SUSTAINABILITY OF HYBRID FLOW CONSTRUCTED WETLAND TREATMENT FOR COFFEE WASTEWATER: THE CASE OF KEGE WET COFFEE PROCESSING PLANT, GIDABO RIVER WATERSHED, ETHIOPIA

MSc THESIS

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DECLARATION

I hereby declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis/dissertation have been duly acknowledged.

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We, the undersigned, members of the Board of Examiners of the final open defense by HEWAN TADESSE have read and evaluated her thesis entitled "SUSTAINABILITY OF HYBRID FLOW CONSTRUCTED WETLAND TREATMENT FOR COFFEE WASTEWATER: THE CASE OF KEGE WET COFFEE PROCESSING PLANT, GIDABO RIVER WATERSHED, ETHIOPIA", and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANAMMOX	Anaerobic Ammonia Oxidation
BOD	Biological Oxygen demand
CW	Constructed Wetland
CWs	Constructed Wetlands
COD	Chemical Oxygen Demand
CPP	Coffee processing plant
CPWW	Coffee processing Wastewater
DO	Dissolved oxygen
EC	Electric-Conductivity
EEPA	Ethiopian Environmental Protection Agency
HFCW	Hybrid Flow Constructed Wetland
HSSF-CWs	Horizontal Subsurface Flow Constructed Wetlands
NbS	Nature-based Solutions
SDGs	Sustainable Development Goals
SPSS	Statistical Package for the Social Sciences
SSF-CWs	Subsurface Flow Constructed Wetlands
TDS	Total Dissolved Solid
TSS	Total Suspended Solid
TP	Total Phosphorus
TN	Total Nitrogen
VSSF-CWs	Vertical Subsurface Flow constructed Wetlands
WW	Wastewater

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ABSTRACT

Constructed wetlands (CWs) are treatment systems for treating wastewater with natural methods using wetland plants. This study evaluated the sustainability of hybrid flow-constructed wetlands (HFCW) planted with vetiver grass for coffee wastewater at the Kege Coffee Processing Plant. The wetland carried a hydraulic loading rate of $64m^3/d$ *and it was evaluated for six different detention times(DT) which were 0.5 days, 1 day, 2 days, 3 days, 4 days, and 5 days. Samples were collected starting from November to January of the year 2021 which is the dry season of the study area. IBM SPSS was used for the analysis of data with One-way statistical analysis of variance (ANOVA) and descriptive analysis. The treatment of the HFCW was tested by analyzing water quality parameters; temperature, turbidity, electrical conductivity (EC), pH, TSS, TDS, DO,* BOD_5*, COD,* NH_3*-N,* NO_3*-N,* PO_4^{3-}*, and* NO_2*-N. The effluent concentrations of these parameters from the constructed wetlands significantly became to the standard limit with an increase in detention time for pH, DO, TSS, turbidity,* PO_4^{3-}*,* NH_3*-N,* BOD_5*, and COD at* $p \leq 0.05$*. But for temperature, EC, TDS,* NO_2*-N, and* NO_3*-N effluent concentration were not significantly changed (*$p>0.05$*). Additionally, percentage concentration removal was increased for TSS, turbidity,* BOD_5*, and COD. However, temperature, EC, TDS,* PO_4^{3-}*,* NH_3*-N,* NO_2*-N, and* NO_3*-N ensure variation with DT. On the other hand, river water quality parameters revealed statistically non-significance (*$p>0.05$*) values between upstream and downstream of the river. River water quality parameter results were below the FAO irrigation water standards except for temperature. Furthermore, from the survey conducted 85.40% of the respondents have awareness of the importance of constructed wetlands and from the total 103 respondents 98.4% of them were recognized to socially accept the CW and 63.11% of them state that the environmental pollution decreases through the constructed wetland. From the respondents, 85.49% of them described that the CW has an economical purpose too (they sell the grass for purposes of house cover, local bed, and animal forage) in addition to the treatment of wastewater (WW). However, 71.43% of the CPP owners responded that the CW was not efficient to carry the WW discharge per day as their processing capacity increases year to year and its sustainability may be at risk due to this. Finally, CW treatment for coffee processing wastewater with an engineered design should be a way out for the current pollution of the Gidabo river watershed.*

Keywords: - Kege coffee processing plant, vetiver grass, constructed wetlands, coffee wastewater, Gidabo River watershed, hybrid flow, and coffee processing plant

1. INTRODUCTION

1.1. Background

Currently, almost all developed countries are trying to adapt to treat wastewater by modifying their processes (Woldesenbet et al., 2015). Wetlands have been involved in the cleaning of wastewater. In the previous century, artificial wetlands started to be constructed to treat different kinds of wastewater, and in the last decades, constructed wetlands (CWs) have been developed into fully engineered systems (Carvalho *et al*., 2017). Similar to these CWs have always been a familiar wastewater management option over the past several years, and have been accepted as effective approaches to traditional wastewater management processes. This is due to the increased effectiveness in removing pollutants, simple construction and operation, lower power requirements, high wastewater management rates, and the possibility to provide substantial natural habitats (Rahman *et al*., 2020).

Constructed wetlands are reasonable and reliable green technologies for the treatment of various types of wastewater (Rahman et al., 2020). Constructed wetlands are attached-growth biological filters that are distinguished from other treatment processes by the use of plants that are adapted to grow in saturated environments (Dereje, 2019). CWs can be classified as free water surface or subsurface flow systems, and a mixture of multiple wetland technologies is recognized as hybrid CWs (Makopondo *et al*., 2020; Rahman et al., 2020)

Coffee processing method can be either dry or wet. The most used coffee processing method in Ethiopia is wet coffee processing methods. In wet coffee processing, a high amount of wastewater is produced and coffee contains over 1500 chemical substances, 850 volatile and 700 soluble, and when prepared correctly involves 13 independent chemical and physical variables (Woldesenbet *et* *al*., 2015). The discharge of untreated wastewater is a major supplier to worsening health conditions and pollution of nearby water bodies (UN-HABITAT, 2008).

Constructed wetlands for wastewater treatment have environmental, social, and economic benefits. It involves adapting to specific site conditions and targeting specific pollutant loads, dependence on solar energy for the treatment processes, protecting vital ecosystems such as rivers and lakes, providing wildlife habitat, creating green areas, and eliminating the use of chemical products as an environmental benefit. Social benefits; leads to society's interaction with wastewater treatment, increasing awareness and education about water problems, and providing great public and regulatory agencies of the. And economical construction, operation, and maintenance costs, used as income generation for example as a recreational area (ElZein *et al*., 2016).

This study was conducted at Gidabo River watershed (southern Ethiopia) which is one of the coffee-producing areas of the country. The sustainability of the hybrid flow constructed wetland coffee wastewater treatment for physical and chemical parameters with an interview survey conduct was assessed.

1.2. Statement of the problem

Coffee processing wastewater is one of the most agro-processing wastes that require payable attention because of its polluting potential due to huge coffee production worldwide (Minuta & Jini, 2017). The wet processing system produces a high volume of polluted effluent which is traditionally discharged easily into the nearby stream or river. And then it required 15–20 liter amount of water for the processing of approximately 1 kg of coffee beans (Dadi et al., 2018). While washed or semi-washed coffee is processed in large quantities, untreated effluents greatly exceed the self-purification capacity of natural waterways (Calvert *et al*., 2014). Coffee wastewaters are high in organic loadings and exhibit a high acidity. Coffee waste is also generally made of a high concentration of suspended solids (Navitha K R & Hina Kousar, 2018).

Coffee wastewater effluents released into the river cause severe illnesses (skin irritation, stomach pain, nausea, and breathing problem) generated by the wet mill (wet processing plant). Therefore, it needs a critical set up of waste management policies which include the way of effluent treatment before unwisely discharging to the environment and alternative waste utilization opportunities (Duguma & Chewaka, 2019).

In most of the coffee-producing areas of Ethiopia, water use conflict and pollution of the river at different locations of the country, there is no conventional storm and wastewater collection and treatment system for coffee processing plants (industries) to Rivers. Practices of illegal disposal of wastewater were identified among the causes of pollution of the Gidabo river and its tributaries (Tekle, 2017). Therefore, different investigators approved that the release of untreated effluents and other solid by-products significantly affects the quality of river water (Duguma & Chewaka, 2019). Generally, coffee effluent discharges are increasing the pollution level of streams and rivers nearby coffee processing plants.

Even if, the treatment of coffee effluents before discharging into the surroundings can block the risk of environmental pollution, poor operation and maintenance of the constructed wetlands is another problem. First, plant varieties including media characteristics are serious variables in the elimination efficiency of CWs because they are regarded as the key biological feature of CWs and alter the key elimination systems of contaminants directly or indirectly across the period. In the second position, the management efficiency of CWs is highly dependent on the optimum operational variables (water depth, hydraulic retention time along with load, and feeding mode including setup configuration) that could occur in variability in the efficiency of elimination of pollutants (Rahman *et al*., 2020).

1.3. Objectives of the study

1.3.1. General objective

The main objective of this study was to assess the sustainability of the hybrid flow constructed wetland treatment for coffee processing wastewater effluents.

1.3.2. Specific objectives

- To analyze the pollutant removal of the HFCW in coffee processing effluent load with physicochemical parameters test at six different detention times; and soil & plant nutrients test.
- To compare the physicochemical characteristics of the Gidabo River watershed upstream and downstream of the coffee processing plant.
- To assess the socio-economic and environmental implications of the HFCW for its future functionality.

1.4. Research questions

This study was intended to answer the following research questions.

- What were the percentage concentration removals of the constructed wetland as well as the physical and chemical characteristics of the effluent as compared to the wastewater discharge standard within the detention times?
- What amount of nitrogen, phosphorus, and potassium nutrients are there on the soil and plant of the HFCW as compared to the control group?

- What were the physicochemical characteristic of the river upstream and downstream of the processing plant?
- What were the responses of the people to the social, economic, and environmental implications of the constructed wetlands for its sustainable use?

1.5. Hypothesis

- Detention time of the coffee wastewater on the HFCW affects the concentration of the parameters.
- Discharging coffee wastewater effluent treated with HFCW to the nearby water body has no impact on the quality of river water.
- Above 50% of the community survey respondents have a positive response on the implication of the constructed wetland.

1.6. Significance of the study

This study will pave the way for alternative use of coffee processing wastewater treatment by determining the efficacy of the hybrid flow constructed wetland and provide more attention to the problems of improper discharging of effluents to rivers or streams. In addition to this, the study has two main significances. First, it gives guideline information to the environmental protection office of the woreda as well as the region about the existing situation related to wet coffee processing wastewater treatment with constructed wetlands. Secondly, the study is used as baseline information for other studies that would like to conduct further detailed investigations. Generally, this study benefits coffee processing plant owners by showing the necessity of the treatment wetlands to protect their health and their surrounding environment from different impacts of wastewater.

1.7. Scope of the study

This study was conducted to study the sustainability of hybrid flow constructed wetland treatment for coffee wastewater in the Gidabo River watershed, particularly for Kege wet coffee processing plant. The hybrid flow CW treatment efficiency was determined and analyzed for different physical & chemical water quality parameters within six different detention times and a hydraulic loading rate of $64m^3/d$. These parameters are hydrogen ion (pH), temperature, turbidity, total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate-N, phosphate, ammonia-N, nitrite-N, dissolved oxygen (DO), and electric-conductivity (EC). In addition to this, the river water quality at the upstream and downstream sides of the wetland was determined for all the above parameters. Finally, an interview survey was conducted for the implication of the wetland.

1.8. Limitations of the study

The study was only limited to a specific place, particularly at the Kege coffee processing plant (CPP) of the Gidabo River Watershed. It was tested to specific parameters as mentioned in the scope of the study. The parameters were also tested for one season coffee harvesting period and the soil and plant samples were taken once at the end of the wastewater (WW) sampling because of the time and financial limits. Biological parameters of the wastewater were not included in this study due to the absence of laboratory materials at that particular time but to know the exact efficacy of the HFCW evaluating the biological parameters is essential. And then the layout and analysis of the constructed wetland was limited with non-consideration of control group except for the soil and nutrient tests.

2. LITERATURE REVIEW

2.1. An overview of constructed wetlands

Constructed wetlands (CWs) are engineered systems built for sewage treatment utilizing normal processes of soil, substrate, plant, and microorganism with a synergistic combination of physical, chemical, and biological purposes (Wu *et al*., 2015). The capability of wetlands to filter, absorb, and metabolize suspended and dissolved matter is the essential esteem behind constructed wetlands (Ulsido, 2014). CWs are one of the natural wastewater treatment systems for treating wastewater with natural approaches and using wetland plants (Dereje, 2019).

Compared to conventional treatment systems, CWs offer an environmentally friendly approach, are low cost, have fewer operational and maintenance requirements, and have a high potential for being applied in developing countries. And have been visualized as cost-effective wastewater treatment know-hows suitable for developing countries (Makopondo *et al*., 2020).

2.1.1. Classification of constructed wetlands

Many types of CWs differ in their main design characteristics as well as in the processes responsible for pollutant removal. The classification of constructed wetlands is based on the type of vegetation used and the hydrological parameters involved (Messo Raude, 2018). According to (Makopondo *et al*., 2020) CWs can be classified based on different parameters. Under hydrological variables, CWs can be classified as free water surface or subsurface flow systems. Further, subsurface flow systems can be classified according to flow direction as either vertical or horizontal (Messo Raude, 2018). Same to that (Wu *et al*., 2015; Dittrich et al., 2021) also classify these as free-surface flow systems (FSF-CW) and subsurface flow systems (SSF-CW). SSF-CWs can be further divided according to the direction of the wastewater flow. Wastewater in SSF-CWs runs either horizontally (in horizontal subsurface flow constructed wetlands (HSSF-CWs)) or vertically (in vertical subsurface flow constructed wetlands (VSSF-CWs)) towards the filter media. In VSSF CWs, there is unsaturated, non-permanent flow, and in HSSF CWs there is ~~s~~aturated non-permanent flow.

In recent time studies mixture of multiple wetlands, technologies are recognized as hybrid CWs, further incorporated for wastewater recovery, and this configuration is usually composed of two phases of multiple models parallel CWs, like vertical flow with the hybrid flow (VF-HF) CWs, hybrid flow with the vertical flow (HF-VF) CWs, and hybrid flow with free water surface flow (HF-FWS) CWs, as well as free water surface flow with hybrid flow (FWS-HF) CWs. Moreover, multiple-stage CWs consisting of more than three CW steps are utilized. Augmented CWs like manmade ventilated CWs, baffled flow CWs, hybrid tower CWs, and step-feeding CWs together with circular flow corridor CWs have been introduced in current years to progress the efficiency of wastewater recycling processes (Rahman *et al*., 2020).

A. Surface flow constructed wetlands

Surface flow (SF) or free-water surface constructed wetland (FWS CW) as its name suggests, wastewater flows across the atmospheric soil. Long retention times and a substantial surface area touching base with running water deliver an effective separation of particulate matter and organic matter. The sediment, plant biomass, and plant litter surfaces are the areas where most of the microbial activity affecting water quality occurs as well as the oxidation of organic matter and transformation of nutrients (Makopondo *et al*., 2020).

FWS CWs are very effective in the removal of organics through microbial degradation and the removal of suspended solids through filtration and sedimentation. Removal of nitrogen is variable and the magnitude of reduction depends on many factors including inflow concentration, the chemical form of nitrogen, water temperature, season, organic carbon availability, and dissolved oxygen concentration and then ammonia is most effectively removed through nitrification in aerobic zones of the water column followed by denitrification of nitrate in anaerobic zones in the litter layer at the bottom (Vymazal, 2011).

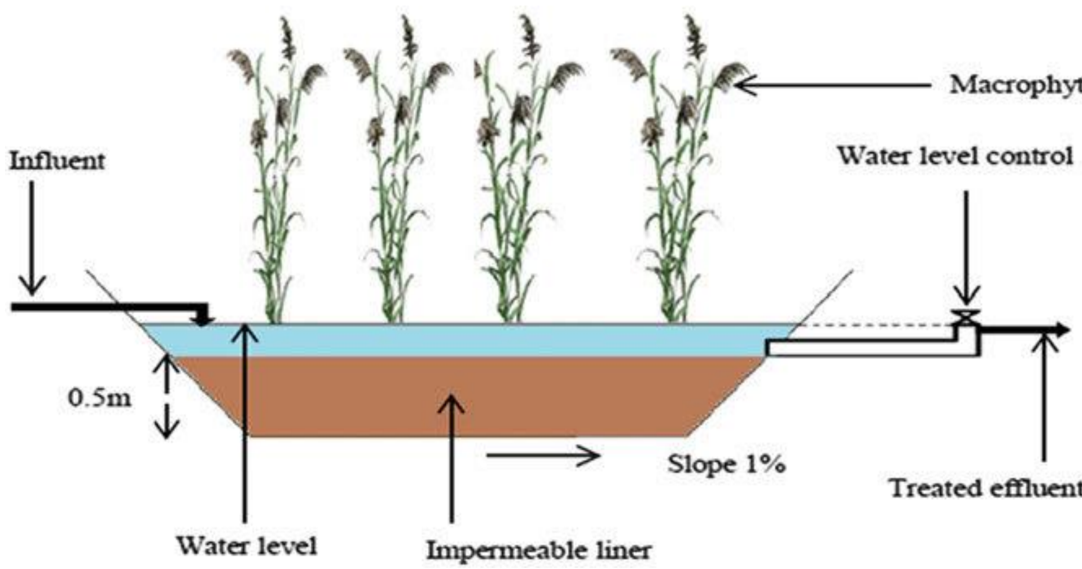

Figure 2.1: Surface flow CW (Source: Fletcher et al., 2020)

B. Subsurface flow constructed wetlands

The amounts of water in these structures are below the substratum floor. They are also complemented by a robust media root network of new power plants. In soil sand and gravel-based humid zones, CW with the subsurface flow may be graded horizontally or vertically according to the direction of flow (Makopondo *et al*., 2020).

a. Vertical subsurface flow constructed wetland

VSSF CWs are shallow excavations or above-ground constructions with an impermeable liner, either synthetic or clay, characterized by intermittent (discontinuous) loading and resting periods where wastewater percolates vertically through the substrate. Intermittent and batch loading enhance oxygen transfer and thus nitrification. The main purpose of plant presence in a VFS is to help maintain the hydraulic conductivity of the bed (Makopondo *et al*., 2020).

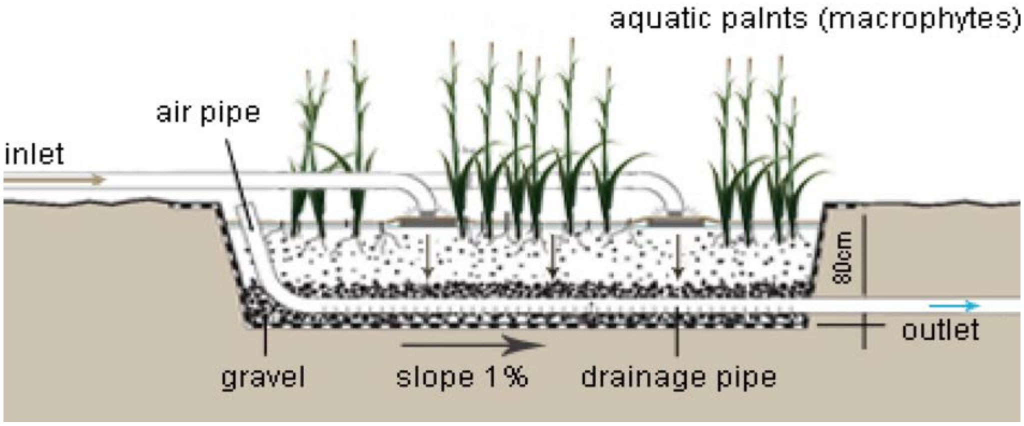

Figure 2.2: Vertical sub-surface flow CW (Source: Onyango *et al*., 2009)

b. Horizontal subsurface flow constructed wetland

Wastewater is pumped into the inlet in horizontal flow systems and gradually flows into the porous environment below the surface of the bed on the horizontal path to the outlet zone where it is collected before exiting at the outlet through a control system level (Makopondo *et al*., 2020).

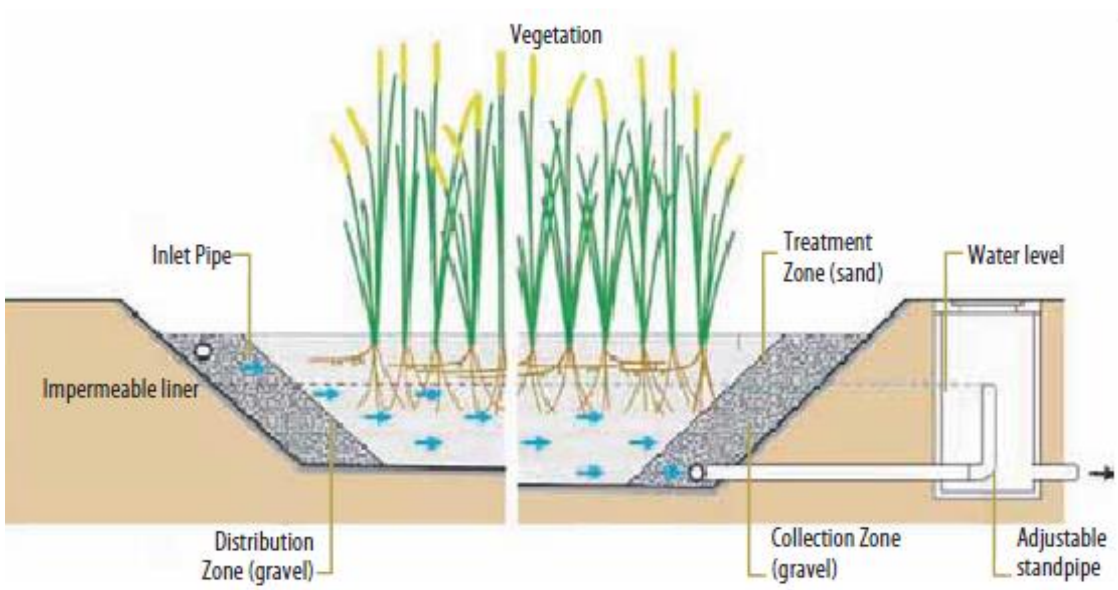

Figure 2.3: Horizontal subsurface flow CW (Source: UN-HABITAT, 2008)

C. **Hybrid Flow Constructed Wetland**

In this system, a mixture of multiple wetland technologies is recognized as hybrid CWs, the advantages of the HSSF and VSSF systems can be combined to complement each other to achieve a higher treatment effect (Rahman *et al*., 2020).

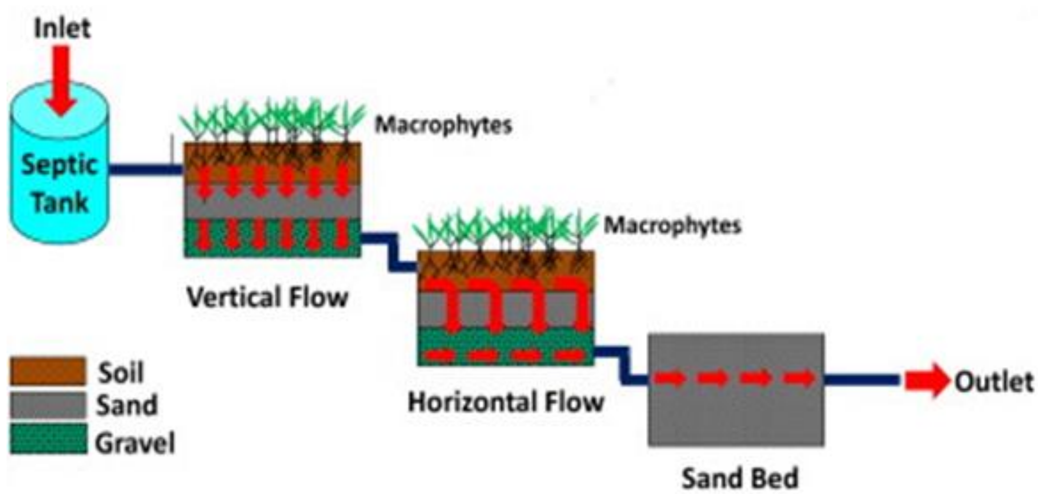

Figure 2.4: Hybrid flow CW (Source: Sehar *et al*., 2015)

2.2. Constructed wetlands wastewater treatment performance

Constructed wetlands serve as important nature-based facilities that aid in environmental restoration and sustainable development. The degree of treatment by CW depends upon the length of hydraulic retention time, type of filter media, plant species used, and nature of microbial consortia. Longer retention time speeds up the treatment of contaminants, although, too-long retention times can have negative effects (Shukla *et al*., 2021)

Based on the study (Choi *et al*., 2021) the effectiveness in pollutant reduction was found to be in the order of organics > nutrients > particulates. As compared to the conventional pollutant removal-based efficiency evaluation, the comprehensive evaluation method provided a more strategic tool for identifying the facilities' strengths and weaknesses.

Treatment of BOD, COD, nitrogen, phosphate, and pathogens are parameters of primary treated sewage in a CW and it was facilitated by a combination of various natural processes including physical, chemical, and biological processes (Shukla *et al*., 2021). Different types of CWs differ in their main design characteristics as well as in the processes liable for pollutant removal. Therefore, Hydrodynamic conditions and hydraulic residence time influence the removal efficiency of pollutants concern and play a critical role in performance evaluation. In the modeling of treatment systems understanding hydraulic residence time is a fundamental requirement in performance evaluation. In general, the performance of constructed wetlands is good for the removal of suspended solids and organic matter (in terms of COD and BOD_5) but varies and is often poor for nutrient nitrogen and phosphorus (N&P) reduction (Messo Raude, 2018).

2.2.1. Pollutants removal mechanisms

In CWs several nitrogen removal processes take place these are Ammonification, nitrification, denitrification, adsorption, adsorption, and uptake through vegetation and volatilization are the most significant removal ways (Angassa et al., 2019).

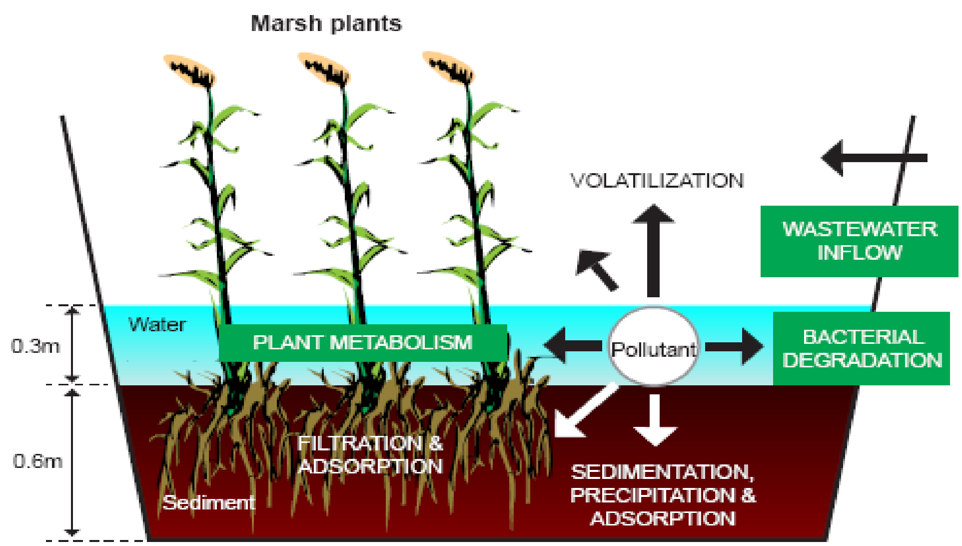

Figure 2.5: Pollutant removal processes in a constructed wetland system (source: Ulsido, 2014)

a. Volatilization

Volatilization may be a significant way for nitrogen removal in constructed wetlands with open water surfaces in the form of ammonia where algal buildups can create high pH values during the day by their photosynthetic activity. In systems with high concentrations of plankton or periphytic algae pH can range values up to greater than 10.0 during the day, thus providing proper environments for ammonia volatilization (Vymazal, 2018).

b. Nitrification and denitrification processes

Nitrification involves the oxidation of ammonia into nitrite and nitrate by autotrophic bacteria in aerobic conditions. Nitrification is influenced by temperature, pH value, alkalinity of the water, inorganic carbon (C) source, moisture, microbial population, and concentrations of ammonium-N and dissolved oxygen (Vymazal, 2018).

Denitrification is the conversion of nitrate to di nitrogen gas (N_2) by heterotrophic bacteria with the help of organic matter and anoxic conditions. It is a process in which organic compounds are decomposed by microorganisms using nitrate instead of oxygen as an electron acceptor (Angassa et al., 2019)

c. Ammonification

Ammonification is a process in which organic nitrogen is converted into ammonia biologically. Ammonia is converted from organic forms through a complex, energy-releasing, multistep, biochemical procedure. In some cases, this energy is used by microorganisms for growth, and ammonia is directly combined into microbial biomass. A large portion (up to 100%) of the organic nitrogen is freely converted to ammonia (Vymazal, 2018). Ammonification is affected by pH, temperature, the ratio of carbon to nitrogen, nutrient availability, and the type of substrate (Angassa et al., 2019).

Table 2.1: Nitrogen transformation in (constructed) wetlands (Vymazal, 2018)

Process	Transformation
Volatilization	Ammonia-N(aq) $\longrightarrow$ ammonia-N (g)
Ammonification	Organic –N $\longrightarrow$ ammonia-N
Nitrification	Ammonia-N $\longrightarrow$ Nitrite-N $\longrightarrow$ Nitrate-N
Nitrate-ammonification	Nitrate-N $\longrightarrow$ Ammonia-N
Denitrification	Nitrate-N $\rightarrow$ Nitrite-N $\rightarrow$ gaseous N_2, N_2O
N_2 Fixation	Gaseous N_2 $\rightarrow$ Ammonia-N $\rightarrow$ Organic_N
Plant/microbial uptake (assimilation)	Ammonia-, nitrite-, nitrate-N $\rightarrow$ Organic-N
Ammonia adsorption, organic nitrogen burial, ANAMMOX (anaerobic ammonia oxidation)	Ammonia-N $\longrightarrow$ gaseous N_2

2.2.2. Removal of nutrients in constructed wetlands

The performance and efficiency of CWs regarding pollutant removal from the wastewater are governed by its components like growth media, plants, microbes, and pattern of water flow in the wetland system. CWs are highly efficient in removing organic loads such as BOD, COD, nitrogen (nitrate, ammonia), phosphate, and pathogens from wastewater (Shukla *et al*., 2021).

A. Nitrate-Nitrogen removal

CWs have been proven successfully in removing nitrogen in an economical and ecologically sustainable way from municipal wastewater and industrial wastewater. The removal process of nitrogen from CW is regulated by various steps. These are volatilization, ammonification, nitrification/denitrification, and plant uptake. In wetlands, the main removal mechanism for nitrogen is essentially a microbial process, which consists of nitrification followed by denitrification. Organic nitrogen is converted to ammonia in the wetland by the process of decomposition and mineralization. Biological nitrification followed by denitrification is a major pathway for nitrogen removal in wetlands (Shukla *et al*., 2021).

B. Phosphate-Phosphorus removal

Phosphate is required for biological growth, but an excess of phosphate leads to eutrophication and other water quality issues within the ecosystem. Phosphate removal mechanisms in wetlands include adsorption, filtration, precipitation, assimilation, and sedimentation. The configuration of CW provides broad uptake of phosphate by biofilm, plant growth as well as by sedimentation and filtration of suspended materials. It is stored in sediments, biota, and water. The process of phosphate removal in CW depends upon redox chemistry, pH, and temperature of the wetland. At low oxygen, concentration phosphate is liberated from the sediments and if the anaerobic condition is not reversed it leaves the wetland. Due to the limited contact opportunity between the wetland and phosphate, its removal in most of the CWs is not very efficient (Shukla *et al*., 2021).

Phosphorous is typically present in wastewaters as orthophosphate, dehydrated orthophosphate (polyphosphate), and organic phosphorous (Dereje, 2019). Constructed wetlands can be possible efficient natural technologies usable to remove P from wastewater and plant species play different contributions to P removal. For the other studied species, P removal was always due to higher than half of the input dose at precipitation. Regularly, considering aboveground biomass, T. latifolia was also the species with the highest value for P uptake: total P supplied ratio (21.8%) whereas other species did not differ among them (average 6.5%) (Maucieri *et al*., 2020). FWS CWs provide sustainable removal of phosphorus but at relatively slow rates. Phosphorus removal occurs from adsorption and precipitation but in the FWS system, it is limited by little contact between the water column and the soil (Vymazal, 2011).

C. BOD removal

Soluble BOD_5 is removed by the microbial growth on the media surfaces and attached to the plant roots and rhizomes penetrating the bed. Some oxygen is believed to be available at microsites on the surfaces of the plant roots, but the remainder of the bed can be expected to be anaerobic (Dereje, 2019). Different studies results show that less than 10g/m^2/day BOD loading reduces BOD up to 30mg/l with 80-90 % removal of BOD **(**Jethwa, 2021).

Table 2.2: BOD loading and removal (as reviewed by (Jethwa, 2021))

S. No.	Authors	Inlet BOD	Outlet BOD
1	EPA	4.5 g/m^2	<30mg/l
2	Hammer	10 g/m^2	<30mg/l
3	Schierup et.al	5 g/m^2	80-90% removal
4	Klomjek and Nitisoravut	11.2-13.8 g/m^2	50% removal
5	Sohair et.al	2.52 kg/m^3/d	92.8%

D. COD removal

Among the subsurface flow wetland systems planted with Vetiver grass, the hybrid system achieved significantly ($p \leq 0.05$) the lowest mean effluent COD of 20.19 mg/L followed by the vertical system at 31.06 mg/L. In the planted systems CW achieved significantly ($p \leq 0.05$) lower mean effluent COD compared to the unplanted systems with the planted hybrid system being the best in COD removal. The planted hybrid system achieved a lower mean effluent COD of 20.19

mg/L compared to the unplanted hybrid system at 38.91 mg/L as Vetiver grass played a significant role in utilizing nutrients such as N and P from wastewater (Austine, 2017).

E. TSS removal

The inlet concentrations of suspended solids vary from very low levels (< 20 mg/L) for systems constructed for tertiary treatment, to adequate for systems constructed for secondary treatment. Outlet concentrations are generally less than 20 mg/L and often less than 10 mg/L. Higher outlet concentrations are generally caused by planktonic production in open water areas of the systems. Generally, the removal of TSS is more rapid than the removal of BOD (Dereje, 2019).

2.2.3. Nutrient uptake in soil and plant at constructed wetlands

As discussed by Kenatu *et al.* (2019) the presence of plants can influence the removal of nitrogen and phosphorus. High above-ground biomass accumulated more nitrogen than phosphorus for leaf and stem growth and development. Plant length and leaf shape also influence nutrient removal. Plant harvesting increases nutrient uptake and biomass production by improving plant growth and the performance of the CW. However, in temperate climates, plant harvesting is insignificant for N and P removal, in tropical climates, where plants grow quickly and throughout the year, the nutrient uptake of the plant is high and harvesting would possibly contribute to significantly higher nutrient removal.

Oxygen is transported from the air through the plant into the rhizome (root zone) and from the soil too (Ulsido, 2014). Plant root hairs and rootlets provide an aerobic environment by rising internal air spaces that transport O_2 (nearly 90%) to the root zone. This aerobic environment supports the activities of aerobic microorganisms that in turn facilitate the decomposition of organic matter and inorganic substances in water through degradation and nutrient uptake (Safia et al., 2015).

2.2.4. The role of emergent vegetation in constructed wetlands

Vegetation plays a critical role in the performance of constructed wetlands and hence selection of the most efficient vegetation type is important. The vegetation not only absorbs pollutants from wastewater but their roots prevent wastewater from taking preferential paths in the substrate that can result in hydraulic short-circuiting which would consequently reduce the retention time in the wetlands (Austine, 2017). The roots also provide a large surface area for the attachment of micro-organisms that degrade the organics in the wastewater (Wu *et al*., 2015). Many studies have used different macrophytes such as Phragmites australis, Typha latifola, and Scripus species by (Dereje, 2019), Vetiver grass (Austine, 2017), and Phragmites karka (Angassa et al., 2019) for wastewater treatment. Also, plants in constructed wetlands are known to be good water filters since they can tolerate high concentrations of trace elements (Messo Raude, 2018).

A. Vetiver grass (*Chrysopogon Zizanioides*)

Constructed wetlands planted with vetiver grass performed significantly better compared to the others in pollutant removal (Austine, 2017). Vetiver grass is a tall (1–2 m), fast-growing, perennial tussock grass. It has a long (3–4 m), massive and complex root system, which can be penetrated the deeper layers of the soil. The dense high fiber, a fine root system that forms an enormous volume accelerates habitat for many symbiotic bacteria, and fungi making the ecology system naturally contribute to the pollutant uptake. Additionally, can absorb large amounts of environmental pollutants such as heavy metals pesticides/herbicides, and petroleum hydrocarbon without effect its growth (Nur *et al*., 2017).

Vetiver grass (*Chrysopogon zizanioides*) has gained wider acceptance in wastewater treatment due to its ability to succeed in unfavorable environments. Vetiver grass can tolerate a wide range of pH, salinity, sodicity, acidity, and heavy metals. In many cases, Vetiver grass has been used to clean up many kinds of pollutants including metals, pesticides, oils, and organic contaminants from wastewater. Vetiver grass eliminates several kinds of pollutants by destroying or converting them to carbon dioxide and water rather than simply immobilizing or storing them (Austine, 2017).

B. Common reed (*Phragmites australis*)

Common reed is the most used plant in CWs. It is a perennial and flood-tolerant grass with an extensive rhizome system that usually penetrates to depths of about 0.6–1.0 m. Stems are rigid with hollow internodes with a range in shoot height from less than 0.5 m to 4–5 m (Dereje, 2019)**.**

C. Cattails (*Typha latifola)*

Cattails (Typhaceae) are vertical rhizomatous perennial plants with joint less stems. The plants are up to 4 m tall with an extensive branching horizontal rhizome system. Cattails prefer standing water however; various species of Typha prefer different water depths and water depth fluctuation (Jan Vymazal, 2013). Cattail species are usually found inhabiting shallow bays, irrigation ditches, lakes, ponds, rivers, and both brackish and freshwater marshes. The most important Typha species found in wetlands are T. latifolia L. (Common cattail, Broad-leaved cattail), T. Angustifolia L. (Narrow-leaved cattail), T. domingensis Pers (Dereje, 2019).

D. Bulrush (*Scripus spp.)*

Bulrushes (Scripus Species) are annual or perennial herbs that grow in tufts or large colonies. Stems are sharply triangular or slightly rounded and softly angled, up to 3 m tall or even taller in some species. Roots penetrate down to 70–80 cm resulting in greater root-zone aeration. However, in constructed wetlands, *Scripus Validus* roots penetrate sometimes only 10–30 cm (Dereje, 2019).

2.2.5. Constructed wetlands coffee processing wastewater treatment

“A study in coffee processing plant (CPP) wastewater (WW) describes that cultivated plant species (*L. multiflorum*) affected the removal effectiveness of total nitrogen, total phosphorous, and total potassium in the systems; though, the best results were obtained by combining the plants with artificial aeration. The average removal of total nitrogen in the cultivated system operating with the aerated influent was 18, 12 and 24% higher than those obtained, respectively, from the non-cultivated system operating with the aerated influent, cultivated system operating with a non-aerated influent and non-cultivated system operating with the non-aerated influent. In the case of total phosphorus it was 9, 6, and 18% higher, for total potassium was 9, 2, and 9% higher, and concerning phenolic compounds was 5, 6, and 14% higher" (Rossmann *et al*., 2012).

2.3. Characteristics of coffee wastewater

In coffee processing, only about 20.69% of the resource taken directly as a useful product, the remains was waste, including pulp, mucilage, and wastewater representing about 79.31% of the biomass of coffee cherry which has to be treated for more valuable uses or, discharged into local water ways (Ulsido & Li, 2016). This pays to environmental degradation because the effluents contain high BOD, COD, and suspended solids. The amounts of coffee wastewater generated by the industries vary depending on the processing technology applied. Wet and dry processing is not similar in surrounding water pollution (Tekle, 2017).

The wastewater coming from wet coffee processing industries can be divided into two. These are the pulping water with high content of quickly fermenting sugars and the effluents from the mechanical mucilage removers. This effluent had high concentrations of suspended solids, dissolved solids, and elevated nutrients like; pectin, proteins, and sugars. Wet coffee processing effluents usually had elevated amounts of conductivity, turbidity, and lower dissolved oxygen to nearby water bodies or receiving environments. The physicochemical parameters of coffee effluent consist of a very high amount of BOD reaching up to (2200 mg/ dm^3) and zero DO values (Tekle, 2017). Chemical compounds such as caffeine, tannins, and chlorogenic acid are present in coffee by-products with eco-toxicological worry which can also limit their value-adding applications (Janissen & Huynh, 2018). According to (Calvert *et al*., 2014) coffee processing waste waters (CPWW) are high in organic loadings and exhibit a high acidity. When washed or semi-washed coffee is processed in large quantities, untreated effluents greatly exceed the self-purification capacity of natural waterways.

Table 2.3: Physicochemical characterization of CPWW as compared to the EEPA limit (source: Tsigereda *et al*., 2013)

Parameters	Mean ± standard deviation	Range	Discharge standard (Ethiopia EPA)
p^H	4.13 ±0.23	3.9-4.4	6-9
BOD mg/L	1697±391	1210-2130	80
COD mg/L	5683±304	5470-6120	250
NH_3 mg/L	4.51±1.62	3.15-6.65	5
NO_3 N mg/L	3.39±0.65	2.70-4.12	20
PO_4^{3-} mg/L	3.32±0.5	2.71-3.45	5
TSS mg/L	197±3225	1564-2310	100
DO mg/L	2.14±0.72	1.09-2.7	>4
EC µs/cm	747 ±64	663-821	1000
Turbidity NTU	271±128.5	185-458	50

2.4. River water pollution with coffee wastewater release

Coffee waste had potential environmental problems and is a reason for water pollution due to the high organic component and acidic nature of surrounding water bodies (Woldesenbet et al., 2014). “Water bodies and ecosystems located downstream of the wet coffee processing plants are at an alarming risk of ecological interruption, and there may also be severe health consequences for the nearby residents. Findings increase the need for further research into the design and implementation of coffee waste valorization and treatment because of sustainable coffee production" (Dadi et al., 2018).

According to Blinová *et al*. (2017), the environmental impact of wet and semi-wet processing is significant. Problems occur through large amounts of effluents disposed into watercourses heavily loaded with organic matter rather than its inherent toxicity. Providing the self-purification of the watercourse is exceeded, the microbial degradation reduces the level of oxygen to anaerobic conditions under which no higher aquatic life is possible. Coffee effluents can kill the micro-organisms and plants that eliminate and absorb the contamination in the water (Duguma & Chewaka, 2019).

Table 2.4: River water characteristics before and after WW release (Rani & Haddis, 2008)

Parameters	River water characteristics	
	Before	After
Temperature (^{O}C)	15	18
Ph	6.5	5.15
BOD_5 (mg/L)	120	7800
COD (mg/L)	176	9780
TSS (mg/L)	520	2880
Phosphate (mg/L)	2.3	4.1
Nitrate (mg/L)	4.0	7.5

Wastewater directly discharged to the nearby water bodies are a source of many severe health problems, these are spinning sensation, eye, ear, and skin irritation, stomach pain, nausea, and breathing problem among the residents of nearby areas. In addition to the effect on human health, wet coffee processing plants are posing environmental hazards due to the large-scale disposal of coffee pulp, husk, and effluents from these units. The presence of toxic compounds like phenols in these byproducts restricts their direct use in agriculture. In addition, the indiscriminate use of fresh coffee pulp also affects crops through acid formation and local heat generation in the process of its fermentation (Woldesenbet et al., 2014).

2.5. Socio-economic and environmental sustainability of constructed wetlands

Constructed wetlands for wastewater treatment have many benefits. Environmental benefits consist of adapting to specific site conditions and targeting specific pollutant loads, dependence on solar energy for the treatment processes, protecting vital ecosystems such as rivers and lakes, providing wildlife habitat, creating green areas, and eliminating the use of chemical products. The social benefit contains leading to society's interaction with wastewater treatment, increasing awareness and education about water problems, and providing great public and regulatory agencies. Economic benefits are less construction, operation, and maintenance cost, used as income generation for example as a recreational area (ElZein *et al*., 2016).

2.5.1. Environmental sustainability of constructed wetlands

With the ongoing climate change caused by human activities, a clear understanding of how increasing global mean temperature affects the hydrological cycle at both global and local scales is crucial. By taking advantage of existing natural ecosystems, such as wetlands, it is possible to combat the trend of a warming planet. Numerous services provided by wetlands can act as essential nature-based solutions (NbS), for achieving different sustainable development goals (SDGs) and particular targets, for instance, by reducing greenhouse gases and environmental toxins, maintaining a stable groundwater level, and even cooling the planet. Once developing wetland management plans there is a needs to replace the business-as-usual approach with an intelligible and inclusive approach, highlighting the possibilities wetland ecosystems provide to coherently address SDGs and their specific targets (Seifollahi-Aghmiuni *et al*., 2019).

2.5.2. Socio-economic sustainability

Kennedy & Mayer (2002) studied the transport of pollutants from urban and agricultural sources in wetland systems is needed to better protect health and to assure the sustainability of wetlands. Consumptive uses of wetlands in different countries include food production, horticultural peat harvesting, forest harvesting, and recreational hunting and fishing. Non-consumptive uses of wetlands include aesthetic, recreational, educational, archaeological, scientific, and heritage uses.

2.5.3. Factors affecting constructed wetland's sustainability

Increasing sustainability of every technology is influenced by the intensity and situations of many variables and materials earlier, during, and after the activity of the technology.

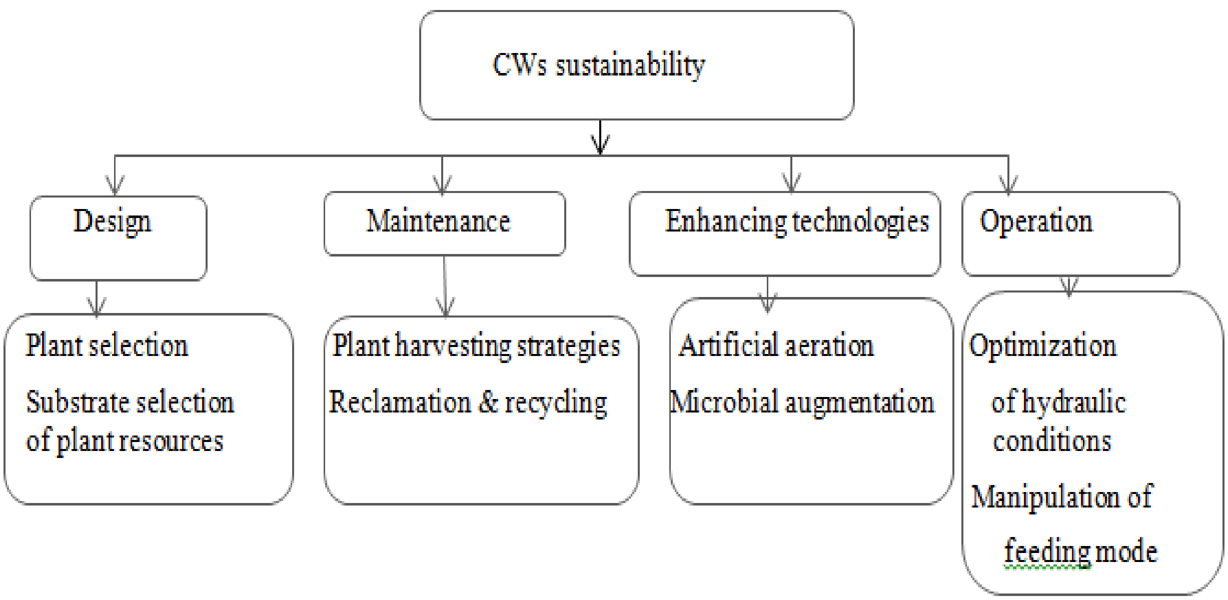

Figure 2.6: Considerations for improving the sustainability of CWs (source: Rahman *et al*., 2020)

Factors such as plant selection, substrate selection, water depth, loading rate, hydraulic retention time, and feeding mode are crucial to achieving the sustainable treatment performance of CW.

Research on maintenance processes and new strategies and technologies is necessary for sustainable CW systems and water quality improvement (Rahman *et al*., 2020).

2.6. Related previous studies

Related studies done before indicates that coffee wastewater discharged to rivers or streams had an impact on the quality of the water and suggested appropriate technology input and community involvement as essential (Tekle, 2017). And performance of constructed wetlands in the treatment of aerated coffee processing wastewater for removal of nutrients and phenolic compounds were studied (Rossmann *et al*., 2012). A pilot-scale constructed wetlands for phytoremediation of municipal wastewater and biomass production were done in Ethiopia to evaluates the phytoremediation and biomass production potential of the wetland plants for municipal wastewater treatment (Angassa *et al*., 2019; Dereje, 2019). Moreover, a study Edna & Pola-albores (2017) on evaluation of hydraulic retention time for treatment of coffee processing wastewater (CPWW) using a laboratory scale Expanded Granular Sludge Bed (EGSB) bioreactor at different HRT (3 to 9 days) were done with a result of 7– 9 days effluents capable to be dischargeable into water bodies.

In addition to that, performance of vetiver grass (*vetiveria zizanioides*) for phytoremediation of contaminated water was evaluated for contaminant removal at varying root lengths and plant density and it determine highest percentage removal with higher accumulation of heavy metals in plant biomass (Nur *et al*., 2017). Finally, economic, environmental, and socio-cultural sustainability of three constructed wetlands were done in Thailand and the sustainability of CWs in very different settings was assessed. The study reveals the importance of the socio-cultural dimension of sustainability; public perception, awareness and knowledge, local expertise, and clear roles for institutions could explain the differences in sustainability of the CWs the author used key stakeholder interviews, questionnaires, and household interview surveys together with existing data. The environmental benefits and the low operation and maintenance costs are also important for sustainability, by justifying the system and avoiding user payments (K. A. Møller, O. Fryd, 2012). All over all, efficacy of constructed wetland with coffee wastewater treatment with detention times was not studied before.

3. MATERIALS AND METHODS

3.1. Description of the study area

Gidabo River watershed is located in south-central Ethiopia within the Main Rift Valley (Tekle, 2017). Geographically, the study area is located 318 km south of Addis Ababa (the capital city of Ethiopia) and 38 km from Hawassa city. The Gidabo River catchment area is one of the major coffee production areas in Ethiopia. Kege CPP is located between $6^{0}\ 40'\ 00''$N to $6^{0}\ 50'\ 00''$N latitudes and $38^{0}\ 00'\ 00''$E to $39^{0}\ 00'\ 00''$E longitudes as indicated on the map.

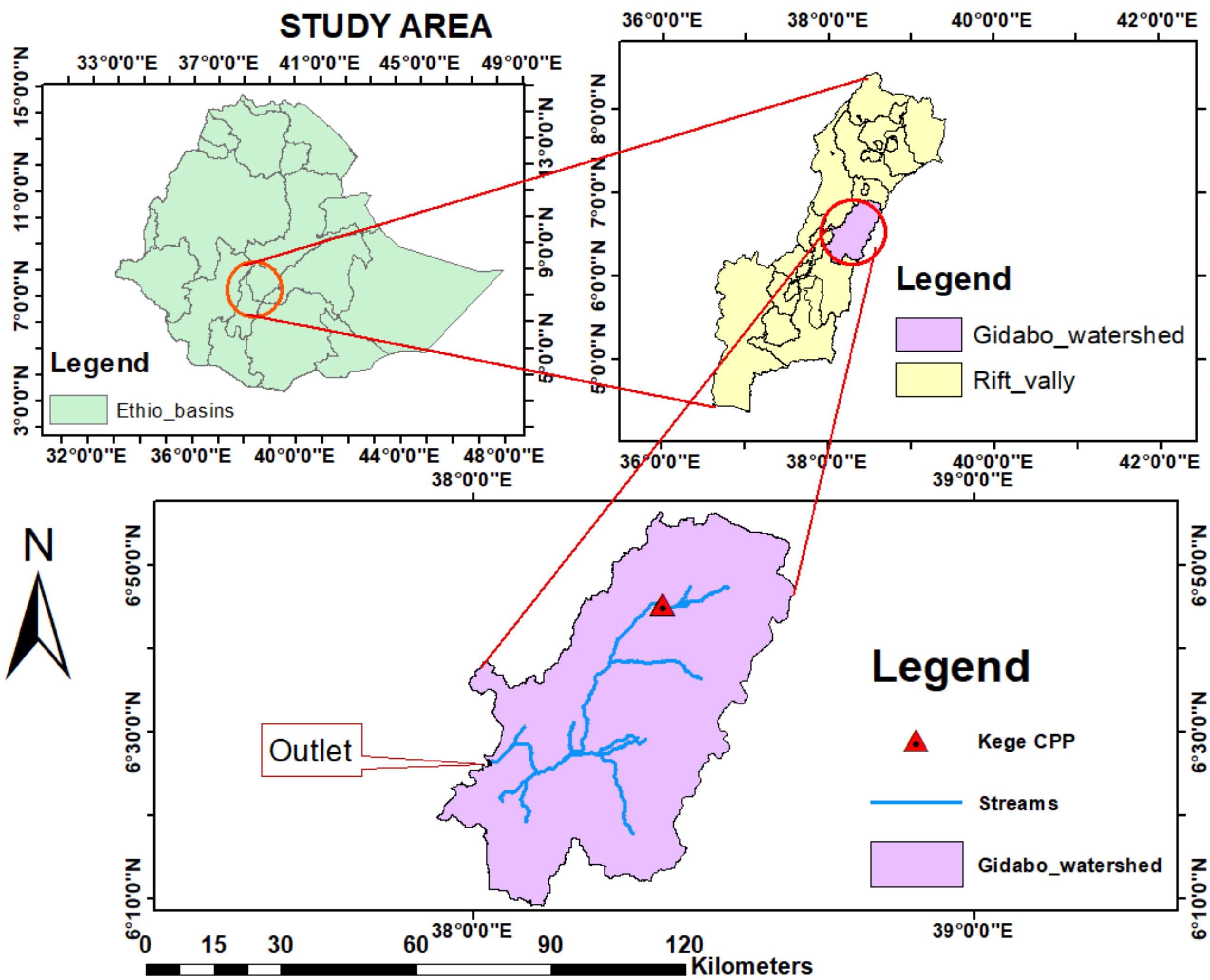

Figure 3.1: Location of the study area (ArcGIS 10.4.1)

According to (Ulsido & Li, 2016), 285 wet mills are found in the Gidabo watershed. Of the 285 wet coffee processing mills, 276 (96.8%) were functional and then Kege wet coffee processing is one of the CPP which discharges coffee wastewater to the Gidabo River watershed.

3.2. Layout of the study constructed wetland and sampling design

The analysis was conducted using a composite sampling method with triplicates. Physical and chemical parameter analyses were used to characterize the coffee wastewater and to assess the performance of the constructed wetland technology effluent with that of the receiving water body on the physicochemical properties analyzed for: pH, Temperature, EC, TDS, TSS, DO, Turbidity, NH_3-N, NO_2-N, NO_3-N, PO_4^{3-}, BOD_5, and COD.

As wet coffee processing is a seasonal activity, the study was conducted during the harvesting period for ripe coffee cherries, which varies from year to year and usually falls between October and January. Therefore; samples were taken for continuous weeks starting from the 1st of November to the 29th of December of the year 2021 coffee processing period. Totally 21 samples with there replications were collected.

Physical parameters were measured onsite and chemical parameters were analyzed in the laboratory. Therefore, samples collected from the River and the CW were transported to the laboratory to be analyzed on the same day and within 4(four) to 6(six) hours difference. For these samples which were not tested within six hours, they were preserved in an ice box and kept cool. And the sampling times were from the morning 2:00 AM to 4:00 AM at the local time for each sample taken days. The samples were collected using one-liter polyethylene bottles which were washed first with distilled water and rinsed with the wastewater.

The constructed wetland was a hybrid flow constructed wetland that was planted with vetiver grass. Its surface area is 12m width *11m length which is 132m^2. The system had also three different ponds indicated as pond 1 (settling thank), pond 2 (gravel pack), and pond 3 (Oxygen pond). The first is of 8m length, 8m width, and 1m depth; the second one of 10m length, 1.5m width, and 1m depth; while the third is of 11m length, 3m width, and 1m depth dimensions respectively with two wetlands. The construction of the wetland was accomplished by constructing 20cm wide furrows with a spacing of 30cm. Vetiver grasses have planted with a spacing of 20cm intervals (Berego et al., 2022).

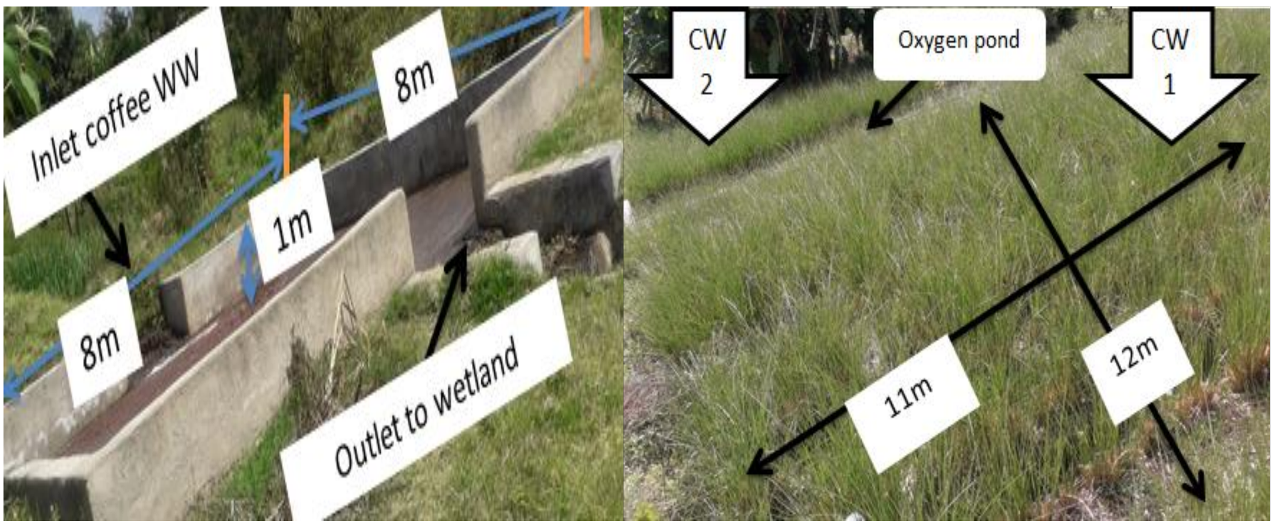

Figure 3.2: Layout of the sedimentation pond and the hybrid flow constructed wetland

3.3. Treatment efficiency of constructed wetland

The wastewater samples were collected at the outlet of the coffee processing plant (or inlet of the CW) and the outlet of the CW treatment system planted with vetiver grass. To compare the percentage removal of the CW, the effluent water was sampled with different detention times. This means that the sample was taken for detention times of zero hours (CPP effluent), 0.5 days, and 1 day, 2 days, 3 days, 4 days, and 5 days on the CWs starting from 10 November to 29 December 2021.

3.3.1. Physical and chemical analysis procedures

This research was conducted for selected physicochemical parameters based on CW removal principles; based on previous studies, and because of financial limits. Coffee WW characteristics exceed the Ethiopian EPA permissible discharge limit standards to surface water pollution (Kebede et al., 2013). “Most physicochemical parameters of coffee WW effluent significantly exceed both the Ethiopian-EPA and United States-EPA guidelines” (Dadi et al., 2018). Wastewater in coffee processing plants holds high BOD, COD, TSS, ammonia-N, and P but low pH. Generally, these effluents did not meet the standard for discharging effluents (Rahmadyanti *et al*., 2020).

3.3.2. Onsite measurements

Parameters such as temperature, turbidity, pH, DO, TDS and electrical conductivity were taken and analyzed in situ by using a thermometer, pH meter, turbidi-meter, DO-meter, and EC-meter (for EC and TDS) respectively. For pH, temperature, TDS, DO, and electric-conductivity the instrument was inserted into the wastewater sample but turbidity has been measured by filing the tube up to the mark of the tube and inserting it into the turbidi-meter based on (APHA, 2017) procedures.

3.3.3. Laboratory analysis

Parameters that were tested in the laboratory for this study such as NO_3-N, Phosphate, NH_3-N, and NO_2-N were tested by using spectrophotometer DR-5000 based on the (HACH, 2005) procedures with a reagent which were added to the samples. DO-meter and incubator (for BOD); reactor block with a colorimeter, small tubes with mixed solutions (for COD); and filter paper and oven dry with conical flask and weighing balance (for TSS) were used.

A. Analysis of Nutrients (Phosphate, Nitrite-N, Ammonia-N, and Nitrate-N)

All of the nutrients have been tested by spectrophotometer (DR-5000) based on the (HACH, 2005) procedures. The procedures which were used are also similar for all phosphate, nitrite, ammonia, and nitrate except for the reagents added. The detailed procedures for phosphate, nitrite-N, ammonia-N, and nitrate-N were discussed in Appendix -1.

B. Analysis of TSS

TSS was conducted by using apparatus filter paper, oven-dry, balance, and conical flask. First, the weight of the paper and the volume of the sample were measured and then wastewater was filtered by the filter paper and the papers with suspended particles were put down to an oven-dry for one hour at 105^{o}C. Finally, the weight was measured by using balance based on (APHA, 2017) standards.

$$TSS\left(\frac{mg}{L}\right) = \frac{(\text{final weight of filter (mg)} - \text{original weight of filter paper (mg)})}{\text{sample volume (ml)}} * 1{,}000 \text{ -------------------------3.1}$$

C. Analysis of BOD

DO meter was used to measure the initial dissolved oxygen concentration and after five days of incubation, the DO meter was used again to measure the final dissolved oxygen concentration. The final DO reading is then subtracted from the initial DO reading and the result was the BOD concentration. Finally to calculate the BOD_5 concentration reading was divided by the dilution factor (APHA, 2017).

$$\text{BOD5} = \frac{DOi - DO5}{f} \quad \text{--3.2}$$

Where: BOD_5 = five-day biochemical oxygen demand

DO_i = initial dissolved oxygen concentration of the prepared solution (mg/l)

DO_5 =dissolved oxygen concentration of the prepared solution after five days (mg/l)

f = dilution factor (bottle volume/sample volume)

D. Analysis of COD

The Chemical Oxygen Demand (COD) is defined as the oxygen required for the water sample for the oxidation of organic and inorganic matter with a strong reacting agent in an acidic medium. It is an indicator of total oxidizable material present in wastewater or water. It determines the measure of oxygen required to oxidize the organic matter in a wastewater sample, under specific conditions of an oxidizing agent, temperature, and time (Tekle, 2017). The titration method has been used to calculate the COD in the samples in mg/L as follows:

$$COD = \frac{(A-B)*N*8000}{\text{sample taken (ml)}} \text{ ---------------------------------------3.3}$$

Where: A = milliliters of Fe $(NH_4)_2(SO_4)_2$ solution required for titration of the blank,

B = milliliters of Fe $(NH_4)_2(SO_4)_2$ solution required for the sample,

N = normality of the Fe $(NH_4)_2(SO_4)_2$ solution, and

$$\text{Normality} = \frac{(\text{mL of } K2Cr2O7)(0.25)}{\text{Fe (NH4)2 (SO4)2 (ml)}} \text{ ---------------------------------------3.4}$$

3.3.4. Determination of pollutants removal percentage

Percentage removals of nutrients/pollutants for different types of constructed wetlands are studied by different researchers. Removal of ammonia-N is 55.1, 48.3, and 84.2 for free water surface (FWS), horizontal flow (HF), and vertical flow (VF) wetlands respectively. Removal of total phosphorus varied between 40 and 60% in all types of constructed wetlands (Vymazal, 2018). BOD reduce in CW up to 30mg/l from 10g/m^2/d loading with 80-90 % removal (Jethwa, 2021). Therefore the pollutants removal percentage of the constructed wetland was calculated mathematically as follows (Shukla *et al*., 2021). Finally, the results were discussed as compared to previous studies in CWs removal percentage on wastewater.

Removal efficiency (R) $= \frac{Ci-Ce}{Ci} * 100\%$ ---3.5

Where, Ci= influent concentration

Ce= effluent concentration

3.3.5. Biomass sampling and analysis

The biomass determination was done once at the end of the experiment. Samples of plants were taken in a zigzag form of the wetland area because the constructed area was large and was constructed to feed about 64m^3/day with a 10m*10m area. On January 24, 2022, the sample plants were harvested to measure biomass productivity and to determine the mg/Kg TN, and mg/Kg of P and K in biomass. The samples were then taken and their contents were carefully separated into roots and plant leaves. Biomass for TN, P, and K concentration, at the CW and control group, was determined in both aboveground and belowground portions. TN, P, and K of the plant root as well as that of the sheet were tested to know the plant uptake from the wastewater as compared to the control group which was not fed by CPWW. Plants biomass was separated into two samples which contain shoots and roots (Nur *et al*., 2017). The vetiver shoots and roots were dried at 70 – 85°C in the oven to a constant weight and the harvestable dry biomass production was then determined by the dry weight of each sample (Dereje, 2019).

3.3.6. Soil and plant nutrient test

In Kege CPP the constructed wetland was planted with vetiver grass starting from 2019 and it was harvested once per year for its new growth and removal of nutrients. But for this study, the treatment performance of the two years old CW planted with vetiver grass was assessed by analyzing the influent concentration and the effluent concentration of the constructed wetland in addition to the soil and the grass tests. As discussed by (Nur *et al*., 2017) Vetiver grass can absorb large amounts of environmental pollutants such as heavy metals, pesticides/herbicides, and petroleum hydrocarbon without any effect on its growth. N, P, K, and pH of the soil were analyzed to see the nutrient amount of the soil from the wastewater, as compared to the control group. The wet weight of the soil was measured and it was also measured after drying (its dry weight) by using the balance in grams. Furthermore, N, P, and K nutrient content were analyzed for the vetiver grass.

A. Laboratory analysis methods for the soil and plant samples

Both soil and plant samples were transported to the laboratory of Horticoop/Horticulture Ethiopia for analysis. The methods of analysis used in this study were those described in Table 3.1. EU ISO 11261:2015 specifies a method for the determination of the total nitrogen (ammonium-N, nitrate-N, nitrite-N, and organic N) content of the soil.

Table 3.1: Methods used for laboratory analysis of plant and soil samples

Plant-root		
Total Nitrogen	TN	Wet digestion (Kjeldahl Distillation)
Phosphorus and Potassium	P & K	Wet digestion (ICP -OES Determination)
Plant/vetiver shoot		
Total Nitrogen	TN	Wet digestion (Kjeldahl Distillation)
Phosphorus and Potassium	P & K	Ash (ICP -OES)
Soil		
Acidity	pH-H_2O	ES ISO 10390: 2014 (1:2.5)
Total nitrogen	TN	ES ISO 11261:2015 (Kjeldahl Method)
Phosphorus and Potassium	P & K	Mehlich-3

Nitrogen in N-N-linkages, N-O-linkages, and some heterocyclic (especially pyridine) is only partially determined. It applies to all types of soils (Altuner & Tekeli, 2019).

3.4. River water testing

The water samples were collected upstream of the CPP on the River and downstream of the CPP on the river. The same as that of the WW testing from the CW physical parameters were measured onsite but chemical parameters were analyzed in a laboratory for the river water. During wet coffee processing, the following methods are the main sources of wastewater. These are pulping, fermentation, and washing (Dadi et al., 2018).

A. De-pulping

De-pulping or removal of pulps was done with the help of water and results in a considerable volume of wastewater.

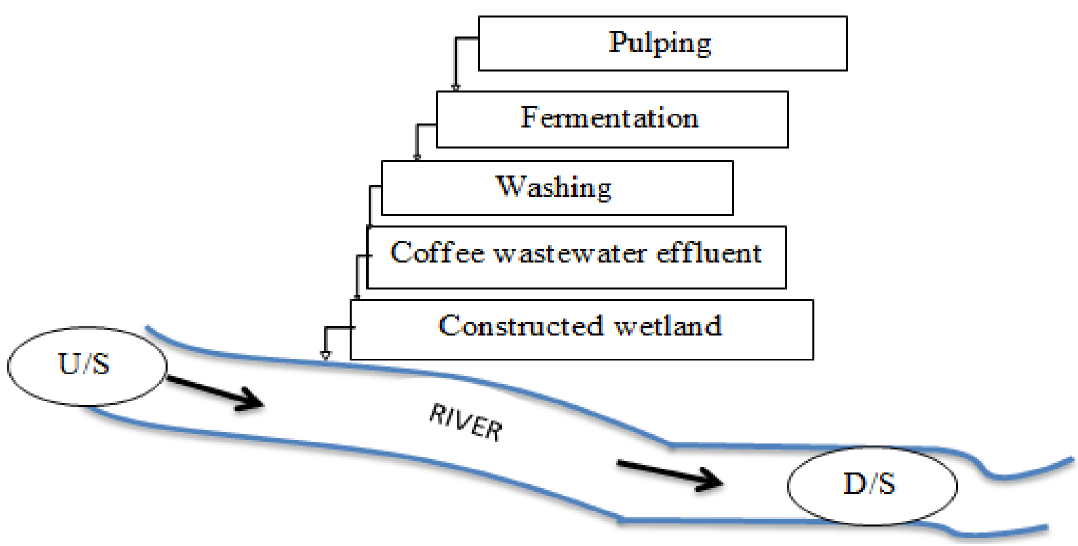

Figure 3.3: Flow diagram showing coffee processing and water sampling points

A. Fermentation

The main purpose of the fermentation process in all methods is to remove the mucilage layer, which is rich in polysaccharides (pectin), and to decrease the water content of the coffee beans.

B. Washing

Washing was mainly the removal of coffee mucilage which contains polysaccharides (pectin), cellulose, and starch. Mucilage can prolong the time needed to dry the coffee beans and, in some cases also lead to mold development, which reduces the final quality of the coffee.

3.4.1. Onsite measurements for river water samples

The number of physical parameters which were tested for the river water was similar to that of the CW: these are pH, Temperature, EC, TDS, TSS, DO, and Turbidity. Therefore, the materials and methods which were used to test river water samples are also the same as that of CWs effluent and CPP effluents. That is temperature, turbidity, pH, DO, TDS and, electro-conductivity were analyzed by using a thermometer, pH meter, turbidimeter, DO-meter, and EC-meter (for EC and TDS) respectively.

Figure 3.4: Sample collection from U/S & D/S of the river and physical parameters testing tools

3.4.2. Laboratory analysis for river water samples

The chemical parameters which were tested were almost similar to that of the parameters tested for the wastewater at the CW (NH_3-N, NO_2-N, NO_3-N, PO_4^{3-}, BOD_5 and COD). And then the materials and methods used were also almost similar but for phosphate, nitrite, nitrate, and ammonia testing the samples from CW were filtered before testing to remove the color of the wastewater. However, the color of the WW was not changed after filtration during that time dilution by distilled water was applied and finally, the result was multiplied by its dilution factor. But since the river water had low color than the samples from the CW no filtration was applied for the samples from the river upstream and downstream. As stated above, the nutrients test for river water samples has been tested by spectrophotometer (DR-5000) based on the (HACH, 2005) procedures. The procedures which were used are also similar for all phosphate, nitrite, ammonia, and nitrate except that for the reagents added. Detailed procedures for phosphate, nitrite-N, ammonia-N, and nitrate-N were discussed in Appendix -1. Therefore; TSS, BOD_5, and COD analysis have also the same materials and procedures as described in topic 3.3 of this study.

3.5. Assessment of socio-economic and environmental implications of the constructed wetland with its sustainability

Since constructed wetlands were a developed technology it needs sustainability assessment in different ways. Surveying assessment is one of the methods in addition to treatment performance assessments.

3.5.1. Sampling technique

The socio-economic and environmental implications and sustainability of the constructed wetland for this study were assessed using stratified sampling methods by preparing questionnaires for an interview/asking for the respondents. The CPP association owners, the daily workers on CPP as well as the farmers around the CPP, and job-related staffs of the woreda are strata of the survey. The questions were prepared first and then respondents have been selected by using systematic random sampling from all the CPP owners, daily workers, the job-related staff of the wereda, and the farmers. Therefore, different materials were prepared for this method. Pen/pencil and printed question papers were used to write the responses of selective individuals and mobile phones were used to take a photograph during the survey conduct time. As observed in the study (Kaffashi *et al*., 2015) face-to-face interviews were applied.

3.5.2. Sample size determination

According to the data from the processing plant, the average number of daily workers was 113 and there are 9 supervisors with 4 waiters in addition to this there are 2 farmers around the processing plant and 10 respondents were selected from environmental protection leaders, natural resource staff and agricultural office leaders of Yirgalem woreda based on their job responsibility at the woreda. Therefore, the total numbers of population were 138. The number of samples was calculated using the (Yamane, 1967) formula. (Yamane, 1967) provided a simplified formula to calculate the sample size.

$$n = \frac{N}{1+N(e^2)} \quad \text{--} \; 3.6$$

Where n = the sample size that the researcher used N = designed total number of population e = designates maximum variability or margin of error (5%). Thus N=138 e = 0.05

Therefore, n= $\frac{138}{1+138(0.05^2)}$= 102.6 this means n = 103 samples

Based on this approach, a total of 103 respondents were selected proportional to the size sampling technique. So by using the above sampling formula the proportional numbers of respondents in each stratum were calculated as:

- From daily workers $\frac{113}{138} * 103 = 84$
- From supervisors $\frac{9}{138} * 103 = 7$

- From the farmers $\frac{2}{138} * 103 = 2$
- From the waiters of the CPP $\frac{4}{138} * 103 = 3$
- From woreda offices $\frac{10}{138} * 103$ =7. Therefore a total of 103 respondents were interviewed.

3.5.3. Questionnaire design

The questionnaire was categorized into six subsections: though, before starting questions an introductory script was used by the interviewer to identify and initiate contact with respondents. The first part was about demographic characteristics which included the gender, occupation, work experience, and educational background of the respondents. The second section includes general know-how questions regarding constructed wetlands and their treatment mechanisms as listed in Appendix-8.

The third section of the survey included some questions to gauge respondents' environmental measurements related to the wetland ecosystems and in particular, Kege-constructed wetlands. These values were measured on two dummy variables and four open-ended variables.

The fourth section of the questionnaire attempted to create respondents' socio-economic measurements of the wetland. This section included questions about economic benefits, the sociability of the wetland on coffee wastewater treatment, awareness of the farmers and public leaders, and the main economic purpose of the river around the wetland.

The fifth section was dialed with aspects of the processing plant which are also arranged by dummy variables and open-ended questions about the wastewater loading amount, carrying amount of the wetland and local disposal methods, maintenance of the treatment ways, and respondent's willingness on constructed wetlands. The last section was general communications about monitoring and evaluation, frequency of evaluations, criteria observed during evaluation, and punishments if there is pollution. Generally, these questioners were written based on the future sustainability of the constructed wetland.

3.5.4. Dependent and independent variables

Gender, occupation, work experience, and educational background were used as dependent variables for the six sections of the interview during the analysis of the results as stated in Table 3.2. Variables are divided as dependent and independent based on their relationship to each other. For example, educational background implies general knowledge of the respondents and work experience is an indicator of the defendant's understanding of the change in the environment and gender implies demographic characteristics.

Table 3.2: Dependent and independent variables

Dependent variables	Independent variables
Gender	Demographic characteristics
Occupation	Socio-economic measurements
	Aspects of the processing plant
	Communications
Work experience	Environmental measurements
Educational background	General know-how questions

3.6. Statistical methods

Statistical analysis software IBM SPSS version 26 was used to measure the mean and standard deviations of the physicochemical results. The statistical analysis methods for the physicochemical parameters were subjected to one-way analysis of variance (ANOVA) at a 95% confidence interval with a 5% level of significance. Means are separated by using a list significant difference (LSD) to determine if there is a significant difference between the treatments within the detention times on the CW. The percentage removal calculations were done by Microsoft Excel 2010. Therefore, the mean values of the effluents from CW were compared with Ethiopian EPA wastewater disposal standards and the river quality mean values were compared to the ambient irrigation water quality standards.

4. RESULT AND DISCUSSION

4.1. Treatment efficiency of the constructed wetland

The comparison of the value of effluent water quality parameters with the discharge standards are presented in Table 4.1 to compare the pollution level of the effluent generated from the constructed wetland to the discharge standards. The parameters were analyzed for different detention times of the WW on the wetland. The mean influent and effluent values for each parameter are presented in Appendix 2. Some of the parameters concentrations decreased as the detention time increased except for pH and DO as well as the concentrations for phosphate, ammonia, nitrite, nitrate, EC, and TDS increased up to the second to third day detention times, which started to decrease in some rate at the fourth and fifth days retention. Furthermore, the concentration removal percentages of the parameters were determined based on the influent and effluent wastewater of the system except for pH and DO.

4.1.1. Dissolved oxygen (DO mg/L) and pH (pH scale)

Dissolved oxygen (DO) is a key parameter to indicate the degree of water quality and organic pollution load which shows the protection of the aquatic ecosystem. The statistical analysis was done with a 95% confidence interval due to this the statistical results are said to be significant between groups if their p-value is less than 0.05 and non-significant results show a p-value of greater than 0.05. The mean DO of the CPP effluent wastewater was 1.66 mg/L. The statistical analysis showed the treatment results were significant (p=0.000). The DO in the wetland systems was increased from 1^{st} 0.5day to the 5^{th} or 5-day detention time as 2.31, 2.67, 2.67, 3.25, 3.85, 3.95 mg/L.

Table 4.1: Physical & chemical parameters concentration (Mean ± SD)

Parameters	Unit	CPP Effluent (CW Influent)	0.5 day	1 day	2 days	3 days	4 days	5 days	Discharge standard EEPA
p^H		4.84± 0.19	4.33± 0.49	4.53± 0.38	4.71± 0.43	5.02± 0.34	5.29± 0.55	5.61±0.46	6-9
Temp	^oC	22.87± 1.01	20.71± 1.01	20.86± 0.84	19.98± 1.33	20.03± 1.76	19.83± 1.60	19.67±1.54	40
EC	µs/cm	1042.32± 52.08	1007.83±80.68	993.69± 11.81	937.10± 62.28	924.64± 68.90	857.51±67.23	716.36±317.45	1000
TDS	mg/L	573± 106.86	506.91± 42.73	499.33± 6.03	468.89±30.84	462.40± 34.59	437.33±18.01	402.63±206.48	3000
TSS	mg/L	631.45± 152.28	439.67±118.37	355.5± 61.58	311.56± 53.17	260± 40.00	205.67± 8.96	173± 20.66	100
Turbidity	NTU	334.22±115.60	171.33± 33.84	117.24± 21.09	126.08± 36.05	92.11±21.77	63.04± 17.53	53.33±7.57	50
DO	mg/L	1.66± 0.51	2.31± 0.49	2.67± 0.16	2.67± 0.43	3.25± 0.38	3.86± 0.10	3.95± 0.09	>4
BOD_5	mg/L	2211± 88.50	931.33± 156.29	836.67± 152.00	667.67± 246.59	538.67±226.33	443.67±237.60	262.67± 71.70	80
COD	mg/L	4162.67±69.97	2059.33±58.73	1650± 438.59	1263.33±343.43	1026.67±33.00	840.33±147.55	504± 104.92	250
PO_4^{3-}	mg/L	3.56± 0.46	3.74± 0.23	3.62± 0.49	3.59± 0.44	3.67± 0.25	2.71± 0.51	2.34± 0.57	5
NH_3 –N	mg/L	3.33± 0.58	3.45± 0.38	3.48± 0.31	3.44± 0.41	3.35± 0.11	2.45± 0.57	2.33± 0.59	5
NO_2 –N	mg/L	0.86± 0.12	0.89± 0.02	0.9± 0.17	0.93± 0.31	0.90± 0.18	0.71± 0.27	0.5± 0.18	__
NO_3- N	mg/L	4.84± 0.24	4.88± 0.12	4.91± 0.14	4.92± 1.79	4.85± 1.42	3.56± 0.55	3.19± 0.79	20

In this study, the reason for these lower DO values are the coffee wastewater by itself have been low DO and the flowing velocity was low on the CW but the values increase with an increase in detention time which may be due to the presence of vetiver grass and the stairs on the system for aeration. The major leading factors affecting the concentrations of DO are input sources such as the dissolution of atmospheric oxygen in water, photosynthesis by autotrophs, and output sources such as respiration, decomposition of organic matter by microorganisms, and evaporation due to high temperature. Furthermore, oxygen concentrations vary with the volume and velocity of water flowing in a stream. The flow with high velocity creating white water areas be likely to be rich in oxygen because more oxygen enters the water from the atmosphere in those areas than in slower, steady areas, and oxygen is also more easily dissolved into water with low levels of dissolved or suspended solids as stated on (Tekle, 2017).

Hydrogen ion (pH) is a measure of the acidity and alkalinity of the water body. It is considered a special parameter in water quality tests as it influences most of the chemical and biochemical reactions that take place in the aquatic ecosystem. The values for pH and DO of the influent are below the applicable limits this is because wet coffee processing waste is acidic and it has low dissolved oxygen concentration. This is inconsistent with similar studies done by (Tekle, 2017; Tsigereda et al., 2013). But after passing the treatment system pH and DO concentrations increased with an increase in retention time and the means were approached to the standards on the 5th day of detention time. The mean pH of the CPP effluent (influent for CW) was 4.84. The statistical analysis indicated the results for different detention times were significantly different ($p=0.030$).The results show that the mean pH values of the samples were not in the range of 6-9 which was stated in the (EEPA, 2003) discharge standards. The pH in the wetland systems was 4.33, 4.53, 4.71, 5.02, 5.29, and 5.61 from 1st 0.5day to the 5th day of detention time. The result increased with detention time but it was slower even if it can't reach the standard limit. This may be due to the metabolism of phosphate and nitrogenous compounds which affects the increase in pH values. Furthermore, the acidic pH is due to the presence of organic acids in the berry skin and pulp of the coffee fruit. As discussed by (Dadi et al., 2018) when the organic waste oxidizes carbon dioxide (CO_2) is released and increases the acidic characteristics of the water.

4.1.2. EC (µs/cm), TDS (mg/L), and TSS (mg/L)

The mean electric conductivity (EC) of the CPP effluent wastewater was 1042.32µs/cm. The results of the treatment systems were statistically not significant at (p=0.204). EC results were decreased from the influent value to the 5day detention time 1042.32± 52.08, 1007.83±80.68, 993.69±11.81, 937.10±62.28, 924.64± 68.90, 857.51±67.23, and 716.36±317.45 orderly with 3.31%, 4.67%, 10.09%, 11.29%, 17.73%, and 31.27% removal for the different detention times. These mean values were low as compared to the provisional limit except that of the 0.5day detention time.

The statistical analysis for the mean TDS concentration removal was non-significant (p=0.381). The mean concentration of CPP effluent (CW influent) TDS by the wetland systems were 573mg/L and the mean concentration by the 0.5 days, 1 day, 2 days, 3 days, 4 days, and 5 days were 506.91, 499.33, 468.89, 462.40, 437.33, and 402.63mg/L respectively. This result indicates that the concentration of TDS was dependent on detention times. The acceptable limit of TDS is up to (3000mg/L) (EEPA, 2003). The EC of the water reflects the quantity of dissolved ionic constituents. The lower dissolved solid indicates a positive impact on water and wastewater quality. The percentage removal concentrations are 11.53%, 12.86%, 18.17%, 19.30%, 23.68%, and 29.73% for the 0.5 days, 1 day, 2 days, 3 days, 4 days, and 5 days detention time respectively.an increase in detention time increases the removal of the dissolved solids.

TSS concentration was decreased from lower to higher detention time but it was above the discharge limit all over the samples. The statistical analysis for the TSS concentration removal shows a high significant difference between the treatment groups (p=0.002). The mean concentration of the influent was 631.45mg/L and the mean concentration by the different retention times were 439.67, 355.5, 311.56, 260, 205.67, and 173 mg/L.

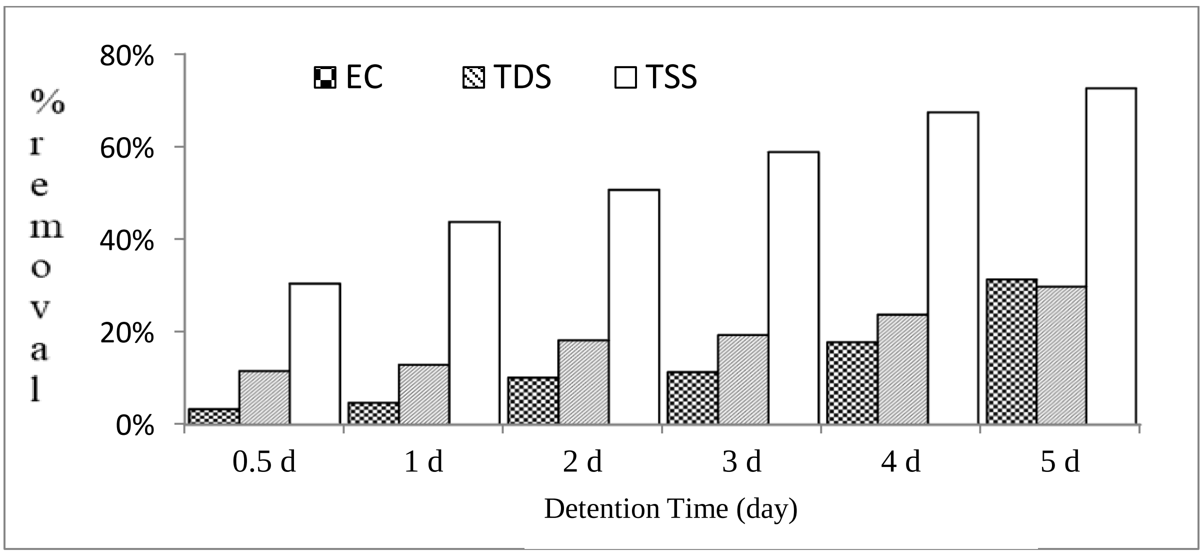

Figure 4.1: EC, TDS, and TSS concentration removal percentage

This implies that TSS concentration is highly dependent on detention times and it decreases as the time increases the relation is inversely proportional. But the percentage concentration removal is directly proportional to the time with 30.37%, 43.70%, 50.66%, 58.82%, 67.43%, and 72.60% for the detention times of 0.5 days, 1 day, 2 days, 3days, 4days, and 5days respectively. The discharge acceptable limit of TSS is up to (100mg/L) (EEPA, 2003). The CW systems couldn't achieve complete removal of TSS this is due to the reason that wetlands produce residual background concentrations of total suspended solids (TSS) which are a by-product of decomposing vegetation and other natural organics in the wetlands (Dereje, 2019).

4.1.3. Turbidity (NTU) and Temperature (^oC)

The statistical analysis for the turbidity concentration shows a highly significant difference between the treatment groups (p=0.001). The mean concentration of turbidity of the CPP wastewater was 334.22 and the mean concentration for the retention times were 171.33, 117.24, 126.07, 92.11, 63.04, and 53.33 NTU for 0.5 days, 1 day, 2 days, 3days, 4days, and 5days respectively. This indicates the values decreased as the detention time increases because of the low velocity and meandering flow (or zigzag flow) of the CW. On the fifth day of detention 53.33NTU were greater than the standard limit by 3.33 NTU only and the percentages removal are increasing opposite to that of the concentration like 48.74%, 64.92%, 62.28%, 72.44%, 81.14%, and 84.04% orderly.

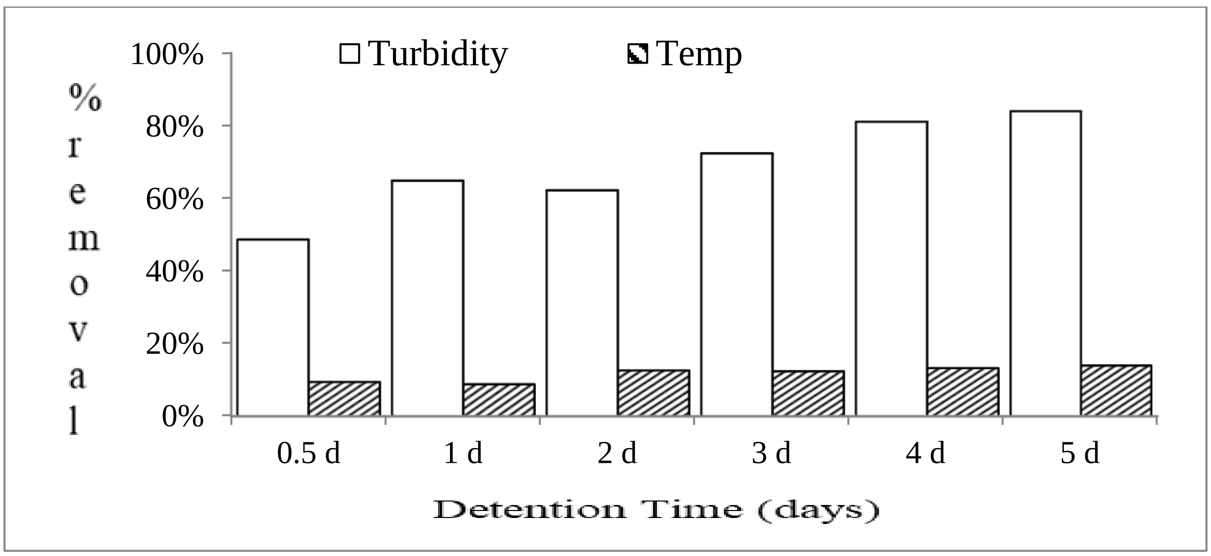

Figure 4.2: Concentrations percentage removal for turbidity and temperature

The mean concentration of temperature of the CPP wastewater was 22.87^oC and the mean concentration for the retention times were 20.71, 20.86, 19.98, 20.03, 19.83, and 19.67 ^oC for 0.5 days, 1 day, 2 days, 3days, 4days, and 5days with removal percentage of 9.44%, 8.80%, 12.64%, 12.40%, 3.31%, and 13.98% respectively. The statistical analysis for the temperature concentration did not show a significant difference between the detention times (p= 0.860). An increase in water temperature decreases the ability of oxygen to dissolve in water, thus its availability to aquatic organisms which may influence their metabolic and other activities. However, mean values were low along the sampling times as compared to the provisional limit (40^oC) (EEPA, 2003) discharge standard.

4.1.4. BOD_5 (mg/L) and COD (mg/L)

The statistical analysis for BOD_5 concentration removal shows a significant difference at (p=0.010) between the retention times. The mean influent loaded into the systems was 2211mg/L and after the 0.5 days, 1 day, 2 days, 3 days, 4 days, and 5 days were 931.33, 836.67, 667.67, 538.67, 443.67, 262.67mg/L respectively. The treatment results indicate the treated water is not within the permissible limits (80mg/L) of (EEPA, 2003), but it was an approach to the standard limit as the detention time increases. In the removal process of treatment using planted wetlands, there was a production of BOD_5 due to the decomposition of plants and other naturally occurring organic materials. This influences the treatment efficiency of planted beds because it increases the concentration in the system. Therefore, the system can’t achieve complete BOD removal due to the lower DO concentrations which are happened in the wetland effluent. The removal of BOD is strongly dependent on retention/detention time up to about 1 day but improves somewhat up to 7.5 days (Dereje, 2019). The concentration removal percentage of BOD has directly proportional to detention time increases as 57.88%, 62.16%, 69.80%, 75.64%, 79.93%, and 88.12% as displayed in Figure 4.3.

COD is commonly used as a measure of the oxygen needed for oxidation of the organic and inorganic materials present in the water/wastewater. The statistical analysis for COD concentration removal did have a significant difference between the systems of the study (p= 0.000). The mean influent loaded into the systems was 4162.67 mg/L and after the 0.5 days, 1 day, 2 days, 3 days, 4 days, and 5 days were 2059.33, 1650, 1263.33, 1026.67, 840.33, 504mg/L respectively. The treatment results show the treated water was not within the permissible limits (250mg/L) of (EEPA, 2003), but it was an approach to the standard limit as the detention time increases the same as that of BOD_5. The concentration removal percentage of COD has directly proportional with detention time as 50.53%, 60.36%, 69.65%, 75.34%, 79.81%, to 87.89% for 0.5 days, 3 days, 2 days, 3 days, 4 days, and 5days respectively as indicated in Figure 4.3. The results of this study are inconsistent with other studies. “COD removal rate became more efficient and less variable with the retention time increase, the best one was 9 days”. High levels of BOD_5 and COD in the CPWW were recorded even after the treatment system decreased. This might be due to the presence of a high amount of organic substances and the slowly degrading compounds present in the coffee berries (Edna & Pola-albores, 2017).

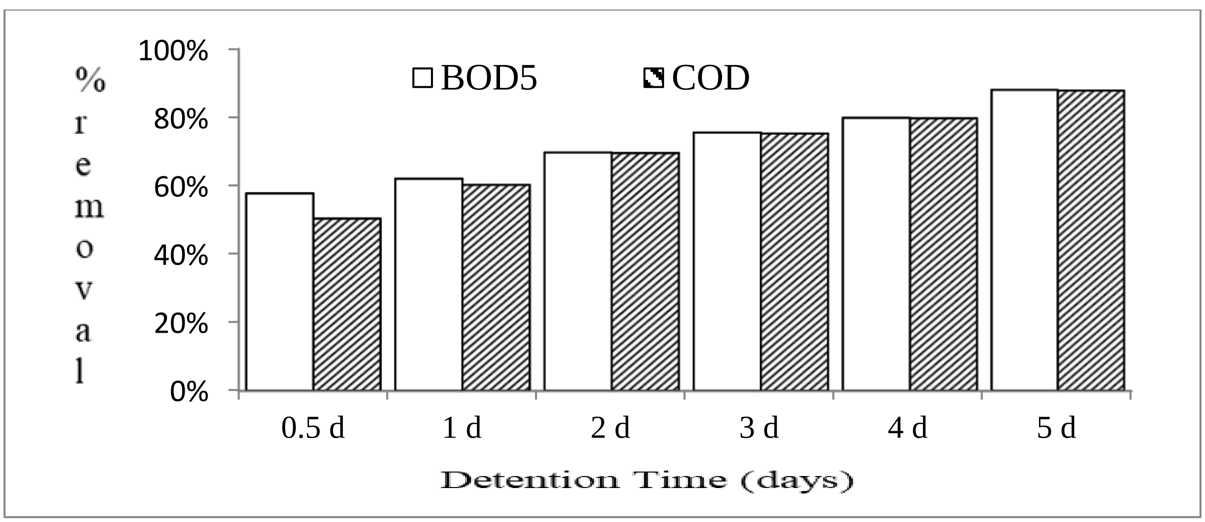

Figure 4.3: BOD_5 and COD concentration removal within retention times

4.1.5. Phosphate (PO_4^{3-}) and Ammonia-N (NH_3-N)

CPWW contained phosphorus and nitrogen; which might be due to the presence of pectin, protein, and sugars in coffee berries. The results from the statistical analysis indicated the overall test on PO_4^{3-} concentration removal does show a significant difference across the samples of the detention times (p= 0.007). The mean influent concentration loaded into the systems was 3.56mg/L which was lower than the permissible limits (5mg/L) (EEPA, 2003). And which recorded by the detention times of 0.5 days, 1 day, 2 days, 3 days, 4 days, and 5 days were 3.74, 3.62, 3.59, 3.67, 2.71, and 2.34mg/L respectively.

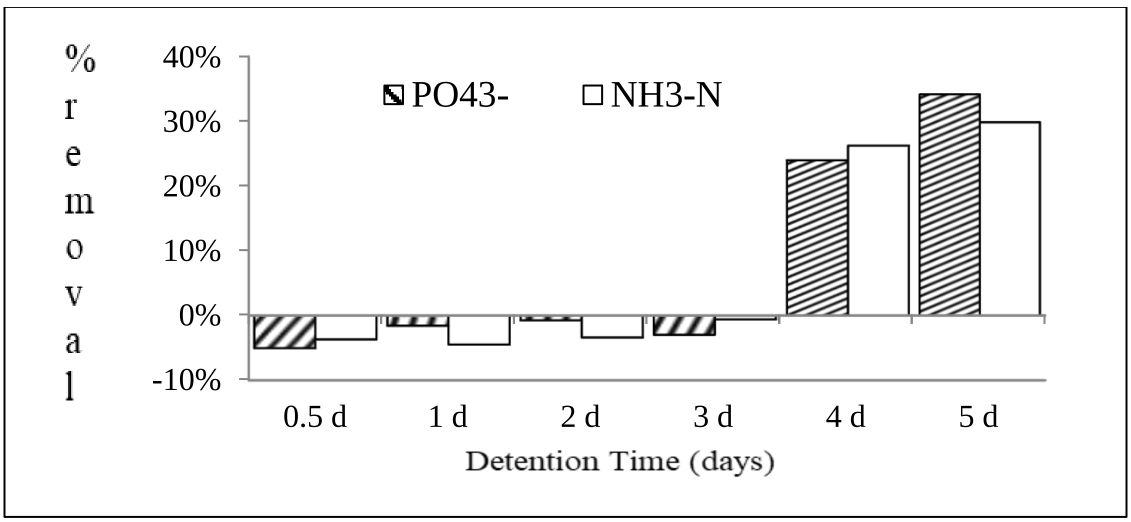

Figure 4.4: Concentration removal percentage for Phosphate and Ammonia-N

The result shows that there was no phosphate removal in the first four detention times instead it increases by 5.06%, 1.59%, 0.75%, and 3.00% but 23.97% and 34.18% removal was recorded at the 5th and 6th days of detention times. Negative removal efficiencies of phosphate on constructed wetlands were also widely reported in different studies (Choi *et al.*, 2021) cited the subsequent mineralization and release of phosphorus compounds in sediments can increase the total phosphorous concentrations in water. However, at the 4 days and five days detention, it decreases by 4.49% and 5.81% respectively. As discussed by (Safia et al., 2015) the increased hydraulic retention time improved the contact time between microbes and wastewater which results in mass transfer and increased dissolved oxygen concentration which ultimately leads to the elimination of nutrients. Based on the results there was observed addition of phosphate at the effluent than the influent on the first three days of hydraulic retention. This may be due to the addition of phosphorous by plant decomposition in the system. And this will be controlled by increasing the retention time and by harvesting the plants when they are matured.

The statistical analysis for the mean NH_3-N concentration removal shows significant difference between the retention times (p=0.012). The mean concentration change/removal by 0.5 days, 1 day, 2 days, 3 days, 4 days, and 5 days from the influent 3.33mg/L were 3.45, 3.48, 3.44, 3.35, 2.45, and 2.33mg/L respectively. However, no removal of NH_3-N occurred at the first four different detention times with an increase in 3.71%, 4.51%, 3.41%, and 0.60%. This may be due to the low DO to support the nitrification process. And then when the DO values increases with detention times the removal of NH_3-N becomes increases by 26.25%, and 29.86% on the 5^{th} day and 6^{th} days of retention time respectively. The NH_3-N discharge permissible limits are (5mg/L) (EEPA, 2003). In agreement to this study negative removal efficiency of ammonium was described as -24.41% on constructed wetland (Berego et al., 2022).

4.1.6. Nitrite-N (NO_2-N mg/L) and Nitrate-N (NO_3-N mg/L)

The 5% level of significance for ANOVA statistical analysis gives the concentration NO_3-N removal between the retention times doesn’t show a significant difference (p=0.182). Influent concentration was 4.84 mg/L and mean concentration removals were 4.88, 4.91, 4.92, 4.85, 3.56, and 3.19mg/L with removal percentages of -0.90%, -1.45%, -1.58%, -0.28%, 26.52%, and 34.02%

for 0.5 days, 1 day, 2 days, 3 days, 4 days, and 5days respectively. Based on the results there is a problem in the removal of nitrogen and NO_3-N removal was not highly affected by detention times in this study. However, all of the mean values are under the discharge standard limit (20mg/L) (EEPA, 2003). Reports on the study (Vymazal, 2018) are not in agreement with this 60.7% removal of NO_3-N.

The statistical analysis with a 5% level of significance for mean values of NO_2-N concentration removal between the retention times does not show a significant difference (p=0.148). Influent concentration was 0.86mg/L and mean concentration removals were 0.89, 0.9, 0.93, 0.90, 0.71, and 0.5mg/L with a percentage removal of -3.88%, -4.65%, -8.53%, -5.04%, 17.44%,and 41.86% for 0.5 days, 1 day, 2 days, 3 days, 4 days, and 5 days respectively. Based on the results there is a problem in the removal of nitrogen and NO_2-N concentration and it was not extremely affected by detention times in this study. Generally, an increase in nutrients (phosphate, nitrate, ammonia) on the constructed wetland may occurred due to the nitrification, denitrification and other degradation processes occurred on the soil, plant, and wastewater of the system.

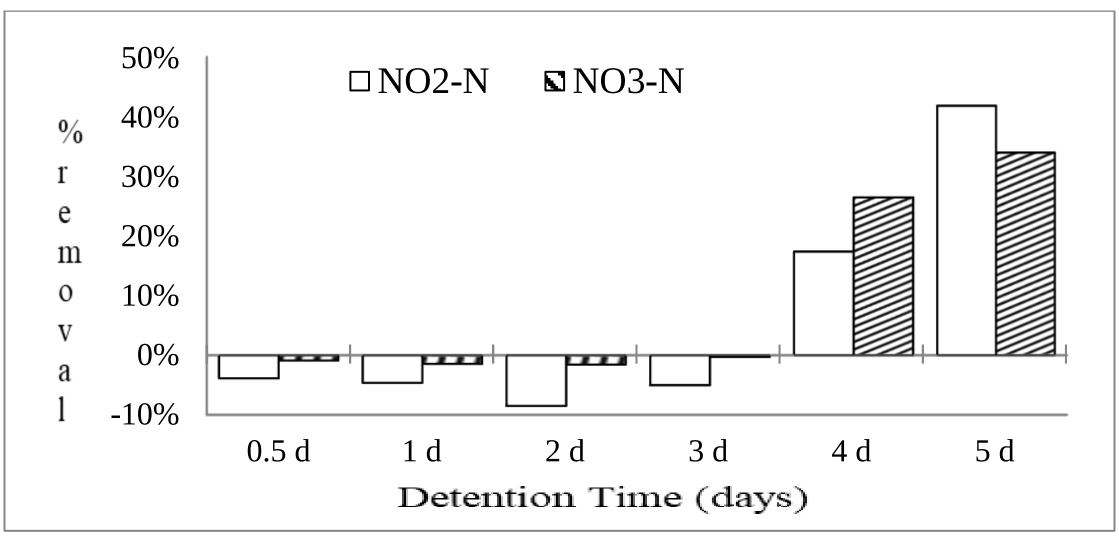

Figure 4.5: Concentration removal percentage for Nitrite-N and Nitrate –N

4.2. Biomass and nutrient test for the vetiver grass

4.2.1. Biomass

The above-ground and under-ground biomass was studied to determine the growth rate of the CW as compared to the Control (without feeding coffee WW to the system). The mean height for shoots at the end of the study period by constructed wetland one (CW1 upper side), constructed wetland two (CW2 lower side), and the control was 153.33, 130, and 82.33 cm. Moreover, the mean height or root depth of samples for CW1, CW2, and control are 127.33, 104.67, and 89.67 cm respectively. The stem density/number of shoots/ in CW1, CW2, and control are 1322, 1196, & 624 stems/m^2 respectively as presented in Table 4.2. The Constructed wetlands have a high growth rate and relatively have high stem/shoot density than that of the control one (which was not fed by coffee wastewater). The difference in the number of plants shoots among the CW1 (1322 shoots/m^2) and CW2 (1196 shoots/m^2) may be due to the influent of the wastewater which was feed CW1 first then it flows to CW2 the concentration of the nutrient becomes decreased when the WW reaches CW2.

Table 4.2: Plant growth characteristics of the CW and the control

	Parameters	CW1	CW2	Control
Vetiver stem	Shoot height (cm)	153.33	130	82.33
	Number of shoot/m^2	1322	1196	624
Vetiver root	Root depth(cm)	127.33	104.67	89.67

Moreover, the control one was not fed wastewater during the study period and its shoot numbers (624 shoots/m^2) and height (82.33 cm shoot and 89.67 cm root) are lower than the others, this may be due to the absence of nitrogen(for growth) which intend to that one. A study (Angassa et al.,

2019) on Phragmites karka for phytoremediation of municipal wastewater and biomass production studied in Addis Ababa, Ethiopia discussed that application of a higher loading rate of 0.05 m/d doubled the above-ground biomass production of the plants than 0.025m/d.

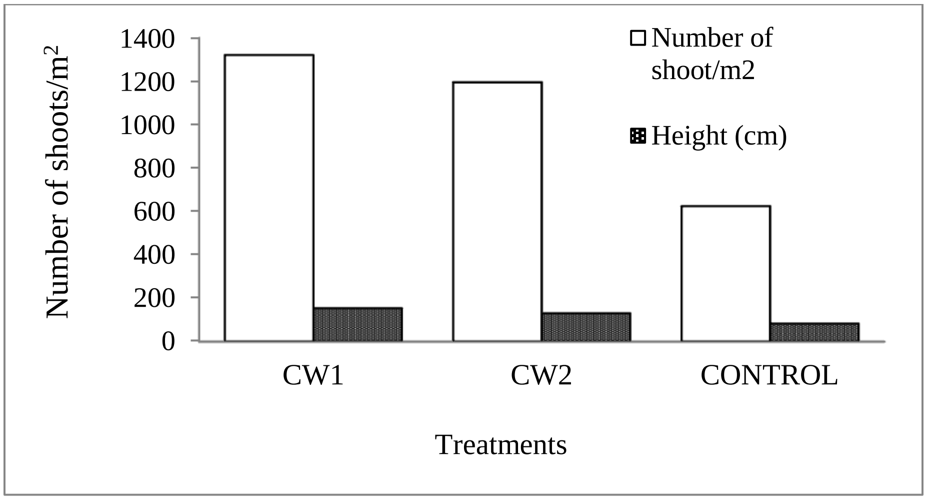

Figure 4.6: Shoot density and height of the grass on the treatments

4.2.2. Nutrients on the soil and vetiver grass

Plant uptake contributes to nitrogen removal in wetlands since they require nitrogen for growth (Austine, 2017). The most significant nutrient source of plants is nitrogen having fertilizers. There was a higher percentage concentration on the shoots of the vetiver grass than on the root and the soil on the constructed wetlands. Therefore, 0.52%, 0.57%, and 0.26% on CW1, CW2, and control respectively are recorded as stated in Table 4.3. This indicates that CWs have higher nitrogen uptake through the leaf of the plants from coffee wastewater than the control. Based on this study the rank for total nitrogen concentrations in plant shoot > plant root > soil on surface flow constructed wetlands feed with coffee wastewater. The same as total nitrogen there was a higher concentration of phosphorus on the shoots of the vetiver grass than on the roots and the soil of the constructed wetlands. Therefore, 2,357.05 mg/Kg, 2,241.79 mg/Kg, and 2,939.72 mg/Kg on CW1, CW2, and the control respectively but the control group has a higher concentration than the CWs as indicated in Table 4.3. Results show that the control which was not fed coffee wastewater has higher phosphorus on the leaf of the plants. This may be due to the lower density of the wetland with a free movement of phosphorus to the plants.

Table 4.3: Nutrient concentration on the soil and plant

Samples	Treatments	TN (mg/Kg)	P (mg/Kg)	K (mg/Kg)	Soil PH
Soil sample	CW1	700	2.32	994.37	8.28
	CW2	900	4.36	1,056.44	6.94
	Control	900	0.91	368.28	7.46
Vetiver shoot	CW1	5200	2,357.05	16,341.30	------
	CW2	5700	2,241.79	18,334.40	------
	Control	2600	2,939.72	15,989.00	-----
Vetiver root	CW1	2400	1,889.44	7,034.85	------
	CW2	2900	1,856.12	7,560.56	------
	Control	2600	1,958.26	7,346.25	-----

Even if the concentration of phosphorus on control is higher, the rank for concentrations are plant shoot > plant root > soil on surface flow constructed wetlands feed with coffee wastewater. However, a study (Austine, 2017) stated that phosphorus removal can be achieved in constructed wetlands by adsorption and precipitation in the soil, and a small amount is also taken up by plants for growth. There was also a higher concentration of potassium on the leaves of the vetiver grass than on the root and the soil of the constructed wetlands the same as that of total nitrogen and phosphorus. Therefore, 16,341.30, 18,334.40, and 15,989.00 mg/Kg on CW1, CW2, and control respectively are recorded in Table 4.3.

This indicates that CWs have higher potassium uptake through the leaf of the plants from coffee wastewater than the control. Based on this study the rank for potassium concentrations is plant shoot > plant root > soil on surface flow constructed wetlands feed with coffee wastewater. Generally, results show that there was a high amount of nutrients, especially potassium concentration in the area in both the soil and plants. It was not only on the CWs in the control group also the potassium concentration is higher than phosphorous and total nitrogen concentration as displayed in Appendix -6. Therefore, the higher concentration of nutrients in the area can lead to a negative removal of nutrients from the wastewater which is observed in this study on topic 4.1. As cited by (Choi *et al*., 2021) due to subsequent mineralization and release of phosphorus compounds in sediments phosphorus concentrations in water were increased.

Soil pH was greater at CW1 than the others at 8.28, 6.94, and 7.46 for CW1, CW2, and the control group respectively. The decrease from constructed wetland one (CW1) to constructed wetland two (CW2) may due to the acidic parameters of the coffee wastewater accumulation. On the other hand, the pH of the control group (7.46) was above the pH value of CW2. This implies that coffee wastewater may have an impact on the pH of the soil.

4.3. Physico-chemical parameters concentration of the River water

The comparison of the value of water quality parameters using a box plot is presented in Figure 4.7

and the WHO and FAO irrigation standards have been given in Table 4.4 to compare the quality of the river water. The mean and standard deviation for all parameters of the river is mentioned in a tabular form in Appendix-4. The results from the analyzed parameters established that the effluent from CW does not have a high significant polluting potential during the wet coffee processing season on the river water. Therefore, the findings from this study have shown a small number of variations in physicochemical parameters throughout the river.

4.3.1. Hydrogen ion concentration (pH)

The pH was a mean of 6.54 ± 0.44 upstream and a mean of 6.87 ± 0.32 downstream during the wet coffee processing period. High pH values (6.87 ± 0.32) were observed in the downstream and low values (6.54 ± 0.44) in the upstream site as shown in Figure 4.7, but this indicated an insignificant impact of effluents from constructed wetland/ treatment wetland in Kege coffee processing plant.

Table 4.4: FAO irrigation water quality standards

Parameter	Unit	FAO Irrigation water standard limits
$_pH$	$_pH$ scale	6.5-8.5
Temperature	^oC	20
EC	µs/cm	<250 excellent quality
TDS	mg/L	<160 excellent quality
TSS	mg/L	200
DO	mg/L	5 - 7 good quality
Turbidity	NTU	-----
BOD_5	mg/L	100
COD	mg/L	300
PO_4^{3-}	mg/L	5
NH_3-N	mg/L	5
NO_2-N	mg/L	-----
NO_3-N	mg/L	5

The pH of the water samples from the upstream and downstream sites generally showed that there was no significant difference ($p=0.274$). The mean pH levels were within the permissible limit at all downstream and upstream sampling sites. Different studies on the direct disposal of coffee wastewater to rivers show that significant impact of pH on water quality. Based on (Dadi et al., 2018) disposal of wastewater from wet coffee processing plants has impacted the pH of downstream water bodies the same to this (Bisekwa *et al*., 2021) also studied coffee wastewater impact the pH of the water samples from the upstream and downstream sites generally showed that there was a significant difference ($p < 0.05$). Therefore, the non-significant result of this study may be due to the treatment of the waste by the constructed wetland.

4.3.2. Dissolved oxygen, DO (mg/L)

DO was with a mean of 5.62 ± 0.17 upstream and with a mean of 5.51 ± 0.47 downstream during the wet coffee processing period. The DO values which were observed in the downstream and upstream sites indicated an insignificant impact of effluents from constructed wetland/treatment wetland in the Kege coffee processing plant. The DO of the water samples from the upstream and downstream sites generally showed that there was no significant difference ($p=0.722$).

A study on the same area done by (Tekle, 2017) with the title of wet coffee wastewater impact on Gidabo river stated that the mean value of DO is 1.655 ± 0.22 mg/l on downstream and 5.325 ± 0.53 mg/l upstream with a significance of ($p=0.018$) indicates that high influence of coffee wastewater disposal. However, this study's results had no significant difference between the sampling points; this may be due to the treatment potential of the constructed wetland.

4.3.3. EC (µs/cm) and TDS (mg/L)

Electrical conductivity (EC) can be regarded as a crude indicator of water quality for many purposes since it is related to the sum of all ionized solutes or total dissolved solids (TDS) content. EC of the river water at U/S and D/S was with a mean of 106.11 ± 9.35µs/cm and 143.22±21.59µs/cm respectively during the wet coffee processing period. The lower EC values (106.11 ± 9.35µs/cm) were observed in the upstream and higher values (143.22 ± 21.59µs/cm) in the downstream site as shown in Figure 4.7, this indicated an effect of effluents from constructed wetland/treatment wetland in Kege coffee processing plant. However, the statistics result of EC of the water samples from the upstream and downstream sites generally showed that there was no significant difference at ($p=0.052$). Despite this fact, the electrical conductivity of the water sample was found within the given limit (less than 250 excellent qualities for irrigation water) as prescribed by FAO Irrigation standard limits.

These results are in agreement with (Dadi et al., 2018); Minuta & Jini, 2017) who found that wet coffee processing wastewater has impacted the EC of downstream water bodies. For example, a comparison of the EC values in the upstream and downstream clearly shows that the EC values were measured to be much higher at the downstream sites during the disposal of coffee wastes. Therefore, based on this study higher downstream mean EC is than the upstream but it is not highly significant, it may be because of the treatment of coffee wastewater by the constructed wetland before discharging to the river.

Total dissolved solids of the river water at U/S and D/S was with a mean of 53.06 ± 4.67mg/L and 71.61 ± 10.78mg/L respectively during the wet coffee processing period. The lower TDS values (53.06 ± 4.67mg/L) were observed in the upstream and higher values (71.61 ± 10.78mg/L) in the downstream site as shown in Figure 4.7, this indicated an effect of effluents from constructed wetland/treatment wetland in Kege coffee processing plant. However, the statistics result of TDS of the water samples from the upstream and downstream sites generally showed that there was no significant difference at ($p=0.052$). Based on this, the total dissolved solids of the water sample was found within the given limit (less than 160 good qualities for irrigation water) as prescribed by FAO irrigation standard limits.

4.3.4. Total Suspended Solids/TSS (mg/L)

TSS of the river water at U/S and D/S were with mean values of 36.45 ± 5.01mg/L and 40.44 ± 11.10mg/L respectively during the wet coffee processing period. The low EC values (36.45 ± 5.01mg/L) were observed upstream and high values (40.44 ± 11.10mg/L) in the downstream site as shown in the box plot Figure 4.7, this difference is attributable to coffee solids waste of effluents from constructed wetland/treatment wetland in Kege coffee processing plant. However, the ANOVA statistics table of TSS of the water samples from the upstream and downstream sites generally showed that there was no significant difference at ($p=0.600$). The total suspended solid of water samples was found within the given limit (200) as recommended by FAO irrigation standard limit. As discussed in (Minuta & Jini, 2017; Bisekwa *et al*., 2021) the suspended solids in the coffee wastewater effluents cause turbidity in the receiving water and may alter the habitat of aquatic microbes. The high TSS might also be attributed to coffee pulp released from coffee processing plants.

4.3.5. Turbidity (NTU)

Turbidity is the amount of cloudiness in the water which is caused by dissolved or total suspended solids and most of the time those are invisible to the naked eye. And it is an important parameter to measure water quality. Turbidity can be caused by Silt, sand, and mud; Bacteria and germs;

Chemical precipitates (Arshad & Shakoor, 2018). The turbidity measure upstream and downstream of the river was with a mean of 34.77 ± 31.59 NTU and 70.83 ± 39.79 NTU respectively. This displayed there are variations among sampling locations but the statistics show that it did not change significantly at ($p = 0.286$). This means no significant difference in turbidity values between the U/S and D/S of the river at a 95% confidence interval. This was because the discharging effluent from the constructed wetland was statistically effective.

4.3.6. Temperature (^oC)

The temperature has a strong influence on many physical, chemical and biological characteristics. An increase in water temperature decreases the ability of dissolved oxygen to dissolve in water. The temperature upstream and downstream of the river was a mean of 20.23 ± 0.79 ^oC and 20.45 ± 1.00 ^oC respectively. This displayed there are no wide variations among sampling locations and did not change significantly at ($p = 0.788$). This means no significant difference in temperature values between the U/S and D/S of the river at a 95% confidence interval. The set limit for no risk on crops as per the WHO and FAO water quality guidelines for irrigation purposes is 20^oC but the results are above the permissible level to some extent, this may be because of the discharging effluent from the constructed wetland. Results are in approach with preceding work undertaken (Bisekwa *et al*., 2021) at Kayanza ecological zone in Burundi in which the temperature in the upstream rivers with a mean of 22.5˚C ± 1.76˚C and 22.7˚C ± 1.38˚C at the downstream of the river in the wet season was reported with a non-significant variation of the sampling points and results are not in agreement with previous work by (Tekle, 2017) at Gidabo river in which 25.50 ±0.71 ˚C on the upstream and 18.30 ±0.42 ˚C on downstream.

4.3.7. BOD_5 (mg/L) and COD (mg/L)

BOD_5 of the river water at U/S and D/S were with mean values of 47.40 ± 1.65 mg/L and 64.31 ± 16.50mg/L respectively during the wet coffee processing period. Low BOD values of (47.40 ± 1.65 mg/L) were observed in the upstream and high values (64.31 ± 16.50mg/L) in the downstream site, this difference is attributable to coffee solids waste of effluents from constructed wetland/treatment wetland in Kege coffee processing plant. However, the statistics table for BOD of the water samples from the upstream and downstream sites generally showed that there was no significant difference at (p=0.152) as discussed in Appendix -5. The biological/biochemical oxygen demand of water samples was found within the given limit (100) as recommended by FAO & WHO irrigation water standard limit but if this continues like this it may rise above the standard limit and it becomes above the control of the self-purification capacity of the river. Therefore, this study results had no significant difference statistically between the sampling points, this may be due to the treatment potential of the constructed wetland.

COD of the river water at U/S and D/S were with mean values of 185.22 ± 12.89mg/L and 234.67± 47.17 mg/L respectively during the wet coffee processing period. Low BOD values of (185.22 ± 12.89 mg/L) were observed in the upstream and high values (of 234.67± 47.17 mg/L) in the downstream site, this difference is attributable to effluents from constructed wetland/treatment wetland in the Kege coffee processing plant. However, the statistics table for COD of the water samples from the upstream and downstream sites generally showed that there was no significant difference at (p=0.155). The chemical oxygen demand of water samples was found within the given limit (300) as recommended by FAO & WHO irrigation water standard limit but if this continues like this it may rise above the standard limit and it becomes above the control of the self-purification capacity of the river.

Therefore, this study results had no significant difference statistically between the sampling points, this may be due to the treatment of the constructed wetland. As discussed by (Bisekwa et al., 2021) effluent discharged from the wet coffee processing factories may have increased the COD and BOD_5 concentrations of the receiving water bodies. The downstream rivers water COD and BOD_5 were high than 40 mg/l and 10 mg/l respectively. In a study done by (Tekle, 2017) on the impact of coffee wastewater discharge on water body 323.00±97.58mg/L upstream and 473.0±179.61mg/L downstream were reported for BOD_5 and 2664 ±1479.27 mg/L the with 3282.5±774.3 mg/L in downstream for COD. Both the above studies show that the BOD_5 and COD of coffee wastewater had an impact on receiving water bodies. However, this study shows that the treated effluent from constructed wetland is non-significant for BOD5 and COD concentrations of the river. Generally, it is in agreement with discussions by (Tekle, 2017) COD values are greater than BOD_5 values. COD values may greater when significant amounts of biologically resistant organic matter are present in the water body. Also, COD values are always higher than BOD values because COD includes both biodegradable and non-biodegradable organic and inorganic compounds while BOD values only indicates biodegradable organic compounds by microorganisms.

4.3.8. Phosphate (PO_4^{3-})

Throughout the wet coffee processing period, PO_4^{3-} of the river water at U/S and D/S were with a mean of 0.32±0.07mg/L and 0.49±0.18mg/L respectively. The statistics result of phosphate concentration of the water samples from the upstream and downstream sites generally showed that there was a non-significant difference at ($p= 0.213$). Regarding that phosphate concentration of the water sample was found within the given limit (5mg/L) as prescribed by FAO & WHO irrigation standard limits. There was no significant variation among the sampling stations for mean values of phosphates. This might be due to the phosphorous in the effluent of the treatment wetland being insignificant to bring a change in concentration in the downstream stations. The other probability is that total phosphorous could be hydrolyzed into other forms due to chemical transformation and storage by various aquatic organisms through its highly dynamic property of phosphorous compounds (Minuta & Jini, 2017). These results are not in agreement with (Rani & Haddis, 2008) studies on coffee wastewater discharge effects in Jimma zone Ethiopia. It were found that the concentration of phosphate in the water quality of the stream before entering the effluent of the coffee processing plant in the stream was 2.3 mg/L which was under permissible limits and the values of water samples of the stream taken from the point after discharging of wastewater from coffee processing plant were 4.1mg/L, which are very high as compared to results of this study.

4.3.9. Ammonia-N (NH_3-N)

Ammonia-N of the river water at U/S and D/S were with mean values of 0.56 ± 0.49 mg/L and 0.77 ± 0.54 mg/L respectively during the wet coffee processing period. The statistical result of an ammonia-N concentration of the water samples from the upstream and downstream sites generally showed that there was a highly non-significant difference at ($p=0.644$). Concerning the ammonia-N concentration of water samples were found within the given limit (5 mg/L) as prescribed by FAO & WHO irrigation standard limits. There was no significant variation among the sampling stations for mean values of ammonia-N. This might be due to the ammonia-N in the effluent of the treatment wetland being insignificant to bringing a change in concentration in the downstream stations.

4.3.10. Nitrite-N (NO_2-N mg/L) and Nitrate-N (NO_3-N mg/L)

Nitrite-N of the river water at U/S and D/S were with mean values of 0.07 ± 0.01 mg/L and 0.08 ± 0.02 mg/L respectively during the wet coffee processing period. The statistical result of the nitrite-

N concentration of the water samples from the upstream and downstream sites generally showed that there was a highly non-significant difference at (p=0.399). There was no significant variation among the sampling stations for mean values of nitrite-N.

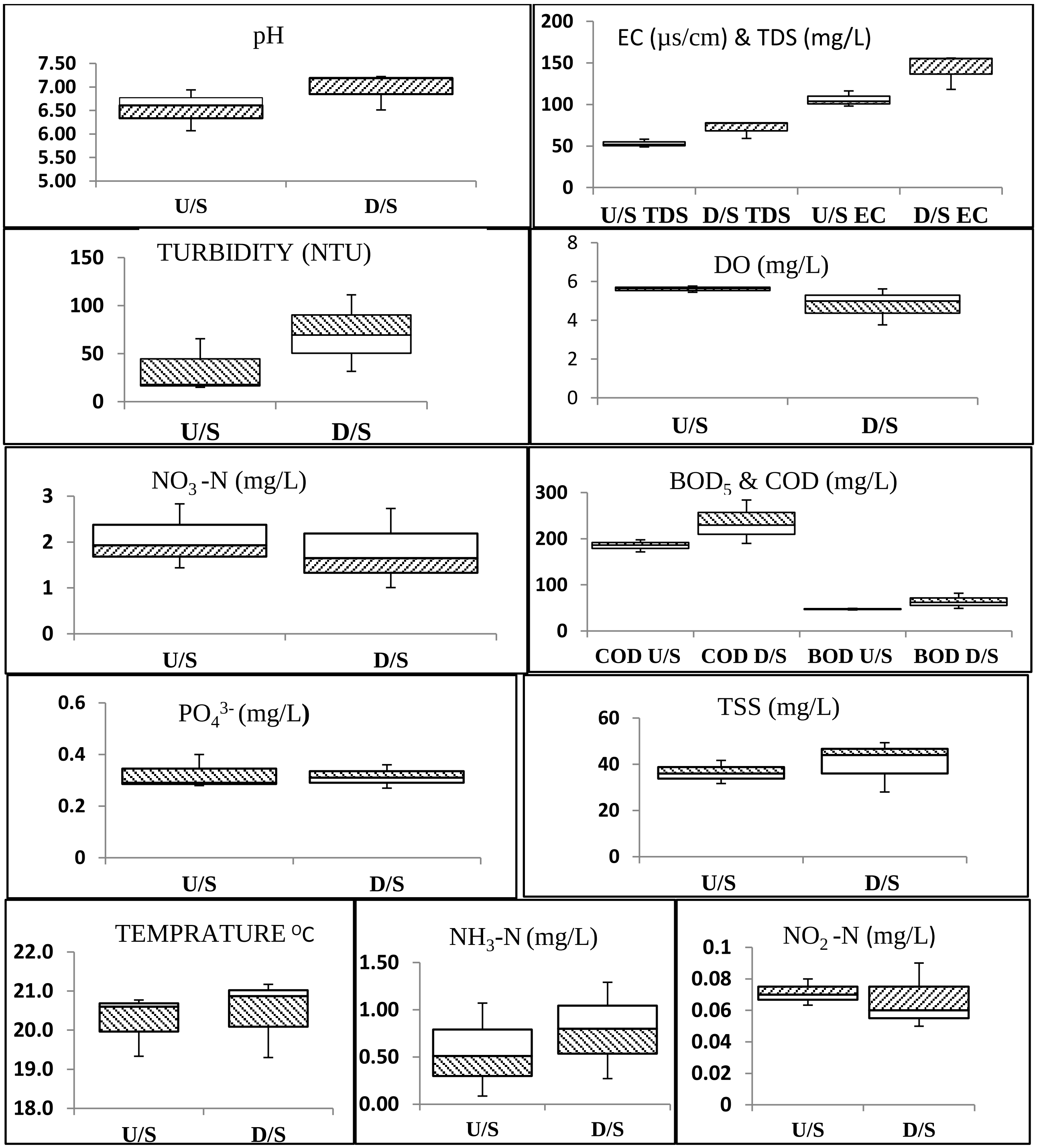

Figure 4.7: Box plot of water quality variables upstream and downstream of the river

Therefore, these results are statistically non-significant between the sampling points; this may be due to the lower concentration of nitrite-N at the coffee processing plant and the treatment efficiency of the constructed wetland. As observed from the analysis of the results, there is a small concentration of nitrite-N both at the constructed wetland as well as the river water this may also happen through the nitrification and plant uptake processes which convert nitrite to nitrate and organic nitrogen respectively. Therefore, the small amount of nitrite is good for the habit of fish and other microorganisms in the river water.

Nitrate-N of the river water at U/S and D/S during the wet coffee processing period was with mean values of 1.80 ± 0.31 mg/L and 2.45± 0.71 mg/L respectively. The statistical result of the nitrate-N concentration of the water samples from the upstream and downstream sites generally showed that there was a highly non-significant difference at ($p=0.215$).The nitrate-N concentration of the water sample was found within the given limit (5 mg/L) as prescribed by FAO & WHO irrigation standard limits. There was no significant variation among the sampling stations for mean values of nitrate-N. Therefore, the study result are not significant difference statistically between the sampling points, this may be due to the treatment of the constructed wetland. Without agreement to the study (Tekle, 2017) reported highly significant difference in concentration values of nitrate-N in river water during coffee processing seasons.

4.4. Socio-economic & environmental implication of the constructed wetland with its future sustainability

4.4.1. Respondent's demographic analysis

Out of the total 103 respondents, 56 (54.4%) of them were males and 47(45.6%) were females. Most of the respondents are daily workers which are 84(81.6%), 6.8% are staff workers and the other 6.8% are CPP owners with 1.9% farmers.

Table 4.5: Descriptive statistics for respondent's gender and occupation

1. Gender	Frequency	Percent	2. Occupation	Frequency	Percent
Male	56	54.4	Farmer	2	1.9
Female	47	45.6	CPP owner	7	6.8
Total	103	100.0	Daily worker	84	81.6
			Waiter	3	2.9
			Office worker	7	6.8
			Total	103	100.0

1.Educational background	Frequency	Percent	2.work experience	Frequency	Percent
Illiterate	34	33.0	2-4 years	10	9.7
Read and write	34	33.0	5-7 years	35	34.0
Primary	20	19.4	8-10 years	34	33.0
Secondary	2	1.9	> above 10 years	24	23.3
Diploma	9	8.7			
BSc degree	4	3.9			
Total	103	100.0	Total	103	100.0

Thirty-three percent (33%) were illiterate, 33.9% received formal education from primary school up to BSc level and the rest 33% of them were read and write with informal education. About 34% of respondents worked five up to seven years, 33% of them worked eight to ten years, 23.3% of them worked above ten years and only 9.7% have two up to 4 years of work experience on the CPP. This indicates respondents have high experience on their working environments as comprehend from their responses.

4.4.2. Respondent's general know-how about constructed wetland

Based on the result indicates that 62.1% of respondents have no general knowledge about CW before they saw it in this study area, and only 37.9% has known the meaning of CW.

Table 4.6: Public perception and knowledge on the CW

Knowledge about constructed wetlands before this HFCW		Frequency	Percent
	Yes	39	37.9
	No	64	62.1
	Total	103	100.0
Treatment efficiency of the CW on coffee WW treatment		Frequency	Percent
	Efficient	88	85.4
	Not efficient	15	14.6
	Total	103	100.0
CW treatment at the CPP		Frequency	Percent
	Functional	90	87.4
	Not functional	13	12.6
	Total	103	100.0

But now 85.4% of them have considered that CW as efficient in wastewater treatment and the remaining 14.6% have considered it was un-efficient or they can't choose it for wastewater treatment. The same to that functionality of the CW on Coffee WW was agreed by 87.4% of the respondents but 12.6% of them said it was not functional. This implies that the CW may be sustainable for the future according to the know-how of the people.

4.4.3. Socio-economic measurements

A. Economic measurements

Economic dimensions are the main supportive methods for sustainable wetland treatments. Due to this the economic benefits of the CW at Kege CPP, the main purpose of the river upstream and downstream of the CPP, and the main crop production by irrigation were discussed with the defendants.

Table 4.7: Responses on economic benefits of CWs

Economic benefits of CWs		The grass has used for house cover	The grass has used as a forage for animals	The grass has used for the purpose of local sleeping pad	Economical construction cost	Total
Occupation	Farmer	2	0	0	0	2
	CPP owner	5	1	0	1	7
	Daily worker	23	18	25	18	84
	Waiter	1	1	1	0	3
	Office worker	5	0	1	1	7
	Total	36	20	27	20	103

As indicated in Table 4.7 the responses for the main economic benefits of the constructed wetland are lower initial construction cost (agreed by 20 respondents), after harvesting the grass was used for local house cover (agreed by 36 respondents), the grass was used as a forage for their animals (agreed by 20 respondents), and the grass was used for a local sleeping pad (which is agreed by 27 respondents). Therefore, this indicates that the economic drives of CWs are not only indirect there are also direct usages of the grass after harvesting it.

Table 4.8: Main types of crops produced on the river sides

Main crop types produced by irrigation on the river		Maize and vegetation	'khat'	Total
Occupation	Farmer	2	0	2
	CPP owner	7	0	7
	Daily worker	71	13	84
	Waiter	3	0	3
	Office worker	7	0	7
	Total	90	13	103

The main types of crop produced on the river sides by irrigation are maize and different types of vegetation as mentioned in Table 4.8 ninety (90) respondents agreed to this. But to some extent "khat" production was practiced by the farmers only 13 respondents agreed from the daily workers. The crops may affect if the river water pollution by coffee waste increases year to year. Due to this sustainable wastewater treatments are the only choices for effective economic benefits of crop production. Furthermore, the purpose of the river water was not only for crop production it was also used for livestock drinking and for coffee processing as indicated in Figure 4.8. As discussed in Table 4.9 from the total of 103 respondents 49 of them tell that the river was used for irrigation, 33 of them state that the river was mainly used by the community for livestock drinking and 21 of them stated that the river water was mainly used for coffee processing.

Table 4.9: Purposes of the river upstream and downstream of the study area

Main purposes of river U/S & D/S of CPP		Irrigation	Livestock	Coffee processing	Total
Occupation	Farmer	1	1	0	2
	CPP owner	3	3	1	7
	Daily worker	36	28	20	84
	Waiter	2	1	0	3
	Office worker	7	0	0	7
	Total	49	33	21	103

Based on this irrigation and coffee processing are counteractive methods because the discharge of highly acidic effluents from the coffee processing affects the crops and irrigated lands of the community.

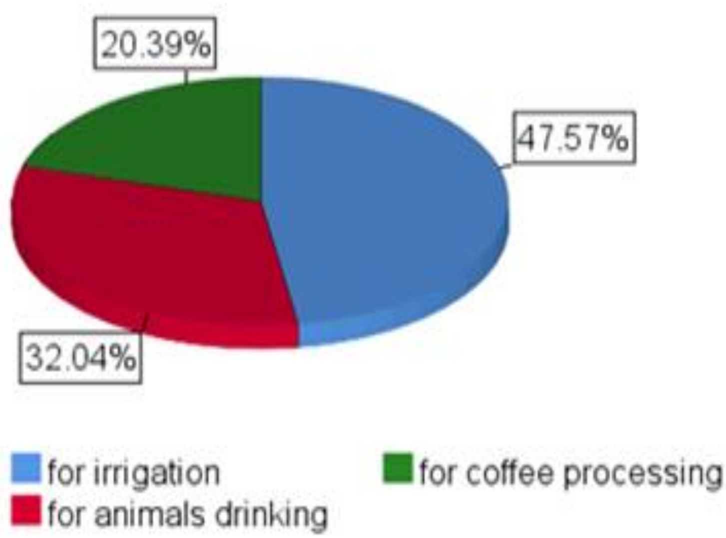

Figure 4.8: Main purposes of the river

That is why treatment of wetland is needed with sustainable functionality. The main purposes of the river upstream and downstream of the processing plant describes through percentage on Figure 4.8. These are irrigation, coffee processing, and livestock drinking with 47.57%, 20.39%, and 32.04% respectively.

B. Social measurements

From the total of one hundred three (103) respondents 101 of them reveal that constructed wetlands are sociable to treat coffee wastewater only two (2) of them tells as not sociable. An increase in awareness of the community about the treatment of wetlands is a major role in the sustainable functionality of the constructed wetland (CW). Therefore, as indicated in Table 4.10 most of the wereda and kebele leaders were aware (as stated by 62 of the respondents) but 34 defendants tell some leaders were aware and 7 of them state none of the leaders were aware. In addition to this some of the farmers are aware (47 of them states as some farmers were aware) then 37 of them stated as most farmers were aware and the remaining 19 defendants state that no one was aware of constructed wetlands.

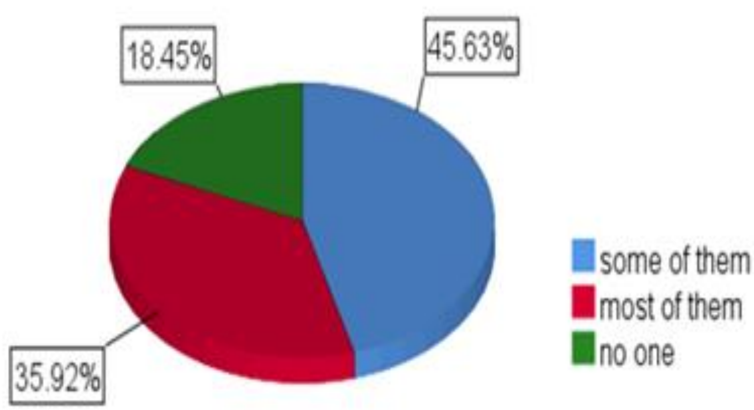

Figure 4.9: Response to farmer's awareness

According to the survey, the percentage of the farmer's awareness was figured out in Figure 4.9.

Table 4.10: Social measurements for the sustainability of constructed wetlands

The sociability of constructed wetlands coffee wastewater treatment					
		Sociable	Not sociable	Total	
Occupation	Farmer	0	2	2	
	CPP owner	7	0	7	
	Daily worker	84	0	84	
	Waiter	3	0	3	
	Office worker	7	0	7	
	Total	101	2	103	
Farmer's awareness of CWs					
		some of them	most of them	no one	Total
Occupation	Farmer	2	0	0	2
	CPP owner	3	1	3	7
	Daily worker	39	33	12	84
	Waiter	0	2	1	3
	Office worker	3	1	3	7
	Total	47	37	19	103
Wereda/ kebele leaders awareness on CWs					
		some of them	most of them	No one	Total
Occupation	Farmer	2	0	0	2
	CPP owner	3	3	1	7
	Daily worker	25	54	5	84
	Waiter	2	1	0	3
	Office worker	2	4	1	7
	Total	34	62	7	103

Therefore, 45.63% is for those who agree with some farmers have awareness; 35.93% indicates those who agree with most farmers have awareness, and the last 18.45% indicates those who agree with no one farmer has awareness of constructed wetlands. In general, the results reveal the importance of the socio-economic measurement of sustainability, public perception, awareness, and knowledge; economic purposes of both the river and the CW explain the sustainability of the CWs. And results indicate strongly that the socio-economic dimension, including the attitudes, awareness, knowledge, and economic purposes of both the river and the CW, is crucial to the sustainability of CWs as stated in a similar study by (K. A. Møller, O. Fryd, 2012).

4.4.4. Environmental measurements

The environmental dimension also affects sustainability, but the effect is indirect.

Table 4.11: The occurrence of farmland impact and river pollution

Impacts of coffee waste on farmlands		There is an impact	No-impact	Total
work experience	2-4 years	5	5	10
	5-7 years	15	20	35
	8-10 years	22	12	34
	> above 10 years	12	12	24
	Total	54	49	103
River pollution by coffee wastewater		There is pollution	No pollution	
Work experience	2-4 years	8	2	10
	5-7 years	19	16	35
	8-10 years	22	12	34
	> 10 years	13	11	24
	Total	62	41	103

To the decision-makers and the public, the existence of the treatment plant is justified by the positive impact on the environment. Social and institutional dimensions are the next important step in developing sustainable wastewater management systems in developing countries (K. A. Møller, O. Fryd, 2012). Coffee wastewater has an impact on farmlands and it has a higher source of pollution for the river water. Of the total survey defendants, 54 of them approved of the impact of the wastewater and 49 of them were not approved of the impact of the wastewater. In addition to this 62 defendants approved of the pollution of the river and 41 of them did not approve of the pollution of the river water.

Table 4.12: River pollution comparison with the past and farmland impact indicators

River pollution as compared to the past		Decreases	Increases	None	Total
work experience	2-4 years	6	3	1	10
	5-7 years	23	12	0	35
	8-10 years	19	9	6	34
	> above 10 years	17	7	0	24
	Total	65	31	7	103
Impact indicators on farm land, plants and crops		crops become dried	damages farm land soil	Coffee & large trees dried	Total
work experience	2-4 years	3	3	4	10
	5-7 years	24	5	6	35
	8-10 years	13	7	14	34
	> above 10 years	7	10	7	24
	Total	47	25	31	103

Based on the survey analysis decision for river pollution it was decreased as compared to past years as indicated in Table 4.11 because there is no direct discharging of coffee waste to the river nowadays. From this 63.11% of them were revealed that the pollution decreases; 30.10% of them reveal that the pollution increases from year to year but the remaining 6.80% of them reveal that neither increases nor decreases as indicated in Figure 4.10. The indicators of the wastewater impact which was discharged from coffee processing industries for the farmland, plants, and crops were mainly mentioned as crop drying, farmland soil damages, and drying of coffee & large trees. Hence these are the main impacts mentioned by respondents, 45.63% of the defendants were reveal that crop drying as an impact, 30.10% of them says even coffee and other large trees become died by the acidic behavior of coffee wastewater, and the remaining 24.27% agree with the damage of the waste on farmland soil. The soil of the farmland decreases its fertility rate after the wastewater reaches the land because the pH of the wastewater is acidic as discussed in topic 4.1.1 of this study. Moreover, the impact on farmland and crops is also discussed the impact on the river and its consequences on the ecosystem.

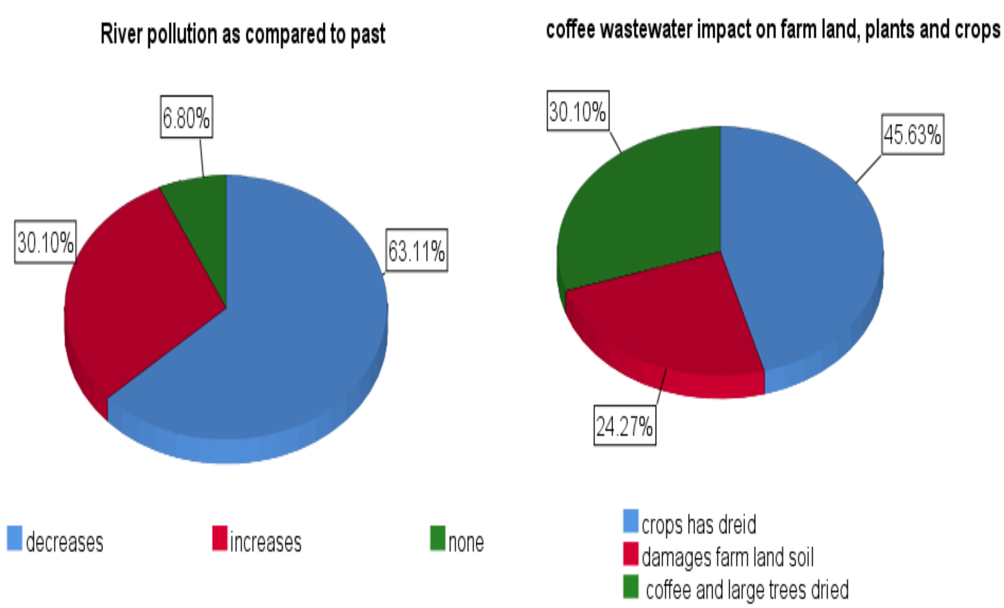

Figure 4.10: River pollution as compared to the past and the wastewater impact

The impacts are human health, abortion for animals, and animal health with 31, 29, and 43 defendants respectively as listed in Table 4.13. Therefore, the percentage reveal of the defendants was discussed based on their work experience in Figure 4.11. Of those who have a work experience of 2-4 years 9.68%, 13.79%, and 6.98% state that human health, abortion for animals, and animal health respectively.

Table 4.13: Problems of direct wastewater discharge and river pollution indicators

Problems of direct applying CPWW to river		human health	abortion for animals	animal health	Total
work experience	2-4 years	3	4	3	10
	5-7 years	10	10	15	35
	8-10 years	9	10	15	34
	> above 10 years	9	5	10	24
	Total	31	29	43	103
River pollution indicators		the color of the river water	The odor of the water changed	the river water becomes turbid by Pulp	Total
work experience	2-4 years	1	4	5	10
	5-7 years	12	11	12	35
	8-10 years	12	12	10	34
	> above 10 years	8	6	10	24
	Total	33	33	37	103

Survey defendants with an experience of 5-7 years tell that 32.26%, 34.48%, and 34.48% for human health, abortion for animals, and animal health respectively; respondents which are experienced 8-10 years tell that 29.03%, 34.48%, and 34.48% for human health, abortion for animals, and animal health respectively. Finally, those which are experienced above 10 years reveals that 29.03%, 17.24%, and 23.26% for human health, abortion for animals, and animal health respectively. This indicates that all the respondents understood the problem of the direct discharging of coffee wastewater to rivers and streams of their environment and they need a constructed wetland or other treatment mechanisms for their coffee processing plant/industries wastewater effluents to treat first before discharging to the environment or water bodies. Consequently, they may treat wastewater before discharging it to rivers and streams based on their knowledge of the negative impacts of the wastewater. This may also lead to sustainable usage of the constructed wetland.

To summarize all these environmental implication of constructed wetland has a positive impact on coffee wastewater treatment and it becomes sustainable for the future as understood from the survey data. This is an indicator of a healthy environment and ecosystem for the future around the study area and the river that of Gidabo river.

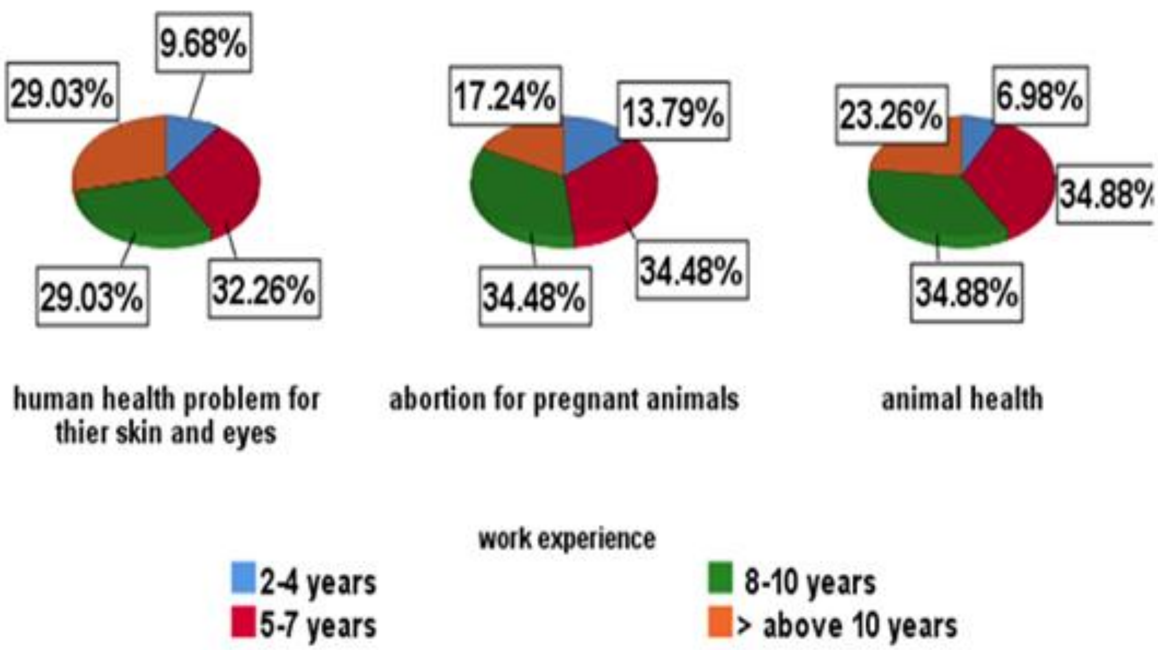

Figure 4.11: Main problems of discharging CPWW to rivers described based on work experience

4.4.5. Aspects of the CPP

The present aspect of the processing plant was discussed especially the wastewater caring capacity of the constructed wetland and the willingness of the CPP owners to use the constructed wetland sustainably. Therefore, the effectiveness of the carrying capacity of the constructed wetlands wastewater loading was revealed that it effective by 29 defendants; 40 defendants tell that was not effective; and the remaining 34 respondents neither tell as effective nor tell as non-effective. In addition to this, the willingness of the coffee processing plant (CPP) owners to use the CW sustainably as indicated in Table 4.14 was accepted by five respondents and two of them were not accept it. From the total daily workers, 82.76% of them accept the effectiveness of the CW; 72.50% of them do not accept its effectiveness.

Table 4.14: Aspects of the coffee processing plant

CW carrying capacity to WW discharge per day		Efficient	Not efficient	None	Total
Occupation	Farmer	0	2	0	2
	CPP owner	2	5	0	7
	Daily worker	24	29	31	84
	Waiter	2	1	0	3
	office worker	1	3	3	7
Total		29	40	34	103
Willingness to use the CW sustainably			Yes	No	
Occupation (only the CPP owners was answer this)		CPP owner	5	2	7

Then 91.18% of them neither accept the effectiveness nor accept the non-effectiveness of the constructed wetlands caring capacity of the coffee wastewater leading per day as indicated in Figure 4.12.

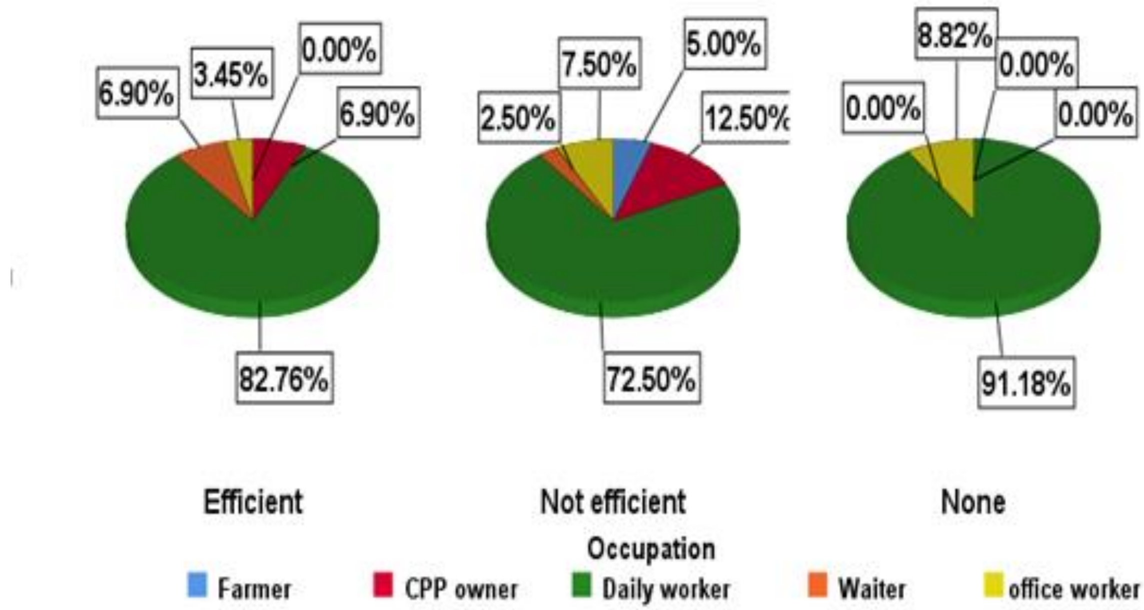

Figure 4.12: CW carrying capacity to the wastewater discharge per day

4.4.6. Communications

Under this sub-topic communications about the monitoring and evaluation of the processing plant were discussed with CPP owners and office workers. During the survey time discussion with CPP owners and the office workers, the following information was verified. There are evaluators for the coffee processing plant from different offices. These are the natural resource office, health office, environmental protection offices, and kebele leaders were observing the discharging mechanism of the wastewater; the surrounding farmer's field, and the river water quality as indicated in Figure 4.13. Then river water quality was observed mainly as 53.40% of defendants reveal it; coffee WW disposal reveals by 33.01% of the respondents; the surrounding farmer's field was revealed by 8.74% of respondents but 4.85% of them did not reveal the evaluation and monitoring of the processing plant. The frequency of monitoring and evaluation was weekly as described by the survey defendants. Finally, the survey conduct specifies punishments for CPP owners if the wastewater entered the water body or nearby farmlands. The penalty was up to closing the processing plant as enumerated during the discussion.

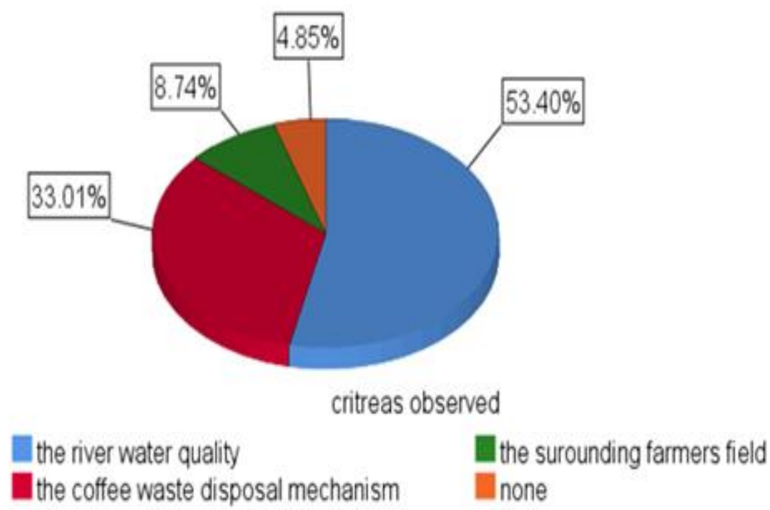

Figure 4.13: Criteria observed by the evaluators

5. SUMMARY, CONCLUSION, AND RECOMMENDATION

5.1. Summary

Concentrations of the influent and effluent of the constructed wetland were conducted for physicochemical parameters. The characteristics of the influent of CW were out of the wastewater discharge standard except for temperature, TDS, PO_4^{3-}, NH_3-N, and NO_3-N which are 22.81 ± 1.01^0C, 573.00 ± 106.86mg/L, 3.56 ± 0.46 mg/L, 3.33 ± 0.58 mg/L and 4.84 ± 0.24 mg/L respectively. Therefore, effluent concentrations from the constructed wetlands could significantly come to the standards limit with an increase in detention time for pH, DO, TSS, turbidity, PO_4^{3-}, NH_3-N, $BOD_{5,}$ and COD at $p \leq 0.05$. But for temperature, EC, TDS, NO_2-N, and NO_3-N effluent concentration were not significantly changed within detention time increases at $p > 0.05$. Percentage concentration removal was increased for temperature, TSS, EC, TDS, turbidity, BOD5, and COD. However, the percentage removal of NO_2-N, PO_4^{3-}, NH_3-N, and NO_3-N ensure variation with the detention time changes. This may be because of the naturally occurring metabolism and decomposition in the wetland system or because a large amount of N and P occurred on the soil and plant affects the removal of ammonia, nitrite, and nitrate.

Plant biomass of the constructed wetland was recorded from 1196 shoots/m^2 to 1322 shoots/m^2 this is higher than the 624 shoots/m^2 of the control. The CWs have higher amounts of N and K nutrients with smaller P on the shoot of the vetiver grass as compared to the control. The control one has a higher P than the CW. The nutrients N, P, and K concentration were ranged as a shoot of the grass > the root > the soil. Furthermore, the soil pH was 8.28 at the entry of the CW and it becomes 6.94 at the endways of the CW with 7.46 in the control group. This is an indicator that the acidic wastewater discharged into that soil was approached to neutral or pH of seven (7) during the treatment processes.

The river upstream and downstream physical and chemical parameters which are pH, Temperature, EC, TDS, Turbidity, DO, TSS, BOD_5, COD, PO_4^{3-}, NH_3-N, NO_2-N, and NO_3-N revealed statistically non-significant ($p > 0.05$) between upstream and downstream of the CPP. The same to these results were under the FAO irrigation water standards except for temperature. So the temperature of downstream was 20.45 ± 1.00^oC and 20.23 ± 0.79^oC upstream of the processing plant. This exceeds the standard limit (20^oC) by a certain amount.

The survey which was conducted to assess the importance of Kege-constructed wetland to the ecosystem and users who were located nearby communities and that aimed to know the understanding of the group of people and their opinions on the constructed wetland for its sustainability. Therefore, among the total defendants, 85.40% of the respondents have an awareness of the importance of constructed wetlands and from the total 103 respondents, 98.40% of them recognized the sociability of the CW. Moreover, 63.11% of them states that the environmental pollution decreases through the constructed wetland and 85.49% of the defendants described that the constructed wetland has an economical purpose in addition to the treatment of wastewater. However, 71.43% of the CPP owners define that the CW was not efficient to carry the WW discharge per day as their processing capacity increases year to year.

5.2. Conclusion

The HFCW has a good performance treatment with an increase in detention time as observed from the results CW treatment was significantly come to standards with an increase in detention time. Treating coffee processing wastewater with HFCW required a residence time of at least four days and CW is essential for coffee processing plants due to its good treatment performance. Results of pH, DO, TSS, turbidity, PO_4^{3-}, NH_3-N, BOD5, and COD at $p \leq 0.05$, accept the hypothesis. But temperature, EC, TDS, NO_2–N, & NO_3-N, are non-significant and reject the hypothesis and which parameters are below the discharge standard limit. On the other hand, nutrients N, P, and K values ordered shoot of the grass > the root > the soil indicates nutrient absorption efficacy of the vetiver grass is higher than the soil for coffee WW treatment.

The coffee wastewater effluent treated with HFCW and discharged to the river watershed has no significant change in concentration of the water physical and chemical parameters as obtained from the statistical results between US and DS of the CPP and parameters were under the FAO irrigation water standards. This indicates the CW treatment has a positive effect on the river water quality.

Finally, there was a positive response to the socio-economic and environmental implications of the sustainable use of constructed wetland. However, the surface area of the constructed wetland was not efficient with an increase the processing capacity of the coffee processing plant, which may lead to affect the functionality of the constructed wetland. So the CW will be sustainably used for the processing plant if the surface area becomes sufficient for the wastewater discharging per day.

5.3. Recommendations

- For further studies, to have an optimum detention time on which all the physical and chemical parameters reach the standard limit, testing with smaller detention time differences has to be studied.
- There must be a CW treatment for all of the CPP for the better quality of the river in the future.
- To design constructed wetlands for coffee processing plants the future capacity of the processing plant wastewater discharging per day should be forecasted.

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APPENDICES

A. Appendix -1

Procedures for water/wastewater nutrients analysis (HACH, 2005)

a) Ammonia, Nitrogen

1. Configure the Spectrophotometer to the correct wavelength settings by choosing stored program

2. Fill a graduated cylinder to the 25-mL mark with deionized water. Pour deionized water into 25mL sample cell. This cell was serving as the blank.

3. After collection bottle has adjusted to room temperature, fill a graduated cylinder to the 25-mL mark with sample. Pour sample into 25mL sample cell.

4. Add three drops of Mineral Stabilizer to each cylinder. Stopper and invert three times to mix.

5. Add three drops of Polyvinyl Alcohol Dispersing Agent to each cylinder. Stopper and invert three times to mix.

6. Pipet 1.0 mL of Nessler Reagent into each cylinder. Stopper and invert three times to mix.

7. Repeat steps 3-6 for all samples.

8. Start a stopwatch for one-minute reaction period.

9. When the timer finishes, insert the blank into the cell holder.

10. Zero the instrument.

11. Wipe the prepared sample and insert it into the cell holder.

12. Read the results in mg/L NH_3^--N.

13. Repeat steps 11-12 for all samples.

14. Dispose of all samples in an appropriately labeled hazardous waste bottle and store in hazardous waste cabinet.

b) Nitrate, Nitrogen

1. Configure the Spectrophotometer to the correct wavelength settings by choosing stored program.

2. After collection bottle has adjusted to room temperature, fill a graduated cylinder to the 25-mL mark with sample. Pour sample into 25mL sample cell.

3. Add one Nitra Ver 5 Nitrate Reagent Powder Pillow and stopper.

4. Start a stopwatch for one-minute reaction period and shake cell vigorously until timer finishes.

5. When the stopwatch finishes, reset and start again for five-minute waiting period.

6. When timer expires, fill a second cell with 25mL of sample. This will serve as the blank sample.

7. Wipe blank and insert it into the cell holder.

8. Zero the instrument.

9. Wipe the prepared sample and insert it into the cell holder.

10. Read the results in mg/L NO_3^--N.

11. Repeat steps 2-10 for all samples.

12. Dispose of all samples in an appropriately labeled hazardous waste bottle and store in hazardous waste cabinet.

c) Nitrite, Nitrogen

1. Configure the Spectrophotometer to the correct wavelength settings by choosing stored program.

2. After collection bottle has adjusted to room temperature, fill a graduated cylinder to the 25-mL mark with sample. Pour sample into 25mL sample cell.

3. Add one NitraVer®3 Nitrite Reagent Powder Pillow and stopper. Swirl cell to dissolve.

4. Start a stopwatch for twenty-minute reaction period.

5. When timer expires, fill a second cell with 25mL of sample. This will serve as the blank sample.

6. Wipe blank and insert it into the cell holder.

7. Zero the instrument.

8. Wipe the prepared sample and insert it into the cell holder.

9. Read the results in mg/L NO_2 –N.

10. Repeat steps 2-9 for all samples.

11. Dispose of all samples in an appropriately labeled hazardous waste bottle and store in hazardous waste cabinet.

d) Phosphate, Phosphorus Reactive

1. Configure the spectrophotometer to the correct stored program.

2. Using a graduated cylinder, measure 25 mL of the sample, and fill a sample cell. Repeat this step for each sample. In between measuring different samples, rinse the graduated cylinder with deionized water.

3. Add the powder pillow packet, PhosVer3, to each sample cell and shake vigorously for thirty seconds.

4. After the thirty second shake period has expired, allow for a two minute reaction period.

5. During this two minutes, prepare a blank for each sample measured by repeating step 2.

6. When the two minute reaction period has expired, clean the blank with a Kim Wipe® and insert into spectrophotometer.

7. Push “Zero” and the display will show 0.00 mg/L PO_4^{3-}

8. Clean the prepared sample and insert it into the spectrophotometer

9. Push “Read” and record the result.

10. Repeat 6-9 for the remaining samples and corresponding blanks.

B. Appendix 2

Table A_1: Mean values of CW influent and effluent quality parameters

Parameters	Samples	Trial 1	Trial 2	Trial 3	Mean	Parameters	Samples	Trial 1	Trial 2	Trial 3	Mean
p^H	Influent	5.05	4.79	4.68	4.84	BOD_5 (mg/L)	Influent	2123.00	2300	2210	2211.00
	12 hr dt	4.9	4.09	4.01	4.33		12 hr dt	1110	864.00	820	931.33
	24 hr dt	4.91	4.16	4.52	4.53		24 hr dt	1006	712	792	836.67
	48 hr dt	4.88	4.22	5.03	4.71		48 hr dt	949	565	489	667.67
	72 hr dt	4.78	4.88	5.41	5.02		72 hr dt	800	406	410	538.67
	96 hr dt	5.06	4.89	5.92	5.29		96 hr dt	712	359	260	443.67
	120 hr dt	5.7	5.12	6.02	5.61		120 hr dt	308	300	180	262.67
Temperature	Influent	22.74	21.94	23.94	22.87	COD (mg/L)	Influent	4082.00	4207	4199	4162.67
	12 hr dt	19.8	21.80	20.53	20.71		12 hr dt	2086	1992.00	2100	2059.33
^0C	24 hr dt	20.9	21.67	20	20.86		24 hr dt	2000	1158	1792	1650.00
	48 hr dt	21	20.47	18.47	19.98		48 hr dt	1656	1115	1019	1263.33
	72 hr dt	21.1	21	18	20.03		72 hr dt	1260	1026	794	1026.67
	96 hr dt	20.5	20.98	18	19.83		96 hr dt	1000	709	812	840.33
	120 hr dt	20	21.02	18	19.67		120 hr dt	600	392	520	504.00
EC (μs/cm)	Influent	1051.00	1089	986.02	1042.01	PO_4^{3-} (mg/L)	Influent	3.08	4	3.59	3.56
	12 hr dt	950	1100.00	973.48	1007.83		12 hr dt	3.66	3.56	4	3.74
	24 hr dt	1000	980.06	1001	993.69		24 hr dt	3.99	3.8	3.06	3.62
	48 hr dt	900	1009	902.31	937.10		48 hr dt	3.95	3.71	3.1	3.59
	72 hr dt	1002	869.86	902.06	924.64		72 hr dt	3.94	3.62	3.44	3.67
	96 hr dt	900	892.52	780	857.51		96 hr dt	3	3	2.12	2.71
	120 hr dt	889	350	910.08	716.36		120 hr dt	2	3	2.03	2.34

Parameters	Samples	Trial 1	Trial 2	Trial 3	Mean	Parameters	Samples	Trial 1	Trial 2	Trial 3	Mean
TDS (mg/L)	Influent	528.00	695	496	573.00	NH_3-N (mg/L)	Influent	3.00	3	4	3.33
	12 hr dt	478	556	278	437.33		12 hr dt	3.43	3.84	3.08	3.45
	24 hr dt	505	493	500	499.33		24 hr dt	3.65	3.66	3.12	3.48
	48 hr dt	451	225.5	112.75	263.08		48 hr dt	3.39	3.06	3.87	3.44
	72 hr dt	501.25	250.63	125.31	292.40		72 hr dt	3.41	3.41	3.22	3.35
	96 hr dt	425	458	429	437.33		96 hr dt	2.5	1.86	3	2.45
	120 hr dt	577.85	288.93	144.46	337.08		120 hr dt	1.99	3.01	2	2.33
TSS (mg/L)	Influent	799.67	503	591.67	631.45	NO_2 -N (mg/L)	Influent	0.80	1	0.79	0.86
	12 hr dt	576	380.00	363	439.67		12 hr dt	0.91	0.89	0.88	0.89
	24 hr dt	420	297.33	349.17	355.50		24 hr dt	0.99	1.01	0.7	0.90
	48 hr dt	360	254.67	320	311.56		48 hr dt	1.2	1	0.6	0.93
	72 hr dt	300	220	260	260.00		72 hr dt	1	1.01	0.7	0.90
	96 hr dt	216	200	201	205.67		96 hr dt	1.02	0.57	0.54	0.71
	120 hr dt	179	190	150	173.00		120 hr dt	0.64	0.56	0.3	0.50
Turbidity NTU	Influent	467.67	265	270	334.22	NO_3 N (mg/L)	Influent	4.57	4.9	5.04	4.84
	12 hr dt	205	137.33	171.67	171.33		12 hr dt	4.88	5.00	4.77	4.88
	24 hr dt	110	100.73	141	117.24		24 hr dt	5.06	4.89	4.78	4.91
	48 hr dt	160	88.23	130	126.08		48 hr dt	4.99	6.67	3.09	4.92
	72 hr dt	98	68	110.33	92.11		72 hr dt	5.25	6.03	3.28	4.85
	96 hr dt	45	64.13	80	63.04		96 hr dt	3.56	3.01	4.1	3.56
	120 hr dt	50	48	62	53.33		120 hr dt	4.05	3.03	2.5	3.19
DO (mg/L)	Influent	1.99	1.92	1.07	1.66						
	12 hr dt	1.8	2.78	2.35	2.31						
	24 hr dt	2.5	2.71	2.81	2.67						
	48 hr dt	3.12	2.63	2.27	2.67						
	72 hr dt	3.68	3.12	2.95	3.25						
	96 hr dt	3.95	3.86	3.76	3.86						
	120 hr dt	4.05	3.88	3.92	3.95						

C. Appendix- 3

Table A_2: Statistical analysis for pH at constructed wetland within detention times

Descriptive

pH	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum	95% Confidence Interval for mean	
							Lower	Upper
pH_0.5d	3	4.333	.49238	.234	4.01	4.9	4.010	4.900
pH_5d	3	5.613	.45622	.220	5.12	6.02	5.120	6.020
pH_1d	3	4.530	.37510	.172	4.16	4.91	4.160	4.910
pH_2d	3	4.710	.43093	.197	4.22	5.03	4.226	5.030
pH_3d	3	5.023	.33858	.163	4.78	5.41	4.780	5.410
pH_4d	3	5.290	.55218	.259	4.89	5.92	4.890	5.920
pH_Zero	3	4.840	.19000	.091	4.68	5.05	4.680	5.050
Total	21	34.339	2.83539	1.336	31.86	37.24	31.866	37.24

ANOVA

Source of Variation	SS	Df	MS	F	P-value	F crit.
Between Groups	3.521	6	0.587	3.333	0.030	2.848
Within Groups	2.465	14	0.176			
Total	5.986	20				

Post Hock

Multiple comparisons

Tukey HSD PH (I)	(J) PH	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
pH_0.5d	pH_5d	-1.2800*	.34262	**.028**	-2.4499	-.1101
	pH_1d	-.1967	.34262	.997	-1.3666	.9732
	pH_2d	-.3767	.34262	.918	-1.5466	.7932
	pH_3d	-.6900	.34262	.448	-1.8599	.4799
	pH_4d	-.9567	.34262	.146	-2.1266	.2132
	pH_Zero	-.5067	.34262	.752	-1.6766	.6632
pH_5d	pH_0.5d	1.2800*	.34262	**.028**	.1101	2.4499
	pH_1d	1.0833	.34262	.078	-.0866	2.2532
	pH_2d	.9033	.34262	.187	-.2666	2.0732
	pH_3d	.5900	.34262	.614	-.5799	1.7599
	pH_4d	.3233	.34262	.958	-.8466	1.4932
	pH_Zero	.7733	.34262	.327	-.3966	1.9432
pH_1d	pH_0.5d	.1967	.34262	.997	-.9732	1.3666
	pH_5d	-1.0833	.34262	.078	-2.2532	.0866
	pH_2d	-.1800	.34262	.998	-1.3499	.9899
	pH_3d	-.4933	.34262	.773	-1.6632	.6766
	pH_4d	-.7600	.34262	.345	-1.9299	.4099
	pH_Zero	-.3100	.34262	.966	-1.4799	.8599
pH_2d	pH_0.5d	.3767	.34262	.918	-.7932	1.5466
	pH_5d	-.9033	.34262	.187	-2.0732	.2666
	pH_1d	.1800	.34262	.998	-.9899	1.3499
	pH_3d	-.3133	.34262	.964	-1.4832	.8566
	pH_4d	-.5800	.34262	.631	-1.7499	.5899
	pH_Zero	-.1300	.34262	1.000	-1.2999	1.0399
pH_3d	pH_0.5d	.6900	.34262	.448	-.4799	1.8599
	pH_5d	-.5900	.34262	.614	-1.7599	.5799
	pH_1d	.4933	.34262	.773	-.6766	1.6632
	pH_2d	.3133	.34262	.964	-.8566	1.4832
	pH_4d	-.2667	.34262	.984	-1.4366	.9032
	pH_Zero	.1833	.34262	.998	-.9866	1.3532
pH_4 d	pH_0.5d	.9567	.34262	.146	-.2132	2.1266
	pH_5d	-.3233	.34262	.958	-1.4932	.8466
	pH_1d	.7600	.34262	.345	-.4099	1.9299
	pH_2d	.5800	.34262	.631	-.5899	1.7499
	pH_3d	.2667	.34262	.984	-.9032	1.4366
	pH_Zero	.4500	.34262	.835	-.7199	1.6199
pH_Zero	pH_0.5d	.5067	.34262	.752	-.6632	1.6766
	pH_5d	-.7733	.34262	.327	-1.9432	.3966
	pH_1d	.3100	.34262	.966	-.8599	1.4799
	pH_2d	.1300	.34262	1.000	-1.0399	1.2999
	pH_3d	-.1833	.34262	.998	-1.3532	.9866
	pH_4d	-.4500	.34262	.835	-1.6199	.7199

D. Appendix-4

Table A_3: River water quality parameters result

Parameters	River U/S				River D/S				FAO & WHO limits
	Trial 1	Trial 2	Trial 3	Mean ±SD	Trial 1	Trial 2	Trial 3	Mean± SD	
p^H	6.94	6.61	6.07	6.54 ± 0.44	7.19	7.22	6.51	6.87 ± 0.32	6.5-8.5
Temp ^{0}C	20.77	20.6	19.33	20.23 ± 0.79	20.87	21.17	19.3	20.45 ± 1.00	20
EC µs/cm	116.33	104	98	106.11 ± 9.35	118.3	155.37	156	143.22 ± 21.59	<250
TDS mg/L	58.17	52	49	53.06 ± 4.67	59.17	77.67	78	71.61 ± 10.78	<160
TSS mg/L	41.67	36	31.67	36.45 ± 5.01	44	49.33	28	40.44 ± 11.10	200
Turbidity NTU	71.20	18.05	15.05	34.77 ± 31.59	111.27	69.49	31.72	70.83 ± 39.79	-----
DO mg/L	5.44	5.64	5.77	5.62 ± 0.17	5.62	4.99	3.77	5.51 ± 0.47	5 – 7
BOD_5 mg/L	48.00	45.54	48.67	47.40 ± 1.65	49	43.1	47.67	64.31 ± 16.50	100
COD mg/L	186.67	197.33	171.67	185.22±12.89	193.33	190	160.67	234.67 ± 47.17	300
PO_4^{3-} mg/L	0.29	0.4	0.28	0.32± 0.07	0.27	0.36	0.31	0.49 ± 0.18	5
NH_3-N mg/L	0.09	1.07	0.51	0.56 ± 0.49	0.8	1.29	0.27	0.77 ± 0.54	5
NO_2 –N mg/L	0.06	0.07	0.08	0.07 ± 0.01	0.09	0.05	0.06	0.08 ± 0.02	-----
NO_3 N mg/L	1.44	1.93	2.83	1.80 ± 0.31	1.65	1.01	2.73	2.45± 0.71	5

E. Appendix -5

Table A_4: One Way ANOVA for BOD_5 and COD (sample analysis)

One Way ANOVA **BOD_5**

Groups	Count	Sum	Average	Variance
U/S river	3	142.21	47.40333	2.716233
D/s river	3	192.94	64.31333	272.306

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	428.92215	1	428.9222	3.119181	0.152	7.708647
Within Groups	550.04453 3	4	137.5111			
Total	978.96668 3	5				

One Way ANOVA **COD**

Groups	Count	Sum	Average	Variance
U/S river	3	555.66667	185.2222	166.1737
D/s river	3	704	234.6667	2225.333

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3667.1296 3	1	3667.13	3.066794	0.155	7.708647
Within Groups	4783.0141	4	1195.754			
Total	8450.1437 3	5				

F. Appendix -6

Table A_5: Soil and plant nutrient laboratory test: a sample table

Horticoop Ethiopia (Horticulture) PLC

Soil and Water Analysis Laboratory

HORTICOOP

Plant Analysis Certificate

Test Overview

Customer: Hawassa University - Hewan Tadesse

Tel: +251 966 31 81 91

Address: Hawassa,

Country: Ethiopia

Information about Sample			
Laboratory Code	22HPA1072	Order Number	HEON/22 - 021
Crop	-	Date Sampled	-
Sampled By	Client	Date Received	February 16, 2022
Location	Hawassa	Report Date	March 10, 2022
Description	Grass Sample Control		

Analytical Result					
Parameter		Result	Unit	Result	Unit
Total Nitrogen	TN	0.26	%		
Calcium	Ca	2,913.38	mg/kg (ppm)	0.29	%
Potassium	K^+	15,989.00	mg/kg (ppm)	1.60	%
Magnesium	Mg^{2+}	743.31	mg/kg (ppm)	0.07	%
Sodium	Na^+	471.29	mg/kg (ppm)	0.05	%
Phosphorus	P	2,939.72	mg/kg (ppm)	0.29	%
Iron	Fe	331.24	mg/kg (ppm)		
Manganese	Mn	111.42	mg/kg (ppm)		
Zinc	Zn	22.25	mg/kg (ppm)		
Boron	B	< 0.470	mg/kg (ppm)		
Copper	Cu	2.62	mg/kg (ppm)		
Molybdenum	Mo	36.33	mg/kg (ppm)		

Page 1 of 2

Analytical Methods	
Parameter	**Examination Standards**
Total Nitrogen	Wet digestion (Kjeldahl Distilation)
All Macro and Micro	Wet digestion (ICP -OES Detrmination)

Zufan Gikidan

Lab. Head

T: +251 11 652 55 89 P.O.BOX: 1646 Debere Zeit, Ethiopia E-mail: Laboratory.horticoop@gmail.com

G. Appendix -7

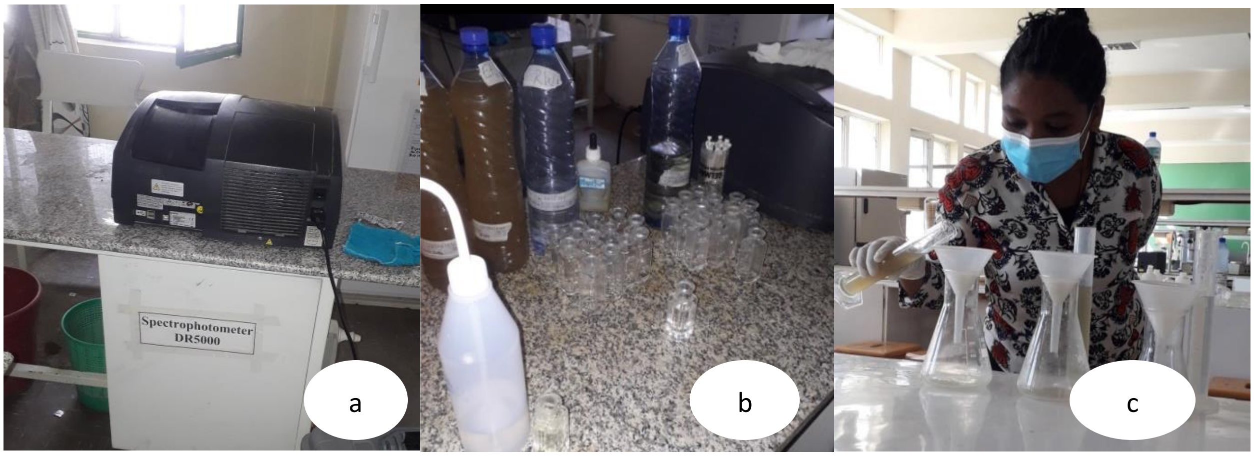

Figure A_1: (a) spectrophotometer (b) test tubes (c) TSS analysis using filter paper

Figure A_2: Field pictures during the survey time and soil sample collection

H. Appendix-8

Interview questions for sample survey

SUSTAINABILITY OF HYBRID FLOW CONSTRUCTED WETLAND TREATMENT FOR COFFEE WASTEWATER: THE CASE OF KEGE WET COFFEE PROCESSING PLANT, GIDABO RIVER WATERSHED, ETHIOPIA. HAWASSA UNIVERSITY THE DEPARTMENT OF WATER RESOURCE AND IRRIGATION ENGINEERING

General direction

Dear sir/madam, I am Hewan Tadesse a postgraduate student from Hawassa university. In order to complete my training program, I am seeking survey data to aid in preparing my research thesis that will contribute to the improvement of constructed wetland sustainable functionality on socioeconomic and environment implication. Since you have been randomly selected for an interview for the study, the aim of this research is to fulfill partially the academic requirements for the award of the degree of masters. I kindly request you to answer the following questions as honestly as possible. All the information provided will be treated with highest degree of confidentiality and its usage will be only for the purpose of this study.

Part one: Demographic characteristics

1. Gender 1.male ---------------------2. female -------------------
2. Occupation of the respondent. 1. Farmer ------------ 2. CPP owner ------- 3. Daily worker 4. Waiter ---------- 5. Natural resource staff ------------- 6. Environmental protection leader ------------ 7. Woreda agricultural office --------
3. Work experience. 1. 2 years 2. 3 years 3. 4 years 4. 5 years 5. Specify if other-----------

4. Educational background of the respondent. 1. Illiterate------------ 2. Read and write -------

3.primary---------------- 4.secondary------------ 5. Diploma --------------- 6. BSc degree---------

Part 2: General knowledge questions

1. Do you know about constructed wetlands?

Yes ---------------------   No? -----------------

2. What a constructed wetland means? ---

----

3. Is Constructed Wetlands (CW) efficient to treat coffee processing wastewater (CPWW)?

YES-------   NO-------

4. If yes (No. 3), have you seen this treatment at Kege coffee processing plant (CPP)?

Yes -----   No ---------------------

5. How treatment by CW is processed? 1.---2.--------------

--------------------3.------------------------ 4.   -------------------------------

Part 3: Environmental measurements

1. Is the river (Gidabo) polluted by the wastewater (WW) from the CPP?

Yes-------------- No ----------------

2. How do you see this pollution of the river? ---------------------------------

3. When you compared to the past do you think the river water pollution increases or decreases?

1. Decreases -------------------- 2.increases ---------------------- 3. I don’t know---------------

4. Is the wastewater effluent from the CPP damage the farm of the surrounding farmers?

1. Yes ------------ 2. No ------------------

5. How much it is dangerous for farm land, plants and crops? 1.--------------2.---------------3.-------

6. What are the problems of direct applying coffee wastewater to the river? -----------------------------

----

Part 4: Socio-economic determinants

1. Are there any economic benefits from CWs? 1. Yes ---------2. No ---------------

2. What are the economic benefits? --

3. Is it sociable to treat coffee wastewater by using constructed wetlands? 1. Yes ------ 2. No ---

4. How many farmers and CPP owners have awareness on CWs?

1. Some of them ----------- 2. Almost all of them ----------- 3. Most of them ----------------

5. They haven't awareness on CW ---------------

5. How many of the wereda/ kebele leaders have awareness on CWs?

1. All of them ----------- 2. Most of them ---------- 3. Some of them----- 5. I don’t know -------

6. Is that Gidabo river have used for irrigation purpose or not?

1. Yes --------- 2. No -------

7. What are the main purposes of the river downstream and upstream of the CPP?

1. For irrigation --------- 2. Livestock drinking ------- 3. For coffee processing ------- 4. Others ---

Part 5: Aspects of the processing plant

1. How many kilograms of wet coffee are processed per day in this CPP? --------------

2. How many litters of water were used per day? ------------------- 3.

Is the CW enough to carry the total loading of the WW per day?

1. Yes ---------- 2. No -------

4. If not (No. 3) which mechanism of disposal do you have to use mostly?

1. Local pit ----------- 2. Natural wetland -------- 3. Direct disposal to river ------ 4. Others ------5.

Does the local pit maintained yearly or not? 1. Yes ----------- 2. No ---------

6. Is the natural wetland on this processing plant efficient to treat the WW?

1. YES ----------- 2. NO --------

7. Is the natural wetland enough to the WW loading per day?

1. Yes ---------- 2. No --------

8. Which WW disposal mechanism is best for you?

1. CW ------------- 2. NW -------------- 3. Local pit -------------

9. Why you select this One? --

10. If CW is best treatment method for you, do you will have to use it every year?

1. Yes ------------ 2. No -------------

Part 6: Communications

1. Is there monitoring and evaluation for the disposal of the wastewater? 1. Yes --- 2. No ---

2. If yes (No. 1), frequency of monitoring and evaluation?

1. every day ------------
2. twice per week --------------
3. weekly -------------

4. yearly --------------
5. mention if others ----------

3. Who is the evaluator? 1. Natural resource office ----------

2. The woreda health office ---------

3. Environmental protection workers --------

4. Others---------------------------

4. What are the criteria observed during evaluation?

1.The river water quality --- 2. The coffee waste disposal mechanism ---- 3. The surrounding farmer's field ------- 4. Others ------------

5. What are the punishments if the CPP effluent pollutes the river?

1. Closing the coffee processing plant ---------------

2. The CPP have to stop working immediately -------------

3. They have written a letter of warning for the CPP owners ----------------

4. Others -------------------

THANK YOU!