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Constructed Wetland System for Domestic Wastewater Treatment: A Case Study in Addis Ababa, Ethiopia

A thesis submitted to the School of Graduate Studies of the Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Environmental Science.

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ACRONYMS

AAWSA	Addis Ababa Water Supply and Sewerage Authority
APHA	American Public Health Association
BOD_5	Biochemical Oxygen Demand
CFU	Colony Forming Unit
COD	Chemical Oxygen Demand
CBO	Community Based Organizations
CW	Constructed Wetland
CPC	Cleaner Production Center
EEPA	Ethiopian Environmental Protection Authority
EIBC	Ethiopian Institute of Biodiversity Conservation.
ESTA	Ethiopian Science and Technology Agency
FC	Fecal Coliforms
GTZ	German Agency for Technical Cooperation
SF	Surface Flow
SSF	Subsurface Flow
HRT	Hydraulic Retention Time
IUCN	International Union for Conservation of Nature and Natural Resources
JWBO	Jehovah's Witnesses Branch Office
L	Litter
MF	Membrane Filter
Ml	Milliliter
Mg	Milligram
M.a.s.l	Meters above sea level
TC	Total Coli forms
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
USEPA	Unite Sates of America Environmental Protection Agency
UNDP	United Nations Development Program
UNIDO	United Nations Industrial Development Organization

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ABSTRACT

During the last decades, constructed wetlands (CW) were very successful when used for treatment of wastewater from different sources such as municipal, domestic, industrial, agricultural and surface runoff. This new approach is designed based on natural processes involving complex and concerted interactions between the plants, the substrate and the inherent microbial community to accomplish wastewater treatment in a more controlled and predictable manner through physical, chemical and biological processes.

In order to evaluate the performance of constructed wetland and generate information a total of 24 samples were collected and analyzed for selected wastewater quality parameters from a Jehovah Witnesses Branch Office wetland constructed to treat domestic wastewater. The parameters analyzed were biochemical oxygen demand, chemical oxygen demand, total suspended solids, ammonium N, nitrate N, total N, orthophosphate, total phosphorus, sulfate, sulfide, temperature, pH, total coliform and fecal coliform. They were all measured using standard methods.

The treatment performance of JWBO wetland was evaluated based on the percentage removal efficiency of the above parameters. Within the study period, the mean removal efficiency of JWBO CW system was 99.3% (BOD_5), 89% (COD), 85% (TSS), 28.1% (NH_4^+-N), 64% (NO_3-N), 61.5% (TN), 28% (orthophosphate), 22.7% (TP), 77.3% (Sulfate), 99% (Sulfide), 94.5% (TC) and 93.1% (FC).

Moreover, though the difference is not as such high, the result of this study indicated that wetland cells planted with *Cyprus papyrus* (cell 1 and 3) showed higher removal efficiency for NO_3-N (82.4%), NH_4^+-N (24.8%), TN (54.8%), PO_4^{3-} (23.5%), and TSS (83.9%) than the other wetland cells. Similarly wetland cells planted with *Phoenix canariensis* (cell 4 and 6) showed higher removal efficiency for TP (17%), S^{2-} (99%), BOD_5 (98%), COD (90%), TC (94%) and FC (91%). While the other wetland cells planted with *Cyprus alternifolia* (cell 2 and 5) showed higher removal efficiency only for SO_4^{2-} (82.2%) than the others. However, these differences were statistically significant ($p<0.05$) only for Sulfate and FC.

The performance efficiency results indicated that, this wetland system has excellent removal capability for biochemical oxygen demand, chemical oxygen demand, total suspended solids, sulfate, sulfide, total and fecal coliform bacteria. However, since the HRT of JWBO CW was very short (2.16 days) the removal efficiency was low for nitrogen (especially ammonium nitrogen) and phosphorus.

In general based on the overall results of the treatment performance of JWBO CW, the application of constructed wetland in Ethiopia can be considered as a technically as well as economically viable option for domestic wastewater treatment.

1. INTRODUCTION

Wastewater is simply water that has been used. It usually contains various pollutants, depending on what it was used for. It is classified into two major categories by source. The first is domestic or sanitary wastewater. This comes from residential sources including toilets, sinks, bathing, and laundry. The second type of wastewater is industrial wastewater. This is a wastewater discharged during the manufacturing processes of industries and commercial enterprises (USEPA, 1998; Tchobanoglous *et al*., 2003). Wastewater also includes the discharges from agriculture, storm water and runoffs (William and James, 1993; USEPA, 1993).

Domestic wastewater together with discharges from industry and agriculture has an impact on environmental conditions in rivers and coastal waters. This is mainly because untreated wastewater usually contains among other contaminants, nutrients mainly nitrogen and phosphorus that can stimulate the growth of aquatic plants, which in turn results in eutrophication problem in rivers and coastal waters (Njau and Mlay, 2000; Muhammad *et al*., 2004).

United Nations Economic and Social Council (2005) said that most of the domestic wastewater generated in developing countries, including Ethiopia, is discharged into the environment without treatment, contaminating downstream water supplies used for drinking water, irrigation, fisheries, and recreational activities. For instance, in Addis Ababa streams serve as natural sewerage lines for domestic and industrial wastewaters, hence making them known for their foul smell and potential health hazard (AAWSA, 2003).

The impacts of untreated wastewater on the environment (such local rivers and streams) and on human health is clear, then proper wastewater treatment is fundamental for maintaining people's health, protecting the quality of the environment and ultimately promoting economic development (Kaseva 2004; Kyambadde, 2005). For this reason, the treatment of wastewater is not only desirable but also necessary. Treatment is necessary to correct wastewater characteristics in such a way that the use or final disposal of the treated effluents can take place in accordance with the rules set by the recent legislative bodies without causing adverse impacts on the receiving waster bodies (Njau and Mlay, 2000).

To protect human health and water quality, wastewater treatment systems must be carefully managed and properly operated. In the last few decades, wastewater engineers have concentrated on conventional wastewater treatment systems (Peter *et al.*, 2005). But most conventional wastewater treatment technologies such as waste stabilization ponds, trickling filter, sequential batch reactors, and activation sludge, which are used in developing countries are not cost effective, need trained manpower for operation and maintenance, and not energy efficient (USEPA, 1993; Simi and Mitchell, 1999; Tanner and Sukias, 2003)

Because of this, the research for appropriate technologies in overcoming the wastewater problems which are causing health and environmental risks in developing countries is becoming more and more important (Peter *et al.*, 2005). The best solution for the wastewater problem will be the technology that is manageable with the local people, cost effective, low technology and environmentally sound. Low technology and low cost wastewater treatment systems are cost effective in developing countries where sufficient land is available for extensive natural or artificial wastewater treatment facilities (Kaseva, 2004).

According to USEPA officials (USEPA, 1993), the emergence of constructed wetland (CW) technology shows great potential as a cost effective, energy efficient, environmentally sound and effective. In order to establish the performance of constructed wetland systems under different conditions various researches have been carried out to investigate constructed wetland systems in the removal of pathogens, organic matter and nutrients.

Most of these researches were carried out under temperate climate (Kaseva, 2004). To date however, very limited research works on the performance of CW, especially under tropical conditions have been reported. In Ethiopia, CW technology has not yet been recognized by concerned institutions as an option for wastewater treatment technology in the country (EEPA, 2003).

Therefore, this study was planed to evaluate the treatment performance of constructed wetlands as an alternative municipal wastewater treatment technology under Ethiopian climatic conditions.

2. LITRATURE REVIEW

2.1 Theoretical Background of wetlands

The Ramsar Convention,(Iran, 1971; Article 1.1), defined wetland as "areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide doesn't exceed six meters." In addition, the convention (Article 2.1) provides that wetland may incorporate riparian and coastal zones adjacent to the wetlands and islands or bodies of marine water deeper than six meters at low tide lying within the wetland (Ramsar Convention Bureau, 1997).

Wetlands have been referred to as a "living machine" (MacDoland, 1994) and "…one of nature's most effective ways of cleansing polluted water" (Rocky mountain institute, 1998). They have been termed "Kidneys of the planet" because of the natural filtration processes that occur as water passes through (Wallance, 1998).

All wetlands, fresh-water or salt, have many distinguishing features, the most notable of which are the presence of standing water, unique wetland soils and plants adapted to or tolerant of saturated soils (William and James,1993; USEPA, 1993). In Ethiopian context marsh areas, swamplands, flood plains, natural and artificial ponds, volcanic creator lakes and upland bogs are treated collectively as wetland ecosystem (EIBC, 2007; Abebe and Geheb, 2004).

According to Luise *et al*. (1999), wetlands provide a number of functions and values; (Wetland functions are the inherent processes occurring in wetlands; wetland values are the attributes of wetland that the society perceives as beneficial). Under appropriate circumstances wetlands can provide; water quality improvement (William, 1997), cycling of nutrients (Nichils, 1983), habitat for fish and wildlife, flood storage and the resynchronization of storm rainfall and surface runoff (Ramsar Convention Bureau, 1997), Passive recreation such as bird watching and photography, active recreation (such as hunting, education and research) and aesthetics as well as landscape enhancement (Tanner and Sukias, 2003).

The recognition of these wetland values and the presence of policies such as “no net loss” of wetlands in some countries have stimulated construction of wetland that have specific objectives such as the mitigation of unavoidable wetland losses, wildlife enhancement, domestic wastewater treatment, mine drainage control, and storm water retention and control (William and James, 1993; Martha, 2003). Because of this fact, currently constructed wetlands are being used at increasing rate for treatment of wastewaters in different sources because of their consistent performance for pollutant removal (Renee, 2001; Muhammad *et al*., 2004)

A “constructed wetland” is defined as human made, engineered areas specifically designed for the purpose of treating wastewater or storm water by establishing optimal physical, chemical and biological conditions that occur in natural wetland ecosystems (Hammer, 1989; USEPA, 1993; Luise *et al*., 1993).

2.2 Types of constructed wetlands and their treatment mechanisms

There are two main types of constructed wetlands: Surface flow (SF) constructed wetlands and Subsurface flow (SSF) constructed wetlands (Hammer, 1992; USEPA, 1993; Tchobanoglous, 1997).

2.2.1 Surface Flow Wetland

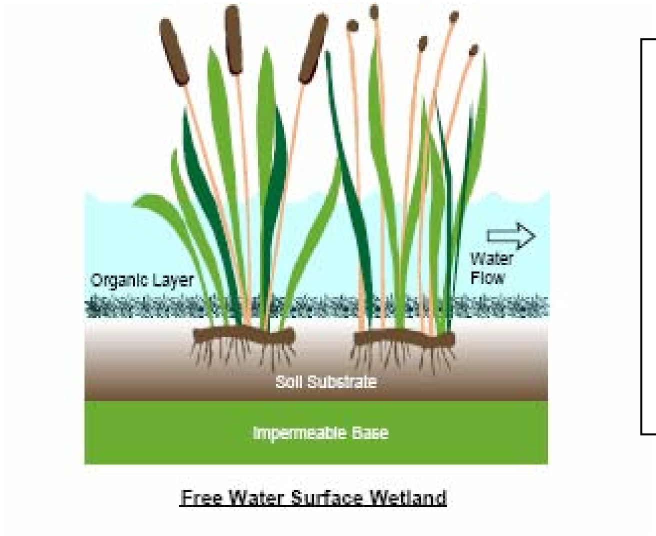
Surface flow constructed wetland systems most resemble natural wetlands both in the way they look and the way they provide treatment. Both designs can be used to treat wastewater from individual and community sources, but surface flow wetlands are usually more economical for treating large volumes of wastewater (Sinclair, 2000). The surface flow (SF) wetland typically consists of a shallow basin, soil or other medium to support the roots of plants and a water control structure that maintains a shallow depth of water (Luise *et al*., 1999) (Figure 1)

As soon as wastewater enters to surface flow wetland cell, natural processes immediately begin to break down and remove the waste materials in the water (Renee, 2001; Kaseva, 2003). Before the wastewater has moved very far in the wetland small suspended waste materials are physically strained out by submerged plants, plant stems, and plant litter in the wetland (Hammer, 1992).

The roots, stems, leaves, and litter of wetland plants also provide a multitude of small surfaces where wastes can become trapped and waste-consuming bacterial can attach themselves to the plant (USEPA, 1993; Sinclair, 2000). These bacteria provide the majority of wastewater treatment. Wind, rain, wastewater and anything else that agitates the water surface can add oxygen to the system. This helps the aerobic bacteria thrive in wetlands near the surface wherever oxygen is present, in addition to this, anaerobic bacteria thrive in the wetland where there is little or no oxygen (USEPA, 1998)

When bacteria consume waste particles in the water they convert them into other substances such as methane, ammonium, sulfate, orthophosphate, carbon dioxide and new cellular material. Some of these substances are used as food by plants and other by bacteria (Christina, 2005). For any of the processes in wetlands to work, the wastewater must remain in the system long enough for treatment to occur naturally. The hydraulic residence time for wastewater in SF systems is based on wastewater strength, the level of desired treatment and climatic factors (William and James, 993; Sinclair, 2000)

Plants help treatment processes of SF wetlands in several ways; filter wastes, regulate flow and provide surface area for bacterial treatment. Floating plants, such as water lilies and emergent plants, such as cattails, shade the water surface and control algal growth (Sinclair, 2000). The advantages of SF wetlands over SSF wetlands are that; their construction, operation, and maintenance are straightforward. The main disadvantage of SF is its requirement of a larger land area than other systems (Luise *et al*., 1999).



General characteristic of SF wetland:-
Water level is above the ground surface; vegetation is rooted and emerges above the water surface: water flow is primarily above ground (Alexandria Water Pollution Control Federation, 1990).

Source: Sinclair, 2000

Figure 1: Surface Flow Wetland Type

2.2.2 Subsurface Flow Wetland

The Subsurface flow (SSF) wetland, which is originated in Europe over 40 years ago (Kyambadde, 2005), consists of a sealed basin or channel with a porous substrate of rock or gravel media and a barrier to prevent seepage. The media also support the root structure of the emergent plants. The design of this system assumes that the water level in the bed will remain below the top of the rock or gravel media (USEPA, 1993; Luise *et al*., 1999; Martha, 2003) (Figure 2).

The treatment processes in SSF wetland system is more efficient than in the SF wetland system; because the media provides a greater number of small surfaces, pores and crevices where treatment can occur. Waste consuming bacterial attach themselves to the various surfaces, and waste materials in the water become trapped in the pores and crevices on the media and in the spaces between media. Chemical treatments also takes place as certain waste particles contact and react with the media (USEPA, 1993)

The biological treatment in SSF wetlands is mostly anaerobic, because the layers of media and soil remain saturated and unexposed to the atmosphere (Sinclair, 2000). However, wetland plants are able to grow extensive roots even in these anaerobic conditions. The area where the roots grow is called root zone and usually includes the upper 0.15 to 0.40 meter of media. If cells are alternated or allowed to rest periodically, or if the water level is regularly cycled, the roots can reach throughout the media layer (Pottir and Karathanosis, 2001)

According to Brix, (1994), wetland plant roots contribute oxygen to the cells which allow some aerobic treatment to take place in the root zone, which stimulates organic matter oxidation and the growth of nitrifying bacteria. This is because vascular wetland plants are equipped with *aerenchyma* or *aerenchymous* tissues containing a network of tiny hollow tubes that traverse the length of the plant allowing gases to move from the above water part of the plant to the roots and rhizomes, and vice versa (Richard *et al.,* 1994) .

In addition, these plants have *lenticels,* or small openings along the plant stems that facilitate the flow of gases in and out. Lenticels may also be located on adventitious roots that develop from the stalk or stem of the plant within the water column (Kandlec and Knight, 1999). Other structural components include "knees" on Cyprus trees (an emergent woody plant) and buttresses, also on certain woody species (Luise *et al*., 1999). Generally, the transfer of gases and in particular of oxygen from the above-water part of the emergent herbaceous plants to the root zone can occur in two basic ways; passive molecular (gas-phase) diffusion and bulk flow of air through internal gas spaces of the plant, (resulting from internal pressurization).

Plants further contribute to wastewater treatment by providing additional surfaces where bacteria can reside and where waste materials become trapped (Faithful, 1996; Kyambadde, 2005). Plants also take-up and store some of the metals and nutrients in the wastewater. Most subsurface flow wetlands are designed so that wastewater travels through the length of the cell one time to receive treatment. Typical retention times range from two to five days for BOD_5 removal and seven to fourteen days for nitrogen and phosphorus removal (Crites and Tchobanoglous, 1998). Due to this, SSF wetlands have most frequently been used to reduce BOD_5 from domestic wastewaters (Godfrey *et al*., 1985; Rechard, 1998)

SSF CW cells are usually designed with aspect ratios, (length to width ratio), of 3:1 or less (USEPA, 1998; Simi and Matchell, 1999). Wider cells tend to be more cost effective because long narrow cells must be deeper and require more treatment media. In addition, the wastewater is less likely to back up in wider cells if too much water enters the system (Luise *et al*., 199).

The SSF type of CW is thought to have several advantages over the SF type since the water surface is maintained below the media surface with little risk of odors, and insect vectors (Vymazal, 2002). In addition, it is believed that the media provide greater available surface area for treatment than the SF concept. Consequently, the treatment responses may be faster in SSF type, which is smaller in area than a SF system designed for the same wastewater conditions (Wallance, 1998; USEPA, 1993).

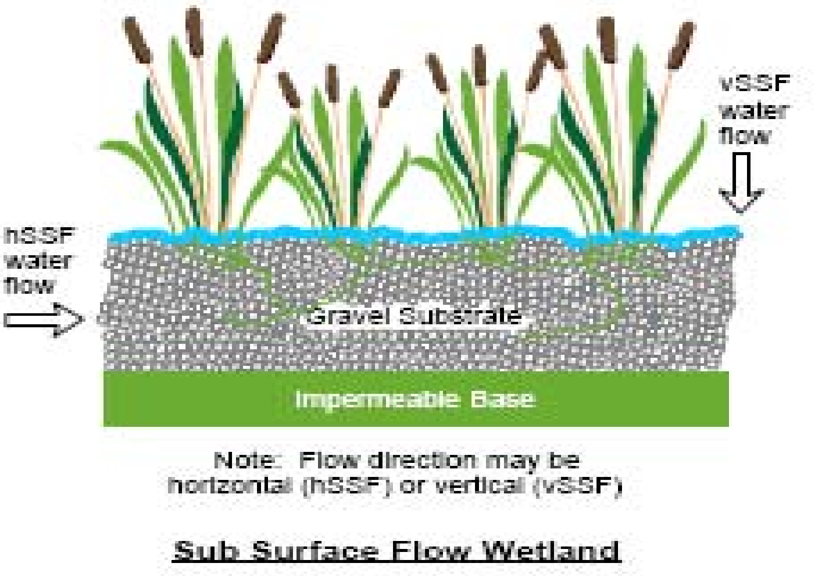


Figure 2: Subsurface Flow Wetland Type

Source: Sinclair, 2000

General characteristics of SSF wetlands:-
Water level is below ground; water flow is through a sand or gravel beds; roots penetrate to the bottom of the bed (Alexandria Water Pollution Control Federation, 1990).

2.3 Selection of Macrophytes

Wetland plants enhance the treatment process of wetlands in several ways such as filter wastes, regulate flow, provide surface area for microbiological treatment, provide shed and control algae growth, contribute oxygen to the cells, take up and store some of metals and nutrients from the wastewater (Sinclair, 2000; Kyambadde, 2005).

Then the presence of wetland plants has been hypothesized to play a key role in wastewater remediation (Luckeydoo and Fausey, 2002). In addition to their aesthetic roles, wetland plants exhibit several properties which enhance wastewater treatment processes and thus make them an essential component of the treatment wetland. These properties influence wastewater treatment through physical effects such filtration, adsorptions followed by sedimentation, provision of surface area for the growth and attachment of microorganisms and shad the water surface and regulating of the undesirable water temperature as well as surplus algal growth (Sinclair, 2000).

Metabolically, plants take up pollutants; produce organic carbon and oxygen, there by improving the water to varying extents (Kyambadde, 2005). Plants in wetland systems have been viewed as storage compartments for nutrients where nutrient uptake is related to plant growth and production. Emergent plants utilize their roots to obtain sufficient nutrients from wastewater. Free floating species have roots with numerous root hairs and successfully obtain nutrients from both the water column and substrate (USEPA, 1988).

They often grow in gravel beds to stimulate uptake and create suitable conditions for the oxidation of the substrate, there by improving the ability of the system to treat wastewater (Njanu and Mlay, 2000). This needs consideration of plant selection and management techniques that create rhizosphere surface area per volume of bed and bed design; optimal depth, HRT and media of constructed wetland (Muhammad *et al,* 2004).

If the wetland plant is intended as a major oxygen source for nitrification in the system, then the depth of the bed should not exceed the potential root penetration depth for the plant species to be used. This will ensure availability of some oxygen throughout the bed profile, but may require management practices which assure root penetration to these depths (USEPA, 1993, Gersberg et al., 1998)

From the standpoint of wastewater treatment, certain plant species appear to be more efficient in CW treatment systems and others may be more tolerant of high pollutant concentrations. It appears that major contribution from the vegetation in SSF system is service of the root/rhizome structure as a substrate for microbial activity and is a limited oxygen source for nitrification (Njanu and Mlay 2000)

Plant species selection can have impacts on sedimentation, plant nutrient accumulation, and the creation of microenvironment that facilitates microbial degradation of contaminants (Luckeydoo and Fausey, 2002). Further more, plant species selected for constructed wetland cells shall be hydrophyte plants suitable for local climatic conditions and tolerant of the concentration of nutrients and other constituents in the wastewater stream and selected for their treatment potentials. Preference shall be given to native wetland plant materials collected or grown from materials adapted to local conditioning (USEPA, 1988; Indian Natural Resources Conservation Service, 2001). Some examples of macrophytes mostly used in constructed wetland systems are *reeds, bulrushes, water hyacinths, cattails, duckweeds, Cyprus papyrus, Cyprus alternifolia* and *lilies* (USEPA, 1993; William and James, 1993).

All wetland plant species didn't have the same capacity to use the above stated mechanisms to remove different pollutants found in the wastewater (Gersberg *et al*., 1985; Kyambadde, 2005). For example, study conducted by Kuet *et al.* (1999) has shown that wetland planted can directly uptake to 20% of the nutrients found within the treatment effluent depending on plant type of the wetland. Another study conducted by Brix, (1994), also showed that the uptake species of emergent macrophytes was 50 to 150 kg phosphorus /ha/year and 1000 to 25,000 kg of nitrogen /ha/year.

The root zone of aquatic plants is also primary site for pollutant uptake and transformation as it is a zone of oxygen transfer between the plant and sediment microbial activity and pollutant oxidation. This also will be depending on the potential root penetration depth and root mat structure of the plant species (USEPA, 1993; Faithful, 1996; Kyambadde, 2005).

2.4 Description of Macrophytes of the Study Area

Jehovah's Witnesses Branch Office constructed wetland is covered with three different plant species, identified in the local areas, namely *Cyprus papyrus*, *Cyprus alternifolia* and *Phoenix canariensis*, which are among the typical characteristic species of wetland ecosystems of Ethiopia (EIBC, 2007). During the assessment time conducted in this study period, it was confirmed that these plant species are common in different wetlands of Ethiopia such as Lake Tana, Lake Awassa, Lake Zeway, and in different Lakes found in Debere-Zeyet.

The *Phoenix canariensis* commonly called palm, is very widely planted as an ornamental plant in warm temperate regions of the world. It is cultivated as a street tree in many of the larger towns and cities with altitude of 1000–2400 m.a.s.l. (Sebsebe *et al.*, 1997) particularly in areas with continental climates where temperatures never fall below 10 °C. (http://en.wikipedia.org/wiki/Canary_Island_Date_Palm accessed on 12 May 2007).

It is also common in most parts of Ethiopia as ornamental plant in cities such as Addis Ababa, Bahir-Dar, and Jimma and in natural wetlands found in different parts of the country (Sebsebe *et al.*, 1997; EIBC, 2007). In addition to these, this plant is used by the local community to make a variety of decorative handicrafts, such as baskets in different parts of Ethiopia (Afework, 2006). These palm attracts many birds particularly pink breasted pigeon to nest in it. The fruits are sweet and much liked by children (Sebsebe *et al.*, 1997)

Cyprus papyrus, commonly called papyrus, is a member of the sedge family (Cyperaceae). It is a monocot that is native to river banks and other wet soil areas in Egypt, Ethiopia, the Jordan River Valley and other parts of the Mediterranean basin. Throughout the world these plants hold great regional importance in weaving mats, baskets, screens and even sandals (Matt, 1997; Sebsebe *et al.*, 1997).

According to Afework (2006) even though it is over utilized and it is at risk currently, in Ethiopia for 'Woyto' community (a particular ethnic group found around Lake Tana) and other local people, Papyrus is an important raw material used for craft making and ceremonial purposes. In addition to this, since the roots of Papyrus is spread over the water forming floating mat, helps to prevent soil erosion and trap polluted sediments in the wastewater. A study conducted by Abe, Ozaki and Kihou (1997) and Kyambadde (2005) showed that *C. papyrus* is useful in wastewater treatment. This study showed that *Cyprus papyrus* reduced the amount of nitrogen and phosphorus in wastewater by more than fifty percent.

Cyprus alternifolia commonly called Umbrella plant, is a semi-aquatic and requires a very moist soil and a medium light exposure for growth. It is also cultivated as a garden plant, within 700–2400 m.a.s.l (Sebsebe *et al*, 1997). During the assessment done in this study period, *C. alternifolia* is common in natural wetland found in Central Rift Valley of Ethiopia, such as in Lake Awassa, Lake Zeway and in different Lakes found in Deber-Zeyet.

Additionally, this plant was more common in natural wetlands found in other parts of Ethiopia. Like that of *C. papyrus*, it is also over utilized and currently it is at risk. For example in Western Gojjam, (Dangella, Achefer, and Mecha districts), this plant was used by the local communities to produce materials that protect themselves from rain. Since most wetlands in these districts are changed into farmlands and others are overgrazed, they have stopped to make such type of material and use plastics to protect themselves from rain.

Though the socio-economic advantages of these wetland plant species are well known, their potential for wastewater treatment is not well understood. For instance, only few studies investigated the potential of *C. papyrus*, (which colonizes many wetlands in Africa), for wastewater treatment (Kyambadde, 2005), but no published information has been found during the preparation time of this study on the potential of *C. alternifolia* and *P. canariensis* for wastewater treatment.

Therefore, there is a need for further research on the wetland plant species adapted to the local ecological conditions of Ethiopia in order to supplement and optimize the treatment efficiency of constructed wetlands.

2.5 Constructed wetlands as an alternative wastewater treatment method

Studies of the feasibility of using constructed wetlands for wastewater treatment were initiated during the early 1950s in Germany, with the first operational horizontal subsurface flow constructed wetland appearing in 1974. In the United States, wastewater treatment using either natural or constructed wetland researches began in the late 1960s and increased dramatically in scope during 1970s (Kyambadde, 2005.)

During the last decades, constructed wetlands were very successful when used for wastewater, and low quality water treatment from different sources (Nicols, 1983; Chris and Vivian, 1997; Rechared, 1998). This new approach is designed based on natural processes involving complex and concerted interactions between the plants, the substrate/media and the inherent microbial community to accomplish wastewater treatment in a more controlled and predictable manner through physical, chemical and biological processes (Simi and Mitchell, 1999; Kyambadde, 2005)

Because they emulate natural systems, CW are effective, reliable, simple, environmental friendly and relatively inexpensive to install and maintain (Gersberg *et al*., 1984; Rogers *et al*., 1991; Dewardar and Bahgat, 1995; Vymazai, 1996; Zuidervaart *et al*.,1999; Coleman *et al*., 2001; Vymazai, 2002.) They have been successfully applied worldwide for biological treatment of municipal and industrial wastewater (USEPA, 1988; Okurut *et al*., 1999; Nzengya and Witshitemi, 2001; Kyambadde *et al*., 2004), and agricultural wastewater (Kenneth, 2001) as well as surface runoff water (William, 1997).

In Uganda, the economic viability of using constructed wetland was deduced from the total annual cost of the wetland and waste stabilization ponds designed for a population equivalent of 4000. The result of this study indicated that the total annual cost for waste stabilization pond was 21% more than that of the constructed wetlands ($11,400) (TomOkin, 2000). The other study done in Ireland by Reddy (2004) showed that the cost of a typical constructed wetland with a size 4650m^2 is about $122,000, which was cheaper by 30% than conventional treatment methods considering the lifespan (which is 30–50 years) and replacement values of the wetland.

The above case studies also confirmed that maintenance cost for constructed wetland was eight times lower than the conventional treatment systems. Based on the overall results of the treatment performance and costs, these researchers concluded that the application of constructed wetlands can be considered both technically and economically viable option for municipal wastewater treatment.

Additionally, CW attracts wildlife such as birds, mammals, amphibians, and variety of dragonflies and other insects (Martha, 2003). For instance, the recent USEPA publications (1999) indicated that more than 1,400 species of wildlife have been identified from constructed and natural treatment wetlands, of these more than 800 species were attributed to CW. Moreover, constructed wetland plants, (especially when they are planted with ornamental plant species), provides a more aesthetically pleasing alternative than other conventional wastewater treatment systems (Richard *et al.,* 1994).

Due to these benefits, over the past twenty years constructed wetlands have been used effectively to decrease the concentrations of various pollutants from different sources particularly in Europe and North America. Despite the numerous articles published on wetland in these countries, in recent years there is a notable gap in the literature regarding constructed wetlands in developing countries for wastewater treatment (Faithful, 1996)

For instance, for the last ten years, only limited wetlands for the treatment of wastewater have been constructed and studied in East Africa e.g. in Uganda, for treating municipal wastewater (Okurut *et al*., 1999), in Tanzania, for treating wastewater from the waste stabilization ponds at the University of Dares Salaam (Mashauri *et al*., 2000; Kaseva, 2003), in Kenya, for domestic wastewater treatment (Oketch, 2000; Nyakango and VanBruggen, 2001) and in Uganda, for municipal domestic wastewater treatment (Kyambadde, 2005). These studies have shown that constructed wetlands are very suitable for treatment of wastewater in tropical climates.

Although constructed wetlands have such a proven effectiveness for treatment of a variety of wastewaters (Hester and Harrison, 1995; Kyambadde, 2005; Muhammad *et al.,* 2004), no work has been done in Ethiopia. For instance, in Addis Ababa, the current wastewater treatment system (stabilization pond and sewer line) serves only a small part (2%) of the population with the design capacity for 70,000 people (Getahun *et al.,* 1999; AAWSA, 2001; AAWSA, 2003; ESTA /CPC, 2004).

Consequently, approximately 73% of the inhabitants "disposed" feces and dirty waters in pit latrine or septic tank and a sizeable part of the population (25%) has no such facilities at all (AAWSA, 2003). In addition to these, more than half of the country's industries are found in Addis Ababa, but very few of them have a treatment plant or a connection to a sewer. These parts of the population and industries dispose their wastewater to natural watercourses and natural wetlands (Getahun *et al.,* 1999; AAWSA, 2003; Afework, 2003).

To solve this problem the Addis Ababa municipality, in collaboration with GTZ (2004) developed five years strategic plan (2004– 2008) for wastewater management options especially for the central part of the city. These options were divided in to two categories. The first one was centralized option, which was planned to expand the existing wastewater treatment plant, by improving the sewer system (Waste Stabilization Pond System) at Kality. The second option was to develop decentralized wastewater treatment options such as trickling filter, biogas digester, dry toilets with urine diversion and vermin composting tanks (AAWSA, 2003). But all of these conventional options (both centralized and decentralized) would require high initial and operational costs, as well as skilled manpower for operation and maintenance (USEPA, 1993; Simi and Mitchell, 1999; Tanner and Sukias, 2003)

For developing countries like Ethiopia that have limited resources for the construction and operation of conventional treatment plants, there should be an option which is economical, but produce an effluent with same, even better quality from the conventional treatment system. This necessities the provision of energy and cost effective secondary wastewater treatment facilities for small communities such as schools, hospitals, military camps, colleges, farms, industries, and universities where on-site wastewater disposal technology is predominant.

2.6 Performance Evaluation of Constructed Wetlands

The use of CW for wastewater treatment was stimulated by a number of studies in the early 1970s that demonstrated the ability of wetlands to remove suspended sediments and nutrients in wastewaters (Nichols, 1983; Godfrey *et al.*, 1985; and Knight, 1990). There are three major important nutrients that are commonly found in municipal wastewaters; nitrogen (N), phosphorus (P), and potassium (K). But the concentration of K is not taken into consideration since K holds no health risk, is not typically present in wastewaters in the optimum combination with N and P, and is often found in great abundance naturally in nature (William and James, 1993; Reed *et al.*, 1995).

Untreated domestic wastewaters can stimulate the growth of aquatic plants which, in turn results in, various environmental pollution related problems. For this reason the treatment of wastewater is not only desirable but also necessary (Knight, 1990). Treatment is necessary to correct wastewater characteristics in such away that the use or final disposal of the treated effluent can take place in accordance with the rules set by the relevant legislative bodies without causing an adverse impact on the receiving water bodies (Njanu and Mlay, 2003).

Thus the two objectives of wastewater treatment, separating wastes from wastewater and preventing pollution of the receiving waters are evaluated differently. Treatment efficiency depends on the extent to which specific waste materials are separated from the wastewater and can be calculated for a number of different Parameters (Christon, 2004).

For domestic wastewater treatment, the pollutants of most concern are biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), total nitrogen (TN), ammonium nitrogen ($NH^+{}_4$-N), nitrate nitrogen (NO_3^-N), orthophosphate(PO_4^{3-}), total phosphorus (TP), sulfate (SO_4^{2-}), sulfide (S^{2-}) and Sanitary indicators-(total Coliforms or fecal Coliforms) (Wallance, 1998; USEPA, 1993; Aimee, *et al.*, 2000). Specification of the wastewater components measured or the form of pollution evaluated is essential for describing the efficiency of wastewater treatment plant. Most often, removal efficiency is expressed as a percentage and these values are used to compare different treatment processes and to determine if a particular treatment plant has accomplished for which it was developed (Christon, 2004)

The major function of wastewater treatment plant is to reduce the organic loading of domestic wastewater so that it can be safely discharged to the receiving stream. The effectiveness of the sedimentation process is monitored through BOD_5, COD and TSS parameter (Smith, 1999). Results of a research conducted in Northern Alabama by Kathleen (2000) showed that constructed wetlands can reduce the organic content, appreciably to an average of 85 percent. She also showed that the effluent BOD_5 was under 22mg/L, which was below the required value (30mg/L).

In addition to this, TSS removal is very effective in SSF CW systems. Most of the removal probably occurs within the first few meters of travel distance from the inlet zone (Smith, 1999). It would appear that with the Hydraulic Retention Time (HRT) of a day, the TSS will be removed to a level of about 10 mg/L (USEPA, 1993). Six constructed wetland projects in Listowel, Santee, Sidney, Arcata, Emmetsburg and Gustine, were evaluated for their performance on the removal of TSS, and showed that the treatment plants removal efficiencies were; 93, 90, 92, 28, 73 and 86 percents, respectively (USEPA, 1988).

A study conducted in Kenya to assess the effectiveness of CW in treating domestic wastewater showed that the removal of BOD_5, TSS, COD, TN, NH_4-N and Orthophosphate were highly effective with a removal value of 98%, 85%, 96%, 90%, 92%, and 88%, respectively (NyaKango and VanBruggen, 1999). This was mainly because this wetland consists of a combination of a SF system followed by three SSF wetland cells in a series adjacent to it.

A case study conducted in Italy, to assess the treatment performance of a SSF CW by Pucci *et al*. (2000), showed high removal efficiencies for COD (93%), TSS (81%), hygienic parameters(TC 99%, FC 99.7%), but relatively low for nitrate (55 %), total nitrogen (50%)and ammonium (30%), very low for total phosphorus (20%). This is mainly due to poor nitrification and denitrification in the system.

There is substantial evidence in the design of CW that a number of cells in series can consistently produce a higher quality effluent. Because this process minimizes the short circuiting effects of any one unit and maximizes the contact area in the subsequent cell (Gearheart, 2004). The series cells allow for a wider range of pollutant removal as well as allowing for the effective removal of fractions of some contaminants i.e. dissolved inorganic, particulates and organic forms (Faithful, 1996).

Because of this, it is generally recommended that for treatment and water quality purposes CW should consist of a minimum of 2 to 3 cells in series (Gearheart, 2004). In addition, this study indicated that if all cells of a CW are planted with different plant species it produces good quality effluent; since multiple plant species within the system maximized root biomass in the wetland substrate resulting in more efficient treatment (Oketch, 2003).

2.7 Fate of Nitrogen, Phosphorus, Sulfur and Coliform Bacteria in Constructed Wetlands

Microorganisms play a crucial role in the transformation and removal of nitrogen in wastewaters. Organic nitrogen is transformed in to NH_4^+-N through a complex biochemical process called ammonification. This process is performed mainly within the root system. The NH_4^+-N produced from this process is preferred for the formation of biomass in growing plant (Kandlec and Knight, 1999)

NH_4^+-N produced by ammonification can then be converted in to NO_2^--N (Nitrite nitrogen) and NO_3^--N by microbial nitrification. NH_4^+-N is transformed first in to NO_2^--N, which is unstable and then in to the chemically stable NO_3^--N. Nitrate nitrogen can be used as a nutrient for plants and may play a role in eutrophication. Nitrification occurs in aerobic conditions with a pH of at least 7.2 units. Denitrification is achieved in anoxic conditions in which nitrate or nitrite serves a respiratory electron acceptor for denitrifying bacteria to carryout the oxidation of carbonaceous organic substrates, with a pH range of 6.5 to 7.5 units (Gersberg *et al*., 1984; Kadlec and Knight, 1996; Simi & Mitchell, 1999; Brix *et al*., 2003). The fate of nitrogenous wastes in constructed wetland is summarized in Figure 3 below.

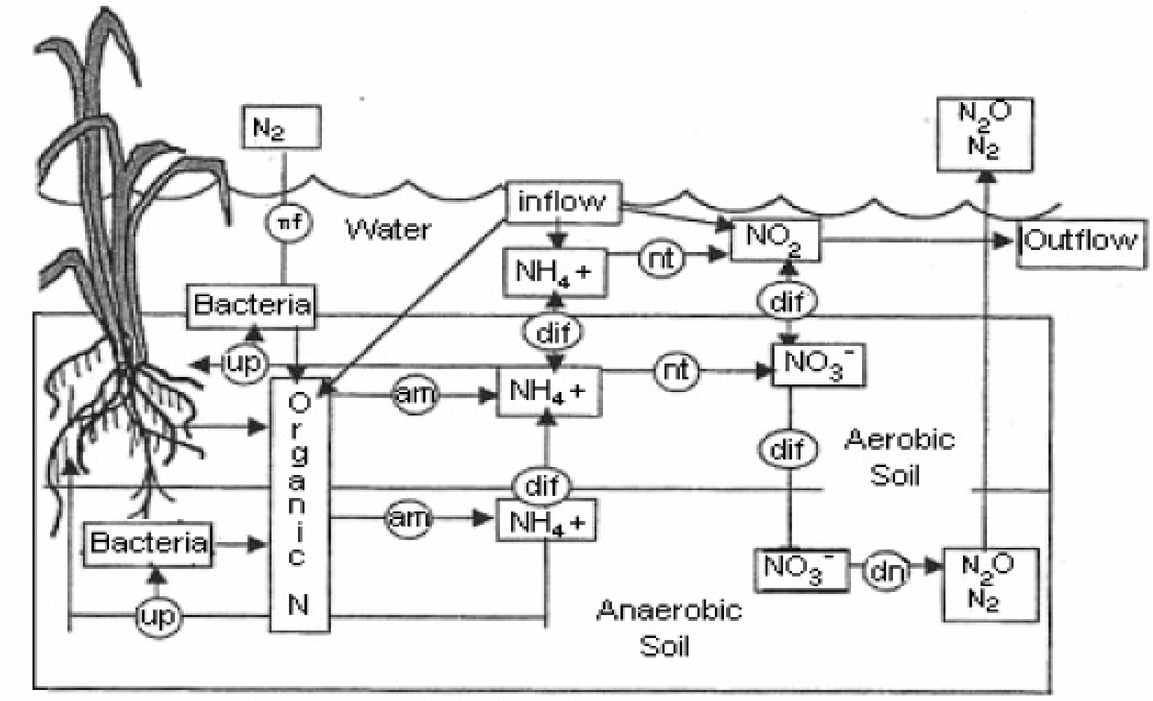


Figure 3: Generalized diagram which shows transformation of nitrogen in constructed wetland systems.

Where am = ammonification, nf = nitrogen fixation, dif = diffusion, nt = nitrification, dn = denitrification, up = uptake

Source: Faulkner, 2004

In addition to nitrogenous waste, domestic wastewaters contain phosphate from cleaning products; because of this it contains high concentration of phosphorus than other wastewater sources (Renee, 2001; Martha, 2005). When determining the role of phosphorus retention by wetlands, particularly wetland substrates, it is important to understand the forms of phosphorus in the system and that have ecological and environmental consequences (Faulkner, 2004).

In wastewater entering a wetland particularly secondarily treated effluent from a sewage treatment plant, (Septic tank), the Phosphorus component will be composed of predominantly reactive phosphate (mainly orthophosphate) (Miriam *et al.*, 2002) and total phosphorus content comprises both inorganic and organic particulate and filterable non-reactive phosphorus forms (Kathleen, 2000). The forms of phosphorus and its transformation in wetland systems is summarized in Figure 4 below

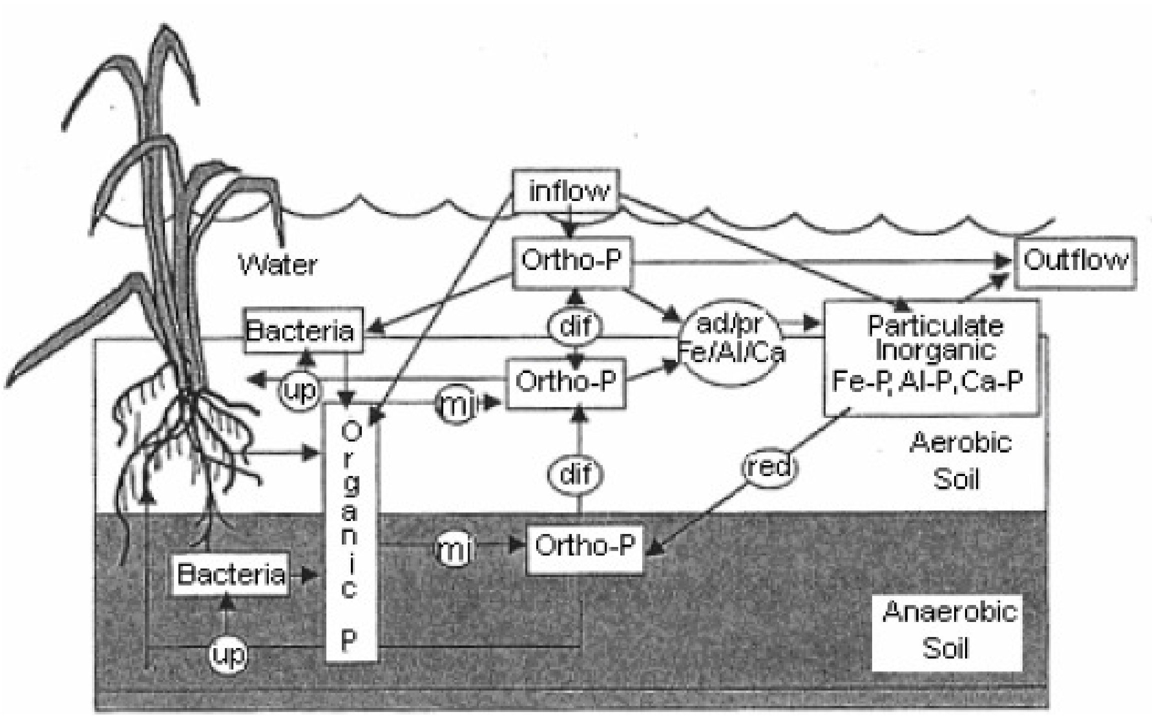


Figure 4: Generalized diagram which shows phosphorus transformations in constructed wetland systems.

Where mi = mineralization, ad/pr = adsorption and precipitation reactions with Fe, Al and Ca, dif = diffusion, red = Fe-reduction, up = uptake

Source: Faulkner, 2004

Because of the limited contact opportunities between the wastewater and the soil, phosphorus removal in most CW systems is not very effective (USEPA, 1988; Reddy, 2004). For example, a gravel media with its high conductivity permit all of the water to flow within the bed but because of the impermeable nature of the bed have only a limited surface area for adsorption, ion exchange and/or chemical reaction to take place because of this, once the active sites are utilized, phosphorus removal ceased (Newman *et al.*, 2000). Some systems in Europe use sand (clay) instead of gravel to increase the phosphorus retention capacity, but selecting this media results in a larger system because of the reduced hydraulic conductivity of sand compared to gravel (USEPA, 1993.)

The results of the investigation done by Miriam *et al.* (2002) on the efficiency of phosphorus retention in CW treating agricultural drainage water for two years (2001-2002) suggested that a minimum HRT to retain at least 50% of the bio-reactive phosphorus was 7 days. These researchers also confirmed that if the HRT exceeded 10 days, the removal efficiency ranged from 50 to 90%, but decreased drastically and was often even negative, if the HRT was shorter than five days. For example, the wetland assessed by this study indicated that, it only retained 2% of the bio-available phosphorus, since the HRT was shorter than seven days.

In addition to nitrogen and phosphorus, sulfur occurs in CW in different forms, but because of their impacts, sulfide and sulfate are the most important in wetlands (William and James, 1993; Renee, 2001). In the wetland systems, sulfate reduction occurs due to the presence of sulfate reducing bacteria in the substrate coupled with sufficient organic material to stimulate their activity (Martha, 2003). These bacteria are a group of prokaryotic microorganisms that use electron donors to reduce sulfate. Sulfate reducing bacteria remove sulfate from the water column by metabolizing sulfate into living tissue or by reducing sulfur to produce energy (Hsu, 1998; Simi and Mitchell, 1999). Forms and the fate of sulfur in CW are summarized in Figure 5.

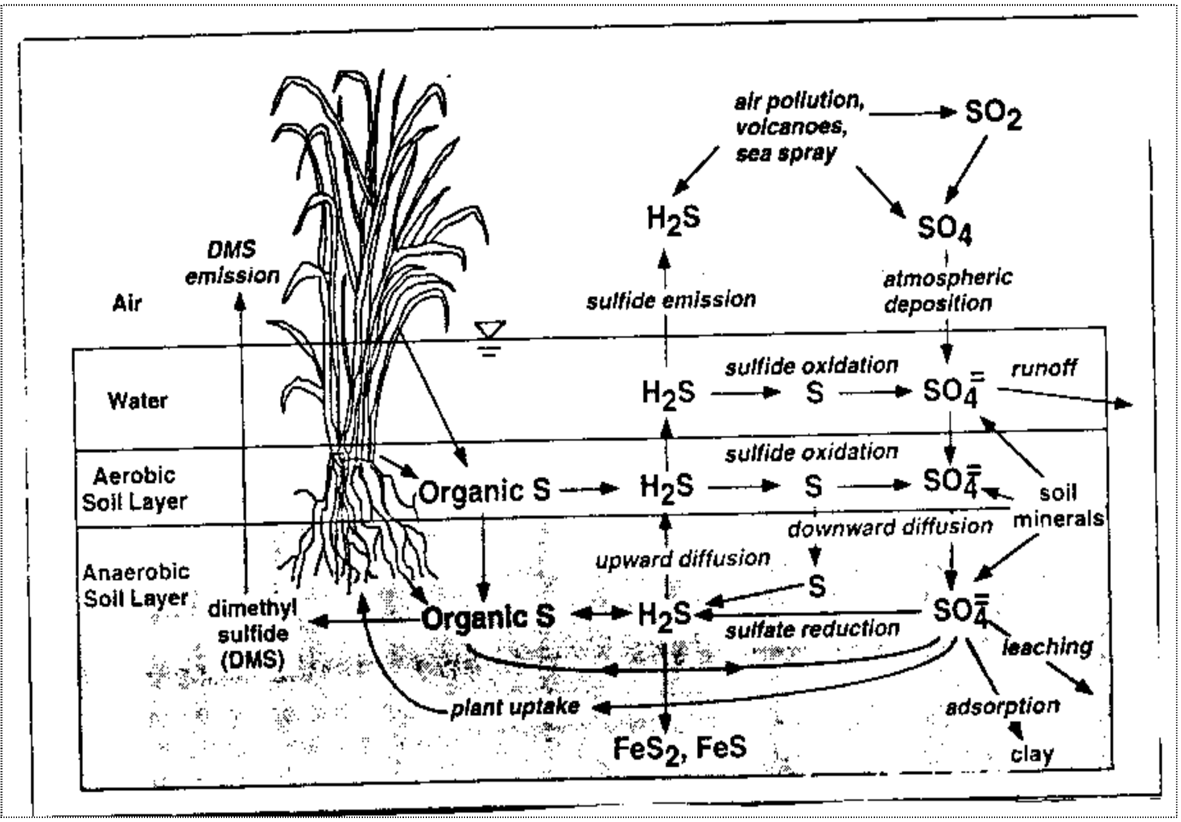


Figure 5: Generalized diagram which shows Sulfur transformations in constructed wetland systems.

Source: William and James, 1993

Evidences for the presence of sulfate reducers in wetlands include blackened sediment due to the resulting precipitation of iron sulfides and the release of sulfides cause the odor familiar to those who carry out research in wetlands, 'the smell of rotten eggs'(William and James, 1993; Fauque,1995). Although it is rarely present in such low concentrations that is limiting to plant or animal growth in wetlands, the hydrogen sulfide that is characteristic of anaerobic wetland sediments can be very toxic to plants and microorganisms, especially when the concentration of sulfate is high (Morse *et al.,* 1987)

A study conducted by Fauque (1995) in New York to assess the efficiency of five constructed wetland for sulfate removal, indicated that sulfate reduction occurred in all five wetlands which varies in degrees of treatment effectiveness from 54–70%. According to his conclusion, this difference in removal efficiency was mainly due to the difference in plant species and the substrates used in each wetland.

The other most important wastewater parameter, especially with regard to human health, is the removal of coliform bacteria (Gersberg *et al*., 1984) which in turn indicates the removal of pathogenic microorganism from the wastewater (Kathleen, 2000; Pucci *et al*., 2000; Christon, 2004). The results showed that on average removal efficiency of coliform bacteria in CW is greater than 90 percent.

In addition to these, the result of a study conducted by Mariade'j *et al*. (2001) demonstrated that a significant removal (more than 90%) of indicator microorganisms can occur in CW receiving domestic wastewater with only 1 to 2 day detention time. But this high percentage removal of indicator bacteria does not always equate with the acceptable level. For instance Tanner and Sukias (2003) reported fecal coliform removal efficiencies of 30% to 85% and suggested that a reduction below 300-500 cfu/100ml is difficult to obtain.

Generally, while constructed wetlands have such a proven effectiveness for treatment of a variety of wastewaters in developed countries, little work has been done in developing countries where the concept of constructed wetlands for wastewater treatment is still a relatively new idea (Kaseva, 2003; Muhammad *et al.,* 2004).

2.8 Rationale

Environmentalists have referred to wetlands as nature's kidney. Much interest has developed in recent years in using CW to remove contaminants from water, whether it is effluent from domestic, municipal, industrial, agricultural wastewaters, or acid-mine drainage (Kenneth, 2000). While constructed wetlands are found to be effective to treat a variety of wastewaters, in Ethiopia, only very few institutions such as Jehovah's Witnesses Branch office has used the system to treat its domestic wastewater.

The primary purpose of this study was to evaluate the effectiveness of JWBO constructed wetland to treat domestic wastewater and to recommend this technology as alternative wastewater treatment facility for other types of wastewaters in the country.

The efficiency of CW varies with site specific parameters such as pH, wastewater temperature, Hydraulic Retention Time and Hydraulic Loading Rate (Kenneth, 2000; Renee, 2001). In addition to these, the original wastewater contaminant concentrations impacts wetland treatment efficiency (Faithful, 1986; Kyambadde, 2005) wetland construction should therefore be designed based upon the original wastewater characteristics (Woulds and Ngwenya, 2006). For example, a study conducted in Scotland (2006) highlighted the importance of site-specific conditions (temperature, pH, HRT and HLR) in regulating the effectiveness of a constructed wetland for domestic wastewater treatment.

In addition to treatment, alternatives of effluent management options, such as infiltration strips, grass filter strips, recycling back through the wetland, irrigation, and direct discharge to water bodies (Kenneth, 2000), must be considered as part of any CW system (John and Partick, 2000). The disposal of effluent needs to include proper design elements and proper regulation approval. Of the above stated effluent management options, the one which is practiced by JWBO was direct discharge to the surface water (nearby stream). However, this requires regulatory testing and monitoring to meet the stringent local standards on pollutant discharge limits of effluent set by National Environmental Quality Standards of Ethiopia (EEPA, 2003).

3. OBJECTIVES

3.1 General Objective

The general objective of this study was to evaluate the treatment performance of constructed wetlands as an alternative municipal wastewater treatment technology under Ethiopian climatic conditions.

3.2 Specific Objectives

- To determine removal efficiency of constructed wetlands for selected wastewater quality parameters; BOD_5, COD, TSS, NH_4^+-N, NO_3^--N, TN, PO_4^{3-}-P, TP, SO_4^{2-}, S^{2-}, and Coliform bacteria of domestic wastewater, taking JWBO CW as a case study,
- To evaluate the removal capacity of different wetland cells planted with *C. papyrus, C. alternifolia* and *P. canariensis* at JWBO CW system,
- To provide the necessary information for local, regional and national governments for wider application of the technology.

4. MATERIALS AND METHODS

4.1 Description of the Study Area

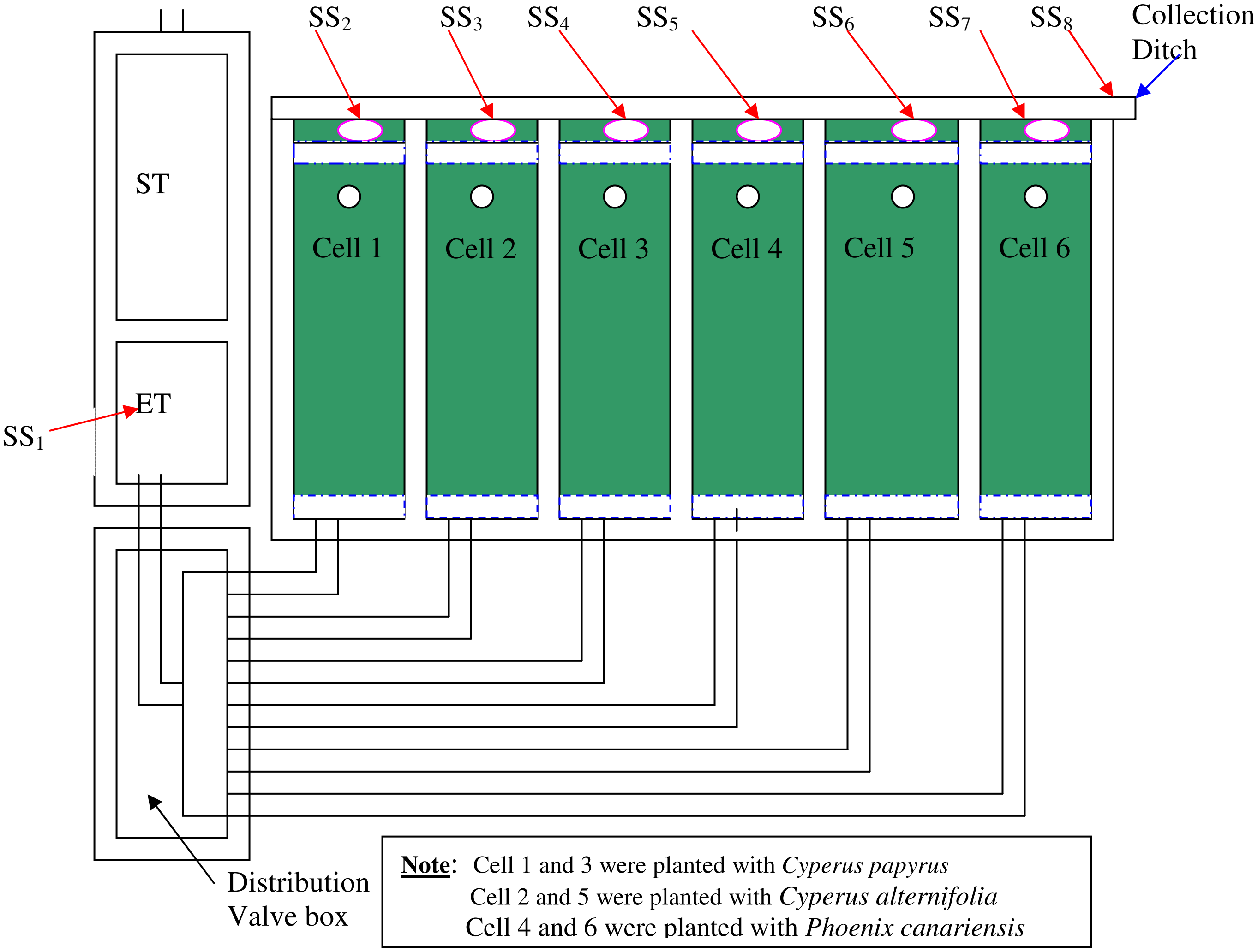
This study was conducted on SSF wetland constructed at Jehovah's Witnesses Branch Office (JWBO) located in South-East part of Addis Ababa, Ethiopia, which has been operating since 2004. The wastewater generated from different parts of the building is delivered in to the septic tank (for primary treatment), with 148.72m^3 (length 14.30m * width 4m * depth 2.6m) capacity. The septic tank contains baffles and other screening materials to prevent the solid materials leaving the settling tank. Then the wastewater enters to the equalization tank, with 36.96 m^3 (Length 4.4m * Width 4.2m * Depth 2.0m) capacity.

The equalization tank provides a multipurpose benefit when considering water budget: the amount of water going in to, flowing out and remaining in the wetland. It will serve as additional settling basins for removing solids as well as storage for excess water during high water input (Kenneth, 2000). In addition to these, this tank contains a gravity flow pumps that releases the influent to the wetland when the depth of the water reaches 1.46m with uniform hydraulic loading rate (17.74m^3) and which happens on average two times per day.

The purpose of such a pump is to discharge the contents intermittently into the wetland. This intermittent discharge permits the filtering material to be completely dosed with a rest interval following after each application of wastewater, thus prolonging the usefulness and efficiency of the wetland system (USEPA, 1993). The discharge from the equalization tank assures complete filling of the cells, thus insuring that every part of the filled cell will be utilized effectively.

This SSF wetland is consisted of six cells, working in parallel, with the area of 98m^2, each cell with length 14m and width 7m for each cell (Figure 6). The total area of JWBO constructed wetland is 588m^2 (length 42m and width 14m). The depth of the wetland is 0.70m, filled with gravel having different sizes (40-80mm and 20-30mm) as a substrate. Each cell received equal volume of influent from the equalization tank and it was regulated by the gate valves of each cell (Figure 8). The effluent of each cell is collected with the help of perforated pipe and released into the collection ditch. All these collected effluents were transported and disposed to the nearby stream.

The wetland, in which this study was conducted, was planted with three plant species, namely *Cyprus papyrus (*Papyrus), *Cyprus alternifolia* (Umbrella plant) and *Phoenix canariensis* (Palm*)* (Figure 7). Of these, *C. papyrus* and *C. alternifolia* were obtained locally at Debre-Zeyet, which is approximately 47 Kilometers from the wetland site, and the other was obtained from Addis Ababa. One plant species was planted in one wetland cell and the species are planted in an alternative way throughout the wetland system. As indicated in Figure 6 and 7; Cell 1 and 3 were planted with *C. papyrus*, cell 2 and 5 were planted with *C. alternifolia* and cell 4 and 6 were planted with *P. canariensis*



Note: Cell 1 and 3 were planted with *Cyperus papyrus*
Cell 2 and 5 were planted with *Cyperus alternifolia*
Cell 4 and 6 were planted with *Phoenix canariensis*

Figure 6: Sketch map of JWBO Wetland and sampling sites for this study

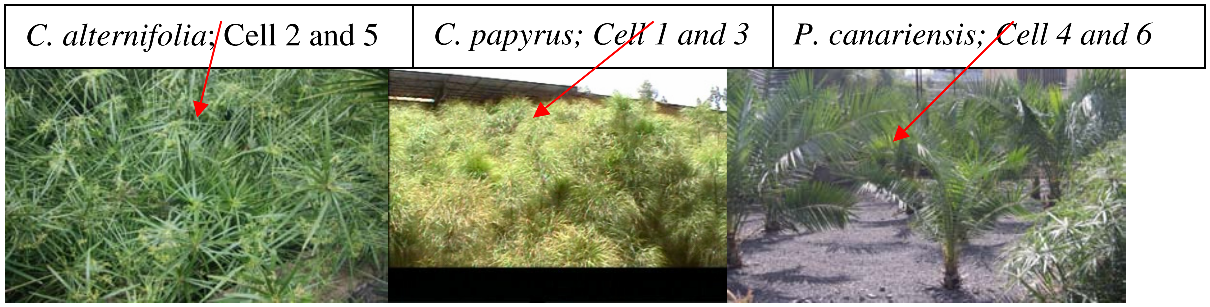


Figure 7: Wetland Cells and the type of Plant species planted at JWBO CW.

A. partial view of JWBO **B. partial view of distribution valves**

Figure 8: Partial view of JWBO and wastewater distribution valves of the wetland

4.2 Sampling

Before sample collection, the hydraulic retention time (HRT) of JWBO CW was calculated. This is because wastewater treatment processes are dependant. Amongst other factors; on the period of time that wastewater physically resides within the wetland. The approximate estimate of HRT for this wetland was obtained by using Darcy's formula (USEPA, 1993)

$$\mathbf{HRT} = \frac{\mathbf{nLWd,}}{\mathbf{Q_{av.}}} \qquad \textbf{------------------ Darcy's Law}$$

Where:

n = effective porosity media, % as a decimal, (for 80mm gravel media its value is 0.35)

L = Length of the bed, (m)

W = Width of the bed, (m)

d = Average depth of liquid in bed, (m)

Q_{av} = the average of the inflow and outflow $\left\{\frac{Q_i + Q_o}{2}\right\}$, ($m^3$/day),

Source: USEPA, 1993

The porosity (n) is used to determine the actual flow velocity in the void spaces in retention time calculation equation. Porosity is equal to void volume/total volume and is expressed as percentage and it is 35% for gravel with the size of 80mm, (USEPA, 1993)

The quantity of inflow to the wetland was determined by measuring the depth of the water in the equalization before the pump was opened and immediately after the pump was closed, (which was uniform in hydraulic loading rate) and the outflow quantity of the wetland was calculated manually using graduated container with a stopwatch.

Based on this, the mean inflow and outflow of the wetland was 35,480 litters (35.48m3) and 27,300litters (27.3m3) per day, respectively. The mean depth of water level of the wetland, (0.33 meter), was calculated by measuring the water levels through the water level monitoring pipe found in each cell of the wetland using a measuring tape. Based on the above data, the calculated hydraulic residence time (HRT) of the wetland was 2.16 days.

To evaluate the performance efficiency of CW, inlet grab samples were collected two days before the outlet ones, according to the estimated hydraulic retention time of the wetland. As indicated from Figure 6 and 9, samples were collected at eight sites (SS_1, SS_2, SS_3, SS_4, SS_5, SS_6, SS_7 and SS_8). SS_1 was in the equalization tank (for influent of the wetland), while SS_2 to SS_7 were in manholes of each wetland cells (for effluent of each wetland cells) and SS_8 was at the collection ditch near the final disposal site (for effluent of the overall wetland system). In all these sites, samples were collected for two months (May 14 to July 14, 2007). A total of 24 samples (three samples per site) were collected every 15 days throughout the study period.

SS 1: at Equalization tank

SS 2 – SS 7: at effluent of each cell

SS 8: at the overall wetland system effluent

Figure 9: Sample sites at JWBO CW systems in which all samples were collected.

For analyses of physicochemical parameters, samples were collected using 500 ml plastic bottles washed with distilled water and repeatedly rinsed with the wastewater at each sample site before the sample was collected. For coliform bacteria tests, sample collection was carried out using glass bottles previously sterilized by autoclaved at 121^{0}c for 15 minutes. Additionally, for plant species identification, three voucher species samples were collected at; cell 1 and 3 for one plant species, cell 2 and 5 for the other one species and the remaining one species was taken from cell 4 and 6 wetland cells (Figure 10).

Planted at cell 2 and 5

Planted at cell 1 and 3

Planted at cell 4 and 6

Figure 10: Wetland plant sampling sites at JWBO CW

4.3 Analysis

A detailed influent and effluent characterization of all collected samples was carried out for both selected physicochemical and bacteriological wastewater quality parameters. The common influent and effluent quality parameters that were determined were: BOD$_5$, COD, TSS, ammonium N, nitrate N, total N, orthophosphate, total phosphorus, sulfate, sulfide, TC, FC, wastewater pH and temperature.

COD, ammonium N, nitrate N, total N, orthophosphate, total phosphorus, sulfate and sulfide were measured calorimetrically by spectrophotometer (DR/ 2010, USA) according to HACH instructions. BOD$_5$ was determined using standard methods of APHA (1998); Total Suspended Solids was determined using gravimetric method while Wastewater temperature and pH was measured on-site during sampling time (when the equalization tank reaches its maximum height) using portable thermometer and pH meter.

The bacteriological quality indicators; Total Coliform (TC) and Fecal Coliform (FC) were evaluated using Membrane Filter (MF) procedures of standard method for the examination of water and wastewater (APHA, 1998). Samples were serially diluted (10^1 to 10^6) using double distilled water and 100 ml of the diluted water was filtered through a filter paper in order to retain bacteria using filtering unit. Then a filter paper, with a pore size 0.45µm, was placed on a surface of absorbent pad socked with Membrane Lauryl Sulfate Broth and incubated at 37°c for Total Coliforms and 44°c for Fecal Coliforms, Yellow Colonies, which are atypical colony characteristic of TC and FC using Membrane Lauryl Sulfate Medium (APHA, 1998), (Annex III: Figure 1 & 2), were counted using colony counter and the results were recorded as the number of Colony Forming Unit (CFU) of TC and FC per 100 ml. Additionally, plant species identifications was done in the National Herbarium of Ethiopia

The product of the influent hydraulic discharge data and the nutrient concentration obtained in the influent divided by the total area of the wetland gives the nutrient loading rate in the wetland (Healy and Cawley, 2001). The removal efficiency of the wetland for each wastewater quality parameters were calculated using the following formula:

$$\text{Efficiency (\%)} = \frac{[C_i - C_e]}{C_i} * 100$$

Where: C_i = is the concentration of the waste material in the influent

C_e = is the concentration of the waste material in the effluent

Source: Christon, 2004

To determine the contribution of wetland plant species; the results obtained from the effluent samples of constructed wetland cells covered with *C. papyrus* (Cell 1 and 3), *C. alternifolia* (Cell 2 and 5) and *P. canariensis* (Cell 4 and 6) plant species were compared against each other.

4.4 Statistical Analysis

Statistical analysis was performed with SPSS package Release 13.00 for windows. The included Mean, Standard Error, Pearson correlation analysis and the Analysis of Variance (ANOVA) testes were done using this package.

5. RESULTS AND DISCUSSION

To evaluate the treatment performance of JWBO CW, selected parameters from the influent and effluent were measured. These were BOD_5, COD, TSS, NH_4^+ N, NO_3^- N, TN, PO_4^{3-}, TP, Sulfate, Sulfide, pH, wastewater temperature and coliform bacteria (TC and FC). During the entire period of the study, a total of 24 samples were analyzed for each wastewater quality parameter.

Table 1 presents the mean influent and effluent concentrations of BOD_5, COD and TSS for each wetland cells and the overall system of JWBO CW. The average influent wastewater temperature and pH values were 25.8 ± 0.3 ^{0}C and 7.1 ± 0.27 pH units, respectively. The mean influent parameter values were: BOD_5 (273.3 ± 21.9 mg/L), COD (619.3 ± 187.3 mg/L) and TSS (201.3 ± 6.7 mg/L), which was equivalent to the mean daily loading rate of 16.5 kg/m^2/day, 37.4 kg/m^2/day and 12.2 kg /m^2/day, respectively.

The mean effluent parameter values of JWBO CW were: BOD_5 (2.0 ± 0.6mg/L), COD (68 ± 11.7 mg/L) and TSS (30.0 ± 10.5 mg/L). The mean pH value was 7.18 ± 0 .013 with a range of 7.15 – 7.19. Figure 11 shows the average removal efficiency of each wetland cells and the overall wetland system of JWBO CW. The average removal efficiency of each wetland cells were within the range of 97.3% - 98.4% for BOD_5, 87% - 89.8% for COD and 81.5% - 84% for TSS (Table 1 and Figure 11). The overall JWBO CW removal efficiency was: BOD_5 (99.3%), COD (89%) and TSS (85%).

Table 1: **Mean BOD$_5$, COD and TSS Influent and Effluent concentration values (mg/L) of JWBO CW**

Wetland cells	BOD$_5$			COD			TSS		
	Influent	Effluent	%	Influent	Effluent	%	Influent	Effluent	%
Cell 1[a]	273.3 ± 21.9	6.3 ± 1.9	97.7	619.3± 187.3	63.7± 14.5	89.7	201.3 ± 6.7	32.7 ± 11.4	83.8
Cell 2[b]	273.3 ± 21.9	7.3 ± 2.3	97.3	619.3± 187.3	76.3± 17.6	87.7	201.3 ± 6.7	37.3 ± 10.2	81.5
Cell 3[a]	273.3 ± 21.9	5.3 ± 0.9	98.0	619.3± 187.3	66.7± 15.2	89.2	201.3 ± 6.7	32.3 ± 12.0	84.0
Cell 4[c]	273.3 ± 21.9	6.0 ± 2.6	97.8	619.3± 187.3	63.3± 11.2	89.8	201.3 ± 6.7	33.0 ± 7.2	83.6
Cell 5[b]	273.3 ± 21.9	5.0 ± 0.6	98.2	619.3± 187.3	80.3± 20.5	87.0	201.3 ± 6.7	34.0 ± 7.2	83.1
Cell 6[C]	273.3 ± 21.9	4.3 ± 0.9	98.4	619.3± 187.3	65.0± 11.5	89.5	201.3 ± 6.7	34.7 ± 7.5	82.8
Overall wetland system	273.3 ± 21.9	2.0 ± 0.6	99.3	619.3± 187.3	68.0± 11.7	89.0	201.3 ± 6.7	30.3 ± 10.5	85.0

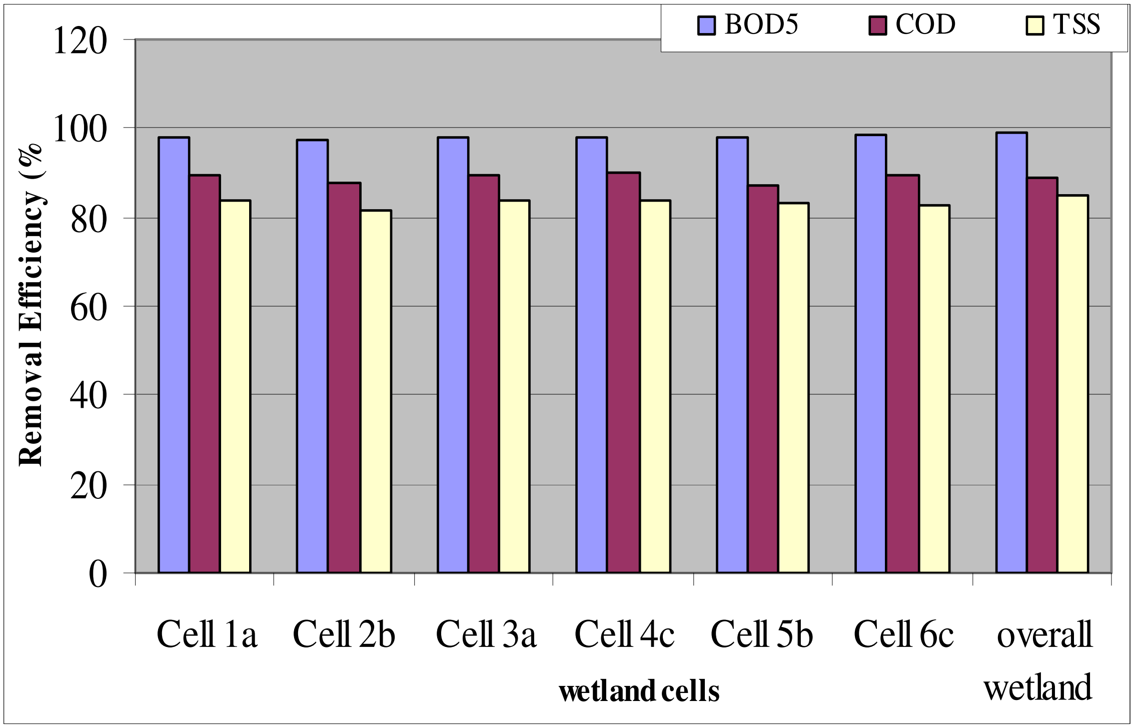


Figure 11: BOD$_5$, COD and TSS Removal Efficiencies of JWBO CW

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[a] wetland cells planted with *C. papyrus* species

[b] wetland cells planted with *C. alternifolia* species

[c] wetland cells planted with *P. canariensis* species

This finding was similar to that of the study done in USA: USEPA (1988) BOD_5 (93%); in Kenya: Nyakango and VanBruggen (1999) BOD_5 (98%), COD (96%) and TSS (85%); in Northern Alabama: Kathleen (2000) BOD_5 (85%); and in Italy: Puccie *et al*. (2000) COD (93%) and TSS (81%).

The result indicated that BOD_5 and COD removal efficiency of JWBO was very efficient with a removal value of 99.3% and 89%, respectively. This showed the effectiveness of constructed wetland systems to remove organic matter in domestic wastewater. The high removal efficiency might be due to the fact that organic matters in domestic wastewater are dominated with readily biodegradable organic matter which is amenable to biological decomposition within a short hydraulic retention time (Reddy and Graetz, 1988).

In addition to this, the media and macrophytes roots in SSF may provide a greater number of small surfaces, pores, and crevices where treatment can occur. Moreover, the availability of vast number of organic matter utilizing microorganisms adapted to the aerobic and anaerobic environment of wetland ecosystems might also facilitate the organic matter removal process of CW more effective (USEPA, 1993; Michael, 2000).

Microbial degradation and mineralization are the major pathways for BOD_5 and COD removal in constructed wetland system that will result an oxidized byproducts such as CO_2, NO_3^-, SO_4^{2-}, PO_4^{3-} and microbial biomass to the system. In constructed wetland systems, organic matter can also be degraded when taken up by wetland plants (Rencee, 2001).

In addition to BOD_5 and COD, the removal of TSS is used as a wastewater quality parameter to monitor the effectiveness of constructed wetlands for the removal of organic matter. Suspended solids in domestic wastewater include a range of organic and inorganic materials but are typically dominated by fecal organic matter and organic particles like bacteria. The result showed that TSS removal efficiency of JWBO CW was also high (85%) as that of BOD and COD (Table 1 and Figure 11).

The high removal efficiency of TSS might be due to the fact that, in SSF constructed wetlands the water flows below the ground through gravel and wetland plant roots. This facilitates the physical, chemical and biological wastewater treatment mechanisms such as sedimentation, aggregation, surface adhesion and biodegradation (Mergaert *et al.*, 1992). These processes improve the efficiency of removing TSS in the SSF constructed wetland within a short hydraulic retention time, within 2 to 5 days (USEPA, 1993).

The ANOVA test result indicated that wetland cells planted with P. canariensis (cell 4 and 6) showed higher removal efficiency for BOD5 (98%) and COD (90%) than wetland cells planted with other plant species. Similarly wetland cells planted with C. papyrus (cell 1 and 3) showed higher removal efficiency for TSS (83.9%) than other wetland cells. However, this difference was not statistically significant ($p > 0.05$), which may be due to lower difference between these wetland cells planted with different plant species (Annex II and III).

JWBO CW effluent concentration values of BOD_5 (2.0 ± 0.6mg/L), COD (68 ± 11.7 mg/L) and TSS (30.0 ± 10.5 mg/L) were compared with the provisional discharge limits values set by National Environmental Quality Standard for domestic wastewater effluent (EEPA, 2003). These limit values were: 80 mg/L for BOD_5, 250 mg/L for COD and 100 mg/L for TSS. The obtained effluent concentration values were below the standard limit values, indicating the effectiveness of the constructed wetland in fulfilling the regulatory limit values to discharge the effluent into surface and inland water bodies.

To analyze the nitrogen removal efficiency of JWBO CW, the influent and effluent NH_4^+-N, NO_3-N and TN were evaluated. Table 2 shows the mean influent and effluent concentrations of each cells and the overall JWBO CW system. The mean influent parameter values were: ammonium-N (38.7 ± 6 mg/L), nitrate-N (14.7 ± 0.9 mg/L) and total-N (107.7 ± 0.8 mg/L), which was equivalent to the daily loading rate of 2.3 kg /m2/ day, 0.9 kg /m2/ day and 6.5 kg/m2/day, respectively.

The removal efficiencies of each wetland cells and the overall JWBO wetland were shown in Figure 12. The amount of ammonium-N removed (% removal) in each wetland cells were: cell 1 (24.8%), cell 2 (25.8%), cell 3 (24.8%), cell 4 (23.2%), cell 5 (23.5%) and cell 6 (22.9%). In the same way, the amount of nitrate-N removed by each wetland cell was: 82.5% in cell 1, 78.4% in cell 2, 82.3% in cell 3, 81.0% in cell 4, 77.6% in cell 5 and 81%

in cell 6, while for total-N it was 54.5%, 55.7%, 53.4%, 57%, 53.9% and 57%, respectively.

The overall removal efficiency of JWBO CW was 28.1% for ammonium-N, 64.4% for nitrate-N and 61.5% for total-N, with the corresponding mean effluent concentrations of 27.8 ± 2.1 mg/L, 5.2 ± 0.6 mg/L and 41.5 ± 4.4 mg/L, respectively (Table 2 and Figure 12).

Table 2: The mean ammonium nitrogen, nitrate nitrogen and total nitrogen influent and effluent concentrations (in mg/L) of JWBO CW

	NH_4^+ -N			NO_3^- -N			TN		
Wetland cells	Influent	Effluent	%	Influent	Effluent	%	Influent	Effluent	%
Cell 1[a]	38.7± 6	29.1±1.8	24.8	14.7 ±0.9	2.6±0.3	82.5	107.7±0.8	49 ± 4.8	54.5
Cell 2[b]	38.7 ±6	28.7±1.6	25.8	14.7 ±0.9	3.2±0.5	78.4	107.7±0.8	47.7±4.7	55.7
Cell 3[a]	38.7 ±6	29.1±1.6	24.8	14.7 ±0.9	2.6±0.4	82.3	07.7 ± 0.8	50.5±5.5	53.4
Cell 4[c]	38.7 ±6	29.7±1.6	23.2	14.7 ±0.9	2.8±0.6	81	107.7±0.8	44.2±5.5	57
Cell 5[b]	38.7 ±6	29.6±1.7	23.5	14.7 ±0.9	3.3±0.4	77.6	107.7±0.8	49.1±4.8	53.9
Cell 6[c]	38.7±6	29.8±1.8	22.9	14.7 ±0.9	2.8±0.6	81	107.7±0.8	46.3±4.0	57
Overall wetland system	38.7±6	27.8±2.1	28.1	14.7 ±0.9	5.2±0.6	64.4	107.7±0.8	41.5±4.4	61.5

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[a] wetland cells planted with C. papyrus species

[b] wetland cells planted with C. alternifolia species

[c] wetland cell planted with P. canariensis

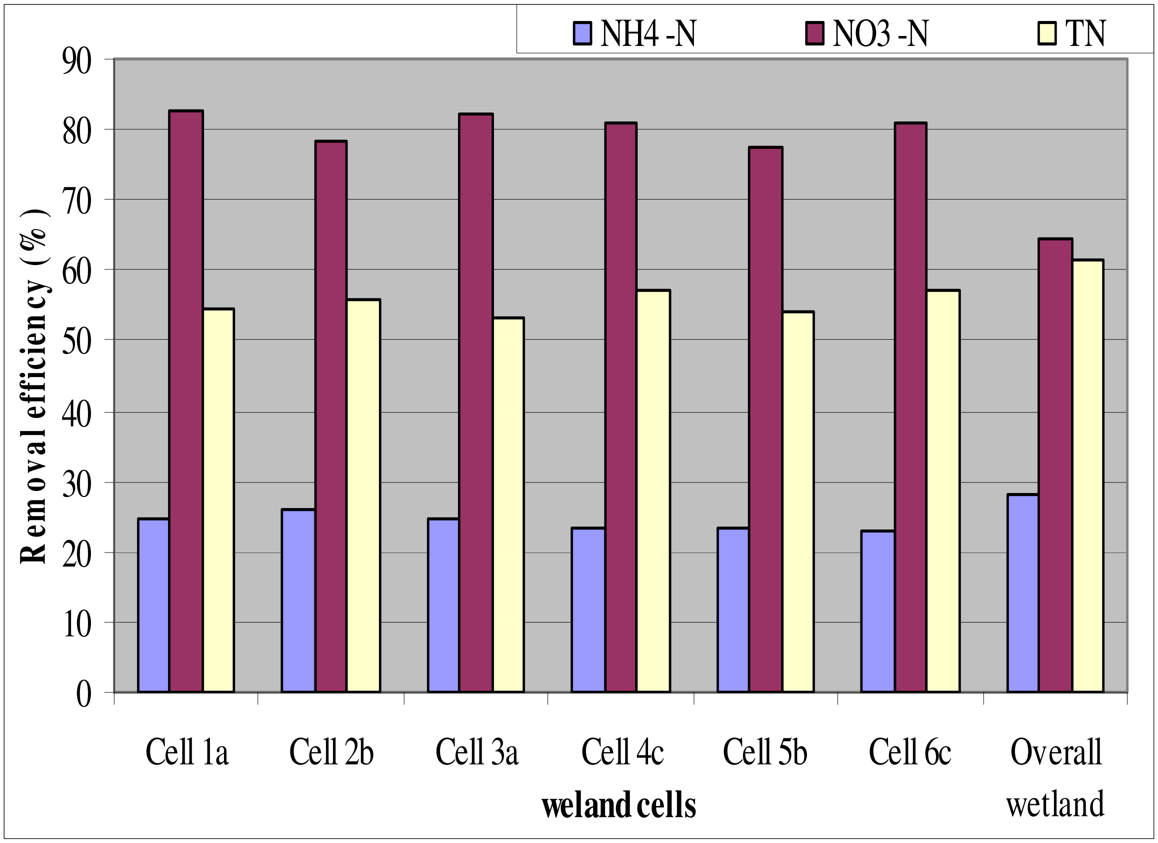

Figure 12: Ammonium N, Nitrate N and Total N Removal Efficiencies of JWBO CW

Similar trends of Nitrogen removal was recorded by Pucci *et al*. (2000) nitrate-N (55%), ammonium-N (30%), and total-N (50%). Similarly, Kaseva (2003) obtained Nitrogen removal efficiency of ammonium-N (11.2% - 25.2%) and nitrate-N (32.2% - 44.3%) using CW with the average HRT of 1.93 days.

On the other hand, the highest removal efficiency (92% for NH_4-N and 90% for TN) was obtained in Kenya by Nyakango and VanBurggen (1999). This difference might be due to the design difference; which consists of a combination of SF system followed by SSF wetland cells in serious which maximizes the retention time and facilitates nitrification process by creating aerobic condition (USEPA, 1993). Moreover, each cell was planted with mixed plant species, which maximizes root biomass in the wetland substrate that in turn results in aerobic degradation around the root zone (Brix, 1994; Oketch, 2003).

Total nitrogen typically consists of varying proportion of particulate organic nitrogen, dissolved organic nitrogen, ammonium nitrogen, nitrite nitrogen and nitrate nitrogen (Reddy and Patrick, 1984; Kadlec and Knight, 1996). In subsurface constructed wetland system mineralization transforms these organic nitrogen to its inorganic constitutes. Because of the optimum pH value (7.18 ± 0.013), in JWBO CW, the hydrolysis of organic nitrogen resulted mainly to ammonium-N. This pathway occurs under both aerobic and anaerobic conditions and it is often referred to as ammonification (USEPA, 1993).

Once ammonium nitrogen is formed and/or entered to subsurface flow wetland system, it can take several possible pathways (Figure 3). The first pathway is nitrification: the aerobic oxidation of ammonium to nitrite by ammonium oxidizing bacteria and the subsequent oxidation of the produced nitrite to nitrate by nitrite oxidizing bacteria. In subsurface flow constructed wetlands nitrification can occur in the oxygenated zones within the rhizosphere of plant roots (William and Jams, 1993).

While this is a very important process in SSF wetland it is likely that the slow diffusion rate of ammonium from anaerobic zone to root zone (aerobic zone) of the wetland limits the importance of this pathway (Brix *et al*., 2003; Richard *et al*., 1994). Consequently, the result showed a low NH_4^+-N removal efficiency in the SSF constructed wetland (28.1%). The second ammonium pathway is biological uptake. Unlike most terrestrial plants, many aquatic plants use ammonium as a nitrogen source (Kanlec and Knight, 1996; Simi and Mitchell, 1999; Brix *et al*., 2003).

Furthermore, the low removal efficiency of ammonium nitrogen might be due to the low HRT of JWBO CW (2.16 days). But different studies (USEPA, 1993; Kenneth, 2000; Michael, 2002) indicated that for effective removal of nitrogen the HRT should not be less than 7 days. This long HRT is important because for nBOD to be reduced, cBOD first must be reduced to a relatively low concentration (<40mg/L) that helps to insure adequate degradation of those soluble and simplistic forms of cBOD that inhibits the activity of nitrifying bacteria (Kanlec and Knight, 1996).

On the other hand nitrate nitrogen removal efficiency of JWBO CW system was: 82.5% in cell 1, 78.4% in cell 2, 82.3% in cell 3, 81% in cell 4, 77.6% in cell 5 and 81% in cell 6, which was higher than the other forms of nitrogen. In constructed wetland system nitrate is removed using several pathways. The first pathway is denitrification, which usually accounts for the bulk of inorganic nitrogen removal in wetlands. This is because nitrate diffusion rate in wetland soils/substrate are seven times faster than ammonium diffusion rate (Kanlec and Knight, 1996; Simi and Mitchell, 1999; Brix *et al*., 2003).

Denitrification is the reduction of oxidized nitrogen compounds like nitrate or nitrite to gaseous nitrogen compounds by various chemo-organotrophic bacteria utilizes nitrate or nitrite as respiratory electron acceptor to carryout the oxidation of carbonaceous organic matter under anoxic condition (Gersberg *et al*., 1984; USEPA, 1998; James and William, 1993; Aimee *et al*., 2000). The second pathway is assimilatory nitrate reduction: where nitrate is taken up and converted to nitrite and then to ammonium by aquatic plants and microorganisms for cell growth (Techobanoglous *et al*., 2003).

The result showed that at $SS_{8,}$ (overall wetland system), the removal efficiency was high for ammonium and total nitrogen, while for nitrate nitrogen it was low. This might be due the aeration effect through the manholes found at each wetland cell and in the effluent collection ditch. This is because for the overall wetland system removal efficiency analysis, samples were collected after the manholes of each wetland cell and at the end of the collection ditch (Figure 9)

Wetland cells planted with *C. papyrus* (cell 1 and 3) showed higher removal efficiency for ammonium N (24.8%), nitrate N (82.4%) and total nitrogen (54.8%) than wetland cells planted with other plant species. But the difference was not statistically significant ($p > 0.05$), which may be due to the lower differences between each wetland cells planted with different plant species (Annex II and III).

JWBO CW effluent concentration values of ammonium nitrogen (27.8 ± 2.1 mg/L), nitrate nitrogen (5.2 ± 0.6 mg/L) and total nitrogen (41.5 ± 4.4 mg/L) were compared with provisional discharge limits values set by National Environmental Quality Standard for domestic wastewater effluent (EEPA, 2003). The discharge limit values were: 5 mg/L for ammonium, 20 mg/L for nitrate and 60 mg/L for total nitrogen. Except ammonium nitrogen, the other nitrogenous waste parameter values were within the standard. This showed that with minimum effort to treat ammonium, the overall wetland effluent concentrations meet admissible standards set by EEPA to discharge it in to surface and inland water bodies.

This excess ammonium in JWBO CW can be removed either by arranging nitrification pre-treatment before the wetland or by treating the effluent with lime or chlorine. Liming converts ammonium ion to ammonia which can be removed from the solution by air stripping. The other treatment option; breakpoint chlorination (supper chlorination), oxidizes ammonium to nitrogen gas (USEPA, 1993)

Table 3 presents the results of mean influent and effluent concentrations of each wetland cell and the overall removal efficiencies of JWBO wetland system for orthophosphate (PO_4^{3-}) and total phosphorus (TP).

The mean influent concentration was 8.04 ± 0.8 mg /L for orthophosphate and 8.9 ± 0.95 mg/L for total phosphorus. Based on the average daily inflow of the study period (35,480 liter per day), the average daily loading rate of orthophosphate and total phosphorus to JWBO wetland was 0.5 kg/ m^2 /day and 0.54 kg/ m^2/day, respectively.

Figure 13 shows the removal efficiency of each wetland cell and the overall wetland system. The removal efficiency of each wetland cell for orthophosphate was: 24.1% (cell 1), 15.7% (cell 2), 21.6% (cell 3), 23.4% (cell 4), 16.7% (cell 5) and 23.4% (cell 6), while for total phosphorus it was 16.9%, 11.2%, 16.1%, 20.2%, 13.9%, and 16.1%, respectively

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The overall removal efficiency of JWBO CW was 28% for orthophosphate and 22.7% for total phosphorus, with the final effluent concentration of 5.8 ± 1.1 mg/L and 6.9 ± 1.2 mg/L, respectively. The analysis of variance test result (Annex II: Table 1) showed that the mean effluent concentrations was not significantly ($P > 0.05$) different from the influent concentrations of the wetland, which shows its poor removal efficiency. Similarly, Pucci *et al*. (2000) obtained 20% TP removal efficiency using subsurface constructed wetland

Table 3: The mean orthophosphate and total phosphorus influent and effluent concentrations values (mg/L) of JWBO CW

Wetland cells	Orthophosphate			Total Phosphorus		
	Influent	Effluent	% removal	influent	Effluent	% removal
Cell 1[a]	8.04 ± 0.8	6.4 ± 1.4	24.1	8.9 ± 0.95	7.4 ± 1.3	16.9
Cell 2[b]	8.04 ± 0.8	6.8 ± 1.0	15.7	8.9 ± 0.95	7.9 ± 0.96	11.2
Cell 3[a]	8.04 ± 0.8	6.3 ± 1.4	21.6	8.9 ± 0.95	7.5 ± 1.3	16.1
Cell 4[c]	8.04 ± 0.8	6.2 ±1.2	23.4	8.9 ± 0.95	7.1 ± 0.96	20.2
Cell 5[b]	8.04 ± 0.8	6.7 ± 1.2	16.7	8.9 ± 0.95	7.7 ± 0.95	13.9
Cell 6[c]	8.04 ± 0.8	6.2 ±1.5	23.4	8.9 ± 0.95	7.5 ± 1.5	16.1
Overall wetland performance	8.04 ± 0.8	5.8 ± 1.1	28	8.9 ± 0.95	6.9 ± 1.2	22.7

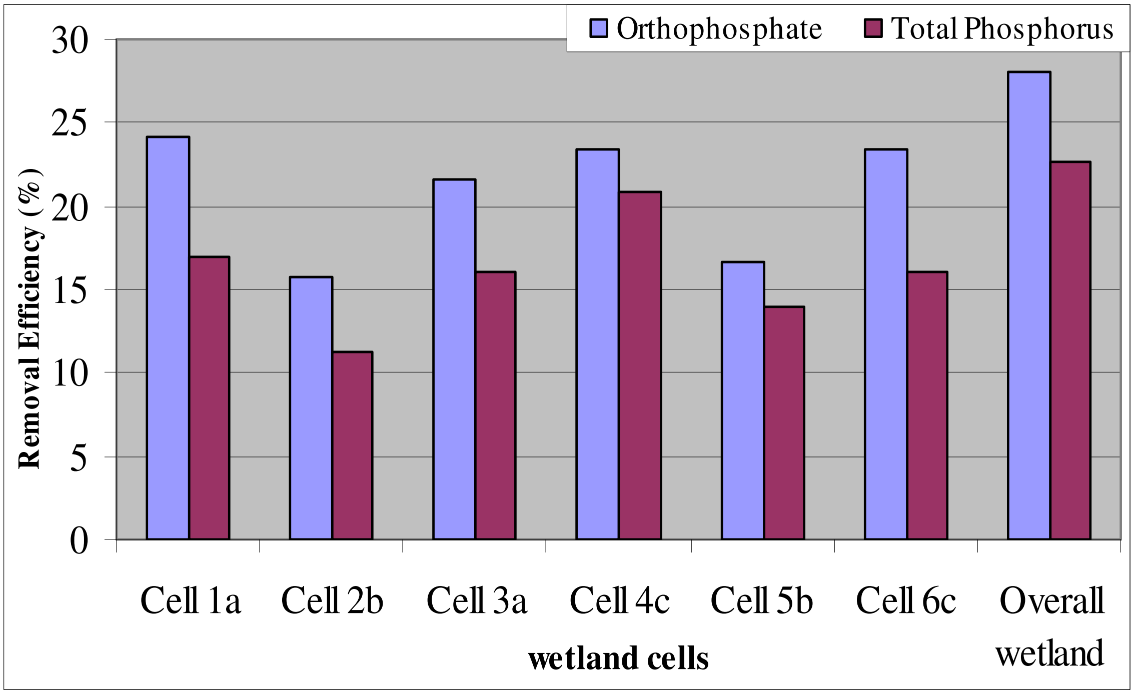

Figure 13: Orthophosphate and Total Phosphorus Removal Efficiencies of JWBO CW

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[a] wetland cells planted with C. papyrus species
[b] wetland cells planted with C. alternifolia species
[c] wetland cells planted with P. canariensis species

The limiting factor for this low phosphorus removal in this wetland system might be the short hydraulic retention time of the wetland, which was 2.16 days for each cells working in parallel. But according to Miriam *et al*. (2002) the minimum HRT to remove 50% of the bio-reactive phosphate was 7 days. For example Nyakango and VanBruggen, (1999) obtained 88% removal efficiency for orthophosphate; this difference might be due to high HRT obtained by using serious cells to maximize the contact area and time

The major pathways (Figure 4) that govern the removal of phosphorus in this wetland systems might be through plant assimilation, substrate adsorption, and precipitation reaction which occur when the inflowing water comes in contact with available aluminum ion, calcium, and other clay minerals in the sediment (Faithful, 1996; Kadlec and Knight, 1996).The mineralization of organic matter results in the release of orthophosphate ion to the wetland system. This orthophosphate can then undergo a variety of subsequent reactions.

Once released, orthophosphates are often rapidly taken up in a range of biological growth reactions. The most important of these is the growth and development of biofilms. Overtime these materials are subsequently degraded and recycled in the sediment and incorporated in to wetland macrophytes biomass which has longer storage time. Another very rapid orthophosphate removal pathway which might be probably competitive with biological uptake is adsorption of orthophosphate onto available cations (Sinclair, 2000).

The ANOVA test result showed that orthophosphate removal efficiency (23.5%) was higher in wetland cells planted with *C. papyrus* (cell 1 and 3) than wetland cells planted with other plant species. Similarly total phosphorus removal efficiency (17%) was higher in wetland cells planted with *P. canariensis* (cell 4 and 6) than other wetland cells. But this change was not statistically significant ($p > 0.05$), which may be due to its lower differences between wetland cells (Annex II and III).

JWBO CW effluent concentration values of orthophosphate (5.8 ± 1.1mg/L) and total phosphorus (6.9 ± 1.2 mg/L) were compared with the provisional discharge limits values (5.0 mg/L for orthophosphate and 10.0 mg/L for total phosphorus) set by National Environmental Quality Standard for domestic wastewater effluent (EEPA, 2003). The obtained effluent concentration values showed that the concentration of orthophosphate was slightly higher than the limit value.

Since phosphorus is a conservative material, (has no any rout for atmospheric emission), it is extremely important to limit its discharge to the environment is well controlled, because once the system is polluted with phosphorus it can be recycled in a system and result in periods of eutrophication over many years (Ponnamperuma, 1972; Flaig and Reddy, 1990; Aisling and Marinus, 2006).

Table 4 presents the mean sulfate and sulfide concentrations of the influent and effluent concentrations of each wetland cells and the overall wetland systems of JWBO. The average influent concentration was 153.3 ± 17.6 mg/L for sulfate and 4.6 ± 0.5 mg/L, for sulfide. Based on the inflow data (35,480 liter per day), the mean daily loading rate of sulfate and sulfide to JWBO wetland was 9.3 kg/m^2/day and 0.3 kg/m^2/day, respectively.

Figure 14 shows the removal efficiency of each wetland cell and the overall wetland of JWBO obtained during the study period. The removal efficiency of each wetland cells for sulfate was: 74.1% (cell 1), 82.8% (cell 2), 73.3% (cell 3), 77.4% (cell 4), 81.2% (cell 5) and 76.7% (cell 6) while for sulfide it was 98.7%, 98.6%, 98.7%, 98.8%, 98.8% and 98.4%, respectively.

The overall removal efficiency of JWBO CW was 77.3% for sulfate and 99% for sulfide, with the final effluent concentration of 34.3 ± 0.9 mg/L and 0.047 ± 0.019 mg/L, respectively.

Table 4: **The mean sulfate and sulfide influent and effluent concentration (mg/L) of JWBO CW**

Wetland cells	Sulfate (SO_4^{2-})			Sulfide (S^{2-})		
	Influent	Effluent	% removal	Influent	Effluent	% removal
Cell 1[a]	153.3 ± 17.6	39.7 ± 8.7	74.1	4.6 ± 0.5	0.058 ± 0.019	98.7
Cell 2[b]	153.3 ± 17.6	26.3 ± 1.5	82.8	4.6 ± 0.5	0.064 ± 0.016	98.6
Cell 3[a]	153.3 ± 17.6	41 ± 8.5	73.3	4.6 ± 0.5	0.06 ± 0.017	98.7
Cell 4[c]	153.3 ± 17.6	34.7 ± 1.5	77.4	4.6 ± 0.5	0.056 ± 0.020	98.8
Cell 5[b]	153.3 ± 17.6	28.3 ± 3.2	81.2	4.6 ± 0.5	0.059 ± 0.011	98.7
Cell 6[c]	153.3 ± 17.6	35.7 ± 2.3	76.7	4.6 ± 0.5	0.074 ± 0.013	98.4
Overall wetland performance	153.3 ± 17.6	34.3 ± 0.9	77.3	4.6 ± 0.5	0.047 ± 0.019	99

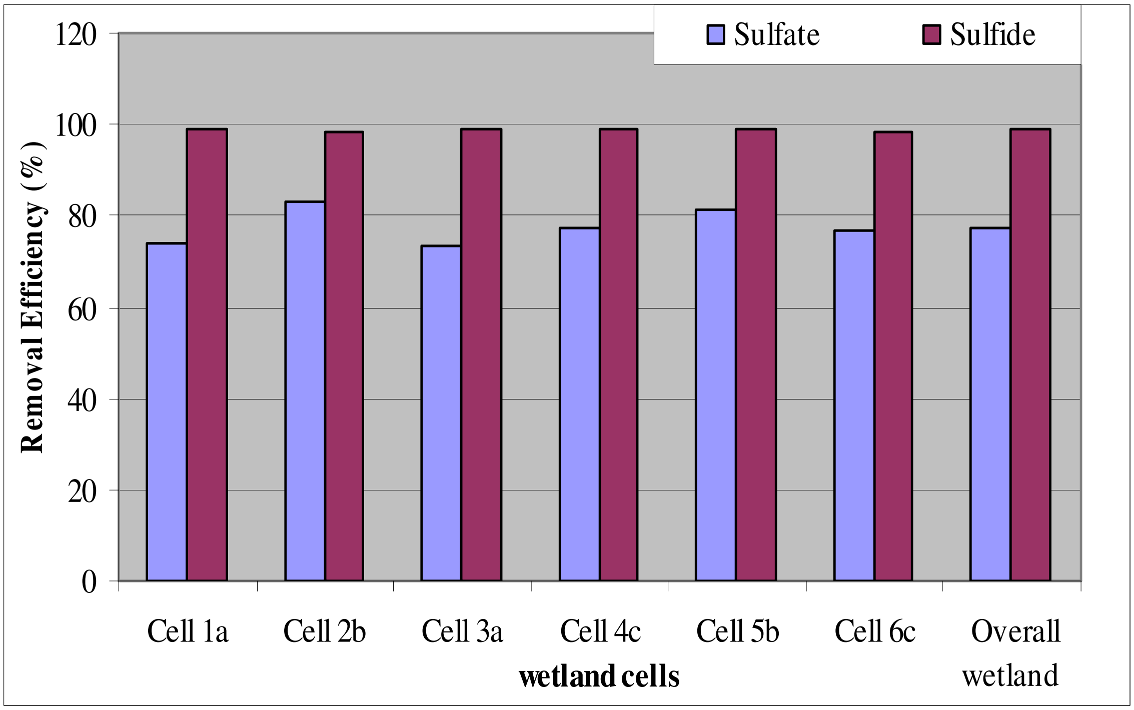

Figure 14: Sulfate and Sulfide Removal Efficiencies of JWBO CW

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[a] wetland cells planted with C. papyrus species
[b] wetland cells planted with C. alternifolia species
[c] wetland cells planted with P. canariensis species

Microorganisms found in constructed wetland systems preferably utilize electron acceptors that provide the highest energy yield. Oxygen provides the highest energy yield and will be utilized first. Once oxygen is depleted nitrate will be utilized as electron acceptor, if nitrate is depleted sulfate is the next in the sequence of electron acceptors. Therefore, this high removal efficiency of sulfate (77.3%) and sulfide (99%) in JWBO CW system might be due to the net anaerobic environment of the system (William and James, 1993).

This is because sulfate reduction can take place when sulfate reducing bacteria, which are obligate anaerobes utilize sulfate as terminal electron acceptor in anaerobic respiration (Aisling and Marinus, 2006). This reaction occurred as the microorganisms assimilate sulfate to sulfide through the transfer of electrons produced by the simultaneous oxidation of the organic compounds (Hsu, 1998; Aisling and Marinus, 2006) (Figure 5).

The ANOVA test result indicated that wetland cells planted with *C. alternifolia* (cell 2 and 5) showed higher removal efficiency for sulfate (82.2%) than wetland cells planted with other plant species. Similarly sulfide removal efficiency (99%) was higher in wetland cells planted with *P. canariensis* (cell 4 and 6) than others. However, this change was statistically significant ($p < 0.05$) only for sulfate (Annex II and III).

In constructed wetland system, sulfide is very unstable and readily reacts with free sorbet metal cations forming metal sulfides such as Zinc Sulfide (ZnS), Lead Sulfide (PbS), and Iron Sulfide (FeS). Additionally, it can also react with hydrogen, forming hydrogen sulfide and this will be evolved to the atmosphere as a gas (Morse *et al*., 1987; Rence, 2001). The effluent of JWBO constructed wetland has odor problem (the smell of rotten eggs) at the final disposal site, and this might be due to hydrogen sulfide produced through the above stated mechanisms in this wetland system. This unstable nature of sulfide makes the removal efficiency of JWBO CW very effective, which removes 99% of sulfide ion.

JWBO CW effluent concentration values of sulfate (34.3 ± 0.9mg/L) and sulfide (0.047 ± 0.019 mg/L) were compared with the provisional discharge limits values (1000.0 mg/L for sulfate and 1.0 mg/L for sulfide) set by National Environmental Quality Standard for domestic wastewater effluent (EEPA, 2003). The obtained effluent concentration values met the standard values, which showed the effectiveness of constructed wetlands in fulfilling the regulatory limit values to discharge the effluent in to surface and inland water bodies.

Table 5 shows the influent and effluent coliform concentrations of each wetland cells and the overall wetland of JWBO. The influent concentration was $6.0 \times 10^7 \pm 6.5 \times 10^5$ for TC and $4.9 \times 10^6 \pm 1.8 \times 10^6$ for FC. Figure 16 shows the removal efficiency of each wetland cells and the overall wetland system. Total Coliform removal efficiency of each wetland cells was: 94.2% (cell 1), 93.8% (cell 2), 94% (cell 3), 94.5% (cell 4), 93.8% (cell 5) and 94.8% (cell 6) while for FC it was 90.2%, 90.4%, 91%, 90.8%, 91% and 91.2%, respectively.

Based on the two month measurements performed from May 14 to July 14, 2007 the overall mean reduction in total and fecal coliforms were 94.5% and 93.1%, respectively with the mean effluent concentration values of $3.3 \times 10^6 \pm 1.1 \times 10^6$ TC and $3.4 \times 10^5 \pm 1.1 \times 10^5$ FC/100ml (Table 5 and Figure 15).

In similar works on CW treatment plants, Pucci *et al*. (2000) reported 99% TC and 99.7% FC removal. Where as Kathleen (2000) and Maria *et al*. (2001) obtained >90% TC removal efficiencies with constructed wetlands in their study areas. However, Kaseva (2003) obtained 43% - 72% TC and FC removal efficiency.

It is known that pathogen removal is more efficient in CW compared to traditional wastewater treatment methods. Fundamental scientific knowledge of the process of pathogen removal in CW is highly limited at present (Peter *et al*., 2005). The difference in performance between these constructed wetlands might be associated with the differences in the types of media and plant species used in the wetland systems (Gersberg *et al*., 1985; Kyambadde *et al*., 2004; Peter *et al*., 2005).

Table 5: Changes in TC and FC density (cfu/100ml) at JWBO CW

Wetland cells	Total Coliform			Fecal Coliform		
	Influent	Effluent	% removal	Influent	Effluent	% removal
Cell 1[a]	6.0×10^7	3.5×10^6	94.2	4.9×10^6	4.8×10^5	90.2
Cell 2[b]	6.0×10^7	3.7×10^6	93.8	4.9×10^6	4.7×10^5	90.4
Cell 3[a]	6.0×10^7	3.6×10^6	94,0	4.9×10^6	4.9×10^5	90
Cell 4[c]	6.0×10^7	3.3×10^6	94.5	4.9×10^6	4.5×10^5	90.8
Cell 5[b]	6.0×10^7	3.7×10^6	93.8	4.9×10^6	4.4×10^5	91.0
Cell 6[c]	6.0×10^7	3.1×10^6	94.8	4.9×10^6	4.3×10^5	91.2
Overall wetland performance	6.0×10^7	3.3×10^6	94.5	4.9×10^6	3.4×10^5	93.1

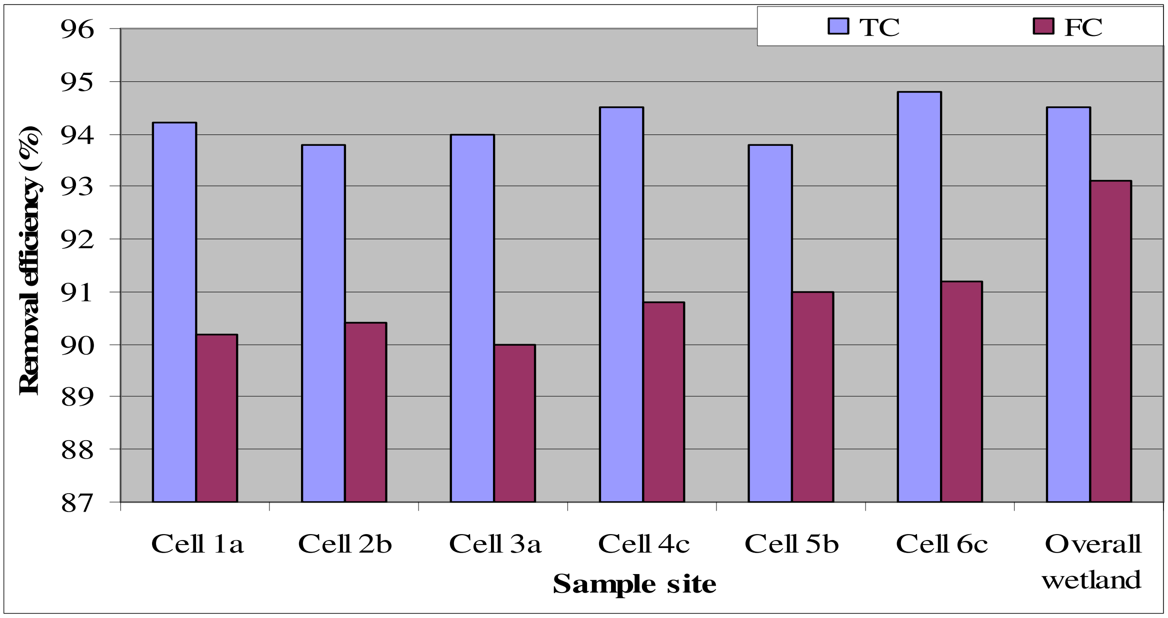

Figure 15: Total Coliform and Fecal Coliform Removal Efficiency of JWBO CW

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[a] wetland cells planted with C. papyrus species
[b] wetland cells planted with C. alternifolia species
[c] wetland cells planted with P. canariensis species

This decline in coliform bacteria concentration could be attributed to biotic and abiotic factors. The removal of coliform bacteria in wetlands is essentially a two stage process. Most microorganisms including coliform bacteria are organic particulates (Suresh and Bruce, 2003). The initial stage of coliform bacterial removal is therefore particle removal. This occurs via the same process in suspended solids: sedimentation, surface adhesion and aggregation (Rogers, 1983; Kyambadde, 2005). A serious of other processes that may occur both before and after coliform bacteria particles have been removed from the water column are important in influencing the viability of coliform bacteria.

The major processes in this category are: the hostility of the environmental conditions (temperature, salinity, and turbidity, reduction of organic matter content), predation and antibiosis (Shiaris, 1985; Faithful, 1996). The result of this study indicated that there was a statistically significant ($p< 0.05$), at the 0.01 level, correlation between coliform bacteria reduction with wastewater temperature and BOD_5 values of the final effluent with the calculated R value of -0.471 ($R^2 = 0.222$) and 0.683 ($R^2 = 0.467$), respectively.

The ANOVA test result indicated that wetland cells planted with *P. canariensis* (cell 4 and 6) showed higher removal efficiency for both TC (94.7%) and FC (91%) than wetland cells planted with other plant species. But this change was statistically significant ($p < 0.05$) only for FC (Annex II and III).

In subsurface flow constructed wetland the presence of wetland plants and gravel media can play a crucial role in increasing the efficiency and effectiveness of coliform bacteria removal. They improve the trapping efficiency for small particles by increasing the surface area of biofilms in the flow path. Small particles are trapped by surface adhesion on the biofilms (Gresberg *et al.*, 1989). Similarly the efficiency of coliform bacteria removal by sedimentation or enhanced sedimentation within planted subsurface areas is improved. The root zone of wetland plant is a highly active biological community supporting a range of metabolic processes

The performance efficiency results indicated that this wetland system has higher pathogen removal capability, though the mean final effluent concentration of TC was above the National Effluent Emission Standard limit values (400 cfu/100ml) set by Environmental

Protection Authority of Ethiopia. But as shown in Figure 16, the local people use the final effluent of JWBO wetland discharged into the nearby river for different purposes such as for body washing, vegetable production, animal fattening, and recreation.

The presence of coliform bacteria, (which in turn indicates the presence of pathogenic microorganisms) in wastewater effluent above the emission standard makes the receiving water unsuitable for direct contact recreational use and some times unsuitable for use as source of water for a public supply (Christone, 2004).

Direct using of the effluent for hand and face washing

Fetching the stream for household use and animal fattening

Figure 16: Pictures which show when local people using the effluent as well as the stream receiving the effluent from the treatment plant

However, one strong advantage of using constructed wetlands to treat wastewater over natural wetlands is that the final effluent can be easily chlorinated (Rence, 2001). In addition to fulfilling the National Emission Standards of the country, chlorine disinfection of constructed wetland effluent can produce waters suitable for unrestricted use (USEPA, 1998). For example a study conducted in Australia (Sinclair, 2000) showed that 30% of the constructed wetland in the country uses the effluent for irrigation of Golf courses, woodlots and parks.

Therefore, it is recommended that JWBO should chlorinate its effluent to fulfill the provisional discharge limits values set by the National Environmental Quality Standard for domestic wastewater effluent as well as to recycle the wastewater to use it for different purposes.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The need for improvement and conservation of the environment in Ethiopia is necessitating the provision of energy and cost effective secondary wastewater treatment facilities for small communities such as schools, hospitals, military camps, colleges, farms, industries, and universities where on-site wastewater disposal technology is predominant.

Constructed wetland system operates using natural processes and usually do not require substantial energy inputs. The biological processes are typically solar-driven as light and carbon sources (from the substrate) are used to derive the microbial and plant processes. Therefore constructed wetlands seem to be appropriate in Ethiopia since there is a year round suitable climatic condition for rapid biological growth, which influence the treatment process in wetlands. But in Ethiopia this technology has not yet been recognized as a treatment option for the wastewater management.

This result showed that the average percentage removal efficiency of JWBO wetland system was: 99.3% (BOD_5), 89% (COD), 85% (TSS), 28.1% (NH_4^+-N), 64% (NO_3-N), 61.5% (TN), 28% (orthophosphate), 22.7% (TP), 77.3% (Sulfate), 99% (Sulfide), 94.5% (TC) and 93.1% (FC). These showed that the treatment performance of JWBO CW was low for ammonium nitrogen, and phosphorus. This was mainly due to the low HRT of the wetland.

Treatment is necessary to correct wastewater characteristics in such away that the use of final disposal of the treated effluent can take place in accordance the rules set by the relevant legislative bodies without causing adverse impacts on receiving water bodies. The result showed that except ammonium nitrogen, coliform bacteria and orthophosphate, the other effluent concentration values were within the standard discharge limit values set by the National Environmental Quality Standard for domestic wastewater effluent (EEPA, 2003). This showed the effectiveness of constructed wetlands in fulfilling the regulatory limit values to discharge the effluent in to surface and inland water bodies.

Thought the difference was not as such high, the result of this study also showed that wetland cells planted with *Cyprus papyrus* (Cell 1 and 3) showed higher removal efficiency in NO_3-N (82.4%), NH_4^+-N (24.8%), TN (54.8%), PO_4^{3-}-P (23.5%), and TSS (83.9%) than the other wetland cells planted with the other two plant species. Similarly wetland cells planted with *Phoenix canariensis* (cell 4 and 6) showed higher removal efficiency in TP (17%), S^{2-} (99%), $BOD5_5$ (98%), COD (90%), TC (94%) and FC (91%).

While wetland cells planted with *Cyprus alternifolia* (cell 2 and 5) showed higher removal efficiency only for SO_4^{2-} (82.2%) than the other wetland cells. In addition to the treatment performance, the three wetland plant species planted at JWBO wetland helps to increase the aesthetic value of their campus, especially for their Conference Hall constructed near the wetland and their campus in general.

Generally, one can conclude that the treatment performance of JWBO wetland system was very encouraging in promoting the use of constructed wetlands as an alternative wastewater treatment system for protecting sensitive water bodies that receive partially treated or untreated effluents. In addition, for developing countries like Ethiopia, that have limited resources for the construction and operation of conventional treatment plants, constructed wetlands are the most economical solutions.

This study indicated the SSF wetlands treatment system can effectively treat wastewaters; fortunately the climatic condition of Ethiopia is favorable for the growth of different wetland plant species which enhance the removal efficiency of constructed wetland system. Therefore, for our country wetland plant species selection and management techniques that create the largest rhizosphere surface area per volume of bed and bed design (optimal depth, HRT, and media) should be explored further.

6.2 Recommendations

Based on the results of this case study and other research outputs done in other countries (with similar conditions) and in order to use this technology in our country as alternative wastewater treatment technology, the following points are recommended:-

- For effective wastewater treatment performance, constructed wetlands should consist of a minimum of two to three cells in serious and all the cells should be planted with different plant species within the system that will increase the root biomass.
- This case study indicated that constructed wetland treatment systems can effectively treat domestic wastewater. But different wetland plant species selection and management techniques that create the largest rhizosphere surface area per volume of bed and bed design (optimal depth, HRT and media type) should be explored with further research

- The significant phosphorus and nitrogen removal will require a long detention time in the wetland system. The longer the wastewater remains in the wetland, the greater the chance of sedimentation, biotic processing and retention of nitrogen and phosphorus nutrients. Consequently, the wetland should be designed according to the objective of the system (removal of nitrogen and phosphorus with more HRT).
- The effluent concentration values of ammonium and coliform bacteria were above the discharge limits set by National Environmental Quality Standard for domestic wastewater effluent. Then additional effluent treatment options such as liming, chlorination, combination of SSF with SF constructed wetland system are required.

- Despite suitable climatic conditions in Ethiopia, no efforts have been made to investigate the effectiveness of constructed wetlands to treat various types of wastewaters. So in the future a detailed research that incorporates all issues of wetland should be undertaken.

- In addition, an advocacy and awareness creation works should be done by concerned institutions in the country on the methods of wastewater treatment that are cheap and highly effective like constructed wetlands.

- Government regulations and legislations need to be enforced in order to ensure that polluters meet environmental standards of effluent discharge in to water bodies and natural wetlands found in different parts of the country.

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ANNEX I. Mean, Minimum and Maximum influent and effluent concentration values of JWBO CW

Table 1: Mean, Std. Error, Minimum and Maximum influent and effluent nitrate N, ammonium N and total N concentration values of JWBO CW

code of the cell		Nitrate -Nitrogen (No3 -N), mg/L	Ammonium ion (NH4+),mg/L	Total Nitrogen (TN), mg/L	Orthophosphate (PO4-P), mg/L	Total Phosphate (TP), mg/L
Influent	Mean	14.7000	38.6667	107.6733	8.0433	8.8733
	Std. Error of Mean	.85049	6.00481	.81407	.67716	.95016
	Minimum	13.10	30.00	106.42	6.80	7.13
	Maximum	16.00	50.20	109.20	9.13	10.40
cell 1	Mean	2.5667	27.1000	49.0233	5.8033	6.4667
	Std. Error of Mean	.03333	1.72143	4.80793	1.40286	1.31318
	Minimum	2.50	24.60	40.17	4.21	4.60
	Maximum	2.60	30.40	56.70	8.60	9.00
cell 2	Mean	3.1667	28.7000	47.6967	6.7833	7.7800
	Std. Error of Mean	.52387	1.57162	4.69050	.99596	.96423
	Minimum	2.50	25.60	38.60	5.05	6.10
	Maximum	4.20	30.70	54.23	8.50	9.44
cell 3	Mean	2.6333	29.0667	50.4700	6.2667	7.4667
	Std. Error of Mean	.44096	1.58360	5.45594	1.37760	1.29786
	Minimum	1.80	25.90	40.17	4.60	5.00
	Maximum	3.30	30.70	58.74	9.00	9.40
cell 4	Mean	2.8333	29.6667	44.2433	6.1600	7.0933
	Std. Error of Mean	.57831	1.58990	5.19199	1.22513	.95815
	Minimum	1.70	26.50	33.90	4.18	5.60
	Maximum	3.60	31.50	50.21	8.40	8.88
cell 5	Mean	3.3333	29.5667	49.0967	6.7000	7.6600
	Std. Error of Mean	.43716	1.73429	4.78874	1.24231	.95023
	Minimum	2.80	26.10	40.00	4.60	6.10
	Maximum	4.20	31.40	56.24	8.90	9.38
cell 6	Mean	2.8333	29.7667	46.2733	6.1667	7.4867
	Std. Error of Mean	.64893	1.80954	4.02542	1.53768	1.50936
	Minimum	1.60	26.30	38.60	3.90	4.50
	Maximum	3.80	32.40	52.22	9.10	9.36
Final effluent	Mean	5.1667	27.7667	41.4700	5.7867	6.8800
	Std. Error of Mean	.63596	2.06263	.69376	1.12761	1.17717
	Minimum	4.10	23.70	40.17	3.66	4.70
	Maximum	6.30	30.40	42.54	7.50	8.74
Total	Mean	4.6542	30.0375	54.4933	6.4637	7.4633
	Std. Error of Mean	.82521	1.05691	4.40850	.38842	.36898
	Minimum	1.60	23.70	33.90	3.66	4.50
	Maximum	16.00	50.20	109.20	9.13	10.40

Table 2: Mean, Std. Error, Minimum and Maximum influent and effluent sulfate, sulfide, TSS, BOD5 and COD concentration values of JWBO CW

code of the ce		Sulfate (SO42-), mg/L	Sulfide Ion (S2-), mg/L	Total Suspended Solid (TSS), mg/L	Biochemical Oxygen Demand (BOD), mg/L	Chemical Oxygen Demand (COD), mg/L
Influent	Mean	153.3333	4.5533	201.3333	273.3333	619.3333
	Std. Error of Mea	17.63834	.48015	6.69162	21.85813	187.25770
	Minimum	120.00	3.60	188.00	230.00	360.00
	Maximum	180.00	5.13	209.00	300.00	983.00
cell 1	Mean	39.6667	.0580	32.6667	6.3333	63.6667
	Std. Error of Mea	8.66667	.01856	11.40663	1.85592	14.49521
	Minimum	25.00	.04	15.00	4.00	36.00
	Maximum	55.00	.10	54.00	10.00	85.00
cell 2	Mean	26.3333	.0640	37.3333	7.3333	76.3333
	Std. Error of Mea	1.45297	.01604	10.17076	2.33333	17.64779
	Minimum	24.00	.05	21.00	5.00	47.00
	Maximum	29.00	.10	56.00	12.00	108.00
cell 3	Mean	41.0000	.0607	32.3333	5.3333	66.6667
	Std. Error of Mea	8.50490	.01676	12.03236	.88192	15.24613
	Minimum	28.00	.04	14.00	4.00	38.00
	Maximum	57.00	.09	55.00	7.00	90.00
cell 4	Mean	34.6667	.0557	33.0000	6.0000	63.3333
	Std. Error of Mea	1.45297	.02080	7.23418	2.64575	11.20020
	Minimum	32.00	.03	21.00	2.00	41.00
	Maximum	37.00	.10	46.00	11.00	76.00
cell 5	Mean	28.3333	.0593	34.0000	5.0000	80.3333
	Std. Error of Mea	3.17980	.01087	7.23418	.57735	20.53723
	Minimum	23.00	.05	22.00	4.00	49.00
	Maximum	34.00	.08	47.00	6.00	119.00
cell 6	Mean	35.6667	.0737	34.6667	4.3333	65.0000
	Std. Error of Mea	2.33333	.01317	7.51295	.88192	11.53256
	Minimum	32.00	.06	22.00	3.00	42.00
	Maximum	40.00	.10	48.00	6.00	78.00
Final effluent	Mean	34.3333	.0467	30.3333	2.0000	68.0000
	Std. Error of Mea	.88192	.01934	10.47749	.57735	11.71893
	Minimum	33.00	.02	17.00	1.00	46.00
	Maximum	36.00	.08	51.00	3.00	86.00
Total	Mean	49.1667	.6214	54.4583	38.7083	137.8333
	Std. Error of Mea	8.57631	.31393	11.90329	18.63877	42.89153
	Minimum	23.00	.02	14.00	1.00	36.00
	Maximum	180.00	5.13	209.00	300.00	983.00

Table 3: Mean, Std. Error, Minimum and Maximum influent and effluent TC, FC concentration Temperature and PH values of JWBO CW

code of the cell		Total Coliform (TC), CFU/100ml	Fecal coliform (FC), CFU/100ml	Wastewater Temperature, 0C	Wastewater pH, pH unit
Influent	Mean	60000000.00	4866666.6667	25.8000	7.1000
	Minimum	53000000.00	2600000.00	25.40	6.83
	Maximum	73000000.00	8500000.00	26.40	7.64
	Std. Error of Mean	6506407.099	1835150.614	.30551	.27000
cell 1	Mean	3500000.0000	480000.0000	23.7333	6.9767
	Minimum	3400000.00	470000.00	23.00	6.75
	Maximum	3600000.00	490000.00	24.70	7.10
	Std. Error of Mean	57735.02692	5773.50269	.50442	.11348
cell 2	Mean	3700000.0000	470000.0000	23.8333	6.9533
	Minimum	2800000.00	460000.00	23.80	6.58
	Maximum	4200000.00	480000.00	23.90	7.58
	Std. Error of Mean	450924.97528	5773.50269	.03333	.31524
cell 3	Mean	3566666.6667	490000.0000	23.3000	6.9700
	Minimum	2500000.00	480000.00	22.20	6.79
	Maximum	4700000.00	500000.00	23.90	7.08
	Std. Error of Mean	635959.46761	5773.50269	.55076	.09074
cell 4	Mean	3300000.0000	450000.0000	23.5333	7.2567
	Minimum	2300000.00	440000.00	22.30	7.22
	Maximum	4000000.00	460000.00	24.30	7.33
	Std. Error of Mean	513160.14394	5773.50269	.62272	.03667
cell 5	Mean	3733333.3333	440000.0000	23.5333	7.0067
	Minimum	3000000.00	430000.00	22.90	6.86
	Maximum	4400000.00	450000.00	24.10	7.09
	Std. Error of Mean	405517.50202	5773.50269	.34801	.07356
cell 6	Mean	3100000.0000	430000.0000	23.5667	7.0467
	Minimum	3000000.00	420000.00	22.30	7.00
	Maximum	3200000.00	440000.00	24.20	7.07
	Std. Error of Mean	57735.02692	5773.50269	.63333	.02333
Final effluent	Mean	3300000.0000	340000.0000	23.4000	7.1767
	Minimum	2000000.00	210000.00	22.60	7.15
	Maximum	5500000.00	560000.00	24.80	7.19
	Std. Error of Mean	1106044.002	110604.40015	.70238	.01333
Total	Mean	10525000.00	995833.3333	23.8375	7.0608
	Minimum	2000000.00	210000.00	22.20	6.58
	Maximum	73000000.00	8500000.00	26.40	7.64
	Std. Error of Mean	3961075.328	360399.79646	.21760	.05134

ANNEX II: The Mean Influent and Effluent Concentration values and the Removal Efficiency of Wetland Cells Plant with three Different wetland plants

Table 4: The mean influent and effluent concentrations (mg/L) along with the mean removal efficiency of wetland cells planted with *C. papyrus, C. alternifolia* and *P. canariensis* plant species at JWBO CW

wastewater parameters	*Cyprus papyrus*[a]			*Cyprus alternifolia*[b]			*Phoenix canariensis*[c]		
	Influent	Effluent	% removal	Influent	Effluent	% removal	Influent	Effluent	% removal
NO_3^- - N	14.7	2.6	82.4	14.7	3.2	78	14.7	2.8	81
NH_4^+ - N	38.7	29.1	24.8	38.7	29.2	24.7	38.7	29.8	23
TN	107.7	54.8	49.1	107.7	55.4	48.6	107.7	55.8	48
PO_4^{3-} - P	8.04	6.2	23.5	8.04	6.8	16.2	8.04	6.2	23
TP	8.9	7.5	16.5	8.9	7.8	13.3	8.9	7.5	17
SO_4^{2-}	153.3	40.4	73.7	153.3	27.3	82.2	153.3	35.2	77
S^{2-}	4.6	0.059	98.7	4.6	0.062	98.7	4.6	0.065	99
TSS	201.3	32.6	83.9	201.3	35.7	82.3	201.3	33.9	83
BOD_5	273.3	5.8	97.9	273.3	6.2	97.8	273.3	5.7	98
COD	619.3	65.17	89.5	619.3	78.33	87.4	619.3	64.17	90
TC, cfu/100ml	6.0 x 10^7	3.7 x 10^6	93.9	6.0 x 10^7	3.9 x 10^6	93.6	6.0 x 10^7	3.9 x 10^6	94
FC, cfu/100ml	4.9 x 10^6	4.7 x 10^5	90.4	4.9 x 10^6	4.7 x 105	90.4	4.9 x 10^6	4.6 x 10^5	91

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[a] cell 1 and 3

[b] cell 2 and 5

[c] cell 4 and 5

ANNEX III: ANOVA Results of Wetland Cells Planted with three Plant Species for each Parameters

		Sum of Squares	df	Mean Square	F	Sig.
Nitrate -Nitrogen (No3 -N), mg/L	Between Groups	1.301	2	.651	1.142	.346
	Within Groups	8.548	15	.570		
	Total	9.849	17			
Ammonium ion (NH4+),mg/L	Between Groups	8.221	2	4.111	.574	.575
	Within Groups	107.450	15	7.163		
	Total	115.671	17			
Total Nitrogen (TN), mg/L	Between Groups	63.634	2	31.817	.556	.585
	Within Groups	858.123	15	57.208		
	Total	921.757	17			

LSD

						95% Confidence Interval	
Dependent Variable	(I) types of plant species	(J) types of plant species	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Nitrate -Nitrogen (No3 -N), mg/L	papyrus	alternifolia	-.6500	.43585	.157	-1.5790	.2790
		Phoenix canariensis	-.2333	.43585	.600	-1.1623	.6957
	alternifolia	papyrus	.6500	.43585	.157	-.2790	1.5790
		Phoenix canariensis	.4167	.43585	.354	-.5123	1.3457
	Phoenix canariensis	papyrus	.2333	.43585	.600	-.6957	1.1623
		alternifolia	-.4167	.43585	.354	-1.3457	.5123
Ammonium ion (NH4+),mg/L	papyrus	alternifolia	-1.0500	1.54524	.507	-4.3436	2.2436
		Phoenix canariensis	-1.6333	1.54524	.307	-4.9269	1.6603
	alternifolia	papyrus	1.0500	1.54524	.507	-2.2436	4.3436
		Phoenix canariensis	-.5833	1.54524	.711	-3.8769	2.7103
	Phoenix canariensis	papyrus	1.6333	1.54524	.307	-1.6603	4.9269
		alternifolia	.5833	1.54524	.711	-2.7103	3.8769
Total Nitrogen (TN), mg/L	papyrus	alternifolia	1.3500	4.36685	.761	-7.9577	10.6577
		Phoenix canariensis	4.4883	4.36685	.320	-4.8194	13.7961
	alternifolia	papyrus	-1.3500	4.36685	.761	-10.6577	7.9577
		Phoenix canariensis	3.1383	4.36685	.483	-6.1694	12.4461
	Phoenix canariensis	papyrus	-4.4883	4.36685	.320	-13.7961	4.8194
		alternifolia	-3.1383	4.36685	.483	-12.4461	6.1694

		Sum of Squares	df	Mean Square	F	Sig.
Total Suspended Solid (TSS), mg/L	Between Groups	30.333	2	15.167	.070	.933
	Within Groups	3257.667	15	217.178		
	Total	3288.000	17			
Biochemical Oxygen Demand (BOD), mg/L	Between Groups	3.111	2	1.556	.194	.826
	Within Groups	120.500	15	8.033		
	Total	123.611	17			
Chemical Oxygen Demand (COD), mg/L	Between Groups	750.111	2	375.056	.651	.536
	Within Groups	8647.000	15	576.467		
	Total	9397.111	17			

LSD

Dependent Variable	(I) types of plant species	(J) types of plant species	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Total Suspended Solid (TSS), mg/L	papyrus	alternifolia	-3.1667	8.50838	.715	-21.3019	14.9685
		Phoenix canariensis	-1.3333	8.50838	.878	-19.4685	16.8019
	alternifolia	papyrus	3.1667	8.50838	.715	-14.9685	21.3019
		Phoenix canariensis	1.8333	8.50838	.832	-16.3019	19.9685
	Phoenix canariensis	papyrus	1.3333	8.50838	.878	-16.8019	19.4685
		alternifolia	-1.8333	8.50838	.832	-19.9685	16.3019
Biochemical Oxygen Demand (BOD), mg/L	papyrus	alternifolia	-.3333	1.63639	.841	-3.8212	3.1546
		Phoenix canariensis	.6667	1.63639	.689	-2.8212	4.1546
	alternifolia	papyrus	.3333	1.63639	.841	-3.1546	3.8212
		Phoenix canariensis	1.0000	1.63639	.550	-2.4879	4.4879
	Phoenix canariensis	papyrus	-.6667	1.63639	.689	-4.1546	2.8212
		alternifolia	-1.0000	1.63639	.550	-4.4879	2.4879
Chemical Oxygen Demand (COD), mg/L	papyrus	alternifolia	-13.1667	13.86202	.357	-42.7129	16.3795
		Phoenix canariensis	1.0000	13.86202	.943	-28.5462	30.5462
	alternifolia	papyrus	13.1667	13.86202	.357	-16.3795	42.7129
		Phoenix canariensis	14.1667	13.86202	.323	-15.3795	43.7129
	Phoenix canariensis	papyrus	-1.0000	13.86202	.943	-30.5462	28.5462
		alternifolia	-14.1667	13.86202	.323	-43.7129	15.3795

LSD

Dependent Variable	(I) types of plant species	(J) types of plant species	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Orthophosphate (PO4-P), mg/L	papyrus	alternifolia	-.7067	1.17314	.556	-3.2071	1.7938
		Phoenix canariensis	-.1283	1.17314	.914	-2.6288	2.3721
	alternifolia	papyrus	.7067	1.17314	.556	-1.7938	3.2071
		Phoenix canariensis	.5783	1.17314	.629	-1.9221	3.0788
	Phoenix canariensis	papyrus	.1283	1.17314	.914	-2.3721	2.6288
		alternifolia	-.5783	1.17314	.629	-3.0788	1.9221
Total Phosphate (TP), mg/L	papyrus	alternifolia	-.7533	1.07889	.496	-3.0529	1.5463
		Phoenix canariensis	-.3233	1.07889	.769	-2.6229	1.9763
	alternifolia	papyrus	.7533	1.07889	.496	-1.5463	3.0529
		Phoenix canariensis	.4300	1.07889	.696	-1.8696	2.7296
	Phoenix canariensis	papyrus	.3233	1.07889	.769	-1.9763	2.6229
		alternifolia	-.4300	1.07889	.696	-2.7296	1.8696
Sulfate (SO42-), mg/L	papyrus	alternifolia	13.0000*	4.74576	.015	2.8847	23.1153
		Phoenix canariensis	5.1667	4.74576	.293	-4.9487	15.2820
	alternifolia	papyrus	-13.0000*	4.74576	.015	-23.1153	-2.8847
		Phoenix canariensis	-7.8333	4.74576	.120	-17.9487	2.2820
	Phoenix canariensis	papyrus	-5.1667	4.74576	.293	-15.2820	4.9487
		alternifolia	7.8333	4.74576	.120	-2.2820	17.9487
Sulfide Ion (S2-), mg/L	papyrus	alternifolia	-.0023	.01503	.879	-.0344	.0297
		Phoenix canariensis	-.0053	.01503	.728	-.0374	.0267
	alternifolia	papyrus	.0023	.01503	.879	-.0297	.0344
		Phoenix canariensis	-.0030	.01503	.844	-.0350	.0290
	Phoenix canariensis	papyrus	.0053	.01503	.728	-.0267	.0374
		alternifolia	.0030	.01503	.844	-.0290	.0350

*. The mean difference is significant at the .05 level.

		Sum of Squares	df	Mean Square	F	Sig.
Orthophosphate (PO4-P), mg/L	Between Groups	1.701	2	.850	.206	.816
	Within Groups	61.931	15	4.129		
	Total	63.632	17			
Total Phosphate (TP), mg/L	Between Groups	1.714	2	.857	.245	.785
	Within Groups	52.380	15	3.492		
	Total	54.094	17			
Sulfate (SO42-), mg/L	Between Groups	514.111	2	257.056	3.804	.046
	Within Groups	1013.500	15	67.567		
	Total	1527.611	17			
Sulfide Ion (S2-), mg/L	Between Groups	.000	2	.000	.063	.939
	Within Groups	.010	15	.001		
	Total	.010	17			

		Sum of Squares	df	Mean Square	F	Sig.
Total Coliform (TC), CFU/100ml	Between Groups	8.23E+11	2	4.117E+11	.977	.399
	Within Groups	6.32E+12	15	4.214E+11		
	Total	7.15E+12	17			
Fecal coliform (FC), CFU/100ml	Between Groups	6.30E+09	2	3150000000	14.318	.000
	Within Groups	3.30E+09	15	220000000.0		
	Total	9.60E+09	17			
Wastewater Temperature, 0C	Between Groups	.093	2	.047	.076	.927
	Within Groups	9.232	15	.615		
	Total	9.325	17			
Wastewater pH, pH unit	Between Groups	.123	2	.061	1.099	.359
	Within Groups	.837	15	.056		
	Total	.960	17			

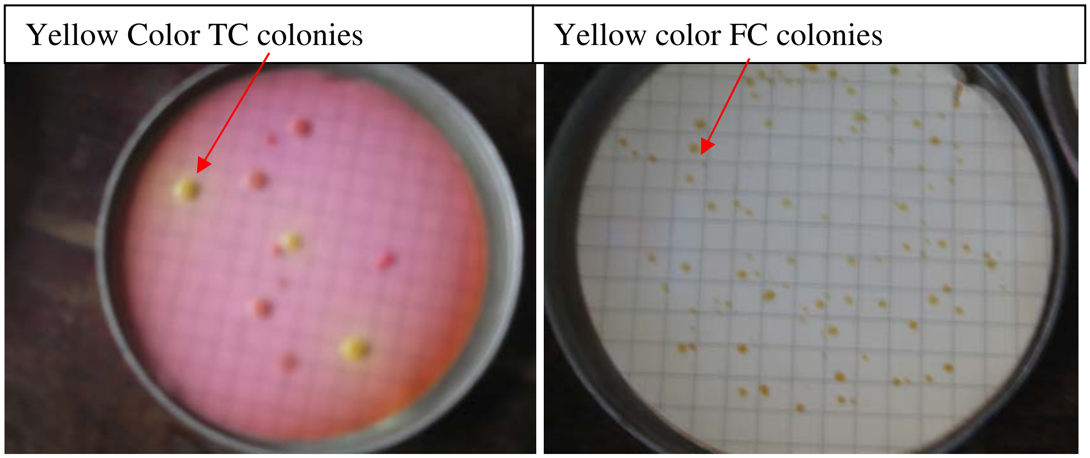
LSD

Dependent Variable	(I) types of plant species	(J) types of plant species	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Total Coliform (TC), CFU/100ml	papyrus	alternifolia	-183333.33	374808.6	.632	-982218.9388	615552.2722
		Phoenix canariensis	333333.33	374808.6	.388	-465552.2722	1132218.939
	alternifolia	papyrus	183333.33	374808.6	.632	-615552.2722	982218.9388
		Phoenix canariensis	516666.67	374808.6	.188	-282218.9388	1315552.272
	Phoenix canariensis	papyrus	-333333.33	374808.6	.388	-1132218.94	465552.2722
		alternifolia	-516666.67	374808.6	.188	-1315552.27	282218.9388
Fecal coliform (FC), CFU/100ml	papyrus	alternifolia	30000.0000*	8563.488	.003	11747.3566	48252.6434
		Phoenix canariensis	45000.0000*	8563.488	.000	26747.3566	63252.6434
	alternifolia	papyrus	-30000.000*	8563.488	.003	-48252.6434	-11747.3566
		Phoenix canariensis	15000.0000	8563.488	.100	-3252.6434	33252.6434
	Phoenix canariensis	papyrus	-45000.000*	8563.488	.000	-63252.6434	-26747.3566
		alternifolia	-15000.000	8563.488	.100	-33252.6434	3252.6434
Wastewater Temperature, 0C	papyrus	alternifolia	-.1667	.45293	.718	-1.1321	.7987
		Phoenix canariensis	-.0333	.45293	.942	-.9987	.9321
	alternifolia	papyrus	.1667	.45293	.718	-.7987	1.1321
		Phoenix canariensis	.1333	.45293	.773	-.8321	1.0987
	Phoenix canariensis	papyrus	.0333	.45293	.942	-.9321	.9987
		alternifolia	-.1333	.45293	.773	-1.0987	.8321
Wastewater pH, pH unit	papyrus	alternifolia	-.0067	.13640	.962	-.2974	.2841
		Phoenix canariensis	-.1783	.13640	.211	-.4691	.1124
	alternifolia	papyrus	.0067	.13640	.962	-.2841	.2974
		Phoenix canariensis	-.1717	.13640	.227	-.4624	.1191
	Phoenix canariensis	papyrus	.1783	.13640	.211	-.1124	.4691
		alternifolia	.1717	.13640	.227	-.1191	.4624

*. The mean difference is significant at the .05 level.

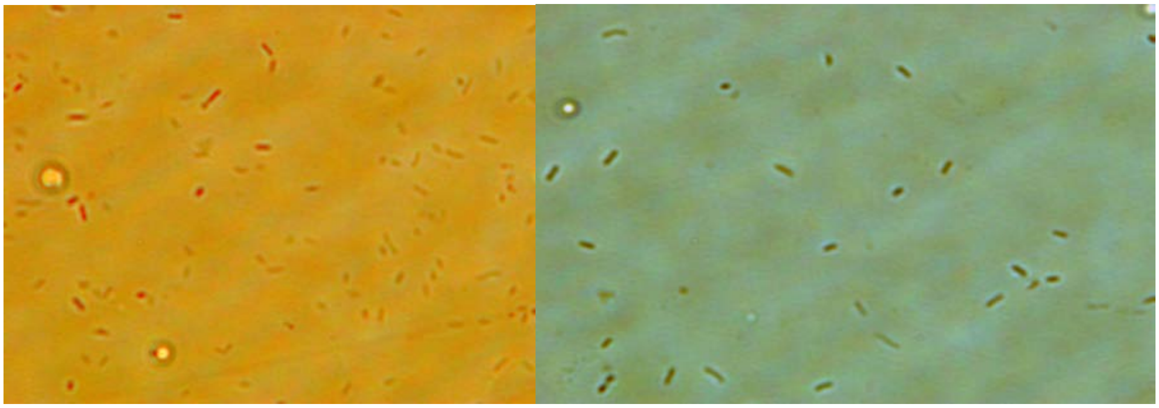
ANNEX IV: Pictures of Coliform Bacteria, Economical values of wetland plants and impacts of Wastewater on natural wetlands of CRV in Ethiopia.

1. Coliform Bacteria Pictures



A. TC Colony Picture of cell 1 effluent **B. FC colony Picture of Cell 1 effluent**

Figure 1: Indicator Bacteria; TC and FC colonies obtained at cell 1 effluent with 10^5 & 10^3 dilutions respectively.



A. TC bacteria of cell 1 effluent B. FC bacteria of Cell 1 effluent

Figure 2: TC and FC bacteria seen with Fluorescent Microscope

2. Pictures which show some of the economical values of wetland plants in Ethiopia

C. papyrus flower for selling at Bahir-Dar

C. papyrus for fishing at Bahir-Dar

Different materials made from *C. papyrus* Bahir-Dar

C. papyrus collected for use, Bahir-Dar

P. canariensis for city decoration, Bahir-Dar

3. Picture of deferent wetland plants in natural wetlands of Ethiopia

C. papyrus, Lake Tana, Bahir-Dar

P. canariensis, Finote-Selam, western Gojjam

C. alternifolia, Lake Awassa

C. alternifolia, lake Zeway

C. alternifolia, Deber-zeyet

4. Pictures which show the impact of wastewater for natural wetland in CRV

Surface runoff from flower Farm, Lake Zeway

Tanney effluent, Chefee Meda, Tekure weha, Awassa

Flower farm effluent, lake Zeway

Declaration

I, the undersigned, declare that this thesis is my original work, it has never been submitted in other university, college or institutions, seeking for similar degree or other purposes. All sources of materials used for thesis have been duly acknowledged

Name: Birhanu Gent Fenta

Signature: _______________

Date: ________________