and there will be 5 sampling campaigns						

Appendix 6: Raw Data; Gammams wastewater treatment plant influent (Historical data)

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (COD) (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Jan-04	22.5	347.5	705.0	129.8	7.5	156.3	463.8	39.0	5.2
Feb-04	22.7	347.5	702.5	130.0	7.3	173.1	513.8	67.8	6.3
Mar-04	22.1	278.0	660.0	125.0	7.4	167.2	496.0	65.8	6.6
Apr-04	5.9	132.5	42.5	5.0	6.9	22.7	67.5	2.5	1.7
May-04	22.9	215.0	615.0	128.8	7.5	186.2	552.5	65.3	4.9
Jun-04	18.4	326.0	710.0	159.0	7.8	258.1	766.0	63.2	8.7
Jul-04	18.4	505.0	613.3	142.5	7.6	244.3	725.0	67.8	5.9
Aug-04	16.3	285.0	655.0	127.5	7.6	228.3	677.5	70.5	3.2
Sep-04	20.3	256.0	642.0	123.0	7.5	205.2	609.0	72.8	3.5
Oct-04	42.6	220.0	597.5	84.8	8.0	182.0	540.0	63.8	2.3
Nov-04	22.4	195.0	672.5	130.0	7.3	181.1	537.5	52.8	2.4
Dec-04	23.7	208.0	732.0	140.0	7.3	252.1	748.0	54.8	8.1
Jan-05	22.9	312.5	732.5	135.0	7.5	239.3	710.0	53.8	8.6
Feb-05	23.6	356.0	674.0	117.6	7.4	292.5	868.0	51.2	10.7
Mar-05	23.7	324.2	662.5	114.3	7.6	292.1	866.7	46.6	6.9
Apr-05	22.3	405.0	694.0	122.9	7.6	357.2	1060.0	57.3	6.3
May-05	20.2	333.8	962.5	168.8	7.7	270.0	801.3	60.5	7.1
Jun-05	18.9	470.0	897.5	168.8	7.8	294.0	872.5	48.8	8.6

Date	**Temperature (°C)**	**Total suspended solids TS:105°C-TDS:1)(mg/l)**	**Total Dissolved Solids (TDS:180°C) (mg/l)**	**Electrical Conductivity (mS/m 25°C)**	**PH**	**Biological Oxygen Demand (BOD) (mg/l)**	**Chemical Oxygen Demand (COD) (mg/l)**	**Total Kjeldahl nitrogen (TKN-N) (mg/l)**	**Orthophosphate (mg/l)**
Jul-05	17.4	296.7	953.3	165.0	7.9	308.9	916.7	61.0	8.2
Aug-05	19.2	414.3	928.8	154.4	7.7	366.5	1087.5	67.0	11.8
Sep-05	19.8	381.7	846.7	151.7	7.7	399.9	1186.7	73.2	10.4
Oct-05	24.4	351.7	811.7	150.0	7.8	236.5	701.7	69.8	8.9
Nov-05	25.1	630.0	811.7	153.3	7.8	360.6	1070.0	96.7	8.2
Dec-05	23.9	583.3	906.7	178.3	8.1	417.9	1240.0	105.0	9.4
Jan-06	24.7	440.0	810.0	146.7	8.3	187.6	556.7	56.0	5.4
Feb-06	25.1	334.3	894.3	161.4	8.3	191.9	569.4	73.9	6.4
Mar-06	22.3	451.4	928.6	154.3	7.6	248.4	737.1	43.0	5.4
Apr-06	21.2	510.0	890.0	147.5	7.7	53.9	160.0	34.3	10.5
May-06	21.8	433.3	1016.7	188.3	7.9	132.6	393.3	74.0	7.0
Jun-06	19.2	390.0	913.3	164.2	8.0	136.8	405.8	49.3	11.2
Jul-06	17.9	398.6	874.3	145.7	8.0	162.5	482.1	54.0	9.8
Aug-06	18.6	585.0	880.0	150.0	7.6	379.1	1125.0	76.3	13.3
Sep-06	22.4	596.0	796.0	145.0	7.4	320.8	952.0	99.4	4.2
Oct-06	22.2	472.9	924.3	141.3	7.7	144.7	429.3	67.7	6.0
Nov-06	22.4	317.5	925.0	156.3	7.5	161.8	480.0	90.8	14.5
Dec-06	25.3	313.3	823.3	148.3	7.4	113.5	336.7	115.0	8.7
Jan-07	24.7	295.0	751.3	135.6	7.5	125.3	371.9	90.5	8.6
Feb-07	24.4	311.7	693.3	127.5	7.5	146.3	434.2	107.7	8.3

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (COD) (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Mar-07	19.9	408.3	615.7	121.4	9.9	210.9	625.7	101.1	5.7
Apr-07	22.9	456.0	686.0	130.0	7.7	287.8	854.0	55.2	7.5
May-07	21.0	461.7	678.3	140.8	8.1	229.2	680.0	372.7	8.4
Jun-07	18.7	428.8	708.8	143.8	7.9	205.1	608.8	174.4	8.8
Jul-07	14.7	326.3	732.5	111.7	7.9	199.3	591.3	140.8	9.6
Aug-07	16.3	412.9	692.9	100.0	7.8	272.5	808.6	140.0	9.7
Sep-07	22.6	491.3	722.5	138.8	7.6	313.8	931.3	134.4	11.4
Oct-07	23.0	507.5	712.5	145.6	8.0	361.4	1072.5	141.1	11.1
Nov-07	24.4	460.0	675.0	140.0	8.1	337.8	1002.5	195.0	8.7
Dec-07	24.3	463.3	700.0	145.0	7.8	328.0	973.3	139.3	14.0
Jan-08	19.6	673.3	707.5	145.0	7.8	289.0	857.5	155.0	5.1
Feb-08	25.0	347.5	627.5	118.8	7.4	241.8	717.5	103.3	5.7
Mar-08	24.0	245.0	732.5	130.0	7.4	210.6	625.0	75.3	5.5
Apr-08	22.1	335.0	742.5	130.0	7.6	270.4	802.5	105.0	9.3
May-08	22.2	356.7	640.0	128.3	7.9	242.6	720.0	145.3	7.8
Jun-08	20.3	440.0	673.3	141.7	7.8	197.1	585.0	143.3	7.5
Jul-08	18.7	530.0	700.0	148.8	7.6	195.5	580.0	123.8	7.9
Aug-08	21.1	350.0	805.0	160.0	8.1	262.9	780.0	175.0	8.0
Sep-08	19.0	330.0	742.5	141.3	7.9	256.1	760.0	143.8	7.2
Oct-08	24.9	350.0	733.3	136.7	7.4	274.1	813.3	146.7	8.1
Nov-08	24.1	286.7	683.3	125.0	7.5	249.4	740.0	107.7	7.5

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (COD) (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Dec-08	24.2	286.7	713.3	130.0	7.7	248.3	736.7	93.3	10.0
Jan-09	24.6	340.0	675.0	122.5	7.6	220.7	655.0	100.0	6.2
Feb-09	22.4	256.7	640.0	115.0	7.6	166.3	493.3	61.3	4.4
Mar-09	23.2	245.0	855.0	145.0	7.8	128.1	380.0	59.0	3.7
Apr-09	22.2	380.0	823.3	153.3	7.7	130.3	386.7	102.3	5.8
May-09	21.9	533.3	810.0	166.7	8.2	244.9	726.7	175.0	6.9
Jun-09	20.1	393.3	853.3	156.7	7.7	283.1	840.0	116.7	8.1
Jul-09	19.6	406.7	846.7	156.7	7.7	260.6	773.3	120.0	7.4
Aug-09	20.5	315.0	845.0	155.0	7.7	246.0	730.0	122.5	7.0
Sep-09	21.2	370.0	783.3	141.7	7.6	207.8	616.7	116.7	7.4
Oct-09	22.0	360.0	696.7	133.3	7.6	224.7	666.7	116.7	7.7
Nov-09	24.5	466.7	690.0	128.3	7.8	249.4	740.0	146.7	8.8
Dec-09	25.2	406.7	650.0	130.0	7.9	251.6	746.7	139.7	7.9
Jan-10	23.4	740.0	800.0	135.0	7.6	368.2	1092.5	98.0	4.8
Feb-10	23.9	353.3	820.0	150.0	7.9	226.9	673.3	120.0	6.7
Mar-10	22.7	510.0	740.0	133.3	8.0	238.1	706.7	119.0	7.7
Apr-10	22.3	630.0	693.3	145.0	8.1	298.8	886.7	183.3	7.6
May-10	18.8	420.0	720.0	137.5	7.6	232.5	690.0	84.5	5.3
Jun-10	18.4	422.5	715.0	141.3	7.7	267.9	795.0	140.0	6.6
Jul-10	20.0	320.0	726.7	143.3	8.0	212.3	630.0	134.7	6.1
Aug-10	21.1	365.0	715.0	132.5	7.5	286.5	850.0	122.5	6.3

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (COD) (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Sep-10	22.5	495.0	702.5	138.8	7.3	323.5	960.0	131.3	9.1
Oct-10	22.8	365.0	710.0	132.5	7.6	254.4	755.0	145.0	7.6
Nov-10	24.3	393.3	680.0	135.0	7.8	288.7	856.7	160.0	7.9
Dec-10	23.5	390.0	670.0	125.0	7.6	232.5	690.0	88.7	5.3
Jan-11	23.0	133.3	716.7	125.0	7.6	112.9	335.0	56.3	2.4
Feb-11	22.4	395.0	940.0	165.0	7.7	193.8	575.0	73.0	3.4
Mar-11	23.6	256.7	950.0	161.7	7.4	91.6	271.7	47.3	1.9
Apr-11	21.9	307.5	1005.0	174.5	7.9	160.5	476.3	86.5	2.9
May-11	21.9	310.0	1290.0	220.0	7.8	144.9	430.0	74.0	2.1
Jun-11	19.5	738.0	1226.0	220.0	8.1	354.5	1052.0	161.0	6.5
Jul-11	16.5	290.0	1200.0	218.3	7.9	197.7	586.7	126.7	4.2
Aug-11	16.8	206.7	1150.0	203.3	8.1	193.8	575.0	117.3	4.2
Sep-11	21.2	337.5	977.5	175.0	7.9	230.8	685.0	58.8	4.9
Oct-11	23.3	310.0	913.3	166.7	7.6	210.1	623.3	53.7	4.9
Nov-11	21.6	325.0	807.5	151.3	7.6	231.7	687.5	56.8	4.7
Dec-11	22.8	263.3	803.3	148.3	7.7	185.9	551.7	47.7	3.4
Jan-12	24.0	305.0	740.0	142.5	7.7	207.3	615.0	47.0	3.8
Feb-12	23.5	305.0	782.5	143.8	7.5	192.1	570.0	42.3	3.0
Mar-12	23.2	220.0	790.0	147.5	7.8	163.4	485.0	61.5	4.4
Apr-12	22.1	446.7	943.3	178.3	7.8	294.3	873.3	78.3	5.1
May-12	21.2	320.0	875.0	161.3	7.6	209.4	621.3	68.3	4.7

Date	**Temperature (°C)**	**Total suspended solids TS:105°C-TDS:1)(mg/l)**	**Total Dissolved Solids (TDS:180°C) (mg/l)**	**Electrical Conductivity (mS/m 25°C)**	**PH**	**Biological Oxygen Demand (BOD) (mg/l)**	**Chemical Oxygen Demand (COD) (mg/l)**	**Total Kjeldahl nitrogen (TKN-N) (mg/l)**	**Orthophosphate (mg/l)**
Jun-12	20.1	290.0	840.0	153.3	7.4	255.0	756.7	71.7	4.8
Jul-12	15.9	313.3	866.7	156.7	7.5	242.6	720.0	62.7	4.8
Aug-12	19.2	350.0	847.5	155.0	7.6	245.2	727.5	58.3	4.8
Sep-12	20.3	386.7	833.3	153.3	7.6	252.8	750.0	63.7	4.4
Oct-12	22.1	414.0	790.0	147.0	7.4	285.1	846.0	58.2	4.4
Nov-12	23.5	355.0	772.5	140.0	7.3	276.3	820.0	56.8	4.1
Dec-12	14.5	335.0	770.0	140.0	7.4	252.8	750.0	52.5	3.8
Jan-13	24.1	346.0	760.0	138.0	7.5	260.2	772.0	57.6	4.8
Feb-13	24.1	323.3	750.0	130.0	7.5	275.2	816.7	54.7	4.0
Mar-13	23.5	333.3	786.7	138.3	7.5	267.4	793.3	54.7	4.1
Apr-13	21.5	417.5	727.5	141.3	7.7	255.3	757.5	59.5	4.6
May-13	20.5	396.7	796.7	148.3	7.4	275.2	816.7	57.0	4.4
Jun-13	17.6	420.0	715.0	141.3	7.6	266.2	790.0	73.0	5.1
Jul-13	15.7	377.5	850.0	157.5	7.4	262.0	777.5	66.3	4.3
Aug-13	16.4	363.3	933.3	166.7	7.5	289.8	860.0	66.7	4.3
Sep-13	20.9	466.7	893.3	166.7	7.9	333.6	990.0	90.7	5.8
Oct-13	22.6	296.0	822.0	148.0	7.6	252.8	750.0	62.6	4.4
Nov-13	22.5	346.7	863.3	155.0	7.6	278.6	826.7	62.0	4.8
Dec-13	23.1	330.0	905.0	170.0	7.6	207.3	615.0	71.5	5.0
Jan-14	19.3	342.5	897.5	172.5	8.2	219.9	652.5	77.3	4.9
Feb-14	22.6	377.5	780.0	140.0	8.1	199.3	591.3	49.5	3.4

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (COD) (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Mar-14	23.5	340.0	930.0	168.8	8.0	211.9	628.8	60.8	3.7
Apr-14	21.9	396.0	908.0	192.0	8.1	236.6	702.0	79.0	5.1
May-14	19.8	555.0	930.0	173.8	8.0	299.1	887.5	79.0	4.9
Jun-14	18.8	390.0	915.0	175.0	8.5	260.3	772.5	106.3	6.6
Jul-14	18.7	385.0	957.5	180.0	8.2	306.7	910.0	100.3	6.5
Aug-14	18.1	382.5	970.0	170.0	7.8	289.8	860.0	75.0	4.7
Sep-14	22.4	365.0	967.5	168.8	7.6	266.2	790.0	73.3	5.2
Oct-14	23.7	474.0	920.0	169.0	7.8	293.2	870.0	83.4	5.9
Nov-14	22.2	277.5	960.0	162.5	7.5	224.1	665.0	55.3	4.0
Dec-14	23.3	1842.5	980.0	172.5	7.9	218.2	647.5	67.0	5.0

Appendix 7: Raw Data; Gammams wastewater treatment plant effluent (Historical data)

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180° C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Jan-04	22.1	19.7	713.3	121.7	7.9	6.1	26.0	1.5	2.7
Feb-04	22.8	9.3	605.0	97.5	7.5	7.3	31.0	1.1	0.2
Mar-04	22.1	20.0	540.0	93.3	7.5	6.8	29.0	11.3	0.9
Apr-04	20.4	34.8	593.3	102.0	7.4	8.5	36.3	5.1	2.8
May-04	22.6	20.0	572.5	98.8	7.4	9.5	40.3	2.7	10.2
Jun-04	19.1	32.5	642.5	120.0	7.6	10.5	44.5	2.9	6.3
Jul-04	21.4	95.0	787.5	110.0	7.3	10.6	45.3	2.7	7.1
Aug-04	17.1	55.0	572.5	90.3	7.3	9.3	39.5	2.3	5.2
Sep-04	20.2	20.0	566.0	93.0	7.3	8.6	36.5	3.8	6.0
Oct-04	21.6	10.0	567.5	95.3	7.4	8.5	36.0	4.6	3.6
Nov-04	22.3	12.0	600.0	101.0	7.5	7.9	33.8	1.5	4.5
Dec-04	22.9	20.0	632.0	112.0	7.5	9.4	40.2	4.2	4.5
Jan-05	22.5	27.0	640.0	112.5	7.7	9.0	38.5	4.1	4.3
Feb-05	23.3	45.7	612.5	99.8	7.6	11.6	49.2	3.4	8.8
Mar-05	23.2	22.0	561.0	89.3	7.7	9.8	41.7	1.7	8.2
Apr-05	22.8	23.6	635.9	100.9	7.6	8.3	35.5	1.6	7.3
May-05	20.4	32.9	866.5	144.0	7.8	9.4	40.1	3.2	7.3
Jun-05	19.5	45.7	815.7	139.3	7.7	10.7	45.4	5.0	5.6
Jul-05	17.4	15.8	860.0	140.0	7.8	9.3	39.7	2.8	8.7

Date	**Temperature (°C)**	**Total suspended solids TS:105°C-TDS:1)(mg/l)**	**Total Dissolved Solids (TDS:180°C) (mg/l)**	**Electrical Conductivity (mS/m 25°C)**	**PH**	**Biological Oxygen Demand (BOD) (mg/l)**	**Chemical Oxygen Demand (mg/l)**	**Total Kjeldahl nitrogen (TKN-N) (mg/l)**	**Orthophosphate (mg/l)**
Aug-05	19.1	31.1	780.0	124.4	7.8	9.8	41.9	1.6	12.5
Sep-05	20.8	39.9	697.5	116.3	8.0	9.3	39.5	2.7	10.2
Oct-05	24.2	29.9	698.6	115.7	7.9	8.7	36.9	2.7	6.4
Nov-05	24.3	22.1	702.5	115.0	7.9	9.1	38.6	2.5	6.1
Dec-05	24.2	20.0	800.0	133.8	7.9	8.4	35.8	1.8	11.6
Jan-06	24.3	24.8	796.7	121.7	7.9	6.2	26.3	1.3	316.2
Feb-06	24.7	37.9	812.9	126.4	7.9	7.4	31.3	2.5	6.1
Mar-06	22.7	36.7	856.7	133.3	7.8	7.0	29.7	1.0	5.0
Apr-06	20.8	56.7	810.0	133.3	7.8	6.5	27.7	0.9	6.1
May-06	22.0	28.0	902.0	146.0	7.8	6.8	29.0	1.9	6.3
Jun-06	18.6	54.0	828.0	131.0	7.6	10.5	44.8	2.7	13.4
Jul-06	19.3	45.7	761.4	115.7	7.6	8.7	37.1	3.7	12.2
Aug-06	18.8	167.5	797.5	122.5	7.6	35.0	148.8	3.1	14.0
Sep-06	21.6	94.3	752.9	114.3	7.5	15.1	64.3	3.1	9.4
Oct-06	22.4	28.0	782.5	122.5	7.8	8.5	36.3	2.3	6.4
Nov-06	22.4	27.1	792.9	127.1	7.9	9.1	38.6	3.5	6.0
Dec-06	24.5	15.0	760.0	120.0	8.0	8.9	37.7	4.7	6.3
Jan-07	24.9	16.0	681.3	110.0	7.9	8.7	37.0	3.7	3.5
Feb-07	24.8	24.0	630.0	102.3	7.7	8.1	34.7	4.2	2.0
Mar-07	23.9	28.0	553.3	91.3	7.7	8.4	35.8	2.6	2.2
Apr-07	22.8	25.0	598.3	79.0	7.7	8.7	36.8	1.6	2.1

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180° C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
May-07	20.4	30.0	632.9	87.8	14.0	11.5	49.0	4.3	4.7
Jun-07	18.2	32.9	648.8	104.4	7.5	10.3	43.6	5.0	8.7
Jul-07	17.5	27.1	677.5	109.4	7.5	10.8	45.9	5.3	5.9
Aug-07	19.7	38.3	624.3	102.5	7.5	16.2	68.8	6.5	6.3
Sep-07	22.5	57.5	613.8	103.8	7.6	9.1	38.8	4.1	4.7
Oct-07	22.8	30.0	618.6	100.0	7.6	8.1	34.3	6.1	3.8
Nov-07	24.1	50.0	593.3	99.3	7.7	7.1	30.0	10.3	5.1
Dec-07	23.4	10.0	630.0	105.0	7.6	8.7	37.0	5.5	9.3
Jan-08	18.5	20.0	656.7	106.7	7.7	8.1	34.7	5.8	4.1
Feb-08	25.3	30.0	580.0	96.0	7.6	9.4	40.0	4.9	3.1
Mar-08	23.6	10.0	643.3	101.0	7.6	6.9	29.3	3.8	4.5
Apr-08	22.2	20.0	640.0	102.0	7.8	8.0	34.0	3.5	3.6
May-08	21.7	43.3	576.7	95.0	7.6	8.5	36.0	6.5	5.3
Jun-08	20.3	36.7	656.7	108.0	7.4	9.7	41.3	3.0	5.9
Jul-08	18.7	15.0	716.7	118.3	7.5	8.1	34.3	5.3	6.7
Aug-08	21.1	730.0	720.0	115.0	7.6	9.3	39.5	7.3	6.1
Sep-08	23.1	10.0	672.5	108.8	7.3	8.3	35.3	3.7	5.6
Oct-08	24.8	20.0	670.0	103.3	7.8	6.8	29.0	3.1	6.1
Nov-08	23.9	13.3	633.3	103.0	7.6	7.6	32.3	3.3	5.5
Dec-08	23.9	25.0	626.7	102.7	7.8	7.1	30.3	2.0	7.6
Jan-09	24.6	35.0	600.0	102.5	7.9	5.6	24.0	2.3	7.1

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Feb-09	22.1	40.0	630.0	103.3	7.8	13.8	58.7	3.5	3.8
Mar-09	23.0	35.0	840.0	125.0	8.0	9.8	41.5	1.5	3.4
Apr-09	21.7	45.0	853.3	133.3	7.9	8.9	38.0	4.9	5.5
May-09	20.6	50.0	783.3	128.3	7.7	6.8	29.0	3.6	5.5
Jun-09	19.9	50.0	780.0	128.3	7.8	7.8	33.0	5.5	4.8
Jul-09	19.4	23.3	770.0	128.3	7.7	10.0	42.7	4.2	6.9
Aug-09	20.3	35.0	725.0	122.5	7.6	9.0	38.5	11.3	4.8
Sep-09	20.8	10.0	676.7	115.0	7.7	8.5	36.3	10.9	3.0
Oct-09	21.8	20.0	626.7	106.7	7.7	7.8	33.3	9.1	1.3
Nov-09	24.2	20.0	576.7	97.3	7.8	7.8	33.0	8.5	1.0
Dec-09	23.7	36.7	586.7	97.3	7.9	9.6	41.0	5.1	2.6
Jan-10	23.0	25.0	660.0	107.5	7.8	6.5	27.5	2.0	3.0
Feb-10	23.6	16.7	723.3	121.7	8.1	6.7	28.7	4.7	1.8
Mar-10	22.7	33.3	630.0	106.0	7.7	7.1	30.3	4.4	0.9
Apr-10	21.7	46.7	623.3	108.3	7.5	6.7	28.3	5.1	2.1
May-10	18.2	20.0	685.0	115.0	7.6	7.3	31.0	7.7	3.0
Jun-10	18.0	37.5	655.0	110.0	7.4	7.6	32.3	5.9	4.9
Jul-10	19.5	23.3	666.7	115.0	7.6	9.2	39.0	7.5	4.9
Aug-10	20.7	35.0	600.0	101.5	7.5	8.1	34.5	5.6	3.0
Sep-10	22.5	25.0	632.5	104.5	7.5	10.6	45.0	8.5	3.7
Oct-10	22.5	25.0	595.0	102.0	7.7	7.2	30.5	8.3	1.3

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Nov-10	22.8	20.0	593.3	100.0	7.8	6.4	27.3	7.3	1.4
Dec-10	23.4	35.0	630.0	108.3	8.1	6.2	26.3	6.0	2.8
Jan-11	22.7	10.0	650.0	106.3	7.9	6.4	27.3	4.1	2.7
Feb-11	22.4	25.0	950.0	155.0	8.1	4.9	21.0	2.7	2.6
Mar-11	22.1	23.3	913.3	146.7	8.0	3.8	16.3	2.0	2.3
Apr-11	21.2	56.7	1055.0	171.3	8.0	6.1	25.8	2.5	1.9
May-11	21.9	40.0	1310.0	210.0	8.1	5.2	22.0	2.5	2.4
Jun-11	18.6	32.0	1228.0	197.0	7.9	7.5	31.8	3.5	2.5
Jul-11	16.5	36.7	1116.7	188.3	8.0	8.3	35.3	5.3	2.3
Aug-11	16.1	20.0	1096.7	181.7	8.0	8.6	36.7	3.7	1.7
Sep-11	21.1	32.5	855.0	148.8	8.0	9.3	39.5	3.5	1.3
Oct-11	22.9	70.0	770.0	136.7	8.0	8.1	34.7	2.9	0.9
Nov-11	21.3	35.0	722.5	125.0	7.9	9.4	40.0	3.9	0.6
Dec-11	23.1	35.0	710.0	123.3	7.7	5.6	23.7	1.6	1.2
Jan-12	24.2	50.0	650.0	112.5	7.6	8.8	37.5	1.8	0.4
Feb-12	23.4	47.5	725.0	123.8	7.7	9.6	40.8	3.6	1.4
Mar-12	23.1	105.0	500.0	103.0	7.8	6.1	26.0	1.2	1.6
Apr-12	22.5	35.0	850.0	146.7	7.8	7.6	32.3	1.7	2.1
May-12	21.1	36.7	797.5	135.0	8.2	7.3	31.0	3.2	2.9
Jun-12	20.0	25.0	733.3	125.0	8.1	9.9	42.3	3.8	2.6
Jul-12	16.0	36.7	793.3	135.0	8.1	11.0	46.7	2.0	4.0

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180° C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Aug-12	18.6	50.0	790.0	128.8	7.9	13.2	56.3	5.6	3.6
Sep-12	19.9	43.3	760.0	126.7	8.1	9.9	42.0	2.2	2.3
Oct-12	21.2	22.5	714.0	122.0	8.1	10.7	45.4	2.2	1.1
Nov-12	22.5	50.0	665.0	115.0	8.0	9.4	40.0	2.3	1.6
Dec-12	22.6	50.0	700.0	120.0	8.0	8.8	37.5	1.9	0.4
Jan-13	24.0	32.0	672.0	114.0	8.0	9.6	40.8	2.3	1.2
Feb-13	24.0	26.7	646.7	110.0	8.2	8.7	37.0	3.5	1.5
Mar-13	23.4	20.0	676.7	115.0	8.2	9.3	39.7	2.4	1.6
Apr-13	20.9	35.0	702.5	117.5	8.2	10.3	43.8	2.9	2.8
May-13	20.5	43.3	746.7	123.3	8.1	31.8	135.3	5.4	2.7
Jun-13	17.3	55.0	672.5	112.5	7.9	14.9	63.3	5.9	1.6
Jul-13	14.9	67.5	770.0	130.0	8.0	9.9	42.3	3.7	1.2
Aug-13	15.4	80.0	846.7	141.7	8.0	9.9	42.0	3.5	0.2
Sep-13	20.6	73.3	780.0	135.0	8.0	7.4	31.3	5.1	0.2
Oct-13	22.9	26.7	695.0	118.8	7.9	11.9	50.5	7.0	0.9
Nov-13	21.6	30.0	843.3	136.7	8.3	11.5	49.0	3.7	0.3
Dec-13	22.5	35.0	755.0	130.0	8.1	19.7	84.0	2.3	1.7
Jan-14	22.4	33.3	660.0	121.3	7.8	7.4	31.5	2.1	3.8
Feb-14	22.7	13.3	615.0	103.8	7.6	7.0	29.8	0.8	0.3
Mar-14	21.7	57.5	807.5	133.8	7.9	15.6	66.5	1.6	0.2
Apr-14	22.1	62.5	928.0	154.0	7.8	9.9	42.0	2.3	0.4

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
May-14	20.3	40.0	827.5	137.5	7.7	9.9	42.0	3.1	0.2
Jun-14	17.9	72.5	807.5	137.5	7.6	17.3	73.5	6.2	0.3
Jul-14	17.7	44.0	840.0	142.0	7.7	10.2	43.2	2.7	0.2
Aug-14	18.0	35.0	832.5	104.5	8.0	13.4	57.0	4.1	0.4
Sep-14	63.4	25.0	837.5	133.8	8.1	13.7	58.5	4.0	0.2
Oct-14	23.2	36.0	820.0	135.0	8.1	15.3	65.0	3.0	0.2
Nov-14	22.1	50.0	865.0	137.5	8.1	13.2	56.0	2.7	0.2
Dec-14	22.8	53.3	892.5	147.5	8.1	10.8	46.0	2.9	2.1

Appendix 8: Raw Data; Otjomuise wastewater treatment plant influent (Historical data)

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Jan-04	22.9	362.5	562.5	117.8	7.8	214.9	651.3	18.5	5.6
Feb-04	23.5	570.0	415.0	110.0	7.3	1040.6	3153.3	46.7	6.5
Mar-04	24.1	532.5	497.5	121.8	7.7	191.8	581.3	61.0	9.9
Apr-04	25.0	2026.7	696.7	155.0	7.6	180.4	546.7	155.0	10.5
May-04	22.7	1450.0	530.0	127.5	7.2	417.9	1266.3	60.5	11.0
Jun-04	18.4	1470.0	662.5	142.5	7.4	652.9	1978.5	74.3	13.8
Jul-04	21.6	750.0	762.5	151.3	8.1	295.7	896.0	102.0	5.5
Aug-04	18.8	640.0	636.0	158.0	8.5	475.9	1442.0	165.0	12.2
Sep-04	19.3	640.0	543.3	110.0	7.4	325.6	986.7	59.0	10.3
Oct-04	23.0	635.0	642.5	166.3	7.5	407.6	1235.0	122.5	16.5
Nov-04	25.1	817.5	722.5	165.0	7.4	443.0	1342.5	105.5	18.9
Dec-04	22.1	430.0	670.0	137.5	7.6	269.0	815.0	110.0	0.1
Jan-05	24.4	112.0	630.0	123.0	7.6	101.6	308.0	27.2	10.5
Feb-05	24.5	180.0	593.3	118.3	7.8	128.2	388.3	52.0	4.4
Mar-05	23.6	255.0	575.0	115.0	7.7	132.0	400.0	41.0	11.3
Apr-05	23.9	303.3	657.5	130.0	8.1	233.9	708.8	75.3	7.2
May-05	20.8	287.5	912.5	158.8	8.0	173.7	526.3	45.8	6.4
Jun-05	18.9	236.7	856.7	151.7	7.8	122.1	370.0	21.3	9.7
Jul-05	16.1	7506.7	906.7	165.0	7.5	715.0	2166.7	105.0	19.0
Aug-05	18.8	640.0	636.0	158.0	8.5	462.0	1400.0	160.0	12.0

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Sep-05	16.8	396.7	870.0	161.7	7.8	343.2	1040.0	130.3	22.7
Oct-05	22.5	386.0	784.0	158.0	7.7	225.1	682.0	95.6	16.0
Nov-05	24.5	420.0	846.7	155.0	7.5	312.4	946.7	94.0	18.0
Dec-05	24.6	640.0	930.0	195.0	8.1	306.9	930.0	165.0	24.0
Jan-06	23.8	515.0	780.0	140.0	7.6	125.8	381.3	32.0	10.5
Feb-06	24.6	270.0	817.5	141.3	7.7	78.4	237.5	37.0	11.2
Mar-06	22.5	665.0	960.0	161.7	7.4	180.4	546.7	58.3	15.0
Apr-06	21.8	1340.0	1220.0	103.5	14.0	656.7	1990.0	115.0	33.0
May-06	20.1	450.0	993.3	181.7	7.7	158.1	479.0	151.0	28.0
Jun-06	19.5	1220.0	1437.5	228.8	7.2	646.8	1960.0	175.0	64.0
Jul-06	18.3	208.0	888.0	143.8	7.7	130.0	394.0	53.4	25.8
Aug-06	19.6	625.0	912.5	172.5	14.0	1204.5	3650.0	220.0	31.3
Sep-06	21.4	1737.5	1257.5	106.5	7.0	397.7	1205.0	400.0	25.5
Oct-06	22.2	604.0	736.0	145.8	7.8	178.2	540.0	170.8	14.9
Nov-06	22.3	495.0	955.0	182.5	7.5	152.2	461.3	182.8	21.0
Dec-06	24.7	336.7	726.7	143.3	7.3	93.0	281.7	145.0	22.3
Jan-07	25.3	1014.0	806.0	176.0	7.6	126.3	382.6	310.0	35.0
Feb-07	25.1	510.0	810.0	170.0	7.6	131.2	397.5	211.3	30.8
Mar-07	23.9	220.0	645.0	138.8	7.6	115.1	348.8	86.0	15.8
Apr-07	23.3	442.5	810.0	160.0	7.5	312.7	947.5	90.8	30.5
May-07	21.0	440.0	742.5	157.5	7.7	180.7	547.5	322.8	31.3

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Jun-07	19.2	862.5	740.0	156.3	7.5	625.8	1896.3	192.5	37.8
Jul-07	17.5	1040.0	814.0	175.0	7.7	206.9	627.0	324.0	23.6
Aug-07	19.9	736.7	783.3	180.0	7.8	226.1	685.0	253.3	27.3
Sep-07	22.0	537.5	795.0	178.8	7.7	291.2	882.5	216.3	46.5
Oct-07	23.2	372.0	798.0	170.0	7.6	258.1	782.0	196.0	40.4
Nov-07	24.0	300.0	732.5	160.0	7.8	217.4	658.8	180.0	31.3
Dec-07	23.7	563.3	676.7	148.3	7.8	334.4	1013.3	194.3	18.7
Jan-08	20.6	2930.0	660.0	141.3	7.6	664.1	2012.5	234.0	10.9
Feb-08	24.2	1710.0	590.0	120.0	7.5	757.4	2295.0	367.5	39.0
Mar-08	24.1	457.5	610.0	126.3	7.5	257.4	780.0	148.8	16.3
Apr-08	22.7	488.0	670.0	149.0	11.1	339.9	1030.0	295.0	25.4
May-08	21.9	870.0	707.5	167.5	8.1	401.0	1215.0	347.5	37.5
Jun-08	20.8	872.5	670.0	187.5	8.1	359.7	1090.0	302.5	32.5
Jul-08	19.0	836.0	688.0	186.0	8.5	417.8	1266.0	337.0	18.2
Aug-08	20.8	772.5	672.5	180.0	8.3	396.8	1202.5	290.0	19.5
Sep-08	20.3	772.5	727.5	170.0	8.2	406.7	1232.5	288.8	21.3
Oct-08	24.2	998.0	792.0	168.0	7.7	593.3	1798.0	310.0	28.4
Nov-08	24.3	515.0	780.0	167.5	8.0	388.6	1177.5	262.5	18.0
Dec-08	24.4	1015.0	705.0	155.0	7.4	512.3	1552.5	250.0	23.5
Jan-09	24.2	1430.0	702.5	151.3	7.6	675.7	2047.5	255.0	19.5
Feb-09	21.7	493.3	603.3	113.3	7.6	192.0	581.7	79.3	9.1

Date	**Temperature (°C)**	**Total suspended solids TS:105°C-TDS:1)(mg/l)**	**Total Dissolved Solids (TDS:180°C) (mg/l)**	**Electrical Conductivity (mS/m 25°C)**	**PH**	**Biological Oxygen Demand (BOD) (mg/l)**	**Chemical Oxygen Demand (mg/l)**	**Total Kjeldahl nitrogen (TKN-N) (mg/l)**	**Orthophosphate (mg/l)**
Mar-09	23.4	400.0	775.0	158.8	7.9	261.5	792.5	154.0	10.5
Apr-09	22.5	2120.0	778.0	166.0	7.7	761.6	2308.0	403.0	24.4
May-09	21.3	377.5	805.0	173.8	7.7	200.9	608.8	166.0	13.2
Jun-09	20.1	510.0	787.5	168.8	7.9	267.3	810.0	169.8	18.0
Jul-09	20.1	506.0	792.0	156.0	7.7	304.3	922.0	150.0	16.2
Aug-09	20.8	306.7	800.0	158.3	7.7	211.2	640.0	140.0	14.7
Sep-09	21.3	892.0	770.0	150.0	7.4	438.9	1330.0	190.0	27.8
Oct-09	22.5	1692.5	767.5	160.0	7.4	667.8	2023.8	241.0	52.0
Nov-09	24.0	570.0	677.5	130.0	7.5	290.4	880.0	142.0	32.0
Dec-09	24.0	1530.0	676.0	128.0	7.3	555.1	1682.0	226.0	46.6
Jan-10	23.3	517.5	627.5	114.3	6.7	251.6	762.5	98.0	10.3
Feb-10	23.6	860.0	717.5	132.5	7.8	334.1	1012.5	106.8	22.0
Mar-10	23.2	810.0	748.0	146.0	7.6	354.4	1074.0	183.8	26.8
Apr-10	21.9	1010.0	687.5	133.8	7.4	398.5	1207.5	143.8	26.5
May-10	20.4	730.0	712.5	143.8	7.4	300.3	910.0	141.3	19.9
Jun-10	17.5	514.0	664.0	130.0	7.4	235.3	713.0	74.0	13.1
Jul-10	19.8	480.0	677.5	133.8	7.5	202.5	613.8	100.8	12.0
Aug-10	21.3	437.5	647.5	123.8	7.6	222.3	673.8	89.8	12.4
Sep-10	22.4	640.0	640.0	123.0	7.4	290.4	880.0	109.0	15.7
Oct-10	23.1	600.0	642.5	121.3	7.4	273.9	830.0	109.5	17.8
Nov-10	23.6	440.0	615.0	111.3	7.6	211.2	640.0	84.3	15.0

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Dec-10	23.3	860.0	710.0	133.0	7.6	398.6	1208.0	130.6	21.6
Jan-11	22.9	312.5	610.0	106.3	7.6	125.4	380.0	41.3	6.1
Feb-11	22.5	565.0	767.5	133.8	7.6	212.9	645.0	65.8	17.4
Mar-11	22.3	384.0	782.0	133.0	7.7	130.5	395.6	46.5	3.0
Apr-11	21.7	337.5	845.0	152.5	7.9	118.0	357.5	71.8	3.3
May-11	21.6	470.0	1000.0	195.0	8.1	247.5	750.0	129.0	5.8
Jun-11	19.2	1698.0	1044.0	209.0	7.9	726.3	2201.0	173.4	12.0
Jul-11	58.7	1195.0	1030.0	195.0	7.6	521.4	1580.0	199.8	11.7
Aug-11	17.7	1174.0	996.0	188.0	7.7	406.6	1232.0	162.0	14.4
Sep-11	21.4	1165.0	837.5	165.0	7.7	523.1	1585.0	70.3	18.8
Oct-11	22.8	1392.5	920.0	173.8	7.2	765.6	2320.0	108.8	27.8
Nov-11	22.1	1130.0	778.0	148.0	7.5	523.4	1586.0	78.8	25.8
Dec-11	21.9	977.5	912.5	145.0	7.6	506.6	1535.0	63.5	32.5
Jan-12	23.0	1232.5	695.0	135.0	7.5	526.4	1595.0	96.0	22.8
Feb-12	23.5	1004.0	670.0	123.0	7.6	405.9	1230.0	57.6	7.5
Mar-12	23.3	293.3	666.7	124.0	7.8	142.5	431.7	50.0	3.9
Apr-12	21.5	215.0	897.5	156.3	7.8	131.2	397.5	35.8	6.3
May-12	19.1	452.0	824.0	147.0	7.8	226.6	686.6	54.5	9.9
Jun-12	19.1	580.0	785.0	140.0	7.7	315.6	956.3	81.0	9.6
Jul-12	16.0	990.0	720.0	138.8	7.8	304.0	921.3	86.0	9.8
Aug-12	17.9	1028.0	780.0	140.0	7.7	456.7	1384.0	90.4	12.9

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Sep-12	20.8	797.5	807.5	151.3	7.8	372.9	1130.0	91.5	12.0
Oct-12	21.5	1212.0	750.0	135.0	7.6	395.7	1199.0	64.8	16.0
Nov-12	23.3	1327.5	717.5	135.0	7.4	503.7	1526.3	101.7	16.8
Dec-12	23.2	1286.7	730.0	135.0	7.6	519.2	1573.3	83.0	21.0
Jan-13	24.1	1456.0	774.0	139.0	7.4	536.6	1626.0	68.3	58.4
Feb-13	22.4	547.5	655.0	118.8	7.6	292.1	885.0	51.0	16.9
Mar-13	23.6	4490.0	732.5	135.0	7.6	533.0	1615.0	113.8	25.0
Apr-13	22.0	982.5	662.5	126.3	7.8	385.3	1167.5	90.3	33.8
May-13	20.0	1317.5	722.5	142.5	7.7	481.8	1460.0	112.3	18.3
Jun-13	18.0	942.5	690.0	137.5	7.6	374.6	1135.0	81.8	12.8
Jul-13	15.7	936.0	770.0	149.0	7.8	400.6	1214.0	80.4	10.8
Aug-13	16.1	630.0	877.5	166.3	7.7	402.6	1220.0	87.8	13.3
Sep-13	20.8	1220.0	857.5	163.8	7.5	535.4	1622.5	105.3	16.5
Oct-13	62.0	670.0	720.0	148.0	7.8	314.2	952.0	74.4	9.9
Nov-13	22.7	1182.5	827.5	157.5	7.7	631.1	1912.5	115.8	13.9
Dec-13	23.0	613.3	750.0	140.0	7.8	239.8	726.7	50.3	7.6
Jan-14	23.0	425.0	870.0	147.5	7.8	196.8	596.3	34.8	4.8
Feb-14	22.4	250.1	650.0	119.5	7.9	92.8	281.3	22.5	5.9
Mar-14	22.9	670.0	780.0	143.8	7.7	516.0	1563.8	55.5	6.6
Apr-14	21.3	548.0	930.0	162.0	7.8	270.6	820.0	56.0	6.0
May-14	65.2	367.5	805.0	152.5	8.0	138.2	418.8	40.5	17.0

Date	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Jun-14	17.3	657.5	805.0	162.5	8.1	270.6	820.0	81.0	7.9
Jul-14	16.7	444.0	820.0	156.0	7.9	189.4	574.0	49.4	6.1
Aug-14	18.8	632.5	825.0	155.0	7.8	285.0	863.8	69.0	8.3
Sep-14	22.7	527.5	835.0	153.8	7.8	244.2	740.0	61.0	7.7
Oct-14	23.3	376.0	890.0	158.0	7.9	217.1	658.0	61.4	7.9
Nov-14	22.5	342.5	842.5	155.0	7.9	138.6	420.0	37.3	5.6
Dec-14	23.4	732.5	1147.5	177.5	7.8	351.9	1066.3	95.8	18.8

Appendix 9: Raw Data; Otjomuise wastewater treatment plant effluent (Historical data)

DATE	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Jan-04	21.6	20.0	555.0	100.0	8.0	11.7	31.5	1.8	3.0
Feb-04	21.3	25.0	550.0	94.0	7.9	10.4	28.0	1.6	0.5
Mar-04	22.7	10.0	480.0	77.3	8.3	10.1	27.3	1.7	0.5
Apr-04	25.0	10.0	496.7	84.7	8.0	11.7	31.7	2.1	0.6
May-04	21.3	33.3	560.0	99.3	7.6	9.4	25.3	4.1	0.7
Jun-04	17.4	30.0	590.0	115.0	7.7	9.3	25.3	1.5	0.3
Jul-04	20.5	50.0	722.5	104.3	7.6	11.8	32.0	2.9	0.6
Aug-04	17.1	22.5	544.0	90.6	7.5	11.6	31.4	2.6	0.6
Sep-04	17.9	23.3	543.3	87.7	7.5	20.5	55.3	2.3	0.6
Oct-04	22.3	43.3	602.5	115.0	7.5	38.1	103.0	28.0	5.2
Nov-04	24.4	37.5	610.0	113.5	7.5	32.7	88.3	21.2	5.4
Dec-04	22.8	20.0	740.0	125.0	7.7	11.8	32.0	3.3	0.8
Jan-05	23.8	18.0	642.0	108.0	7.6	15.8	42.8	1.6	12.5
Feb-05	24.1	15.0	597.5	92.8	7.5	15.1	40.8	1.0	13.9
Mar-05	23.4	15.0	560.0	92.5	7.6	11.7	31.5	2.1	11.5
Apr-05	23.8	20.0	570.0	91.0	7.7	47.7	129.0	2.2	9.0
May-05	20.7	1786.7	816.7	150.0	7.8	533.3	1441.3	73.5	4.1
Jun-05	19.0	27.5	812.5	136.3	8.0	18.7	50.5	2.2	1.4
Jul-05	16.9	272.0	730.0	120.0	7.7	111.1	300.2	3.6	0.7

DATE	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Aug-05	18.9	50.0	820.0	125.0	7.6	37.0	100.0	0.5	5.3
Sep-05	18.3	160.0	764.0	126.0	7.7	181.6	490.8	22.9	3.6
Oct-05	22.1	120.0	722.5	117.5	7.8	36.0	97.3	17.2	2.9
Nov-05	23.6	60.0	705.0	117.5	7.8	126.0	340.5	3.1	1.1
Dec-05	22.8	20.0	740.0	125.0	7.7	11.8	32.0	3.3	0.9
Jan-06	23.8	30.0	745.0	116.3	8.1	19.2	52.0	1.5	1.8
Feb-06	32.9	77.5	752.5	109.0	8.0	24.8	67.0	3.0	0.6
Mar-06	22.3	20.0	795.0	150.0	7.8	10.9	29.5	97.0	0.3
Apr-06	21.6	30.0	840.0	135.0	7.9	10.4	28.0	1.5	0.5
May-06	19.7	516.7	866.7	142.7	7.8	8.4	22.7	1.5	0.5
Jun-06	19.5	522.5	807.5	133.8	7.9	15.5	42.0	1.7	9.5
Jul-06	18.2	504.0	738.0	118.0	7.8	11.5	31.2	11.9	0.3
Aug-06	19.1	262.5	762.5	120.0	7.9	15.0	40.5	4.1	1.3
Sep-06	21.2	460.0	790.0	121.3	7.6	19.7	53.3	18.0	0.7
Oct-06	22.2	20.0	722.5	115.0	7.8	13.2	35.8	1.5	0.6
Nov-06	22.2	35.0	765.0	127.5	7.6	11.3	30.5	1.7	1.1
Dec-06	24.5	25.0	696.7	121.7	7.6	13.1	35.3	21.1	1.1
Jan-07	25.1	15.0	660.0	123.0	7.6	34.7	93.8	21.3	0.7
Feb-07	25.1	33.3	687.5	132.5	7.8	15.7	42.5	19.8	2.0
Mar-07	23.8	23.3	637.5	103.3	7.7	12.7	34.3	1.1	3.7

DATE	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Apr-07	22.8	1976.7	655.0	105.3	7.7	12.2	33.0	0.8	3.2
May-07	20.7	36.7	660.0	110.0	7.8	12.7	34.3	7.6	1.4
Jun-07	18.8	20.0	690.0	113.8	7.6	14.8	40.0	4.5	4.1
Jul-07	17.3	46.0	694.0	116.0	7.7	22.1	59.6	9.9	1.6
Aug-07	19.7	33.3	676.7	115.0	7.6	19.5	52.7	7.7	1.7
Sep-07	21.5	85.0	680.0	116.3	7.7	35.2	95.3	7.8	4.8
Oct-07	22.6	182.5	670.0	111.0	7.7	72.6	196.2	20.8	4.5
Nov-07	23.6	33.3	637.5	105.0	7.8	31.3	84.6	9.2	3.3
Dec-07	23.5	20.0	630.0	105.0	7.7	16.0	43.3	8.6	2.6
Jan-08	19.8	36.7	610.0	106.7	7.6	8.6	23.3	5.6	1.8
Feb-08	24.8	10.0	533.3	87.3	7.7	13.0	35.0	6.7	2.8
Mar-08	23.9	270.0	545.0	94.5	7.7	88.0	237.8	37.7	10.4
Apr-08	22.0	218.0	580.0	114.0	7.7	82.9	224.0	102.2	14.2
May-08	20.7	750.0	542.5	100.3	7.6	267.3	722.5	101.5	7.8
Jun-08	20.5	732.5	602.5	107.5	7.5	207.9	562.0	86.4	3.1
Jul-08	18.0	386.0	648.0	110.0	7.8	115.4	311.8	37.7	1.0
Aug-08	20.3	210.0	660.0	111.3	7.7	83.7	226.3	20.7	1.0
Sep-08	20.3	655.0	625.0	123.8	7.8	217.2	587.0	61.3	0.7
Oct-08	24.2	382.0	640.0	107.6	7.8	126.8	342.6	56.2	4.9
Nov-08	24.3	153.3	617.5	102.5	7.8	56.5	152.8	18.2	0.9

DATE	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Dec-08	24.2	386.7	552.5	95.5	7.6	126.3	341.3	17.9	0.6
Jan-09	24.1	840.0	585.0	101.3	7.6	289.7	783.0	70.4	0.9
Feb-09	22.4	1087.5	512.5	89.5	7.5	293.2	792.5	56.6	1.0
Mar-09	22.8	43.3	727.5	120.8	7.9	11.7	31.5	0.9	0.7
Apr-09	22.0	1918.0	698.0	120.0	7.6	430.4	1163.2	120.4	1.2
May-09	21.3	830.0	715.0	123.8	7.5	180.7	488.5	48.3	1.1
Jun-09	20.1	837.5	705.0	120.0	7.8	178.4	482.3	40.6	0.7
Jul-09	19.8	32.5	690.0	117.0	7.8	14.4	38.8	8.5	0.6
Aug-09	20.8	513.3	713.3	118.3	7.8	139.9	378.0	16.4	0.6
Sep-09	21.1	2247.5	648.0	116.0	7.5	493.9	1334.8	106.8	0.7
Oct-09	22.2	617.5	627.5	121.3	7.6	201.3	544.0	53.3	0.8
Nov-09	23.9	967.5	577.5	99.5	7.7	276.6	747.5	76.3	0.8
Dec-09	23.7	1346.0	594.0	106.8	7.5	455.1	1230.0	119.0	11.4
Jan-10	23.2	710.0	532.5	92.8	7.8	183.8	496.8	62.0	0.5
Feb-10	78.1	647.5	655.0	115.0	7.8	186.7	504.5	42.0	0.9
Mar-10	18.4	848.0	620.0	109.0	7.8	241.6	653.0	73.6	18.0
Apr-10	21.4	143.3	603.3	108.3	7.6	47.7	129.0	24.7	0.8
May-10	19.9	427.5	632.5	111.3	7.5	129.4	349.8	24.3	0.4
Jun-10	17.0	214.0	600.0	105.0	7.6	59.5	160.8	17.7	0.6
Jul-10	19.9	77.5	625.0	108.8	7.6	31.6	85.5	9.6	2.8

DATE	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Aug-10	21.4	25.0	597.5	102.5	7.7	13.4	36.3	17.3	0.4
Sep-10	22.6	40.0	600.0	105.8	7.5	13.5	36.6	16.1	1.1
Oct-10	22.5	3015.0	607.5	103.8	7.6	445.9	1205.3	88.3	0.7
Nov-10	23.3	25.0	570.0	97.8	7.6	14.4	39.0	11.5	0.6
Dec-10	22.7	27.5	625.0	108.8	7.7	13.9	37.5	19.5	0.6
Jan-11	23.4	10.0	590.0	98.0	7.7	9.7	26.3	5.0	0.5
Feb-11	22.9	35.0	712.5	121.3	7.7	8.3	22.5	5.9	0.3
Mar-11	22.2	34.0	752.0	126.6	7.7	8.2	22.2	2.8	0.2
Apr-11	21.8	37.5	820.0	138.8	7.8	8.3	22.5	3.2	0.2
May-11	21.2	15.0	975.0	165.0	7.8	7.8	21.0	4.1	0.1
Jun-11	19.5	22.5	1035.0	172.5	7.8	9.8	26.5	3.7	0.2
Jul-11	17.4	40.0	1022.5	176.3	7.7	12.3	33.3	4.6	0.1
Aug-11	18.0	916.7	992.0	168.0	7.7	190.6	515.0	33.6	0.1
Sep-11	21.2	33.3	827.5	141.3	7.7	18.6	50.3	3.3	0.3
Oct-11	23.0	127.5	830.0	140.0	7.8	61.4	166.0	12.2	0.8
Nov-11	21.5	50.0	700.0	126.0	7.72	17.5	47.2	6.4	0.4
Dec-11	21.8	303.3	600.0	125.0	7.9	38.1	103.0	7.2	0.2
Jan-12	23.0	70.0	647.5	116.3	7.9	24.4	66.0	5.7	0.3
Feb-12	23.6	744.0	626.0	114.0	7.7	226.7	612.6	43.3	0.2
Mar-12	23.4	15.0	693.3	120.3	7.8	10.1	27.3	1.3	0.5

DATE	Temperature (°C)	Total suspended solids TS:105°C-TDS:1)(mg/l)	Total Dissolved Solids (TDS:180°C) (mg/l)	Electrical Conductivity (mS/m 25°C)	PH	Biological Oxygen Demand (BOD) (mg/l)	Chemical Oxygen Demand (mg/l)	Total Kjeldahl nitrogen (TKN-N) (mg/l)	Orthophosphate (mg/l)
Apr-12	21.9	77.5	850.0	147.5	7.9	26.7	72.3	4.9	0.4
May-12	18.8	174.0	798.0	138.0	8.1	78.6	212.4	15.8	1.9
Jun-12	19.1	517.5	717.5	125.0	7.8	233.3	630.5	43.8	0.3
Jul-12	15.6	202.5	730.0	123.8	7.9	81.1	219.3	13.4	0.4
Aug-12	18.0	632.0	746.0	127.0	7.8	225.0	608.2	35.1	0.3
Sep-12	20.4	245.0	767.5	127.5	7.7	107.8	291.3	11.6	0.7
Oct-12	21.3	496.0	726.0	124.0	7.7	206.8	559.0	32.2	0.4
Nov-12	22.9	267.5	700.0	120.0	7.7	107.8	291.3	14.8	2.0
Dec-12	22.7	943.3	700.0	123.3	7.7	306.5	828.3	54.7	0.4
Jan-13	24.0	238.0	692.0	123.0	8.3	84.9	229.4	15.9	0.2
Feb-13	23.4	1653.3	672.5	112.5	7.6	417.4	1128.0	48.8	0.4
Mar-13	23.4	147.5	680.0	117.5	7.9	64.8	175.3	11.9	0.4
Apr-13	21.5	255.0	635.0	109.8	7.9	100.4	271.3	22.6	0.2
May-13	20.0	347.5	710.0	122.5	7.9	137.4	371.3	19.6	0.2
Jun-13	17.8	235.0	667.5	116.3	7.7	76.5	206.8	12.3	0.4
Jul-13	15.8	354.0	718.0	128.0	7.9	125.8	340.0	19.2	0.2
Aug-13	16.0	272.5	772.5	142.5	7.7	143.9	389.0	20.6	0.2
Sep-13	20.7	497.5	785.0	136.3	7.8	153.6	415.0	27.0	0.2
Oct-13	22.6	65.0	744.0	129.0	7.9	26.9	72.6	4.7	0.2
Nov-13	22.6	27.5	775.0	132.5	8.1	13.2	35.8	3.7	0.2

DATE	**Temperature (°C)**	**Total suspended solids TS:105°C-TDS:1)(mg/l)**	**Total Dissolved Solids (TDS:180°C) (mg/l)**	**Electrical Conductivity (mS/m 25°C)**	**PH**	**Biological Oxygen Demand (BOD) (mg/l)**	**Chemical Oxygen Demand (mg/l)**	**Total Kjeldahl nitrogen (TKN-N) (mg/l)**	**Orthophosphate (mg/l)**
Dec-13	22.7	73.3	736.7	125.0	8.0	50.1	135.3	6.5	0.2
Jan-14	23.4	146.7	810.0	138.3	7.9	43.7	118.0	5.2	0.2
Feb-14	22.2	236.7	710.0	118.8	8.0	59.8	161.5	7.7	0.2
Mar-14	22.6	165.0	725.0	125.0	8.0	35.1	94.8	5.2	0.2
Apr-14	59.5	175.0	872.0	148.0	8.1	21.0	56.8	2.5	0.2
May-14	19.0	45.0	807.5	140.0	8.1	15.5	42.0	2.8	0.2
Jun-14	16.3	82.5	817.5	138.8	8.1	21.4	57.8	2.4	0.2
Jul-14	16.3	610.0	792.0	138.0	7.9	176.2	476.2	17.7	0.2
Aug-14	18.4	72.5	800.0	135.0	8.0	24.1	65.3	3.5	0.2
Sep-14	22.2	352.5	817.5	136.3	7.8	90.5	244.5	23.1	0.3
Oct-14	64.3	1060.0	852.0	111.8	8.0	316.6	855.6	43.8	0.2
Nov-14	22.0	180.0	877.5	145.0	8.1	43.7	118.0	9.4	0.2
Dec-14	23.1	710.0	865.0	146.3	8.1	245.8	664.3	31.0	0.2

Appendix 11: Gammams wastewater treatment plant (Primary data)

Gammams wastewater treatment plant influent

Date	**Temperature (°C)**	**Turbidity (NTU)**	**pH**	**Electrical Conductivity (mg/l)**	**Biological Oxygen Demand (mg/l)**	**Chemical Oxygen Demand (mg/l)**	**Total Nitrogen (mg/l)**	**Total Phosphates (mg/l)**
20-Jan-16	22.8	260.0	8.0	1.0	154.0	753.0	0.9	6.0
27-Jan-16	26.1	271.0	7.7	155.0	267.9	796.0	0.9	8.0
03-Feb-16	25.0	234.0	7.5	135.0	90.0	531.0	0.4	6.7
10-Feb-16	28.0	268.0	7.4	140.0	255.0	467.0	0.6	8.4
17-Feb-16	25.0	4.7	8.0	160.0	6.0	45.0	3.0	0.5

Gammams wastewater treatment plant effluent

Date	**Temperature (°C)**	**Turbidity (NTU)**	**pH**	**Electrical Conductivity (mS/m 25°C)**	**Biological Oxygen Demand (mg/l)**	**Chemical Oxygen Demand (mg/l)**	**Total Nitrogen (mg/l)**	**Total Phosphates (mg/l)**
20-Jan-16	25.0	6.4	7.5	160.0	9.4	40.0	4.2	0.9
27-Jan-16	27.4	5.0	7.3	155.0	9.2	39.0	6.4	0.4
03-Feb-16	23.0	7.1	8.2	155.0	8.0	33.0	0.4	0.4
10-Feb-16	28.0	4.4	8.0	155.0	10.0	26.9	1.1	0.5
17-Feb-16	25.0	257.0	7.6	150.0	230.0	997.0	0.4	8.7

Appendix 12: Otjomuise wastewater treatment plant (Primary data)

Otjomuise wastewater treatment plant influent

	Temperature (°C)	Turbidity (NTU)	Electrical Conductivity (mS/m 25°C)	pH	Biological Oxygen Demand (mg/l)	Chemical Oxygen Demand (mg/l)	Total Nitrogen (mg/l)	Total Phosphates (mg/l)
20-Jan-16	23.0	236.0	145.0	7.0	270.1	819.0	0.8	18.4
27-Jan-16	26.3	278.0	135.0	8.1	264.5	802.0	0.7	17.9
03-Feb-16	22.0	264.0	175.0	7.6	88.0	612.0	0.9	18.6
10-Feb-16	26.0	377.0	130.0	7.4	230.0	321.0	0.6	24.8
17-Feb-16	25.0	25.1	145.0	7.9	20.0	92.0	1.0	1.4

Otjomuise wastewater treatment plant effluent

	Temperature (°C)	Turbidity (NTU)	Electrical Conductivity (mS/m 25°C)	pH	Biological Oxygen Demand (mg/l)	Chemical Oxygen Demand (mg/l)	Total Nitrogen (mg/l)	Total Phosphates (mg/l)
20-Jan-16	24.0	78.0	130.0	7.6	27.0	73.0	0.7	1.2
27-Jan-16	22.1	15.9	145.0	7.2	16.7	45.0	0.8	0.7
03-Feb-16	23.0	7.1	145.0	8.2	8.0	33.0	0.4	0.4
10-Feb-16	26.0	45.0	135.0	7.8	53.3	144.0	0.7	2.1
17-Feb-16	25.0	247.0	140.0	7.7	300.0	799.0	0.3	42.5