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# ANALYSIS OF CYPRUS PAPYRUS WASTEWATER TREATMENT EFFICIENCY IN GLASS FIBER CONSTRUCTED WETLAND UNDER DIFFERENT DENSITY IN BAHIR DAR CITY, ETHIOPIA

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# BAHIR DAR UNIVERSITY
# COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

## GRADUATE PROGRAM

### TITLE

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**MSc Thesis**

**By:**

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**MSc Thesis**

**By:**


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A thesis submitted to College of Agriculture and Environmental sciences graduate program in partial fulfillment to the requirements for the degree of Master of Science (MSc.) in “ENVIRONMENT AND CLIMATE CHANGE”

November, 2020

Bahir Dar, Ethiopia

## THESIS APPROVAL SHEET

As member of the Board of Examiners of the Master of Sciences (M.Sc) thesis open defense examination, we have read and evaluated this thesis prepared by Mr. **Abere Amogn Demeke** entitled "**Analysis of *Cyprus papyrus* wastewater treatment efficiency in glass fiber constructed wetland under different density**". We hereby certify that, the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Science (M.Sc) in **Environment and Climate Change**.

Board of Examiners

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# DECLARATION

I, Abere Amogn Demeke, hereby declare that this thesis entitled "**Analysis of *Cyprus papyrus* wastewater treatment efficiency in glass fiber constructed wetland under different density**" submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in "**Environment and Climate Change**" to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by **Mr. Abere Amogn Demeke** ID. No.BDU1100808. is the original work done by me under the supervision of **Dr. Ayalew Wondie, Dr. Derege Tsegaye** and **Ms. Abrehet Kahassaye** this thesis had not been published or submitted elsewhere for the requirement of a degree program to the best of my knowledge and belief.

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# DEDICATION

Dedication to my father Amogn Demeke, Father you are the main reason for being what am I.

# LIST OF ABBREVIATIONS /ACRONYMS

| | |
|---|---|
| AGB | Above ground biomass |
| APHA | American Public Health Association |
| BGB | Below ground biomass |
| BOD | Biochemical oxygen demand |
| COD | Chemical oxygen demand |
| CSA | Central statistical agency |
| CW | Constructed wetland |
| EC | Electrical conductivity |
| EEPA | Ethiopian Environmental protection Authority |
| EPA | Environmental Protection Authority |
| NTU | Nephelometric Turbidity unit |
| OC | Organic carbon |
| TDS | Total dissolved solid |
| TN | Total nitrogen |
| TP | Total phosphorus |
| TRP | Total reactive phosphors |
| TSS | Total suspended solid |
| UNDP | United nation development program |
| USEPA | United States Environmental Protection Agency |
| WHO | World health organization |
| WWTP | Waste water treatment plant |
| µs/cm | micro/ millisiemens per centimeter |

# *ABSTRACT*

*Unsafe industrial and domestic waste disposal causes surface water contamination and different health problems in many developing countries like Ethiopia. To tackle the pollution problem research based mitigation method is highly needed. Therefore, this study was aimed to analysis Cyprus papyrus wastewater treatment efficiency in glass fiber constructed wetlands under different density. Total* 12 *glass fiber wetlands were constructed with dimensions of 1.5m length, 1.5m width and 0.8m depth. Four treatments unplanted (control), planted with low (61), medium (84) and high (125) density of Cyprus papyrus with three replication were used under the same gravel and sand substrate. The data were analyzed using SPSS version 20. The treatment beds were irrigated with wastewater sourced from Bahardar city administration. The result showed that the average above ground dry biomass of Cyprus papyrus in low, mid and high density treatment beds were 9.0ton/ha, 12.27ton/ha and 15.82ton/ha in 14 weeks growing period respectively. Except temprature, the analysis of variance showed a significant difference at ($p<0.01$) among the treatments. The removal efficiency of high density Cyprus papyrus BOD, TSS, TDS, turbidity, TA, SC, $PO_4^{3-}$, $NO_3^-$ and ammonia were 68.4%, 63.7%, 19.9%, 83.5%, 34.2%, 36.2%, 75.6%, 21.2% and 88.5%, respectively during five days duration of wastewater in the glass fiber constructed wetland had significant difference at 0.01. And also the removal efficacy of heavy metals Cu, Cr, and Zn were 66%, 45.8%, and 66.1% respectively in effluent from high density Cyprus papyrus had significant difference at 0.01. Density of plant directly proportional to pH and DO and inversely proportional to other parameters whereas, temperature was found under oscillation relationship. Thus, Cyprus papyrus reduced substantially the concentrations of most physicochemical parameters and heavy metals. Finally, wastewater treatment by using Cyprus papyrus could be encouraged in Ethiopia.*



***Keywords****: wastewater, Cyprus papyrus, constructed wetland, nutrients and heavy metals*

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# Chapter 1. INTRODUCTION

## 1.1 Background and justification

Wastewater is any water that has been adversely affected in quality by anthropogenic influence (Abdel *et al.,* 2010). The day to day activities of man is mainly water dependent and therefore discharge 'waste' into water. Some of the substances include body wastes (faeces and urine), hair shampoo, hair, food scraps, fat, laundry powder, fabric conditioners, toilet paper, chemicals, detergent, household cleaners, dirt, micro-organisms (germs) which can make people ill and damage the environment ( Amoatey and Bani, 2011). In the most common usage, it refers to the municipal wastewater that contains a broad spectrum of contaminants resulting from the mixing of wastewaters from different sources. Currently used traditional treatment options like activated sludge, most often, do not provide adequate treatment as they completely fail to eradicate pathogenic organisms from wastewater (Ibrahim *et al*., 2020). The seventh goal of the declaration means to ensure environmental sustainability, and reverse the loss of environmental resources, where wetlands are one. In recent years, constructed wetlands are considered the best choice for the tertiary treatment of wastewater due to their low operating costs, low investment, little maintenance needs, and low energy requirements (Wu *et al*., 2015). Wetlands provide an essential habitat for many plants and animals, but can also serve as detention basins for storm water flows. Many wetlands receive and reduce nutrients and pollutants and as a result they are sometimes described as "the kidneys of the landscape" (Mitsch and Gosselink, 2007).

Along with the increased population comes an establishment of industries and release their untreated effluents to the river network and lakes (Hamere Yohannes* and Eyasu Elias, 2017). In Bahir Dar City sixty-four percent of the respondents discharge their wastewater in to the streets and open fields and the inadequacy of sanitation services resulted in defecating in open fields and discharging of raw wastewater into inappropriate places and these, in turn, have created serious environmental problems (Fesseha Hailu, 2012). Farms are irrigated with water from the lake and river waters that are heavily contaminated by waste disposal from different sides of the cities. With the increase in the urban population and industrialization, these water sources have now become further contaminated with various pollutants, among which are heavy metals (Mekonnen Getahun & Yihenew G. Selassie, 2013). However, gradual availability and uptake of heavy metals by plants is of major concern as it may enter to humans through food web (FAO, 2006). To evaluate causes and impacts on river water quality and to develop mitigation strategies, monitoring of pollutants is needed (Aymer Awoke *et al.*, 2016). To establish sustainable conditions in the surface water and reduce human health risks, addressing the pollution problem and start mitigation processes is highly needed. Environmental studies as well as establishment of management systems are necessary (Eriksson & Sigvant, 2019).

Constructed wetlands are among the recently proven efficient technologies for wastewater treatment. Compared to conventional treatment systems, constructed wetlands are low cost, easily operated and maintained, and have a strong potential for application in developing countries, particularly by small rural communities. However, these systems have not found widespread use, due to lack of awareness, and local expertise in developing the technology on a local basis (Kivaisi, 2001). Based on Wu *et al.* (2016) Constructed wetland (CW) is a system engineered for treating wastewaters by using plants, soil and microorganisms, to improve the water quality and is an effective treatment system alternative where suitable land is available at low cost. Several advantages can also be obtained from the use of CW for wastewater treatments; for examples, removal of both inorganic and organic matter, use minimal energy input, etc (perbangkhem & polprasert, 2010) Constructed wetlands were initially developed about 40 years ago in Europe and North America to exploit and improve the biodegradation ability of plants.

*Cyprus papyrus* (papyrus) is a large herbaceous sedge commonly found in waterlogged environments in the African tropics. Such wetland ecosystems provide ecological and socio-economic services related to the harvesting of aerial biomass, wastewater treatment, hydrological functions and climate modification (Güereña *et al*., 2015). The Eco hydrology concept of mutual regulation (Harper *et al*., 2016) explains how nutrient availability in swamps is determined by the presence of emergent macrophytes themselves. Papyrus is able to dominate the riparian fringe of tropical swamps, where continuous growth conditions naturally lead to intense biotic interactions and steep competition. Papyrus can have very high C: N: P ratio (Boar, 2006) in comparison to temperate wetland plants; a characteristic that provides an indication of its high nutrient efficiency and during processing, organic substances present in wastewater and undergo a process of oxidation of organic or inorganic compounds in the form of ions such as $NO_3$-, $NH_4^+$ and so can be absorbed by Papyrus.

According to Harper *et al*. (2016) In Papyrus occur on several processes, namely: Phytoacumulation (phytoextraction) is a process in which Papyrus interesting substance that accumulates contaminants from media around the roots of plants, this process is also called hyperacumulation, Rhizofiltration (rhizo = root) is the adsorption or deposition of substances in wastewater out by the roots to attach to the roots of Papyrus, Phytostabilization the attachment of a particular contaminant substances in the roots of Papyrus may not be absorbed into the plant stem. Due to this at present an attention has been directed towards the capacity of papyrus to control water pollution and to treat wastewater (Azza *et al.*, 2000). Wetlands are found in different parts of the world including in Ethiopia, even though an exhaustive inventory of wetlands is not done yet, wetlands are estimated to cover about 2% of the country's land coverage (Afework Hailu, 2005). Despite their small area coverage, wetlands in Ethiopia are among the most productive ecosystems, and have immense economic, social, and environmental benefits. The importance of our wetlands goes beyond their status as habitat of many endangered plant and animal species but they are a vital element of national and global ecosystems and economies.

### 1.2 Statement of the problem

Unsafe industrial and domestic waste disposal causes surface water contamination in many developing countries like Ethiopia. This is particularly true towns and the rural hinterland villages downstream of cities that are dependent on rivers passing through an industrialized area like Bahir Dar City and soundings. Especially discharge of untreated industrial waste is a major problem for many communities dwelling near rivers basins through causing different health problems (Arega Shumetie and Molla Alemayehu, 2014). Human beings pollute the environment with their industrial and domestic wastes, in Bahir Dar city there is no conventional municipal wastewater collection and treatment system (Fesseha Hailu, 2012). In addition to this *Cyprus papyrus* has been adversely affected by degradation through over-utilization of its resources. This had led to decrease in the Lake Tana and river Abay surrounding wetlands covered by papyrus there for harvesting of papyrus without conservation measures in place may endanger.

Many wetlands receive and reduce nutrients and pollutants, as a result they are sometimes described as “the kidneys of the landscape” and as “biological supermarkets” because of the extensive food webs and rich biodiversity they support (Mitsch and Gosselink, 2007). Excessive nutrient enrichment is one of the most serious threats to wetland ecosystems. Several conventional methods are available for treatment of wastewater. However, most of them are costly and not economically feasible and environmentally sound due to their secondary environmental impact. The ability of native aquatic plants (macrophytes) to assist the breakdown of human and animal derived wastewater, remove disease-causing microorganisms and pollutants has only recently been scientifically investigated (Hunt *et al*., 2009). Wastewater treatment using natural plants (*Cyprus papyrus*) has been considered the most environmentally friendly method. In addition to the above reason to select *Cyprus papyrus* for wastewater treatment it is also native in Ethiopia and is not invasive species.

Many researchers such as Azza et al., (2000), Yalcuk, A., & Ugurlu, A. (2009), Dewedar et al., (2006), Yezbie Kassa and Seyoum Mengistou. (2014), Andualem Mekonnen et al., (2015), Calheiros et al., (2014), Yadav *et al*., (2018), Theophile *et al*., 2011, Hamad *et al*., (2020) Studied wastewater treatment efficiency and growth of aquatic macrophyte species (*Cyprus papyrus*) etc., under constructed wetlands. However they lack of consider plant density, constructed wetlands from cement and metals which react with wastewater (change property of water) and also without replication of the treatment beds. Even some researchers taken sample directly from the lake in the papyrus side as treated and no papyrus side as a control and conclude with analysis few parameters. Cyprus papyrus planted in the surrounding of few wastewater disposal of the study area like Bahir Dar University but they did not done laboratory analysis. Untreated wastewater disposal water scarcity and problem of wastewater reuse, wetland degradation surrounding Lake Tana and river Abay is visible problem in the study area. Therefore construction and restoration of wetland, determination of plant density and study wastewater treatment potential of *Cyprus papyrus* helps to propose solutions. Hence this research was intended to fill the research gap on wastewater treatment potential *of Cyprus papyrus under different density* with in glass fiber constructed wetlands (did not react with wastewater).

## 1.3 Objectives of the study

### 1.3.1 General objective

The overall objective of this study was to analysis *Cyprus papyrus* wastewater treatment efficiency in glass fiber constructed wetlands under different density. Bahir Dar City Ethiopia.

### 1.3.2 Specific objective

The specific objectives of this study were to:

- Assess plant biomass production and nutrient storage of *Cyprus papyrus* under different density
- Analysis physical and chemical characteristics of wastewater influent and effluent under different treatment
- Examine selected wastewater heavy metal removal efficiency of *Cyprus papyrus*

### 1.4 limitation of the study

There were different complexities and challenges during the study. The data for this study was collected during COVID 19. Even if the challenge to monitor all necessary data, it was collected appropriately. Another limitation of this study was that it did not analysis below ground biomass and plant nutrient content. Lack of previous studies to compare with the result of this finding was one of the significant limitations that we come across in this study.

# Chapter 2. LITERATURE REVIEW

## 2.1 Definition and concepts of wetlands

Ramsar Convention Secretariat (2013) "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 does not exceed six metres" and "May incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands". Pittock *et al*. (2015) "places where water is the primary factor controlling plant and animal life and the wider environment, where the water table is at or near the land surface, or where water covers the land". (Coward in *et al*., 1979) wetlands are "lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water" and "must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year".

## 2.2 Physico- Chemical Parameters of wastewater

It is very essential and important to test the water before it is used for drinking, domestic, agricultural or industrial purpose. In general, the contaminants in wastewater are categorized into physical, chemical and biological. Some indicator measured to determine these contaminants include Water must be tested with different physic-chemical parameters (Obuobie *et al*., 2006). Some physical test should be performed for testing of its physical appearance such as temperature, color, odour, pH, turbidity, TDS etc, while chemical tests should be perform for its BOD, COD, dissolved oxygen, alkalinity, hardness and other characters. DO is one of the most important parameter. Its correlation with water body gives direct and indirect information e.g. bacterial activity, photosynthesis, availability of nutrients, stratification etc. (Premlata and Vikal, 2009).

Conductivity shows significant correlation with ten parameters such as temperature, pH value, alkalinity, total hardness, calcium, total solids, total dissolved solids, chemical oxygen demand, and chloride and iron concentration of water. The availability of good quality water is an indispensable feature for preventing diseases and improving quality of life. It is necessary to know details about different physico-chemical parameters such as color, temperature, acidity, hardness, pH, sulphate, chloride, DO, BOD, COD, alkalinity used for testing of water quality and heavy metals such as Pb, Cr, Fe, Hg etc. are of special concern because they produce water or chronic poisoning in aquatic animals (Patil *et al*., 2012).

### 2.2.1 Effect of untreated urban and industry waste disposal on aquatics ecosystem and environment

In most developing countries, the rapid pace of urbanization is a challenge to urban environmental management specially, water bodies near to industrial area have been extremely affected from disposal of waste which can alter the physical, chemical and biological nature of the receiving water body. So, industrial waste is the most common source of water pollution in the present day and it increases yearly due to the fact that industries are increasing because most countries are getting industrialized (Osibanjio *et al*., 2011). Industrial waste-water originates from the wet nature of industries which require large quantities of water for processing and disposal of wastes. Most industries are therefore, located near water sources (Adekunle and Eniola, 2010).

Macrophytes are the common features of an aquatic ecosystem. Accumulation of nutrients in an aquatic ecosystem leads to eutrophication resulting into massive growth of the macrophytes and weeds. Main cause of nutrient accumulation is rapid urbanization and anthropogenic pressure. Storm water runoff and discharge of sewage into the lakes are two common ways that various nutrients enter the aquatic ecosystem, resulting into the death of those systems (Sudhira & Kumar, 2000). These human activities include release of untreated waste and effluents into rivers and directly to the lake due to operation of factories and industries (Odada *et al*., 2004).

## 2.3 The use of aquatic macrophytes in water pollution control

In the wetlands, nutrient removal from wastewater occurs due to different mechanisms: (1) plant uptake; (2) microorganisms residing on the plant roots which transform nutrients (mainly N) into inorganic compounds ($NH4^{+}$ and $NO3^{-}$) which are directly available to plants; and (3) physical processes, such as sedimentation and filtration, as a consequence of nutrient uptake, in planted wetlands large volumes of biomass are produced (Billore *et al*., 1999). The presence of macrophytes lead to an increase in wetland performance in terms of biological oxygen demand (BOD), ammonia-N and pathogen bacteria reduction. On the other hand, the low removal rates obtained in the unplanted bed could suggest that the nitrification/ denitrification processes may have been limited by inadequate microbial activity in an unplanted gravel and sand medium (Ciria & Solano, 2005).

### 2.4 Ecological characteristics of *Cyprus papyrus*

*Cyperus papyrus* is one of the largest emergent aquatic sedges found growing in both lentic and lotic environments (Kaggwa *et al*., 2001). Surface water depth in the wetland had a significant relationship with papyrus growth rate which was supported by the site condition. However, it is important to note that insects/rodents were responsible too for mortality of culms. Higher papyrus growth can be achieved in areas with stable water regimes, undisturbed substrate, and availability of nutrients combined with minimal disturbances from human activities at the site. Low growth rate of papyrus was observed in disturbed floodplain of Wasare which was characterized by high culm density and stunted growth (Rongoei *et al.*, 2016).In most aquatic ecosystems, aquatic plants (hydrophytes) are important components of food web dynamics. Much of the food is derived from plants. The majority of aquatic plants are consumed only after they have died and partially decomposed into detritus. Detritus is eaten primarily by aquatic insects, invertebrates and larger crustaceans (Rejmánková, 2011). These detritivores are in turn consumed by fish. Lastly, the fish are consumed by the top predator such as sharks (Rejmankova, 2011).

Papyrus and other aquatic vegetation provide important living and breeding substrate for small animals such as aquatic insects, snails and crustaceans which intern supply food for fish and waterfowl (Karlberg, 2015). Umbels are the large, spherically shaped, reproductive structures that serve as the main photosynthetic surface as well. Below the ground or water surface, the rhizomes of the papyrus plant occur, followed by hairy-like root extensions, which float freely back and forth beneath the plant with water movement. The two parts of a papyrus plant, culm and umbel, occur above-ground while the rhizome and roots compose its below-ground parts and when these plants die, decomposition releases the nutrients back into the water but when the macrophytes are replaced by harvesting, then significant amounts of nutrients can be removed from water systems (Awange, 2006). Papyrus culms growing in wetland quadrats are affected by different factors. Average culm size, density, water quality and soil characteristics have relationship with growth rate of culms in quadrats. Culm length was categorized into mature and young as their growth rates differed (Rongoei & Outa, 2016).

### 2.4.1 Growth and reproduction of *Cyprus papyrus*

Wetland ecosystems provide a number of important services including the supply of potable water, a source of protein from fish stocks, the attenuation of flood waters and the purification of *domestic, industrial and agricultural wastewater (Kansiime et al. 2007). Cyprus papyrus* is tall, robust, leafless aquatic plant can grow 4 to 5 m (13 to 16 ft) high and it forms a grass-like clump of triangular green stems that rise up from thick, woody rhizomes. Each stem is topped by a dense cluster of thin, bright green, thread-like stems around 10 to 30 cm (4 to 10 in) in length, resembling a feather duster when the plant is young.

Papyrus can be found in tropical rain forests, tolerating annual temperatures of 20 to 30 °C (68 to 86 °F) and a soil pH of 6.0 to 8.5. It flowers in late summer, and prefers full sun to partly shady conditions. Like most tropical plants, it is sensitive to frost (Christenhusz *et al*., 2017). A study by Boar et al. (1999) where culm density of *Cyprus papyrus* ranged from 86 to 133 culms $m^2$ across two study years. The papyrus plant is relatively easy to grow from seed, though in Egypt, it is more common to split the rootstock and grows quite fast once established. Extremely moist soil or roots sunken in the water is preferred and the plant can flower all year long. Vegetative propagation is the suggested process of creating new plants. It is done by splitting the rhizomes into small groups and planting normally and it can reach heights of up to 16 feet tall (Christenhusz *et al.*, 2017). At a global scale, different ecosystems and their species play different roles in the maintenance of essential life support processes such as energy conversion, biogeochemical cycling, and evolution (Assessment, 2003).

### 2.4.2 Biomass production and carbon sequestration potential of *Cyperus papyrus*

Tropical papyrus wetlands have the ability to assimilate and sequester significant amounts of carbon. Furthermore, wetland systems have the potential to provide a powerful climate change mitigation tool through carbon sequestration, as a result of significant carbon accumulation in detritus and peat (Saunders *et al*., 2012). As well as carbon sequestration, papyrus wetlands also provide numerous other ecosystem services which have environmental and socio-economic benefits, such as the treatment of wastewater, the provision of a potable water supply and a source of fish protein, and increased biodiversity (Kansiime *et al*. 2007). The high rates of primary productivity of papyrus dominated wetlands have been shown to result in the accumulation of significant carbon stores (Jones and Humphries, 2002).

A very general estimate of the carbon stocks associated with detrital and peat deposits in papyrus wetlands indicated that up to 11 Gt C may be stored in these wetlands across central and eastern Africa, this estimate is similar to that of Page *et al.* (2011) who suggested that peatlands in the tropical African region represent a carbon stock of approximately 7 Gt C. The CO2 absorbed by the papyrus does not release back into the ecosystem as it is retained by the plant, and after harvesting, the culms and leaves are used for different purposes. Thus, papyrus and other macrophytes serve as a carbon sink and the resulting environmental benefits are immense. Papyrus thus serves as an important niche for carbon conversion and locking and hence, regarded as an important contribution to mitigating climate change.

### 2.5 Water Pollution and Treatment Technologies

In view of the aforesaid problems, recently much attention has been focused on the development of more effective, lower-cost, robust methods for wastewater treatment, without further stressing the environment or endangering human health by the treatment itself. Extensive studies have been undertaken in recent years with the aim of finding alternative and economically feasible technologies for water and wastewater treatment (Kumar &Lee, 2012). A number of methods such as coagulation, membrane process, adsorption, dialysis, foam flotation, osmosis, photocatalytic degradation and biological methods have been used for the removal of toxic pollutants from water and wastewater. However, their applications have been restricted by many factors, such as processing efficiency, energy requirement, engineering expertise, economic benefit and infrastructure, all of which precludes their use in much of the world (Kumar &Lee, 2012). Compared to literature values, nitrification, plant uptake and the overall system treatment efficiency were high, indicating a high potential of this system for biological nutrient removal from wastewaters in the tropics (Kyambadde *et al*., 2005).

## 2.6 Global Water Pollution and Human Health

Many of the major problems that humanity is facing in the twenty-first century are related to water quantity and/or water quality issues. These problems are going to be more aggravated in the future by climate change, resulting in higher water temperatures, melting of glaciers, and an intensification of the water cycle, with potentially more floods and droughts, with respect to human health, the most direct and most severe impact is the lack of improved sanitation, and related to it is the lack of safe drinking water, which currently affects more than a third of the people in the world. Therefore, discharge of inadequately treated wastewater to the environment could pose significant environmental and human health issues (Shahid *et al*., 2015). Additional threats include, for example, exposure to pathogens or to chemical toxicants via the food chain (e.g., the result of irrigating plants with contaminated water and of bioaccumulation of toxic chemicals by aquatic organisms, including seafood and fish) or during recreation (e.g., swimming in polluted surface water) (Schwarzebach *et al*., 2010).

## 2.7 Preliminary and Primary Wastewater Treatment Processes

Preliminary treatment of wastewater generally includes those processes that remove debris and coarse biodegradable material from the waste stream and/or stabilize the wastewater by equalization or chemical addition. Primary treatment generally refers to a sedimentation process ahead of the main system or secondary treatment. In domestic wastewater treatment, preliminary and primary processes will remove approximately 25 percent of the organic load and virtually all of the nonorganic solids. In industrial waste treatment, preliminary or primary treatment may include flow equalization, pH adjustment or chemical addition that is extremely important to the overall treatment process. Preliminary treatment (removes materials that can cause operational problems, equalization basins are optional). Primary treatment (remove ~60% of solids and ~35% of BOD) (Devatha *et al*., 2016). Primary and secondary treatment removes the majority of BOD and suspended solids found in wastewaters. However, in an increasing number of cases this level of treatment has proved to be insufficient to protect the receiving waters or to provide reusable water for industrial and/or domestic recycling (Sonune & Ghate, 2004).

### 2.8 Biological wastewater treatment

Biological treatment is an important and integral part of any wastewater treatment plant that treats wastewater from either municipality or industry having soluble organic impurities or a mix of the two types of wastewater sources. The obvious economic advantage, both in terms of capital investment and operating costs, of biological treatment over other treatment processes like chemical oxidation; thermal oxidation etc. has cemented its place in any integrated wastewater treatment plant (Arun M., 2011). Biological treatment using aerobic activated sludge process has been in practice for well over a century. Increasing pressure to meet more severe discharge standards or not being allowed to discharge treated effluent has led to implementation of a variety of advanced biological treatment processes in recent years. High removal efficiencies for biochemical oxygen demand, ammonium-nitrogen (NH4–N) and phosphorus (P) fractions in papyrus-based CWs (68.6–86.5%) compared to *Miscanthidium* (46.7–61.1%) and unplanted controls (31.6–54.3%) (Kyambadde *et al*., 2005).

### 2.9 Constructed Wetlands for Wastewater Treatment

Constructed wetlands are nowadays considered as low-cost alternative for effective wastewater treatment especially where suitable land can be available (Rababah, 2007). Even though wastewater treatment is accomplished through the integrated combination of physical, biological and chemical interactions amongst biotic and abiotic components of the ecosystem, macrophytes cultivated in constructed wetlands make one of the essential components in the treatment process. Plants are known to provide surface area for microbial growth, to uptake pollutants and nutrients, and also to transport oxygen from the atmosphere to the rhizosphere (Armstrong *et al*., 1990). Oxygen enhances the microbial biodegradation process in the root zone and alleviates the stress associated with the anoxic conditions (Brix, 1996). Plant biomass produced in the wastewater treatment process is an added value of the constructed wetland since it can be exploited as food, medicine, paper and biofuel (Polprassert, 2007).

Wastewater is any water that has been adversely affected in quality by anthropogenic influences. The pollutants from the wastewater are harmful to the public health and the environment, and they are toxic to the aquatic organisms as well. The wastewater treatment helps to remove contaminants from water to decrease pollutant load. Available water and wastewater treatment methods are often chemically, energetically, and operationally intensive, and they may not be feasible in Africa (Wang, *et al*., 2014) and generally in many developing countries like Kenya, Ethiopia etc. Thus, in an attempt to innovate applicable and sustainable technologies, constructed wetlands (CWs) have been used as promising wastewater treatment alternative (Andualem, *et al*., 2015 and Odinga et al., 2013) these constructed wetlands are considered to be a sustainable solution to wastewater treatment issues in small communities (Araújo *et al*., 2008 and Chen *et al*., 2008). Studies on constructed wetland systems vegetated with macrophytes have shown that the percentage reductions of physicochemical parameters are generally high especially in the tropics, where climatic conditions are able to sustain vegetation all the year round.

Song *et al*. (2006) reported that use of constructed wetlands in China resulted in 99.7% reduction in faecal coliforms load. Gude *et al*. (2014) updated recent developments in wetlands design, modeling and operation and vegetation for wastewater treatment and removal of a variety of pollutants including some onsite treatment processes. In addition to municipal wastewater, various types of wastewater including agricultural, industrial and landfilled leachate have been treated by CWs. Recently, CWs have been used as a cost-effective and environmental friendly system for treatment of wastewater from tannery industry. Horizontal subsurface flow CWs implemented in Portugal, showed effective performance in treatment of high organic loading tannery wastewater with wide range of hydraulic variations (Calheiros *et al*., 2014). According to Jia *et al*. (2014) studied a four-stage wetland with a rapid filter, a down-flow substrate constructed wetland, an up-flow wetland, and a surface flow constructed wetland to enhance nutrient removal efficiency for the influent from a heavily polluted river. Around 70% of TN and 60% of TP and NH4 +-N could be removed using the four-stage system, with 0.58 mg/l of NH4 +-N, and 0.24 mg/l TP in the effluent.

### 2.10 Potential of *Cyprus Papyrus* in Constructed Wetlands for Wastewater Treatment

*Cyprus papyrus* is large, emergent, aquatic perennial may grow to more than 5 m high, making it one of the largest sedges in the world. The culms can be so dense and impossible to penetrate by human that the species is an ideal candidate for biofencing. The most conspicuous features of Cyperus papyrus are the bright, green, smooth, bladeless flowering culm and the “featherduster” flowering head (Viji *et al*., 2014). This plant has a relatively high potential of producing biomass from solar energy, which is one of the criteria for the selection of macrophytes to be used in constructed wetlands (Perbangkhem and Polprassert, 2010). Some macrophytes including *Phragmites* sp. and *Typha* sp. are well known for their potentials in constructed wetlands for wastewater and fecal sludge treatment and literature on their performances is well documented (Kadlec, 1995). These well-known macrophytes are however not found in all regions of the world and effort is being made worldwide to select potential candidates to be exploited locally in wetland technology. The present study aimed at assessing the potentials of *C. papyrus* in domestic wastewater treatment using a laboratory scale horizontal flow constructed wetlands. Morphological parameters, as well as productivity of the plant and the treatment efficiency of the vegetated wetlands are investigated with respect to nutrient load and wetland's configurations.

The nature, design, plant type and microbial activity of constructed wetland systems are the main components for wastewater treatment (Truu *et al*., 2009). Papyrus showed higher ammonium-nitrogen and total reactive phosphorus (TRP) removal (75.3% and 83.2%) than Miscanthidium (61.5% and 48.4%) and unplanted controls (27.9% ammonium-nitrogen) (Erina and Wiyono, 2012). Any oxygen transferred from the shoots to the roots is utilized for root respiration and decomposition of the abundant organic matter by heterotrophic bacteria (Okurut, 2000). Constraints on development that led to the WWTP (Waste Water Treatment Plant) to the domestic problems of its own. In order to improve the quality of the environment and minimize pollution originating from domestic (housing/residential), needed environmental service programs, which one of them is the selection and application of new technologies urban domestic wastewater treatment is 'simple and apropriate' to the community that is: simple, easy and cheap and affordable in the system operation and maintenance. One of the appropriate technology that can treat domestic wastewater is the wetland technology for domestic wastewater treatment (Sim, 2004). *Cyperus papyrus* and *Phragmites karka* plants from the wetlands of Lake Tana significantly influenced the rate of removal of nutrients in domestic wastewater (Yezbie and Seyoum, 2014).

### 2.11 Municipal waste heavy metals

The term ‘‘heavy metal’’ refers to any metal and metalloid element that has a relatively high density ranging from 3.5 to 7 g cm3 and is toxic or poisonous at low concentrations, and includes mercury (Hg), cadmium (Cd), arsenic (As), chromium (Cr), thallium (Tl), zinc (Zn), nickel (Ni), copper (Cu) and lead (Pb). Having mainly excessive amounts of heavy metals such as Pb, Cr and

Fe, as well as heavy metals from industrial processes are of special concern because they produce water or chronic poisoning in aquatic animals (Ellis, 1989). Heavy or toxic metals are trace metals which are detrimental to human health and having a density at least five times that of water. Once liberated into the environment through the air, drinking water, food, or countless varieties of man-made chemicals and products, heavy metals are taken into the body via inhalation, ingestion and skin absorption. If heavy metals enter and accumulate in body tissues faster than the body's detoxification pathways can dispose of, then a gradual build-up of these toxins occurs. High concentration exposure is not a necessity to produce a state of toxicity in the body, as heavy metal accumulation occurs in body tissues gradually and, over time, can reach toxic concentration levels, much beyond the permissible limits. (Khanna, 2011).

The supply of wastewater coming from industrial land municipal sources and associated wastes to soil dates back 400 years and is a usual practice now in different parts of the globe. Internationally, it is projected that 20 million (20m) hectares (ha) of arable land are watered with some sort of wastewater. In various African and Asian cities, studies propose that agriculture relied on watering with wastewater contributes for 50 % of the vegetable source to urban areas (Bjuhr, 2007). Potentially toxic elements (PTEs) including cadmium (Cd), chromium (Cr III and Cr VI), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn). High levels of pollutants mainly organic matter in river water causes an increase in biological oxygen demand (Kulkarni, 1997) chemical oxygen demand, total dissolved solids, total suspended solids and fecal coli form. They make water unsuitable for drinking, irrigation or any other use (Hari, 1994). Plants can accumulate heavy metals in their tissues in concentrations above the permitted levels which is considered to represent a threat to the life of humans, and animals feeding on these crops and may lead to contamination of food chain, as observed that soil and plants contained many toxic metals, that received irrigation water mixed with industrial effluent (Amin *et al*., 2010). Most of the rivers in the urban areas of the developing countries are the ends of effluents discharged from the industries. African countries and Asian countries experiencing rapid industrial growth and this is making environmental conservation a difficult task (Agarwal & Saxena, 2011).

### 2.12 Wastewater reuse

The use of treated, diluted, and even raw domestic wastewater for agricultural irrigation is becoming an essential component of a more sustainable and integrated water resources management, especially in water-scarce regions. More than 20 million hectares are currently being irrigated with wastewater worldwide by about 200 million farmers. The use of (treated) wastewater in agriculture has great potential but cannot be dealt with in isolation from local, regional, and global water and sanitation management systems (Gatto *et al*., 2015). Treated wastewater maintains environmental quality while providing sustainable agriculture and preserving scarce water sources. Treated wastewater is another important source of nonconventional water resources, which is currently used for irrigation, aquifer recharge, fish culture, cooling, construction, and in some industries. Worldwide the most common use of treated wastewater has been for agricultural irrigation (Abdelrahman *et al*., 2011). According to Van *et al*. (2010) the relationships between urban development, water resources management and wastewater use for irrigation have been studied in the cities of Accra in Ghana, Addis Ababa in Ethiopia and Hyderabad in India. Large volumes of water are extracted from water sources often increasingly far away from the city, while investments in wastewater management are often lagging behind. The resulting environmental degradation within and downstream of cities has multiple consequences for public health, in particular through the use of untreated wastewater in irrigated agriculture. The case of wastewater irrigation shows the risks of such a nexus, where city effluents might re-enter the urban food chain.

The assessment of some of the underlying causal relations and possible future developments helps to explain why urban water management is becoming more 3 challenging at the institutional, organisational, technical and political level, and in which way the challenges could be addressed (Van *et al*., 2010). All three cities have in common the fact that heavily polluted water is used for irrigation, not as a planned means to address water scarcity but due to widespread pollution of existing irrigation sources. Irrigation in Accra and Addis Ababa can be classified as informal smallholder irrigation, but in Hyderabad farming is supported by public irrigation infrastructure, initially intended to convey freshwater. Cities are large 'organisms' which consume and transform huge amounts of energy, water, food and materials into goods and waste products. Water is a particularly vital resource needed for the survival of humans and cities. In places where, in response to rapid urbanization, water supply has outpaced sanitation coverage and wastewater management, pollution of natural water bodies and the use of wastewater in irrigated agriculture have become common realities (Raschid-Sally and Jayakody, 2008).

# Chapter 3. MATERIAL AND METHODES

## 3.1 Description of the study area

### 3.1.1 Location of the study area

This study (experiment) was conducted in *Amhara* regional state, *Bahir city* specifically Bahir Dar university in Peda compass, 37°23′57″ East and 11° 34′ 24″ North with 1794 m above sea level (Figure 3.1). Bahir Dar, the capital of Amhara National Regional State, is situated on the southern shore of Lake Tana, the source of Blue Nile River, approximately 565 kms northwest of Addis Ababa. According to CSA (2007), the total population of Bahir Dar metropolitan area was 180,174 and projected to become 212 785 in 2015. It is a rapidly expanding town with commercial centers, small industries, and residences in all sectors of the town.

### 3.1.2 Climate of the Study Areas

The study area temperature fluctuates from January to December. The annual mean temperature ranged from 18.5°C to 21.1°C in 1990-2019 (30 years), whereas annual mean temperature for 2019 was 20.6°C (Figure 3.2). The highest mean monthly maximum temperature occurs in the month of April, which was about 30.1°C, and the lowest mean monthly maximum temperature in the months of August, which was about 25.1°C in 2019. The mean monthly minimum temperature ranges from 9.6°C in January to 17.1°C in May in 2019. There was a significant seasonal variation in the amount of rainfall. About 60.3% of the mean annual rainfall occurs in 2 rainy months of July and August with an average annual rainfall was estimated varying from 800 to 1200 mm with "Woina Dega" type of agroecological zone (Kasim *et al*., 2018).

### 3.1.3 Topography of the study area

The city's topography is characterised by flat plain. However, there are pockets of conical hills, rugged and undulating features dotting the city's landscape. The average elevation of Bahir Dar is estimated to be between 1786m above sea level (near the lake shore) and 1886m above sea level on the summit of Bezawit Hill (Kasim *et al*., 2018).

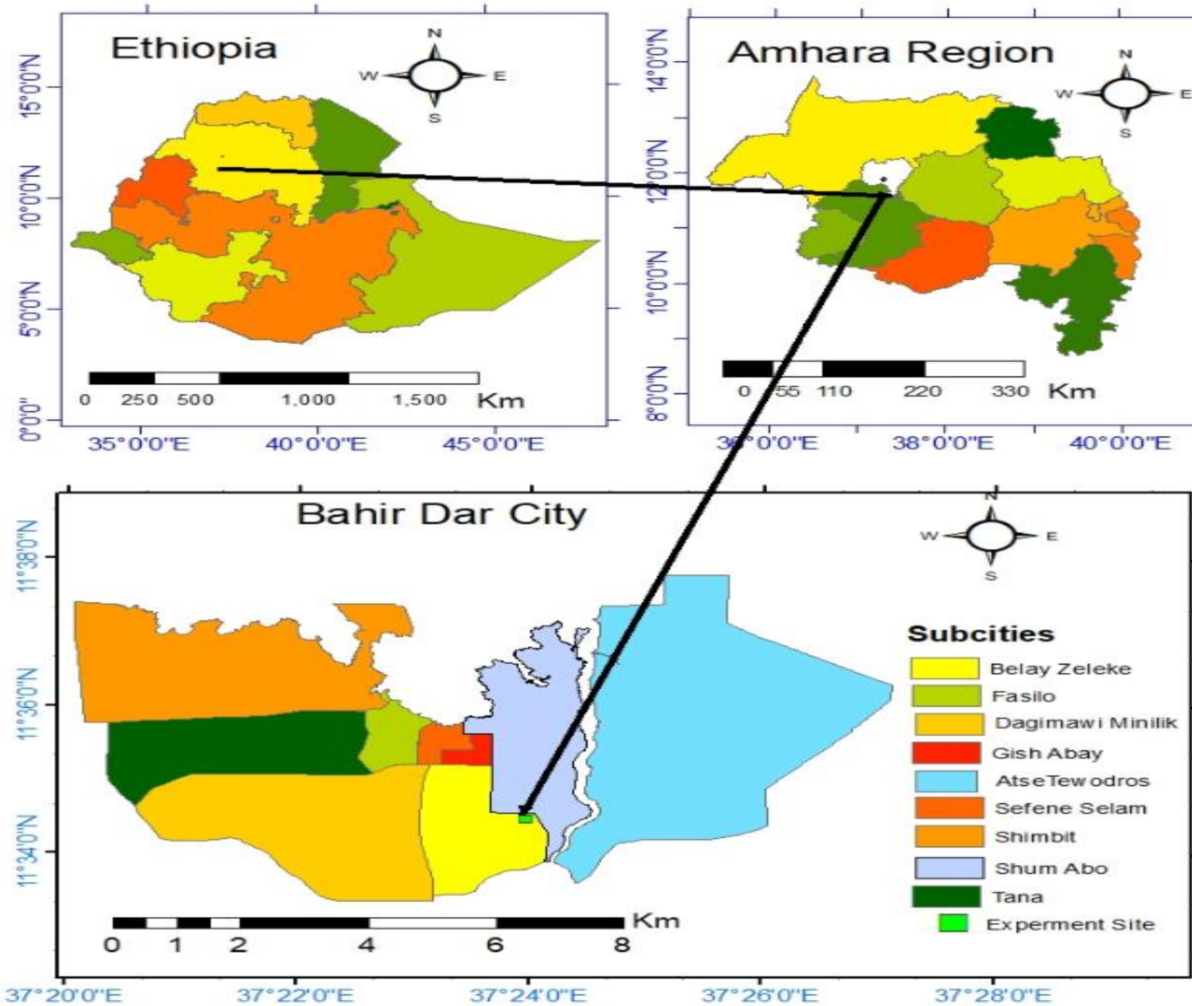


Figure 3.1 map of the study area

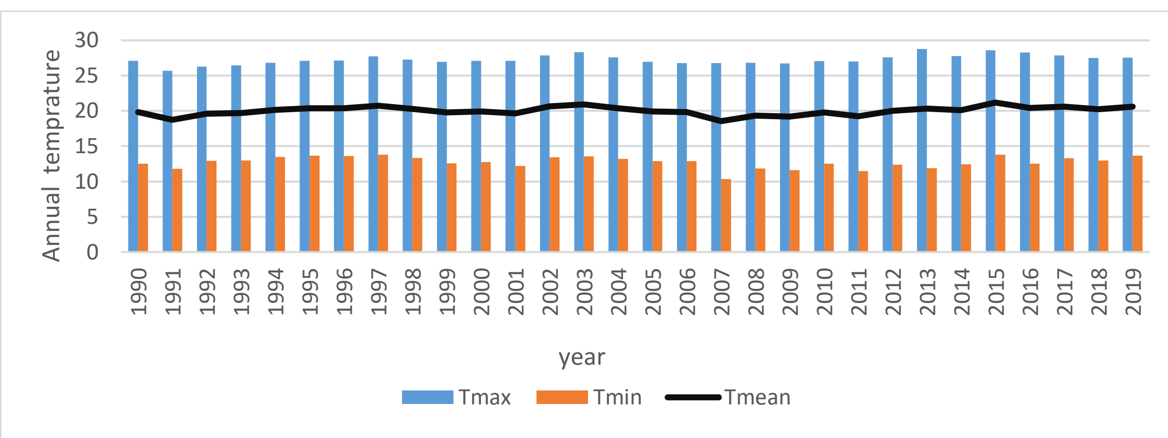


Figure 3.2 30 years Annual mean, maximum and minimum temprature of the study area from Amhara metrology agency.

### 3.2. Sources of Data

Data for this study were captured from two sources: primary and secondary sources. The primary data were the first hand information; the data were collected directly by the researcher from the study area. The main primary sources of data were the growth characteristics survey data, plant dry biomass and physicochemical characteristics both in the field and laboratory. Hence, field observation and measurement and laboratory analysis were primary data sources. The sources of secondary data were from literatures, organization departmental reports, journal, magazine, Internet and reports which contain related information on liquid waste treatment and *Cyprus papyrus.*

### 3.3 Experimental design (sampling design)

*Cyprus papyrus* plants were purposely selected due to their ability to remove suspended solids, nutrients and heavy metals (Theophile *et al*., 2011). The experimental study were conducted both on the field and in the laboratory. Twelve wetlands CW1, CW2, CW3, up to CW12 of 1.5m Length* 1.5 m width* 0.8 m depth each were constructed using Glass fiber tanks (Figure 3.3). The system consists of four treatment beds with three replication aligned in parallel was designed. The field experiment was conducted based on steam density Bed (plant growth media) one, bed two, bed three, and bed four. The steam density of *Cyprus papyrus* 0, 12, 24 and 36 per bed initial density of *Cyprus papyrus* respectively in 14 weeks growing period with total surface area of each glass fiber tanks (2.25m$^2$), 1.5 m *1.5m*.8m (L*W*D) Table 3.1. The classification of plant density was based on different literature review and our field survey 5- 60 plants /m$^2$ minimum and maximum plant density respectively in the surrounding of Lake Tana and river Abay wetlands. Mean culm density ranged from 9.2 to 133 culms/m$^2$ from sites in central and eastern Africa (Saunders *et al*., 2014). *Cyperus Papyrus* high density of 37 culms/m$^2$ (Rongoei & Outa, 2016). Other growth substances were similar and the wastewater applied to each treatment beds by horizontal subsurface flow. The rhizome of the plant was taken and count the shoots and plant on each bed or pot. Coarse and fine gravel and sand were used as a substrate 15 to 30mm size except one in the out let with 40-80 mm gravel to prevent clogging which was the recommended gravel size by USEPA (2000).The substrate was filled to a height of 45 cm.

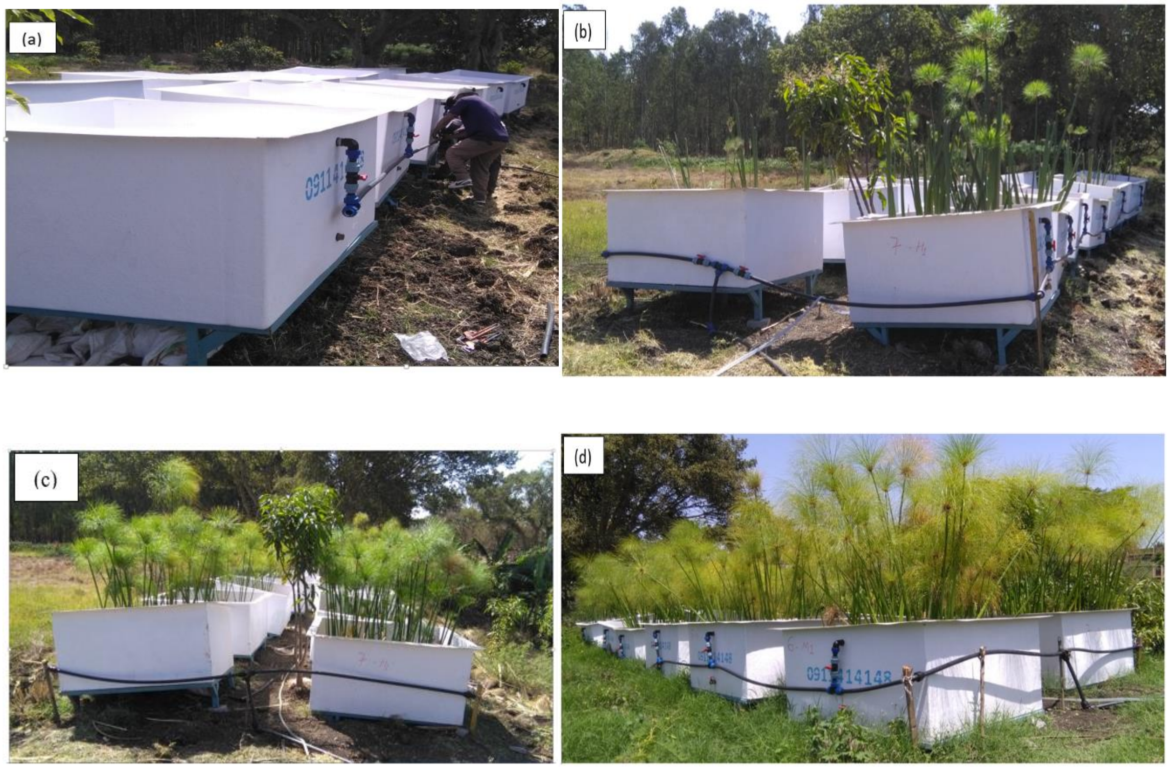


Figure 3.3 Installation (a), plantation day (b), after eight weeks (c) and after fourteen weeks (d) Aspect of *C. papyrus* in the glass fiber tanks constructed Wetlands.

Rhizomes carrying young shoots of *C. papyrus* plants average 10 cm height in the planting time except some long (culms) plants shows in figure 3.3 (a) until the plant adapted the new wetland glass fiber and removed long (culms) plants after two weeks when the plant acclimated well. The treatment beds randomly assigned control, low, medium and high desity papyrus. Selected Rhizomes were taken from the man made wetlands (nursery) in side Bahir Dar university Peda campus and transplanted into their respective treatment beds with surface area of $2.25m^2$ at different density. Each treatment bed were fed with the influent wastewater with the same average flow rate except clean water free of wastewater was used for watering in the two weeks of acclimatization period. Similar methods also by (Hoffmann and Platzer, 2010). Wastewater used in the study was domestic liquid wastes discharged from the Bahir Dar City. The nature, design, plant type and microbial activity of constructed wetland systems were the main components for wastewater treatment (Truu *et al*., 2009). Figure 3.3 shows the gass fiber constructed tanks did not react with wastewater.

Table 3.1. Experimental design

| Variation | Control(C) | Low(L) density | Medium(M) density | High(H) density |
|---|---|---|---|---|
| Type of plants | No plat | *Cyprus Papyrus* | *Cyprus Papyrus* | *Cyprus Papyrus* |
| Water fed | Wastewater | Wastewater | Wastewater | Wastewater |
| Replication | 3 | 3 | 3 | 3 |
| Detention time (days) | 5 | 5 | 5 | 5 |
| Water depth | 20 cm | 20 cm | 20 cm | 20 cm |
| Initial steam density /bed | No plant | 4 rhizome/12 shoots | 8 rhizome /24 shoots | 12 rhizome/ 36 shoots |
| Dimension (L x W x H) of constricted glass fiber | 1.5m*1.5m* 0.8m | 1.5m*1.5m*0.8m | 1.5m*1.5m*0.8m | 1.5m*1.5m*0.8m |
| Substrate | Gravel and sand | Gravel and sand | Gravel and sand | Gravel and sand |
| Observation parameter | pH,$BOD_5$, DO,TSS,TDS, $NO_3^-$, Ammonia, $PO_4^{3-}$ Turbidity, SC, TA, Temprature, Cu, Cr, Zn | pH,$BOD_5$,DO,TSS ,TDS, $NO_3^-$, Ammonia, $PO_4^{3-}$, Turbidity, SC, TA, Temprature, (TP, TN and C only plant biomass), Cu, Cr, Zn | pH,$BOD_5$,DO,TSS, TDS, $NO_3^-$, Ammonia, $PO_4^{3-}$, Turbidity, SC, TA Temprature, (TP, TN and C only plant biomass), Cu, Cr, Zn | pH,$BOD_5$,DO,TSS, TDS, $NO_3^-$, Ammonia, $PO_4^{3-}$, Turbidity, SC, TA, Temprature, (TP, TN and C only plant biomass), Cu, Cr, Zn |

### 3.4 Data collection from the treatment beds

3.4.1 Measurement of the growth parameters of the plants

Plant density in the treatment bed, plant height, stem diameter and biomass were considered growth parameters of the young plants and Plant density by counting, plant height by meter tab, stem diameter by caliper were measured every two weeks. Above ground Biomass of papyrus was determined by harvesting (0.3 m x 0.3 m) quadrats in each plantedbeds in the $14^{th}$ weak. Culms were cut level with the subtrate and harvested from the entire 0.3x0.3m quadrat. Fresh weight was determined for the harvested materials (above- ground parts) then were oven dried to until a constant weight at 105°C and dry weight was determined by sensitive balance. But we did not measure below ground biomass and nutrent content in this study. it was dificult to measure below ground biomass because in the plantting time the rhizomes has high below ground biomass (*Cyprus papyrus* reprodeced by rehzom). So it is difficult to identify the old and new rehzomes grown with in glass fiber tanks constracted wetland (Serag, 2003).

3.4.2 Measurement of plant nutrient content.

Prior to nutrient analysis; leaf and stem samples were pulverized and made into fine powder by grinder shows in (appendix figure 1 b). The powder of each sample was used in the analysis for total nitrogen (TN), total phosphorus (TP) in the laboratory. The concentration of N in plant tissues was determined using the Kjeldahl method, while P was measured by the molybdate ascorbic acid method and amount of C sequestration also determined by, amount of above ground dry biomass * 43.5% for herbaceous plants (Ma *et al*., 2018), because *Cyprus papyrus* is herbaceous plant which contain 43.5 % of carbon from plant total dry above ground biomass.

### 3.5 Analysis and measurement of physico-chemical parameters of water quality

Samples for physico-chemical parameters of water quality were collected from influent (into beds) wastewater before treatment and effluent from beds (out of beds). 12 different outlet points were labelled from treatment beds to represents sampling point for the effluent wastewater. Three samples from influent( before treatment) and 12 samples from treated wastewater effluent coming out of treatment beds were taken in one sampling time for with in seven sampling times so, the total samples were 105 in seven sampling time. Samples were taken after acclimation period for seven times with one week interval after established plants grew fully. The physicochemical parameters such as pH, temperature (T°), specific conductance (SC), dissolved oxygen (DO) were measured on site by using YSI DO meter, total dissolved solids (TDS) by using TDS Sensor/Meter, total suspended solid (TSS) by using filter paper, turbidity by terbidometer, biological oxygen demand ($BOD_5$) by using dilution and $BOD_5$ bottle, alkalinity is determined by simple titration in presence of phenolphthalein and methyl orange indicators. Nitrate, phosphate, ammonia, heavy metals (Cu, Cr, Zn) were measured by using Palintest Photometer 7100 systems (precise, modern means of water analysis) with ±1.0% accuracy. Generally physical and chemical parameters of wastewater were determined using outline standard methods for examination of wastewater manual that uses standard chemicals and measures using YSI DO meter and Palintest Photometer 7100, (APHA, 1998). The removal efficiency of the treatment beds for each wastewater quality parameter was calculated using the following formula:

$$\text{Removal Efficiency (\%)} = [(Ci - Ce)/Ci]\ 100 \qquad \ldots\ldots\ldots 1$$

Where, Ci is the concentration of the waste material in the influent (before treatment) and Ce is the concentration of the waste material in the effluent after treatment (Yezbie Kassa and Seyoum Mengistou, 2014).

**3.6 Statistical analysis**

The data were analyzed through one-way analysis of variance (ANOVA) at 95% confidence level to compare the performance efficiency of each treatment bed with respect to nutrient removal and also above ground biomass production and nutrients storage of *Cyprus papyrus* under deferent density using Statistical Package for Social Sciences (SPSS) software, Version 20.0.

# Chapter 4. RESULT AND DISCUSSION

## 4.1. Biomass production, growth and nutrient storage of *Cyprus papyrus* under different density

The process of acclimatization is the process of adjustment to the experimental plant of the new environmental conditions, namely the glass fiber tanks constructed wetland. In the first two weeks acclimatization period plants were irrigated pure water. Observations during the study showed that at two weeks of the beginning of planting, the papyrus Plant looks dry on the fiber glass tanks. After two weeks of planting, papyrus blossomed again beginning to look as well. After two weeks, Plant watered with wastewater from municipals.

### 4.1.1 Biomass production and growth of *Cyprus papyrus* under different density

From the density of 12/36, 8/24, and 4/12 rhizome fragments and shoots respectively per 2.25 $m^2$, 125, 84, and 61 plants were obtained respectively in high, medium and low density of Cyprus papyrus after 14 weeks growing period in the glass fiber tanks constructed treatment beds during which the system was continuously fed with domestic wastewater. Figure 4.2 shows that plant density increase with increase growing period proportionally in all experimental planted beds. Because high number of rhizomes growing high number of plants. Similar result also Theophile *et al*. (2011) conclude that from a density of 6 rhizome fragments per $m^2$, 33 plants per $m^2$ were obtained after 6 weeks acclimation in the filter bed during which the system was continuously fed with primary treated wastewater. Another study also from a density of 6 rhizome fragments per $m^2$ at the start of the study, 41 plants per $m^2$ were obtained after 3 weeks acclimation in the treatment bed planted with C. papyrus, where the system was continuously fed with primary treated wastewater; a density of 81 plants per $m^2$ was recorded during the last experimental period in the treatment beds (Yezbie Kassa and Seyoum Mengistou, 2014).

The plant growth rate of *Cyprus papyrus* in high, mid and low density *Cyprus papyrus* fed by wastewater were estimated 1.91 cm/day, 1.93cm/day and 1.96 cm/day average plant height growth *(Figure 4.1)* and 0.23mm/day, 0.24mm/day, 0.27mm/day average plant diameter (*Figure 4.3)* respectively. This indicates that growth performance of papyrus was very fast however low density had high growth rate compare from medium and high density *Cyprus papyrus specially after eight weeks* because low density had enough space, nutrient and sunlight.

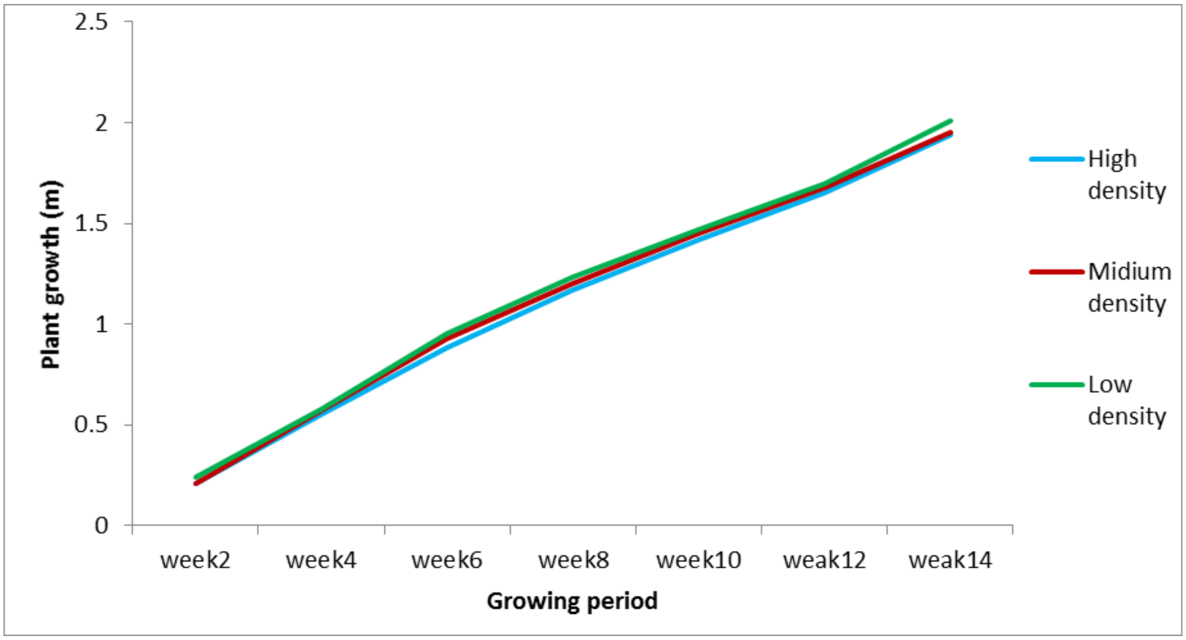


Figure 4.1 Cyprus papyrus average plant height per bed within 14 weeks growing period at deferent density.

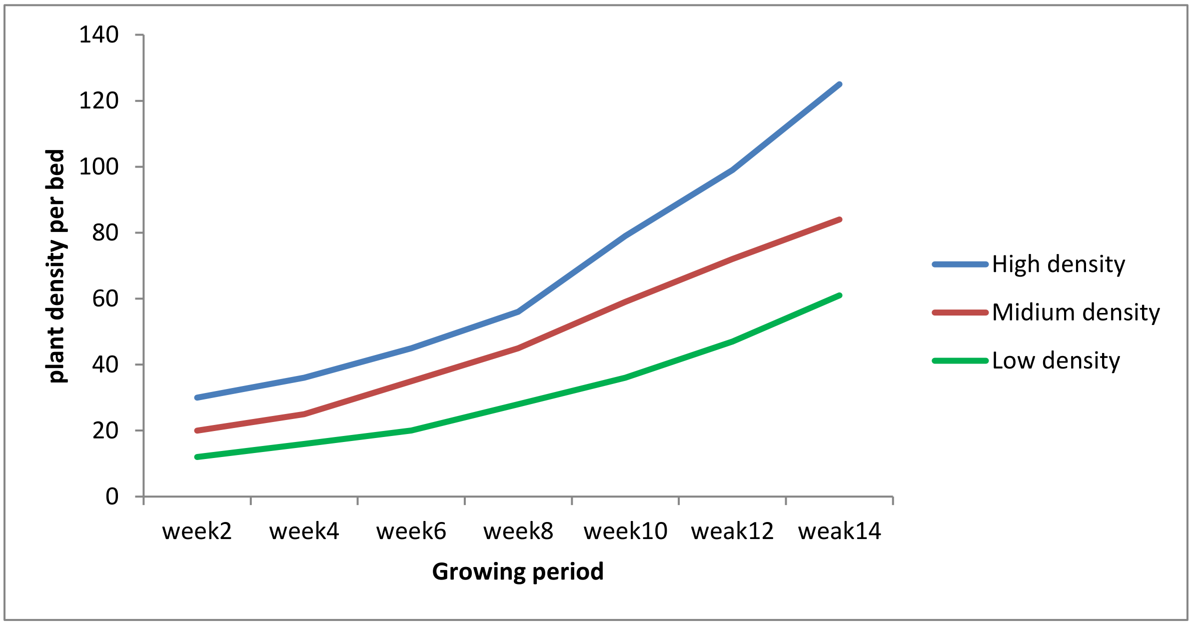


Figure 4.2 Cyprus papyrus average plant density per bed within 14 weeks growing period at deferent density.

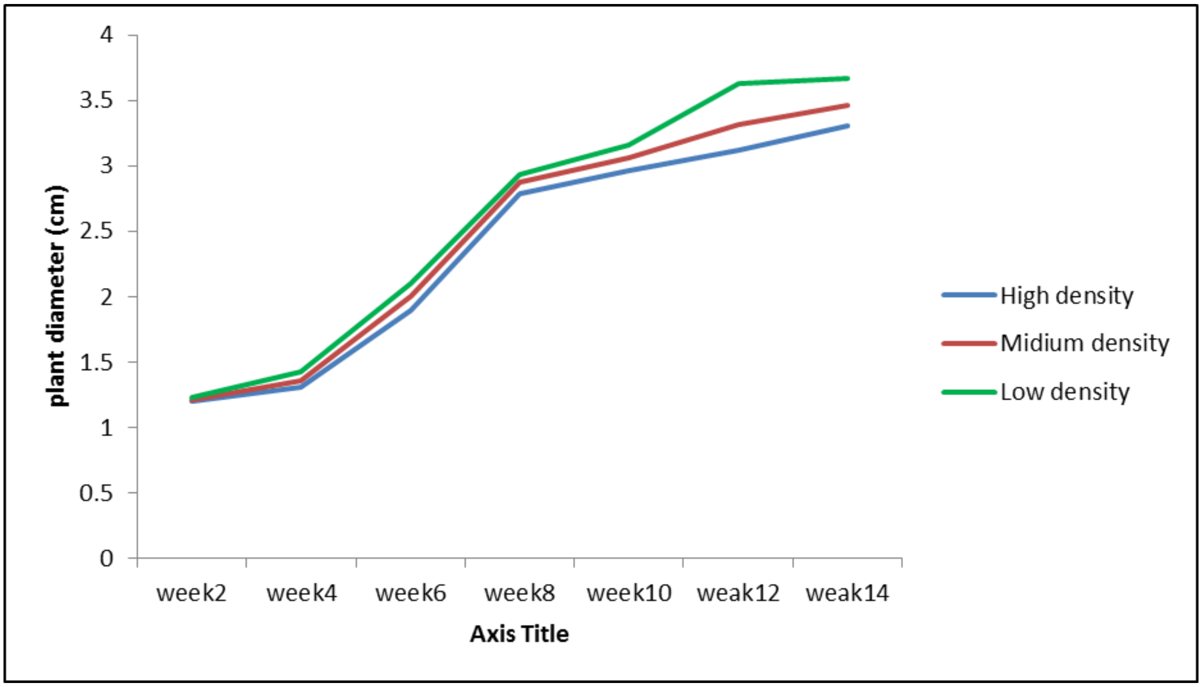


Figure 4.3 *Cyprus papyrus* average plant diameter within 14 weeks growing period at deferent density.

As indicated in Table 4.1 plant density had significant change above ground biomass. The above ground biomass in low, mid and high density were 9.0ton/ha, 12.27ton/ha and 15.82ton/ha respectively in 14 weeks growing period. This showed that density had significant effect on biomass production of *Cyprus papyrus*. Boar et al. (1999) conclude that 26.6 ton/ha above ground biomass was produced in 86 culms density per $m^2$. In addition to this from the wet biomass the average moisture content of the plant were above 81%. In herbaceous plants, water normally constitutes 70- 90% of fresh weight, although in rare cases it can be less than 70% (Dimitrakopoulos & Bemmerzouk, 2003). This indicates that *Cyprus papyrus* had high evapotranspiration rate and relies pure water into the atmosphere and wastewater purification. When these plants die, decomposition releases the nutrients back into the water but when the macrophytes are replaced by harvesting, then significant amounts of nutrients can be removed from water systems, similar result also conclude by (Awange, 2006).

4.1.2 Nutrient storage of *Cyprus papyrus* under different density

*Cyprus papyrus* had higher average plant nitrogen concentration (2.44%) than phosphorus (0.14%). The total phosphors (TP) from average above ground dry biomass *Cyprus papyrus* were 0.013ton/ha, 0.017ton/ha and 0.022ton/ha and the total nitrogen (TN) 0.22ton/ha, 0.3 ton/ha, and

0.39ton/ha and also sequestered carbon 3.91ton/ha, 5.33ton/ha and 6.88 ton/ha respectively low, medium and high density of *Cyprus papyrus* in 14 weeks growing period (Table 4.1). The high biomass and nutrient contents of the plants may have been caused by the high nutrient levels in the surrounding water. Nitrogen is considered to be the most important nutrient, and plants absorb more nitrogen than any other element (Näsholm et al., 2009). Similar result also conclude 2.22% TN from above ground dry biomass of *Cyprus papyrus* (Yezbie and Seyoum, 2014). The phosphorus concentrations were 0.10% culms, and 0.13% umbels in *Cyprus papyrus with receiving domestic wastewater* (Chale, 1987). In addition to this the rhizome and root of *Cyprus Papyrus* provided more microbial attachment sites; more efficient filtering, trapping and settlement of suspended particles, high surface area for pollutant adsorption, uptake and assimilation in plant tissues and high oxygen transfer capabilities for organic and inorganic matter oxidation in the rhizosphere. This indicates that the fast growth and high biomass production was very important not only to treat wastewater by uptake nutrient but also sink carbon from atmosphere spatially in high density.

Table 4.1. Mean above ground dry Biomass, nutrient storage, carbon sequestration and moisture content of C. Papyrus in the glass fiber tanks constructed wetlands.

| Treatment | Unit | high density | Mid density | low density | P value |
|---|---|---|---|---|---|
| | | Mean | Mean | Mean | |
| Density | Steam/m$^2$ | 55[a] | 37[b] | 27[c] | ** |
| AGB | ton/ha | 15.82[a] | 12.27[b] | 9.00[c] | ** |
| TP | ton/ha | 0.022[a] | 0.017[b] | 0.013[c] | ** |
| TN | ton/ha | 0.39[a] | 0.3[b] | 0.22[c] | ** |
| C | ton/ha | 6.88[a] | 5.33[b] | 3.91[c] | ** |
| MC | % | 81.71 | 81.88 | 81.86 | ns |

*The means, followed by the same letter in a row are not statistically different at (P<0.05).*
** The mean difference is significant at the 0.01 level.
Ns= the mean difference is not significance both at 0.01 and 0.05 level.

Similar result also 4.88 ton/ha carbon can sequestrate by *Cyprus papyrus* (Saunders, 2007). This could maximize wetlands potential as carbon sink (Saunders, 2014). Macrophytes had higher nitrogen concentration than phosphorus and similar result was observed by (Mueleman *et al*., 2002). Tropical papyrus wetlands had the ability to assimilate and sequester significant amounts of carbon. Papyrus can have very high C: N: P ratio (Boar, 2006) in comparison to temperate wetland plants; a characteristic that provides an indication of its high nutrient efficiency. Generally density has significant effect in TP, TN and C amount in ton/ha harvested sampled *Cyprus papyrus* in constricted wetland. Wetlands are the most effective terrestrial carbon sinks as their vegetation has high gross primary productivity (Lolu *et al*., 2019).

## 4.2 physical and chemical characteristics of influent and effluent wastewater under different treatment

The physicochemical characteristics of the influent and effluent monitored at the inlet and the outlets of in the glass fiber tanks constricted wetlands in the configuration. The monitoring of water quality in the systems revealed that, the physicochemical characteristics of the effluent were progressively improved upon since a dramatic decline was recorded from the inlet to the outlets of the experimental beds in most parameters (Table 4.2).

### 4.2.1 Total dissolved solid and Turbidity

The influent TDS value were 699 mg/L, reduced into 652.5mg/L, 608 mg/L, and 598 mg/L and 559.3mg/L (Table 4.2) with removal efficiency of 6.6%, 13%, 14.4% and 19.9% ( Table 4.3) in unplanted, low, medium and high density *Cyprus papyrus* treatment beds respectively. This indicates that when density increase removal efficiency increase because uptake of high nutrient content. Because TDS is the sum of the cations and anions in water. Theophile *et al*. (2011) conclude similar result TDS influent, reduced into 7.1% and 28.9% in unplanted and planted of Cyprus papyrus value respectively. Turbidity of influent 32.99 NTU reduced into effluent 21.16NTU, 17.35NTU, 9.63NTU and 5.43NTU with removal efficiency of 35.8%, 47.4%, 70.8% and 83.5% in control (no plant), low, medium and high density of Cyprus papyrus treatment beds respectively. Analytical results of ANOVA and least significant difference (LSD) value confirmed that values of TDS and Turbidity had statistically significant differences at ($p<0.01$) between planted and unplanted treatment beds. Because when the number of plant increase the nutrient uptake also increase, TDS and turbidity value becomes decrease. Similar result also reported by (Patil *et al*., 2012).

Table 4.2 physicochemical characteristic of the effluent monitored at the inlet and the outlets of in the glass fiber constricted wetlands

| Parameters | Influent Values (before treatment) | Effluent Values( after treatment) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Un planted (control) | planted with *Cyprus papyrus* | | | | | | |
| | | | Low density | Mid density | High density | p value | CV % | LSD | |
| | | | | | | | | 0.01 | 0.05 |
| TDS (mg/l) | 699.00 | $652.5^{a}$ | $608^{ab}$ | $598^{ab}$ | $559.3^{b}$ | ** | 4.8 | 80.1 | 55.11 |
| BOD (mg/l) | 88.20 | $65.22^{a}$ | $56.37^{b}$ | $36.06^{c}$ | $27.86^{d}$ | ** | 3.9 | 4.9 | 3.4 |
| TSS (mg/l) | 800.43 | $577.60^{a}$ | $528.8^{a}$ | $391.1^{b}$ | $290.0^{C}$ | ** | 4.9 | 60.4 | 41.5 |
| DO(mg/l) | 1.16 | $1.17^{b}$ | $1.990^{a}$ | $1.993^{a}$ | $2.34^{a}$ | ** | 6.5 | 0.33 | 0.23 |
| Turbidity(NTU) | 32.99 | $21.16^{a}$ | $17.35^{b}$ | $9.63^{c}$ | $5.43^{d}$ | ** | 4.7 | 1.74 | 1.19 |
| Temprature(°C) | 22.67 | 22.48 | 22.60 | 21.98 | 22.32 | Ns | 2.1 | 1.28 | 0.88 |
| TA(mg/l) | 303.65 | $266.6^{a}$ | $238^{ab}$ | $229^{ab}$ | $199.67^{b}$ | ** | 8.5 | 55.8 | 38.4 |
| SC(µS/cm) | 1482.83 | $1361.7^{a}$ | $1279^{a}$ | $1040^{b}$ | $945.60^{b}$ | ** | 4.5 | 144 | 99.5 |
| pH | 6.27 | $6.51^{b}$ | $6.77^{ab}$ | $6.80^{a}$ | $6.83^{a}$ | ** | 1.4 | 0.27 | 0.18 |
| $NO_3^-$ (mg/l) | 1.46 | $1.38^{a}$ | $1.31^{ab}$ | $1.31^{ab}$ | $1.15^{b}$ | ** | 5.4 | 0.19 | 0.13 |
| Ammonia (mg/l) | 38.54 | $19.70^{a}$ | $9.87^{b}$ | $8.19^{b}$ | $4.42^{c}$ | ** | 9.2 | 2.68 | 1.84 |
| $PO_4^{3-}$ (mg/l) | 4.15 | $3.30^{a}$ | $1.86^{b}$ | $1.12^{c}$ | $1.01^{c}$ | ** | 10 | 0.53 | 0.36 |

** The mean difference is significant at the 0.01 level.
Ns= the mean difference is not significance both at 0.01 and 0.05 level.
CV= Coefficient of variance
LSD=least significant difference
*The means* Values *followed by the same letter* on the same row are *not statistically s*ignificantly *different at p<0.01.*

Table 4.3 Percentages removal efficiency of Physicochemical Parameters of the effluent in the planted and the unplanted glass fiber Constructed Wetlands

| Parameters | Effluent Values % removal efficiency | | | |
|---|---|---|---|---|
| | planted with *Cyprus papyrus* | | | Unplanted(control) |
| | High density | Mid density | Low density | Mean |
| | Mean | Mean | Mean | |
| BOD | 68.4 | 59.1 | 36 | 26 |
| DO (increase) | 50.4 | 41.8 | 41.7 | 0.8 |
| TSS | 63.7 | 51.1 | 33.9 | 27.8 |
| Turbidity | 83.5 | 70.8 | 47.4 | 35.8 |
| TDS | 19.9 | 14.4 | 13 | 6.6 |
| TA | 34.2 | 24.5 | 21.6 | 12.1 |
| SC | 36.2 | 29.8 | 13.7 | 8.1 |
| pH(increase) | 8.1 | 7.7 | 7.3 | 3.6 |
| $NO_3^-$ | 21.2 | 10.9 | 10.2 | 5.4 |
| Ammonia | 88.5 | 78.7 | 74.3 | 48.8 |
| $PO_4^{3-}$ | 75.6 | 73 | 55.1 | 20.4 |

### 4.2.2 Specific conductance and total alkalinity

In the current study the specific conductance of influent 1482.8µS/cm reduced into effluent 1361.7µS/cm, 1279µS/cm, 1040µS/cm and 945.6 µS/cm (Table 4.2) with removal efficiency of 8.1%, 13.7%, 29.8% and 36.2% (Table 4.3) in control (no plant), low density, medium density and high density of Cyprus papyrus treatment beds respectively. This important to conclude when plant density increase the treatment efficiency also increase significantly. Large specific conductance values were associated with anthropogenic sources, such as wastewater treatment discharge from larger urban areas. The result showed that effluents from high and medium density of Cyprus papyrus treatment beds were under and near to the range of the Ethiopian effluent standard limits respectively, for EC which 1000µs/cm (EEPA, 2003).

Water conductivity is mainly attributed to the dissolved ions liberated from the decomposed plant matter and input of inorganic and organic wastes. So when plants uptake dissolved ions the conductivity of water becomes decrease proportionally. In this study the alkalinity value of influent 303.65 mg/l reduced in to effluent 266.6 mg/l, 238 mg/l, 229mg/l and 199.67 mg/l (Table 4.2) with removal efficiency of 12.1%, 21.6%, 24.5%, and 34.2% (Table 4.3) in control (no plant), low, medium and high density of *Cyprus papyrus treatment beds* respectively. Because dissolved ions absorbed by plants in the treatment beds particularly high density plants the alkalinity value becomes reduced. Analytical results of ANOVA and least significant difference (LSD) value confirmed that values of SC and TA had statistically significant differences at ($p<0.01$) between planted and unplanted treatment beds (Table 4.2).

4.2.3 Biological oxygen demand

The influent concentration of BOD 88.2 mg/l reduced to 65.22, 56.37, 36.06 and 27.86 mg/L (Table 4.2) with removal efficiency values of 26%, 36%, 59.1% and 68.4 % ( Table 4.3) in control, low, mid and high density of *Cyprus papyrus* treatment beds respectively with in five day detention time. It had significance difference at 0.01 value of p with in treatment beds. The BOD values 27.86 mg/l obtained at the effluents in high density *Cyprus papyrus* treatment beds were under the recommended discharge standards; the WHO recommended values for discharge should not exceed 30 mg L-1 for BOD. That means plant density increase BOD removal efficiency also increase. Because when plants absorb nutrients the concentration reduced and biological oxygen demand reduced proportionally. Yadav *et al*. (2018) and Theophile *et al*. (2011) concluded that a $BOD_5$ removal efficiency 71.38% were achieved through constructed wetlands planted with *Cyprus papyrus* with gravel. Biodegradation of organic material takes place in biofilms along the roots and stems of plants, and the bed surface, enhancing the reduction of the BOD value (Stefanakis *et al*., 2014).

Biological oxygen demand (BOD) removal in wetlands is due to physical and biological processes that involve sedimentation and microbial degradation, principally by aerobic bacteria attached to plant roots. With respect to this parameter, the performance of the planted bed was higher than that of the unplanted control. This is in agreement with different authors (Naylor et al., 2003). On the other hand, the low removal rates obtained in the unplanted bed could suggest that the nitrification/ denitrification processes may have been limited by inadequate microbial activity in an unplanted gravel and sand medium, similar conclusion also by (Ciria *et al*., 2005). The high removal efficiencies for BOD and nutrients in papyrus-based CWs indicated the system's ability to treat high oxygen demanding and nutrient rich wastewater properly. This is in agreement with different authors (Kyambadde *et al*., 2005). Wastewater treated by high density BOD value 27.8 mg/l, were under irrigation water reuse (agriculture and aquaculture) EPA 2012 guide line the recommended treated wastewater maximum value 30 mg/l based on new research evidence.

4.2.4 Total suspended solid

In the current study, the average TSS value in the influent wastewater was 800.43 mg/L (Table 4.2). Following treatment in, TSS reduced to 27.8% (577.6 mg L-1) in control bed, 33.9% (528.8 mg L-1) in low density bed and reduction rate increased to 51.1% (391.1 mg L-1) and 63.7%(290 mg L-1) in mid and high density treatment beds respectively. This result indicates that when the pant density increase the TSS removal efficiency also increase. It had significance difference at 0.01. TSS greater proportional decrease with the addition of Plant density (Erina and Wiyono, 2012). The same result by Dewedar *et al*. (2018) also conclude that the removal efficiency of TSS was 51% by *Cyprus Papyrus.* This was due to the presence of vegetation and substrate such as gravel, the TSS was removed when the wastewater passes through the system at a low speed and settle down. Zurita *et al*. (2009) documented the elimination of TSS by wetlands, due to the impaction of particles onto the roots and stems of the plant or onto the gravel particles in the constructed wetland systems. The root structure of *Cyprus Papyrus* was played important functions in the treatment of wastewater by enhancing settlement and entrapment of suspended particles, increasing microbial fixation sites and surface area for adsorption of contaminants. Similarly conclude by (Perbangkhem and Polprasert, 2010).

4.2.5 Ammonia

The value of ammonia in the influent was 38.54 mg/L and decreased gradually to 19.7 mg/L, 9.87 mg/L, 8.19 and 4.42 mg/L (Table 4.2) with removal efficiency 48.8%, 74.3%, 78.7%, and 88.5%(Table 4.3) in control (unplanted), low, mid and high density of *Cyprus papyrus* treatment beds respectively. Analytical results of ANOVA and least significant difference (LSD) value confirmed that values of Ammonia had statistically significant differences at ($p<0.01$) between planted and unplanted treatment beds. The planet density affect removal efficiency especially high density has significance difference with low density. Ammonia removal is not only by plant uptake but also nitrification process ammonia change in to nitrate. Nitrification processes due to the high density of the roots and increased oxygen transport to the root zone that collectively increase the treatment surface area and improved ammonia removal performance.

Previous studies had reported comparative results. Ammonia is directly toxic to fish in the unionized form, which is favored at high temperatures and pH, and it also reduces the ability of fish to utilize oxygen**.** Yalcuk and Ugurlu (2009) could remove 61.3% of ammonia using constructed wetlands with *Cyprus papyrus*. Another study also states that Papyrus has higher ammonium-nitrogen removal (75.3%) than Miscanthidium (61.5%) and unplanted controls (27.9%) (Erina and Wiyono, 2012). They also stated that Parameter values $NH_3$ decrease proportional to the density Plant. The effluent quality of papyrus-based CWs 9.87 mg/L, 8.19 mg/L and 4.42 mg/L in low, medium and high density respectively are less than the national discharge limits of 10 mg/L for Ammonia. It had significance difference at $p<0.01$ between treatment beds. This clearly showed that plant uptake, together with other removal mechanisms such as nitrification–denitrification, microbial uptake, adsorption to plant roots and sediments, played a crucial role in biological nutrient removal from these CWs. Similar result also conclude by (Kyambadde *et al*., 2004; 2005). These results were also in agreement with Abou-Elela *et al*. (2013) who reported that nitrogen and phosphorus uptake by *Cyprus Papyrus* was better than other plants evaluated. Municipal wastewater contains high levels of pollutants since it is a collection of wastes from various sources of human activities (Tenge *et al*., 2018).

4.2.6 Nitrate

The $NO_3^-$ treatment potential of control, low, medium and high density *Cyprus papyrus* were 5.4%, 10.2%, 10.9% and 21.2%. It had significant difference planted from unplanted at $P<0.01$(Table 4.2). This reflects that conditions existed for nitrification (García-Avila *et al*., 2019). During processing, organic substances present in wastewater and undergo a process of oxidation of organic or inorganic compounds in the form of ions such as $NO_3^-$, $NH_4^+$ and so can be absorbed by Papyrus. The result showed that even if $NO_3^-$ was produced by nitrification process but lower than the $NO_3^-$ absorbed by Cyprus papyrus. This due to root rhizosphere of *Cyperus papyrus* well colonized by $N_2$ fixing bacteria and high rate of nitrogen fixation have been recorded intact root system of papyrus. Based on Negisa *et al*. (2019) *Cyprus papyrus* Municipal Wastewater removal efficiency of $NO_3^-$ were 22%. Another studies on nitrogen removal treatment have confirmed that unplanted treatment had lower nitrogen removal compared with planted treatment (Yang *et al*., 2001 and Lin *et al*., 2002).

4.2.7 Phosphate

ANOVA and Post Hoc LSD tests indicated that statistically significant differences ($p<0.01$) in removal of $PO_4^{3-}$ between planted and control treatment beds and also among planted treatment beds. All of the planted treatment beds had better efficiency in the removal of $PO_4^{3-}$ compared to unplanted treatment bed. The $PO_4^{3-}$ removal efficiency of unplanted, low ,mid and high density of Cyprus papyrus treatment beds were 20.4%, 55.1%, 73%, 75.6% respectively (Table 4.3). This was due to high density plant uptake high amount of phosphate value and produced large amount of biomass. Yezbie and Seyoum (2014) conclude that average removal efficiency for $PO_4^{3-}$ of the treatment beds was 84.05% for *C. papyrus,* and 50.20% for the control (un-planted). Erina and Wiyono (2012) reported that Papyrus showed higher phosphorus removal efficiency (83.2%) than Miscanthidium (48.4%). The removal efficiency of the plants may be due to a combination of mechanisms favored by the plants and adsorption of certain nutrients. The pollutants removal of macrophytes by plant uptake and storage affects the wastewater treatment processes in different ways, similarly (Erina and Wiyono, 2012).

4.2.8 Temprature, ph and DO

Analysis of Varian's and LSD test showed that temperature had non-significance difference between unplanted and planted treatment beds (Table 4.2). It was between 21.9-22.6 °C indicating the absence of any thermal pollution within the range of the Ethiopian effluent standard limits for T°, which are 40°C, units (EEPA, 2003). The water temperature controls the rate of all chemical reactions, and affects reproduction microorganisms. Drastic temperature changes can be fatal to fish (Patil *et al*., 2012). But there were significant difference between planted and unplanted bed and also between planted beds with different density in other parameters. Hydrogen ion concentration (pH) of the effluent 6.83, and 6.80, in high and medium density treatment beds had significant difference from control 6.51 but low density was not significant at $P<0.01$ (Table 4.2). The effect of leaving excess hydroxyl ions which cause sudden rises in the pH to around 7.82 (Lin *et al*., 2002). The dissolved oxygen (DO) influent value 1.16 mg/l increase in the treatment beds 1.17 mg/l, 1.99 mg/l , 1.993 mg/l and 2.34 mg/l in unplanted, low, medium and high density treatment beds respectively(Table 4.2). It had significance difference at $P<0.01$ among treatments. This is due to uptake of nutrient by plants reduced BOD value and increase DO value. Similar result also reported ph increase 7.2 to 7.8 and DO also increase 0.28 to 1.3 respectively influent and effluent from Cyprus papyrus treatment beds (Dewedar et al., 2006). Because plants uptake ions (acidic) the ph value becomes increased and near to neutral. All treated water temprature, ph value and high density DO value were under irrigation water reuse (agriculture and aquaculture) EPA guideline 2012 the recommended treated wastewater pH, temprature and DO value is 6.5-8.4, < 40 °C and > 2 mg/l based on new research evidence.

### 4.3 Heavy metal removal efficiency of *Cyprus papyrus*

The heavy metal concentration of the influent and effluent monitored at the inlet and the outlets of in the glass fiber tanks constricted wetlands in the configuration (Table 4.4). The monitoring of water quality in the systems showed that, the heavy metal concentration of the effluent were progressively improved upon since a dramatic decline was recorded from the inlet to the outlets of the experimental beds.

#### 4.3.1 Copper (Cu)

The Copper (Cu) in the influent was 0.56mg/L and decreased gradually to 0.39mg/L, 0.27mg/L, 0.22 mg/l and 0.19mg/L (Table 4.4) with removal efficiency 30.3%, 51.7%, 60.7%, and 66% (Table 4.5) in control (unplanted), low, mid and high density of *Cyprus papyrus* respectively. Cu value in planted treatment beds had significance difference from unplanted treatment beds at P<0.01, But also significance with in planted beds. Because Cu was accumulated into plants as an essential micronutrient, so when plant density increase cu constriction decries in treated wastewater proportionally.

Table 4.4 selected heavy metals characteristics of the effluent monitored at the inlet and the outlets of in the glass fiber constricted wetlands.

| Parameters | Influent Values (inlet) | Effluent Values ( out let) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Un Planted (control) | planted with Cyperus papyrus | | | | | | LSD | |
| | Mean | Mean | Low density | Mid density | High density | p value | CV | | 0.01 | 0.05 |
| Cu (mg/l) | 0.56 | 0.39[a] | 0.27[b] | 0.22[b] | 0.19[c] | ** | 11.8 | | 0.08 | 0.059 |
| Cr (mg/l) | 0.24 | 0.22[a] | 0.18[ab] | 0.15[b] | 0.13[b] | ** | 10.3 | | 0.06 | 0.042 |
| Zn (mg/l) | 0.62 | 0.50[a] | 0.41[b] | 0.24[c] | 0.21[c] | ** | 9.2 | | 0.05 | 0.034 |

** The mean difference is significant at the 0.01 level.
CV= Coefficient of variance
LSD=least significant difference
*The means* Values *followed by the same letter* on the same row are *not statistically s*ignificantly *different at p<0.01*

Table 4.5 Percentages Reduction selected heavy metal (Cu, Cr and Zn) of the Effluent in the plated and the unplanted glass fiber Constructed Wetlands

| Parameters | Effluent Values % removal efficiency | | | |
|---|---|---|---|---|
| | planted with Cyperus papyrus | | | Unplanted(control) |
| | High density | Mid density | Low density | |
| | Mean | Mean | Mean | Mean |
| Cu | 66 | 60.7 | 51.7 | 30.3 |
| Cr | 45.8 | 37.5 | 25 | 8.3 |
| Zn | 66.1 | 61.2 | 33.8 | 19.3 |

According to the World Health Organization (WHO) suggested that the permissible limit for Cu in drinking water was 0.05 mg L-1 (Vanetti *et al*., 2009). But the average concentration of cu in this study untreated wastewater was 0.56 mg/L. This is above ten times greater than the permissible limit of cu in drinking water. *Cyprus papyrus* was effective in removing heavy metals, but the rate of removal depends on the plant density. Cu was accumulated into plants as an essential micronutrient (Zabotto *et al*., 2020). The high density *Cyprus papyrus* treated wastewater Cu value were 0.19 mg/l which was under irrigation water reuse EPA guideline 2012 the recommended treated wastewater value Cu, reuse for irrigation (agriculture and aquaculture) was 0.2 mg/l based on new research evidence.

### 4.3.2 Chromium (Cr)

The influent concentration of Cr 0.24 mg/l reduced into 0.22 mg/l & 8.3%, 0.18 mg/l & 25 %, 0.15 mg/l & 37.5% and 0.13mg/l & 45.8% effluent concentration and removal efficiency in control, low, medium and high density Cyprus papyrus treatment beds respectively (Table 4.4 & 4.5). Cr value of Planted *Cyprus papyrus* treatment beds had significant difference compare from control at $P<0.01$. Several plant species including *Cyprus papyrus* and *Phragmites australis* have been shown to accumulate high levels of various heavy metals (Deng *et al*., 2004). My results could be supported by other studies showing the efficiency of constructed wetland system for the removal of not only nutrient and pathogenic bacteria (Dewedar et al., 2005), but also heavy metals (Batty and Younger, 2004; Deng *et al*., 2004; Maine *et al*., 2006). In addition to this the treated wastewater Cr value were 0.13 mg/l which had not significant difference with irrigation water reuse EPA guideline 2012 based on new research evidence the recommended treated wastewater Cr value, reuse for irrigation (agriculture and aquaculture) is 0.1mg/l.

### 4.3.3 Zinc (Zn)

In the current study, the average Zinc (Zn) value in the influent wastewater was 0.62 mg/L (Table 4.4). Following treatment in constricted wetlands Zn concentration reduced by19.3% (0.50mg/L) in control bed, 33.8% (0.41mg/L) in low density treatment beds and reduction rate increased to 61.2% (0.24mg/L) and 66.1%(0.21 mg/L) in mid and high density bed respectively (Table 4.4 &4.5). The planted treatment beds effluent value had significant difference compare from unplanted treatment beds even high and medium density planted treatment beds had significant change low density treatment beds at $p<0.01$. This indicates high Zn removal efficiency with high density, because of Zn was an essential micronutrient and highly required for plant metabolism. Similarly, (Papoyan *et al*., 2007). The Zn removal increased with increasing the number of plant stems and reached a maximum value (83%) (Hamad, 2020). Microbial symbionts such as mycorrhizae could influence the accumulation of metals in the wetland (Sheoran and Sheoran, 2006).

Generally density of plant directly proportional to pH and DO and inversely proportional to other parameters whereas, temperature was found under oscillation relationship. Similar result also

(Erina and Wiyono 2012). Even at low concentration of heavy metals, the effects are highly to aquatic environments and natural degradation (Carolin et al., 2017).

### 4.4 Correlation of plant density with wastewater removal efficiency Cyprus papyrus

Plant density positively correlated with wastewater treatment efficiency of Cyprus papyrus. Such as BOD (.926**), TSS (.793**), TDS (.807**), $NO_3^-$ (.686*), $NH_3$ (.886**), $PO_4 3^-$, (.922**) Turbidity (.936**), SC (.946**), Cu (.864**), Cr (.756**), and Zn (.831**) Appendix Table 3. Because when the plant density increase the nitrification, nutrient absorption rate also increase. A greater ratio of plant biomass to wetland volume can enhance the contact between plant roots and wastewater resulting in a greater nutrient removal (Zhu and Ketola, 2011).

### 4.5 compression of treated wastewater from EPA 2012 recommended irrigation water reuse standards

The effluent value of most parameters in high density Cyprus papyrus treatment beds were under EPA 2012 guide line maximum limit for irrigation of agriculture, garden and aquaculture except row eaten crop the EPA recommended BOD value less than 10 mg/l( Table 4.7). The use of reclaimed water for irrigation is allow irrigation of food crops with reclaimed water only if the crop is to be processed and not eaten raw (EPA 2012). This indicates that wastewater treated by high density of Cyprus papyrus was very important for irrigation purpose.

Table 4.7 comparison of high density treated wastewater with EPA 2012 standard recommended for irrigation water reuse maximum limit

| Parameter | High density treated effluent value | EPA (2012) standard recommended for irrigation water reuse maximum limit |
|---|---|---|
| BOD | 27.86 mg/l | 30 mg/l |
| DO | 2.34 mg/l | >2mg/l |
| TDS | 559.3 mg/l | --- |
| SC | 945.60 µS/cm | 1000 µS/cm |
| PH | 6.83 | 6.5-8.4 |
| Turbidity | 5.43 mg/l | --- |
| TA | 199.67 mg/l | --- |
| TSS | 290.0 mg/l | --- |
| $NO_3^-$ | 1.15 mg/l | 5mg/l |
| $PO_4^{3-}$ | 1.01 mg/l | --- |
| Ammonia | 4.42 mg/l | 10 mg/l |
| Cu | 0.19mg/l | 0.2mg/l |
| Zn | 0.21 mg/l | 2mg/l |
| Cr | 0.13 mg/l | 0.1 mg/l |

# Chapter 5. CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

This study was conducted for *Cyprus papyrus* substrate with garble and sand of wastewater physicochemical parameter *removal* efficiency. The result showed that it does produced large amount of biomass with in short period of time. Progressive increase above-ground dry biomass with increase the plant density. It was observed that *Cyperus papyrus planted* from the glass fiber tanks constructed wetlands significantly influenced the rate of removal of nutrients in wastewater. *Cyprus papyrus* wetlands had the ability to absorb nutrients and sequester significant amounts of carbon. *It* effectively reduced the concentrations of most physicochemical parameters and heavy metals. The result of the present work also revealed that *Cyprus papyrus* were hopeful for accumulating heavy metals.

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Generally density of plant directly proportional to pH and DO and inversely proportional to other parameters whereas, temperature was found under oscillation relationship. Because when the plant density increased the nitrification and nutrient absorption rate also increased. A greater ratio of plant biomass to wetland volume can enhance the contact between plant roots and wastewater resulting in a greater nutrient removal. The analysis showed that most measured parameters in the high density *Cyprus papyrus* treated wastewater effluent value were under the EPA 2012 recommended maximum limits for irrigation. So it could be used for irrigation of agriculture, garden and aquaculture except row eaten crop the EPA recommended BOD value less than 10 mg/l. These results allow us to conclude that *Cyperus Papyrus* could be a species of macrophyte ideal for wetlands built on a large scale, due to its high elimination efficiencies.

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## 5.2 Recommendation

According to the results obtained, the construction of wetland planted with *Cyperus Papyrus* is recommended because it achieved high yields in the elimination of both physical and chemical pollutants present in wastewater. Moreover, the high density *Cyprus papyrus* effluent treated wastewater can further be reused for agricultural purposes without significant causing health-related hazards to the farmers, given that the measured parameters in the effluent were within the standard recommended EPA guide line 2012 maximum limits irrigation water reuse except raw eat crops. These results suggested that Cyprus papyrus had capacity to enhance the treatment process and that use of *Cyprus papyrus* wetlands in wastewater treatment should be encouraged in Ethiopia. *Cyrus papyrus* shall be expanded in the shores of Lake Tana.

The development of this experimental system into a large-scale pilot unit offers an attractive alternative for low-level income countries (community) to reduce pollution, carbon sink, protect the environment, traditional and economical importance. *Cyperus papyrus* occur locally in tropical regions like Ethiopia. The study suggests that these macrophytes possess high biomass production and remove nutrients, thus making constructed treatment wetlands incorporating these macrophytes vegetation is a promising wastewater treatment option for wider application.

The study was conducted only in one macrophyte species (*Cyprus papyrus*), so the government and another concerned body should select different environmental friendly and efficient wastewater treatment potential spices, and another investigation should be conducted.

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# APPENDIX

Appendix Table 2 field and laboratory raw data

| Treatment | TDS( mg/l) | TSS (mg/l) | TA (mg/l) | BOD (mg/l) | DO (mg/l) | TU (NTU) | SC | Temprature (°C) | ph | $NO_3^-$(mg/l) | Ammonia (mg/l) | $PO_4^{3-}$ (mg/l) | Cu | Cr | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Influent(untreated) | 704 | 820.5 | 363.3 | 90.9 | 0.7 | 35.58 | 1499.3 | 22.5 | 6.4 | 1.49 | 15.83 | 4.7016 | 0.4633 | 0.211 | 0.490 |
| Control | 655 | 566.8 | 263.3 | 65.1 | 1.16 | 20.55 | 1372.5 | 22.0 | 6.5 | 1.35 | 18.7 | 3.292 | 0.388 | 0.23 | 0.485 |
| Low density | 632 | 538.8 | 227.1 | 57.4 | 1.95 | 16.8 | 1353.3 | 22.46 | 6.7 | 1.20 | 9.36 | 2.0633 | 0.3108 | 0.177 | 0.425 |
| Medium density | 616 | 381.0 | 228.5 | 37.2 | 2.07 | 9.95 | 1017.6 | 22.45 | 6.71 | 1.37 | 8.66 | 1.02 | 0.2295 | 0.165 | 0.205 |
| High density | 586 | 326.7 | 205.7 | 30.2 | 2.53 | 5.4 | 931 | 22.6 | 6.9 | 1.06 | 4.091 | 0.91 | 0.2041 | 0.13 | 0.212 |
| Influent | 694 | 780 | 244 | 85.5 | 1.63 | 30.39 | 1449.7 | 22.84 | 6.3 | 1.44 | 61.25 | 4.87 | 0.6646 | 0.258 | 0.766 |
| Control | 650 | 578.4 | 263.3 | 65 | 1.2 | 20.95 | 1317.6 | 22.58 | 6.63 | 1.37 | 20.5 | 3.52 | 0.387 | 0.235 | 0.506 |
| Low density | 580 | 518.5 | 237.1 | 53.3 | 2.01 | 17.81 | 1290.3 | 22.7 | 6.8 | 1.33 | 11.61 | 1.9916 | 0.3 | 0.188 | 0.416 |
| Medium density | 592 | 401.0 | 229.3 | 35.2 | 1.91 | 10.3 | 1071.3 | 21.18 | 6.8 | 1.257 | 8.583 | 1.22 | 0.1766 | 0.158 | 0.276 |
| High density | 590 | 246.7 | 203.3 | 25.9 | 2.4 | 5.7 | 1001.5 | 21.77 | 6.7 | 1.19 | 4.6 | 1.12 | 0.205 | 0.125 | 0.208 |
| Influent | 699 | 800.8 | 303.65 | 88.2 | 1.16 | 33 | 1499.5 | 22.67 | 6.1 | 1.46 | 38.54 | 2.8918 | 0.5639 | 0.235 | 0.628 |
| Control | 652.5 | 587.6 | 273.3 | 65.55 | 1.17 | 21.97 | 1395.05 | 22.81 | 6.4 | 1.41 | 19.9 | 3.09 | 0.389 | 0.200 | 0.509 |
| Low density | 612 | 528.9 | 250 | 58.4 | 2.02 | 17.43 | 1196 | 22.66 | 6.8 | 1.4 | 8.667 | 1.528 | 0.1985 | 0.161 | 0.400 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Medium density | 586 | 391.5 | 294.2 | 35.8 | 1.9 | 8.65 | 1033 | 22.32 | 6.9 | 1.31 | 7.33 | 1.12 | 0.243 | 0.113 | 0.243 |
| High density | 502 | 296.6 | 190 | 27.5 | 2.1 | 5.2 | 904.3 | 22.6 | 6.9 | 1.20 | 4.56 | 1 | 0.181 | 0.131 | 0.227 |

# Author's biography

Abere Amogn Demeke was born in 1992 and grew up in a rural area, Koti kebele in Yilmana Densa District, west Gojjam Administrative Zone, Amhara National Regional State, Ethiopia. He holds bachelor's degree in Natural resource management /Narm/ with 3.92 CGPA from Debre markos University, Ethiopia in Jun 2013. After this he was done in trade and transport offices for one year, Technical Vocational Education and Training/ TVET/ college for two years in Amhara National Region State, Soil physics and chemistry laboratory technician in department of Natural resource management /Narm/ College of Agricultural and environmental Sciences Bahir Dar University for one year. The author joined Department of Natural resource management /Narm/ in College of Agricultural Sciences Arba Minch University since 2017. After five years' work experience he joined in Bahir Dar University since 2018 for master's degree in Environment and climate change. Climate change and variability, wastewater management, soil and forest carbon sequestration, Ecology and Application of GIS and remote sensing in environmental management are the author's interest areas of research.