ENVIRONMENTAL POLLUTION AND MANAGEMENT OF WET COFFEE PROCESSING WASTEWATER IN BURUNDI

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Environmental Pollution and Management of Wet Coffee Processing Wastewater in Burundi

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature …….....Date …….……

Emile Bisekwa

This thesis has been submitted for examinations with our approval as University Supervisors.

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DEDICATION

This work is dedicated to my beloved Mother (Minani Imelte) who had a great dream for my success in education but passed on my wife, son, daughters, nephews, and nieces to serve as an inspiration for hard work and testimony that with God all things are possible**.**

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ABBREVIATIONS AND SYMBOLS

AAS	Atomic Absorption Spectrophotometer
AFNOR	Agence Française de Normalisation
APHA	American Public Health Association
ASA	Activated Sludge Aeration
ASV	Anodic Stripping Voltammetry
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CPC	Coffee Production Country
CSS	Coffee Silver Skin
CWWTP	Coffee Wastewater Treatment Plant
DO	Dissolved Oxygen
FAO	Food Agriculture Organization
ICO	International Coffee organization
ICP-MS	Inductively Coupled Plasma-Mass Spectrophotometer
IITA	International Institute of Tropical Agriculture
ISABU	Institut des Sciences Agronomiques du Burundi
IWRM	Integrated Water Ressources Management
MINAGRIE	Ministère de l'Agriculture et de l'Elevage
SCG	Spent Coffee Ground
STOAT	Sewage Treatment Operation and Analysis over Time
TSS	Total Suspended solid
UV	Ultra Violet
WCPF	Wet Coffee Processing Factories
WCPTP	Wet Coffee Processing Treatment Plant
WHO	World health Organization

ABSTRACT

Arabica coffee is cultivated by smallholder farmers for commercial purposes, and it is mainly processed using wet Coffee Processing Technology. Burundi has more than 250 Coffee Processing factories owned by private, cooperative and government which discharge effluents to the receiving water bodies. The aim of this study was to determine the physico-chemical properties of wet coffee processing plants effluent and environmental effects in Burundi. Levels of physico-chemical parameters in wastewater from Coffee Processing factories were studied, and the impact of wet coffee processing effluents on water quality of receiving water bodies were studied in Kayanza, Gitega and Makamba. The dynamic simulator Sewage Treatment Operational Analysis Overtime was used to simulate and optimize treatment design. The samples were collected from the effluent released from the selected wet coffee processing factories and Upstream and downstream of discharge points in the receiving rivers/Streams using pre-cleaned plastic bottles. pH, TDS, EC, DO, Salinity, were analyzed onsite by using Trace2o Hydrocheck HC1000 multi-parameter. Samples were prepared and analyzed using standards methods as described in AFNOR and APHA. Various simulation models were implemented using STOAT to simulate treatment processes in studied design approaches such as ASAL 1 model; BOD model; and SSED 1 model. Data were analyzed using Rstudio-1.0.153, GenStat 64-bit Release 14.1 and SPSS. The study found that coffee wastewater does not meet Burundi Effluent Discharge standards for TSS, COD, BOD_5 and pH. However, Nitrates, Nitrites, DO, Phosphates, salinity, EC, TDS, Chlorides, Pb, Cu and NH_4^+ were in conformity with the set standards. All sites downstream had COD, BOD_5 and TSS values above recommended standards while pH was below the allowable limits set by WHO and Burundi standards. The result from WCPTP designed by STOAT met the required standards for discharge in surface water bodies.

CHAPTER ONE

INTRODUCTION

1.1 Background

Coffee is one of the most important agricultural Commodities in the world. Burundi is among coffee producing countries, with an average of $50 to 60 million per year in export earnings, which corresponds to between 70 and 80% of national export earnings (Nibasumba, 2013). It belongs to the family *Rubiaceae* and it has many species. Arabica Coffee (93%) and Robusta (7%) are the two predominant varieties of the subfamily cultivated in Burundi for commercial purposes. Coffee is produced by a large number of countries throughout the world. However, the ten largest coffee producing countries include Brazil, Vietnam, Colombia, Indonesia, Ethiopia, Honduras, India, Uganda, Mexico and Guatemala are responsible for approximately 80% of the world production (CPC, 2019). Processing coffee cherries into green coffee is generally divided into wet method and dry method (ICP, 2019). Most coffee produced in Burundi is Arabica coffee which is processed using the wet method for coffee cherry. The wet processing method requires specific equipment and adequate amount of water. The wet processing method is more advanced than the dry processing method and leads to better quality coffee bean (Novita, 2016). Wet coffee processing is generally used on Arabica coffee; however, it is now also being used on Robusta coffee. The spent coffee wastewater contains large amounts of organic compounds like fatty acids, lignin, cellulose, hemicellulose, and other polysaccharides. The wet processing method generates a huge amount of coffee processing effluent, rich in suspended organic matter, organic and inorganic compounds in solution, with great polluting potential, which must be adequately treated before discharge to the environment. Environmental pollution caused by poor waste management is an alarming challenge for developing countries to meet the millennium development goals (Thenepalli et al., 2017). This sector is essential for the reduction of poverty and the economic growth of Burundi and supports the agricultural economy of households and the agribusiness sector. It contributes to the generation of income and

employment through coffee processing, storage, and transport activities (Minagrie, 2000).

According to the National Confederation of Coffee Producers' Associations (CNAC, 2018), Burundi has more than 250 coffee processing factories. Most of the coffee washing plants has yet to install wastewater treatment systems. However, due to poor construction quality and poor management, the large number of the small wastewater treatment plants do not meet the Burundi National Standards (MIWESPU, 2014). Coffee processing factories generate high levels of water pollution due to untreated wastewater. The growing coffee sector raises a historical problem of pollution of the environment. Non-treatment of coffee wastewater is an important source of environmental pollution. The coffee pulp emits CO_2 and methane; two greenhouse gases to global warming. It can also cause destruction of the ozone layer if these gaseous emissions contain halogenated derivatives, commonly known as Chlorofluorocarbons (CFCs), which are produced in particular when the combustion of waste is at low temperature. Excessive use of water and chemicals in the manufacture and treatment of finished products by industry pose a serious threat to the quality of the water. Most industries discharge their effluent to nearby streams as a measure to dilute it.

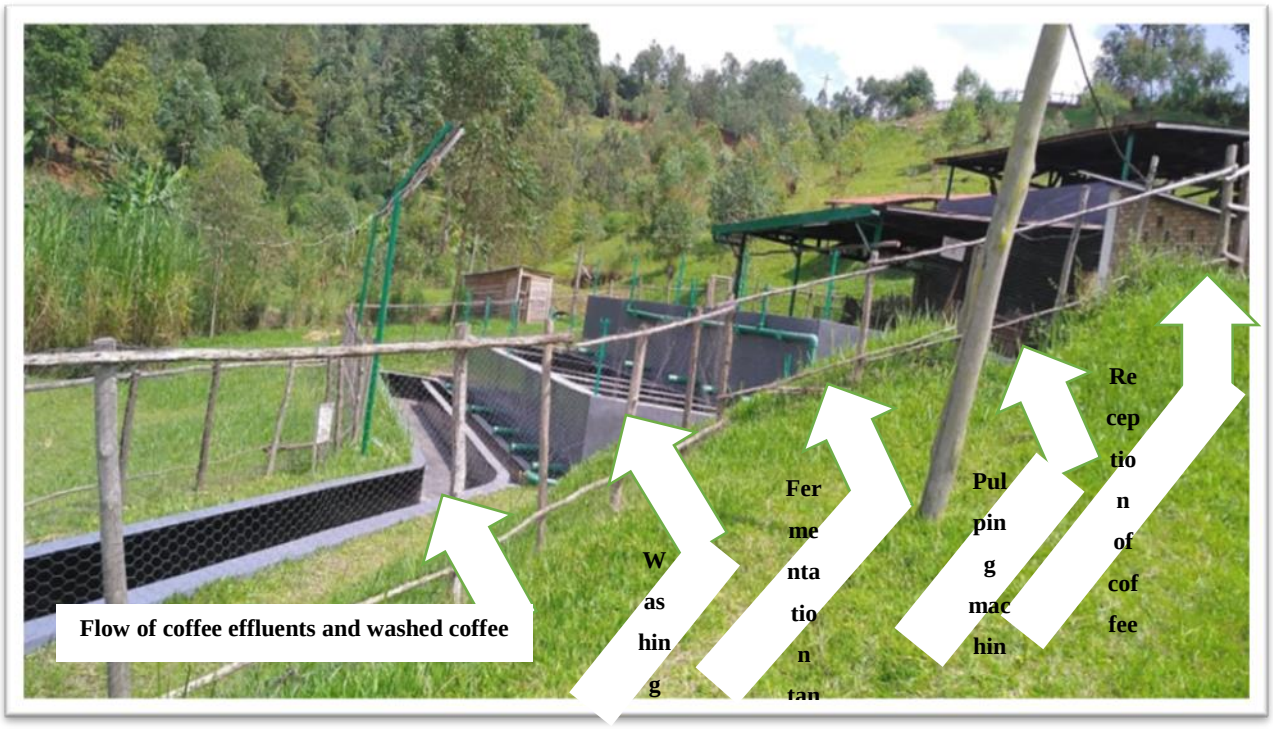


Plate 1.1: Wet coffee processing plant

Plate 1.2: Coffee wastewater from wet coffee processing factory

1.2 Statement of the problem

In Burundi, wet coffee processing factories pose a threat of water pollution as a result of wastewater that is not treated or recycled and discharged into natural waterbodies that can be consumed in downstream by the population. The water resource is exploited without respecting the principles of integrated water resources management (IWRM) due to the lack of a coordination structure between the various users of water resources upstream and downstream of the watershed (basin committees and sub-basins). According to Bikwemu (2015), the construction of wet coffee processing factories did not take into consideration environmental protection except for a small number, this causes the pollution of rivers by the spill of wastewater from depulping which is sent directly to the surface water without treatment. Wastewater from coffee processing that is discharged to the surrounding areas has serious effects on human health and the environment.

1.3 Justification

The increase in the number of wet coffee factories leads to the generation of high quantities of coffee processing wastes mainly coffee pulp and coffee wastewater which are discharged into natural water system which flow into rivers or penetrate into ground water causing pollution to both the surface and ground water. Coffee processing factory produces a high pollution burden to wastewater because wet coffee processing factories discharge huge amount of untreated effluent with high concentrations of organic matter, nutrients, suspend matter and highly acidic wastewater (Yemane, 2015).

No recent studies have been conducted to assess the level of the pollution, this study is significant to characterize the coffee processing wastewater and assess its effect on the physico-chemical properties of receiving water bodies in major coffee growing zones. This will also contribute to future interventions in the areas of environmental management around coffee processing areas in Burundi.

1.4 Hypotheses

1.4.1 Null hypotheses

1. Levels of BOD_5, TSS, COD, DO, EC, pH, Temperature, NO_3^-, Copper, Lead and PO_4^{3-} in wastewater from WCPT exceed the standards for discharge to the environment.

2. Wet coffee processing effluent has no significant impact on levels of BOD_5, COD, TSS, DO, EC, pH, T^o, NO_3^-, NO_2^- and PO_4^{3-} in necessary surface water bodies

1.5 Objectives

1.5.1 Main objective

The main objective of the study was to determine the physico-chemical properties of wet coffee processing plants effluent and environmental effects in Burundi.

1.5.2 Specific

1. To determine the levels of BOD_5, TSS, COD, DO, EC, pH, T^o, NO_3^-, Copper, Lead, NO_2^- and PO_4^{3-} in wastewater from wet coffee processing plant in Burundi.

2. To assess the effect of discharge of wet coffee processing plants effluent on the Biological BOD_5, Copper, Lead, TSS, COD, DO, EC, pH, T^o, NO_3^-, NO_2^- and PO_4^{3-} of receiving water bodies in Burundi.

3. To optimize a wastewater treatment design for wet coffee processing wastewater using STOAT software.

1.6 Scope of the study

The overall scope of this thesis is to study the effect of wet coffee factories effluent (wet coffee processing effluents) on the physico-chemical properties and pollution of receiving water bodies of some rivers and streams.

1.7 Significance of the study

The data generated from the study will provide useful information on the level of physico-chemical parameters in wet coffee processing wastewater and the negative impact of wet coffee processing wastewater on the physico-chemical properties of receiving waterbodies in Burundi. The information generated from the study will also provide critical information on the coffee wastewater management in Burundi.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Freshwater is a vital resource for life. It merits special attention, as it is highly altered and seriously endangered by human activities. Population growth, rapid urbanization, industrialization, unsustainable use of fertilizers and pesticides together with the lack of awareness by the public regarding the protection of the environment has led to pollution that can affect the physicochemical and biological quality of the receiving aquatic environment (Bulton et al., 2001). Untreated wastewater has a high possibility of transferring pollutants/toxic elements to humans through food chains. Coffee processing wastewater are laden with heavy metals (Copper, Lead), fats, oils, cellulose, hemicelluloses, tannins, antioxidants, caffeine, polyphenols and flavonoids. Applications in the field of coffee factories residue management promote maintainable growth of the country's economy.

A study conducted by Devi (2019) around the coffee washing station in Zimma zone (Ethiopia) to assess the effect of effluent generated from coffee processing plant on the water bodies and human health in its vicinity showed that the wastewater from wet coffee factory was seriously polluted with organic matter. The study reported the following results as characteristics coffee wastewater from coffee processing plant effluent in Zimma zone, Ethiopia: T ºC (upstream 25 and downstream 22), pH (upstream 3.57 and downstream 4.45), COD (upstream 25,600 mg/l and downstream 15,780 mg/l), BOD (upstream 14,200 mg/l and downstream 10,800 mg/l), phosphate (upstream 7.3 mg/l and downstream 4.6 mg/l), nitrate (upstream 23 mg/l and downstream 10.5 mg/l) and suspended solids (upstream 5870 mg/l and downstream 2080 mg/l). While the average values of the characteristics of nearby water bodies (River) before and after receiving coffee processing wastewater were the following: T ºC (before 15 and after 18), pH before 6.5 and after 5.15), BOD_5 (before 120 mg/l and after 7800 mg/l), COD

(before 176 mg/l and after 9780 mg/l), TSS (before 520 mg/l and after 2880 mg/l), phosphate (before 2.3 mg/l and after 4.1 mg/l) and nitrate (before 4.0 mg/l and after 7.5 mg/l) (Devi, 2019).

Another study conducted by Nyerere, 2018 on Analysis of the quality of wastewater generated by coffee processing plants, case of coffee processing managed by cooperatives in Burundi showed that the effluent data from the existing coffee wastewater treatment design has failed to assure accepted effluents levels regarding TSS, BOD_5, COD and pH allowable limits according to Burundi standards. The study reported the following results as the characteristics of the treated effluent: pH (4.82 and 5.29), TSS (432 mg/L and 176 mg/L), BOD5 (1050mg/L and 950 mg/L), COD (3960 mg/L and 1840mg/L).

A diagram of coffee processing water system is shown below (Figure 2).

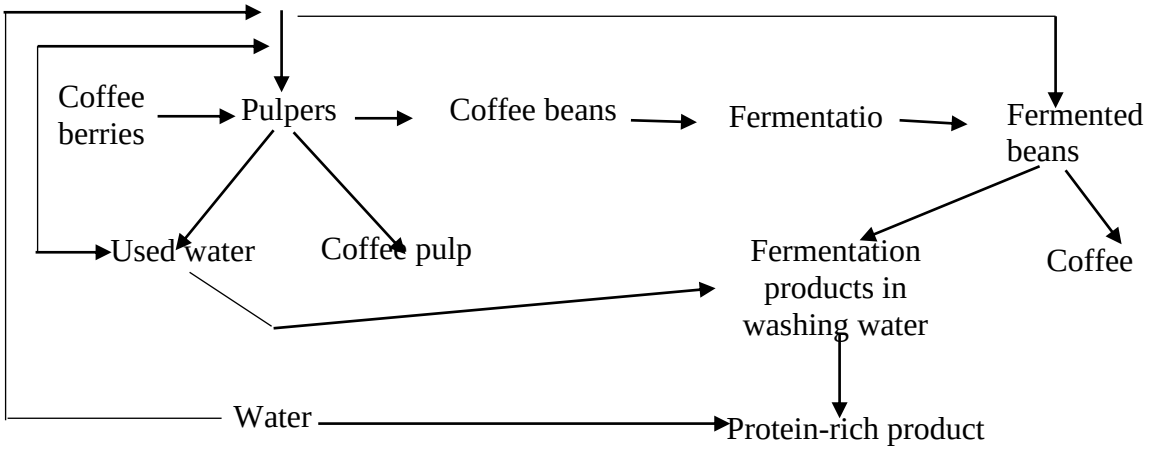


Figure 2. 1: Water usage in coffee processing using the wet method (wet fermentation method).

On average, it requires about 10 – 20 liters of water to obtain 1 kg of clean bean coffee, however the volume of water used depends on the pulping process, fermentation and transportation of the coffee beans.

2.2 Wet coffee processing

Coffee cherries are picked from the coffee trees through selective harvesting or strip harvesting. The cherries are then processed to produce green beans following either the dry processing method or the wet processing method. Figure 2.2 illustrates the steps of coffee processing.

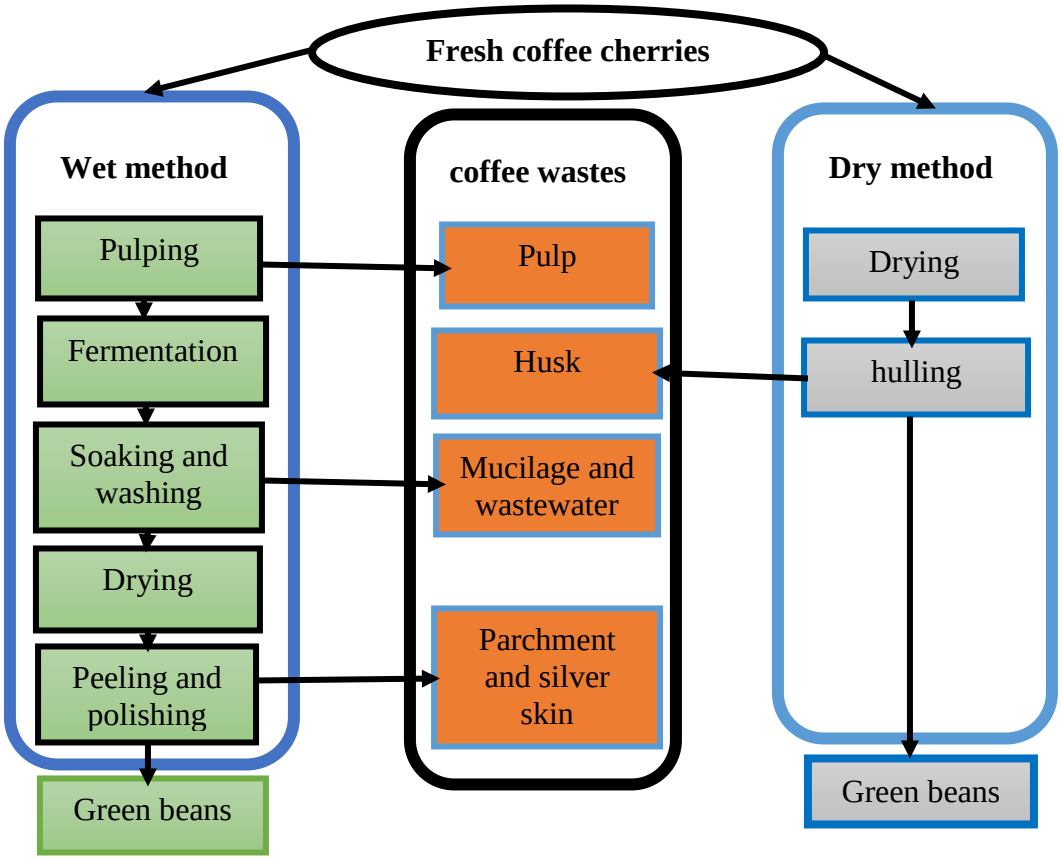


Figure 2.2: Primary coffee processing pathways

In the wet processing method, the pulp is detached from the parchment exposing slick mucilage which is removed through fermentation. This step is followed by drying and washing the beans in the parchment. Removal of parchment by hulling provides clean coffee. Several steps in the wet method of coffee treatment make it rather expensive but provides a high quality coffee (Wanyonyi, 1999). Many wet coffee factories are established in the major coffee agro-ecological areas of the country. The major steps involved in wet method are described as follows:

2.2.1 Harvesting of coffee cherries

The fresh cherries are harvested at fully ripened stage once the skin color start turning deep red. Harvesting is done manually by hand-picking. Ripened cherries are hand-picked and collected in plastic bags, basins or in baskets. The harvesting takes some time; it takes about a day to harvest 25kg per person. The harvesting season is from March to June.

2.2.2 Cherry grading

The cherry is selected out before pulping. To remove immature, diseased, pest damaged, dry cherries, leaves, twigs and other foreign materials. The selected cherries are subjected to pulping to remove the external layer (Mutua, 2000). Grading of fresh harvested coffee is done based on ripeness. Stones and heavy materials impurities are removed from the bottom; hard, partially dried cherries float and are thrown from the top (Wilson, 1999).

2.2.3 Pulping

This is the mechanical process of removing the pulp from the fresh cherry in a parchment coffee. The skin and beans are separated. The lighter immature beans are then isolated from the heavier, mature beans through washing channels or by rocking the beans through a sieve into a tank of water (Hicks, 2002).

2.2.4 Fermentation

The beans are retained in fermentation tanks for 2-3 days, the slimy layer of the berry is split up from its parchment by natural enzymes. Chemical products such as lime, alkaline carbonates can be applied for mucilage removal which precipitates the pectin's in the form of soluble pectates, which are then easily eliminated by washing (Mutua, 2000).

2.2.5 Soaking and washing

After fermentation, the coffee beans are then washed continuously to remove the fermentation break-down products. Insufficient washing at this stage can produce undesirable tastes in final product. Fully wet parchment coffee has a humidity content of 50-54%. Soaking of parchment under water after complete fermentation for about 12 hours improves the quality of coffee both in color and flavor. The fermented parchment is washed to remove the degraded mucilage and acid before soaking (Wickramasinghe et al., 2001).

The parchment coffee is washed with clean water to remove any dirt or abides of mucilage or sugars. Final washing is done in real channels by pushing the parchment with wooden sweeps against a stream of water. About 50 liters of water is applied in washing 10 Kg of parchment.

2.2.6 Drying

Freshly pulped coffee has a moisture content of about 55% and has to be reduced by drying to 11%. This is the right moisture content for proper storage, hulling and roasting. Sun drying is used by spreading on wire mesh tables for two weeks. Mechanical drying method (Mutua, 2000). If drying is carried out quickly, 'case hardening' may occur, the surface is over dried and shrinks irreversibly to prevent movement of moisture from within the bean outward. The bean may become pale and bleached in appearance signifying flavor deterioration. Field studies show that when drying is done too quickly under excessively warm temperatures, the cup flavor is lost (Sivetz et al., 2004).

2.2.7 Storage

This involves keeping the parchment coffee well dried in a suitable place (Greenco, 2017). An important recommendation for safe storage is to ensure that products accepted into storage are sufficiently dry (for coffee beans this is around 11- 12.5% mc on a dry weight basis). In several countries regulations guide and limit the maximum moisture content of coffee in the domestic marketing chain. The moisture content of dry cherry might be slightly higher between 12-13.5% without supporting mould growth and ochratoxin formation(Grading et al., 2016).

2.3 Coffee processing wastes

The coffee processing wastes include; coffee pulp, husk, CSS, and SCG.

2.3.1 Coffee pulp and husk

Depending on the coffee processing method (wet or dry) coffee pulp and husk is the primary waste of coffee factories. The amount of coffee pulp and husk generated for one ton of fresh coffee is approximately 0.5 and 0.18tons respectively (Perraud et al., 1995). Pulp and husk are high in carbohydrates, proteins and minerals, with small amounts of organic compounds such as tannins, caffeine and chlorogenic acid.

2.3.2 Coffee Skin Silver (CSS)

CSS is produced during the roasting process. The CSS accounts for a small portion of the entire coffee berry (1-2%), it is rich in total dietary fiber, phenolic compounds and antioxidant (Murthy, 2012).

2.3.3 Spent coffee grounds (SCG)

SCG are generated throughout the production of solubilized instant coffee, by which roasted and ground coffee beans are heat or steam treated to generate a coffee extract for consumption. The residue left after extracting is known as the SCG. An estimated six millions tons of SCG is generated worldwide annually (Mussatto, Carneiro, Silva,

Roberto, & Teixeira, 2011). One ton of green coffee generates 650 kg of SCG (Murthy, 2012).

2.4 Waste regulation in Burundi

2.4.1 The waste

According to Article 14 of Law No. 1/010 of 30 June 2000 on the Environment Code of the Republic of Burundi. Waste is any residue of a process of extraction, exploitation, production, where control or treatment of the quality does not make it possible to use it. Waste can be termed as any movable asset abandoned or that its holder intends to abandon. Waste are: solid, liquid and gaseous.

By ministerial decree 770/468 of March 2014, the joint Minister of Water, Environment, Spatial Planning and Urbanism and the Minister of Public Health and the Fight Against AIDS, the government adopted the national standards for discharges of domestic and industrial wastewater. The set National Standards for the various parameters are as shown below (MIWESPU, 2014):

- Chemical oxygen demand (COD): 150 mg/L
- Biochemical oxygen demand (BOD_5): 30 mg/L
- Total suspended matter: 50 mg/L
- pH: 6 - 9
- Nitrates (mg/L NO_3^-): 50 mg/L
- Phosphates (mg/L PO_4^{3-}): 30 mg/L
- Total Nitrogen: 12 mg/L
- Phosphorus: 5 mg/L
- Temperature: 35 ºC

2.4.2 Impact of wastewater on the environment

Fermentable waste disposed in a landfill, during their process of biological degradation, generates leachate that through pollute the environment. Damaging the groundwater (groundwater) through infiltration. Watercourses and lakes are polluted by leachate.

Due to deposits of bio-waste in the water, anaerobic fermentation occurs producing CO_2, methane (CH_4), ammonia (NH_3), hydrogen sulphide (H_2S), fatty acids, amino acids and other toxic compounds such as phenols, cresol, mercaptans, that make normal aquatic life difficult. (Ndayahoze, 2011).

2.5.6 Chemical Oxygen Demand (COD)

COD constitutes the amount of oxygen expended by chemically oxidizable materials in the water. It is representative of maximum of the organic compounds but also oxidizable inorganic salts (sulfides, chlorides, etc.). This is particularly useful for assessing the operation of treatment plants (Rodier, 2009). The value of COD is an important indication, with which one can characterize the global pollution of water or wastewater by organic or inorganic compounds (NAHIMANA, 2007) expressed in mg/l. Some oxidizing agents such as ceric sulfate, potassium iodite (KI), and potassium dichromate ($K_2Cr_2O_7$) have been used to determine COD. Of these, potassium dichromate has been shown to be the most effective. It can be described by this reaction:

Organic compounds + $Cr_2O_7^{2-} \rightarrow CO_2 + H_2O + Cr^{3+}$ …… Equation 2.1

Table 2.1 compare the organic load, expressed in COD, of different types of effluents. Even treated coffee effluents have a much higher organic load than domestic black water (Manon, 2015).

Table 2.1: Comparison of organic load of coffee wastewater with other types of effluent

Type of effluent	COD mg/L
Domestic black waters treated.	20 to 60
Untreated domestic black waters.	300 to 400
Effluent of treated coffee processing.	3,000 to 7,000
Bovine effluents.	10,000 to 20,000
Pig effluents.	20,000 to 30,000
Silage effluents.	30,000 to 80,000

2.5 Wastewater pollution parameters from wet coffee processing plant

2.5.1 pH

Water's pH measures the concentration of hydrogen ions (H^+) in the water. Industrial wastewater pH typically ranges from 6.5 to 7.5. Low pH speeds up the release of metals from rocks or its sediments in the stream. These metals can affect aquatic, metabolism and ability to take up water.

2.5.2 Temperature

Water's temperature is an ecological factor which causes important ecological changes. Respiration of organisms is temperature-related; respiration rates can increase by 10% or more per 1^{o}C temperature rise (Leynaud, 1986). Therefore, increased temperature does not only reduce oxygen availability, but also increases oxygen demand, which can add to physiological stress of organisms.

2.5.3 Electrical Conductivity

EC is a good indicator of the degree of mineralization of water where ion performances based on concentration. High salt concentrations in wastewater effluents can increase the salinity of the receiving water bodies, which result in adverse ecological effects on the aquatic biota (Rodier, 2009).

2.5.4 Dissolved Oxygen

DO is one of the important elements of natural water systems; oxygen is required by fish and other aquatic animal species. River/Stream must have a minimum of 2 mg/L DO to sustain life, while 4 mg/L is required by most game fish. Oxygen is also an important element to sustain an aerobic state as the end products of chemical and biochemical reactions in anaerobic systems generate odor, color and taste. When biodegradable substances are released into a stream/river, microorganisms transform the organics into new cells and oxidized waste products. Throughout this process, DO is depleted. The rate and amount of DO depletion is dependent upon the quantity of organic matter and the dilution capacity of the stream/river. DO increases during photo synthesis (Bliefert et al., 2001).

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$ **..... Equation 2. 2**

According to (Wetzel et al., 1991), the concentration of DO depends on temperature, pressure and ion concentration. Unpolluted water corresponds to an DO content of 9.1 mg/L at 20° C.

2.5.5 Biological Oxygen Demand (BOD_5)

BOD_5 measures the quantity of biodegradable organic matter contained in water. It measures also the oxygen taken up by the bacteria during the oxidation of organic matter. The test usually runs for a five days' period.

2.5.7 Total Suspended Solids (TSS)

TSS is defined as particles large enough to not pass through the filter used to separate them from the water. Suspended solids soak up heat from sunlight, increasing water temperature and subsequently reducing levels of dissolved oxygen. Photosynthesis also decreases, since less light penetrates the water. High levels of suspended solids can be considered as a form of pollution. Such an increase can also run to a warming of the

water, which will have the effect of reducing the quality of the habitat for the cold-water organisms (Hebert et al., 2001).

2.5.8 Total Nitrogen (TN)

Nitrogen (N) is a component of municipal wastewater, storm water runoff from urban and agricultural lands, and wastewater from several types of industrial processes. Environmental and health problems related with excessive amounts of nitrogen include, methemoglobinemia, in infants. Nitrogen is also found in four chemical forms; organic nitrogen, ammonia nitrogen, nitrite nitrogen and nitrate nitrogen. Inorganic forms comprise nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3), and nitrogen gas (N_2).

Nitrate-nitrogen (NO_3^--N)

Nitrates are the oxidized forms of nitrogenous compounds in inorganic form. Nitrate is a nutrient which is found in sewage discharge, fertilizer runoff, and leakage from septic systems. Nitrates (NO_3^-) is very soluble in water and is readily transferred in streams and groundwater (Liu et al., 2014).

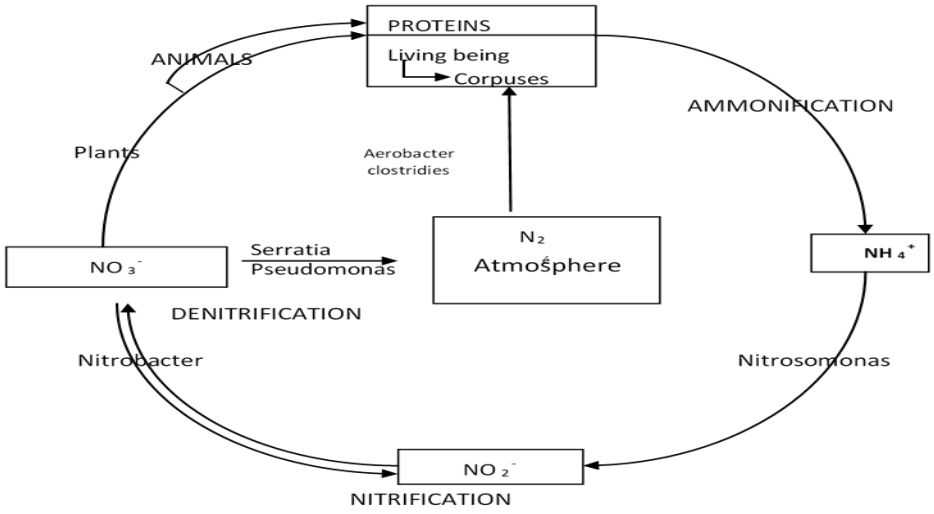


Figure 2.3: The nitrogen cycle.

The main steps of this cycle are: ammonification, nitrification, and denitrification

Ammonification: This step leads to the release of ammonia from nitrogenous materials or the release of ammonium from nitrogen discharges or living organic matter.

N Organic → NH_3 + Carbon Products …… Equation 2. 3

This process occurs without use of microorganisms. However, there may also be a process with the microorganisms.

Nitrification: the oxidation of the ammonium ion to nitrite via autotrophic bacteria or nitrifying bacteria (Nitrosomonas) and occurs in 2 stages:

Nitrification

$NH_4^+ + 3/2O_2 + H_2O \rightarrow NO_2^- + 2H_3O^+$ ……...….. Equation 2. 4

Nitration

$NO_2^- + 1/2\ O_2 \rightarrow NO_3^-$ ……. Equation 2. 5

The global equation is:

$NH_4^+ + 2O_2 + H_2O \rightarrow 2H_3O^+ + NO_3^-$ …… Equation 2. 6

Nitrogen accounts 78% of air, Oxygen 21%, the remaining 1% consisting of "rare" gases.

Denitrification

Denitrification is the microbial process of reducing nitrate and nitrite to gaseous forms of nitrogen, principally nitrous oxide (N_2O) and nitrogen (N_2). It is also a response to changes in the oxygen (O_2) concentration of their immediate environment. Bacteria *Serratia* transform nitrates into nitrogen, which returns directly to the atmosphere.

2.5.9 Total phosphorus (TP)

Phosphorus (P) occurs in natural waters and in wastewaters practically as phosphates (PO_4^{3-}). It is essential to the growth of organisms and can be the nutrient that limits the primary use of water body. Phosphates emanate from a variety of sources comprising agricultural fertilizers, domestic wastewater, detergents, industrial process wastes and geological formations (Peters et al., 2005). The discharge of wastewater containing phosphorus cause algae growth in abundant quantities to cause flavor and odor in drinking water supplies (WHO, 2011). Removal of phosphorus is a crucial step in wastewater treatment plants. Phosphates are categorized as orthophosphates, polyphosphates and organic phosphates.

2.5.10 Dissolved Heavy metals in coffee effluent

Heavy metal pollutants are introduced in rivers/streams significantly as the effect of various industrial operations. These consist of Lead, Zinc, Copper, Chromium, Cadmium, and Manganese. A large number of heavy metals are carcinogenic and cause health issues. These toxic materials may result from mining, Tanning, Fuel combustion, Lead-soldered food cans, Battery plants, Pesticides, industrial and domestic waste as well as the processing of radioactive materials(Njogu, 2011). Some of the metals are required in small amounts for plant and animal growth. Some of these micronutrients are also toxic at higher concentrations, and may be found in certain types of wastewaters. Cadmium, mercury and lead, are toxic even at low concentrations. Heavy metals do not breakdown in the treatment plants. Several methods are applied for metal determination such as: Inductively Coupled Plasma Mass Spectrophotometer (ICP-MS), X-ray Fluorescence (XRF), Anodic Stripping Voltammetry (ASV) and Atomic Absorption (AAS). AAS was used in the determination of heavy metals in the study.

2.6 Conventional Wastewater treatment process

The main objective of wastewater treatment is to enable effluents to be discharged without causing harm to human health or to the natural environment. For the treatment

of effluent, several systems can be applied (Martin, 2013). Table 2.2 presented below gives an indication of the classification of methods applied.

Table 2.2: Classification of wastewater treatment methods

Treatment	Processes
Biological	Activated sludge process, Aerated lagoon, Trickling filters, Rotating biological contactors, Pond stabilization, Anaerobic digestion, Biological nutrient removal
Chemical	Chemical precipitation, Adsorption, Disinfection, chlorination, Other chemical applications
Physical	Screening, Comminution, Flow equalization, Sedimentation, Flotation, Granular-medium filtration

2.6.1 Physico-chemical treatment

The physical-chemical treatment of effluent has been applied only moderately. The principle uses products such as lime, and aluminum sulphate which after reacting with substances existing in the pulp and the mucilage of the coffee, such as pectin, form flocks that can precipitate in areas where the water velocity is low, i.e. in a sedimentation basin. The physical treatment is mainly centered on permitting the wastewater pass through zones where the velocity of the water is so low that the heaviest particles will precipitate. After this, a filter of grit and sand can be found in which another portion of the contaminants is trapped. Chemical coagulants that are frequently used in effluent treatment include alum ($Al_2(SO_4)_3.18H_2O$), Ferric chloride ($FeCl_3.6H_2O$), ferric sulfate ($Fe_2(SO_4)_3$), ferrous sulfate ($FeSO_4.7H_2O$) and lime ($Ca(OH)_2$). Organic polyelectrolytes are sometimes used as flocculation aids. Removal of suspended solids through chemical treatment involves a sequences of three unit operations: flocculation, rapid mixing, and settling. First, the chemical is added and completely dispersed throughout the wastewater by fast mixing for 20-30 seconds in a basin with a turbine mixer (Bhargava, 2016). Coagulated particles are then conveyed

together via flocculation by mechanically inducing velocity gradients within the liquid. Flocculation takes 15-30 minutes in a basin having turbine or paddle-type mixers. The final phase is illumination by gravity.

2.6.2 Biological treatment

The biological treatment uses microorganisms which play a key role in the treatment of wastewater. The biological treatment can be separated based on the form of contact between the coffee wastewater and the oxygen in the air:

- ✓ Ponds with natural aeration or maturation ponds
- ✓ Ponds with mechanical aeration

The aerobic ponds or the stabilization ponds are widely used due to simplicity, cheap construction, low maintenance and good treatment efficiency in warmer temperatures. The principal processes which take place in stabilization ponds are of biological nature. The treatment is driven by bacteria, algae and other microorganisms which feed themselves on the organic load found in wastewater. The organic load is decomposed to the extent that the detrimental effect on the receiving water bodies is diminished. Some of the detrimental effects which are attributed to these ponds are the odor, proliferation and growth of flies, mosquitoes and other insects, can also threaten nearby aquifers (Martin, 2013).

2.7 Design of wastewater treatment system

Wastewater treatment is often divided into three namely; primary, secondary and tertiary treatment as per the elimination/removal of the principal elements of concern in wastewater (Iyer, 2011). Primary treatment plants use physical treatment such as screening, sedimentation, flow equalization and flotation to remove pollutants that are floatable solids, secondary treatment plants make use of removal of BOD, COD from wastewater and tertiary treatment plants utilize nutrients removal such nitrogen, sulfate and phosphorus.

2.7.1 Modelling coffee wastewater using Sewage Treatment Operational Overtime Software (STOAT)

STOAT is a dynamic sewage treatment works modeling package which is used to perform and optimize wastewater treatment design (Smith et al., 1998). Its analysis of the activated sludge model process can be made either with the COD-based IAWQ models or the BOD models developed by Jones 1978. Therefore, the ASAL model 1 has to be implemented to stimulate the operation for activated sludge aeration tank in Coffee wastewater treatment plant. This model handles manly the BOD_5 removal, whereas the other processes such as nitrification or denitrification are not clear fixed in it.

2.7.2 Description of the existing design of wet coffee processing treatment plant

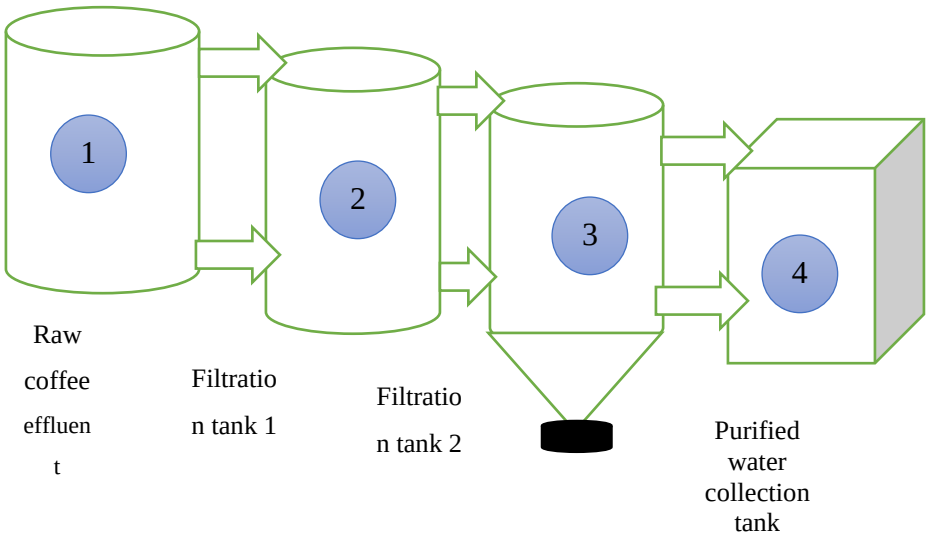


Figure 2.4: Flow diagram of the existing coffee wastewater treatment design (Source; Nyerere et al., 2018)

During the treatment, the water to be treated enters the first tank, the treated water leaves the 4th tank and is rejected into the natural environment. The wastewater enters through tank 1 which is directly connected with the water evacuating pipes coming from the cherry pulping machine and the washing of the coffee after fermentation. After a brief

stay in tank 1, when the level of communication with tank 2 is reached, the water flows into tank 2 and until the last tank (Tank 4) where the treated water is discharged into the surrounding aquatic environment. The first basin receives all the wastewater from the coffee pulping and washing operations. It contains gravel and rubble which serve as a barrier to the beans on the one hand which have escaped the sieve placed upstream thus playing the role of screening, on the other hand the support of bacteria participating in the process of degradation of organic matter. The second basin has the same dimensions as the first and is filled with gravel, rubble and sand to retain the finest particles. A liming operation is carried out in Tank 3. They put five bags, not unwrapped but with holes of 25 kg of lime making a total of 125 kg. These bags stay in this bin for two weeks. The fourth basin has a useful volume of 10 m^3 and contains five bags of charcoal packed with holes. After this stage, the planned treatment is completed and the water is discharged into the receiving environment (Nyerere et al., 2018).

CHAPTER THREE

MATERIALS AND METHODS

The field study was undertaken from October 2019 to June 2020. The study undertaken to assess the current situations on the constraints and potential effect of wet coffee processing wastewater.

3.1 Study area and population

Burundi has three major coffee growing Agro-ecological zones (Gitega, Kayanza and Makamba) with 250 wet coffee processing factories (WCPF) that comprise of private (100 WCPF), cooperative (47 WCPF) and government owned factories (103 WCPF). Kayanza province is in the humid Central Plateau, in Buyenzi region. It is the best coffee growing area. Gitega province (Political capital of Burundi), is in the dry Central Plateau, in Kirimiro region and Makamba province is in Eastern depression, in Buragane region (Figures 3.1 and 3.2, Table 3.1).

Table 3.1: Description of study areas

Variable	Unit	Kayanza	Gitega	Makamba
Longitude	Degree (º)	29.6278° E	29.9246° E	29.8034° E
Latitude	Degree (º)	2.9235° S	3.4273° S	4.1385° S
Elevation	M	1500-1850	1500-1650	1250-1400
Rainfall amount	Mm	1200-1400	1200-1300	1200-1300
Air temperature	^{0}C	15-17	17-19	19-23

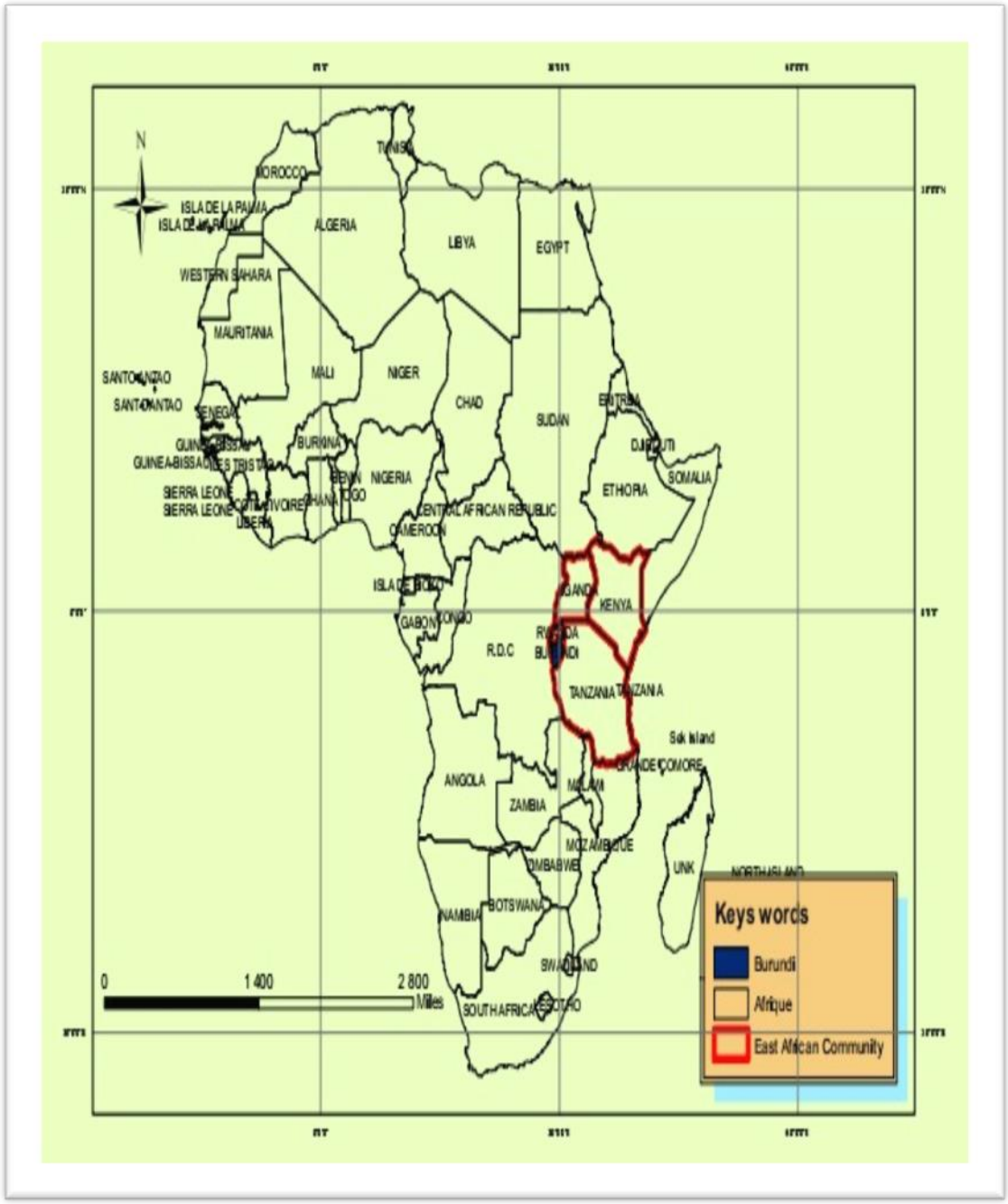


Figure 3.1: Map of Africa showing Burundi (Source: Bisekwa et al., 2021)

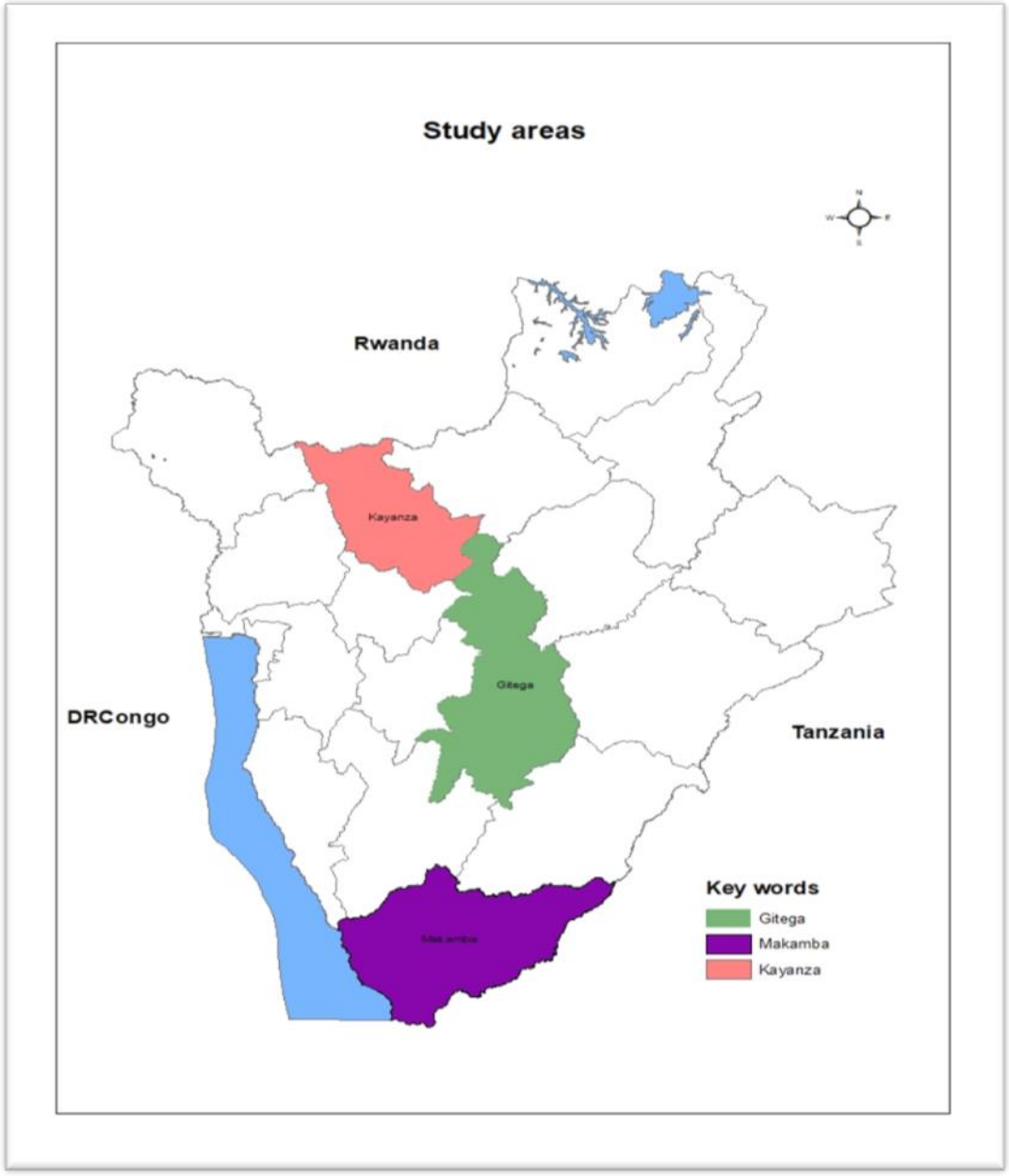


Figure 3.2: Map of Burundi showing the study areas location (Source: Bisekwa et al., 2021)

3.2 Target population

Target population refers to a precise group related to a particular study. Mugenda and Mugenda approaches (2003) defines a population as a set of individuals or objects that contain the same form of characteristics. The target population for this study was 38 wet coffee factories (18 Publicly, 12 Privately and 9 Cooperatively owned functional wet coffee processing factories) in Kayanza province, 20 wet coffee factories (14 Publicly, 3 Privately and 3 Cooperatively owned functional wet coffee processing factories) in Gitega province and 6 wet coffee factories (all publics) in Makamba province making the total population of 64 wet coffee processing factories.

Table 3.2: Target population

Target	Total Number	Percentage
Kayanza's factories	38	59.38
Gitega's factories	20	31.25
Makamba's factories	6	9.38
Total	64	100

3.3 Sample size and sampling procedure

3.3.1 Sampling procedure

The sampling process took into account various issues and was dependent on the water quantities used in the factory. Factories near rivers/streams, purpose, wastewater treatment, complexity, and current situations of factories (wet coffee processing plants). The study used purposive sampling. Kayanza, Gitega, and Makamba provinces which constitute the major coffee growing agro-ecological zone of Burundi were chosen in this study.

3.3.2 Sample size

According to Mugenda and Mugenda approaches (2003), for a study population less than 10,000, a sample size lying between 10 and 30% is a good representation of the

target population and therefore, 30% was selected for this study. 11 factories in Kayanza province (38*0.3), 6 factories in Gitega province (20*0.3) and 2 factories in Makamba province (6*0.3) were selected making a larger population of 19 factories (19 wet coffee processing factories).

3.4 Study design

The study was broken up into the following broad areas;

1. Determination of wastewater quality from coffee processing technology factories in Kayanza, Makamba and Gitega Coffee growing Ecological Zones in Burundi.
2. Assessment of the effect of coffee processing technologies effluent on the physicochemical properties of receiving water bodies in Kayanza, Gitega and Makamba.
3. Optimization of a wastewater treatment plant using STOAT Software.

3.5 Experimental design

The experimental was conducted using a Complete Randomized Design (CRD) with replication. Physical and chemical analyses were used to characterize the coffee wastewater and assess the effect of coffee processing technologies effluent on the physicochemical properties of receiving water bodies. Samples were analyzed for; pH, T, salinity, EC, TDS, DO, Cl^-, NO_2^-, NO_3^-, PO_4^{3-}, Pb, Cu, TSS, COD and BOD_5.

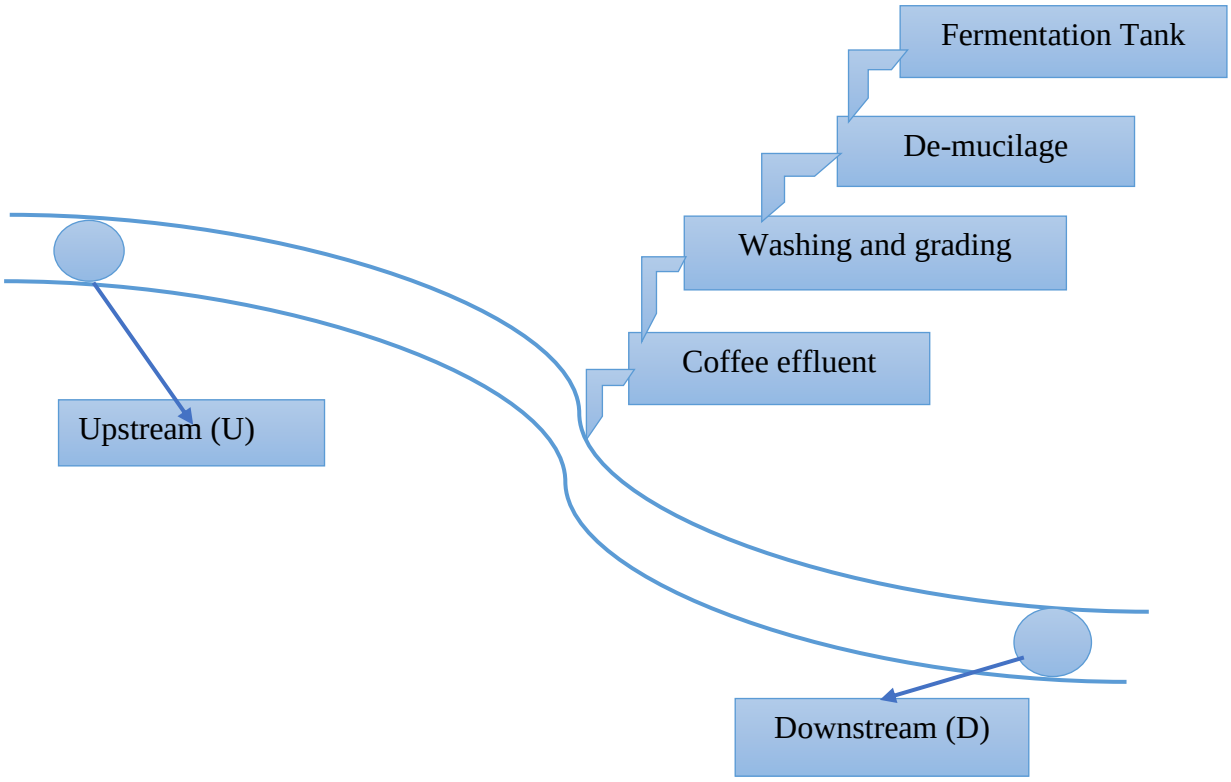


Figure 3.3: Flow diagram showing flow diagram of coffee factory and river water sampling points (Source: Bisekwa et al., 2021)

3.6 Water sampling and pretreatment

Samples were collected from discharge points of selected wet coffee processing factories and nearby rivers at upstream (U) and downstream (D) of discharge points (With a maximum of 150 m above and below the wet coffee processing discharges point). Samples were collected from April to June 2020, the period of coffee harvesting season. Samples were collected in plastic bottles which were pre-cleaned by washing in non-ionic detergent, washed with tap water and later soaked in 10% HNO_3 for 24 hours and finally rinsed with deionized water. Samples were transported to either ISABU laboratory (Soil and food products analysis laboratory of ISABU) and Laboratory of Chemistry and Environmental Analysis in University of Burundi. Some measurements were done on-site such as pH, temperature, and electric conductivity, DO, TDS using

Trace2o Hydrocheck HC1000 multi-parameter Electrochemical Meter kit T20-AN-P270. Water samples for BOD_5 were collected on clean plastic bottles and stored in refrigerator. Analysis for $BOD_{5,}$ COD, TSS, Chlorides and Nutrients were performed in the laboratory using standard methods in AFNOR (1997) and APHA (2005). Samples for heavy metals determination were pretreated with 1% nitric acid and kept in the refrigerator for analysis. On-site pretreatment was done by adding H_2SO_4 for COD, phosphates and ammonium analysis, HCl for Nitrates and nitrites analysis.

3.7 Analytical procedures

The methods of analysis used were those described by the standard methods for the examination of water and wastewater (APHA, 2005) and the standards (AFNOR, 1997).

3.7.1 Onsite measurement

All physical parameters for surface water were analyzed onsite using Trace2o Hydrocheck HC1000 multi-parameter Electrochemical Meter kit T20-AN-P270 (Plate 3.1) except TSS. These included; pH, temperature, salinity, EC, TDS and DO.

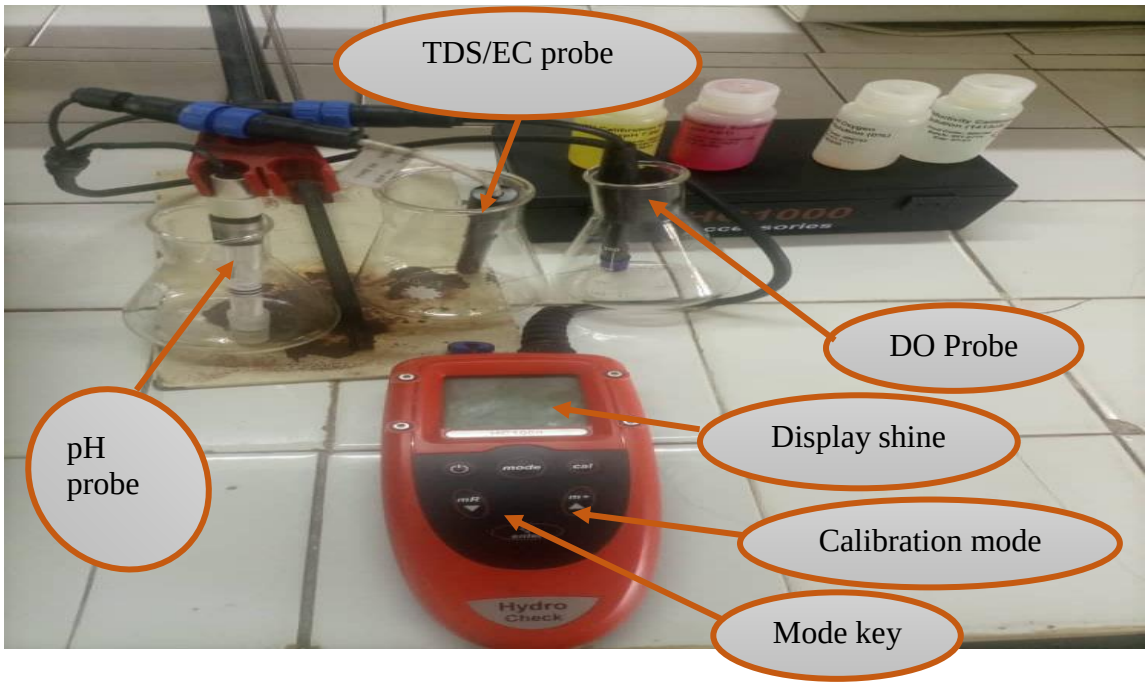


Plate 3.1: Trace2o Hydrocheck HC1000 multi-parameter

3.7.1.1 Analysis of pH

pH was measured using Trace2o Hydrocheck HC1000 multi-parameter Electrochemical Meter kit T20-AN-P270 with temperature compensation at 25 ºC as described in APHA, 2005 and AFNOR, 1997. The model was calibrated using pH calibration standards 4.0, 7.0, 10.0; The probe of the calibrated meter was immersed in water sample, the water was stirred for a few seconds to obtain homogeneity. After stabilization, the pH reading was read and recorded in triplicates.

3.7.1.2 Analysis of Temperature

Temperature was measured using Trace2o Hydrocheck HC1000 multi-parameter Electrochemical Meter kit T20-AN-P270. Once the probe was immersed in water, sample was stirred for a few seconds for homogeneity. The readings were read and recorded in triplicates. Each time before and after taking a reading the probe was rinsed with distilled water before dipping in water sample.

3.7.1.3 Analysis of EC and TDS

EC and TDS were measured using Trace2o Hydrocheck HC1000 multi-parameter Electrochemical Meter kit T20-AN-P270. The model was calibrated using Conductivity calibration standards 1413 µS/cm. The probe was immersed in water, stirred gently as described in APHA, 2005 and AFNOR, 1997. The readings were taken and recorded in triplicates. Before inserting in the next sample, the probe was rinsed in distilled water.

3.7.1.4 Analysis of Salinity

Salinity was measured using Trace2o Hydrocheck HC1000 multi-parameter Electrochemical Meter kit T20-AN-P270. The probe was immersed in water; the water sample was stirred gently for a few seconds for homogenization. After the stabilization, salinity reading was read and recorded in triplicates.

3.7.1.5 Analysis of DO

DO was measured using Trace2o Hydrocheck HC1000 multi-parameter Electrochemical Meter kit T20-AN-P270. The probe was immersed in water sample and stirred gently for homogeneity. After stabilization, DO reading was read and recorded in triplicates.

3.7.2 Laboratory analysis

3.7.2.1 Analysis of COD

Sample was oxidized using hot sulfuric solution of potassium dichromate with silver sulfate. Chlorides were masked by adding mercury sulfate as described in APHA, 2005 and AFNOR, 1997. Tube containing COD reagents was taken and 2 ml of water sample were added and was agitated for homogeneity and digested at 148 ºC during 2 hours. The solution was cooled to ambient temperature and measured in the photometer NOVA 60. COD reading was read and recorded in triplicates.

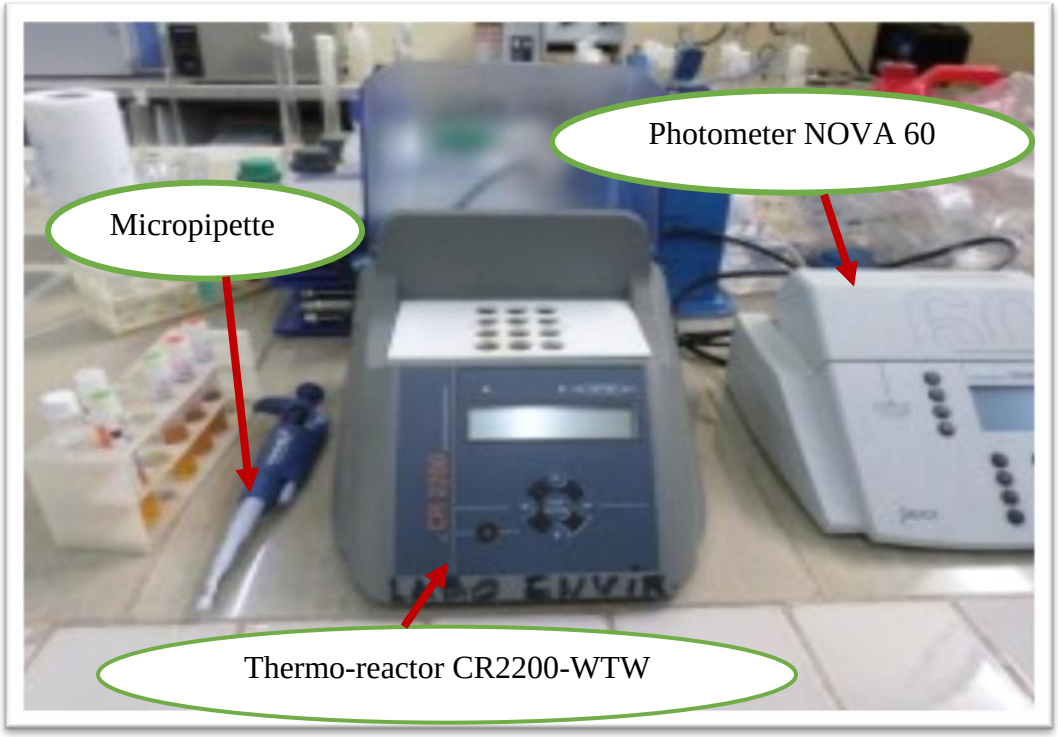


Plate 3.2: Apparatus and materials used for COD measurement.

3.7.2.2 Analysis of BOD_5

BOD_5 was measured using manometric method using amber colored bottles topped with an "OXYTOP®" head as described in APHA, 2005 and AFNOR, 1997. The bottles containing the sample were placed in an incubator at 20 ºC. BOD_5 reading was read and recorded in triplicates after 5days.

Plate 3.3: Apparatus used for BOD_5 measurement

3.7.2.3 Analysis of TSS

TSS was determined by filtration (Filtered with whatman N° 41) of a volume of water (1liter) and dried at 105° c in an oven WT-Binder 7200Tuttling/Germany during 24h. TSS was given by the following formula [14]:

$$\mathbf{TSS}(mg/l) = \frac{M_1 - M_0 * 100}{V\ sample} \quad \text{..... (1)}$$

Where: M_0 = Mass of the filter before use (mg / l), M_1 = Mass of the filter after use (in mg / l), V = Volume of water used (in ml).

3.7.2.4 Analysis of Chlorides

The chloride was determined by titration method as described in AFNOR, 1997. 50ml of water sample were titrated with standard silver nitrate after the addition of 1 ml of K_2CrO_4 solution till the brownish ting appeared. The blank determination was also carried out using distilled water. The chemical reactions in two steps are as follows:

$$\mathbf{AgNO_3\ (aq) + K_2CrO_4\ (aq) + Cl\text{-}\ (aq) \rightarrow AgCl\ (S) + K_2Cr_2O_4\ (aq) + NO_3\ (aq)}$$

Equation 3. 1

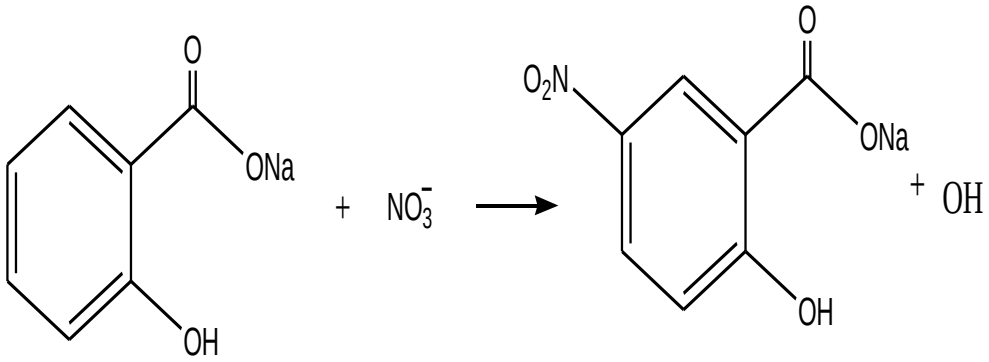
$$\mathbf{AgNO_3\ (aq) + K_2CrO_4\ (aq) \rightarrow 2KNO_3\ (aq) + Ag_2CrO_4\ (aq).}$$ **……..... Equation 3. 2**

The chloride was determined using: $\mathbf{Cl\ (mg\ /\ l) = \frac{X*0.01*35.45*1000}{V\ sample}}$ **……..... (2)**

Where: X = Volume of titrant used for titration of sample, V = Volume of sample

3.7.2.5 Nitrates measurement

Sodium salicylate method was used in this study. Nitrates were reacted with sodium salicylate forming a yellow complex sodium paranitrosalicylate which was determined using colorimetric method as described in APHA, 2005 and AFNOR,1997. Equation of the reaction is as follows:

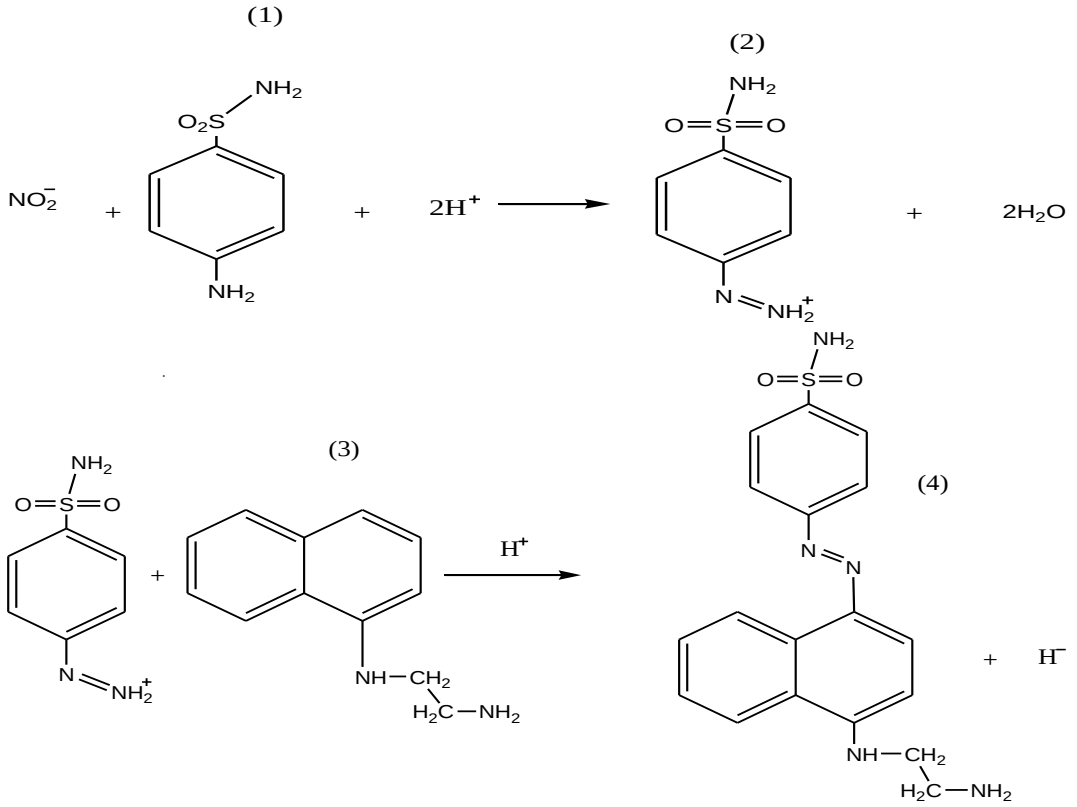


Equation 3. 3

The measurement was done at a wavelength of 543 nm using UV-visible spectrophotometer.

3.7.2.6 Analysis of Nitrites

This was measured using colorimetric method. This method involved Diazotization of sulfanilamide (2) which reacted with N-1 naphthylethylenediamine (3) forming a complex (4). The reaction is as follows,



Equation 3. 4

A 50 ml sample was treated with 2 ml of color reagent mixed for 10 minutes and its absorbance read from spectrophotometer set at 543nm.

3.7.2.7 Analysis of Ammonium

Volumetric method was used in this study. In an alkaline environment, ammonia was displaced and entrained by water vapor as described in APHA, 2005 and AFNOR, 1997. A 40 ml of sodium carbonate were added to 50 ml of water sample. After distillation in 20 ml of boric acid, few drops of colored indicator were added. The ammonium content expressed in milligrams per liter is given by the relationship:

$$\mathbf{NH_4(mg/l) = \frac{(V_1 - V_0) * 0.05 * 18 * 1000}{V_2}} \quad \text{..... (3)}$$

Where: V_1 = Volume of titrant used for titration of sample, V_2 = Volume of sample,

V_0 = Volume of titrant used for titration of blanc.

3.7.2.8 Analysis of Phosphates

The concentrations of PO_4^{3-} was measured using colorimetric method after sample digestion as described in APHA, 2005 and AFNOR, 1997. Digestion was necessary to release phosphorus as orthophosphates since phosphorus occurs as a combination of organic matter. In Colorimetric method ammonium molybdate reacts under acidic conditions to form molybdophosphoric acid in dilute orthophosphate solution. In the presence of vanadium, yellow vanadomolybdophosphoric acid forms with an intense yellow color which is proportional to phosphate concentration. Absorbance of sample was measured at 430 nm and compared to the calibration curve of known standards to give the actual concentration of phosphates in the sample.

3.7.2.9 Analysis of Dissolved Lead and Copper

The wastewater samples were analyzed for dissolved heavy metal concentrations by using Flame Atomic Absorption Spectrophotometer Perkin-Elmer Analyst 400 (Hi-tech Detection systems) directly after filtration with a Whatman N°.41 filter paper as described in APHA, 2005. A series of standards were prepared for instrumental calibration from stock solution analytical grade AAS standards solutions. A standard and blank sample was run after every 10 samples to check instrumental gist. The concentrations of the dissolved heavy metals were analyzed in triplicates.

3.8. Optimization of a wastewater treatment plant with the purpose of reducing pollution

Optimization of wastewater treatment depends on the characteristics of coffee processing effluent. In this study STOAT software was used.

3.8.1 Coffee wastewater treatment plant

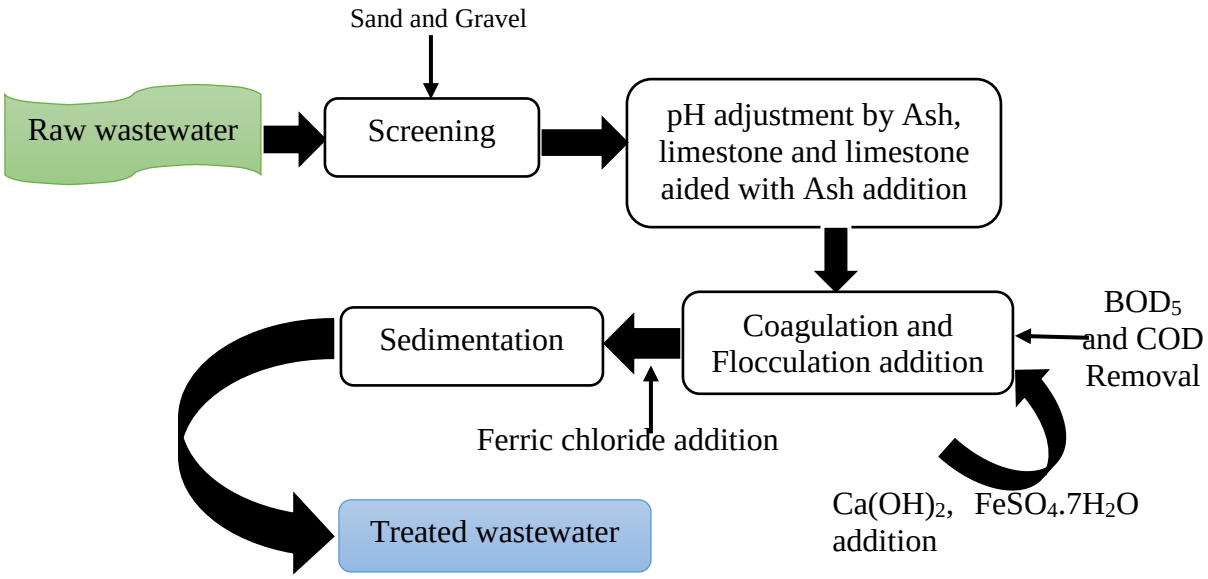


Figure 3.4: Design of wastewater treatment process

Sewage Treatment Operational Analysis Overtime (STOAT) is a software that uses modelling to stimulate dynamically of wastewater treatment performances (Dudley et al., 1992). It has developed by WRc plc England and can be used to stimulate individual treatment processes or the whole treatment plant. The simulator adopted models that enable optimization the response of wastewater treatment plants in the influent loads and operating conditions. It addressed various models for all common wastewater treatment processes and established standards methods for performing these evaluations.

There are three models that have been used in this work: BOB_5 model in the primary and secondary treatment tanks, ASAL 1 model in the secondary treatment tank and SSED 1 model in secondary settling tank. The ASAL 1 model handles mainly the BOD_5 removal influent, whereas the other processes such as nitrification or denitrification are not Cleary embedded in it. The reason for exploring coffee wastewater treatment plant is to

propose an optimum design regarding TSS, COD, BOD_5 removal capacities and pH adjustment.

Sand and gravel were applied in an attempt to lower TSS in screening and secondary sedimentation tank processes. Ash and limestone applied in an attempt to achieve an acceptable pH level for coffee effluent discharged into the primary tank process while Lime and Fe_2SO_4 were applied in an attempt to lower BOD_5 and COD in the activated sludge aeration process. The units used in STOAT were adjusted to the units in the field, namely screening, primary tank, Activated sludge aeration tank, and secondary sedimentation, as well as the number and dimension of each unit.

The following are the dimension's details used in STOAT software run: Primary Tank: (Model: BOD, Number of stages: 3, Volume (m^3): 5000 m^3, Surface area (m^2): 600 m^2); Activated Sludge Aeration Tank: (Process model: ASAL 1, Volume (m3): 3600 m^3, Number of stages: 1, Wastage method: Variable Time); Secondary Sedimentation Tank: (Model: SSEDT, Number of vertical layers: 8, Depth of Tank (m): 3 m, Surface area (m^2): 600 m^2, Depth of feed (m): 3). A sinusoidal mathematical function was used to simulate an ideal diurnal variation of flowrate and loading. Such a function was used for the STOAT sensitivity simulations (Figure 4.19), namely:

$C = Co\ (1 + a \sin \omega.t')$ ……. ….. (4)

where,

C = parameter value;

Co = mean parameter r value;

A = amplitude (taken to be 0.5);

$\omega = 2\pi f$, and f (frequency) = 1/24, i.e. one wavelength in 24 hours;

t' = time (t-6) to get correct phase, i.e. minimum at midnight.

3.9 Statistical Data Analysis

The data were subjected to appropriate statistical analysis using R-studio-1.0.153, GenStat 64-bit Release 14.1, Statistical Package for Social Scientists (SPSS) and Microsoft Excel package. SSPS was used to test correlation between wet coffee processing technologies effluents.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Determination of coffee wastewater quality

Table 4.1: Physico-chemical properties of wastewater from wet coffee processing at the study locations/areas.

Variable	Unit	Kayanza	Gitega	Makamba	Standard level
		Physical			
pH	pH scale	4.1±0.4^{a}	4.2±0.3^{a}	4.1±0.3^{a}	6 – 9
Temperature	ºC	21.3±1.1^{c}	23.7±1.1^{a}	23.0±0.3^{b}	35
EC	µS/cm	734.5±15.8^{a}	867.9±54.7^{a}	862.4±75.7^{a}	-
TDS	mg/l	443.0±56.4^{a}	414.5±83.3^{a}	431.9±39.0^{a}	1200
DO	mg/l	8.7±0.4^{a}	4.6±0.4^{b}	2.8±0.3^{b}	>1
Salinity	mg/l	432.6±55.0^{a}	339.9±98.2^{b}	425.0±39.2^{ab}	-
TSS	mg/l	2481.3±45.6^{a}	2640.9±60.0^{a}	2595.8±32.0^{a}	50
		Chemical			
BOD_5	mg/l	6738.8±467.1^{a}	7300±388.0^{a}	5792.5±488.1^{a}	30
COD	mg/l	11936±600.3^{b}	14019.2±392.9^{a}	10025±498.0^{b}	150
PO_4^{3-}	mg/l	6.0±1.6^{b}	7.4±1.8^{ab}	9.5±1.5^{a}	30
Cl^-	mg/l	61.6±7.8^{a}	55.6±8.5^{a}	35.7±6.4^{b}	250
NH_4^+	mg/l	6.5±2.5^{a}	5.6±1.8^{ab}	4.7±0.8^{b}	-
NO_3^-	mg/l	18.1±3.9^{a}	22.7±4.1^{a}	18.83±2.7^{a}	50
NO_2^-	mg/l	0.6±0.1^{a}	0.7±0.2^{a}	0.8±0.2^{a}	-
Cu	mg/l	0.2±0.02^{c}	0.3±0.1^{b}	0.4±0.2^{a}	1
Pb	mg/l	<0.01	<0.01	<0.01	0.05

Means (Averages) with different letters in the same row are significantly different (Student-Newman-Keuls test at $p<0.05$) at 5%.

The obtained results from the effluent released from wet coffee processing plant showed that there were variations in physical-chemical parameters between and among the sampling sites. The study found that wastewater did not meet the Burundi Effluent Discharge standards (MIWESPU, 2014) for TSS, COD, BOD_5, pH. However, Nitrates, Nitrites, DO, Phosphates, salinity, EC, TDS, Chlorides, Pb, Cu and NH_4^+ were in conformity with the set standards.

Table 4.2: Average values and SD for the physico-chemical parameters of wastewater at the study areas among the study months.

		Kayanza		Gitega		Makamba	
Variables		**April**	**June**	**April**	**June**	**April**	**June**
Physical							
pH		4.2±0.4	4.0±0.4	4.1±0.2	4.2±0.3	4.1±0.4	4.1±0.3
Temperature	ºC	21.0±1.2	21.5±1.0	23.1±0.9	24.4±0.9	22.8±0.3	23.1±0.4
EC	µS/cm	841.6±86.3	927.9±76.8	973.4±84.6	762.3±115.1	707.2±57.8	1017.7±29.9
TDS	mg/l	420.1±90.8	465.9±117.5	478.1±83.8	350.9±115.1	353.7±80.3	510.2±29.9
DO	mg/l	10.2±5.23	7.2±1.7	5.8±2.3	3.3±0.4	0.8±0.1	4.8±0.9
Salinity	mg/l	409.7±89.0	455.6±56.6	333.3±68.8	346.4±77.7	345.0±76.8	505.0±35.4
TSS	mg/l	2444.0±100.7	2522.6±214.7	2679.9±180.8	2601.9±166.3	2751.8±158.6	2440.0±120.0
Chemical							
BOD_5	mg/l	7481.6±451.1	5996.1±402.7	7300.0±371.5	7250.0±615.6	5792.5±332.9	5710.1±332.9
COD	mg/l	12745.6±417.9	11127.3±694.3	14416.8±456.1	13621±892.4	10200±545.6	9820.0±500.6
PO_4^{3-}	mg/l	7.8±1.8	4.2±1.9	12.6±2.1	2.2±1.4	12.5±1.39	6.5±0.3
Cl^-	mg/l	67.3±17.3	55.9±17.2	42.3±16.8	68.9±21.1	34.9±10.9	63.6±10.9
NH_4^+	mg/l	6.2±2.4	6.7±2.7	6.8±1.5	4.5±1.7	5.3±0.6	4.4±0.3
NO_3^-	mg/l	23.7±4.7	12.6±2.9	27.4±3.8	18.0±3.0	18.1±4.8	19.5±2.8
NO_2^-	mg/l	0.9±0.2	0.3±0.1	1.3±0.3	0.1±0.01	1.3±0.08	0.2±0.1
Cu	mg/l	0.2±0.1	0.2±0.1	0.2±0.06	0.4±0.1	0.3±0.03	0.6±0.1
Pb	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	0.01

Average (n=114) concentrations of selected physicochemical parameters of coffee wastewater compared with wastewater with maximum allowable standard concentration for wastewater discharged to waterbodies.

The maximum effluent COD and BOD_5 concentrations obtained from this study were higher than the acceptable limit respectively representing the pollution caused by the coffee processing wastewater. This showed that large amount of chemical and biochemical substances in the effluent are released from the coffee processing wastewater into the rivers or streams. They also indicated that there could be low oxygen available for living organisms in the wastewater when employing the organic matter present. The wet processing factories use large amount of water for pulping,

fermentation and washing of the coffee cherries. Large quantities of wastewater and the coffee wastes are therefore generated and discharged without treatment into the nearby rivers or streams, except for a few factories which are privately or cooperatively owned. The results displayed in the Tables 4.1 and 4.2 indicated that the wastewater was deeply polluted with high acidity, organic load and suspended matter in April and June. Organic load was measured in terms of COD and BOD_5, acidity in terms of pH, suspended solid in terms of total suspended solids.

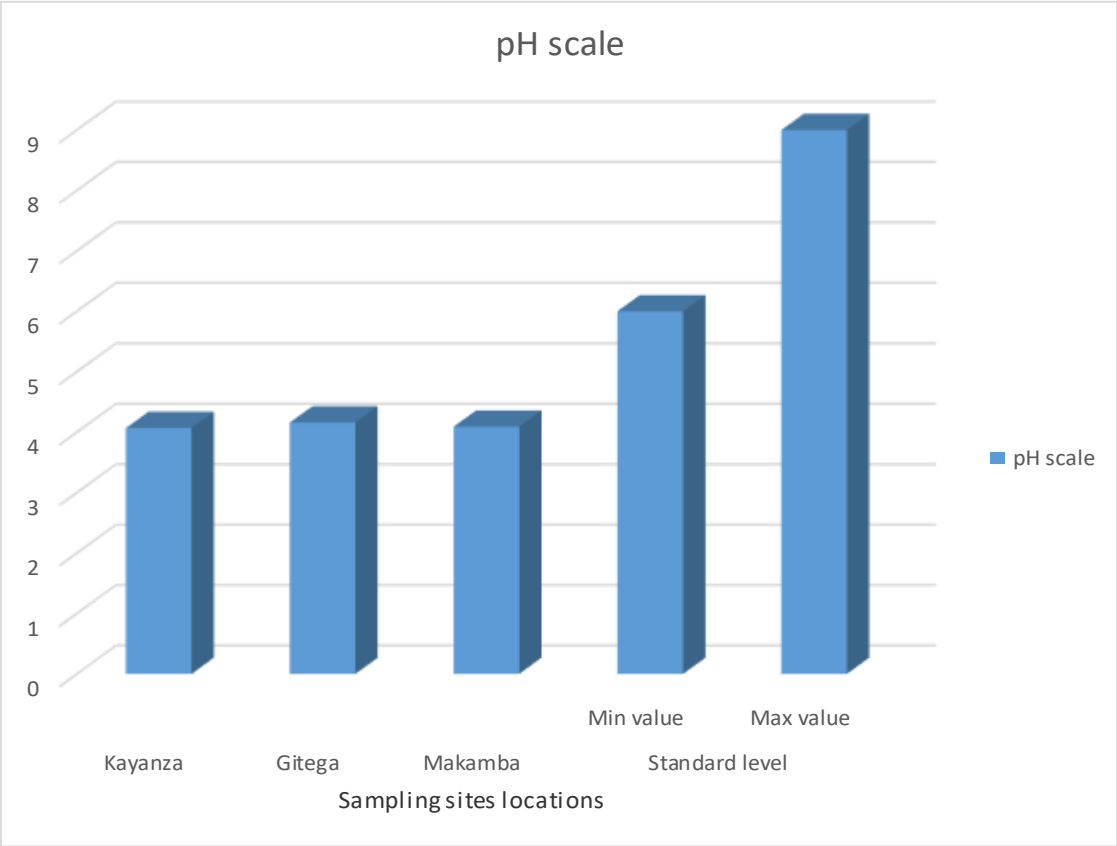


Figure 4.1: Spatial variations of pH

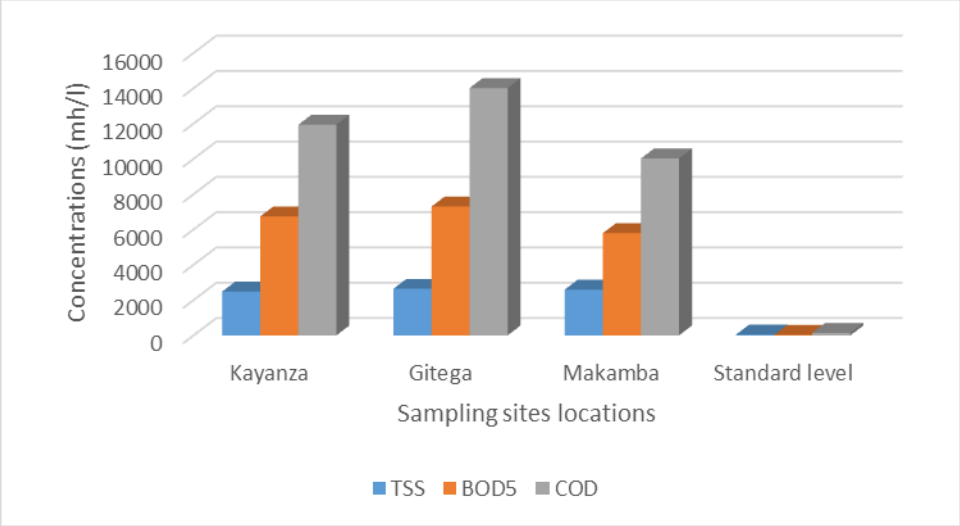


Figure 4.2: Spatial variations of TSS, BOD_5 and COD

Overall, COD and BOD_5 of coffee wastewater measured during this research vary significantly from one location to another (Figure 4.2), this may be due to several factors. First, fermentation may have not been completed while additional time may have resulted in higher TSS and COD concentration in coffee wastewater fermentation. Second, the purity of the water used for fermentation may have an impact on the concentrations of these values in the generated coffee wastewater.

Table 4.3: Physico-chemical Quality parameters of wastewater at various wet coffee processing factories/ownerships

Variable	Unit	Private	Public	Cooperative	Standard level
			Physical		
pH	pH scale	4.1±0.2	4.0±0.3	4.3±0.5	6 – 9
Temperature	ºC	20.8±1.2	23.0±1.2	21.7±1.3	35
EC	µS/cm	798.3±20.5	924.9±97.1	844.0±81.5	-
TDS	mg/l	397.6±48.2	451.3±54.4	424.2±87.3	1200
DO	mg/l	7.1±1.5	6.9±2.1	6.3±1.0	>1
Salinity	mg/l	391.3±50.9	399.3±71.0	412.7±85.6	-
TSS	mg/l	2258.2±32.6	2575.2±108.6	2709.3±71.4	50
			Chemical		
BOD_5	mg/l	7431.6±832.9	5940.9±253.0	7525.3±574.6	30
COD	mg/l	12000±844.5	11610±618.2	14273±476.3	150
PO_4^{3-}	mg/l	6.2±1.4	7.2±1.6	6.5±1.2	30
Cl^-	mg/l	56.5±17.7	51.4±15.9	68.6±24.6	250
NH_4^+	mg/l	4.4±2.1	6.5±2.3	6.3±1.9	-
NO_3^-	mg/l	24.5±8.3	17.5±3.1	20.1±9.2	50
NO_2^-	mg/l	0.8±0.1	0.7±0.2	0.4±0.1	-
Cu	mg/l	0.2±0.02	0.3±0.02	0.3±0.01	1
Pb	mg/l	<0.01	<0.01	<0.01	0.05

Mean ± std. dev (n=24, private; n=60, Public and n=30, cooperative).

The nitrate concentration level of coffee effluent at all locations and wet coffee processing factories varied between 18.118.1 ± 3.9 to 22.7 ± 4.1 mg/l (table 4.2) and from 17.5 ± 3.1 to 24.5 ± 8.3 mg/l (Table 4.3), respectively. The results recorded in April and June (Table 4.4) differed significantly ($P<0.05$), this might be due to the fertilizers used by the farmers in their fields that is discharged to the water bodies by runoff in which the same contaminated water is also used in pulping, fermentation and coffee washing because most of the wet coffee processing factories in Burundi use the

water from rivers and streams. The nitrates concentrations level was in conformity with the standards (MIWESPU, 2014).

Ammonium concentrations were in range of 4.9 ± 0.8 to 6.6 ± 1.8 mg/l (Table 6) and 4.4 ± 2.1 to 6.6 ± 2.3 mg/l (Table 4.3), respectively between locations and various wet coffee processing factories. Ammonium is a critical parameter for fish in aquaculture due to its toxicity and it can eventually cause cell death in the central nervous system when it is in high concentration (NAYAL, 2008). The results showed that there was significant difference in all sampling sites ($P<0.05$) and temperature was below the permissible limit for discharge effluents (Tables 4.1, 4.2, 4.3 and 4.4). The difference could be due the fertilizers used in the surrounding fields by farmers which came to rivers water by runoff.

Values indicate that there was no significant difference in levels of pH between the period of April and June. Paired samples test revealed that as it is presented (Table 4.4 and Fig. 4.1) the results recorded in April and June did not differ significantly for TSS while the values of COD and BOD5 differed significantly due to the seasons (Wet and Dry seasons). This difference could be due the organic loads from the surrounding areas and came to water bodies by runoff.

Table 4.4: Average values for the Physico-chemical parameters of wastewater at wet coffee processing plants in wet and dry months

Variable	Unit	Wet/April	Dry/June	Standard level
Physical				
pH	pH scale	4.10 ± 0.31	4.14 ± 0.36	6 – 9
Temperature	ºC	21.84 ± 1.22	21.81 ± 1.78	35
EC	µS/cm	818.61 ± 3.98	892.82 ± 2.37	-
TDS	mg/l	406.88 ± 2.37	441.72 ± 2.12	1200
DO	mg/l	7.58 ± 0.57	5.89 ± 0.38	>1
Salinity	mg/l	371.06 ± 2.04	441.00 ± 1.95	-
TSS	mg/l	2535.64 ± 14.7	2492.84 ± 2.04	50
Chemical				
BOD_5	mg/l	7796.38 ± 468.20	6135.33 ± 389.19	30
COD	mg/l	13370 ± 501.31	11885.33 ± 651.75	150
PO_4^{3-}	mg/l	9.33 ± 1.06	3.95 ± 1.04	30
Cl^-	mg/l	57.13 ± 1.08	60.48 ± 9.24	250
NH_4^+	mg/l	5.98 ± 0.71	5.49 ± 0.47	-
NO_3^-	mg/l	25.41 ± 1.88	16.11 ± 1.87	50
NO_2^-	mg/l	1.02 ± 0.60	0.23 ± 0.12	-
Cu	mg/l	0.21 ± 0.02	0.26 ± 0.02	1
Pb	mg/l	<0.01	<0.01	0.05

pH values varied from one location to another and from one coffee processing factory to another, the pH varied between 4.14.1 ± 0.3 to 4.2 ± 0.4 (table 4.2) and from 4.0 ± 0.3 to 4.3 ± 0.5 (table 4.3), these results show that the wastewater were highly acidic. The acidic pH is due to the presence of organic acids such as carboxylic acids in berry skin and pulp.

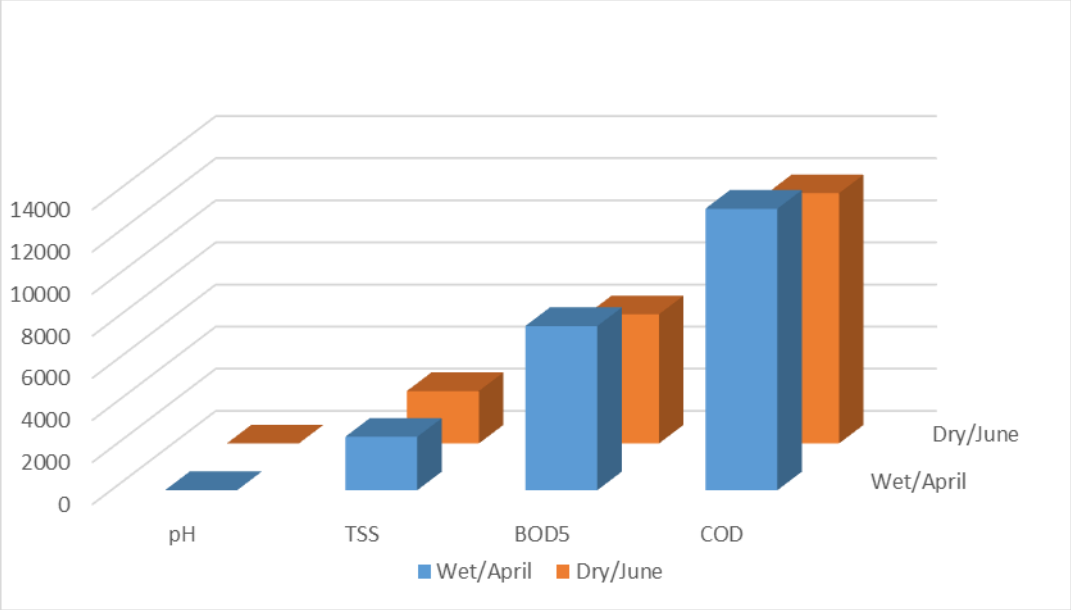


Figure 4.3: Spatial variations of pH, TSS, COD and BOD_5 according to seasons

These findings are in agreement with what was reported by the authors [(Devi, 2019), (Yemane, 2015)]. The mean pH values were significantly lower (acidic) in the coffee effluent. This could be due to fermentation of mucilage, sugars in the fermentation tank. The sugar ferments in the presence of yeasts to alcohol and CO_2. However, in this situation the alcohol is quickly converted to acetic acid in the fermented pulping water. The acidification of sugars dropped the pH around 4 (Enden, 2002).

Mean Concentration of TSS was in the range of 2481.3 ± 45.6 to 2640.9 ± 60.0 mg/l in the locations (Table 4.2) and from 2258.2 ± 108.6 to 2709.3 ± 71.4 mg/l for the various wet coffee processing factories (Table 4.3). The higher value of TSS in coffee processing wastewater could be due to the presence of pectin, protein and sugar which are biodegradable in nature. The concentration of the organics also varied with quantity of water used for processing of coffee berries (Selvamurugan et al. 2010). These results were higher than the acceptable limit [(MIWESPU, 2014)] and did not change significantly ($P<0.05$) due to the seasons. Based on the standard discharge limit value, the TSS adversely affect the nearby rivers or streams by increasing the dissolved oxygen

demand by sedimentation and establishing oxygen demand sludge deposit, which cause turbidity in the receiving water bodies and may change the habitat of aquatic microorganisms.

The pollution profiles for Chemical Oxygen Demand in the effluent released from wet coffee processing factories was in range of 10025 ± 498.0 to 14019.2 ± 392.9 mg/l (table 4.2) and 11610 ± 618.2 to 14273 ± 476.3 gm/l (Table 4.3) in the three locations and from the wet coffee processing factories respectively. BOD_5 values were in the range of 5792.5 ± 488.1 to 7300 ± 388.0 mg/l (table 4.2) at to three sample locations and 5940.9 ± 253 to 7525.3 ± 574.6 mg/l (table 4.3) from the wet coffee processing factories, these results changed significantly ($P< 0.05$) due to the seasons. This change in results recorded in April and June might be attributed to the different air temperature which affects the fermentation. Burundi effluent discharge standards has a limit value of COD (150 mg/l) and BOD_5 (30 mg/l) [(MIWESPU, 2014), (WHO, 1995)]. This high level of BOD_5, COD in the coffee processing effluent could be due to the presence of high amount of organic substances and to the slowly degrading compounds present. Various researchers reported high pollution from wet processing [(Hue et al., 2006), (Yemane, 2015), (Shanmukhappa et al., 1998)] caused by COD and BOD_5 contents of coffee effluent.

TDS values of the coffee wastewater effluent among locations and all the wet coffee processing factories varied respectively between 414.5 ± 83.3 to 443.0 ± 56.4 mg/l (table 4.2) and 397.6 ± 48.2 to 451.3 ± 54.4 mg/l (Table 4.3), all the results were lower than the set standards along the sampling points (Tables 4.1, 4.2, 4.3 and 4.4) and they did not change significantly ($P<0.05$) due to the seasons (April and June). The amount of TDS at all the sites might be due to the high mucilage coming out of the fermentation tanks. The high TDS can be toxic to freshwater animals causing osmotic stress and can give increase to obnoxious odors from the decay of organic matter and vulgar smell.

The average values of coffee wastewater temperature ranged at all locations and various wet coffee processing plants between 21.3 ± 1.1 to 23.7 ± 1.1°C (Table 4.2) and 20.8 ± 1.2 to 23.0 ± 1.2 °C (Table 4.3) respectively. The results showed that there was significant difference in all sampling sites ($P<0.05$) and temperature was below the permissible limit for discharge effluents.

The Electrical Conductivity (EC) varied between 734.5 ± 15.8 to 867.9 ± 54.7 µS/cm (Table 4.2) and from 798.3 ± 20.5 to 924.9 ± 97.1 µS/ cm (Table 4.3) respectively among the locations and the various wet coffee processing factories. The EC rose steadily with increase in TDS and salinity (Mburu et al., 2020). High significant variation was observed between the types of coffee washing station and EC (Table 4.5) and these results showed that they did not differ significantly at a 95% confidence interval due to the seasons (Wet and Dry seasons).

The DO values were in the range of 2.8 ± 0.3 to 8.7 ± 0.4 mg/l (Table 4.2) and 6.3 ± 1.0 to 7.1 ± 1.5 mg/l (Table 4.3) in coffee wastewater samples collected among the locations and various wet coffee processing plants, respectively. The lowest values were obtained from Makamba during wet season (Table 4.4). The variation may be attributed to oxygen consumption by aerobic organisms due to increase in oxygen demanding wastes. DO concentrations below 1 mg/l may adversely affect the surrounding river or stream and survival of biological communities and hence all water pollution. DO concentration value changed significantly at 95% confidence interval in most of periods and significant ($P<0.01$) correlation was observed between DO and Ammonium (Table 4.5). The biological indicators were negative correlated with pH and DO while positive correlations were noticed in BOD_5 and COD of coffee wastewater. This showed that there was hypoxia or anoxia which affected taxa richness and all diversity indices.

Phosphates concentration levels ranged between 6.0 ± 1.6 to 9.5 ± 1.5 mg/l (Table 4.2) and 6.2 ± 1.4 to 6.51.2 mg/l (Table 4.3) in the sample locations and various wet coffee processing factories respectively. The concentrations of phosphates were statistically significant ($p<0.05$) among all the locations and changed significantly at 95%

confidence interval as compared to the results recorded in April and June. The phosphates concentrations of the effluent do not appear to pose any threat to the receiving water bodies (Tables 4.1, 4.2, 4.3 and 4.4).

The concentrations level of nitrites in the coffee wastewater were found to be statistically significant ($P<0.05$) among all locations. The average nitrite concentrations were in range of 0.6 ± 0.1 to 0.8 ± 0.2 mg/l (Table 4.2) and from 0.4 ± 0.1 to 0.8 ± 0.1 mg/l (Table 4.3), respectively across locations and various wet coffee processing factories. The nitrites concentrations of the effluent do not appear to pose any threat to the receiving water bodies as compared the standard for discharge effluent (MIWESPU, 2014). The concentrations level of nitrites in the coffee wastewater were found to be statistically significant ($P<0.05$) among all locations. The results recorded in April and June differed significantly. This might be due to the runoff containing the fertilizer used in the surroundings farms by the farmers (Bisekwa et al., 2020)

Table 4.5: Correlations values (r) among physico-chemical parameters.

	pH	T	EC	TDS	DO	Salinity	COD	BOD_5	TSS	PO_4^{3-}	Cl^-	NH_4^+	NO_3^-	NO_2^-	Cu
pH	1	0.04	0.36**	0.34**	-0.41**	0.37**	0.33*	0.39**	0.04	0.34**	0.46**	-0.20	0.55**	0.19	-0.07
T	0.04	1	-0.28*	-0.41**	-0.66**	-0.42**	0.33*	0.37**	0.16	-0.52**	0.12	-0.20	-0.02	-0.54**	0.18
EC	0.36**	-0.28*	1	0.93**	0.02	0.92**	0.28*	0.27*	0.39**	0.44**	0.04	-0.05	0.47**	0.30*	0.21
TDS	0.34**	-0.41**	0.92**	1	0.12	0.99**	0.22	0.22	0.30*	0.45**	0.09	0.05	0.51**	0.36**	0.02
DO	-0.41**	-0.66**	0.02	0.12	1	0.09	-0.22	-0.28*	-0.06	0.15	-0.47**	0.58**	-0.33*	0.56**	-0.14
Salinity	0.33**	-0.42**	0.92**	0.99**	0.09	1	0.22	0.22	0.29*	0.46**	0.09	0.02	0.53**	0.37**	0.03
COD	0.33*	0.33*	0.27*	0.21	-0.22	0.22	1	0.98**	0.52**	-0.33*	0.27*	0.05	0.37**	0.26	-0.20
BOD_5	0.30**	0.32**	0.27*	0.22	-0.28*	0.23	0.98**	1	0.51**	-0.26	0.28*	0.01	0.42**	0.23	-0.12
TSS	0.04	0.16	0.40**	0.30*	-0.06	0.29*	0.52**	0.51**	1	-0.26	0.29*	0.14	0.06	0.01	0.01
PO_4^{3-}	0.30**	-0.52**	0.44**	0.45**	0.15	0.46**	-0.33*	-0.26	-0.26	1	-0.21	-0.09	0.28*	0.36**	0.37**
Cl^-	0.46**	0.12	0.04	0.09	-0.47**	0.09	0.26*	0.28*	0.28*	-0.21	1	-0.25	0.24	-0.22	-0.34**
NH_4^+	-0.20	-0.20	-0.05	0.05	0.58**	0.02	0.05	0.01	0.14	-0.09	-0.25	1	-0.26*	0.42**	-0.52**
NO_3^-	0.52**	-0.02	0.46**	0.51**	-0.33*	0.53**	0.37**	0.42**	0.06	0.28*	0.20	-0.26*	1	0.12	-0.08
NO_2^-	0.19	-0.54**	0.30*	0.36**	0.56**	0.37**	0.26	0.23	0.01	0.36**	-0.22	0.42**	0.12	1	-0.12
Cu	-0.07	0.18	0.21	0.02	-0.14	0.03	-0.21	-0.12	0.01	0.37**	-0.34**	-0.52**	-0.07	-0.12	1

** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level; **df**: 112

From the study, it was noted that the pH level has a strong significant negative correlation with DO, this value shows that with increase or decrease in the values of pH. DO also decreases or increases respectively in their values. A significant positive correlation was found between TDS and EC, Salinity, and Nitrates, therefore, with increase or decrease in the values of TDS, the values of EC, Salinity, and Nitrates ion increases or decreases respectively. DO bears significant positive correlation with Ammonium ion and nitrates ion (Mburu et al., 2020). COD has a strong significant positive correlation with TSS, BOD_5. The concentrations of chloride ranged between 35.7 ± 6.4mg/l at Makamba to 61.6 ± 7.8 mg/l at Gitega and from 51.4 ± 15.9mg/l (Public) to 68.6 ± 24.6 mg/l (cooperative), respectively at the study locations (Table 4.2) and wet coffee processing owners (Table 4.3).

The mean concentrations of copper were in conformity with standards level and varied between 0.2 ± 0.02 to 0.4 ± 0.2 mg/l and 0.2 ± 0.02 to 0.3 ± 0.01 mg/l respectively across locations and the various wet coffee processing factories. These concentrations do not appear to cause problems to the nearby rivers and streams. In this study, the lead values for all the samples both during the dry season or wet season did not exceed the limit of detection of AAS.

4.2 Assessment of the effect of coffee processing technologies effluent on the physicochemical properties of receiving water bodies

From March to July, there were changes in the amount and quality of the effluent discharged from wet coffee processing plants. During the rainy season, the coffee wastewater quantity and quality is usually different from the dry season. Inefficient use of water, contaminated water sources and use of polluted water in the wet processing of coffee cherries are all major issues in coffee producing countries.

The results from the analyzed parameters established that the coffee effluent has a significant polluting potential during the wet coffee processing season. The findings from this study revealed that there were variations in physicochemical parameters among the course of rivers and streams following the discharge and indicating the

increasing impact of the effluents on the nearby downstream water bodies. High concentrations were observed at downstream (D) locations than upstream (U) locations according to the values presented below. However, different to the other parameters, the amount of pH values was obtained higher in the upstream and lower pH were observed at downstream locations for most of the rivers and streams. It was evident that the wastewater was highly polluted with organic load, nutrients and suspended solids. As a result, the polluting potential of wet coffee processing is enormous at locations below effluents discharges points. Although the measured pollutions parameters downstream along the sampling sites were highly reduced compared to the raw coffee wastewater, TSS, BOD_5 and COD were still very high to meet the discharge standards limits set by Burundi (MIWESPU, 2014)

Table 4.6: Physical characteristics of receiving waterbodies/ Rivers or streams in Kayanza sampling sites

Variables		pH		T		EC		TDS		DO		TSS		Salinity	
Unit				ºC		µS/cm		mg/l		mg/l		mg/l		mg/l	
Seasons		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
A	U	6.5±0.03$^{bc\ def}$	6.8±0.08^{e}	19.2±0.01^{a}	19.2±0.06^{a}	78.1±0.61^{e}	86.4±0.10^{f}	38.9±0.06^{f}	42.7±0.06^{g}	6.99±0.10^{f}	6.72±0.02	16.1±0.32^{b}	22.4±0.^{64b}	50.0±0.50^{ab}	39.8±0.29^{b}
	D	4.7±0.02^{b}	5.2±0.05^{b}	20.8±0.20^{b}	20.5±0.06^{a}	138.3±0.58^{g}	137.8±2.09^{d}	119.1±0.10^{i}	70.0±0.10^{b}	11.2±0.56^{g}	7.38±0.02^{f}	137.5±0.62^{b}	156.1±0.12^{c}	90.0 ±1.50^{g}	70.4±0.65^{d}
B	U	6.5±0.03^{bc}	6.8±0.03^{e}	20.6±0.50^{b}	22.5±0.06^{e}	54.8±0.51^{b}	94.1±0.15^{h}	37.2±0.71^{c}	72.3±0.06^{i}	3.4±0.07^{b}	7.10±0.02	193.3±1.15^{f}	214.7±0.58^{h}	40.1±1.10^{a}	65.0±0.29^{e}
	D	5.5±0.01^{e}	5.72±0.01^{e}	20.8±0.40^{b}	23.0±0.12^{f}	64.8±0.06^{b}	291.3±0.58^{h}	47.2±0.12^{c}	143.9±0.85^{f}	4.6±0.14^{b}	7.52±0.34^{f}	339.1±1.42^{c}	352.1±0.06^{e}	55.2±1.60^{b}	140.3±0.58^{h}
C	U	6.4±0.01^{b}	6.4±0.01^{b}	20.4±1.10^{b}	21.2±0.06^{d}	91.3±0.10^{h}	105.1±0.10^{i}	38.0±0.06^{e}	52.7±0.06^{g}	7.13±0.08^{f}	7.07±0.04	242.5±0.87^{h}	115.3±0.58^{e}	50.0±1.00^{ab}	50.0±0.06^{c}
	D	4.9±0.11^{c}	4.91±0.11^{a}	21.1±1.50^{bc}	23.5±0.12^{h}	95.2±0.17^{e}	265.3±0.58^{g}	102.6±0.25^{h}	130.7±0.55^{e}	7.30±0.23^{e}	7.81±0.05^{g}	842.9±0.12^{f}	205.5±0.87^{d}	67.8±1.00^{d}	130.7±1.21^{g}
D	U	6.5±0.07$^{bc\ de}$	6.4±0.04^{b}	22.0±0.02^{c}	19.8±0.12^{b}	92.3±0.10^{i}	92.3±0.10^{g}	45.1±0.15^{i}	45.1±0.15^{f}	6.7±0.02^{e}	6.70±0.02	267.7±1.04^{i}	208.0±0.75^{g}	60.0±0.15^{bc}	50.1±0.12^{c}
	D	5.5±0.01^{e}	5.7±0.01^{e}	22.2±0.14^{c}	20.5±0.29^{a}	154.0±0.58^{i}	203.3±0.58^{f}	102.6±0.17^{h}	102.6±0.17^{d}	6.8±0.01^{d}	6.83±0.01^{e}	1176.6±0.81^{h}	825.7±0.58	80.0±0.05^{e}	100.3±0.58^{f}
E	U	6.5±0.04$^{bd\ c}$	6.5±0.04^{c}	21.1±0.70^{f}	21.3±0.^{06d}	41.9±0.35^{a}	84.4±0.06^{e}	20.6±0.15^{a}	42.5±0.06^{e}	4.5±0.02^{b}	6.68±0.02	233±0.55^{g}	195.0±0.06^{f}	50±0.02$^{ab\ c}$	40.1±0.12^{b}
	D	6.0±0.47^{f}	5.9±0.06^{f}	23.9±0.23^{g}	22.3±0.51^{e}	72.6±0.32^{c}	348.0±1.00^{i}	21.3±0.12^{a}	175.9±0.25^{i}	4.8±0.15^{b}	7.03±0.06^{e}	608.5±0.40^{d}	583.4±0.64^{g}	55.3±0.05^{b}	150.4±0.75^{i}
F	U	6.3±0.42^{a}	6.4±0.06^{b}	22.9±0.01^{cd}	20.3±0.26^{c}	80.9±0.25^{f}	76.3±0.06^{c}	40.5±0.06^{g}	38.2±0.06^{c}	6.58±0.27^{e}	6.09±0.01	127.2±0.30^{e}	117.7±0.29^{e}	40.0±0.51^{a}	40.1±0.12^{b}
	D	5.9±0.02^{f}	5.9±0.03^{f}	23.0±0.01^{d}	20.5±0.01^{a}	115.5±0.12^{f}	103.6±0.10^{b}	58.0±0.10^{e}	150.8±0.64^{g}	7.15±0.21^{de}	6.22±0.12^{c}	653.6±0.46^{e}	575.3±0.58^{f}	60.1±0.20^{c}	50.0±0.06^{b}
G	U	6.8±0.09^{g}	6.1±0.01^{a}	23.1±0.02^{d}	21.2±0.00^{c}	114.5±0.12^{j}	118.8±0.06^{j}	47.4±0.23^{j}	59.4±0.06^{h}	4.83±0.29^{c}	6.60±0.01	86.2±0.30^{d}	10.5±0.06^{a}	45.0±0.50^{a}	30.3±0.55^{a}
	D	6.6±0.02^{i}	5.9±0.01^{f}	23.5±0.01^{f}	21.5±0.01^{de}	115.6±0.12^{f}	120.4±0.15^{c}	58.0±0.06^{e}	160.4±0.17^{h}	5.18±0.08^{c}	6.81±0.15^{e}	1524.3±0.61^{i}	65.3±0.17^{b}	75.1±0.08^{f}	60.3±0.58^{bc}
H	U	6.6±0.08$^{cde\ f}$	6.5±0.06^{d}	23.2±0.01^{e}	23.1±0.01^{g}	82.6±0.17^{g}	78.1±0.15^{d}	41.0±0.06^{h}	38.6±0.06^{d}	6.71±0.03^{e}	5.05±0.05	54.8±0.30^{c}	63.3±0.35^{b}	50.0±0.58^{ab}	40.0±0.75^{b}
	D	5.5±0.01^{e}	5.2±0.01^{c}	23.5±0.02^{f}	23.4±0.25^{g}	277.7±0.58^{i}	360.3±0.58^{j}	99.7±0.15^{g}	186.9±0.52^{j}	8.28±0.21^{f}	5.78±0.02^{b}	858.2±0.30^{g}	917.7±0.46^{j}	90.0±1.12^{g}	180.0±0.06^{j}
I	U	6.5±0.02^{df}	6.5±0.02^{d}	23.9±0.02^{g}	22.9±0.12^{f}	59.8±0.30^{a}	72.8±0.06^{b}	36.2±0.04^{d}	36.2±0.06^{b}	3.47±0.05^{a}	3.40±0.05	86.1±0.19^{d}	101.6±0.40^{d}	60.0±0.12^{b}	40.2±0.64^{b}
	D	4.5±0.01^{a}	5.5±0.01^{d}	24.2±0.01^{g}	23.0±0.12^{f}	72.8±0.06^{d}	180.6±0.72^{e}	90.5±0.20^{f}	91.5±0.20^{c}	3.58±0.07^{a}	3.58±0.07^{a}	1524.6±0.57^{g}	834.6±0.40^{i}	90.2±0.02^{g}	90.7±1.15^{e}
J	U	6.5±0.10$^{bc\ def}$	6.5±0.01^{d}	22.5±0.05^{d}	22.3±0.55^{g}	65.7±0.12^{c}	47.6±0.21^{a}	29.4±0.06^{b}	23.8±0.61^{a}	5.46±0.02^{d}	6.03±0.17	8.05±0.09^{a}	12.4±0.12^{a}	30.5±0.11^{a}	30.0±0.06^{a}
	D	6.3±0.01^{h}	6.0±0.01^{g}	24.5±0.12^{h}	23.1±0.06^{g}	75.8±0.20^{d}	54.6±0.35^{a}	33.1±0.15^{b}	27.7±0.10^{a}	5.56±0.02^{c}	6.49±0.01^{d}	48.6±0.40^{a}	59.0±0.12^{a}	40.9±0.06^{a}	55.5±0.32^{b}

Table 4.7: Chemical characteristics of receiving waterbodies/ Rivers or streams in Kayanza sampling sites

Variables		COD		BOD_5		PO_4^{3-}		Cl^-		NH_4^+		NO_3^-		NO_2^-		Cu	
Unit		mg/l		mg/l		mg/l		mg/l		mg/l		mg/l		mg/l		mg/l	
Seasons		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
A	U	45.1±0.71^{e}	30.0±0.06^{e}	27.0±0.40^{e}	16.9±0.12^{de}	0.43±0.20^{d}	0.71±0.02^{f}	26.3±1.35^{c}	36.4±0.89^{e}	3.3±0.10^{c}	2.88±0.01^{g}	0.17±0.04^{a}	0.77±0.04^{b}	0.07±0.02^{c}	0.01±0.00^{f}	0.10±0.01^{d}	<0.01
	D	290.5±2.20^{d}	245.3±0.58^{d}	152.1±2.11^{c}	147.9±0.23^{d}	0.89±0.06^{f}	0.93±0.03^{e}	31.9±0.89^{a}	55.2±1.35^{g}	3.6±0.09^{a}	3.96±0.01^{i}	11.6±0.15^{d}	1.71±0.04^{a}	0.26±0.01^{d}	0.02±0.00^{b}	0.11±0.01^{b}	<0.01
B	U	85.1±1.55^{g}	60.3±0.58^{f}	51.6±1.5^{g}	22.0±0.06^{f}	0.55±0.01^{f}	0.94±0.15^{g}	15.7±0.51^{a}	24.5±1.35^{b}	4.08±0.37^{c}	1.44±0.00^{c}	8.1±1.00^{f}	1.94±0.07^{e}	0.01±0.005^{a}	0.01±0.00^{f}	<0.01	<0.01
	D	1400±12.5^{g}	1250.1±0.12^{g}	732.2±2.55^{f}	530±0.75^{f}	0.68±0.01^{e}	0.95±0.10^{e}	38.1±0.89^{d}	33.8±1.78^{bc}	5.40±0.01^{b}	3.74±0.45^{h}	19.5±0.88^{g}	5.10±0.21^{c}	0.08±0.01^{b}	0.03±0.00^{c}	<0.01	<0.01
C	U	15.0±0.50^{b}	10.0±0.06^{b}	10.1±0.5^{b}	6.00±0.06^{b}	1.1±0.01^{g}	0.25±0.01^{c}	34.6±0.89^{d}	46.1±0.89^{f}	8.1±0.02^{e}	2.35±0.45^{e}	9.7±0.33^{g}	1.09±0.06^{c}	<0.01	0.01±0.00^{f}	<0.01	<0.01
	D	540.0±2.5^{f}	490.4±0.64^{f}	297.1±1.0^{e}	265.3±0.58^{e}	4.6±0.89^{j}	0.59±0.01^{c}	35.5±0.89^{c}	50.2±1.35^{f}	8.9±0.21^{d}	3.04±0.21^{e}	11.7±0.48^{d}	1.21±0.25^{a}	<0.01	0.02±0.00^{b}	<0.01	<0.01
D	U	80.5±0.02^{f}	65.3±0.58^{g}	36.0±0.02^{f}	25.0±0.35^{g}	0.14±0.01^{c}	0.14±0.01^{b}	26.6±1.77^{c}	26.6±1.77^{bc}	1.98±0.21^{b}	1.92±0.21^{d}	1.31±0.33^{b}	1.31±0.33^{d}	0.01^{a}	0.01±0.00^{f}	<0.01	<0.01
	D	390.3±0.25^{e}	345.2±0.29^{e}	258±0.50^{d}	145.3±0.52^{d}	0.39±0.02^{a}	0.40±0.01^{b}	34.6±1.77^{c}	34.6±0.75^{cd}	2.98±0.31^{a}	1.98±0.01^{b}	3.94±0.48^{a}	3.94±0.48^{b}	0.01^{a}	0.03±0.01^{c}	<0.01	<0.01
E	U	5.0±0.02^{a}	5.00±0.06^{a}	3.00±0.01^{a}	2.1±0.12^{a}	0.52±0.01^{e}	0.84±0.02^{g}	20.4±0.89^{b}	29.0±1.35^{d}	6.06±0.21^{d}	1.08±0.00^{b}	11.3±0.51^{h}	3.57±0.10^{f}	0.25±0.01^{g}	0.001±0.0	<0.01	<0.01
	D	1400±12.5^{gh}	1250.3±0.58^{g}	756±7.51^{g}	690±0.75^{g}	0.57±0.01^{c}	0.95±0.16^{d}	45.8±0.51^{e}	32.8±0.89^{bc}	7.26±0.37^{c}	3.66±0.10^{g}	16.2±1.07^{f}	3.98±0.09^{b}	0.37±0.03^{e}	0.01±0.00^{f}	<0.01	<0.01
F	U	80.0±0.15^{f}	65.0±0.52^{g}	53.0±1.20^{h}	15.0±0.06^{d}	0.42±0.02^{d}	0.03±0.00^{a}	28.4±0.01^{c}	36.4±0.89^{e}	3.60±0.09^{c}	0.78±0.10^{a}	10.9±0.25^{h}	1.93±0.13^{e}	0.06±0.01^{c}	0.001±0.00	0.11±0.01^{e}	<0.01
	D	250±0.12^{c}	230.7±1.1^{c}	151±0.65^{c}	137.9±0.07^{c}	0.47±0.02^{b}	0.10±0.01^{a}	35.8±1.35^{c}	40.5±1.35^{e}	4.86±0.01^{b}	1.61±0.01^{a}	11.5±0.58^{d}	7.60±0.01^{e}	0.11±0.01^{c}	0.01±0.00^{f}	0.12±0.01^{c}	<0.01
G	U	20.0±1.5^{c}	15±0.12^{c}	12.1±0.03^{c}	9.1±0.03^{c}	0.52±0.01^{e}	0.43±0.01^{d}	16.5±0.51^{a}	23.9±0.89^{b}	6.30±0.95^{d}	2.52±0.01^{f}	5.92±0.62^{e}	0.93±0.06^{bc}	0.10±0.01^{d}	<0.01	0.06±0.02^{b}	<0.01
	D	85.0±0.12^{b}	75±0.06^{b}	50.4±0.12^{b}	47.0±0.75^{b}	1.07±0.02^{g}	1.00±0.01^{f}	28.9±0.51^{a}	31.0±0.75^{b}	9.5±0.82^{e}	3.10±0.62^{e}	7.03±0.20^{c}	7.45±1.03^{e}	0.11±0.01^{c}	0.01±0.00^{f}	0.07±0.02^{a}	<0.01
H	U	5.1±0.29^{a}	4.98±0.03^{a}	2.99±0.06^{a}	2.23±0.06^{a}	0.51±0.01^{e}	0.05±0.01^{a}	36.9±1.35^{d}	17.0±1.23^{a}	3.54±0.27^{c}	0.72±0.01^{a}	9.68±0.10^{g}	0.38±0.04^{a}	0.04±0.01^{b}	0.003±0.00	0.10±0.01^{d}	<0.01
	D	1650.2±1.1^{i}	1530±0.64^{i}	861.3±1.15^{h}	1020±0.75^{i}	1.29±0.05^{h}	0.59±0.01^{c}	38.4±1.35^{d}	28.4±1.77^{a}	4.86±0.12^{b}	2.17±0.02^{c}	16.7±1.06^{g}	3.83±0.02^{b}	0.27±0.02^{d}	0.09±0.00^{e}	0.11±0.01^{b}	<0.01
I	U	34.7±0.58^{d}	25.0±0.06^{d}	17.03±0.06^{d}	15.1±0.12^{d}	0.12±0.01^{b}	0.12±0.01^{b}	36.6±1.35^{d}	29.0±2.13^{c}	1.08±0.01^{a}	1.09±0.02^{b}	3.59±0.49^{d}	3.59±0.49^{g}	0.01±0.00^{a}	0.01±0.00^{f}	<0.01	<0.01
	D	1700.6±1.1^{j}	1470±0.69^{h}	1040±0.58^{i}	985.5±0.81^{h}	1.20±0.03^{i}	1.20±0.03^{g}	40.0±0.44^{d}	36.6±1.35^{d}	3.24±0.01^{a}	3.24±0.01^{f}	5.99±0.14^{b}	6.0±0.14^{d}	0.06±0.01^{b}	0.05±0.00^{d}	<0.01	<0.01
J	U	45.3±0.58^{e}	29.8±0.29^{e}	28.03±0.06^{e}	23.8±0.29^{g}	0.09±0.01^{a}	0.53±0.01^{e}	27.7±1.02^{c}	25.4±1.02^{b}	3.48±0.21^{c}	0.72±0.01^{a}	2.27±0.03^{c}	0.38±0.01^{a}	0.22±0.02^{f}	0.005±0.00	0.02±0.00^{a}	<0.01
	D	59.8±0.29^{a}	52.0 ±1.15^{a}	35.1±0.12a	30.0±0.17^{a}	0.62±0.02^{d}	1.18±0.02^{g}	29.0±1.35^{a}	28.1±0.51^{a}	4.92±1.02^{b}	2.52±0.01^{d}	6.00±0.26^{c}	1.55±0.05^{a}	0.39±0.02^{e}	0.01±0.00^{a}	0.08±0.01^{a}	<0.01

Table 4.8: Physical characteristics of receiving waterbodies/ Rivers or streams in Gitega sampling sites

Variables		pH		T		EC		TDS		DO		TSS		Salinity	
Unit				ºC		µS/cm		mg/l		mg/l		mg/l		mg/l	
Seasons		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
K	U	6.4±0.02	6.6±0.04	21.6±0.06	23.9±0.15	54.2±0.21	61.7±0.12	21.8±0.17	30.7±0.10	0.63±0.02	2.57±0.02	60.7±0.58	48.3±0.29	30.3±0.58	30.2±0.29
	D	5.9±0.18	6.1±0.01	21.8±0.06	25.1±0.12	60.2±0.26	131.7±0.15	30.6±0.03	66.1±0.06	1.82±0.02	2.64±0.01	473.3±1.53	425.3±0.58	46.0±1.00	70.3±0.58
L	U	6.8±0.02	6.5±0.01	22.6±0.10	22.2±0.21	66.4±0.20	54.9±0.10	27.6±0.06	27.2±0.06	0.98±0.01	2.05±0.01	12.0±1.00	9.37±0.23	30.0±0.06	30.0±0.06
	D	6.4±0.02	5.1±0.02	23.8±0.06	23.9±0.06	69.2±0.25	143.0±0.12	33.4±0.12	70.8±0.10	1.01±0.02	2.98±0.01	130.3±5.13	123.1±0.81	50.4±0.55	70.0±0.17
M	U	6.5±0.06	6.6±0.01	23.8±0.03	23.8±0.12	64.7±0.75	65.9±0.10	34.7±0.44	32.78±0.02	0.89±0.01	3.20±0.01	71.3±1.53	61.7±0.17	40.1±0.12	40.0±0.23
	D	5.8±0.05	5.3±0.01	24.1±0.06	24.1±0.06	81.4±0.20	185.9±0.15	41.0±0.10	92.4±0.06	0.96±0.02	3.35±0.03	393.7±9.29	362.3±0.29	60.3±0.58	90.7±1.21
N	U	6.1±0.05	6.3±0.01	23.5±0.42	23.6±0.10	41.4±0.20	52.5±1.76	33.8±0.26	25.8±0.06	8.15±0.31	2.72±0.01	181.0±1.00	172.2±0.17	20.0±0.29	20.0±0.06
	D	5.7±0.02	5.2±0.03	25.6±0.08	25.4±0.06	82.1±0.40	117.0±0.10	41.5±1.48	58.0±0.06	9.13±0.13	2.81±0.01	547.0±1.00	615.6±0.58	60.2±0.46	60.4±0.64
O	U	6.2±0.04	5.9±0.04	22.3±0.15	22.5±0.40	58.6±0.56	37.0±0.15	21.0±0.10	18.6±0.03	2.38±0.02	2.60±0.01	83.3±1.53	71.3±0.29	30.0±0.06	20.0±0.06
	D	5.9±0.02	4.6±0.01	24.2±0.29	23.1±0.06	63.0±0.49	140.8±1.73	29.7±0.20	70.6±1.25	2.59±0.04	2.67±0.01	247.3±2.08	221.3±0.26	46.0±0.35	70.4±0.64
P	U	6.5±0.01	6.5±0.01	22.2±0.26	21.7±0.26	67.7±0.42	73.4±0.17	32.8±0.25	36.9±0.06	1.07±0.02	2.97±0.01	82.7±0.58	65.3±0.29	39.3±1.15	40.1±0.17
	D	5.9±0.12	5.9±0.02	23.2±0.06	23.5±0.06	117.4±0.40	78.1±0.06	59.5±0.10	139.3±0.26	1.84±0.06	3.08±0.02	202.7±2.52	192.0±0.87	60.3±0.46	60.9±0.81

Table 4.9: Chemical characteristics of receiving waterbodies/ Rivers or streams in Gitega sampling sites

Variables		COD		BOD_5		PO_4^{3-}		Cl^-		NH_4^+		NO_3^-		NO_2^-		Cu	
Unit		mg/l		mg/l		mg/l		mg/l		mg/l		mg/l		mg/l		mg/l	
Seasons		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
K	U	5.03±0.06	5.0±0.06	2.10±0.10	2.0±0.06	0.07±0.01	0.06±0.01	19.4±0.82	13.3±0.89	6.12±0.36	2.15±0.01	5.19±0.26	0.66±0.10	0.08±0.03	0.001±0.00	0.11±0.01	0.18±0.01
	D	250.1±0.12	200.4±0.69	143.3±0.58	142.9±0.12	0.13±0.01	0.16±0.00	19.8±0.51	61.2±3.54	12.1±0.21	3.23±0.02	9.60±0.54	2.43±0.10	0.11±0.04	0.01±0.00	0.12±0.01	0.20±0.01
L	U	10.1±0.12	8.10±0.17	3.50±0.01	3.42±0.14	0.09±0.01	0.12±0.01	15.9±0.03	13.9±0.51	8.04±0.21	1.38±0.21	3.99±0.43	0.69±0.11	0.03±0.00	0.01±0.00	0.14±0.00	0.31±0.02
	D	259.7±0.58	244.9±0.23	98.7±1.15	98.7±1.21	0.10±0.01	0.44±0.01	17.4±0.51	23.9±0.51	8.46±0.36	1.77±0.06	5.12±0.05	1.66±0.13	0.04±0.01	0.05±0.01	0.15±0.01	0.35±0.01
M	U	40.0±0.06	30.0±0.06	17.0±0.06	17.0±0.17	0.16±0.02	0.06±0.01	16.8±0.02	12.4±0.89	4.86±0.01	1.20±0.10	4.47±0.02	1.62±0.04	0.04±0.01	0.01±0.00	0.15±0.01	0.39±0.01
	D	1450.3±0.58	1380.3±0.58	573.3±0.58	573.3±0.58	0.21±0.06	0.76±0.02	35.8±0.51	21.6±1.35	8.70±0.37	1.62±0.01	7.34±0.37	4.54±0.09	0.11±0.01	0.04±0.01	0.16±0.01	0.42±0.02
N	U	90.1±0.09	75.3±0.58	49.4±0.64	48.7±0.46	0.11±0.01	0.09±0.01	ND*	15.4±0.35	ND*	1.07±0.01	ND*	5.16±0.30	ND*	0.01±0.00	0.19±0.02	0.50±0.01
	D	450.5±0.87	420.4±0.69	212.4±0.64	211.3±1.15	0.13±0.01	0.26±0.02	ND*	16.5±0.51	ND*	1.61±0.01	ND*	6.06±0.20	ND*	0.02±0.00	0.21±0.00	0.51±0.01
O	U	10.0±0.29	5.0±0.06	3.50±0.01	3.51±0.01	0.07±0.01	0.63±0.02	25.6±1.42	19.5±1.77	9.60±0.52	2.15±0.01	1.71±0.08	0.38±0.02	0.02±0.01	0.001±0.00	0.08±0.01	0.12±0.01
	D	260.0±0.12	254.7±0.58	175.3±0.64	175.3±0.58	0.11±0.01	2.40±0.12	28.8±0.87	45.9±1.08	9.84±0.10	3.94±0.03	2.30±0.06	0.91±0.04	0.03±0.01	0.01±0.00	0.09±0.01	0.15±0.02
P	U	15.2±0.07	5.10±0.12	2.10±0.17	1.97±0.05	0.06±0.01	0.09±0.01	20.7±1.02	20.4±0.89	5.88±0.21	1.56±0.10	4.42±0.44	1.02±0.06	0.02±0.01	0.01±0.00	0.22±0.00	0.23±0.01
	D	421.1±1.01	337.3±3.28	147.9±0.23	148.4±0.69	0.84±0.01	0.21±0.01	21.3±0.89	51.1±1.42	7.80±0.27	2.34±0.01	6.37±0.45	1.09±0.05	0.04±0.01	0.03±0.01	0.21±0.01	0.25±0.01

ND*: Not Determined

Table 4.10*:* Physical characteristics of receiving waterbodies/ Rivers or streams in Makamba sampling sites

Variables		pH		T		E.C		TDS		DO		TSS		Salinity	
Unit				ºC		µS/cm		mg/l		mg/l		mg/l		mg/l	
Seasons		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Q	U	6.6±0.04	6.3±0.01	22.5±0.01	22.6±0.20	67.7±0.42	136.0±3.52	34.1±0.15	66.8±0.06	0.61±0.01	1.77±0.03	200.8±6.66	175.5±0.23	40.0±0.06	70.0±0.15
	D	5.7±0.01	5.8±0.01	23.0±0.06	24.3±0.29	90.8±0.44	209.7±0.58	45.2±0.15	104.6±0.12	0.65±0.01	1.93±0.05	682.0±1.00	648.4±0.29	50.1±0.12	100.1±0.17
R	U	5.8±0.02	6.4±0.01	22.7±0.17	22.3±0.35	137.2±0.17	145.8±0.29	68.7±0.06	72.8±0.12	0.62±0.02	1.85±0.03	269.3±6.25	235.7±0.17	61.4±0.53	69.7±0.51
	D	5.4±0.02	5.0±0.01	23.1±0.05	23.6±0.21	145.1±0.21	226.7±0.58	72.4±0.12	114.1±0.06	0.64±0.02	1.94±0.02	588.0±2.65	489.6±0.12	70.1±0.23	110.7±1.15

Table 4.11: Chemical characteristics of receiving waterbodies/ Rivers or streams in Makamba sampling sites

Variables		COD		BOD_5		PO_4^{3-}		Cl^-		NH_4^+		NO_3^-		NO_2^-		Cu	
Unit		mg/l		mg/l		mg/l		mg/l		mg/l		mg/l		mg/l		mg/l	
Seasons		Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Q	U	5.07±0.12	5.04±0.07	2.10±0.17	2.04±0.06	0.57±0.01	0.09±0.01	17.4±0.51	22.8±1.35	4.50±0.36	1.22±0.04	8.31±0.92	0.61±0.08	0.18±0.13	0.01±0.00	0.20±0.00	0.45±0.01
	D	679.6±0.64	629.6±0.64	291.7±0.58	292.2±0.29	1.67±0.03	0.60±0.01	23.0±0.89	23.9±1.77	4.86±0.00	3.23±0.07	13.4±0.56	1.18±0.06	0.48±0.01	0.02±0.00	0.21±0.00	0.48±0.00
R	U	5.03±0.06	5.04±0.07	2.20±0.06	2.20±0.01	0.08±0.01	0.01±0.00	16.8±0.89	14.5±1.35	4.86±0.02	1.80±0.01	8.36±0.39	1.75±0.05	0.38±0.23	0.01±0.00	0.17±0.01	0.42±0.02
	D	700.2±0.29	610.7±0.15	314.7±0.52	314.5±0.81	0.25±0.01	2.08±0.02	22.5±1.35	18.0±1.02	5.04±0.12	2.06±0.23	10.3±0.52	7.59±0.07	0.45±0.01	0.05±0.01	0.17±0.01	0.46±0.01

4.2.1 pH of rivers water

The pH values (Tables 4.6, 4.8, 4.9) in the rivers upstream during wet season varied from 5.8 ± 0.02 to 6.8 ± 0.08 as related to 5.9 ± 0.04 to 6.8 ± 0.03 recorded in dry season (June) and showed wide variations between samples from different sites. The pH findings did not differ significantly ($P<0.05$) due to the seasons. The pH values in the rivers downstream ranged from 4.5 ± 0.01 to 6.4 ±0.01 during wet season (April) in Kayanza, Gitega and Makamba agro ecological zones in Burundi. While the pH values during dry season varied in the range of 4.6 ± 0.01 to 6.1 ± 0.01 and changed significantly. High pH values were observed in the upstream and low in down streams locations (Figure 4.4), these indicated clearly the negative impact of wet coffee processing factories in Kayanza, Gitega and Makamba Agro ecological zones in Burundi.

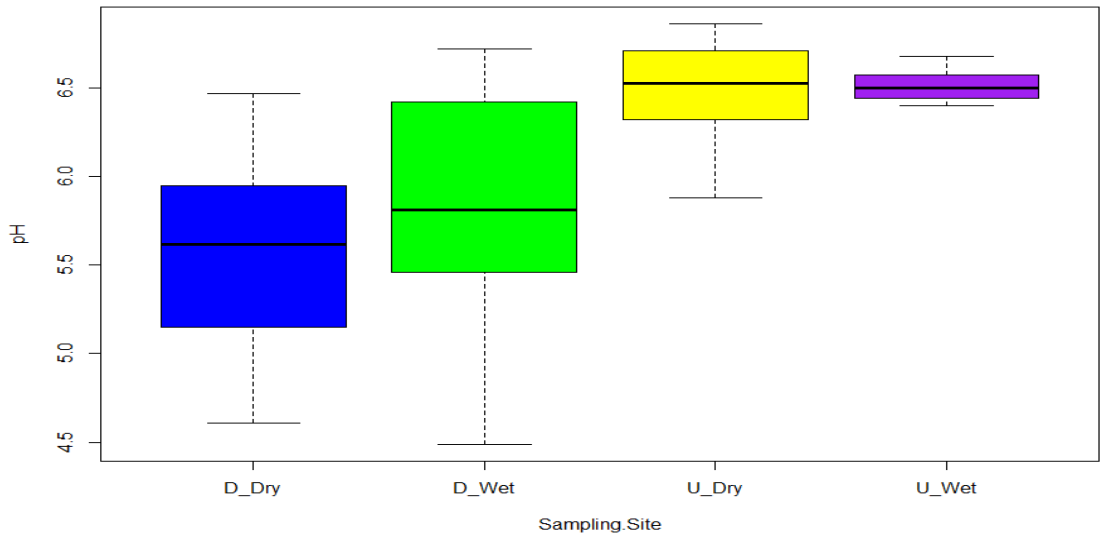


Figure 4.4: pH levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

The low pH observed at downstream locations is probably due to the discharge from wet coffee processing factories effluents. The lowest pH levels were found at Nakagogo site

(4.5) indicating the negative impact of coffee wastewater, this could be due to wet coffee processing factory which is near Nakagogo river that discharged the polluted water in this river. There was a significant difference in overall pH between the two seasons at 95 % confidence level. The difference could be attributed to the agricultural runoff and to the coffee waste water discharged without treatment.

This finding is in consistent with similar study done in Jimma zone by Yemane et al. (2015) that reported high pH was observed at upstream sites than downstream sites. Unlike the other parameters, the amount of pH was found high in the upstream site (7.11) and lower pH values at downstream locations of most rivers. Thus indicating the negative impact of coffee wastewater discharged without any treatment. Extremes in pH can make a river inhospitable to life. Low pH is especially harmful to immature fish and insects. Acidic water also speeds the leaching of heavy metals harmful to fish (Liu et al., 2019).

4.2.2 Temperature

The temperature level in the downstream of rivers water in wet and Dry seasons was found within in the range of 20.8 ± 0.40 – 24.2 ± 0.12 ºC; 19.2 ± 0.06 – 23.9 ± 0.15 ºC, respectively. The results displayed wide variations among sampling locations and did not change significantly ($P<0.05$) due to the study seasons.

The temperature in the upstream rivers water which ranged from 19.2 ± 0.01 to 23.9 ± 0.02 in wet season as compared to the results recorded in dry season which ranged from 20.8 ± 0.20 to 24.5 ± 0.12 º C varied from one river to another in Kayanza, Gitega and Makamba Agro ecological Zones in Burundi and were below 25 º C, which is the proposed limit for no risk according to WHO, FAO quality guidelines (Water Quality Regulations, 2006) for discharging effluent to natural surface water bodies. The high temperature indicated presence of active microorganisms which increased it.

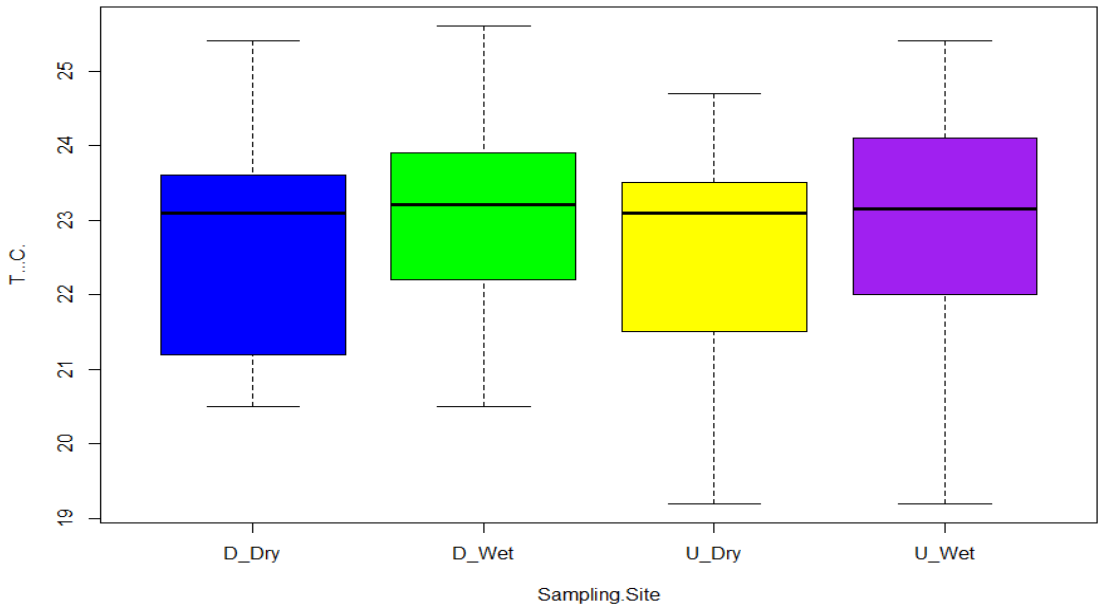


Figure 4.5: Temperature levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

Based on the findings and on the guidelines, the temperature of the effluent (Tables 4.6, 4.8 and 4.10) did not appear to pose any threat to the water ecosystem of the receiving water bodies [(Annon, 1989), (Bliefert et al., 2001)] (22 – 25 ºC) for fair water quality. These results are in agreement with preceding work undertaken by Hadis and Devi (2007) in Jimma zone in which the water temperature downstream of receiving waterbodies after receiving coffee effluents was reported at 22°C.There was no significant difference in temperature values between the two seasons at 95 % confidence interval (Figure 4.5), this might be due low temperature during sampling period.

4.2.3 Electrical Conductivity

The EC in water is the reflection of quantity of ionic constituent's dissolves in it. The more the ions, the higher the conductivity. The EC profile of the up streams and down streams water bodies varied significantly ($P<0.05$) and ranged from 41.4 ± 0.20 – 137.2

± 0.17 µS/cm and from 37.0 ± 0.32 to 184.1 ± 0.15 µS/cm respectively up stream's results recorded in wet and Dry seasons.

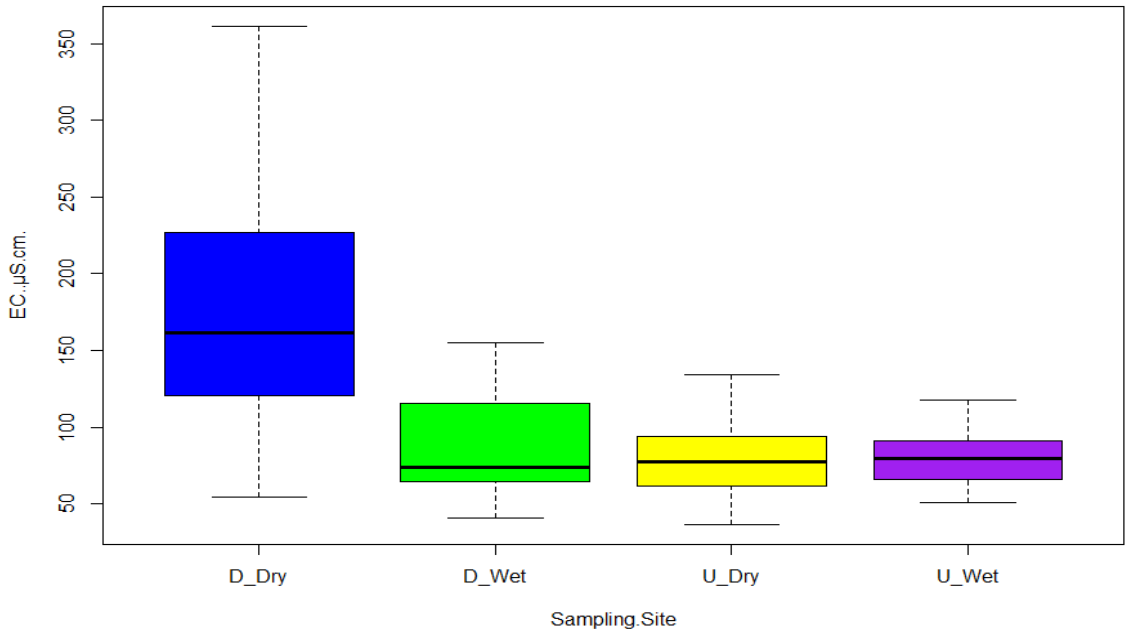


Figure 4.6: E.C levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

While the down stream's results recorded in Wet and Dry seasons ranged respectively from 42.6 ± 0.32 – 277.7 ± 0.58 µS/cm and from 54.6 ± 0.35 to 360.3± 0.58. These values were low all long the sampling points (Tables 4.6, 4.8 and 4.9) as compared to the provisional river water quality limit less than 400 µS/cm (Annon, 1989).

The relatively higher amount of EC at the downstream locations (Figure 4.6) might be caused by the high mucilage coming out from wet coffee processing technologies. A sudden increase or decrease in conductivity in body of water can indicate pollution. Agricultural runoff or sewage could increase EC due to the additional chlorides,

phosphates, and nitrates. In this case the additional of dissolved solids will have a negative impact on water quality.

4.2.4 Total Dissolved Solids

TDS values ranged from 20.6 ± 0.15 – 68.7 ± 0.06 mg/l and from 23.8 ± 0.61 to 92.3 ± 0.06 mg/l respectively for up stream's results recorded in Wet and Dry seasons while the down stream's results recorded in Wet and Dry seasons varied respectively from 30.6 ± 0.10 to 186.9 ± 0.02 mg/l and from 27.7 ± 0.10 to 139.7 ± 0.15 mg/l. The TDS of the water samples generally varied significantly ($p<0.05$) through the study period (Figure 4.7). High TDS were found at the downstream sites of the discharged points; however, the effluents quality appeared to be compliant with the regulations of TDS (Tables 4.6, 4.8 and 4.10), indicating that the water can be suitable for direct domestic use (Bliefert et al., 2001). The results show that the results of the current study agree with the findings reported by Tadesse et al., 2016 and Yemane et al., 2015. The high values of TDS can be toxic to fresh water animals causing osmotic stress and can give increase to obnoxious odors from the decay of organic matter and vulgar smell (Yemane, 2015).

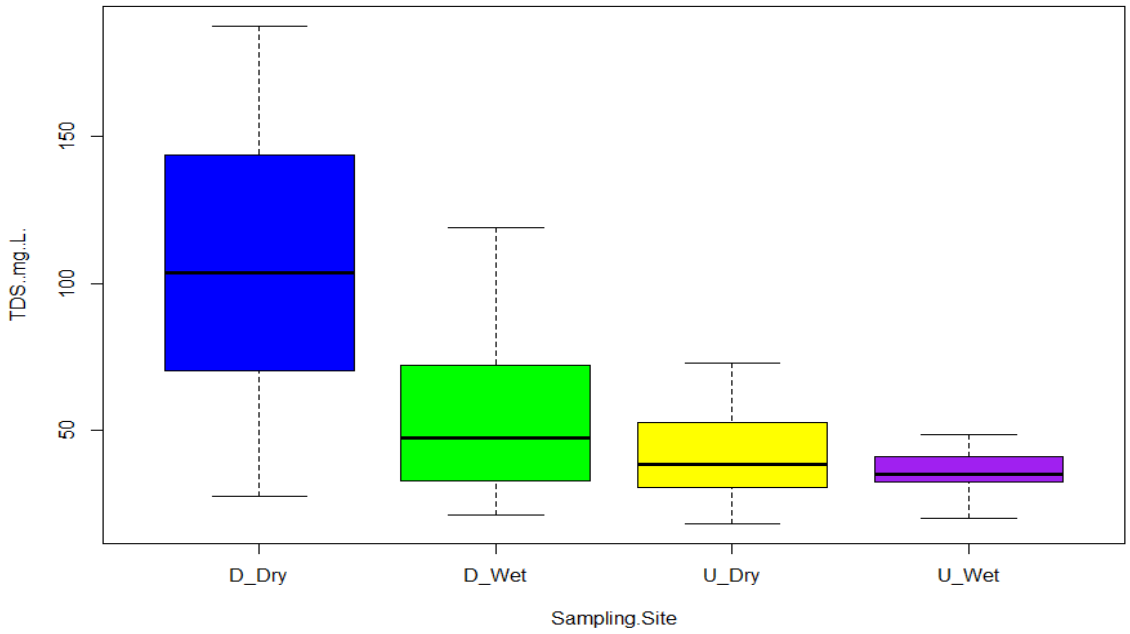


Figure 4.7: TDS levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

4.2.5 Dissolved Oxygen

The DO concentrations levels in the upstream of the rivers ranged from 0.63 ± 0.02 – 8.15 ± 0.31 mg/l and from 1.77 ± 0.03 to 7.10 ± 0.02 mg/l for the results recorded respectively in wet/April and Dry / June seasons and changed significantly due to the seasons. DO concentrations in the downstream of the rivers water ranged from 0.96 ± 0.02 to 11.2 ± 0.56 mg/l and from 1.93 ± 0.05 to 7.81 ± 0.05 mg/l respectively for the results recorded in April and June and these showed wide variations between samples from different sites.

These DO values changed significantly at a ($P<0.05$) confidence interval (Figure 4.8). Based on the findings, the results found in all rivers in Makamba (Muhwima & Nyakibingo) and in Gitega (Ruvyironza, Mavuvu, nyakijanda, Gashanga Nyamugari except Kagogo rivers) along up and down stream locations were lower than the

acceptable limit 3 – 5 mg/L (Annon, 1989), which indicated the pollution of these rivers (Bliefert et al 2001). The low DO contents at the locations mentioned above could be due to the organic and mineral load from the wastewater coming from the surrounding areas which consumed the Oxygen during their oxidation processes (CISHAHAYO, 2010).

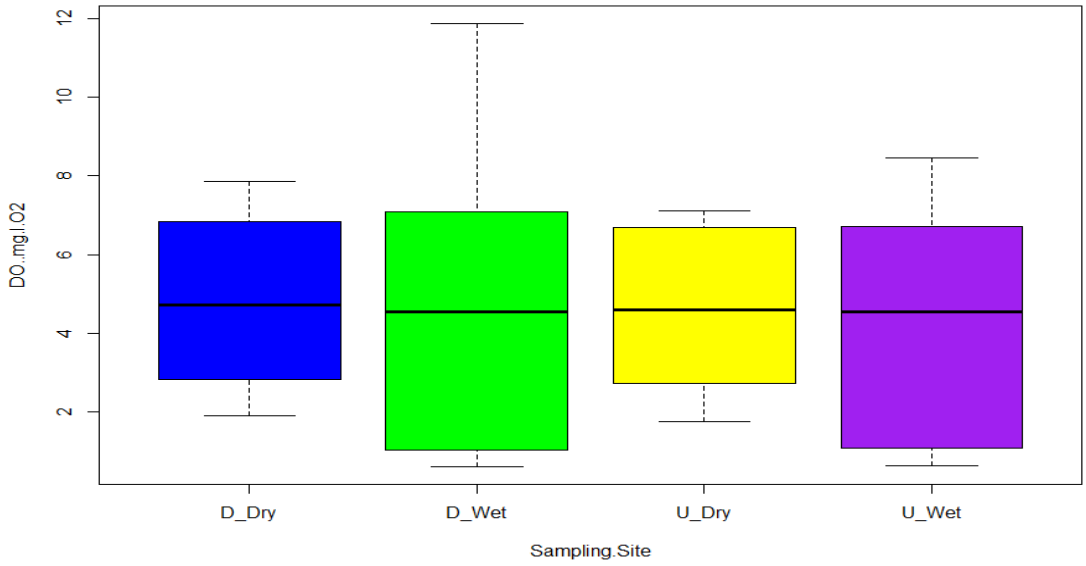


Figure 4.8: DO levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

Low oxygen conditions can cause a variety of water quality problems and suffocation of fish and other aquatic animals. DO level that is too high or too law can harm aquatic life and affect water quality.

4.2.6 Total Suspended Solids (TSS)

Generally high values were recorded at downstream whether in wet and dry seasons as compared to upstream sites. The mean TSS values in the upstream locations of the river during wet and dry seasons ranged between 8.05 ± 0.09 to 467.7 ± 1.04 mg/l and 9.37 ± 0.23 to 501.4 ± 0.75 mg/l (Table 4.6, 4.8 and 4.10) respectively and changed significantly ($P<0.05$) due to the seasons in major agro ecological zones in Burundi. This change could be due to the various organic material that ends up in the rivers by runoff during wet season.

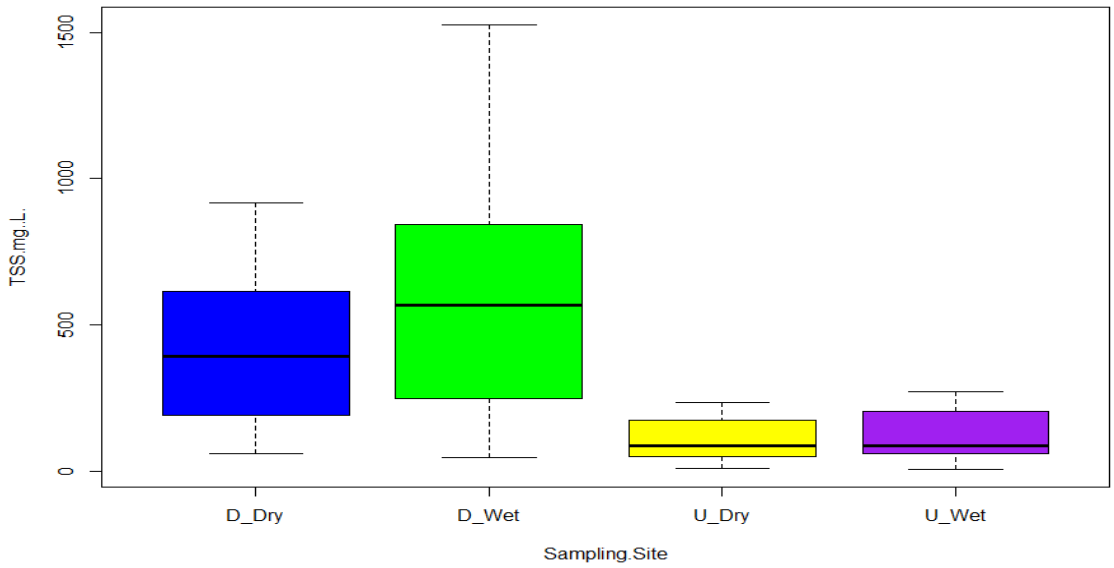


Figure 4.9: TSS levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

At downstream locations, the TSS values in wet and dry seasons varied respectively from 48.6 ± 0.40 to 1524.3 ± 0.61 mg/l, from 59.0 ± 0.12 to 1634.6 ± 0.40 mg/l with wide variations between sites (Figure 4.9). There was significant difference in overall TSS between the two seasons at 95% confidence level. The difference is attributable to coffee solids waste during coffee processing. Based on the WHO (1995) standard and

the overall assessment and classification of stagnant and running surface water according to their river water quality (Annon, 1989), the TSS concentrations along all down streams locations / sites were most higher than the acceptable limit less than 30 mg/L, which indicated the pollution of the rivers. These values were in the agreement with the data reported by Yemane et al., 2015. Based on the standard limit values, TSS in all sampling points (rivers) should adversely affect the use of water for various purposes (Sewe, 2010). High TSS Can cause turbidity in the river and may change the habitat of aquatic microorganisms.

4.2.7 Salinity

Water salinity concentrations levels were not significantly different among locations (Table 4.6, 4.8 and 4.10). The highest salinity values were observed at downstream sites both in wet and dry seasons. There was no significant difference in salinity recorded in both seasons.

During wet season, the concentration of salinity in the upstream were varied from 20.0 ± 0.29 – 61.4 ± 0.53 mg/l while the concentrations downstream ranged between 40.9 ± 0.06 to 130.0 ± 1.12 mg/l with wide variations between sites. While during dry season, salinity in upstream and downstream samples varied widely respectively from 20.0 ± 0.06 – 90.2 ± 0.29 mg/l and from 50.0 ± 0.06 to 180.0 ± 0.06 mg/l. At downstream, there was significant difference between the two seasons ($P<0.05$) (Figure 4.10). This difference might be due to the coffee effluents discharged into the receiving water bodies without any treatment. High salinity can decrease plant growth and water quality and degraded stock of water supplies.

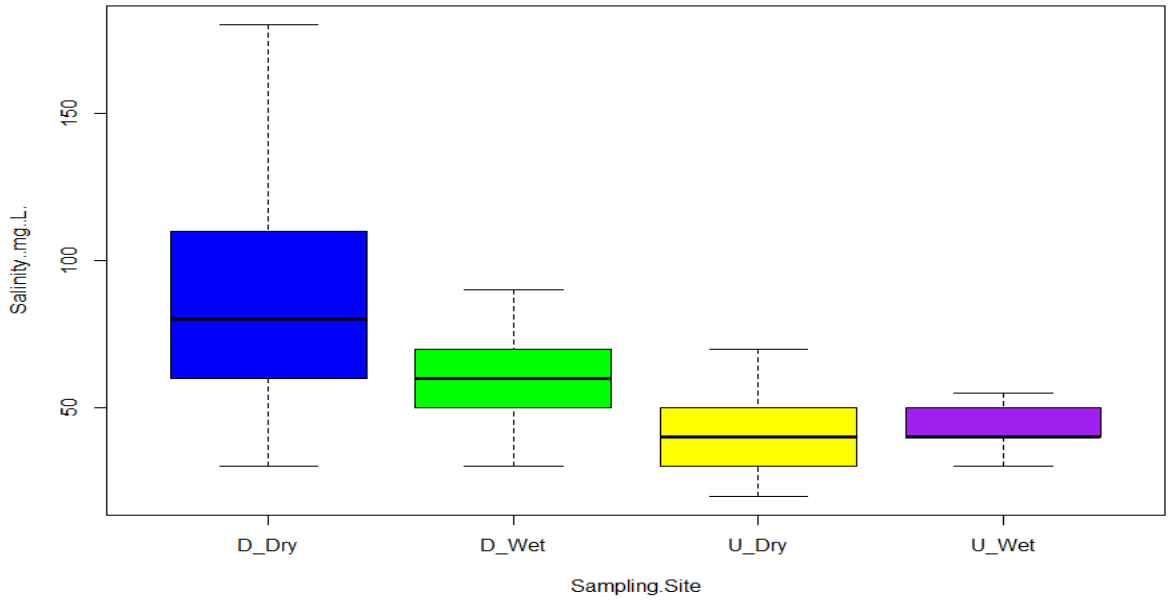


Figure 4.10: Salinity levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

4.2.8 Chemical Oxygen Demand (COD)

The average mean values of COD varied widely from 5.03 ± 0.06 to 120.0 ± 0.11mg, 4.98 ± 0.03 to 114.7 ± 0.52 mg/l for the up stream's results recorded respectively in wet and dry seasons (Fig. 4.11). While at downstream COD values ranged from 59.8 ± 1.15 – 1700.6 ± 1.5mg/l and 60.7 ± 1.15 – 1530.4 ± 0.64, respectively for the results recorded in wet and dry seasons with wide variations between sites and locations (Tables 4.7, 4.9 and 4.11). The highest average mean values of COD and BOD were observed at the upstream sites both in Wet and Dry (45.1 ± 0.71 mg/l) at Nyakagezi, (75.3 ± 0.58 mg/l) at Kagogo river, (60.3 ± 0.58 mg/l) at Ruvubu 2, (65.3 ± 0.58 mg/l) at Nyandibika, (120.3 ± 0.15 mg/l), (45.3 ± 0.58 mg/l), these values indicated poor water quality according to overall assessment and classification of stagnant and running surface water according to their river water quality 40 – 80 mg/L (Annon, 1989). The high concentrations COD was observed at downstream sites as compared to the upstream

sites (Figure 4.11), thus indicating the pollution strength of the receiving water bodies. There was also significant difference between the two seasons at 95% confidence interval.

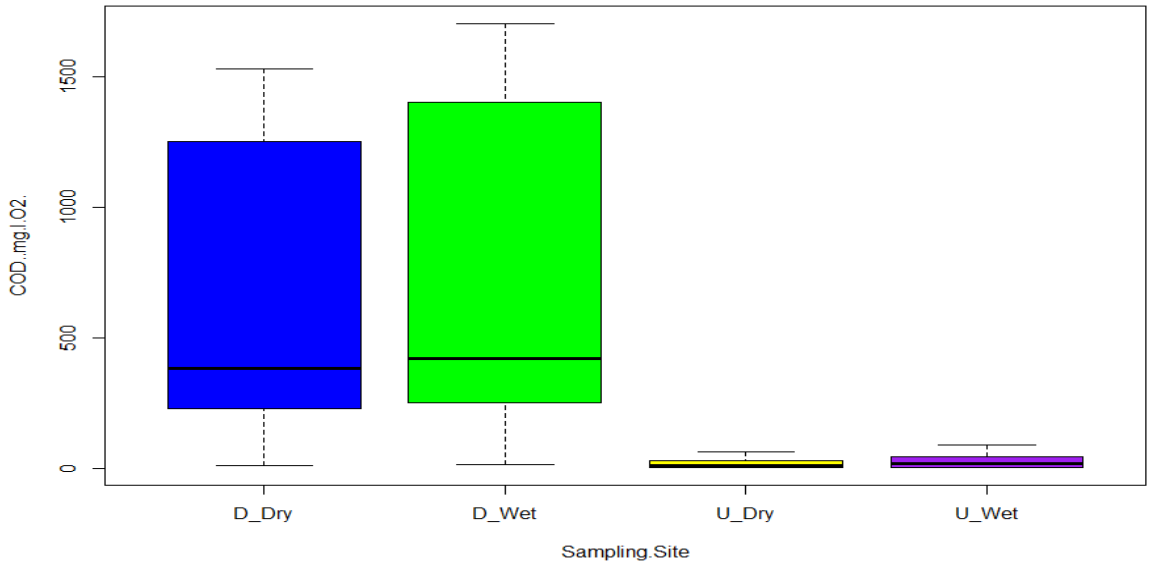


Figure 4.11: COD levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

This difference was caused by the various large amount of chemical and biological demanding substances released from the wet coffee processing factories into the rivers without any treatment in the major agro-ecological zones in Burundi (Kayanza, Gitega and Makamba). The findings from the study were in agreement with what was reported by Devi, 2019; Yemane et al., 2015 and Ejeta et al., 2016.

4.2.9 Biochemical Oxygen Demand (BOD_5)

During Wet and Dry seasons, the rivers water BOD_5 values at the upstream sites ranged widely between 2.10 ± 0.10 to 53.0 ± 1.20; 1.97 ± 0.05 to 48.7 ± 0.46, respectively (Tables 4.7, 4.9 and 4.11). Whereas at downstream sites BOD_5 recorded varied between 35.07 ± 0.12 – 1040.3 ±0.58 mg/l; 51.9 ± 0.17 – 1020.4 ± 0.75 mg /l in both the wet and

dry seasons respectively. The effluent discharged from the wet coffee processing factories in Kayanza, Gitega and Makamba may have increased the COD and BOD_5 concentrations of the receiving water bodies (Figure 4.12).

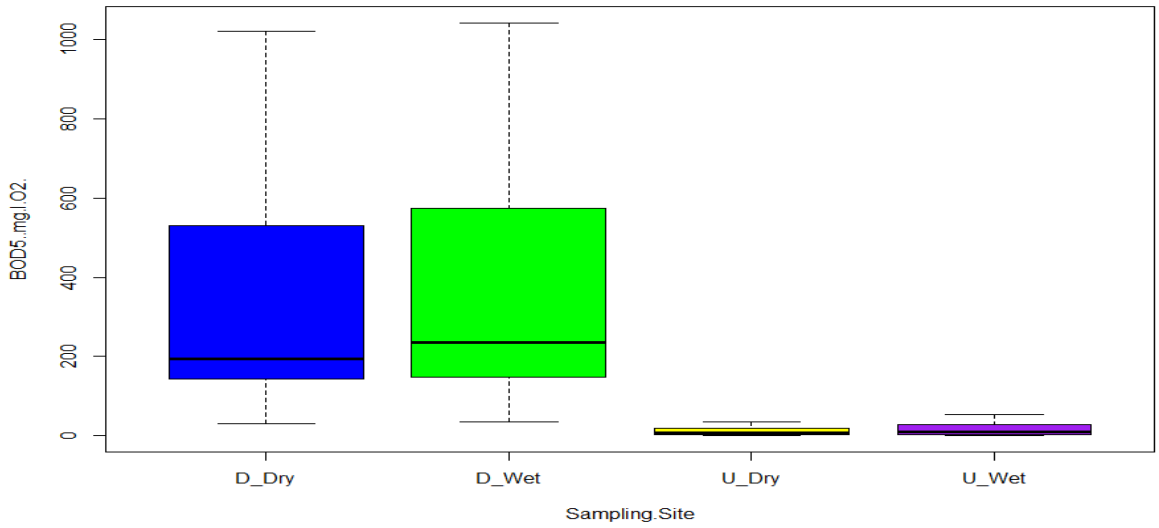


Figure 4.12: BOD_5 levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

The downstream rivers water COD and BOD_5 were higher than 40mg/l and 10mg/l, respectively as recommended by WHO (2005). The values are in the agreement with what was reported by other researchers (Devi, 2019; Yemane et al., 2015; Ejeta et al., 2016). Water with high concentrations of BOD_5 can be a warning sign of algal bloom, however, high oxygen concentration during the day could likely be followed by low oxygen concentration at night and very low concentrations when the bloom breakdowns. There was significant difference between the two seasons at $P<0.05$, the difference could be attributed to the dilution effect during wet season.

4.2.10 Phosphates

The range of phosphates concentrations varied widely from 0.06 ± 0.01 – 1.10 ± mg/l and from 0.03 to 1.94 ± 0.15 mg/l, during the wet and dry seasons respectively for up stream's results with wide variations between the sites (Figure 4.13). Whereas the down stream's results recorded in wet and dry seasons varied from 0.10 ± 0.01 to 4.60± 0.89; 0.16 ± 0.01 to 4.26 ± 0.10 mg/l respectively with wide variations between sites (Tables 4.7, 4.9 and 4.11) and changed significantly ($p<0.05$).

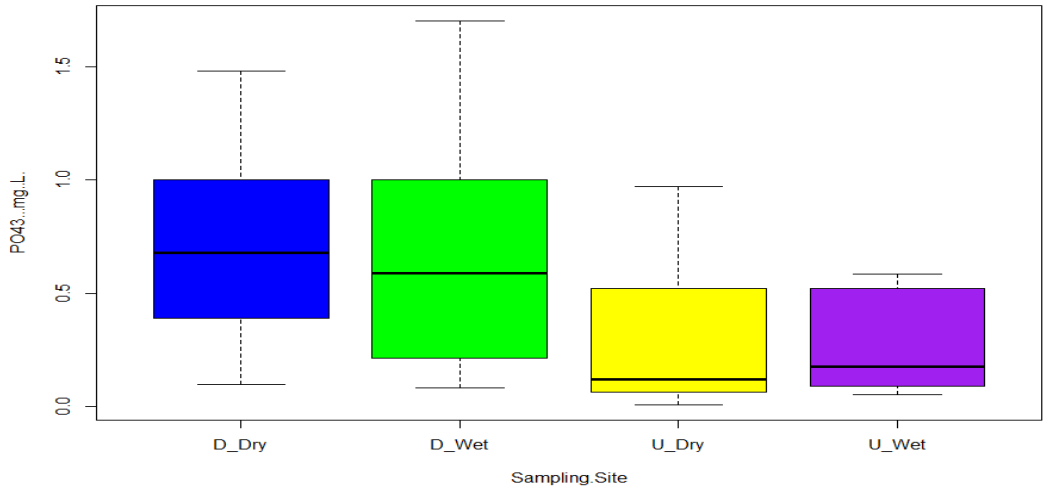


Figure 4.13:PO_4^{3-} levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

Comparison of the result obtained in this study from the study done by Hadis et al., 2007 showed high phosphate concentrations than that obtained in this study (0.78 – 0.82 mg/l). According to (MIWESPU, 2014) phosphates concentrations are within the standard limit 30 mg/L, therefore this parameter did not cause change or pollution to the receiving water bodies. The presence of PO_4^{3-} in water increases eutrophication and similarly promotes the growth of algae. The difference in PO_4^{3-} observed in downstream sites could be due to different effluent quantities discharged into the receiving water

bodies from wet coffee processing factories in major coffee growing ecological zones in Burundi.

4.2.11 Chlorides (Cl^-)

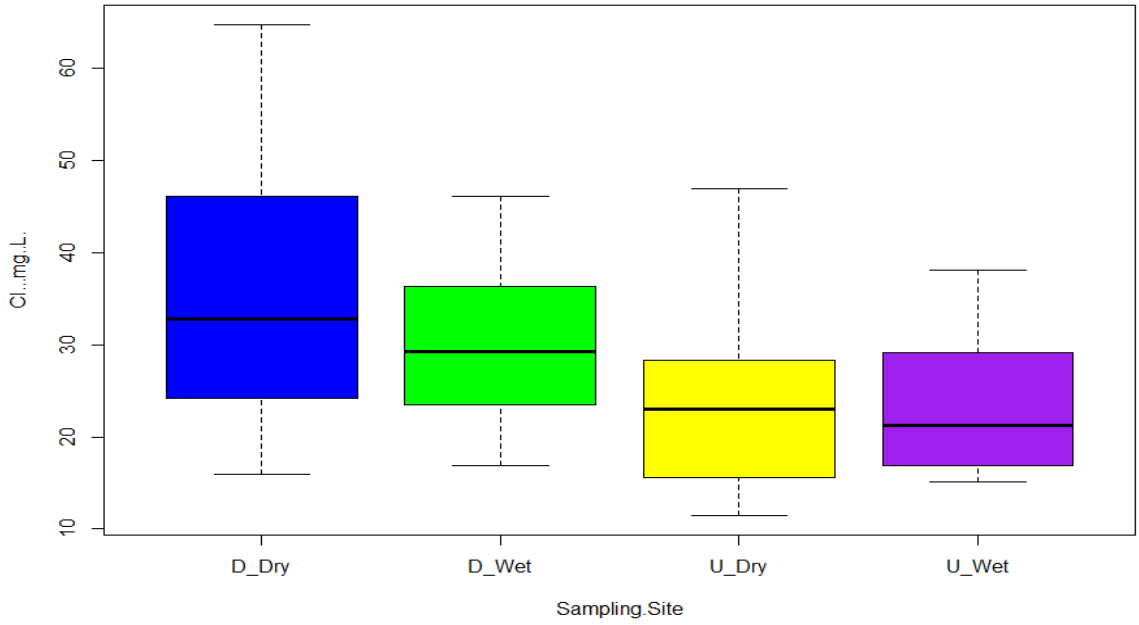


Figure 4.14: Cl^- levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

The chlorides concentrations values at the upstream and downstream sites varied significantly and ranged from 15.7 ± 0.51 – 36.9 ± 1.35 mg/l; 12.4 ± 0.89 – 36.4 ± 0.89 mg/l for the wet and dry season respectively for upstream's results, whereas at downstream sites, Cl^- Values varied widely from 17.4 ± 0.51 – 45.8 ± 0.51mg/l; 16.5 ± 0.51 – 61.2 ± 3.54 mg/l for the results recorded in wet and dry seasons respectively. High Cl^- concentrations found at downstream of the discharged points (Figure 4.14) could be due to wet coffee effluents without any treatment. However, the effluents qualities appeared to be within the set standards.

4.2.12 Nitrates (NO_3^-)

The nitrate concentrations levels in the downstream of rivers water ranged from 2.30 ± 0.06 – 19.5 ± 0.88mg/l; 0.91 ± 0.04 – 7.60 ± 0.02mg/l for the wet and dry season respectively and differed significantly ($P<0.05$). These values show wide variations between samples from different sites (Figure 4.15).

Based on the WHO (1995) standard, the nitrates concentrations along downstream sites were within the acceptable river water quality, which indicated that the wet coffee processing factories effluents did not contribute to poor Nitrates level of the receiving water bodies. The results show that the results of the current study agree with findings reported by Haddis A. & Devi R. (2008). The low nitrates concentrations at downstream sites for the results recorded in Dry seasons as compared to wet season may be due the decreasing of the use of fertilizers in the surrounding fields by farmers which came to rivers water by runoff (Bisekwa et al., 2020).

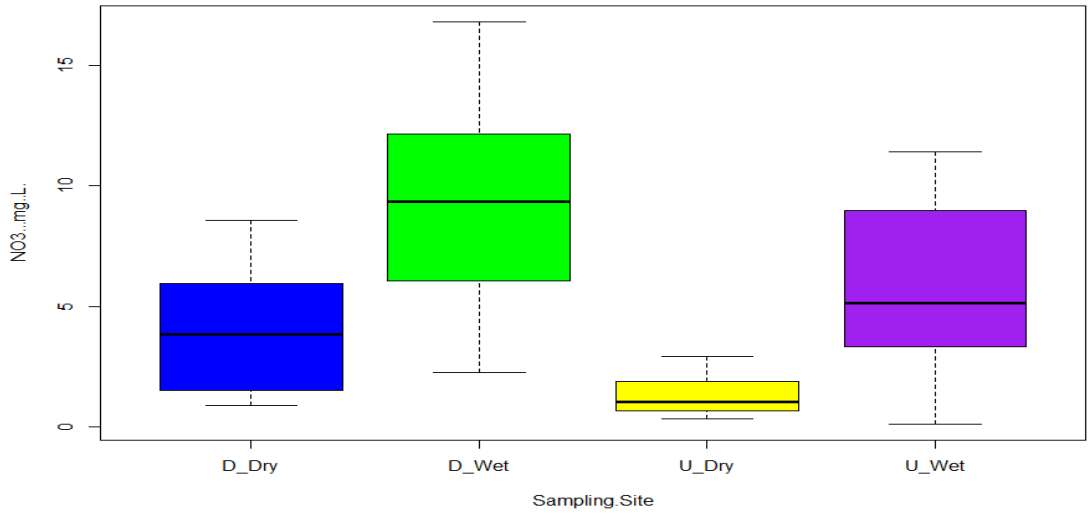


Figure 4.15: NO_3^- levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

4.2.13 Ammonium (NH_4^+)

The ammonium concentrations were in the range of 2.92 – 9.54 mg/l and 1.62 – 3.96 mg/l downstream sites respectively during wet and dry seasons. The results show that the results of the current study agree with findings reported by Yemane et al., 2015 and Ejeta et al., 2016. In the upstream sites, ammonium concentrations were in the range 1.08 – 8.10 mg/l and 0.72 – 2.88 mg/l respectively in wet and dry seasons. There was significant difference in NH_4^+ recorded in both periods (April and June seasons) (Figure 4.16). This difference could be attributed to the run off from agricultural areas.

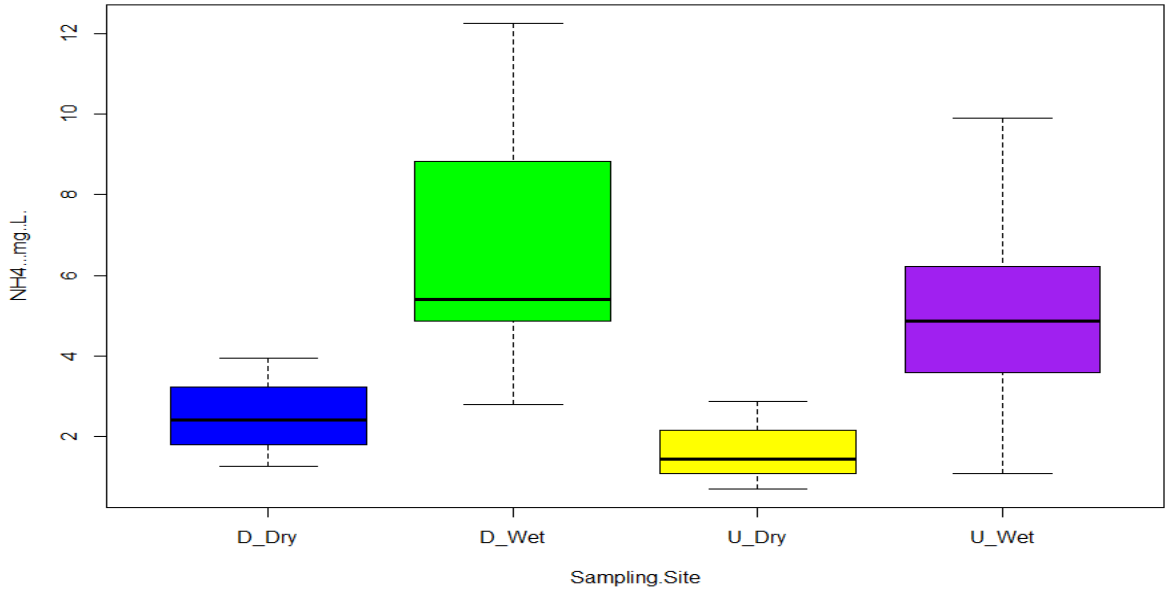


Figure 4.16: NH_4^+ levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

The general trend observed was increasing in Ammonium concentrations in downstream sites and this might be due to coffee wastewater effluents released from wet coffee processing factories in major coffee growing ecological zones in Burundi without any treatment (Bisekwa et al., 2020).

4.2.14 Nitrites (NO_2^-)

NO_2^- concentrations ranged between 0.05 – 0.39 mg/l with a mean of 0.18 ± 0.13 mg/l and 0.01 – 0.08 mg/l with a mean of 0.03 ± 0.02 mg/l at the downstream sites respectively during the months of April and June. Whereas at the upstream, Nitrites concentrations were almost below the limit of detection in Kayanza sampling sites. The increase in NO2- concentrations at downstream sites during Wet and dry seasons was due to the concentrations from wet coffee processing factories effluents in major coffee growing ecological zones in Burundi (Figure 4.17). The nitrites values of the samples

from all the sites were below the recommended WHO, 1999 standards and overall assessment criteria for river water quality (Annon, 1989).

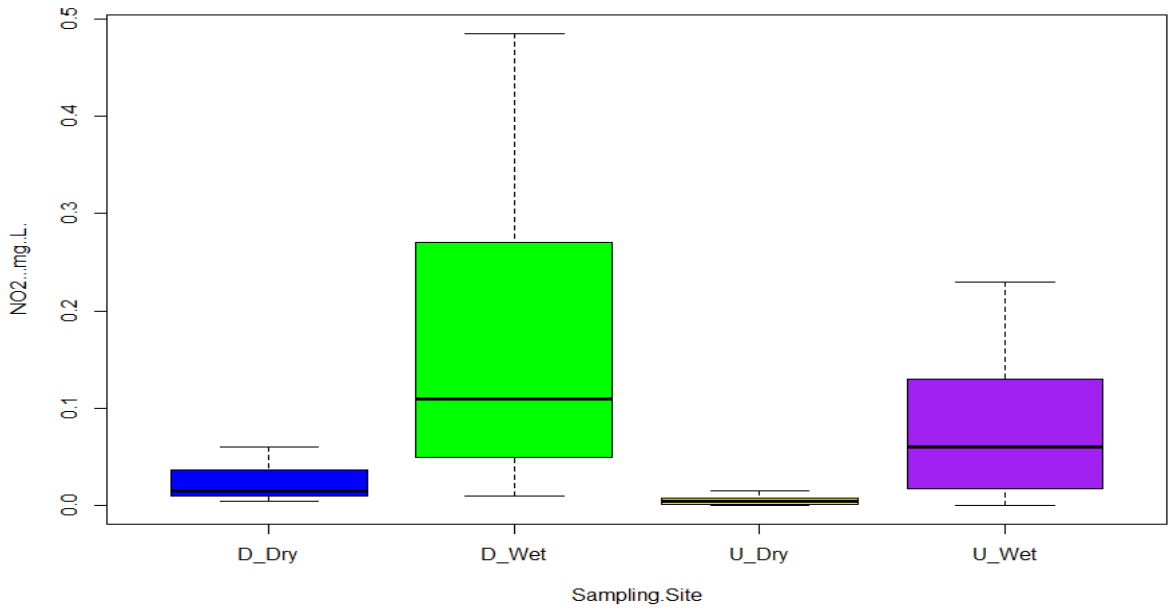


Figure 4.17: NO_2^- levels of water in rivers at upstream (U) and Downstream (D) of effluent discharge point.

There was no significant difference in nitrite recorded in both seasons (Wet and Dry seasons). This was due to conversion of the available nitrites during wet season to nitrates.

4.2.15 Dissolved Copper (Cu)

Copper is toxic to most of forms of aquatic life at relatively low concentrations. Increased quantities of copper make water distasteful to drink. The concentrations of copper (Cu) are presented (Tables 4.7, 4.9 and 4.11). The concentrations of Cu were within the permissible limit standards and overall assessment criteria for river water quality. In Kayanza growing ecological zone, the copper values for all the samples during dry season were below the limit of detection of AAS and thus below the limit

standards (MIWESPU, 2014). In this case, the coffee effluents (Tables 4.1, 4.2 and 4.3) from all locations did not contribute to increase in Cu levels in studied areas (Bisekwa et al., 2020).

4.2.16 Dissolved Lead (Pb)

Lead is a toxic element that accumulates in the skeletal structures. The toxic effects of Pb to fish decrease with increasing water hardness and dissolved oxygen (Njogu et al., 2011), (Orwa et al., 2014). Lead concentrations were below the Limit of Detection (LOD) of the AAS, both in the coffee processing wastewater (Bisekwa et al., 2020) and in river water samples from Up and down stream sites in both seasons (Wet and Dry seasons).

4.3 Optimization of a coffee wastewater treatment plant

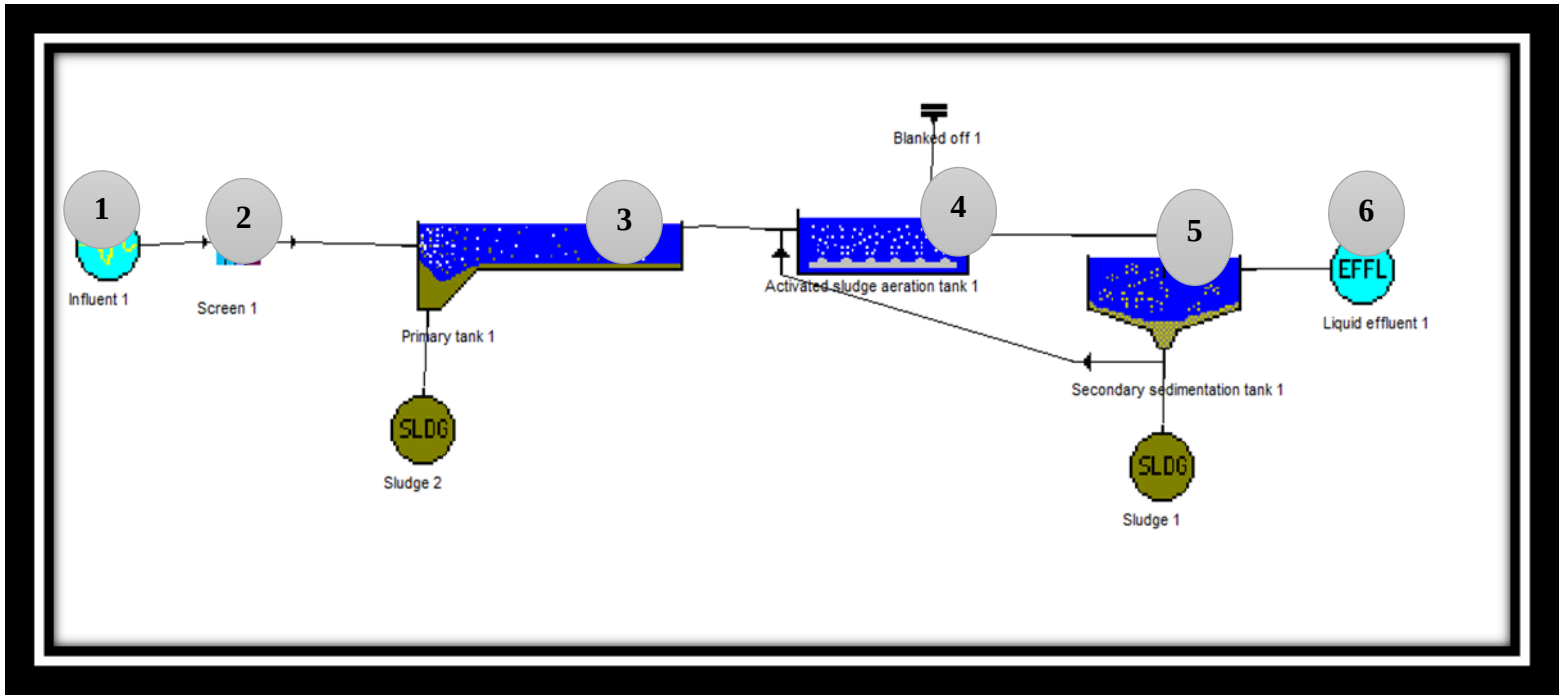


Figure 4.18: A schematic flow diagram for CWWTP activated sludge process representation in STOAT (source: Emile, 2020)

This process was composed by CWW influent (1) and flow divider to push CWW. CWW will pass through screening (2) and primary tank (3) to the Activated Sludge Aeration tank (4). After ASA Tank, the water will be channeled to the secondary sedimentation tank (5). After treatment, part of the water will return to the ASA Tank and other parts will be discharged (6).

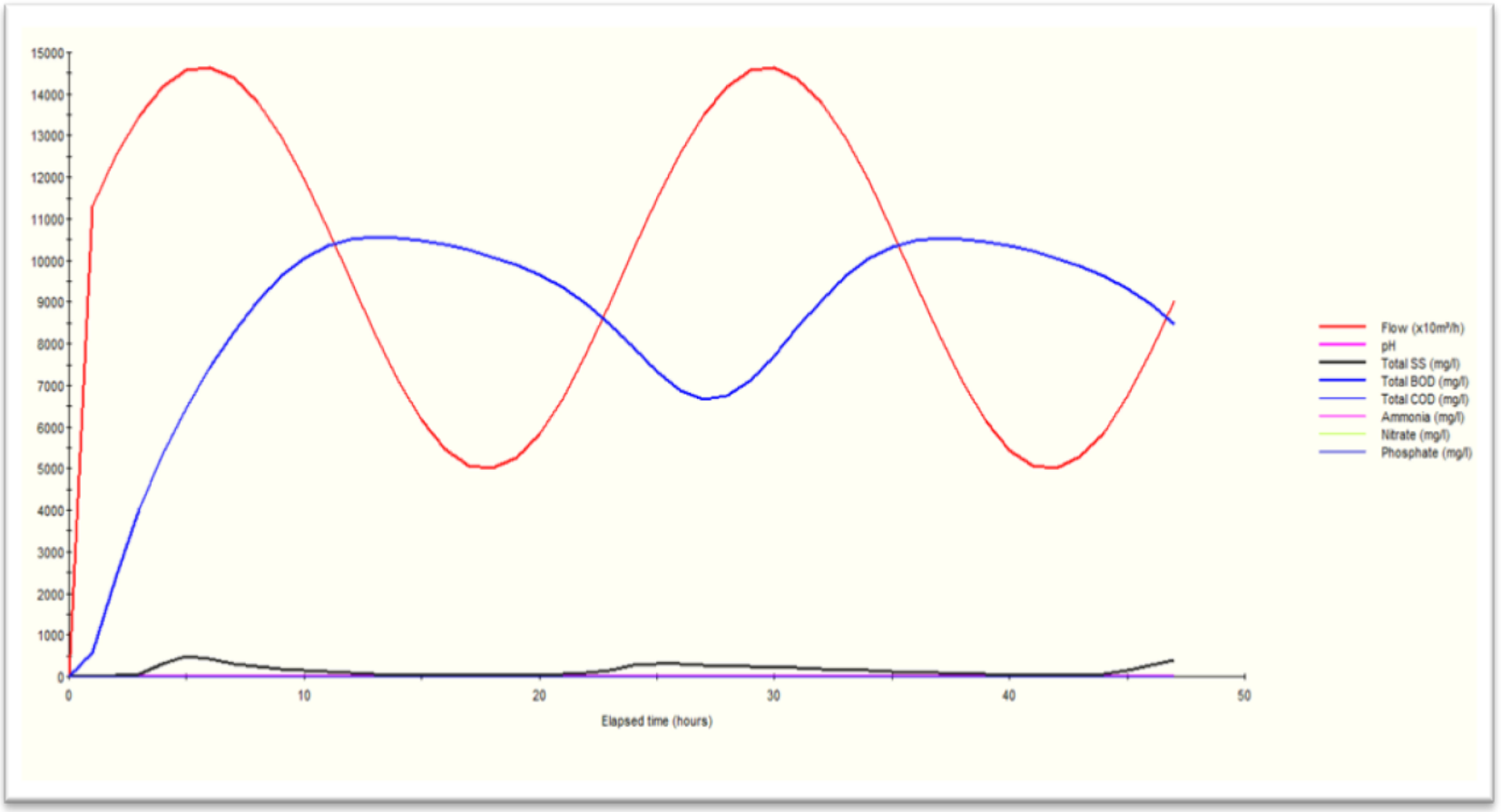


Figure 4.19: Show Effluent profile simulated by STOAT Software along 48h run time

As shown in the figure 4.19, the BOD_5 begins to drop after 24h, this gives an idea of the time required by ASA it will take to reach a suitable treatment level. TSS profile in the generated effluent shows that it has reached a steady state according to the ongoing treatment occurring in the ASA tank. The effluent profile as shown in the above figure reveals that significant biological treatment has been accomplished for both soluble and particulate biomasses along the time of stimulation run of 48hours. Figure 4.19 shows also that low levels of COD, Nitrate have been reached even at early hours of the simulation which means a successful removal was attained by the secondary settling tank of produced flocks in the aeration tank. Only BOD_5 took more time to be lowered in this proposed scheme, thus this module is reasonable as activated sludge biomaterials need a specific period to reach an efficient activity in treating the included soluble and suspended organic mass in the influent.

Table 4.12: Characteristics of influent and effluents generated from coffee wastewater treatment design

Item	pH	COD (mg/l)	BOD5 (mg/l)	TSS (mg/l)
Influent	4.19	16680	7806.4	1403.3
Effluent 1 (Treatment 1)	8.28	315.6	67.9	21.11
Effluent 2 (Treatment 2)	8.27	343.8	76.6	25.56
Effluent 3 (Treatment 3)	7.98	153	31.9	28.22
Maximum allowable limits	6 – 9	150	30	50

TSS of coffee effluent data before applying sand and gravel ranged from 1402 – 1404 mg/l with a mean of 1403.3 ± 12.2 mg/l and this concentration is much higher than the Burundi standards and the WHO, 1999 environmental allowable limits, while TSS effluent values were almost identical in all cases and acceptable when compared to the Burundi Standards (MIWESPU, 2014) and WHO, 1999 environmental requirement and were reported at 21.11mg/l, 25.56 mg/l and 28.22 mg/l respectively after the available substances (sand and gravel) were applied. The result show that the treatment efficiency

made by scheme 1 is satisfactory for TSS. This is in agreement with what was reported by Hayden, 2019.

pH influent values before applying ash and limestone were in the range of 4.14 – 4.29 with a mean of 4.19 ± 0.11 which is under Burundi Standards (MIWESPU, 2014) and WHO, 1999 environmental allowable limits. After applying limestone, ash and the combination of limestone and ash, the pH was almost identical and acceptable when compared to Burundi and WHO environmental requirement. pH effluent values were 8.28, 8.27, 7.79 respectively.

COD values before the available substances (Ash, Lime and Sulfate ferric) were applied ranged between 16667 – 17004 mg/l with a mean of 16880 ± 27.15 mg/l. After bubbling air through amended with 1% of lime, Fe_2SO_4 and limestone COD values ranged from 309.9 to 316.5 mg/l with a mean of 315.6 mg/l, these values were too high and not acceptable when compared to Burundi Standards (MIWESPU, 2014) and WHO, 1999 environmental requirement for coffee wastewater effluent discharged to surface water. COD effluent values ranged between 335.9 – 345.6 mg/l after applying 1% of lime and Fe_2SO_4 which was also higher.

After applying 1% of lime, 10g of Fe_2SO_4 and 200mg of Ash, COD values ranged between 150.1 – 153.9 mg/l with a mean of 153 ± 2.12 mg/l which is acceptable as compared to Burundi Standards (MIWESPU, 2014) and WHO, 1999 Environmental standards. It was speculated that saturated lime effluent under aerated conditions raise the water pH to around 8.0, which would have stimulated microbial activities, and this is in agreement the present findings. The results of microbial activities are a rapid conversion of organ carbon (BOD_5) to CO_2 (Hue et al., 2006).

Before applying Ash, Lime and Sulfate ferric in this study, the BOD_5 values ranged between 7800.2 – 7812.3 mg/l with a mean of 7806.4 ± 10.5 mg/l. BOD_5 removal proved higher efficiency when 1% of lime, 10g of Fe_2SO_4 and 200mg of Ash were applied. BOD_5 values ranged between 30.20 – 33.12 mg/l with a mean of 31.9 ± 0.95

mg/l which is acceptable according to Burundi and WHO standards. This finding is in agreement with what was reported by Hue et al. 2013 that 1% of lime helped reducing BOD_5 to less than 300 mg/l (Hue et al., 2006).

The existing technology was designed for the treatment of coffee effluent by filtration on the sand but the communication channel located between the filtration tank 1 and 2 (Figure 2.4) excludes the principal of purification by filtration. The liming operation was done in the wrong place (Figure 2.4_Tank 3), this operation should be done before the effluents entered the filtration tanks to raise the pH in the conditions favorable to the growth of microorganisms. However, the proposed design approach in this study, in which the activated sludge aeration tank conjugated with the secondary sedimentation tank is more convenient and achieved reasonable results.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the findings of this study, the physicochemical analysis of the coffee processing wastewater established that the parameters namely; pH, BOD_5, COD and TSS were much higher than the set standard by Burundi and WHO. It was also noted that the wet coffee processing factories in Kayanza, Gitega and Makamba coffee growing ecological zone contain large amounts of organic and nutrient load. The untreated wastewater is discharged directly into the nearby pits that are intended to serve as waste stabilization ponds but are neither appropriately constructed to accommodate the generated waste during peak processing time while some wet coffee factories discharge their effluent directly into nearby water bodies. This leads to overflow of raw effluents into natural watercourses and damages the surface waters and aquatic life. There is therefore a need to install and implement the appropriate wastewater treatment technologies in all the coffee processing factories to improve the quality of the wastewater to meet the discharge standards in order to protect the human health and the environment. The findings also show that Coffee wastewater discharged without any treatment contributes to the pollution of receiving water bodies. Therefore, the Coffee wastewater generated around the rivers was found to have a great negative impact on the receiving water bodies' quality, hence mitigation measures need to be put in place to protect the receiving water bodies from being polluted.

The simulated design looks to be a technically feasible scheme with respect to TSS, COD and BOD_5 profile in the coffee wastewater treatment plant. This scheme will be able to give considerable treatment efficiency and the implementation of this treatment model will help improving the quality of wastewater in order to protect the human health and the environment. In the future, there is need to check the efficiency removal of TSS, COD, BOD_5 and the adjustment of pH by doing more runs and analysis on different

criteria with help of STOAT Software. Behind this wastewater treatment design five perspectives of clean technology are proposed as support measures in the success of wastewater treatment in the processing of cherry coffee in Burundi: Save water upstream and the possibility of recycling water, Pricing of water used, Energy recovery, Reuse of treated wastewater in small-scale agriculture, integrated water resources management (IWRM) approach.

5.2 Recommendation

Results of the present study can be used by policy makers to come up with polies and strategies to protect the environment and the quality of receiving water bodies. With increased wet coffee processing factories activities within the major coffee growing ecological zones, the organic load, suspended matter and pollutants entering the receiving water bodies will continue to increase and further diminish the quality of water of the various water bodies. Introduction of cost-effective, cleaner production technologies must be enforced, such as on-site waste separation and reduction, and effluent recycling.

It is therefore recommended that inappropriate disposal of the coffee wastes should be discouraged and there is need for each wet coffee processing factory to install and implement a wastewater treatment plant with a view to treat the wastewater before being discharged into the nearby rivers, streams and open lands. It thus becomes important to carry out Environmental Impact Assessment (EIA) for any proposed wet coffee processing plants and Environmental Audits for existing factories

I suggest that the Ministry of the Environment, Agriculture and Livestock, which has the prerogatives, to take adequate measures to protect the rivers which continue to suffer from heavy pollution during the coffee season. Given the physicochemical characteristics of coffee effluents and the inefficiency of treatment systems, this ministry must increase awareness among stakeholders in the coffee sector and collaborate with the regulatory authority for the coffee sector to limit the multiplicity of wet coffee

processing plants without the power to treat wastewater and respect environmental standards.

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APPENDICES

Appendix I: Publication 1 Abstract

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RESEARCH ARTICLE
Volume 6 - Issue 3

Effluent Quality of Wet Process Coffee Processing Factories in Coffee Growing Ecological Zones in Burundi

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Abstract

Arabica coffee is cultivated by smallholders for commercial purposes, and it is commonly processed using wet Coffee Processing Technology. Burundi has more than 250 Coffee Processing factories which discharge their effluents to water bodies. The goal of this study was to determine the levels of physicochemical parameters in wastewater from Coffee Processing Technology factories in major coffee growing ecological zones in Burundi. Wastewater samples were collected from 19 sites representing private, public and cooperative owned coffee processing stations. Physicochemical analyses were determined in-situ field and laboratory conditions using standard procedures. Results indicate that the wastewater does not meet Burundi Effluent Discharge standards for Total Suspended solids, Chemical Oxygen Demand, Biochemical Oxygen Demand, pH. The data revealed that the wet coffee processing pollutes the environment in terms of pH, Total Suspended solids, Chemical Oxygen Demand, Biochemical Oxygen Demand. There is need to install quality polishing technologies to treat the water before disposal.

Keywords: Water pollution; BOD_5; Effluent quality; Wastewater; Wet coffee processing

https://sciforschenonline.org/journals/water-and-waste/IJWWT176.php.

Appendix I: Publication 2 Abstract

Scientific Research Publishing

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Wet Coffee Processing Discharges Affecting Quality of River Water at Kayanza Ecological Zone, Burundi

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Abstract

Wet coffee processing leads to the generation of large volumes of wastewater, whose discharge to the environment leads to pollution of freshwater bodies. Kayanza is a major coffee growing area in Burundi with more than 40 wet coffee processing factories (WCPF) that discharge effluents directly to receiving water bodies without treatment. This study was carried out to assess the effect of coffee wastewater on the physicochemical properties of receiving waterbodies in Kayanza coffee growing ecological zone. Currently, no study has been done to analyze the effluent from the WCPF and assess the level of pollution. This study will therefore provide valuable data on the water pollution from coffee processing plants. Ten (10) rivers in the Kayanza coffee growing zone were studied during the months of April and June, 2020. Water samples were collected upstream (U) and downstream (D) of the effluent discharge points in triplicate. Samples were analyzed for pH, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD_5), Temperature, Salinity, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Total Suspended Solids (TSS), Nitrates, Nitrites, Lead (Pb), Copper (Cu), Chlorides and Ammonium ions using standard methods. Physical parameters were analyzed in situ whereas chemical parameters were analyzed in the laboratories in Burundi Institute of Agricultural Sciences (ISABU) and University of Burundi. Data were analyzed using R-studio-1.0.153, GenStat 64-bit Release 14.1 and SSPS. Results on the physicochemical parameters indicated that coffee factory effluent has a polluting potential during coffee processing peak. The concentrations of the physicochemical parameters were significantly ($p < 0.05$) higher downstream (D) compared to upstream (U) of the river water sampling points. All downstream sites had

COD, BOD_5, TSS and pH values above allowable limits set by WHO and Burundi. The polluting impact of public wet coffee processing factories was significantly higher than that of private and cooperatives owned factories ($p < 0.05$). Measures should be taken in order to protect water bodies.

Keywords

Wastewater, Water Pollution, Kayanza Zone, Wet Coffee Processing