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Efficiency of wastewater treatment plants situated in Zomba, Malawi

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Abstract

The need for sanitation and sustainable water management is an issue of growing importance in the world. Wastewater treatment is of high importance, mainly due to two reasons, to protect the environment and to prevent contamination of water resources, which can lead to the spreading of diseases.

More then 25% of the population in Malawi does not have access to safe drinking water sources and UNICEF's monitoring showed, in 2008, that only 56% of the population have access to improved sanitation facilities. Over the last 60 years a drastic population increase has occurred in the town of Zomba in southern Malawi. The municipal water treatment plant has not managed to keep up with the growing population, which has resulted in untreated sewage water being emitted straight in the Likangala River that runs through the city. People living in the nearby area of the river are using the water for drinking, washing and irrigation. The university in the city, Chancellor College, owns a small wastewater treatment plant that also has its outlet in Likangala River. This treatment plant has been poorly maintained and neglected by the university, which has resulted in a non-working pond system.

The purpose of this study is to evaluate the efficiency of these two wastewater treatment plants. Water samples were collected from different parts of the plants, in order to compare differences in concentrations at the inlet, during the purification process, and at the outlet. Analyses were made on nitrate, phosphate, sulfate, magnesium, chloride, sodium, potassium, manganese, calcium, zinc, iron, copper, lead, chromium and cadmium. Analyses were carried out by using AAS, UV and IC. Field measurements were also performed for pH, temperature and conductivity. The results were compared with guideline values established by the WHO and the Malawian bureau of standards.

The results of the study showed that both plants exhibit elevated levels of iron and manganese in effluents. No nutrients, except phosphate, exceeded the guideline values for drinking water, but for many nutrients there was also no significant reduction. The high phosphate levels in both plants are alarming given the increase in algae growth these levels can contribute to. Further studies are necessary at both plants to examine the content of the wastewater, especially pathogen levels.

Keywords: Malawi, Zomba, Wastewater treatment, treatment efficiency, guidelines

Referat

Behovet av sanitet och hållbar vattenhantering är en fråga av ökande betydelse i världen. Rening av avloppsvatten är av stor vikt, främst på grund av två anledningar, för att skydda miljön och för att förhindra föroreningar av vattenresurser, vilket kan leda till spridning av sjukdomar.

Mer än 25 % av befolkningen i Malawi saknar tillgång till säkra dricksvattenkällor och UNICEF:s övervakning visade under 2008 att endast 56 % av befolkningen har tillgång till förbättrade sanitära anläggningar. I staden Zomba i södra Malawi har en drastisk populationsökning skett under de senaste 60 åren, vilket har resulterat i att det kommunala vattenreningsverket inte lyckats hålla jämna steg och vid tillfällen har obehandlat avloppsvatten släppts ut i Likangala floden som rinner genom staden. Människor som bor i flodens närområde använder flodvattnet för att dricka, tvätta och till bevattning. Stadens universitet, Chancellor College, äger ett mindre reningsverk som även det har sitt utlopp i Likangala floden. Detta reningsverk har varit dåligt underhållen och försummats av universitetet, vilket har resulterat i en icke fungerande dammsystem.

Syftet med denna studie är att utvärdera effektiviteten av dessa två vattenreningsverk. Vattenprover samlades in från olika delar av reningsverken, detta för att kunna jämföra skillnader i halter vid inlopp, under reningsprocessen och vid utloppet. Analyser gjordes på nitrat, fosfat, sulfat, magnesium, klorid, natrium, kalium, mangan, kalcium, zink, järn, koppar, bly, krom och kadmium. Analyser utfördes med användning av AAS, UV och IC. Fältmätningar utfördes också på pH, temperatur och konduktivitet. Resultaten jämfördes med riktvärden som fastställts av WHO och Malawian Bureau of Standards.

Resultaten från studien visade att båda anläggningarna uppvisade förhöjda halter av järn och mangan vid utloppet. Inga näringsämnen, förutom fosfat, översteg riktvärdena för dricksvatten, men för många näringsämnen fanns också ingen signifikant minskning. De mycket höga fosfathalterna i både reningsverken är alarmerande med tanke på ökningen av algtillväxt dessa nivåer kan bidra till. Ytterligare studier behövs vid båda reningsverken för att undersöka innehållet i utloppsvattnet, speciellt patogennivåer.

Nyckelord: Malawi, Zomba, vattenrening, reningseffektivitet, riktvärden

Preface

This minor field study was performed in the summer and fall of 2012 and major part of the study was carried out during two months at Chancellor College in Malawi.

The supervisors of the thesis were professor Ingmar Persson at the Department of Chemistry, Inorganic and Physical Chemistry at the Swedish University of Agricultural Sciences and professor Samson M I Sajidu at the Department of Chemistry at the Chancellor College, University of Malawi.

The project was supported by scholarships from the Swedish International Development Agency (Sida) through the Committee of Tropical Ecology (ATE) at Uppsala University.

First off all I would like to thank my supervisors Samson M I Sajidu and Ingmar Persson. Thank you for all your guidance and support. I would also like to thank professor Jonas F Mwatseteza and professor Timothy T Biswick at the Department of Chemistry at the Chancellor College, University of Malawi for guidance and making my stay in Malawi memorable and enjoyable. Thanks to Daniel Lundberg at the Department of Chemistry, Inorganic and Physical Chemistry at the Swedish University of Agricultural Sciences for guidance and help in finding a project and finalizing my report. I wish to thank the technicians working with me at Chancellor College; Chikumbusho M H Kayira, Charles Nkukyumila, Timothy Mguntha and Upile Chitete for all their guidance regarding the work I performed but also for all the conversations we had on everything from Malawian politics to religion. I have learned a lot from you. Lastly, I would like thank Agnes Forsberg and Malin Mellhorn, my friends and colleagues who performed their minor field studies in connection to mine.

Populärvetenskaplig sammanfattning

Tillgång till rent dricksvatten är en mänsklig rättighet enligt FN. Trots detta anger UNICEF att mer än 25 % av människorna i Malawi saknar tillgång till rent dricksvatten. Urbaniseringen i utvecklingsländer ökar drastiskt och denna ökning sätter allt större press på avloppssystem och reningen av avloppsvatten. Vattenrening är av stor betydelse, främst på grund av två anledningar, för att skydda miljön och för att förhindra föroreningar av vattenresurser, vilket kan leda till spridning av sjukdomar.

I ett land som Malawi, där vattenburna sjukdomar är en av de största dödsorsakerna bland barn, är ett fungerande vattensystem av största vikt. I staden Zomba i södra Malawi har en drastisk populationsökning skett under de senaste 60 åren, vilket har resulterat i att det kommunala vattenreningsverket inte lyckats hålla jämna steg och vid tillfällen har obehandlat avloppsvatten släppts ur i Likangala floden som rinner genom staden. Människor som bor i flodens närområde använder flodvattnet för att dricka, tvätta och till bevattning. Stadens universitet, Chancellor College, äger ett mindre reningsverk som även det har sitt utlopp i Likangala floden. Detta reningsverk har varit dåligt underhållen och försummats av universitetet, vilket har resulterat i en icke fungerande dammsystem.

Syftet med denna studie är att utvärdera effektiviteten av dessa två vattenreningsverk i Zomba. Analyser gjordes på åtta stycken näringsämnen och sju stycken tungmetaller. Ett näringsämne är ett element som är livsnödvändigt för organismer och växter. Om inte vattnet renas ordentligt finns det dock en risk att dessa nivåer är skadliga när de släpps ut i floder och andra vattendrag. I växter kan detta leda till missväxt vilket kan i ett land som Malawi, som är starkt beroende av sitt jordbruk, få förödande konsekvenser. Ett för högt intag av näringsämnen hos människor och andra organismer kan orsaka skador på hälsan. Några av de tungmetaller som undersöktes är nödvändiga för de flesta organismer men vid mycket låga doser, medan andra är direkt skadliga även i små doser.

Vattenprover samlades in från olika delar av reningsverken, detta för att kunna jämföra skillnader i halter vid inlopp, under reningsprocessen och vid utloppet. Även pH, temperatur och konduktivitet mättes i fält. Resultaten jämfördes med riktvärden som fastställts av WHO och Malawian bureau of standards.

Resultaten från denna studie visade att båda anläggningarna uppvisar förhöjda halter av järn och mangan. Inga näringsämnen, förutom fosfat, översteg riktvärdena för dricksvatten, men för många näringsämnen fanns heller ingen signifikant minskning. De mycket höga fosfathalterna i både reningsverken är alarmerande med tanke på ökningen av algtillväxt dessa nivåer kan bidra till. Ytterligare studier behövs vid båda reningsverken för att undersöka innehållet i utloppsvattnet. Hur höga patogenhalter vattnet innehåller är av intresse varför en undersökning på detta skulle vara nödvändig.

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1. Introduction

The need for sanitation and sustainable water management is an issue of growing importance in the world. Increased urbanization puts extra pressure on the already existing wastewater treatment plants. Although the UN states that access to safe drinking water and sanitation is a human right, today 2.6 billion people lack improved sanitation facilities according to figures from WHO/UNICEF and over 780 million people still use unsafe drinking water sources (UNICEF, 2012, Internet).

Wastewater treatment is of high importance, mainly due to two reasons: to protect the environment and to prevent the contamination of water resources, which can lead to the spreading of diseases. It is especially important in urban and industrial areas where water often contains high concentrations of pathogens and substances such as heavy metals that may be harmful to people and organisms. Untreated wastewater let out in streams, rivers and on land without purification can be a danger to many kinds of life forms. For humans there is a high risk of transmission of water related diseases. On land it can damage and destroy crops and form ponds, which can function as breeding pools for insects and other organisms (Fasinmirin et al., 2009). An overload of nutrients can also lead to eutrophication of rivers, lakes and oceans.

1.1 Malawi

Malawi is a country located in the southeast part of Africa, see figure 1. An area of 118 480 km^2 and a population size of about 15 million makes Malawi one of the most densely populated countries in Africa (WHO, 2012, Internet). According to UNDP, Malawi is one of the world's poorest countries, ranking 171 out of the 182 countries studied in the Human Development Index (UN, 2011, Internet). Malawi is landlocked, which has made the country vulnerable and dependent on its neighboring countries for export and import. Malawi has agriculture as its main industry. With 90% of the population depending on agriculture, both as income and food source, years with crop failure has struck hard on the population and at several times the country has suffered from mass starvation.

Figure 1: Malawi, located in the southeast part of Africa (Istanbul-city-guide, 2007-2012)

According to UNICEF, one of the major causes of death amongst young children in Malawi is water-borne diseases. More than 25% of the population in Malawi does not have access to safe drinking water sources and UNICEF's monitoring showed, in 2008, that only 56% of the population have access to improved sanitation facilities (UN 1, 2012, Internet; UNICEF, 2008, Internet).

Urbanization is growing at a rapid pace in Malawi; the UN estimates that it is the country that has the fastest urbanization rate in the world. The rapid urbanization is putting pressure on the already existing wastewater treatment plants and the need for more treatment plants is growing as the cities grow.

1.2 Zomba

Zomba, situated in the southern part of Malawi, is the fourth largest city with a population of approximately 91,900 people (NE, 2010, Internet). Zomba experiences tropical climate with three seasons: hot rainy, cool dry and hot dry seasons. Zomba lies in the shadow of a plateau with the same name, which serves not only as a popular tourist destination but also provides the city with fresh drinking water that is supplied through the recently established Mulunguzi dam. It is mainly the formal areas, areas intended for housing according to the city's general planning and building regulations, of Zomba that have adequate access to water supply. While the impoverished informal areas, areas where homes are built on land without legal claim or an area where housing are not in compliance with current planning and building regulations, have little or no access to water supply. In the informal areas, where the majority of the city's inhabitants live, people mainly rely on the municipal water points. Sometimes these points run dry and people are then forced to acquire water from unprotected water sources. About 27% of Zomba's inhabitants have access to piped water (UN Habitat, 2011).

Figure 2: Malawi, red arrow points out the location of the city Zomba (Nationmaster, 2003-2013).

Wastewater in the municipality is managed by the municipal WWTP and after treatment the treated water is being emitted to the Likangala River, which starts at Zomba plateau and runs through the city and finally flows into Lake Chilwa, situated at the border to Mozambique. The sewage system does not cover the entire city, which has led to a wide use of pit latrines, especially in the informal settlements; this has resulted in pollution of the groundwater. The lack of specific regulations for the management of the informal settlements has not only contributed to the contaminated groundwater but also to the pollution of rivers in the city, as a lot of waste and rubbish are dumped in the rivers. A major contributor to pollution in rivers is also industrial and domestic effluents (UN Habitat, 2011).

1.3 Background to the project

Water quality analyses have been carried out at two different wastewater treatment plants in Zomba. One investigation was carried out at the municipal water treatment plant and another analysis at a smaller plant owned by Chancellor College, both located in the southeast part of Zomba. The water from both plants is emitted into Likangala River, which runs approximately 50 km all the way down to lake Chilwa (Masamba and Malwafu, 2008). On its way to Lake Chilwa people in the nearby area use the river water for drinking, washing and irrigation. Lake Chilwa is a closed lake, with water outflow only through evaporation, which means it is very sensitive regarding pollution. Previous studies in the Likangala river show that a high amount of bacteria were found in the river and human consumption were not recommended (Chidya et al., 2011). Previous studies also show high levels of sodium, iron and chloride in Lake Chilwa (Masamba and Malwafu, 2008; Chidya et al., 2011). Also high nitrate and manganese levels were detected in Likangala River close to the municipal WWTP (Chidya et al., 2011).

1.3.1 Zomba wastewater treatment plant

The municipal wastewater treatment plant in Zomba started running in the 1950's. The wastewater flowing into the treatment plant is domestic, coming from households, hospitals, army barracks and other large institutions. In 1950 it was designed to provide water to a population of 35,000 people. Today there are about 92,000 people living in the Zomba municipality and the sewage treatment has not managed to keep up with the growing population, which has resulted in untreated sewage water being discharged straight in the Likangala River (Ferguson and Mulwafu, 2001). The authorities in charge of the plant should analyze the water continuously, but due to lack of equipment and resources this has not been done at the sewage treatment plant in Zomba. Therefore, there is no recent information on how effectively the treatment plant is working.

1.3.2 Chancellor College wastewater treatment plant

The treatment plant at Chancellor College was established in 1974, the same year that the university started. Chancellor College is the largest college of the five colleges in Malawi. Approximately 5000 students attend Chancellor College and about 50 % of them are also residents on the campus. The Chancellor College sewage has been poorly maintained and neglected by the college, which has resulted in a non-working pond system.

1.4 Aim

The aim of this study was to examine and evaluate the treatment performance of two wastewater treatment plants situated in the city of Zomba, Malawi. This was done by analyzing water samples taken at the two treatment plants and comparing with guideline values established by the WHO and the Malawian bureau of standards.

2. Theory

2.1 Domestic wastewater

The water used by a community is called domestic wastewater and contains a mixture of all household wastewater. Household water means water coming from toilets, showers, dishing, laundry, other cleaning, etc. Wastewater contains everything from large floating and suspended materials to very small solids and dissolved substances. The composition of human faeces and urine is composed principally of proteins, carbohydrates and fats. Besides these compounds, faeces contain many millions of intestinal bacteria and, to a lesser extent, many other organisms. The majority of these are harmless and some are even useful, but a significant minority can cause human diseases (Mara, 2003). Urine also contains high amounts of nutrients such as nitrogen, phosphorus, potassium and sulfur (Jönsson et al., 2005).

2.2 Nutrients

A nutrient is an element that is essential to organisms and plants. In domestic wastewater high levels of essential elements such as nitrogen (N), phosphorus (P), potassium (K), sulfur (S), chlorine (Cl), sodium (Na), magnesium (Mg) and calcium (Ca) are often found (Smith, 2005). This is mainly due to the high levels of nutrients in urine and faeces, but also to the use of for example detergents in households (Shilton, 2005). Unless the water is purified properly there is a risk that these levels are harmful to plants and organisms when emitted into streams and rivers. In plants, this can lead to crop failure, which can have devastating consequences in a country like Malawi that is highly dependent on its agriculture. An excessive intake of nutrients in humans and other organisms can cause damage to health. In domestic wastewater both bacteria and plants can help reduce the nutrient levels in wastewater through mineralization and uptake (Mara, 2003).

Most nutrients appear in wastewater in the form of free ions, except for a few. Sulfur is present as sulfate (SO_4^{2-}) in wastewater. Nitrogen appears in many different forms in wastewater, as nitrate (NO_3^-), ammonia (NH_4^+) and some times in the form of nitrite (NO_2^-). In this study, nitrogen was analyzed in the form of nitrate, since in a well-aerated pond system most nitrogen will be found in the form of nitrate (Sajidu, 2012, personal communication). In wastewater phosphorus is present as phosphate ($HPO_4^-/H_2PO_4^{-2}$), both in suspended and soluble form (Shilton, 2005). This form of phosphorus is immediately available for organisms since it is dissolved. There are no guideline values regarding phosphate for drinking water since it is not directly toxic to humans. However, a high concentration of phosphate contributes to high levels of algae in the water. This can in turn contribute to eutrophication; therefore, it is essential not to release water into rivers and streams with excessive levels of phosphate (WHO, 2011).

2.3 Heavy metals

Cadmium (Cd), copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), lead (Pb) and chromium (Cr) are all classified as heavy metals and can be very harmful. Some of the metals, Cu, Zn, Fe and Mn, are essential for most organisms but at very low levels, whiles others, Cd, Pb and Cr, are directly harmful even in small doses

(Sterner, 2003). Heavy metals are especially toxic to animals, either through direct uptake or through biomagnification. Metals have very few gaseous paths, which makes them more prone to bind to sediments, soils and other particles or to precipitate. Bacteria, algae and plants are also likely to have an uptake of metals. In domestic wastewater, the metal source is everything from batteries and other electronic components to bleaching, cleaning and disinfecting agents (WHO, 2011).

2.4 Guideline values

The values obtained from the two WWTP were compared with the guidelines for drinking water set by both the World Health Organization (WHO, 2011,2004) and the Malawian bureau of standards (MBS, 2008).

Table 1: Standards according to WHO and MBS. NA: data not available. *Taste threshold value. ** Not directly hazardous to humans but contributes to eutrophication.

Compound	WHO guidelines	MBS guidelines
Nutrients	mg/l	mg/l
NO_3^-	50	6.0-10.0
PO_4^{3-}	NA 0.5**	-
SO_4^{2-}	NA 250*	200-400
Na	200	100-200
K	NA	25-50
Ca	NA 100-300*	80-150
Cl	NA 250*	100-200
Mg	NA	30-70
Metals		
Cu	2	0.5-1.0
Mn	0.4	0.05-0.1
Cd	0.003	0.003-0.005
Zn	3	3.0-5.0
Fe	1.0-3.0	0.01-0.2
Pb	0.01	0.01-0.05
Cr	0.05	0.05-0.1
Other parameters		
pH value at 25°C	6.5–8.5 (no unit)	5.0-9.5 (no unit)
EC at 25°C	NA	70-150 (ms/m)

2.5 Temperature and pH

Extreme pH values and temperatures can inhibit processes, such as mineralization, or the function of microorganisms in treatment plants. Generally a pH between 6-8 is desirable for the biological oxidation of most wastes. In aerobic treatment plants organisms are usually mesophilic, where ideal temperature is 20-40 °C. To a certain level, increased temperature leads to an increase in biological activity (Gomes, 2009).

2.6 Conductivity (EC)

A material's ability to conduct electric current is called electric conductivity, which is basically the concentration of dissolved salts that represents a salinity hazard. Wastewater contains much higher concentrations of salts than drinking water. In irrigation, salt concentrations should not be to high, meaning the electric conductivity should be less then 75 mS/m. If the conductivity is higher than recommended, the crop's ability to absorb water and nutrients is interfered. Though there are some plants, for example cotton, which can tolerate medium to high levels of salinity (Mara, 2003).

3. Site description, purification and processes

There are different ways of purifying water depending on what the wastewater carries and to what extent treatment is required. There are generally three stages in the process of treating sewage water called primary, secondary and tertiary treatment.

3.1 Purification and processes at the Zomba municipal WWTP

The municipal wastewater treatment plant consists of both biological filter plants and maturation ponds. The wastewater will first pass through two screens, which cleans the water from the largest particles. After filtration the water is separated and stored in two identical settling ponds, so particles can settle and later on be removed. The water then runs into biological ponds where the water is sprinkled on rocks where bacteria, living on the rocks, degrade the organic matter. Finally, the water flows down into two, one after the other, maturation ponds where there is an uptake of nutrients in water lettuce (*Pistia stratiotes*) before releasing the water into Likangala River.

Figure 3: View of Zomba WWTP. The two maturation ponds shown in the picture are about 150 m long (Google Map Maker, 2012).

Figure 4: Screening at the municipally WWTP.

Preliminary treatment - Screening

The first step in the wastewater treatment is called screening, where steel bars works as screens, removing large floating objects and big mineral particles. Screening is mainly to prevent damage of the equipment, but also to prevent objects from accumulating on the surface of the stabilization ponds later on in the process (Mara, 2003).

Primary treatment - Sedimentation tank

When the largest particles have been removed in the screening process, water runs into two sedimentation tanks. The sedimentation tanks are over 15 m deep and cone shaped, the dimensions of the tanks makes the water flow very slowly, which enables the largest particles to settle by gravity (AWWA Staff, 2010).

Figure 5: One out of two sedimentation tanks at the municipal WWTP.

Secondary treatment – Biofiltration

When the sewage water has passed through the sedimentation tanks it runs into a biofiltration tank that consists of a 2-3 m deep bed with rocks that are about 50-100mm large. The water that runs into these tanks are sprinkled mechanically over the rocks, percolating down through the rocks and flows in the bottom into drain pipes leading the water to the next step in the treatment process. At the surface of these rocks, a microbial film is formed where the bacteria in this film can oxidize organic material in the water. The film formed grows in thickness and is eventually peeled off by the water flow; in the next treatment process these solids are removed (Mara, 2003). An important process that takes place in the biofiltration is nitrification. Nitrification is a two-step aerobic process where ammonia is oxidized to nitrite and then nitrite is oxidized to nitrate, both steps are facilitated by the present of different type of bacteria (Gomes, 2009).

Figure 6: Biofiltration at the municipal WWTP.

Tertiary treatment - Maturation ponds

In the last stage of the treatment there are two maturation ponds. The water surface in these ponds is covered with water lettuce (*Pistia stratiotes*) in order to reduce the number of algal suspended solids. By depriving the algae of sunlight the water lettuce inhibits the algae, which cannot

Figure 7: Sampling at the final maturation pond at the municipal WWTP.

reproduce nor grow. The roots of the water lettuce will contribute in reducing nitrogen, phosphorous and metals in the water by absorption of these substances. One disadvantage with these ponds is that they can act as mosquito breeding ponds. To prevent this, fish that eat mosquito larvae can be introduced in the ponds. Only a couple of years ago the water in these ponds was so clean that there were fish living in the ponds. By the time of sampling, conditions were too poor for fish to survive (Sajidu, 2012, personal communication). Further explanation on the processes that occurs in maturation ponds follows in chapter 3.2 below.

3.2 Purification and processes at the Chancellor College

The Chancellor College wastewater treatment plant consists of so-called waste stabilization ponds where the water, in different stages, is purified from sewage. The water runs through six ponds, which runs in a series in sets of two. The first two ponds are anaerobic and runs in series. After the anaerobic treatment, the wastewater runs into two facultative ponds, the term facultative indicates that these ponds consists of both aerobic and anaerobic conditions, and lastly the water reaches its final stage in three maturation ponds. The first three ponds at Chancellor College WWTP are in duplicate and run parallel with each other, the water from the two last facultative ponds is then being emitted into a larger, joint, maturation pond. At the time of sampling, only the last three ponds were working. The water was led past the first three and directly into the fourth pond, which then acted as an anaerobic pond.

Figure 8: A view over Chancellor College WWTP. The process starts at the largest dark green pond, which is about 1600m². By time of sampling only the last three ponds were working (Google Map Maker, 2012).

Waste stabilization ponds

In a county with warm climate, such as Malawi, waste stabilization ponds are an easy and relatively inexpensive way to treat wastewater. The process is entirely natural and uses only the energy from the sun to purify the wastewater. Since the purification is slow and depends on the amount of time the water can stay in each pond section, it requires a large area of land (Mara, 2003). Below is a description of how the Chancellor Colleges treatment plant should operate if maintained properly.

Primary treatment - Anaerobic ponds

The first step in the purification is the anaerobic pond. The main function of this pond is to remove BOD, biochemical oxygen demand, which is the amount of oxygen required for bacteria to break down organic material in wastewater. The removal rates are strongly linked to temperature and pH, a high temperature generates high removal (Gomes, 2009). Because of the high amount of untreated water that runs in to the anaerobic pond it does not contain any dissolve oxygen or algae. The anaerobic pond is also an important step in which floating material is removed. If these were to continue into the facultative ponds they would block out the sunlight, which is needed for algal photosynthesis (Mara, 2003).

In raw wastewater a high amount of the nitrogen occurs in the form of ammonia (NH_3), while a small amount is in the form of organic nitrogen, mainly in the form of urea and amino acids (Mara, 2003). In anaerobic ponds organic nitrogen is converted to ammonia through mineralization, which is a process that occurs when bacteria feed on organic nitrogen. Ammonia can then be removed from the anaerobic ponds by volatilization. In water, NH_3 exist in equilibrium with ammonium (NH_4^+), which form that dominates the water depends on pH and temperature. NH_4^+ starts to convert to NH_3 when pH is above 6.6, while at pH 9.2 the two forms are at equilibrium. Another way for nitrogen to be removed from anaerobic ponds is through denitrification, a process where nitrate are reduced, by anaerobic bacteria, to nitrous oxide or nitrogen gas and escapes to the atmosphere. At pH levels around 7.0-8.5 conditions ate optimum for denitrification to occur (Shilton, 2005).

A reduction of sulfate can occur in the anaerobic ponds. The reduction occurs through sulfate-reducing bacteria that reduce the sulfate to sulfide. A removal of heavy metals can also occur in the anaerobic ponds, this due to absorption of heavy metals to solids that later on settles. Heavy metals can also precipitate as metal sulfides (Shilton, 2005). Chlorine is not directly toxic humans but can contribute to unpleasant taste in the water. Since chlorine is an extremely active chemical it can react with many substances in wastewater such as iron and manganese (AWWA Staff, 2010).

Figure 9: The inlet pipe to the first anaerobic pond at the Chancellor College WWTP. By time of sampling, this pond was not working and no water was stored there.

Secondary treatment - Facultative ponds

In this set of ponds, there are both anaerobic and aerobic conditions. At the bottom of the ponds there are anaerobic conditions while it is aerobic on the surface. Solids and biomass settles in the facultative ponds, here they are decomposed by anaerobic bacteria which produces methane or hydrogen sulfide, forming an anaerobic sludge layer at the bottom of the ponds. At higher levels, close to the surface, there are oxygen-producing algae present that oxygenate the water through photosynthetic processes; bacteria then utilize the oxygen as they oxidize organic waste (Shilton, 2005). In this manner bacteria and algae interact, bacteria providing algae with carbon dioxide while algae provides bacteria with oxygen, as seen in figure 10. Oxygen is also added to the system from the surface area, where the amount of mixing due to wind effects plays an important role. Apart from the algae providing oxygen to the water, the algae also absorb nutrients, mainly nitrogen and phosphorus. The amount of algae in the pond will vary depending on temperature and loading. As a result of the large number of microalgae, the ponds are normally colored green (Mara, 2003).

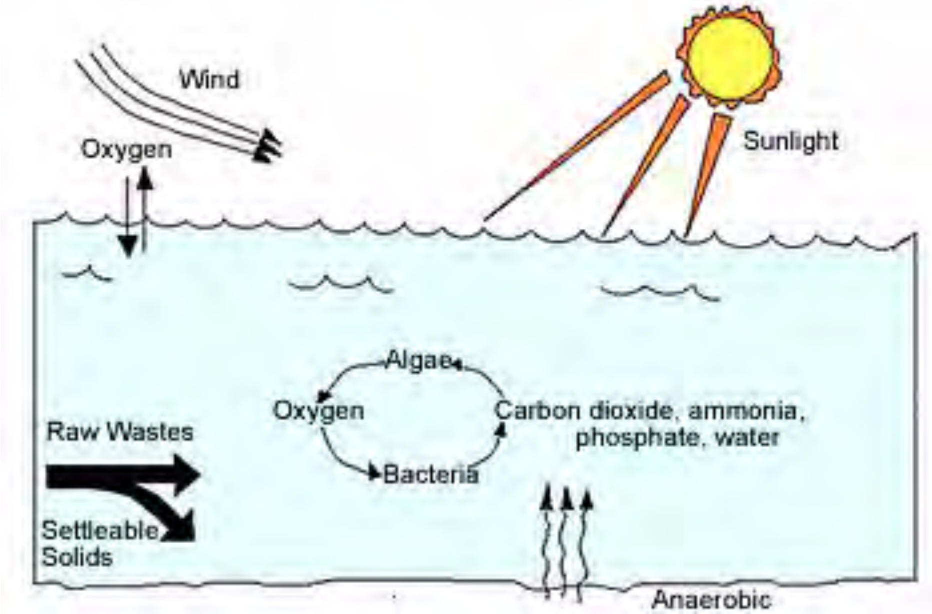

Figure 10: Processes occurring in a facultative pond (Mountain Empire, 2013).

The interaction between bacteria and algae also affects the pH level of the ponds. When algae or plants growing in ponds utilizes carbon dioxide, due to photosynthesis, faster than it is replaced by bacterial respiration, the pH raises in the water as hydroxide is released, see equation 1.

$$nHCO_3^- + nH_2O \leftrightarrow (CH_2O)n + nH_2O + nOH^- \quad \text{(Kayombo, 2005)} \qquad (1)$$

In the facultative ponds ammonia is removed from the water mainly through incorporation into algal biomass. At high pH nitrogen can also be lost by volatilization of ammonia and by denitrification of nitrate in the anaerobic layer (Mara, 2003).

The removal of phosphate in WWTP depends mostly on how much phosphate that leaves the water column and enters the sludge layer through sedimentation as organic phosphorus and precipitation as inorganic phosphorus. Since phosphate does not have a gaseous form the removal depends on the relationship between how much is being deposited and how much phosphate that is being brought back into the water column, phosphate can return to the water column through mineralization and re-solubilisation (Shilton, 2005). Another important removal of heavy metals is adsorption and bioaccumulation of pond algae and bacteria that later on is followed by sedimentation (Shilton, 2005).

Heavy metals are removed from facultative ponds through absorption of heavy metals to solids that later on settles. Another important removal of heavy metals is adsorption and bioaccumulation of pond algae and bacteria that later on is followed by sedimentation (Shilton, 2005).

Figure 11: Fourth pond normally working as a second facultative pond at the Chancellor College. By time of sampling, serving as anaerobic pond

Tertiary treatment - Maturation ponds

The maturation ponds are the last stage before the water is being emitted into Likangala River and here only aerobic conditions occur. The water coming from facultative ponds contains a high level of enteric pathogens and the maturation ponds work primarily to reduce these viruses and bacteria but there can also occur a reduction of nutrients and metals in the ponds (Mara, 2003; Shilton, 2005).

In maturation ponds nitrogen removal occurs, as in facultative ponds, through incorporation into algal biomass and at times volatilization (Mara, 2003). Studies has shown that in maturation ponds nitrogen removal can also occur through nitrification in the water column followed by denitrification in sediments (Shilton, 2005). For denitrification to occur anoxic conditions is required. An electron donor is also needed, this can be organic matter, sulfide or another added donor. Anoxic conditions occur in pond sediments where the nitrate is reduced by facultative bacteria to nitrogen gas and escapes to the atmosphere (Gomes, 2009).

For the phosphorus to be maintained in the sediments, either as microbial material or as chemical complexes, it is important that there are aerobic conditions in the surface sediments. In especially maturation ponds phosphorus can be precipitated as insoluble hydroxyapatite at pH levels above 9.5 (Shilton, 2005). Therefore the most effective way to remove phosphorus from wastewater is said to be to increase the numbers of maturation ponds (Kayombo et al, 2005).

Removal of metals in waste stabilization ponds varies depending on metal, but most removal of metals occurs through sedimentation of solids to which the metals are adsorbed. At high pH some heavy metal cations can form insoluble precipitation with anions such as hydroxide and phosphate. An uptake of heavy metals can also occur in both algae and bacteria. Generally, removal of metals increases with the number of ponds in the system, especially if the system consists of maturation ponds as final ponds (Shilton, 2005).

Figure 12: Fifth pond that should normally work as the first of two maturation ponds at the Chancellor College. By time of sampling the function of the pond was more similar to that of a facultative pond.

4. Materials & Methods

4.1 Sampling and preparation

4.1.1 Zomba WWTP

Samples were collected at the inlet after the screening, after the biofiltration, between the two maturation ponds, at the last maturation pond, at the outlet, in the river 50 meters upstream the outlet and 50 meters downstream the outlet. Sampling was performed using a grab sampling method. In the seven different locations, six ½ liter plastic bottles were collected at each point. The bottles were rinsed with distilled water several times before sampling. Three of the six bottles were acidified, adding 1 ml of nitric acid, and used for metal analyses. The acidification brings the pH down to two or lower and is done in order to avoid adsorption of metals to the walls of the containers and to keep the metals in the solution.

4.1.2 Chancellor College WWTP

Samples were taken from three different places at the treatment plant. Due to the fact that only three ponds were actually working at time of sampling, samples were taken at the inlet, between the fifth pond and the sixth pond, and at the outlet using a grab sampling method. Eighteen bottles were brought out into the field to be able to gather six samples at each point. By time of sampling four bottles were leaking. The inlet and outlet were considered the most important sampling points, so only two samples where taken between the fifth and sixth pond. Samples were taken at each point using a grab method with ½ liter plastic bottles that had been treated the same way as for the Zomba WWTP. For samples gathered to analyze the heavy metals, 1 ml of nitric acid was added straight after sampling into three of the bottles collected at each site. The same procedure was then used as that on the samples from the Zomba WWTP.

4.2 Field measurements

4.2.1. Temperature and pH

All water samples were measured for pH value and temperature. The pH meter was portable and brought to the field where it was calibrated before used. The pH and temperature meter used was from Martini Instruments named pH 55. The instrument had a pH range between -2.0 to 16.0 and an accuracy of ±0.1 pH at 25 degrees Celsius and a resolution of 0.1 pH. The temperature range was -5.0 to 60.0 °C with an accuracy of ±0.5°C and a resolution of 0.1°C.

4.2.2 EC

An electric conductivity (EC) meter was brought in the field to measure the EC. The electric conductivity represents the total salinity of the water. The EC meter used was portable from Martini Instruments and named EC 59 and also calibrated in the field. The instrument had an EC range of 0-3999µS/cm and an accuracy of ±2%.

4.3 Analyses

To analyze for total metals, the acidified samples were digested using the nitric acid digestion method (APHA, 1985). When digested, metal levels were determined using the AAS. The samples that were not acidified were stored in a refrigerator until analysis. Ion exchange chromatography (IC) was used to determine levels of nitrate, sulfate, chloride and fluoride, whilst an UV spectrophotometer was used to determine iron and phosphates.

4.3.1 AAS

One method for analyzing metal ions in water is to use an atomic absorption spectrometer (AAS). The AAS provides a quantitative determination of the amount of ions in a liquid by measuring the amount of optical radiation (light) being absorbed by free atoms in the gaseous state.

Different lamps had to be used for each of the elements, since elements absorb light of different wavelength. The AAS machine consists of a hollow cathode lamp, an atomizing unit, a monochromator and a detector. In the atomizing unit a 2000°C flame vaporizes the samples, turning all metal salts into metal ions and then into metal atoms. The hollow cathode lamp excites the atoms and an estimation of amount of ions can be made by measuring how much of the light is being absorbed (Simonsen, 2003). The measured values obtained from the different samples were fit to a calibration curve; standards were prepared as described in APHA (1985).

4.3.2 UV/VIS

Ultraviolet-visible spectrophotometry (UV/VIS) uses light in the ultraviolet and visible ranges, where molecules absorb light energy in the form of photons. Basically a spectrophotometer consists of a light source that transmits light through a solution then records how much light is absorbed. By measuring the light absorbed in a couple of standards, with known concentrations of a substance, the concentration of an unknown sample can be obtained using a calibration curve. Standards were prepared as described in APHA (1985).

4.3.3 IC

A ion chromatography (IC) was used for measuring nitrate, chloride and sulfate. The chromatograph consists of three components: an elution liquid, a stationary phase and the water sample which is analyzed. The interaction between these phases contributes to the separation of components in a sample. The elution liquid is needed to transport the ions through the system. The stationary phase holds charged particles and thereby determines the amount of charged particles in the liquid. The components, which in this case consist of different nutrients, are kept more or less firmly in the stationary phase that works as an ion exchanger. The difference in rate is due to the fact that substances have different affinities; tendencies to interact with other substances or compounds. To determine levels of nutrients a calibration curve is made (Simonsen, 2003).

5. Results

The table below presents the results from analyzes carried out by AAS. At the Chancellor College WWTP, only two ½ liter bottles were collected and analyzed at the pond site. Therefore there are no standard deviations for samples taken at those points. For standard calibration curves obtained for AAS, see Appendices 1-6.

Table 2: Results from analyses of sodium, potassium, calcium, magnesium, zinc and manganese carried out by AAS. For both Chancellor College WWTP and Zomba WWTP there were three samples taken on each location, except for samples taken at the pond at CC WWTP where only one sample was collected.

	Na (mg/l)		**K (mg/l)**		**Ca (mg/l)**		**Mg (mg/l)**		**Zn (mg/l)**		**Mn (mg/l)**	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
CC WWTP												
Inlet	17.3	0.6	15.6	2.0	6.6	0.6	5.2	0.4	0.8	0.1	0.3	0.0
Pond	17.7		19.3		3.9		4.6		0.6		0.4	
Outlet	17.3	0.1	20.2	1.7	3.8	0.4	4.7	0.3	0.5	0.2	0.3	0.0
Zomba WWTP												
Inlet	8.7	0.1	91.7	1.6	9.8	0.3	6.0	0.0	0.2	0.1	0.7	0.0
After biofilt.	8.7	0.0	19.2	0.6	5.7	0.5	4.8	0.1	0.0		0.7	0.1
Between pond	9.1	0.0	23.5	1.0	4.8	0.5	5.0	0.2	0.0		0.6	0.1
After last pond	8.9	0.1	21.3	1.5	5.6	1.5	4.9	0.4	0.0		0.7	0.1
Outlet	9.0	0.1	20.5	1.5	5.4	0.9	4.7	0.0	0.0		0.6	0.0
Upstream	8.0	0.1	6.3	0.4	7.0	1.5	4.2	0.1	0.0		0.0	
Downstream	8.1	0.2	7.6	0.3	11.7	0.8	4.2	0.2	0.0		0.5	0.1

Cu, Cd, Cr and Pb were all below detection limits.

Table 3 shows the results obtained from analyzes with spectrophotometry. For standard calibration curves obtained for spectrophotometry, see Appendices 7-8.

Table 3: Results from analyses on iron and phosphate carried out by spectrophotometry. For both Chancellor College WWTP and Zomba WWTP there were three samples taken on each location, except for samples taken at the pond at CC WWTP where only one sample was collected.

	Fe (mg/l)		**PO_4^{3-} (mg/l)**	
	mean	SD	mean	SD
CC WWTP				
Inlet	24.1	1.9	67.7	6.1
Pond	15.6		49.5	
Outlet	16.2	0.8	50.5	0.3
Zomba WWTP				
Inlet	48.3	0.9	163.4	13.8
After biofilt.	5.4	1.3	32.2	3.8
Between pond	2.7	0.2	21.4	1.5
After last pond	3.0	0.4	19.1	0.6
Outlet	3.6	0.2	21.3	0.4
Upstream	1.1	0.1	4.1	0.4
Downstream	1.4	0.1	6.4	0.2

Table 4 shows the results obtained from analysis on the IC.

Table 4: Results from analyses on nitrate, chloride and sulfate carried out by IC. For both Chancellor College WWTP and Zomba WWTP there were three samples taken on each location, except for samples taken at the pond at CC WWTP where only one sample was collected.

	NO_3^- (mg/l)		**Cl (mg/l)**		**SO_4^{2-} (mg/l)**	
	mean	**SD**	**mean**	**SD**	**mean**	**SD**
CC						
Inlet	27.8	0.9	32.3	0.1	0.0	
Pond	5.6		13.5		0.0	
Outlet	9.5	3.2	34.0	8.2	0.0	
Zomba						
Inlet	36.1	12.8	129.5	8.2	0.3	0.4
After biofilt.	50.8	1.0	22.8	3.0	0.6	0.5
Between pond	27.5	1.5	31.7	3.8	0.0	0.0
After last pond	27.3	0.7	28.1	0.8	0.0	0.0
Outlet	24.5	2.3	26.6	0.4	0.2	0.5
Upstream	5.4	0.4	4.5	0.1	1.0	0.0
Downstream	4.8	1.1	5.6	0.7	0.9	0.2

Table 5 below shows results from field measurements.

Table 5: Results from measurement on pH, Temperature and EC carried out in field. For both Chancellor College WWTP and Zomba WWTP measurements were made on three samples taken on each location.

	pH		Temperature (°C)		EC (mS/m)	
	mean	SD	mean	SD	mean	SD
CC WWTP						
Inlet	7.2	0.1	22.1	0.2	620	22.3
Between ponds	6.6	0.1	21.9	0.1	570	17.0
Outlet	6.9	0.1	21.6	0.2	616	3.6
Zomba WWTP						
Inlet	7.0	0.2	21.8	0.2	1523	41.0
After bio	6.6	0.1	21.8	0.1	373	2.9
Between pond	6.7	0.1	19.7	0.2	390	29.0
After last pond	6.7	0.1	19.3	0.5	370	24.4
Outlet	6.9	0.1	19.4	0.5	367	17.9
Upstream	6.9	0.1	18.8	0.3	109	6.5
Downstream	6.8	0.1	19.4	0.1	129	14.9

6. Discussion

6.1 Zomba WWTP

6.1.1 Nutrients

The mean concentrations of Na, K, Ca, Mg, Cl and SO_4^- where all found to be lower then the safe limits for drinking water set by both WHO and MBS. This indicates that the concentrations of these substances are currently not emitted from Zomba WWTP at levels considered a danger for humans. However, these results tell nothing about whether the facility reduces these substances to the extent required. Neither the concentrations of Na, Mg nor SO_4^{2-} were over the guideline values at the inlet. Therefore, no conclusions can be drawn about the effectiveness of the plant with respect to these nutrients.

Potassium and chloride had mean concentrations at the inlet of 91.7 mg/l and 129.5 mg/l respectively, which were higher than the guideline values. This on the other hand shows an ability to effectively reduce high concentrations of these nutrients. The potassium reduction could be due to an uptake by plants in the maturation ponds, whiles the removal of chloride could be due to reactions with other substances.

Mean nitrate concentrations were found to be higher at the outlet than the guideline values set by the MBS, whiles downstream results showed values below the MBS guidelines. In this case, the WHO guideline values were significantly higher than the MBS and all nitrate concentrations, even at the inlet, were found below the WHO guideline values. Since the second treatment consist of a biofilter, organic nitrogen were converted to ammonium and later on oxidized to nitrate; hence the increase in nitrate concentrations after the biofilters. The nitrate reduction in Zomba WWTP could be due to uptake by plants in the maturation ponds. The pH levels in the maturation ponds were not high enough to be favorable neither for denitrification to occur nor for ammonia to dominate the water and thereby be removed through volatilization in any great extent. A more efficient reduction might occur in the Zomba WWTP if pH levels were higher.

Mean phosphate concentrations at both outlet and downstream significantly exceeded the recommended guideline values established by WHO. There was, however, a substantial reduction from the levels at the inlet but not enough reduction that the levels would fall within the guideline value of 0.5 mg/l. The high phosphate levels may contribute to increased algae growth in Likangala River and Lake Chilwa. Since removal of phosphate mainly occurs in maturation ponds and a precipitation as insoluble hydroxyapatite at a pH level above 9.5, one way of approving the removal might be to add an extra maturation pond to the system or increase the pH in the current ponds.

6.1.2 Metals

No zinc was found in the water being emitted from the Zomba WWTP. At the inlet only low zinc concentrations were found, below both guideline values. The same reasoning is valid for this metal as for some of the nutrients. When wastewater containing such low concentrations of zinc it is not possible to draw any conclusions regarding the plant's efficiency.

In the case of iron, high levels were found at the outlet and in the river water 50 meter above and below the outlet. Iron levels were below the values set by the WHO but significantly higher than the values set by the MBS. Mean iron concentrations at the inlet were 48.3 mg/l, which is considerably higher than both guideline values, this showing a significant iron reduction after wastewater treatment at Zomba WWTP. The reduction of iron could be related to the reduction of chloride that also occurred after the biofilters, as these two substances tend to react with each other.

No manganese was found in the river water upstream the WWTP. But values above both WHO and MBS guideline for drinking water were found in the outlet and downstream the outlet. The wastewater at the inlet contained 0.7 mg/l manganese. Compared with manganese content at the outlet, 0.6 mg/l, there was no significant reduction of the metal. This indicates that the Zomba WWTP is not particularly effective at reducing manganese.

Since removal of metals, just as removal of phosphate, mainly occurs in maturation ponds through sedimentation and precipitation, a raise of pH or an increase of number of ponds could be a way of removing these substances more efficiently.

6.1.3 Temperature, pH and EC

Temperatures during the purifying process were within or just below the recommended levels. During the entire treatment process pH values were around 6.5-7.0,which is within the values recommended to maintain a good environment for biological oxidation to occur. The water being emitted from the WWTP was found to have a mean value of 6.9, which is in the range of what is set by the WHO and the MBS. There were low pH values in all maturation, this can be an indication that the algae do not manage to use the carbon dioxide, photosynthesis, as fast as the bacteria releases it. Since there were water lettuce growing in the maturation ponds one could expect the pH to be higher. The low pH values and the fact that the pH values did not increase during the cleaning process may be an indication of high levels of pathogens. Normally, it can be expected that pH would rise when pathogens are reduced during treatment. This due to the release of carbon dioxide through respiration and then photosynthesizing algal would contribute to an increase in pH.

The MBS has set EC guideline values to range between 70-150 mS/m. The EC at the outlet was 367 mS/m, which means that the EC value at the outlet was more than four times smaller than the value at the inlet (1523mS/m). Despite the significant reduction in electrical conductivity the purified water still exhibits too high EC. This clearly follows the above-mentioned results, where Fe, NO_3^- and PO_4^{3-} were found in excessive levels.

6.2 Chancellor College WWTP

6.2.1 Nutrients

The mean concentrations of Na, K, Ca, Mg, Cl^- and NO_3^- where all found to be lower then the safe limits for drinking water set by both WHO and MBS. This indicates that the concentrations of these substances are not emitted from Chancellor College WWTP at levels considered as danger for humans. However, concentrations in the inlet of most of these nutrients where also low, making it hard to draw any conclusions whether the Chancellor College WWTP is efficient in reducing nutrients if they were to come at higher concentrations.

For sodium and magnesium, there was hardly any reduction in concentrations, while potassium and chloride had an increase in concentration. The increase may be due to errors in analyses. The uptake of sodium, magnesium and potassium can be expected to occur in plants, but since the Chancellor College WWTP was poorly maintained at the time of sampling no plants were growing in the ponds and therefore an uptake could not occur. A removal of chloride was not expected since no measures have been taken to remove chloride from the wastewater. Since the levels of chloride were much lower than the guideline values they should not give rise to an unacceptable taste. Nitrate reduction mainly occurred in the anaerobic pond, the reduction could be due to denitrification in the pond. Field measurements showed a pH level of 7.2, which is a condition that is optimum for denitrification to occur.

Phosphate levels at all sample points were ten times higher than the guideline values recommended by the WHO. Difference in concentration between the inlet and outlet were low, indicating the sewage system's inability to reduce levels of phosphate. No uptake of phosphorus in plants can take place and the pH are to low for phosphorus to precipitate as any insoluble compound. By letting plants grow in the maturation pond an uptake would increase as well as the pH levels. An increase in number of maturation ponds is also a way to improve removal.

6.2.2 Metals

Zinc behaves similarly to other nutrients in the WWTP. The concentration exhibited was lower than both guidelines, but the overall reduction from inlet to outlet was small. It can be assumed that the treatment process would not work well if higher concentrations were to occur at the inflow, with an imminent risk that the discharge water would contain a hazardous amount of zinc as a result.

Both iron and manganese were found in significantly high amounts. Manganese concentrations were below the recommended values set by the WHO but MBS guideline values were exceeded significantly at all three sample points. An increase in concentration had occurred between inlet and outlet. It was only a small difference in concentrations, which may indicate that it was an observational error and that the concentrations actually were about the same and no reduction occurred in the WWTP. At the outlet, iron was found in considerably higher values than both guideline values. A reduction in concentration from the inlet had occurred, but the reduction was far from enough to reach the guideline values. Both iron and manages were at the time of sampling emitted from CC WWTP at levels considered a danger for humans. The impact these levels can have on the water in Likangala River is difficult to predict.

Metals are removed from wastewater through uptake in algae and bacteria, sedimentation and precipitation. Since the Chancellor College WWTP was not working properly by time of sampling there was only one pond acting as maturation pond. It is important that this treatment system is maintained properly to make sure that there are enough ponds to treat wastewater. If the pond system would be working as designed, a removal of both metals and nutrients would increase. If there were for example water lettuce growing in the maturation ponds, like the maturation ponds at the Zomba WWTP, an increase in uptake of both metals and nutrients would be expected.

6.2.3 Temperature, pH and EC

During the entire treatment process pH values were between 6.55 -7.17, which is within the values recommended to maintain a good environment for biological oxidation to occur. The water being emitted from the WWTP were found to have a mean value of 6.87, which are in the range of what is set by the WHO and the MBS. A pH reduction between inlet and outlet were observed, just as for Zomba WWTP, this can be an indication that the algae do not manage to use the carbon dioxide as fast as the bacteria releases it and it could also be an indication that there are high levels of pathogens in the water. Temperatures were at levels recommended for a good biologic activity during the entire purification process.

EC guideline values, set by the MBS, range between 70-150mS/m. The EC at the outlet was 616 mS/m, not very different form the EC values at the inlet and the pond. The results show that there is only a small decrease in EC value, 4 mS/m between inlet and outlet. This follows the above-mentioned results, where iron, manganese and phosphate were found in excessive levels. For irrigation; these EC values could lead to crop failure.

6.3 Analyses

Results from analyses performed in laboratory could be a source of error. When preparing standards for analyses by AAS, IC and UV there were too few instruments. When preparing the standards for each of the analyses, an automatic pipette was used to measure the correct amount of the various substances. The same tip was used for all standards, due to shortage of tips and reuse was the only option. To prevent contamination by substances other than desired, the tip was rinsed several times with deionized water. It would be preferable not to have to re-use the tip but this possibility was not present, therefore there is a risk that the standards were not fully correct.

7. Conclusion

It can be concluded from the results that some of the substances analyzed, at both Zomba WWTP and Chancellor College, were emitted in levels above recommended guideline values when the study was conducted.

Both plants exhibit elevated levels of iron and manganese. No nutrients, except phosphate, exceeded the guideline values for drinking water, but for many nutrients there were also no significant reduction. If the amount of nutrients would increase in the domestic water, there is a risk that the WWTPs would not be able to clean the water from these substances and the treated water would be discharged into the Likangala River in excessive levels. The very high phosphate levels discharging from both WWTP are alarming given the increase in algae growth these levels can contribute to.

Samples were taken during the Malawian winter, meaning the dry season. During the rainy season, Chancellor College WWTP is exposed to higher water flows and there is a risk that the retention time in the various pond sections is reduced. This may also contribute to a lower extent of purification and concentrations of nutrients and metals may increase. The municipal WWTP can regulate the flow into the different sections in a way than the CC WWTP cannot and therefore the Zomba WWTP are not as affected by seasonal variations as the College WWTP. However, in rain season the high levels of nutrients and metals are diluted.

Only by observing the color and odor of the water at the outlet of the Chancellor College WWTP, one can easily conclude that the water is still contaminated. Further studies are necessary to examine the content of the wastewater, especially pathogen levels. The importance of the plant being a priority for the university and maintained properly is clear. If all the ponds would work as designed, excessive levels might not be emitted from the treatment plant.

One way to avoid the Zomba WWTP to exhibit elevated levels of metals and nutrient could be to construct a third maturation pond. This would increase the removal of both phosphorus and metals. The water emitted from the municipal WWTP did not have an unpleasant odor or color. Nevertheless, there is reason to recommend that more analyses are carried out and further parameters, for example pathogens, should be examined.

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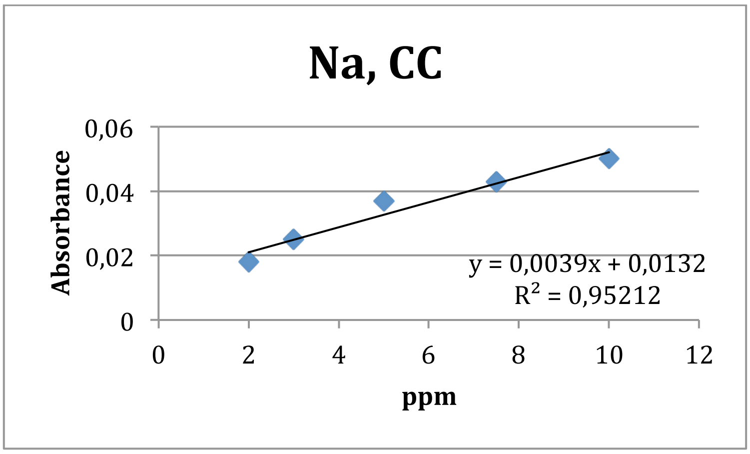
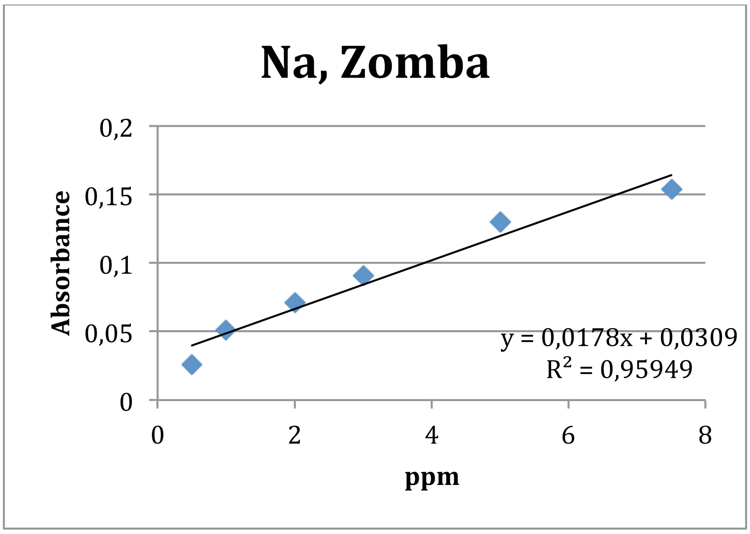
Appendix

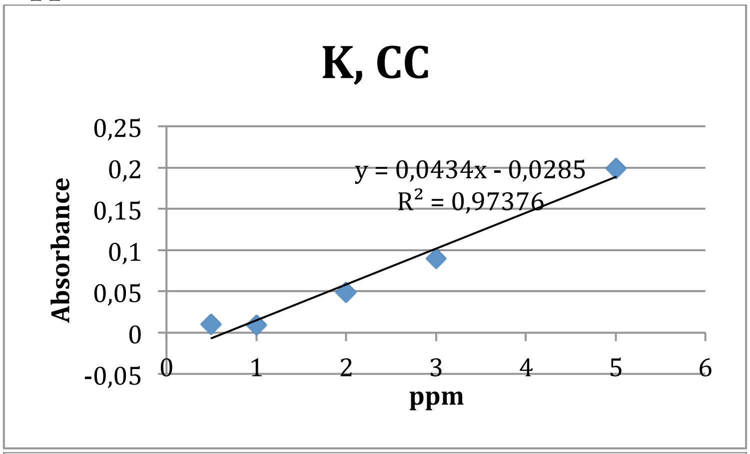
Appendix 1

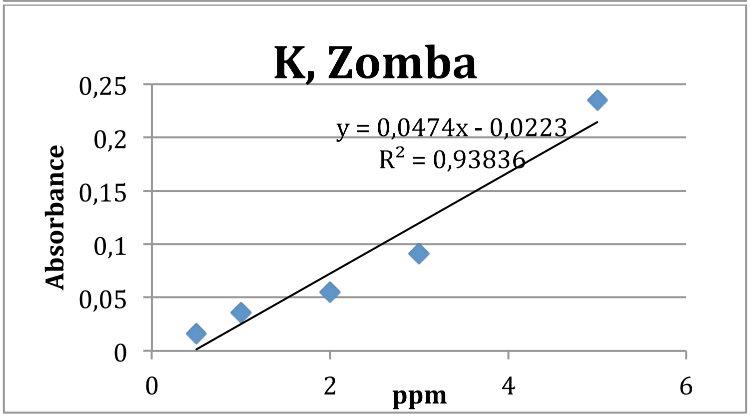
The sodium standard curve for Chancellor College was modified; two standards, 0,5 ppm and 1 ppm, were removed from the curve when these was considered inaccurate.



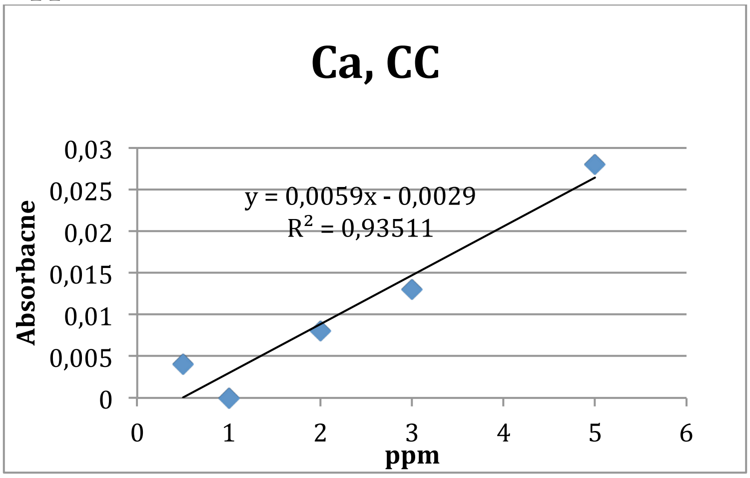


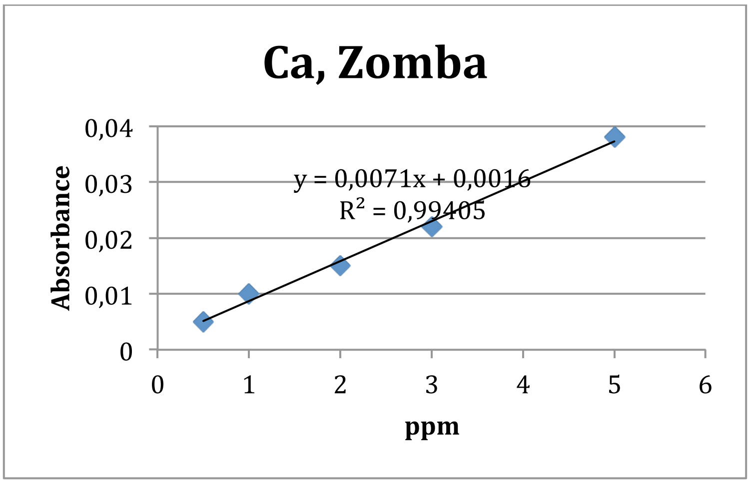
Appendix 2



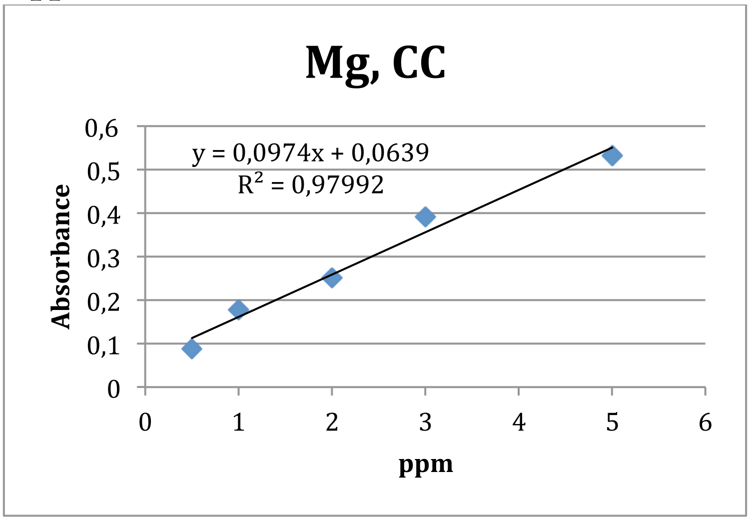


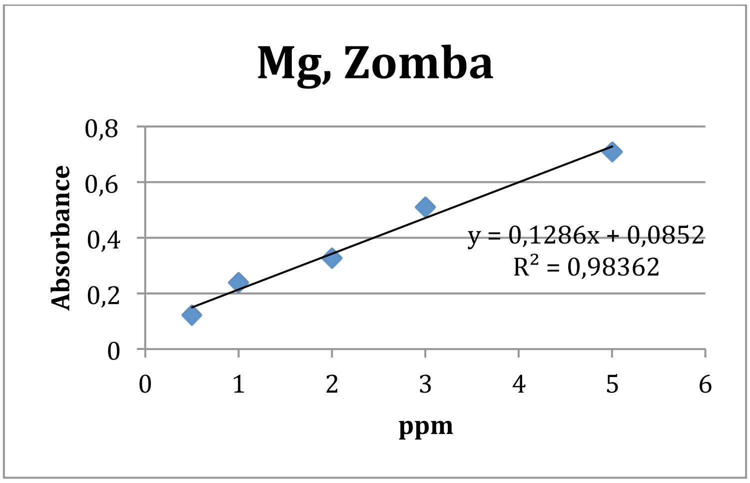
Appendix 3



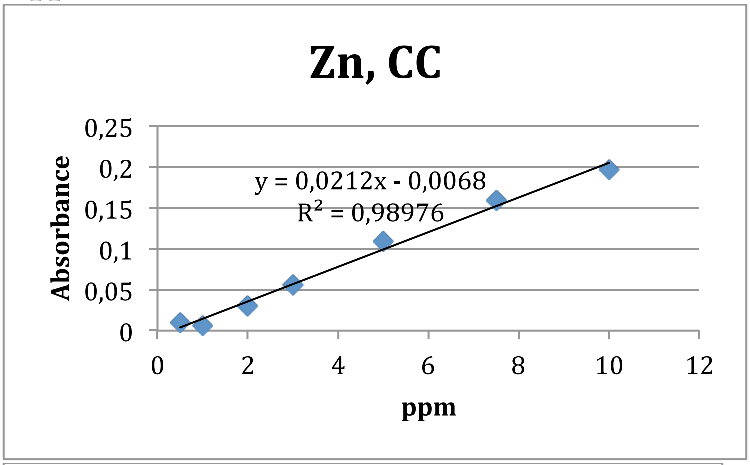

Ca, Zomba
Absorbance
0,04
0,03
0,02
0,01
0
0
1
2
3
4
5
6
ppm
y = 0,0071x + 0,0016
R² = 0,99405

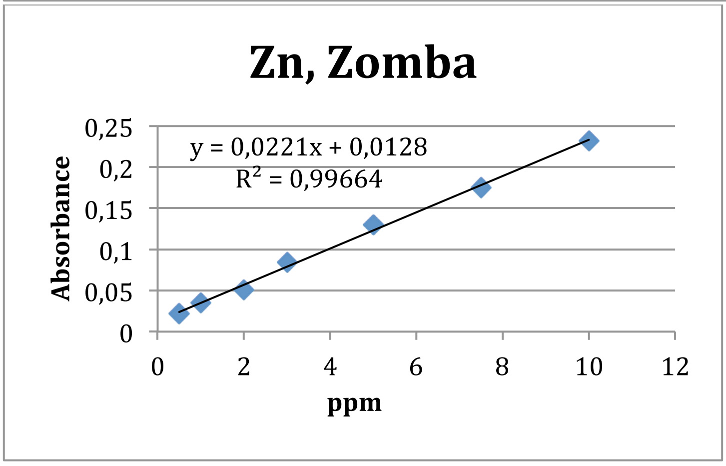
Appendix 4


Mg, CC
Absorbance
0,6
0,5
0,4
0,3
0,2
0,1
0
0
1
2
3
4
5
6
ppm
y = 0,0974x + 0,0639
R² = 0,97992

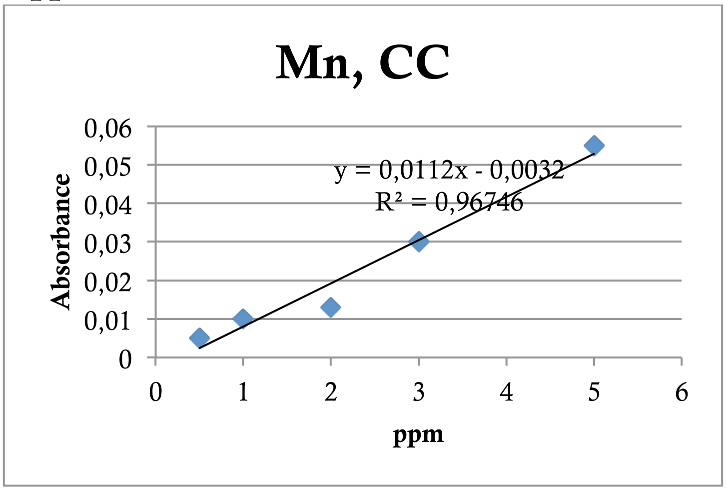

Mg, Zomba
Absorbance
0,8
0,6
0,4
0,2
0
0
1
2
3
4
5
6
ppm
y = 0,1286x + 0,0852
R² = 0,98362

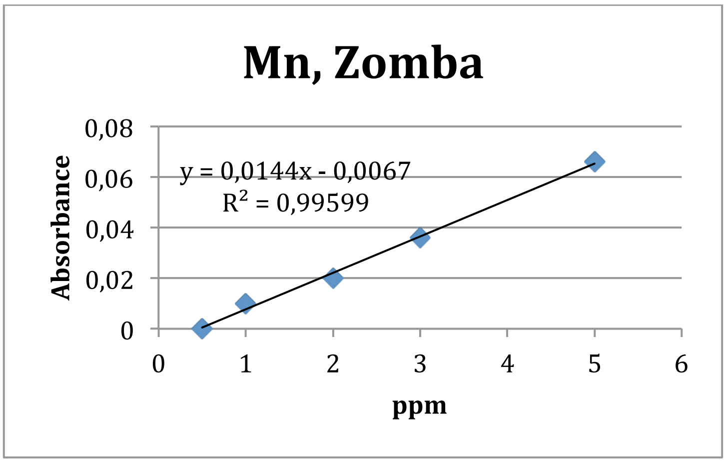
Appendix 5



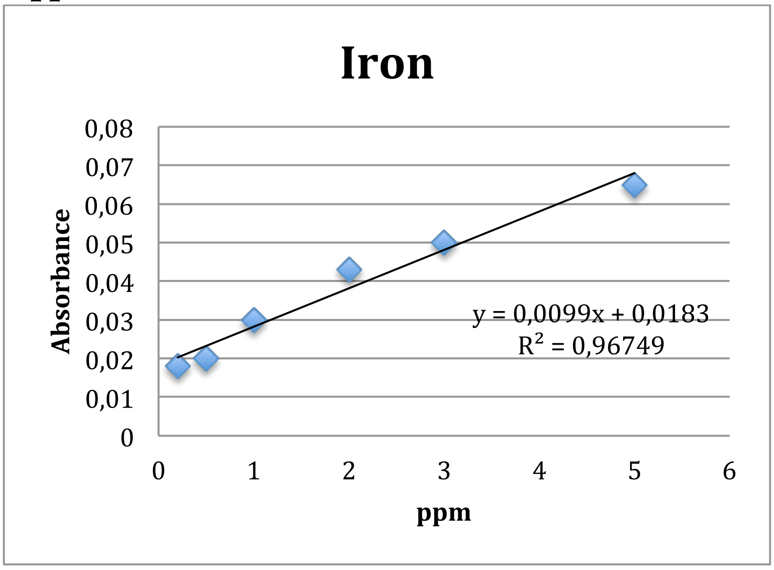


Appendix 6





Appendix 7



Appendix 8