# INVESTIGATING THE IMPACT OF RUTI ABATTOIR WASTEWATER EFFLUENT ON RIVER RWIZI WATER QUALITY

**BY**

**ATUGASHA DEN**

**(B. Eng. in Env. Eng. and Mgt, KYU)**

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# DECLARATION

I, *Atugasha Den*, hereby declare that this submission is my own work and that to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree of the university or other institute of higher learning except where due acknowledgement has been made in the text and reference list.

**Atugasha Den**

Signed: …………………………………… Date: …………………………….

# APPROVAL

The undersigned hereby approve that they have read and hereby recommend for submission to the Directorate of Research and Graduate Training of Kyambogo University, a dissertation titled “Investigating the Impact of Ruti Abattoir Wastewater Effluent on River Rwizi Water Quality” in fulfilment of the requirements for the degree of Master of Science in Water and Sanitation Engineering of Kyambogo University.

**Principal Supervisor**

Dr. Charles Onyutha

Signature: ………………………… Date: ……………………………

**Co-Supervisor**

Dr. Anne Nakagiri

Signature: ………………………… Date: ……………………………

**Co-Supervisor**

Dr. Japheth Kwiringira

Signature: …………………………. Date: ……………………………

# DEDICATION

To my family, parents and my brothers who have made tremendous contributions towards my education and up bringing up to now.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| BOD | Biochemical Oxygen Demand |
| CARPT | Computed Radioactive Particle Tracking |
| COD | Chemical Oxygen Demand |
| CW | Constructed Wetland |
| IAEA | International Atomic Energy Agency |
| NEMA | National Environment Management Authority |
| OECD-FAO | Organization for Economic Co-operation and Development and Food Agriculture Organization |
| PET | Position Emission Tomography |
| RMAA | Red Meat Abattoir Association |
| SDG | Sustainable Development Goal |
| SPECT | Single Photon Emission Computed Tomography |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| UBOS | Uganda Bureau of Statistics |
| UN | United Nations |
| UNFPA | United Nations Fund for Population Activities |
| WHO | World Health Organization |
| WSP | Wastewater Stabilization Pond |
| NWSC | National Water and Sewerage Corporation |

# ABSTRACT

The rapid population growth in developing countries including Uganda has increased food demand leading to high demand of meat from abattoirs. The abattoirs generate substantial amounts of solid waste and wastewater effluent during their operations. The discharge of untreated abattoir effluents into the environment leads to water pollution due to the high organic load to the environment. This study aimed at investigating the impact of Ruti abattoir wastewater effluent on the water quality of River Rwizi. Water samples were collected at the abattoir, downstream and upstream the point where the abattoir effluent enters River Rwizi. The samples were tested for total nitrogen and phosphorus, biological oxygen demand (BOD) and chemical oxygen demand (COD). Heavy metals such as nickel, arsenic, copper, chromium, iron, and mercury were also tested. The abattoir wastewater to open environment and flows to River Rwizi that increases COD levels of river water. The mean COD values at the abattoir 604.9±153.9 mg/l, upstream 83.0±3.1mg/l and downstream 252.3±61.4 mg/l. The COD level was above the National Environment Management Authority recommended water quality limit of 70mg/L. The use of raw and activated carbonised rice husks for the treatment of nitrate phosphate-polluted water studied. COD removal efficiencies increased with increase in contact time 5, 15 and 20 minutes were 79, 88, and 91%, respectively. Furthermore, COD efficiencies for dosages 1, 2, 3, 4 and 5 g were 52, 65, 72, 74 and 91% respectively. Secondly, carbonised activated rice husks at dosage of 5 g and 20 minutes contact time in reducing COD. The study calls on the abattoir to improve on their wastewater management techniques and community to improve on existing water treatment methods used.

**Keywords:** Abattoir Effluent, River Rwizi and Water Quality.

# CHAPTER ONE: INTRODUCTION

## 1.1 Background

Meat and its products are important component of diet and in developed countries consumption of meat as source of protein per person is too high. In developing countries, abattoir meat production is increasing due to influence in meat consumption. However, abattoir has other terms meaning the same and those slaughterhouses or meat packing plants. Globally, meat production generates significant wastewater, with countries like Brazil and the USA being major contributors (Bustillo-Lecompte and Mehrvar, 2017).

According to United Nations Fund for Population Activities UNFPA (2019), there is high population growth in developing countries. Uganda's population growth rate is high, estimated at 3.0% with a population of 34.6 million in the 2014 national census, (Uganda Bureau of Statistics UBOS, 2016). Mbarara City has population of 195,318 people UBOS, 2017) with estimate of increase to 216,800 people in 2019 (UBOS web, 2020). To meet the high demand for food to sustain this increasing population, several livestock are slaughtered at abattoirs that generate both solid and waste such as blood, Untreated wastewater, nutrients, proteins.

Abattoir activities pollute both surface and ground water which indirectly affect human health using water sources (Odoemelan and Ajunwa, 2008; Patra *et al*., 2007); Raymond 1977). Abattoirs effluents discharged in open environment led to water pollution due depletion of oxygen which is attributed to large quantities of organic load Olayinke *et al*., 2013). The effects of the abattoir effluents on water quality depend on the protection of water resources. Globally the abattoir wastewater management is challenge because of their pollution potential in india (Rajpal *et al*., 2022). In developing countries like in sub-Saharan region, water resource protection is poor. This could be why there have been many studies on abattoir effluent on water quality for instance in Ghana (Weobong and Adinyira 2011; Adonu *et al*., 2017) and in Nigeria (Omole and Ogbiye, 2013; Okoye *et al*., 2018; Bello and Oyedemi, 2009; Gana and Emigilati, 2019). It is also possible that even for other developing countries like Uganda, the abattoirs are severely influencing water quality as found out by (Alinaitwe, 2019; Odongo *et al*. 2013; Shukri, 2018). The abattoir effluent could be a threat to Uganda and most Mbarara communities drawing water from River Rwizi since there is lack of adequate treatment of abattoir effluents, high population growth rate (UBOS, 2016).

According to Uganda Vision 2040, most communities should be accessing safe drinking water in Uganda. Access to safe drinking water at affordable rate according United Nations, UN (2015) committed on improving water quality in Sustainable Development Goal (SDG) by 2030 by reducing pollution, dumping and hazardous chemical material and reducing by half of untreated wastewater and sustainably promote recycling and safely reuse worldwide. Human activities generate wastewater that is environmentally harmful when not handled well and can cause diseases due to pathogenic organisms, viruses or bacteria, lead to oxygen depletion in water bodies like shallow wells, rivers and lakes that are loaded with wastewater containing chemicals and heavy metals from factories. Enrichment of natural water with salts that result into abnormal growth of plants and algae causes Odour (Sen *et al*., 2013). Wastewater must be treated before discharging to the environment and if untreated it contaminates water bodies. Abattoir wastewater effluent increases bacteriological quality in streams according Seiyaboh and Izah (2017) hence harmful to human health when stream water is consumed without being treated.

Abattoir effluents are loaded with organic matter s like bacteria pathogens (Jega *et al*., 2018; Iweriolor and Anyiam, 2023), nitrates, phosphates and suspended solids that have high oxygen demand for their biochemical degradation (Olanyika *et al*., 2013). Wastewater infiltrates into the ground and some is washed away by storm water to nearby water sources, which contaminate water source points, which are adjacent to abattoirs. The treatment methods, which are available for abattoir effluent, are stabilization ponds, septic tanks and soak away pits, natural treatment systems like swamps and other plants during their development cycle. This research focused on assessing the impacts of abattoir effluent on quality of water for human consumption. River Rwizi water quality was investigated by characterizing water chemical component.

## 1.2 Statement of problem

Mbarara City has population growth rate of 8.6% according to Census 2014 with population of 195,013 people (UBOS, 2017) and estimated to be 216,800 people in 2019, (UBOS, web 2020). The high population in Mbarara city has led to sharp increase in demand of meat products, which has subsequently increased the number of livestock slaughtered daily at Ruti abattoir leading to increased wastewater generation. The average number of sheep, cows, goats slaughtered daily are averagely 25, 37 and 61 respectively according to abattoir records. The Ruti abattoir wastewater is partially treated on site using septic tank, which removes suspended solid. Septic tanks have low efficiency of 30% (Bustillo LeCompte and Mehvar, 2017) of Biochemical Oxygen Demand (BOD) and sludge production of 5-20% on abattoir effluent (Bustillo LeCompte and Mehvar, 2015). Effluent after Septic tanks need post further treatment before discharging to meet the Uganda national standards regulated by National Environment Management Authority (NEMA) limits due to the complexity of organic matter strength effluent (Bustillo LeCompte and Mehvar, 2015). The composition of organic matter is Total Nitrogen (TN), Total Phosphorus (TP) pathogenic matter, (Bustillo LeCompte and Mehvar, 2015). This makes River Rwizi surface water not safe for home consumption/drinking which contravenes with water United Nation (UN), Sustainable Development Goal (SDG), and 2030 goal 6 of access to safe drinking water since poor communities living along the riverbanks fetch water from River Rwizi.

Abattoir effluent cause chest pain, respiratory diseases and outbreak of water borne diseases (Jega *et al*., 2018) after drinking water contaminated by effluent. However, post treatment of wastewater using constructed wetlands have high organic matter strength of 78.2, 99.9, 97.4% removal of TN, BOD, COD, from abattoir effluent respectively (Odongo *et al*., 2015). River Rwizi Mean dissolved oxygen (DO) levels range between 31.40 to 55.73 mg/l (Atwebembeire *et al*., 2018). These levels are above NEMA recommended level of 5 mg/l. Abattoir effluent have very high E. coli counts (Businge *et al*., 2021). Rice husks are easy to operate and do not require skilled labour. Rice husks will help wastewater treatment thus improving, thus River Rwizi surface water quality as a source for human consumption hence improving the public health of communities.

## 1.3 Objectives

### *1.3.1 General objective*

The main objective was to investigate the impact of Ruti abattoir wastewater effluent on River Rwizi water quality.

### *1.3.2 Specific objectives*

i) To assess wastewater effluent management at Ruti abattoir.

ii) To characterise the quality of wastewater effluent generated at Ruti abattoir.

iii) To quantify the impact of Ruti abattoir effluent on River Rwizi water quality.

iv) To explore a cheaper method of treating wastewater from Ruti abattoir.

## 1.4 Research questions

The research questions were as follows:

i) What is the wastewater effluent management practiced at Ruti abattoir?

ii) What are the characteristics of the Ruti abattoir wastewater effluent?

iii) To what extent does the Ruti abattoir effluent impact the quality of River Rwizi?

iv) To what extent can raw and activated rice husks treat wastewater from abattoir?

## 1.5 Justification

There is high volume of wastewater generated at Ruti abattoir during animal slaughtering process. Abattoir discharge wastewater to open environment and drain into River Rwizi when it is partially treated. High organic load in abattoir wastewater pollutes rivers and streams (Olayinka *et al.*, 2013) making River Rwizi unsafe source of drinking water downstream. Human health of Mbarara communities drawing water from river is threatened and environment degraded because of surface run off into River Rwizi when it rains. Safe drinking water quality is important for human health (WHO, 2011) and the environment, hence a need to determine River Rwizi the water quality which acts as water source for communities living along the river.

## 1.6 Significance

i) The research focused on gaps in sanitation and wastewater effluent management at the abattoirs.

ii) The general aesthetics at abattoir and public health of the communities around the abattoirs will be improved

iii) Further, the research results will motivate abattoir authorities to improve on their wastewater effluent management and treatment will improve River Rwizi water quality by reducing on contamination from point source.

iv) The environment will also be safe for workers and surrounding communities. Develop cheaper and affordable water treatment method used by local communities living along River Rwizi.

## 1.7 Scope of the study

### *1.7.1 Time scope*

The research started in August 2019 and ended in November 2025

### *1.7.2 Geographical scope*

This research study done at the Ruti abattoir is the largest abattoir in the area and River Rwizi both located in Ruti Ward, Southern Division, Mbarara city. This study focused on investigating the impact of Ruti abattoir effluent discharge on River Rwizi water quality. Ruti abattoir discharge off partially treated abattoir effluents to open environment that flows into River Rwizi that is located on lower end of the abattoir.

### *1.7.3 Content scope*

Water quality characterized by analyzing for different elements in effluent and river water both upstream and downstream. However, more focus was on quality of effluent discharged at the abattoir into River Rwizi and how the river water was for human consumption.

## 1.8. Conceptual framework of the study

The independent variables form the core operational inputs of Ruti Abattoir that are the primary sources of potential pollution. These factors include the scale of production, measured by the number of animals slaughtered per day, and the volume of water used in the process. Together, these variables determine the fundamental amount of organic waste (such as blood, fat, and gut contents) and the total volume of wastewater generated. The most critical independent variable, however, is the wastewater effluent treatment method employed by the abattoir. This represents the key intervention point, as the choice and efficacy of this treatment process directly dictate the concentration of pollutants before the effluent is released into the environment.

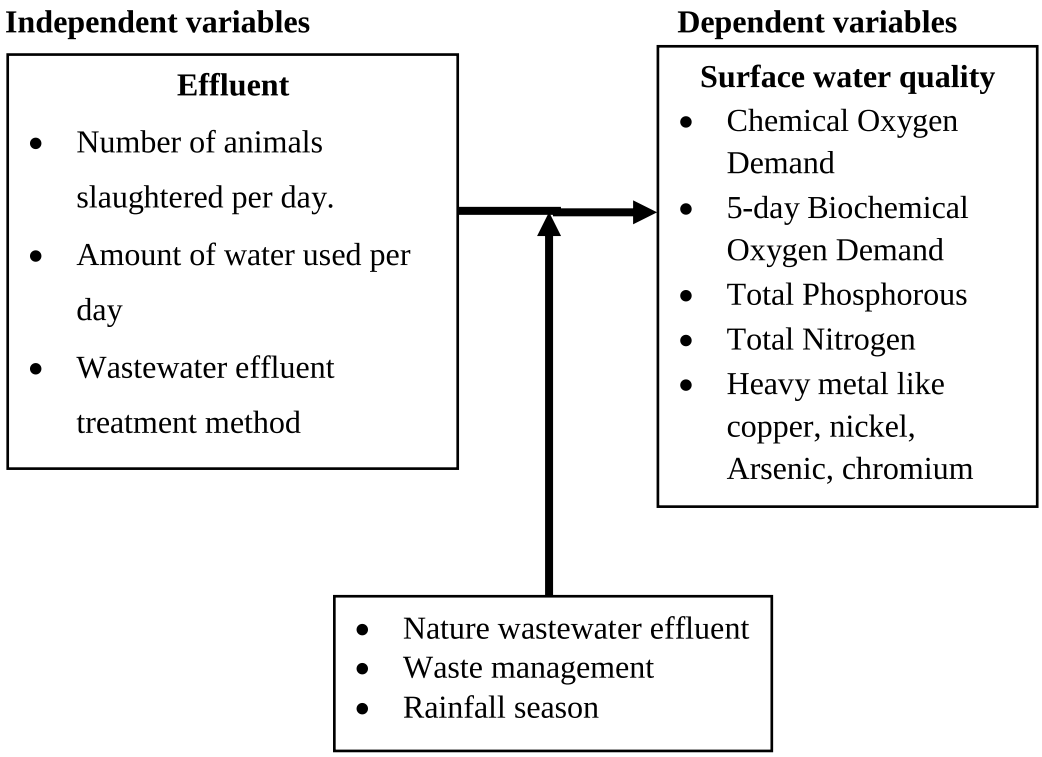

**Figure 1.1:** Conceptual framework.

The dependent variable is the resultant surface water quality of River Rwizi, which is the central outcome this study seeks to measure and understand. This variable is operationalized through specific physicochemical parameters that serve as indicators of pollution. These include measures of organic load, such as Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD), which signify the oxygen-depleting potential of the waste. Furthermore, nutrient levels like Total Nitrogen and Total Phosphorous are measured to assess the risk of eutrophication, while the presence and concentration of heavy metals like copper, arsenic, and mercury are analyzed to evaluate toxicological risks to aquatic life and human health.

Mediating variables are contextual factors that can influence or modify the strength of the relationship between the abattoir effluent and the River Rwizi water quality. The inherent nature of the wastewater itself, such as its strength and chemical composition, affects its polluting potential. Furthermore, the abattoir's broader waste management practices, including solid waste handling and spill prevention, can contribute additional pollutants that exacerbate the wastewater's impact. Finally, external factors like rainfall season play a crucial role; heavy rains can cause runoff that washes pollutants into the river, while dry seasons may result in a more concentrated effluent discharge due to lower river flow rates, thereby intensifying the impact.

# CHAPTER TWO: LITERATURE REVIEW

## 2.0 Introduction

This chapter reviewed abattoir waste, slaughterhouse wastewater generation, and waste management, wastewater treatment processes in abattoir and wastewater treatment methods, policies, regulations and standards for discharge of effluent into the environment.

## 2.1 Abattoir waste

Abattoir waste is a collection of bi-products at the abattoir. Abattoir waste is generated by slaughterhouse operation activities for the purposes of recovering edible parts of slaughtered animals consumed by human beings as food. The process of animal slaughtering, lead to generation of significant amount of both solid and liquid waste. The solid wastes are both organic and inorganic such as bones, horns and liquid waste include dissolved solids, urine, blood, and cleaning water. Abattoir operations potentially pollute both surface and ground water (Patra *et al*., 2007) which indirectly negatively impact on the health of the people sourcing water from nearby water sources.

A study by Bello and Oyedemi (2009) on impacts of abattoir activities and management in residential neighbourhoods in Ogbomoso, Nigeria revealed that abattoir operations negatively affect health and life quality of people living in proximity.  This is associated with meat and by- products of abattoir due to food borne diseases. The bi-products differ for different animals slaughtered at the abattoir for example for cattle and sheep are 66% and 68% of their live weight (Jayathilakan *et al*., 2012).

Abattoirs are major contributor to water pollution sources such as surface and ground water sources. Based on Red Meat Abattoir Association (RMAA, 2010), South Africa water-scarcity in the country and projections indicated that in 2020 water demand was equivalent to supply. Water quality was contamination by abattoir wastewater.  Abattoirs use large amounts of water on a daily basis and 84% of water used was discharged as wastewater (RMAA, 2010). These abattoirs consume a lot of water for sanitation purposes like cleaning meat, offal and floor of the slaughterhouse resulting into significant amount of wastewater.

According to Chukwu *et al*., (2011) physico-chemical properties of abattoir wastewater contaminate streams, which make water source reduce its importance to human due to organic load.  Abattoir wastewater characteristics are suitable for biological treatment. Generating bio-energy consumes large quantity of wastewater. Alternative methods are necessary to reuse or treat wastewater to extract electric and bio-energy. The feathers contain 86.53% of crude protein that is important for feed formulation (Al-Munimm, 2021). DARD (2009) identified different purposes of bi-products, based on their significance to agro-industrial as shown in the table 2.1.

**Table 2. 1:** Different groups of abattoir waste with its by-products and their industrial uses.

| **Group** | **By-product** | **Use** |
|---|---|---|
| Soft organs | stomachs, offals, lungs, carcass trimmings, reproductive structures, floor sweepings, drainage trappings, condemned meat | meat/bone meal;<br>feeding to crocodiles |
| Hard organs | horn and hoof | Horn/hoof meal, fertilizer, pet-chew toys, gelatine |
| Blood | Blood | Blood meal, used in animal feed |
| Gut contents and manure | Gut contents and manure | compost or fertilizer;<br>Biogas production. |
| Feathers / pig hair | Feathers / pig hair | Protein meals |

***Source: Department of Agriculture and Rural Development SA, 2009***

Some researchers indicated that abattoir operations have a pollution impact on both surface and groundwater and has negative impact on air quality that has a potential health impact to residents who live in proximity of the abattoirs (Odoemelan and Ajunwa, 2008; Patra *et al.*, 2007; Raymond, 1977). Water pollution influences the life of the inhabitants such as fish, which directly affects the fish yield, which significantly affects the human diet (Aina and Adedipe, 1991). The discharge of untreated abattoir wastewater to the streams depletes oxygen. Streams enriched with nutrients, which rapidly increase toxification of the systems (Nwachukwu *et al.*, 2011). The impact lead to outbreak of human diseases like respiratory, chest and water borne diseases (Mohammed and Mus, 2012).

Abattoir waste disposal in Uganda is one a major challenge on their operation. Wastes generated at abattoir are disposed of without following proper discharge procedure, which make the wastes significantly harmful to humans and aquatic life. Studies in Nigeria and Ghana have indicated that abattoirs often discharge untreated wastewater directly into the environment, sometimes polluting water bodies used by communities (Gana and Emigilati, 2019; Omole and Ogbiye, 2013).

In Uganda, the increase in meat demand has directly increased its production and has potentially increased the amount of wastewater effluent produced at the abattoir thus influencing the concerns about the current situation. Abattoir effluent is highly polluted (Weobong and Adinyira, 2011). The effluent discharge chemical and physical properties discharge standards issued by NEMA under National Environment Act, Cap 181 formally known as National Environment Act, (2019) considers the National Environmental (Standards for Discharge of Effluent into Water and Land) Regulation, 2020. The community near abattoir complains of the effluent discharged without proper treatment, and pollution of their water sources among others. Carcasses handling throughout the processes of preparation and transportation to markets are critical concern to human health after consumption.

## 2.2 Global red meat industry

Animals are slaughtered in large numbers in Mbarara City due to increase in demand for meat products from the constantly increasing population. The increase in production of meat processes has led to increased constant pollution (Akinro *et al*., 2009).

The Department of Agriculture, Fisheries and Forestry, South Africa (DAFF, 2012) discovered that livestock is growing so fast and contributes 40% of the world's agriculture sector. Most people depend on livestock in agricultural sector as source of income and food security and most of the valuable assets depend on animals as credit security and a storage of wealth.

### 2.3 Abattoir waste management

Roberts and De Jager (2008) designed a four-process model of waste management as shown in Figure 2.1.

a. **Blood:** The hygiene of slaughtering animals using a hollow knife significantly reduce the contamination and the blood collected and used as food such as sausages for human, animal feed and fertilizers for farming.
b. **Stomach contents:** Roberts and De Jager (2008), these contents are disposed of by burying them in pits. Other stomach waste disposal methods are landfill sites or using them as fertilizers in fields.
c. **Wastewater:** Untreated wastewater is discharged into open environment and municipal drainage systems or used to irrigate gardens. Treated wastewater is recycled and used for cleaning the abattoir.
d. **Condemned parts:** These parts include bones and carcass, hooves; horns can be as animal feeds, crafts and raw material for button industries respectively.

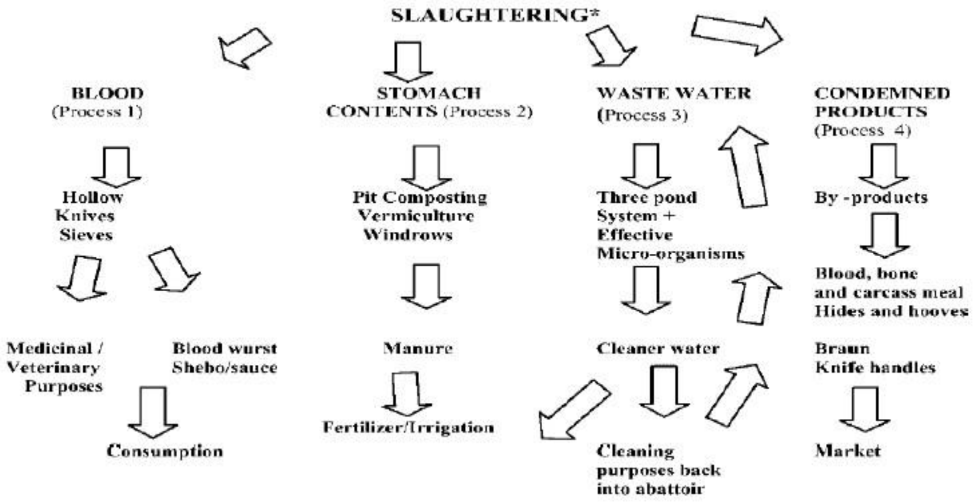

**Figure 2.1:** Waste Management Model for Red Meat Abattoirs.

*Source: Roberts and De Jager (2008)*

### 2.4 Slaughtering and processing of meat

The animal slaughtering is automated more efficient over the few years. Some improvement happened in skin and hide removal, stunning evisceration and part separation techniques. COWI (2000) categorised cattle slaughtering and processing as;

Pre-handling of cattle brought at abattoirs in trucks and kept in holdings section before slaughtering them.

Stunning and bleeding of cattle are done in slaughter zone before stunning them with either electric shock or a bolt pistol. The hides are removed by hoisting them with hide legs. Bleeding, sticking, then takes place, with the blood collected in a trough for disposal or for further processing.

Dressing and hide removal, the bled carcasses are conveyed to the slaughter hall where dressing and evisceration take place. The carcasses are hanged and laid in cradle. Hooves and head are removed. Water is used to clean the head where some meat, tongue and brain are separated and recovered. Hides are preserved using salt.

Evisceration process is where paunch and intestines are cleaned for manure and more processing. Offals are split, cleaned with water and conveyed to storage zone.

Carcass cutting and boning are done when they are chilled for easy handling. Boning is a process of separating meat from bones. Recent technological developments have made boning when still warm and this process is called hot boning (Ponnampalam and Holman, 2023).

Carcasses and viscera are checked for their suitability to be used as food for human. Carcass and components are kept together till inspections are finished.

During the process of boning and cutting inedible parts like fats, hair, bones and condemned offal are generated. The generated inedible parts are used as animal feeds and others are sent to factories to process them into feeds (Aniebo *et al*., 2009).

### *2.4.1 Slaughterhouse wastewater*

The slaughterhouse wastewater has steadily been increasing in past years (Aleksić *et al*., 2020) due to high demand of meat. According to OECD/FAO (2023) projected increased meat demand grew for chicken, mutton, beef and pork in 2032 by 15, 15, 11 and 10%, respectively on the market. The global annual consumption will be at 35.3kgs per capita in 2025 (OECDFAO, 2016).

Most abattoirs generate wastewater during cleaning process, both before and after slaughter of animal, cleaning of floor and equipment used during slaughtering process. Water used for cleaning carcass differ depending on the animal being slaughtered e.g. 1.6 - 9.0 $m^3$/tonne for cattle, and 5.6 - 8.3 $m^3$/tonne for sheep (European Emission, 2005).

In Uganda, most cattle slaughtered have pathogenic *Leptospira* species (Alinaitwe *et al*. 2019). Pathogens increase in animals (Maizatul *et al*., 2017). These constitute a health hazard and appropriate treatment and disposal of wastewater must consider its hazard. The need to remove pathogens should therefore be borne in mind when selecting the type of treatment system to install. Wastewater effluent constitutes high level of organic matter, oil and grease, and nitrogenous compounds (Sirianuntapiboon and Yammer, 2006) in terms of COD of 1,000-10,000 mg/L, $BOD_5$ of 1,000-8,000 mg/L, Total Nitrogen (TN) of 100–800 mg/L.

### *2.4.2 Pollutant transport monitoring*

Tracers are characterized by physical, biological and atomic properties. Tracers are widely used to measure the amount of flow rate of gas, liquids and solids. Radioactive tracers are used in industrial reactor diagnosis because of their chemical property of having more than one isotope. Radioactive tracers are used to visualize the flow in wide range of technologies like Position Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT) and Computed Radioactive Particle Tracking (CARPT). Tracers are used in quantifying the quality of substances (IAEA, 2012). Dyer tracers Lithium

(LiBr) is good in solid materials and Brilliant Blue FCF are conservative tracers in water samples for its simplicity (Rosqvist and Bendz, 1999).

### *2.4.3 Pollutant characterization*

Slaughterhouse wastewater produced during meat processing are categorized as harmful because of their complex composition in nature of fibers, proteins, fats, high organic contents, pathogens, and veterinary pharmaceuticals (Bustillo-Lecompte and Mehrvar, 2017). Slaughterhouse effluents have almost same characteristics as municipal sewage (Damaceno *et al.*, 2019). The wastewater threatens aquatic life and leads to microbiological contamination due to algal bloom that reduces oxygen in water bodies. Findings from this current study indicate that the meat processing has a potential to worsen scarcity of clean water availability, thereby adversely affecting the range of uses of such water bodies (Tekenah *et al.*, 2014). Arsenic in water bodies leads to increase in microbes and cause cancer and skin diseases (Adesiyan *et al.*, 2018).

## 2.5 Wastewater treatment process in abattoirs

Most slaughtering houses require specialized treatment processes with respect to handling their effluent before releasing it to the environment. The abattoir wastewater handling and treatment is subject to National Environmental Act, Cap181 and National Environment (Standards for Discharge of Effluent into Water or Land) Regulations 2020. Conventionally there are three stages involved in wastewater treatment and this includes primary, secondary, tertiary, and treatment (Mareddy, 2017).

Primary Treatment consists of temporarily holding the effluent in a quiescent basin where heavy solids can settle to the bottom while oil, grease and lighter solids float to the surface. The heavy particulates settle and weak float on top. They are removed before discharging wastewater for secondary treatment. It involves the following processes; screening, grit removal and oil/grease trapping ( Hegazy *et al.*, 2025).

Secondary Treatment includes the removal of dissolved and suspended biological matter. Secondary treatment done by bacterial and other water-borne microorganisms. Secondary treatment involves chemical treatment e.g. Chlorination to remove the microorganisms from the treated water prior to discharge or tertiary treatment (Darra *et al.,* 2023).

Tertiary Treatment is treatment beyond primary and secondary treatment to allow discharge into sensitive or fragile ecosystem such as low- Flow Rivers, coral reefs, water sources and others. The treated effluent can be disinfected physically like use of lagoons before discharging it to wetlands, streams and rivers. Treated wastewater is reused after removal of contaminants such as the nutrients, pollutants and pathogens (Matheyarasu *et al.*, 2015).

### *2.5.1 Conventional methods of water treatment*

In most water, treatment processes combine coagulation, flocculation, sedimentation, filtration and disinfection overlapping each other to produce safe, clean drinkable water to communities. These methods of treatments are widely used in Uganda by National Water Sewerage Corporation (NWSC) and umbrella sanitation facilities under the Ministry of Water and Environment.

Coagulation is addition of chemicals into water. Using Iron salts and Hydrolytic Aluminium salts as coagulates lead to formation of suspended solids. Coagulation and flocculation are termed as physicochemical operations to water for turbidity and organic water removal (Karuma *et al.*, 2013; Zinicovcaia, 2016). Umar *et al.*, (2016) summarises the chemical transformations that occur during the coagulation process as shown in chemical equations 2.1 and 2.2 using aluminium sulphate and ferric chloride as coagulants respectively below.

$Al_2(SO_4)_3 + 6H_2O = 2Al\ (OH_3) + 3H_2SO_4$ Equation 2.1

$FeCl_3 + 6H2O = Fe\ (OH)_3 + 3HCl$ Equation 2.2

The process of flocculation follows to bind particles together into big agglomerates particles that settle down at the bottom due to weight gained or light particulates float during sedimentation. Filtration through a membrane media such as sand removes the remaining particulates to produce clean and safe water.

### *2.5.2 Household methods of water treatment*

Most households purify water safe for consumption by boiling water in saucepan and the water boils for time between 30 minutes and one hour. During cooling process, large particles settle at the bottom of the saucepan before decanting clean and safe water. The other methods water in safe guard tablets to treat water in jerry cans or water tanks depending household capacity of consumption while the others households ceramic water filters (purifying) on a low scale due to low household income (Ding, 2017).

### *2.5.3 Agricultural waste in wastewater treatment*

Agricultural waste, such as rice husks, coconut shells, sugarcane bagasse, and other plant-based materials, have been widely studied as potential adsorbents for water treatment. These materials are renewable, low-cost, and readily available, making them an attractive option for water treatment applications (Tyagi and Anand, 2024). One of the most studied agricultural waste materials is rice husk (Dalai *et al*., 2015). Rice husk is a by-product of the rice milling process and contains a high amount of silica, making it an excellent adsorbent for heavy metals and other pollutants. Studies have shown that rice husk can effectively remove pollutants such as lead, cadmium, copper, and zinc from wastewater (Huang *et al*., 2019).

Another commonly studied agricultural waste material is coconut shells. Coconut shells contain high carbon, making them effective for removing organic pollutants from water (ee). Studies have shown that coconut shell-based activated carbon can effectively remove organic compounds such as phenol, benzene, and chlorophenol from wastewater (Ahsan *et al*., 2018; Kulkarni *et al*., 2020).

Sugarcane bagasse is another agricultural waste material that has been studied for water treatment applications. Sugarcane bagasse contains a high amount of cellulose, making it effective for removing dyes and other organic pollutants from wastewater. Studies have shown that sugarcane bagasse can effectively remove dyes such as methylene blue and reactive red from wastewater (Liu *et al.,* 2018; Ali *et al*., 2021).

Other agricultural waste materials studied as adsorbents for water treatment include wheat straw, sawdust, and orange peel. These materials have shown promise for removing pollutants such as heavy metals, organic compounds, and dyes from wastewater (Zhao *et al.*, 2019; Ibrahim *et al.*, 2020); Saleem *et al.*, 2021).

### *2.5.4 Utilising Agricultural Wastes as Precursors for Activated Carbons*

Activated carbon, derived from agricultural waste materials including coconut shells, sawdust, and peanut shells, is extensively used in wastewater treatment owing to its exceptional adsorption capacity and versatility. Agricultural waste-derived activated carbons possess advantageous characteristics for the elimination of pollutants, such as a substantial surface area, a structure with small pores, and functional groups on the surface (Blachnio *et al.*, 2020) . These materials have successfully eliminated various pollutants from wastewater streams, like heavy metals, emerging pollutants and organic compounds, demonstrating their effectiveness in wastewater treatment.

Coconut shells are extensively researched agricultural waste materials for producing activated carbons because of their abundant carbon content and porous nature (Sujiono *et al.*, 2022). By employing carbonization and activation techniques, coconut shells transformed into activated carbons possess significant surface area and porosity (Liu *et al*., 2020). Coconut shell-derived activated carbons have a porous structure that offers a large surface area, enabling excellent adsorption of pollutants in wastewater (Sujiono *et al.*, 2022). Research has demonstrated that activated carbons generated from coconut shells have high adsorption capabilities for a wide range of contaminants, such as heavy metals, organic compounds, and dyes. This makes them well-suited for use in wastewater treatment applications (Chew *et al*., 2023).

Sugarcane bagasse, a fibrous byproduct remaining after the extraction of juice from sugarcane, possesses the potential properties to be utilised for the creation of activated carbon, making it a valuable agricultural waste material. Sugarcane bagasse has cellulose, hemicellulose, and lignin, which can be transformed into carbon-rich activated carbons via carbonization and activation procedures, (Dwiyaniti *et al.,* 2020; Kakom *et al.*, 2023).

Sugarcane bagasse-derived activated carbons have demonstrated significant surface area and porosity, making them ideal for pollutant adsorption application in wastewater treatment (Dwiyaniti *et al*., 2020). Activated carbons generated from sugarcane bagasse have proven to be effective in eliminating various wastewater contaminants  these include nutrients, organic pollutants and heavy metals,  (Sujiono *et al*., 2022).

Rice husks, which are produced during the process of milling rice, have been studied as potential sources for the synthesis of activated carbon since they are readily available and contain a significant amount of silica. Rice husks can be transformed into activated carbons with significant surface area and porosity by utilizing pyrolysis and chemical activation techniques (Ahiduzzaman and Sadrul, 2016).

Rice husk-derived activated carbons possess a porous structure that creates optimal conditions for adsorption, rendering them highly efficient in eliminating pollutants from wastewater. Rice husk-derived activated carbons have been found to have high adsorption capabilities for heavy metals, organic compounds, and dyes, which makes them a viable choice for applications in wastewater treatment (Dalai *et al*., 2015).

Wheat straw, the residual stems remaining after the harvest of wheat, is an easily accessible agricultural byproduct that can also be used for the synthesis of activated carbon. Wheat straw consists of cellulose, hemicellulose, and lignin. These components can be transformed into activated carbons with a high carbon content using pyrolysis and chemical activation methods (Neme *et al*., 2022). Research conducted by Gupta *et al.* (2016) has demonstrated that activated carbons generated from wheat straw exhibit a significant surface area and porosity, making them very suitable for adsorbing pollutants in wastewater treatment applications. Activated carbons generated from wheat straw have proven to be effective in eliminating organic pollutant, nutrients and heavy metals (Gaikwad and Kinldy, 2009; Guo *et al*., 2017; Iriakuma *et al*., 2016; Mortada *et al*., 2023; Sossalla *et al*., 2021).

Researchers have investigated the use of banana peels, which are often thrown away as agricultural waste by banana processing firms, as a potential source for producing activated carbon. Cellulose, hemicellulose, and lignin found in banana peels can be transformed into carbon-rich activated carbons using pyrolysis and chemical activation methods (Zhang *et al*., 2019). Banana peel-derived activated carbons have demonstrated a substantial surface area and porosity, making them very suitable for adsorbing pollutants in wastewater treatment applications (Soni *et al.*, 2020). Activated carbons made from banana peels have proven to be effective in eliminating organic pollutants, dyes and heavy metals, from wastewater.

Orange peels, which are produced as a byproduct of citrus processing businesses, have been studied as potential materials for making activated carbon. Orange peels contain cellulose, hemicellulose, and pectin. These compounds can be transformed into activated carbons with a high carbon content using pyrolysis and chemical activation methods (Razali *et al*., 2022). Studies have demonstrated that activated carbons obtained from orange peels have significant surface area and porosity, making them suitable for effectively adsorbing pollutants for  wastewater treatment (Razali *et al*., 2022). Activated carbons made from orange peels have proven to be excellent in eliminating many types of pollutants from wastewater, such as heavy metals, organic pollutants, and dyes.

Maize cobs, which are produced as a byproduct of maize farming and processing, have been investigated as potential sources for the manufacture of activated carbon (Dhaliwal *et al*., 2020; Nabulo *et al*., 2006). Corn cobs consist of cellulose, hemicellulose, and lignin, which can be transformed into carbon-rich activated carbons using pyrolysis and chemical activation techniques (Gong *et al.*, 2017). Corn cob-derived activated carbons have demonstrated significant surface area and porosity, making them ideal for adsorbing pollutants in various wastewater treatment methods (Liu *et al.,* 2020). Activated carbons generated from corn cobs have proven to be excellent in eliminating many types of pollutants from wastewater, such as heavy metals, organic pollutants, and dyes.

The potential of mango seeds, which are typically abandoned as agricultural waste in mango processing companies, has been explored for their suitability as raw materials for the synthesis of activated carbon (Bhardwaj *et al*., 2020). Mango seeds consist of cellulose, hemicellulose, and lignin, which can be transformed into carbon-rich activated carbons using pyrolysis and chemical activation techniques (Razali *et al*., 2022). Mango seed-derived activated carbons have significant surface area and porosity, making them ideal for adsorbing pollutants from wastewater treatment (Razali *et al*., 2022). Activated carbons generated from mango seeds have proven to be effectively eliminate organic pollutants, dyes and Peanut shells, which are produced as by-products in peanut processing companies, have been investigated as potential sources for the synthesis of activated carbon. Peanut shells consist of cellulose, hemicellulose, and lignin, which can be transformed into carbon-rich activated carbons using pyrolysis and chemical activation techniques (Kumar and Shanthakumar, 2016). Peanut shell-derived activated carbons have significant surface area and porosity, making them suitable for adsorbing pollutants in wastewater treatment applications (Fuadi *et al*., 2012; Rashidi and Yusup, 2017). Activated carbons generated from peanut shells have proven to be highly successful in eliminating a wide range of pollutants from wastewater, such as heavy metals, organic pollutants, and colours (Mustafa et al., 2024; Senanu et al., 2023).

Palm kernel shells, which are a byproduct of palm oil production, have been examined as potential materials for the synthesis of activated carbon. Palm kernel shells consist of hemicellulose, cellulose, and lignin, that transform into carbon-rich activated carbons by means of pyrolysis and chemical activation methods (Ahiduzzaman and Sadrul Islam, 2016). Palm kernel shell-derived activated carbons have significant surface area and porosity which makes them adsorb pollutants in various applications for wastewater treatment (Fuadi *et al*., 2012; Rashidi and Yusup, 2017).

Activated carbons generated from palm kernel shells have proven to be effective in eliminating various wastewater contaminants and these are various pollutants, dyes and heavy metals, (Bi *et al*., 2011).

### *2.5.5 Factors affecting water treatment process*

The type of adsorbent used can greatly affect the effectiveness of the treatment. The physical and chemical properties of the adsorbent, such as surface area, pore size distribution, and surface functional groups, can affect its ability to adsorb pollutants from water (Mohan *et al.*, 2014). Therefore, selecting the appropriate adsorbent based on the type of pollutant removed is crucial for effective water treatment.

The pH of the solution also plays an important role in adsorption. The solution's pH affects the adsorbent's surface charge and the pollutant's ionization state. The optimum pH for adsorption varies depending on the type of pollutant and the adsorbent used (Liu *et al.*, 2018). For example, some adsorbents, such as rice husk, are more effective for heavy metal removal at low pH, while others, such as coconut shell-based activated carbon, are more effective at neutral pH (Hameed *et al.*, 2008).

Contact time is another important factor affecting water treatment efficiency using agricultural waste-based adsorbents. The contact time refers to the amount of time that the adsorbent is in contact with the polluted water. Generally, longer contact times result in higher pollutant removal efficiency (Saleem *et al.*, 2021). However, the optimum contact time varies depending on the type of adsorbent and the initial pollutant concentration.

The initial pollutant concentration also affects the efficiency of water treatment using agricultural waste-based adsorbents. Higher initial pollutant concentrations require longer contact times or higher amounts of adsorbent to achieve the desired level of pollutant removal. Therefore, it is important to consider the initial pollutant concentration when designing a water treatment system using agricultural waste-based adsorbents (Zhao *et al.,* 2019).

Batch adsorption experiments involve mixing a known concentration of pollutant with a known amount of adsorbent in a solution and measuring the concentration of pollutant in the solution at different time intervals. By analyzing the data obtained from batch adsorption experiments, the efficiency of the adsorbent can be determined. This method provides information on the maximum adsorption capacity of the adsorbent and the kinetics of the adsorption process (Saleem *et al.*, 2021).

### *2.5.6 Analysis of the performance of adsorbents*

Kinetic and isotherm modelling involves fitting experimental data into mathematical models to describe the adsorption process. Kinetic models describe the rate of adsorption, while isotherm models describe the equilibrium adsorption capacity of the adsorbent. By analysing the parameters obtained from kinetic and isotherm modelling, the efficiency of the adsorbent can be determined (Zhao *et al.*, 2019).

Spectroscopic and microscopic characterization techniques can provide information on the surface properties and morphology of the adsorbent, which can affect its adsorption capacity. Techniques such as Fourier transform infrared spectroscopy (FTIR), X-ray diffraction (XRD), and scanning electron microscopy (SEM) is used to characterize the adsorbent before and after adsorption (Liu *et al.*, 2018). These techniques can provide insight into the chemical and physical changes that occur during the adsorption process and can help to optimize the adsorption conditions.

## 2.6 Literature gap analysis

Firstly, there exists a significant deficiency in the localisation of the literature. The review adeptly consolidates worldwide and regional studies on abattoir pollution from nations such as Nigeria, Ghana, and South Africa; nevertheless, it fails to provide a comprehensive synthesis of previous information pertinent to Uganda and, more importantly, the River Rwizi basin. The study references other Ugandan research (Alinaitwe, 2019; Odongo *et al*., 2013) but fails to offer a comprehensive overview of the pollution pressures affecting River Rwizi from additional sources, including urban runoff, agricultural pesticides, and municipal trash. This exclusion complicates the contextualisation of the abattoir's contribution in relation to other pollution sources. A concentrated examination of the distinct hydrological, topographical, and socio-economic attributes of the River Rwizi basin would have established an essential benchmark for assessing the abattoir's specific impact, as advocated by catchment management principles (Nseka *et al*., 2022).

The review discusses agricultural waste as adsorbents in a predominantly generic fashion, neglecting to critically evaluate their appropriateness for the specific pollutant characteristics of abattoir effluent. The text presents an extensive inventory of materials such as rice husks, coconut shells, and banana peels, highlighting their effectiveness against various contaminants, including dyes, phenols, and heavy metals (Ahmaruzzaman & Gupta, 2011; Blachnio *et al*., 2020). Nevertheless, it does not establish a direct correlation between this literature and the principal contaminants of concern from abattoirs, namely high-strength organic wastes (BOD, COD), nutrients (Nitrogen, Phosphorus), and infections. A notable deficiency exists in the analysis of the efficacy of these particular agricultural by-products in relation to the intricate composition of lipids, proteins, and blood found in abattoir effluent, which presents a difficulty separate from the treatment of synthetic dye solutions or individual metal pollutants.

Third, a notable deficiency exists in the discourse of socio-economic and governance aspects affecting abattoir waste management. The review comprehensively addressed the technical dimensions of waste treatment but neglects essential material regarding economic limitations, regulatory enforcement difficulties, and community awareness that influence the efficacy of pollution control initiatives in developing settings. Although Uganda's National Environment Management Authority (NEMA) standards are referenced, the review fails to address studies examining the implementation gap or the capabilities of regulatory bodies to oversee and enforce compliance among small and medium-sized enterprises, such as abattoirs. Comprehending these obstacles is crucial for formulating viable and lasting treatments, as highlighted by studies on environmental governance in analogous contexts (Rajpal *et al*., 2022).

The literature evaluation inadequately addresses the public health and ecological risk assessment aspect. It states that abattoir effluent can lead to waterborne infections and respiratory issues, using studies such as Jega *et al*. (2018). Nevertheless, it fails to explore the current literature that quantitatively correlates pathogen load from abattoirs (e.g., E. coli, Salptirella) with health outcomes in downstream communities or evaluates the ecotoxicological risks posed by heavy metals present in the effluent to aquatic organisms in receiving rivers. A comprehensive examination of epidemiological and ecotoxicological studies would have enhanced the rationale for the research and established a framework for assessing the potential implications of the measured water quality metrics.

# CHAPTER THREE: METHODOLOGY

## 3.0 Introduction

This section contains information on study area, data collection tools, procedure or undertaken to attain results.

## 3.1 Study area

The study conducted covered Ruti abattoir as shown in Figure 3.1, surrounding areas and River Rwizi found in Ruti ward, Nyamitanga, Mbarara Southern Division in Mbarara City. Ruti abattoir is located at 00.6238950S and 030.631480N about 268 meters from River Rwizi in the source direction.

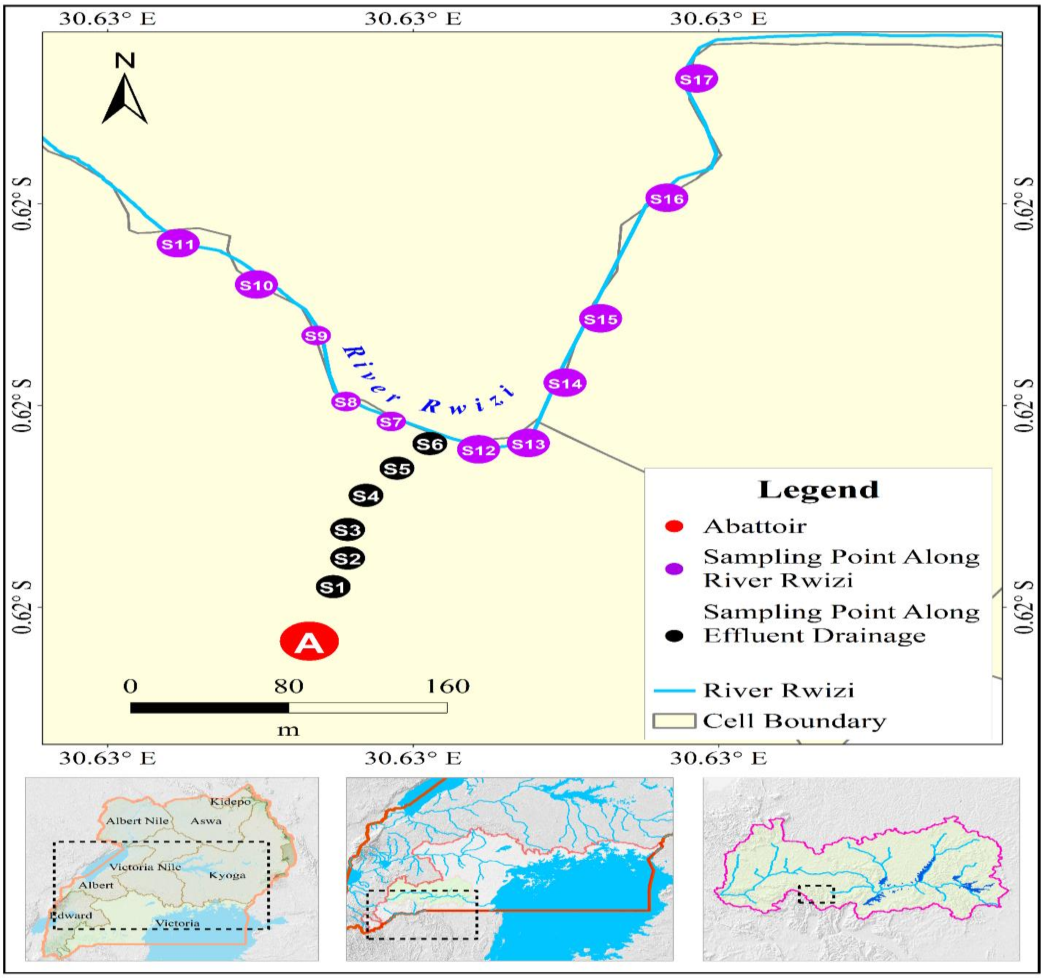

**Figure 3.1:** Sample points for Ruti abattoir effluent flow and River Rwizi.

Ruti abattoir is a major abattoir in Mbarara City based on the animals slaughtered per day. The animals slaughtered daily are sourced within the western region of Uganda and others delivered from abroad from Tanzania. The research focused on the Ruti abattoir wastewater quality discharged to the environment.

## 3.2 Data collection procedures and analysis

The research was done in different stages of field data collection, laboratory stage and finally data analysis stage**.**

### *3.2.1 Research field data collection methods*

The field data was gathered by abattoir survey, observations, interviews and questionnaire. Geographical Information System (GIS) coordinates of the study area of the Ruti abattoir were collected using Global Positioning System (GPS)

### *3.2.2 Ruti abattoir facility survey*

The researcher carried out survey in and around the study area of Ruti abattoir and got acquaintance with the area, abattoir management, technical workers that include veterinarians, community and butchers. Ruti abattoir was inspected and the community to identify the way both solid and wastewater are being managed and wastewater management practices in accordance with Uganda wastewater discharge limit by NEMA the authorized lead agency. The researcher also visited Mbarara City offices and sought of permission from city veterinary and medical officers to access the abattoir and neighbourhood and carryout survey along the river.

### *3.2.3 Observations*

This method was used to collect data on abattoir operations and how the generated waste is managed. In the process of observation of different facilities at the abattoir different operations sections under the study and photographs were taken from slaughtering section.

### *3.2.4 Tracing wastewater effluent flow from abattoir to River Rwizi*

Different types of waste produced, how it is disposed of and wastewater management process currently were identified. Brilliant Blue FCF a nontoxic tracer has best properties with liquid. Potential of hydrogen was tested and found to be neutral and safe for human pH of the dye is verified before applying it to check if it is safe and neutral. The dye was mixed in water on a ratio of 20g/20ml which was poured at the discharge point of the effluent. The effluent turned blue after 3 hours blue strained water was discharged in River Rwizi which indicated that effluent reaches the river. The abattoir is at 268 m as shown on the map (Figure 3.1) south of River Rwizi. Sample was done the quality of both water and effluent. Samples were collected at the discharge point at Ruti abattoir discharge point to River Rwizi and both upstream and downstream sample points were identified and marked.

### *3.2.5 Interviews*

Interviews were structured in a way that answering the research questions focusing on the current wastewater effluent management at the abattoir as issued by Uganda environmental Agency NEMA standards about discharge limits to land and water bodies. The people interviewed were the Mbarara

City Veterinary Officer, City Health Officer, Veterinary Officers attached to the Ruti abattoir.

### *3.2.6 Water sampling and sample size*

Ruti abattoir as the area of the study was identified and was selected due to its location being close to River Rwizi, operations and wastewater effluent management.

The abattoir effluent and water sample from picked from the effluent discharge point and along the flow direction until it reaches River Rwizi and both upstream and downstream samples were collected.

The selection of sampling points for this study was methodically developed to elucidate a definitive cause-effect relationship between the effluent discharge from the Ruti abattoir and the water quality of River Rwizi, adhering to a recognised environmental impact assessment methodology. The main sample location was the effluent discharge point of the abattoir (S1), which acted as the definitive source of possible contaminants. To monitor the dispersion and attenuation of these pollutants, additional points (S2 to S6) were established at 25-meter intervals along the effluent drainage channel leading to the river, facilitating the observation of variations in contaminant concentration prior to entering the receiving water body (Muhirwa et al., 2010). To evaluate the baseline water quality of the river before the impact of the abattoir's effluent, upstream locations (S7 to S11) were designated at distances of 25, 25, 25, 50, and 50 meters from the confluence point. To accurately measure the precise effect of the abattoir, a succession of downstream locations (S12 to S17) were designated at progressively greater distances (25, 25, 25, 50, and 100 meters) from the effluent intake site. The downstream spatial gradient is essential for assessing the mixing, dilution, and possible degradation of pollutants, serving as a standard methodology for analysing point-source contamination (Bartram and Ballance, 1996). The utilisation of a portable GPS for geo-referencing all places guaranteed accuracy and reproducibility for further monitoring endeavours, thereby establishing a solid geographical framework for assessing the abattoir's effect on River Rwizi.

At some point it was observed that some community members and abattoir workers use river water for domestic use such as bathing, cooking and washing clothing and on 3 kilometres on the downstream National Water and Sewerage Corporation (NWSC). The samples were collected in clean plastic water bottles of 500ml between 0630 hours to 0840hours which is the peak time of abattoir operation. Sample bottles were labelled using code S1 to S17 and were immediately placed in cool ice box with ice cubes to control temperature during transportation. The water sample bottles were cleaned with distilled water to avoid contamination before use. Samples were transported from Mbarara to Makerere University, College of Natural Science Biochemistry Laboratory in ice cooler box for analysis. The water samples were analysed in a time frame of 58 hours from the time of collection. The sample point coordinates for both effluent drainages from discharge to open environment.

**Table 3. 1:** Water sample collection points

| Name | Drainage | Longitude | Latitude |
|---|---|---|---|
| Abattoir | | 30.63137 | -0.62380 |
| S1 | Abattoir | 30.63161 | -0.62348 |
| S2 | | 30.63162 | -0.62328 |
| S3 | | 30.63164 | -0.62308 |
| S4 | | 30.63170 | -0.62285 |
| S5 | | 30.63194 | -0.62266 |
| S6 | | 30.63202 | -0.62249 |
| S7 | Up stream | 30.63184 | -0.6223 |
| S8 | | 30.63167 | -0.62220 |
| S9 | | 30.63152 | -0.62175 |
| S10 | | 30.63127 | -0.62140 |
| S11 | | 30.63094 | -0.62111 |
| S12 | Down stream | 30.63228 | -0.62253 |
| S13 | | 30.63250 | -0.62249 |
| S14 | | 30.63263 | -0.62207 |
| S15 | | 30.63281 | -0.62163 |
| S16 | | 30.63315 | -0.62080 |
| S17 | | 30.63329 | -0.61998 |

### *3.2.7 Secondary data collection*

The secondary data gathered by reviewing various literature from journals, published and unpublished documents such as documents, articles, internet and library of material related with researcher’s thesis. Most of the data was gathered from the internet especially Google Scholar.

### *3.2.8 Sampling of Respondents*

A purposive sampling technique was used to identify key informants (abattoir managers, city officials). For the community and butchers, a random sampling approach was employed. The sample size was determined based on accessibility and the need to get diverse perspectives from users of the river and workers at the facility

## 3.3 Laboratory analysis of selected chemical parameters for wastewater and water quality

The chemical parameters analysed were Total Phosphorus, Total Nitrogen 5-day Biochemical Oxygen Demand ($BOD_5$), Total Nitrogen, Chemical Oxygen Demand (COD), and heavy metals parameters were Copper, Nickel, Arsenic, Chromium, Mercury and Iron. These parameters were analysed in the Chemistry Laboratory, College of Natural Resources at Makerere University. Standard methods for water and wastewater ALPHA (1998) were followed during samples parameters analysis. All laboratory analyses for each parameter (BOD, COD, heavy metals, etc.) for every sample were performed in triplicate, and the mean values are reported.

### *3.3.1 Apparatus used during experiment*

The list of the apparatuses was volumetric flask, round bottom reflex flask, Absorption spectrometer, glass beaker, container, Jerri can, plastic bottles, conical flask, test tubes, oven, funnel, weighing scale, filter paper, Atomic Absorption Spectrometry, burette, pipette, Erlenmeyer flask and gloves. The Brilliant Blue FCF was mixed in the Ruti abattoir wastewater discharged to the environment and track its flow until it joins the River Rwizi.

*Figure 3.2: Some of the apparatus used in experiment procedures*

Where; (a) Filtration, (b) Activation, (c) Washing off activating agent, (d) Drying activated carbonised rice husks, Running UV/Vis spectrophotometer, (e) Analytical balance, (f) Beakers with raw rice husks and (h) UV/V is spectrophotometer.

### *3.3.2 Chemical Oxygen Demand (COD)*

Reagent used for testing COD was digestion solution preparation which was prepared as per Standard methods for water and wastewater (ALPHA, 1998) and contained 10.21 g of potassium dichromate oxide, 500ml of water, 167 ml of sulphuric acid and 33.3g of mercury (II) sulphate. The sulphuric acid was prepared of concentration 5.5% silver sulphate ($kAgHSO_4$) in 100ml of sulphuric acid and stand was left to dissolve for two days. 1ml of sample was diluted in 10 ml of D. $H_2O$ 10X from the diluted sample poured 1ml in tube 1, 0.5 ml in tube 2 and 0.22 ml in tube 3. The samples were heated using chemical oxygen demand reactor for 90 minutes to acquire full absorption.

### *3.3.3 Biochemical Oxygen Demand (BOD)*

$BOD_5$ of the water samples was determined following a method described by Delzer and McKenzie (2003) using Consort pH multiparameter meter (C3030). 100 ml of the water sample was transferred into a clean and dry 200 ml glass beaker. The pH of the samples was determined and recorded. The Dissolved Oxygen was determined for the same sample in the beaker. The used sample was incubated at $20^oC$ in a digital incubator for five days and then dissolved oxygen was determined again. The $BOD_5$ was determined by calculating the difference in oxygen levels between the first test and the second test, in milligrams per liter (mg/L), which is the amount of BOD

### *3.3.4 Total Nitrogen (TN)*

The total nitrogen was determined using spectrophotometer following ALPHA (1998) procedures at wavelength of 580mm. The samples were diluted with distilled water in a falcon tube at a ratio of 1:10. A nitriver 2 pillow powder was added into the falcon tube then it was swirled and a time of ten minutes to rest to complete reaction. The samples were put into spectrophotometer sample holder before closing. The sample results were read directly from the spectrophotometer.

### *3.3.5 Total Phosphorus (TP)*

Sample of Total Phosphorus was determined using spectrometer following ALPHA (1998) procedure. 5ml of the sample was put in a test vial, then a potassium persulfate pillow Sacket was added to photosphonate. The solution was agitated for 5 minutes to activate the reaction and rested for fifteen minutes to complete reaction. The sample blank was prepared of distilled water to set the spectrometer to zero. The samples were poured into sample tube before putting them in the spectrometer sample holder and close. The results were read directly from the spectrometer.

### *3.3.6 Heavy metals*

The water samples and samples collected from the upstream and downstream were to be tested in the laboratory for content of heavy metals elements of Copper, Arsenic, Chromium, Iron and Nickel.  The samples were digested by addition of 1 ml of concentrated nitric acid to 50 ml of the water in glass beaker. The sample heated to boil, let to cool and filtered into 50 ml volumetric flask. The selected heavy metals were analysed by Atomic Absorption Spectrometry (AAS).

### *3.3.7 Adsorbent preparation*

The rice husk obtained from Kakunyumunyu Mill in Bulangira Town Council, Kibuku District in Eastern Uganda were used. Rice husks were washed repeatedly with double-distilled water to remove dust and soluble impurities, and this was followed by drying at 105±3 ℃ for 24 hours. It was sieved using meshes to get the desired adsorbent size of 30 micrometres and stored in an airtight container. COD was selected for performance evaluated for two reasons. Firstly, the COD test can be completed in a few hours, whereas the BOD test requires a 5-day incubation period (Delzer and McKenzie, 2003). This made COD a far more practical and efficient parameter for conducting the numerous batch experiments required to test different dosages and contact times. Secondly, COD measures the oxygen equivalent of the total organic matter that can be chemically oxidized, including both biodegradable and non-biodegradable (refractory) compounds. This provides a more complete and rapid assessment of the treatment efficacy of the rice husk adsorbents against the full spectrum of organic pollutants present in the abattoir wastewater."

### *3.3.8 Determination of COD by titration*

3.3.8.1 Preparation of Potassium dichromate (K2Cr2O7) solution

To 800 ml distilled water in volumetric flask was added 6.13 g of Potassium dichromate dried at 105 °C for two hours and then stirred well to dissolve the content and make up the solution to 1000 ml and mix well.

3.3.8.2 Preparation of Silver Sulphate-Sulfuric Acid solution

10 grams of silver sulphate was dissolved in 500 ml concentrated sulfuric acid and the solution was made up to 1000 ml swirl the flask to mix well. The solution was allowed to stand for 24 hours to dissolve well before using it.

3.3.8.3 Preparation of Mercury sulphate solution

0.1 grams of $HgSO_4$ was dissolved in 5 ml of concentrated Sulfuric acid.

3.3.8.4 Preparation of Ferrous ammonium sulphate Solution (0.025 M)

9.8 g of ferrous ammonium sulphate was dissolved in a solution of 100 ml of distilled water and 20 ml of concentrated Sulfuric acid. The solution was cooled and made the solution to 1000 ml of distilled water. The solution was standardised to determine the actual concentration to calculate the chemical oxygen demand.

3.3.8.5 Preparation of Ferroin Indicator

3.5 grams of Iron Sulfate heptahydrate and 7.5 grams of Phenanthroline monohydrate were added to 400 ml of distilled water. The solution was dissolved in 100 ml to make 500 ml of the solution

### 3.3.8.6 Test for Chemical Oxygen Demand

10 ml of sample was taken into a round bottom reflex flask. Glass beads were added to prevent the solution from bumping into the flask while heating. 1 ml of Mercury sulphate ($HgSO_4$) solution was added to the flask. 5 ml of Potassium dichromate ($K_2Cr_2O_7$) solution was added. 15 ml silver sulphate- Sulfuric acid solution was added. The solution was heated using a hot plate for 2 hours. 2-4 drops of ferroin indicator were to the flask. The solution was titrated with 0.025 M ferrous ammonium sulphate solution to the endpoint. the blank preparation was prepared in the samw way using distilled water. The COD was calculated using the following equation 3.1.

$$COD\ (mg/L) = 8000\ \{fM(V_B - V_s)\} \qquad \text{Equation 3.1}$$

Where,

f – Dilution Factor (where applicable)

M – Molarity of standardized Ferrous Ammonium sulphate solution

$V_B$ – Volume consumed in titration with blank preparation

$V_S$ – Volume consumed in titration with sample preparation

## 3.4 Statistical data analysis

The data were analysed using both qualitative and quantitative analysis. The results analysed using student *t*-test for samples since the samples are less than 30 in number. The confidence level of 95% was used to significantly establish the different water quality mean parameters for both upstream and downstream flow down to River Rwizi.

ANOVA data analysis was done to determine the mean and variance for upstream and downstream of River Rwizi. The differences were significant at *p*-value ≤0.05 using equation 3.2 and 3.3

$$\boldsymbol{q} = \bar{y}_1 - \bar{y}_2 \times \left( \boldsymbol{M_r} \sqrt{\frac{\mathbf{1}}{z_1} + \frac{\mathbf{1}}{z_2}} \right) - \mathbf{1}$$

Equation 3.2

$$M_r = \sqrt{\frac{(z_1 - 1){S_1}^2 + (Z_2 - 1){S_2}^2}{Z_1 + Z_2 - 2}}$$

Equation 3.3

where $\bar{y}_1$ and $\bar{y}_2$ are the mean values of parameters (such as $BOD_5$), $S_1$and $S_2$ denote the standard deviations of the parameters (such as $BOD_5$) from upstream and downstream of the river and $Z_1$ and $Z_2$ denotes the sample sizes from upstream river flow and downstream river flow respectively.

## 3.5 Validity and reliability of instruments

The researcher collected data based on a triangulation approach. The interview and questionnaire guides were reviewed by my supervisors, who amended and edited them focusing on having quality research and reliable data collection approach. Correlation between observation and responses from critical interviewees was ensured to have facts and reliable results. The water samples were taken to laboratory to be analysed using Standard methods for water and wastewater (ALPHA, 1998) and procedures were critically observed during the process.

# CHAPTER FOUR: RESULTS AND DISCUSSIONS

## 4.0 Introduction

This chapter presents study findings. It also shows data collected from the respondents, wastewater effluent management, characterization of water samples, the effluent impact to River Rwizi and exploring cheap water treatment method using rice husks.

## 4.1 Description of the study population

### *4.1.1 Gender of Respondents*

The table 4.1 below illustrates representation of the 52 respondents interviewed during the study. Male and female constituting 56 and 44 %, respectively. The majority the population who fetch or draw water from River Rwizi use it for domestic purposes. There is a high population of male compared to female due to nature of human activities along the river such as abattoir operation, brick laying and tree and flower nursery beds along the trench of the river Rwizi.

**Table 4.1:** Gender of Respondents.

| Sex | Frequency | Percentage |
|---|---|---|
| Male | 29 | 56 |
| Female | 23 | 44 |
| Total | 52 | 100 |

### *4.1.2 Categories of respondents*

The respondents were categories in three groups that is community who use River Rwizi water and live along the river, technical/butchers at Ruti abattoir and key informants who include some Mbarara City officials, butchers and community members. Results are as illustrated in the table 4.2 below.

**Table 4.2:** Illustrates the Categories of Respondents.

| Category | Frequency | Percentage |
|---|---|---|
| Community | 38 | 73 |
| Technical/butchers | 9 | 17 |
| Key informant | 5 | 10 |
| Total | 52 | 100 |

In this study, the community has the highest frequency of interviewees because they are the end user of river water for different purposes including domestic, commercial and farming with 73%. Then Ruti abattoir butchers with 17% since they have critical information on the operation and waste management at the abattoir. In addition, the city officials were interviewed as key informants during study constituting a 10% of the total persons interviewed. According to Nseka *et al*. (2022), a small population is involved in butcher business while a biggest population of the community is involved in farming. This is evident through increasingly diminishing grassland and forest cover by 64 and 71% while settlement and farmland increased by 79 and 50%, respectively between 1990 and 2020.

### *4.1.3 Period of community using river water*

The table 4.3 illustrates the period respondents have lived along the River Rwizi from 0-5, 6-10, 11-15, 16-20 and 21-25-year groups.

**Table 4.3:** Period of community using river water.

| Years | Frequency | Percentage |
|---|---|---|
| 0-5 | 18 | 47 |
| 6-10 | 12 | 31 |
| 11-15 | 6 | 16 |
| 16-20 | 1 | 3 |
| 21-25 | 1 | 3 |

The highest percentage of people 0-5, 6-10-, and 11-15-years range of 47, 31, and 16%, respectively. The people drawing water from the river has increased in the last ten years by 78%, which indicates the population pressure on River Rwizi.

### *4.1.2 Period the respondents have lived along River Rwizi*

Table 4.4 illustrates the time the community members have lived along the river as categorized raging from below 0-5, 6-10, 11-15, 16-20, 21-25, year groups as 42%, 29%, 21%, 3% and 05% respectively. The highest number of people have lived along the river for less than ten years.

**Table 4.4**: Illustrates the year groups respondents have lived along River Rwizi.

| Years | Frequency | Percentage |
|---|---|---|
| 0-5 | 16 | 42 |
| 6-10 | 11 | 29 |
| 11-15 | 8 | 21 |
| 16-20 | 1 | 3 |
| 21-25 | 2 | 05 |

### *4.1.3 Description of River water usage*

The table 4.5 describes how the community uses river water by the respondents from the community living and working along River Rwizi. 71% are using river water for domestic purposes this includes drinking water, cooking food and washing utensils and clothing, 21% for watering the flowers for sale and 8% for washing bay of motor vehicles. The 68% of community members extracting water from the river do not know that the abattoir pollutes water by releasing their effluents to the environment.

**Table 4.5:** Show the categories of river water usage.

| River water use | Frequency | Percentage |
|---|---|---|
| Domestic | 27 | 71 |
| Washing bay | 8 | 21 |
| Watering plants | 3 | 8 |
| Total | 38 | 100 |

High number of the interviewed community are using water for domestic purposes and they do not treat it.  The people using river water don't know its quality and based on the interviews with Mbarara City veterinary and medical department officials it was observed that Ruti abattoir wastewater effluent contaminates the water body of River Rwizi though they don't know contamination levels. According to Mugonola *et al*., (2015), about 84% of population along River Rwizi rely on farming and a very small portion are involved in other activities. This explains why domestic water use because of farming.  Secondly, in Lake Mburo National Park, River Rwizi is the main water source for both domestic and industrial use and in Mbarara and the neighbouring towns of Bwizibwera, Sanga and Biharwe.

## 4.2 Assessment of wastewater effluent management at Ruti abattoir

The study focused on how the abattoir operations; its housing practices and wastewater effluent is generated and how it's managed at Ruti abattoir.

### *4.2.1 Abattoir operations and housekeeping practices*

The study discovered that animal slaughtering and dressing of the carcass section is a cemented floor, but worn out (Figure 4.1). Animals are slaughtered on the floor and this slaughtering operation/procedure is not hygienic and puts the meat contamination at high risk by pathogens. The Ruti abattoir situation and conditions apparently are supposed to be clean and hygienic and if not monitored closely it has potential adverse environmental and human impacts. The hygienic status at the abattoir facility depends majorly on the cleanliness for both solid and wastewater effluent management produced at Ruti abattoir facility.

The slaughterhouse floor is cemented and is blood not controlled during slaughter operations. During study, it was discovered that abattoir management has clear waste management as shown in the figure 4.1 and a large number of butchers do not have protective gears such as aprons, hand gloves, nose masks, though all had gumboots during slaughtering process.

**Figure 4.1:** Butcher not wearing hand gloves.

The abattoir slaughtering section is inadequate slaughtering equipment in place do not promote hygienic improvement. Abattoirs are contributing to the issue of potential health dangers and possible food-borne diseases in food chain (Adeyemi and Adeyemo, 2007).

During cow, goat or sheep slaughtering process, they positioned on their back on slaughterhouse floor and evisceration done on the floor. The meat and the carcasses are cleaned on the dirty floor and the cut into pieces, the meat is weighed before loading them on the waiting vehicles or in boxes tied on motor cycles outside the slaughterhouse.

Poor in-house practices (Figure 4.2 and 4.3) observed were cemented floor is not regularly cleaned with a disinfectant. Poor hygienic and abattoir management failure to manage waste generated at the facility may lead to meat contamination in the long run. Discharge of blood and animal faeces into streams and rivers depletes oxygen and over enrichment of nutrient in the receiving eco-system leads to contamination and toxin accumulation.

The facility has a shelter, which limit exposure of meat to high temperature reducing the risk of meat contamination and development of micro –organisms such as *E.coli* and salmonella**.**

**Figure 4.2:** Showing the Poor in-house practices at Slaughtering and animal dressing at the facility.

Community on the downstream use the contaminated water for domestic use, brick laying, nursery bed irrigation and washing vehicles.

**Figure 4.3:** Poor waste handling at the slaughterhouse.

### *4.2.2 Wastewater effluent generation*

Water use is very important in the operation of the abattoir and large quantities of water is used to clean meat, carcass and for cleaning of the floor of the slaughtering section. This increases the amount of wastewater generated and it requires appropriate waste management and treatment at the facility. The abattoir management need to continue using clean water and increase on water storage facility since they are inadequate to ensure constant water supply to facilitate the abattoir operation during water shortage supply to the abattoir. (Maranan *et al*., 2008). Water shortage compromises the hygienic and sanitation of the abattoir. During this study, it was, discovered that Ruti abattoir has water storage facility in form of overhead water tanks and a shallow ground water source. In addition, interview results from the butchers and the abattoir administration officials portrayed that the wastewater generated depends on the number of animals slaughtered per day. Averagely on a daily basis 35 cow, 60 goats, and 20 sheep are slaughter and water required is over 100 litres for cows, less than 50 litres for both sheep and goats and a lot of water used to clean the floor.

### *4.2.3 Wastewater effluent management at the abattoir*

The wastewater effluent produced at Ruti abattoir while cleaning meat, intestines and cleaning slaughterhouse floor is channelled into a close drainage channel to the septic tank. The septic tank was found full and there is no routine empting schedule. During the study and abattoir visits, it was discovered that there is a discharge duct from the septic tank to the open environment without treatment, which flows to River Rwizi. According to Oruonye (2015), abattoir waste generated provide the breeding and sanctuary for parasite. This creates a potential health hazard to the community leaving around the facility.

Some of the workers at the Ruti abattoir confirmed that their waste effluent from their operations discharged on the land from the septic tank flows to the River Rwizi. Naila (2008) reported that people using water from river contaminated with effluent from the abattoir caused health issues to women and children

### *4.2.4 Tracing the wastewater effluent to River Rwizi*

Wastewater effluent discharged from the abattoir septic tank was tracked by use of Brilliant Blue FCF as a dye tracer to stain flow pathways in porous media such as water and soil. Brilliant Blue FCF dyes are used widely as tracers in natural systems on account of their high detectability and ease of assay by fixed-wavelength fluorometry (Flury and Wai 2003). The dying properties of Brilliant Blue FCF was used to trace how effluent flows from discharge point to the river. When Brilliant Blue FCF was mixed (Figure 4.4.) with water, it produced dark blue color. This color quantifies the quality of the substance (IAEA, 2012).

**Figure 4.4:** Mixing Brilliant Blue FCF in effluent at discharge.

The effluent and storm runoff from the abattoir discharge to wetland and then, flows to River Rwizi as shown in Figure 4.5. The effluent channelled to the septic tank is not treated before discharging it to the environment, hence contamination of surface water leading to river pollution which a potential hazard to the community living downstream of the river.

**Figure 4.5:** Ruti abattoir wastewater discharge to the river.

### *4.2.5 Air pollution at the abattoir*

Shortage of water and mixture of blood and faecal matter leads to odour, breeding zone for bacteria and occasioned bio-degradation. Oruonye (2015) indicated that water shortage led affected the hygiene of the abattoir and led to a stench. Blood treatment is by boiling to make animal feeds at the abattoir. Some leach to the swamp and flows to River Rwizi. This is another point source within the facility not managed well and due to poor wastewater treatment at the abattoir. Bello and Oyedemi (2009) study confirmed abattoir generate bad odour leading to air pollution leading to respiratory ailment.

## 4.3 Characterization of wastewater effluent and River Rwizi water quality

The samples were collected from the abattoir discharge point to its point discharge into River Rwizi, then both upstream and downstream of the river. The parameters characterized of the wastewater effluent were Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen, Total Phosphorus and heavy metals tested were Copper, Nickel, Arsenic, Chromium and Mercury. The results from the laboratory tests in table 4.6, which illustrates characterization of the water samples as collected from the field.

**Table 4.6:** Summary of the chemical and physical properties of the water at the abattoir, upstream and downstream.

| **Sample point** | **Cu (mg/L)** | **Ni (mg/L)** | **As (mg/L)** | **Cr (mg/L)** | **Hg (mg/L)** | **BOD mg/L** | **COD (mg/l)** | **TP (mg/L)** | **TN (mg/l)** |
|---|---|---|---|---|---|---|---|---|---|
| S1 | 0.857 | 0.232 | 1.49 | 0.50 | 21.7 | 1400 | 766.20 | 1.434 | 123.911 |
| S2 | 1.203 | 0.365 | 2.67 | 0.79 | 7.2 | 3800 | 725.48 | 1.175 | 147.091 |
| S3 | 1.075 | 0.277 | 2.21 | 0.40 | 3.6 | 2900 | 622.97 | 1.028 | 95.559 |
| S4 | 0.282 | 0.105 | 3.28 | 0.42 | 2.7 | 2200 | 519.34 | 0.580 | 40.572 |
| S5 | 0.246 | 0.023 | 4.44 | 0.38 | 1.9 | 4100 | 390.56 | 0.445 | 42.653 |
| S6 | 0.232 | 0 | 2.31 | 0.21 | 1.5 | 600 | 390.56 | 0.124 | 5.543 |
| S7 | 0.099 | 0 | 4.07 | 0.35 | 0 | 2700 | 84.07 | 0.032 | 1.985 |
| S8 | 0.176 | 0.174 | 3.45 | 0.53 | 0.1 | 1700 | 83.45 | 0.086 | 1.920 |
| S9 | 0.200 | 0 | 3.33 | 0.30 | 2.3 | 1400 | 78.33 | 0.046 | 1.382 |
| S10 | 0.233 | 0 | 8.82 | 0.31 | 0 | 1000 | 80.82 | 0.023 | 1.751 |
| S11 | 0.088 | 0 | 8.57 | 0.44 | 0 | 800 | 88.57 | 0.073 | 7.138 |
| S12 | 0.106 | 0 | 2.49 | 0.26 | 0 | 4700 | 301.58 | 0.094 | 2.147 |
| S13 | 0.150 | 0.065 | 3.76 | 0.49 | 1.6 | 800 | 283.35 | 0.183 | 9.212 |
| S14 | 0.102 | 0 | 3.65 | 0.21 | 0 | 4100 | 276.68 | 0.017 | 4.960 |
| S15 | 0.074 | 0 | 3.12 | 0.13 | 0.2 | 1700 | 252.86 | 0.054 | 2.835 |
| S16 | 0.096 | 0 | 12.80 | 0.46 | 3.4 | 1400 | 148.97 | 0.062 | 2.834 |
| S17 | 0.157 | 0 | 9.70 | 0.49 | 4.5 | 2500 | 144.89 | 0.026 | 2.691 |

Chromium (Cr), Arsenic (As), Nickel (Ni), Copper (Cu), Zinc (Zn), Mercury (Hg), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Nitrogen (TN) and Total Phosphorus (TP).

In Gombe, Nigeria, Bhattacharya and Venkobachar (1984) reported that the transition metals were associated with abattoir effluent. Table 4.6 shows that the concertation of COD and BOD are very high compared. Metal found present in water and wastewater include Chromium, Arsenic, Nickel, Copper, Zinc and Mercury. However, iron was not found the both River Rwizi water and wastewater. TP and TN are high in abattoir wastewater and low in River Rwizi water present. The NEMA states that the following metals cause adverse potential impact to environment: Chromium (Cr), Arsenic (Ar), Nickel (Ni), Copper (Cu), Zinc (Zn), Mercury (Hg). It is clear that if a poisonous metal's content is below a threshold at which no noticeable effects occur, then its presence might not be dangerous. It should be known that certain heavy metals, such as Al, Cu, Cr, Fe, Mn, and Ni, are either dangerous in trace amounts or necessary wastewater.

### *4.3.1 Comparison of Copper levels*

The copper level at the first three sample points from the abattoir are higher than the NEMA limit of 0.5 mg/L while the rest of sample points for the abattoir, upstream and downstream are below the NEMA limit as illustrated in Figure 4.6. In a physicochemical study of water body around abattoir, it is reported that copper was found to be below USEPA limit of 0.5 mg/L. in this study, the sample points adjacent to the abattoir have a higher copper level.

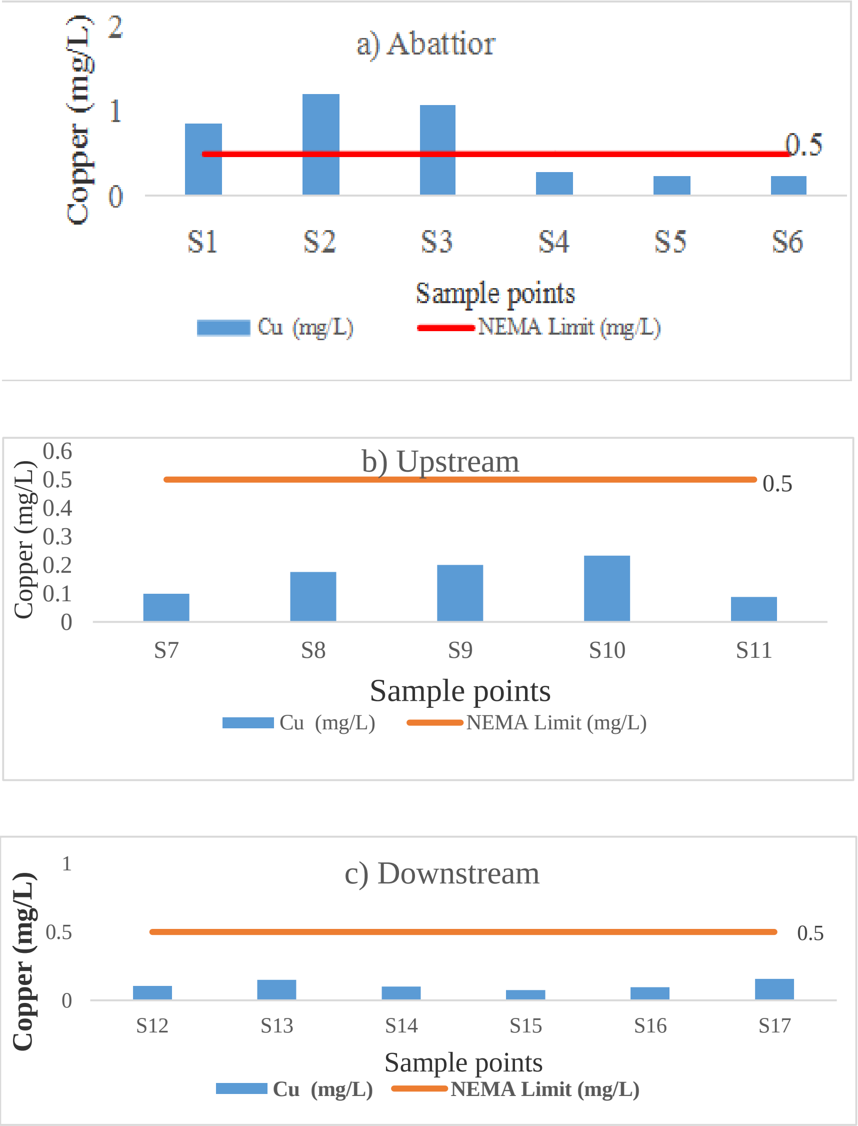

**Figure 4.6:** Comparison of copper levels for (a) abattoir, (b) upstream and (c) downstream with NEMA limit.

The copper concentration in abattoir effluent was high of 0.65±0.45mg/L. At point S4 there is another wastewater from a milk processing plant, which dilutes the water up to River Rwizi for upstream, the sharp increase of copper in River Rwizi water at S10 was due to intersection of inflow of wastewater from the penstock and blooding boiling area.

### *4.3.2 Comparison of nickel levels*

Nickel level for abattoir, upstream and downstream was found to be below the NEMA limit of 0.5 mg/L as shown in Figure 4.7. However, the level is higher than the 0.1 mg/L WHO limit. This study is in agreement with (Ogunlade *et al*., 2021), in which it was found that nickel level ranged from 0.6-1.25 mg/L in water body receiving effluent from abattoir.

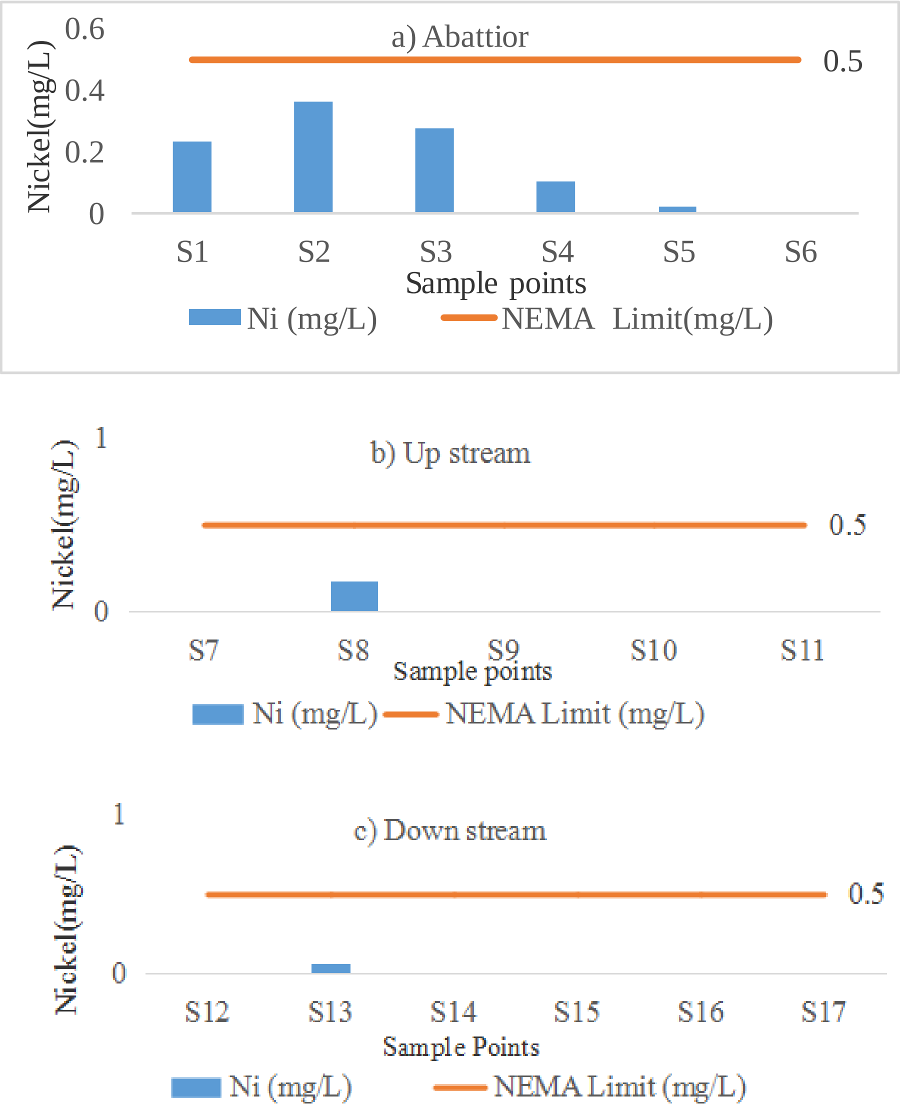

**Figure 4.7:** Comparison of nickel levels for (a) abattoir, (b) upstream and (c) downstream with NEMA limit.

There was increased amount of nickel at S2 point due to sedimentation blockage by reeds section and starts reducing due to absorption by the reeds At S8 the waste effluent flow from the penstock and blood cooking area flow that section to the River Rwizi point.  S13 on the downstream, the spike is due to water coming from the brick laying area that flow from slaughtering area outside the abattoir.

### *4.3.3 Comparison of Arsenic levels*

The high levels of arsenic found upstream (S10, S11) and downstream (S16, S17) suggest sources other than the abattoir are significant contributors, likely agricultural runoff or geological weathering as seen in Figure 4.8. One significant environmental contaminant that may cause cancer is arsenic. It can cause both acute and long-term toxicity based on exposure levels and length of time. Arsenic has been detected in huge amounts in various rice brands sold in Kampala and root source associated with polluted water sources which provides water to swamps where rice is grown (Sembajwe *et al*., 2023). All sample points have arsenic levels higher than the NEMA limit of 0.1 mg/L thus pausing a great risk to the users of the water.

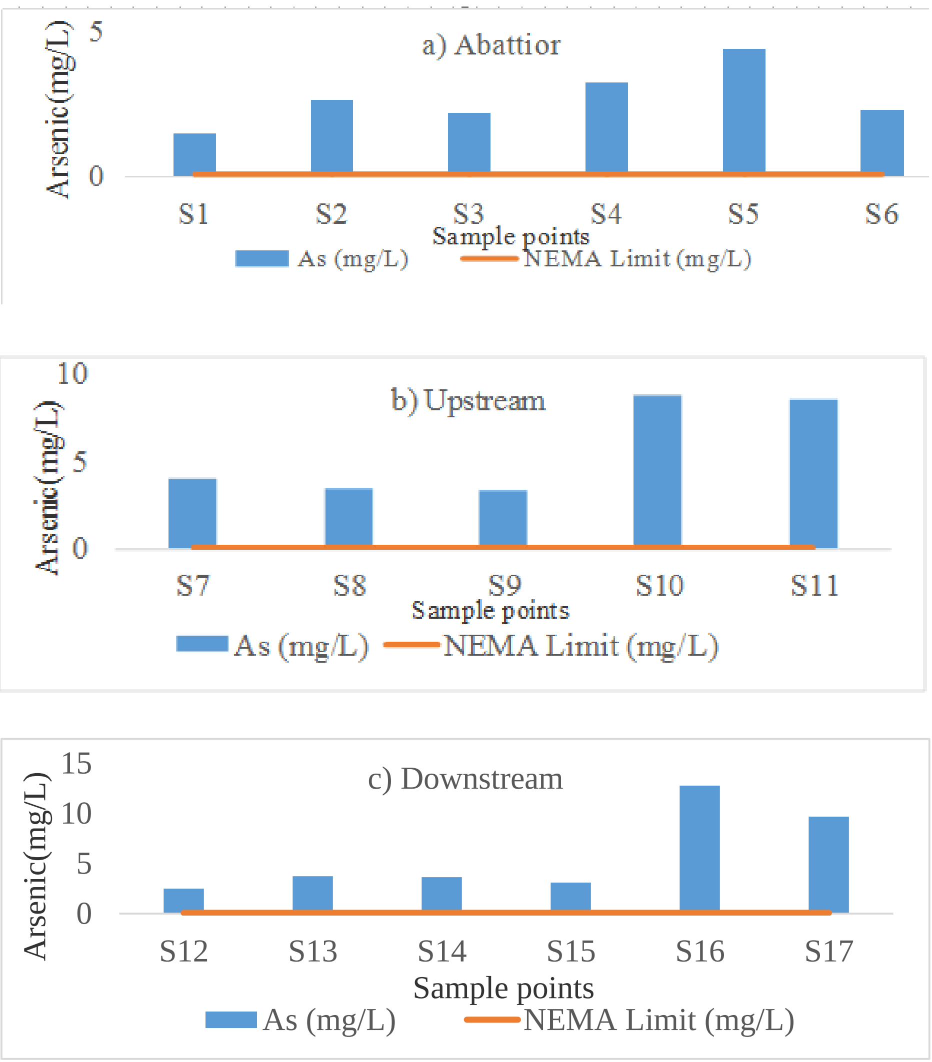

**Figure 4.8**: Comparison of arsenic levels for (a) abattoir, (b) upstream and (c) downstream with NEMA limit.

The wastewater discharged from the abattoir had low content of Arsenic beyond the NEMA limit – and compared to average.

The River Rwizi water had high content at position S16 and S17 which influence storm water run-off from the road through residential houses and cattle grazing area before pouring into River Rwizi. The samples were collected during a rainy season. High level of Arsenic was attributed to Agriculture activities and industrial waste discharge to the river on the upstream.

### *4.3.4 Comparison of Chromium levels*

This study reports that all sample points were found to have chromium levels higher than the NEMA of 0.05 mg/L. Sample points (S1 and S2), (S7, S8 and S11) and (S13, S16 and S17) had the highest chromium levels each of at least 0.3 mg/L for Abattoir, upstream and downstream respectively as shown in Figure 4.9. In 2016, a similar study carried out by Ibrahim and Abdu reported in Nigeria, chromium level of 0.1 was reported which is below the limit of 0.5 mg/L.

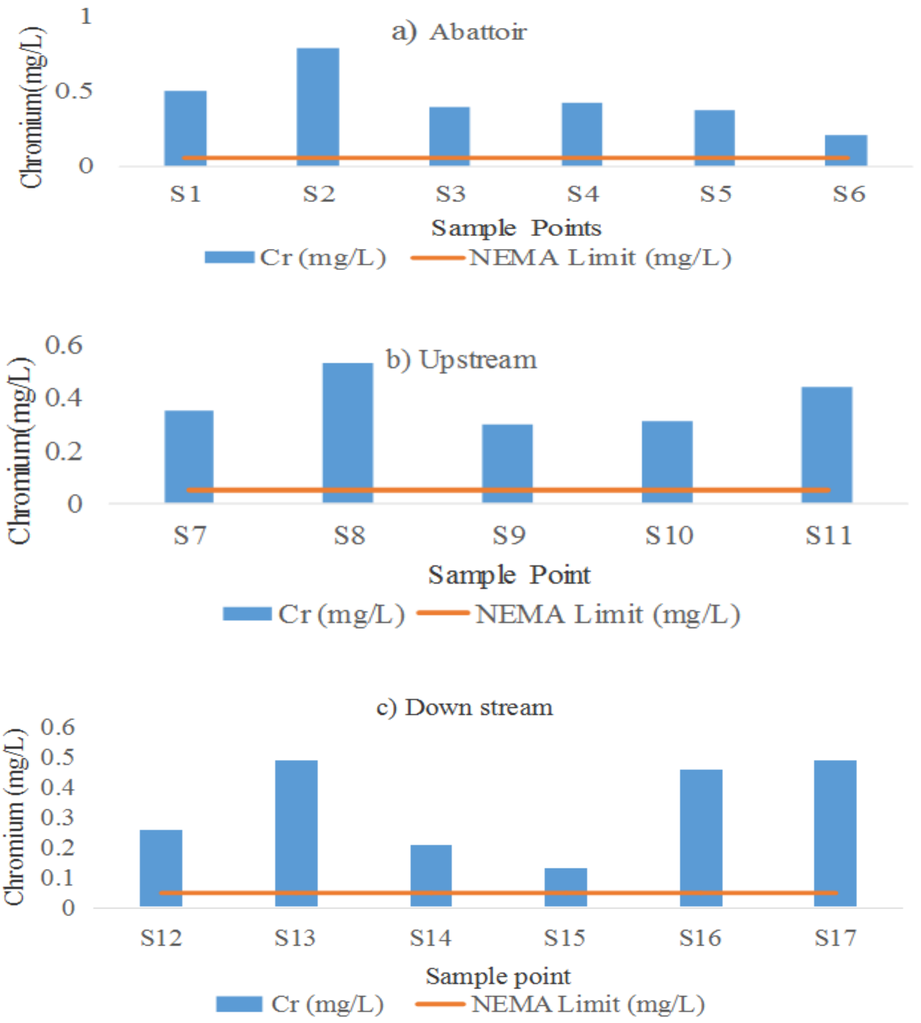

**Figure 4.9:** Comparison of chromium levels for (a) abattoir, (b) upstream and (c) downstream with NEMA limit.

At S2 there is sedimentation due to change of flow influenced by reeds creating a high deposit of Chromium at that point.

There is high concentration of chromium in the river and this could be attributed on the human activities upstream.

### *4.3.5 Comparison of Mercury levels*

Almost all sample points at abattoir, upstream and downstream had mercury levels higher than the NEMA limit of 0.01 mg/L with exception of point S7, S10 and S11 along the upstream and S12 and S14 long downstream respectively as illustrated in Figure 4.10. Mercury when taken in by fish can be biologically converted into methylmercury in aquatic environment by sulphate reducing bacteria, a form which is very toxic to animals of all forms of mercury compounds (Barone *et al*., 2021).

There is high content of mercury in abattoir wastewater at discharge point S1 29.7mg/L and thereafter, is dramatic decrease due to absorption by grass and reeds and it continues decreasing until discharge to River Rwizi.

At stations S7, S8 and S10 there is no trace of mercury because the river flow is turbulent. The mercury is dissolved in river water. The increase of mercury at station S9 is influenced by palms trees on riverbanks which do absorb mercury (Ali *et al*., 2025). On This explains point S13, S16 and S17 with values of 1.6, 3.4, and 4.5 mg/L

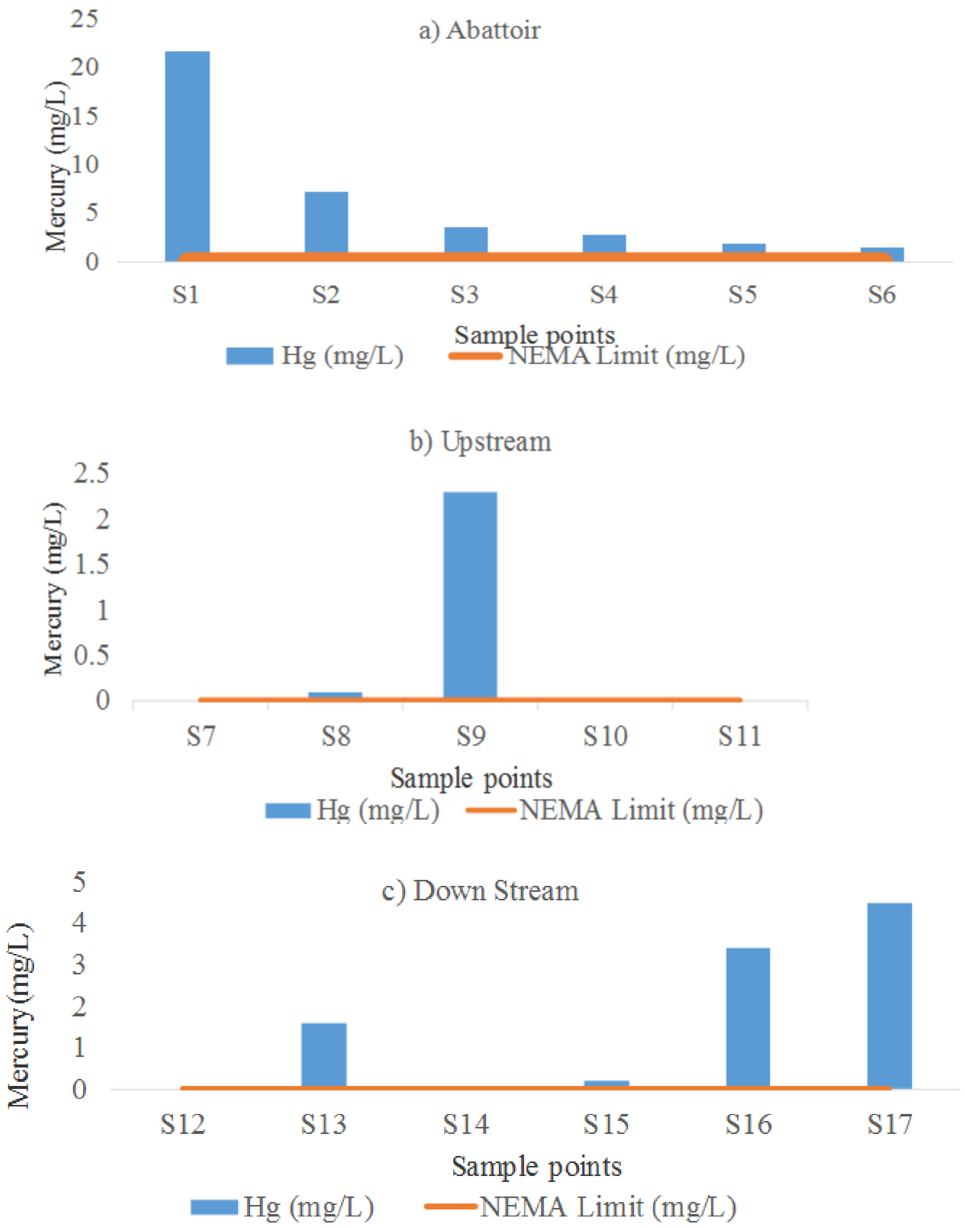

**Figure 4.10*:*** Comparison of mercury levels for (a) abattoir, (b) upstream and (c) downstream with NEMA limit.

### *4.3.6 Comparison of Chemical Oxygen Demand (COD) levels*

In all sample points at the three different sections of the river, the COD level was found to be higher than the NEMA limit requirement of 70 mg/L as sheen in Figure 4.11. The observed high levels of COD are explained by the organic chemical constituents of abattoir wastewater. This water contains blood which is rich in organic matter which is the observed COD. Most similar studies have found COD levels to be significantly high. For example, studies by Shukri (2017) and Magaji and Chup (2012) reported maximum COD levels of 215.50 and 12559 mg/L respectively. It should be noted that the later was local study on the impact of Kalerwe Abattoir wastewater effluent on the water quality of the Nsooba Channel. The highest COD level was found at S1 of a value 766.2 mg/L while the lowest value was found at S9 with a value of 78.33 mg/L.

Large amounts of water are typically used in abattoir operations to clean different process areas and wash the meat (Sajidu *et al.*, 2007). As a result, wastewater from abattoirs has a very high concentration of soluble and insoluble organics, including salts, grease, blood, inorganic and organic particles, paunch grass, and chemicals introduced during processing (Raheem and Morenikeji, 2010). Direct washing into the flowing water occurs with blood, urine, fat, and meat tissues, as well as with indigestible stomach contents (manure) (Liu and Haynes, 2011).

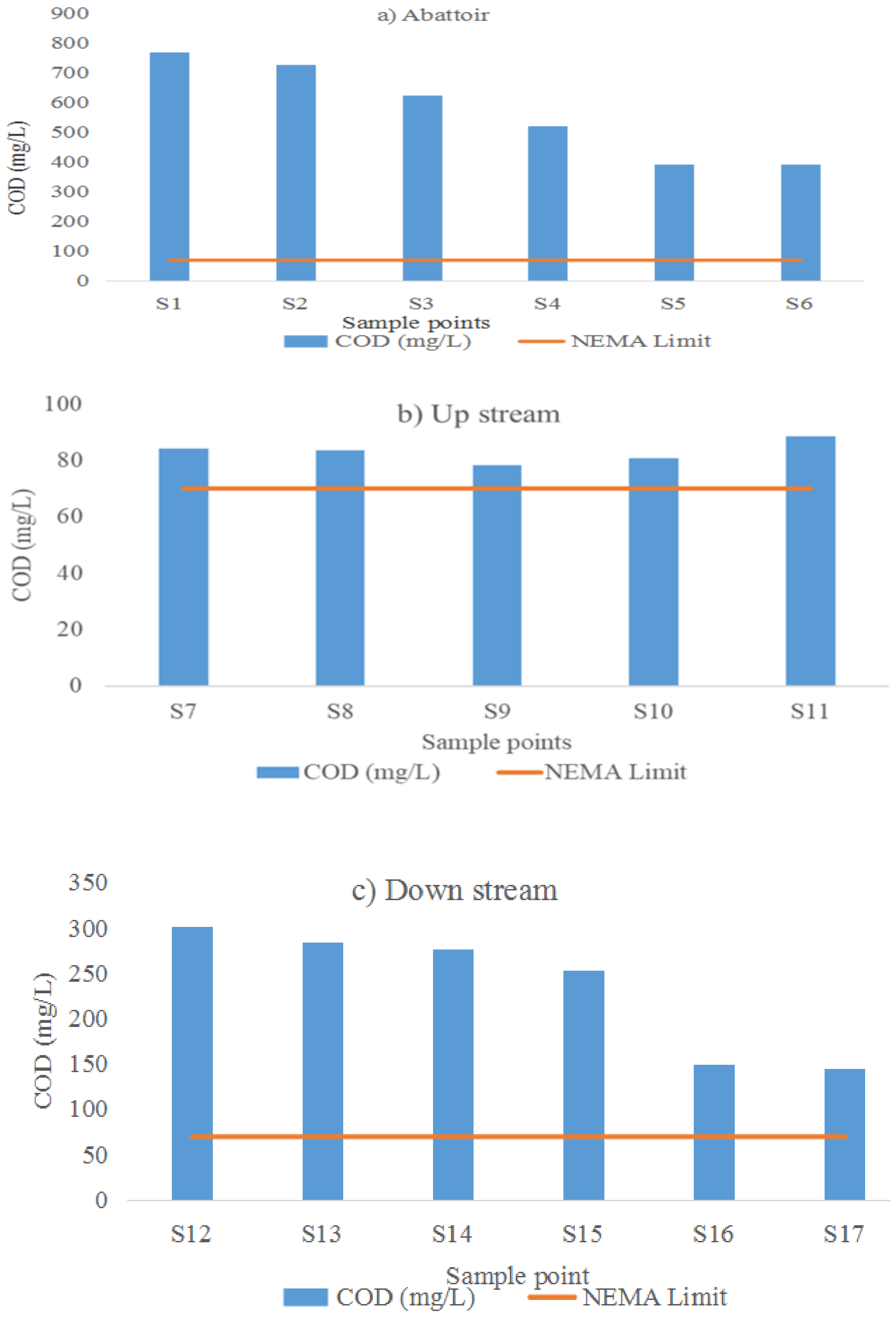

**Figure 4.11:** Comparison of COD for (a) abattoir, (b) upstream and (c) downstream with NEMA limit.

The amount of COD present in abattoir wastewater discharged at outlet point is very high at 766.20 mg/L. There is reduction of COD due to absorption by organic matter such as the reeds from S2 to S6 upstream the quality of COD. The upstream of River Rwizi water COD is slightly above the limit. Downstream the increase COD at point S12 is due to inflow of abattoir effluent into the river and it gradually reduce due to dilution in river.

The observed decrease in COD concentration from the abattoir discharge point (S1) along the drainage channel to the river (S6) is attributed to several natural attenuation processes: Heavier suspended organic solids settled out of the water column as the flow velocity decreased in the open channel and wetland. The effluent flowed through an area with reeds and grasses. This vegetation and the associated soil acted as a natural filter, physically trapping particles and adsorbing dissolved organic matter. Native microorganisms in the soil and water began to biodegrade the organic matter, using it as a food source, thereby reducing the COD load before the effluent reached river (Liu and Haynes, 2011). This combination of physical, chemical, and biological processes constitutes a natural, albeit insufficient, treatment system.

### *4.3.7 Comparison of Total Nitrogen levels*

At the abattoir, the total nitrogen was high for the first five sample points while from the sixth sample point of the abattoir and upstream and downstream had levels below the NEMA limit of 10 mg/L. The highest level was at S2 with 147.091 mg/L while the lowest value of 1.382 mg/L was noted at S9 as indicated in figure 4.12 below. In a study by (Husam and Nassar, 2019) total nitrogen amount to 154 ± 12 mg/L was reported along Gaza strip due to abattoir influence. Nitrogen in abattoir waste is the organic nitrogen from proteins that form the highest part of blood by composition. This nitrogen has potential to nutrient enrich the waterbody. This results into nourishment of aquatic plants while animals thrive as sun light, oxygen and other materials necessary for their growth are absorbed during eutrophication process greatly reduced during eutrophication process.

The Total Nitrogen level increase between S1 and S2 in figure 4.12 (a) is influenced by reeds absorbing the nitrogen and slowing the flow causing sedimentation.

Figure 4.12 (b), At S11 total Nitrogen (TN) has a sharp increase due to being on a low terrain of the grazing area and cattle drink water from this point. The increase at point S13 to 9.212mg/L influenced by entry point of wastewater from a small hooves cleaning area outside the abattoir and flow from washing bay near Ruti abattoir.

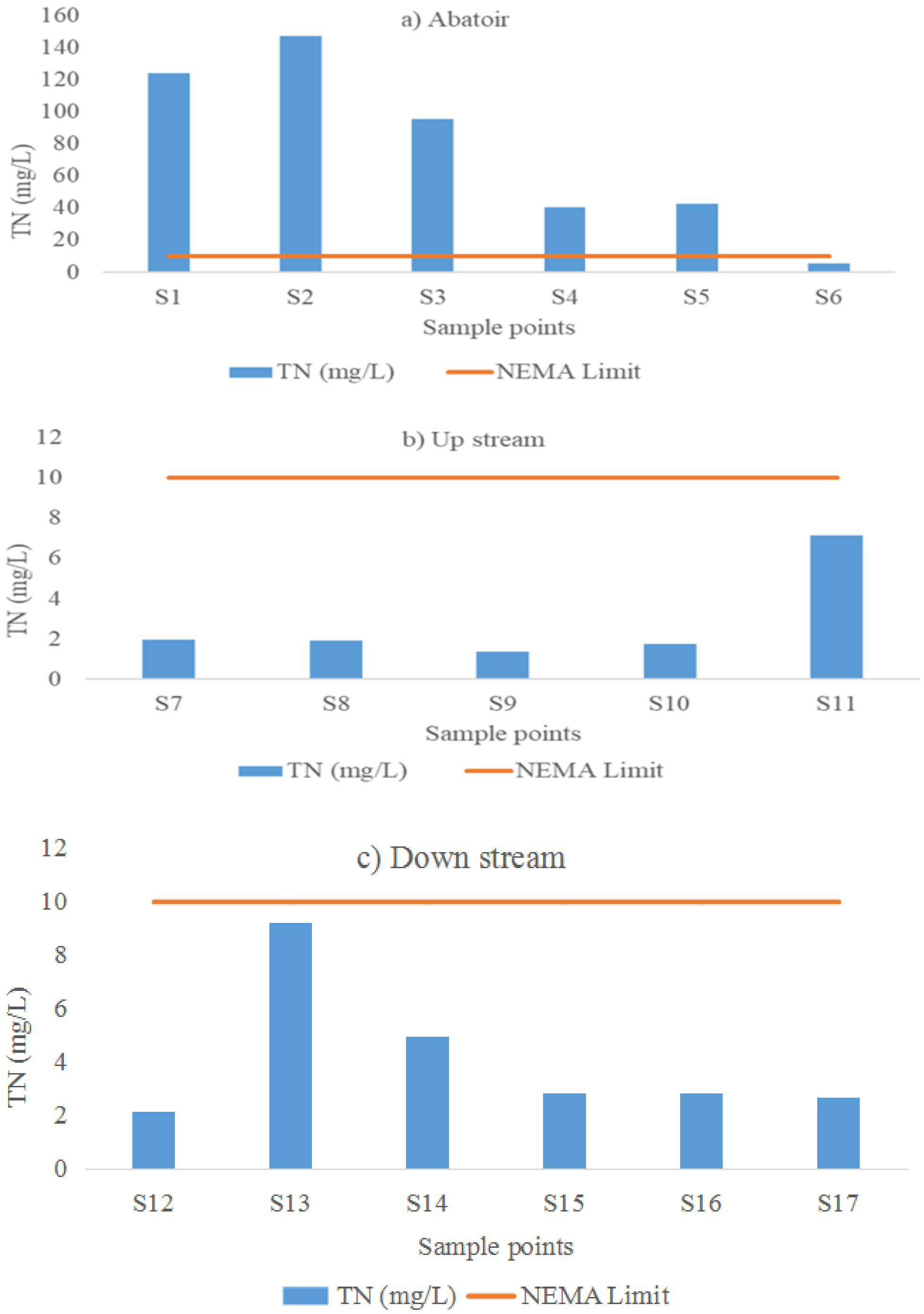

**Figure 4.12*:*** Comparison of total nitrogen levels for (a) abattoir, (b) upstream and (c) downstream with NEMA limit.

### *4.3.8 Comparison of Total Phosphorus levels*

In all sample points at the three different sections of the river, the total phosphorus level was lower than the NEMA limit requirement of 5 mg/L as illustrated in Figure 4.13. The abattoir sample points had higher total phosphorus levels than any other point along the upstream and downstream. The level of phosphorus decreased as one moved away from the abattoir point. In a similar study by (Wastewater, 2016), a maximum total phosphorus level of 53 mg/L was reported.

The total phosphorus discharge in wastewater generated from Ruti abattoir has discharge point S1 at 1.434 mg/L and it reduced due to sedimentation and absorption by plants as reeds by biological treatment process. The Phosphorus level in River Rwizi water is tending to zero on upstream. However, on the downstream, there is an increase at the position S13 due to the amount of wastewater flowing from hooves and brick laying area on the side of the river.

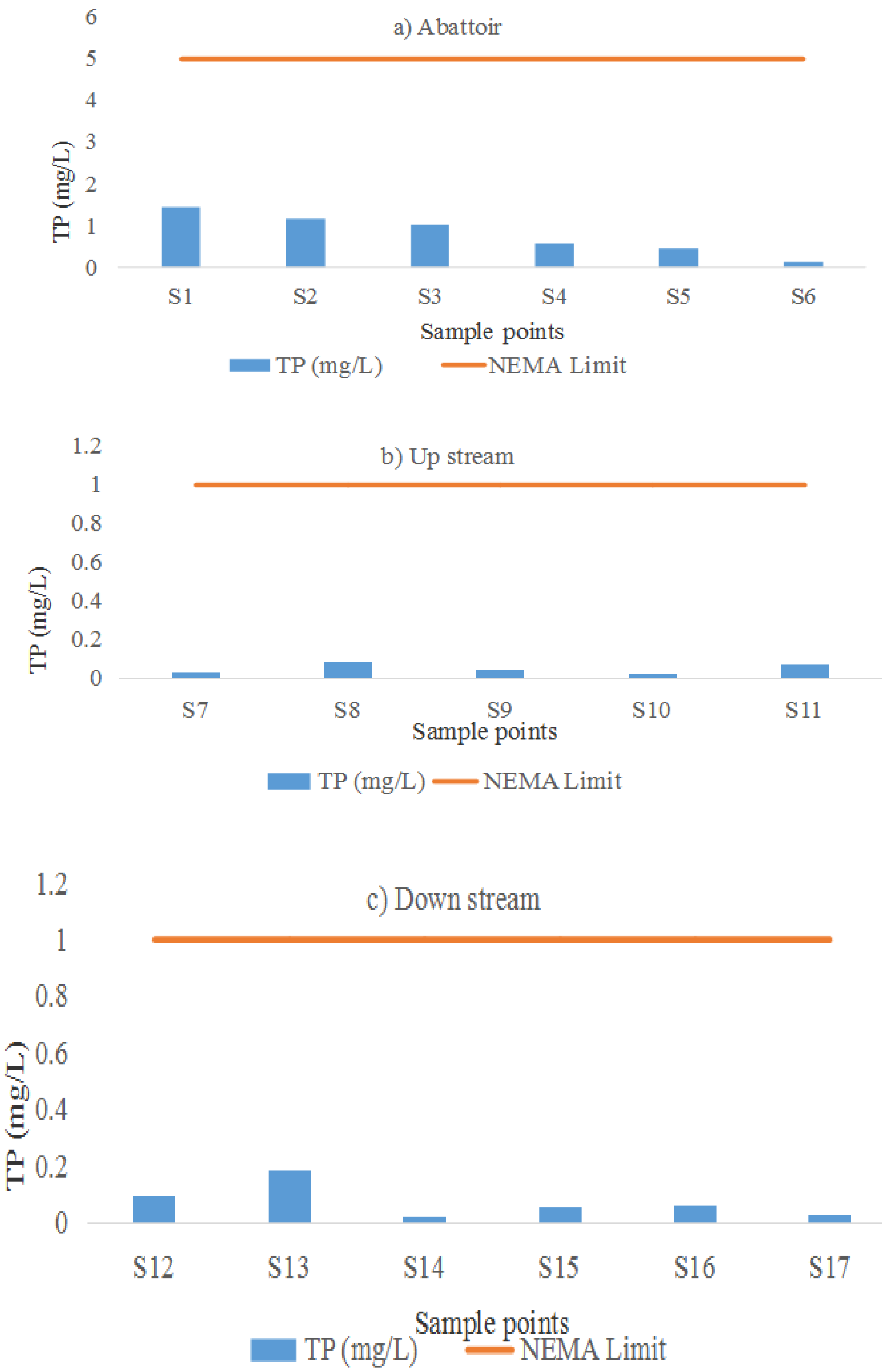

**Figure 4.13:** Comparison of total phosphorus levels for (a) abattoir, (b) Upstream and (c) downstream with NEMA limit.

### *4.3.9 Comparison of BOD levels*

In the figure 4.14 indicates that BOD levels at the abattoir sampling points are notably high, ranging from approximately 600 mg/L to 4100 mg/L. The highest BOD value of 4100 mg/L was observed at S5, while the lowest is 600 mg/L at S6. These values are significantly above the NEMA limit of 50 mg/L, indicating severe organic pollution at the abattoir discharge points. This is expected, as abattoirs generate large amounts of organic waste, including blood, fat, and other animal by-products, which contribute to high BOD levels.

The BOD levels upstream of the abattoir are also elevated, ranging from approximately 800 to 2700 mg/L. Although these values are lower than those at the abattoir are, they are still well above the NEMA limit. This suggests that the river may already be impacted by other sources of pollution before reaching the abattoir or that there is some backflow or diffusion of pollutants from the abattoir affecting the upstream points.

Similar studies on the impact of abattoir wastewater on river water quality have reported comparable findings. These high BOD levels were attributed to the discharge of untreated wastewater containing blood, fat, and other organic materials from the abattoir.

Another study on the impact of abattoir effluents on the Asa River in Nigeria reported BOD levels ranging from 800 to 3500 mg/L, again similar to the findings in this study. The researchers noted that the high BOD levels led to oxygen depletion in the river, adversely affecting aquatic life and water quality.

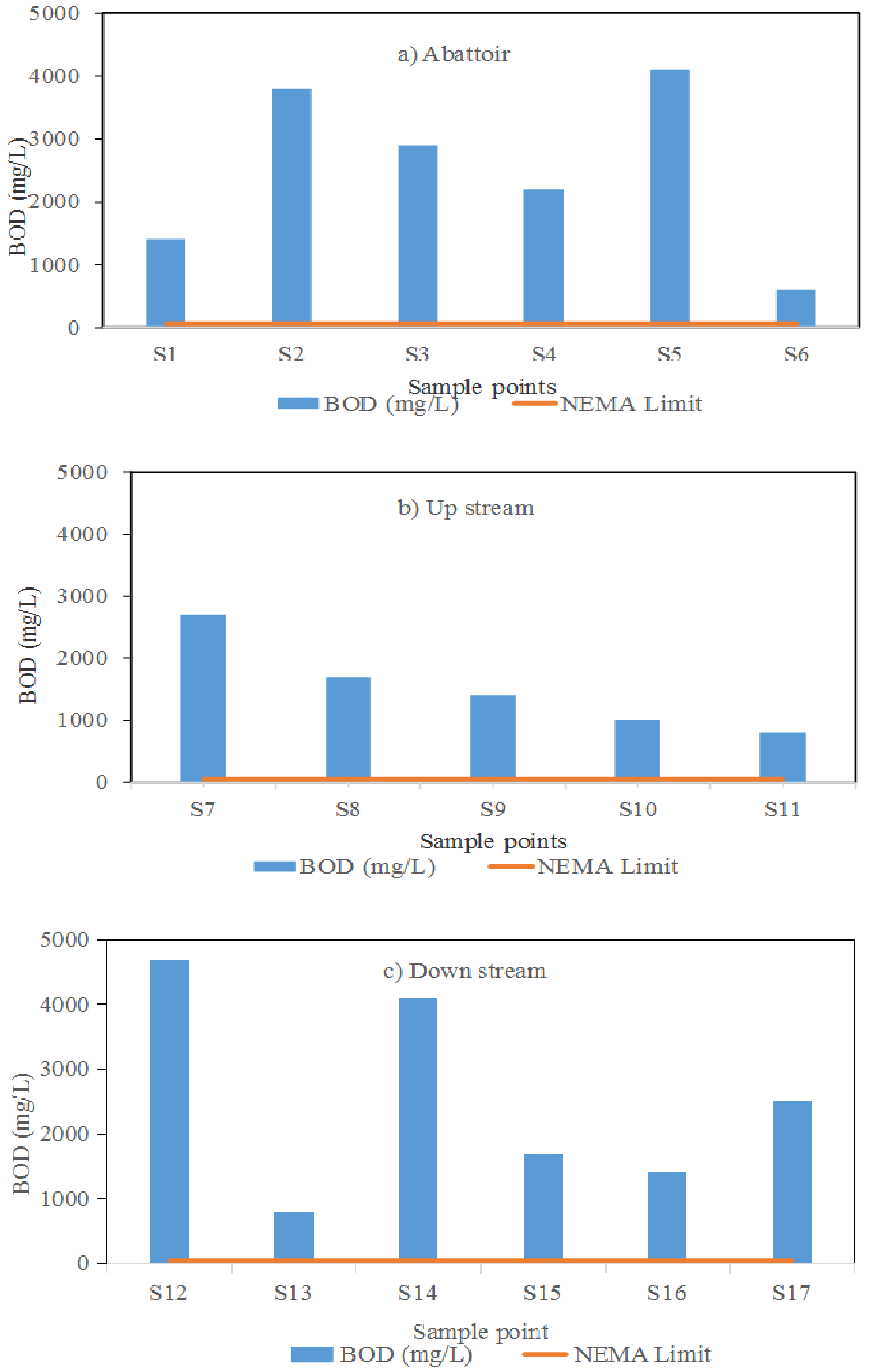

**Figure 4.14:** Comparison of BOD levels for (a) abattoir, (b) upstream and (c) downstream with NEMA limit.

In Figure 4.15 (c), the BOD levels remain high, ranging from 800 to 4700 mg/L River Rwizi downstream. The highest downstream BOD value of 4700 mg/L is observed at S12, which is even higher than the maximum value recorded at the abattoir. The persistence of high BOD levels downstream suggests that the river's self-purification capacity is overwhelmed, and the pollutants are being carried further along the river.

The NEMA limit for BOD in water bodies is 50 mg/L, which is intended to protect aquatic life and ensure water quality. All the BOD values recorded at the abattoir, upstream, and downstream sampling points exceeded this limit, often by several orders of magnitude. This indicates a severe violation of water quality standards and highlights the urgent need for intervention to reduce organic pollution from the abattoir.

**Table 4.7:** Summary of the chemical properties of the water at the abattoir, upstream and downstream.

| **Sample site** | **Abattoir** | | **Upstream** | | **Downstream** | |
|---|---|---|---|---|---|---|
| **Parameter** | **Mean (mg/L)** | **St.dev. (mg/L)** | **Mean (mg/L)** | **St.dev. (mg/L)** | **Mean (mg/L)** | **St.dev. (mg/L)** |
| Copper | 0.649 | 0.448 | 0.159 | 0.063 | 0.114 | 0.032 |
| Nickel | 0.167 | 0.147 | 0.035 | 0.078 | 0.011 | 0.027 |
| Arsenic | 2.733 | 1.021 | 5.648 | 2.797 | 5.920 | 4.267 |
| Chromium | 0.449 | 0.191 | 0.385 | 0.096 | 0.339 | 0.159 |
| Iron | NIL | NIL | NIL | NIL | NIL | NIL |
| Mercury | 6.433 | 7.753 | 0.480 | 1.018 | 1.617 | 1.935 |
| BOD | 2530.000 | 1246.327 | 1520 | 667.533 | 2650 | 1422.049 |
| COD | 604.910 | 153.416 | 83.048 | 3.383 | 252.280 | 61.421 |
| TP | 0.798 | 0.495 | 0.052 | 0.027 | 0.073 | 0.061 |
| TN | 75.888 | 54.887 | 2.835 | 2.417 | 4.150 | 2.659 |

## 4.4 Quantification of impact of the wastewater effluent by comparing upstream and downstream chemical and physical results

The water sample results for each chemical and physical properties are quantified and evaluated to check its impact to the river water quality. Abattoir wastewater has potential impact on water quality (Muhirwa *et al.* 2010). The statistical significance of $p<0.05$ for student t-test paired two sample for mean and ANOVA analysis to compare mean of water samples from River Rwizi.

### *4.4.1 Comparison of copper and downstream and upstream levels*

The water quality analysis of River Rwizi includes the measurement of copper (Cu) concentrations at the abattoir, upstream, and downstream locations. The table 4.8 shows the copper concentrations reported are 0.649 mg/L, 0.159 mg/L, and 0.114 mg/L, respectively. Comparing these results with the (NEMA, 2020) discharge limit of 0.500 mg/L for copper; it is evident that the copper concentrations in River Rwizi are well below the regulatory threshold at all three locations. Based on the results, copper concentrations at the abattoir, upstream, and downstream locations are below the NEMA limit. Form the statistical analysis with *p-value* of 0.034 in table 4.9, indicates that the levels of copper in the water are relatively low and do not pose an immediate concern for water quality in terms of copper contamination. However, it is important to continue monitoring copper levels to ensure they remain within acceptable limits and to identify any potential sources of copper pollution that may influence the river ecosystem.

**Table 4.8:** Student t-test of paired two sample for means for copper downstream and upstream levels.

| | *DOWNSTREAM* | *UPSTREAM* |
|---|---|---|
| Mean | 0.106 | 0.160 |
| Variance | 0.001 | 0.004 |
| Observations | 5 | 5 |
| Pearson Correlation | -0.153 | |
| Hypothesized Mean Difference | 0 | |
| df | 4 | |
| t Stat | -1.642 | |
| P(T<=t) one-tail | 0.088 | |
| t Critical one-tail | 2.132 | |
| P(T<=t) two-tail | 0.176 | |
| t Critical two-tail | 2.776 | |

**Table 4.9**: Results of ANOVA for copper downstream and upstream levels.

SUMMARY.

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| ABATTOIR | 5 | 0.938 | 0.188 | 0.023 |
| DOWNSTREAM | 5 | 0.065 | 0.013 | 0.001 |
| UPSTREAM | 5 | 0.174 | 0.0348 | 0.006 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.091 | 2 | 0.045 | 4.544 | 0.034 | 3.885 |
| Within Groups | 0.119506 | 12 | 0.010 | | | |
| Total | 0.210 | 14 | | | | |

Where; SS =sum of squares, df=degrees of freedom, MS=mean square

### *4.4.2 Comparison of Nickel for downstream and upstream levels*

The nickel concentrations measured at all three locations, namely 0.167 mg/L, 0.035 mg/L, and 0.011 mg/L, respectively in shown in table 4.10 are significantly below the NEMA limit of 0.500 mg/L. This suggests that the water in River Rwizi meets regulatory standards for nickel concentration, indicating good water quality in terms of nickel content. In a study by Ofomatah *et al.* (2023) on effects of abattoir effluent and dumpsite on the physicochemical properties and heavy metal levels of soil and water within Ogbor hill, Aba, It was reported that nickel concentrations ranged from 0.103 to 0.205 mg/L. Both findings report low levels of nickel and no significant influence of abattoir activity on the nickel levels with a p-value of 0.034 in table 4.11

**Table 4.10:** Student t-test of paired two sample for means for nickel downstream and upstream levels.

| | *DOWNSTREAM* | *UPSTREAM* |
|---|---|---|
| Mean | 0.013 | 0.0348 |
| Variance | 0.001 | 0.0061 |
| Observations | 5 | 5 |
| Pearson Correlation | 1 | |
| Hypothesized Mean Difference | 0 | |
| Df | 4 | |
| t Stat | -1 | |
| P(T<=t) one-tail | 0.187 | |
| t Critical one-tail | 2.132 | |
| P(T<=t) two-tail | 0.374 | |
| t Critical two-tail | 2.776 | |

**Table 4.11:** Results of ANOVA for downstream and upstream levels.

SUMMARY.

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| ABATTOIR | 5 | 0.938 | 0.188 | 0.023 |
| DOWNSTREAM | 5 | 0.065 | 0.013 | 0.001 |
| UPSTREAM | 5 | 0.174 | 0.035 | 0.006 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.091 | 2 | 0.045 | 4.544 | 0.034 | 3.885 |
| Within Groups | 0.120 | 12 | 0.010 | | | |
| Total | 0.210 | 14 | | | | |

Where; SS =sum of squares, df=degrees of freedom, MS=mean square

### *4.4.3 Comparison of Arsenic for downstream and upstream levels*

The water quality analysis of River Rwizi reveals elevated concentrations of arsenic (As) at the abattoir, upstream, and downstream locations. The arsenic concentrations reported are 2.733 mg/L, 5.648 mg/L, and 5.920 mg/L, respectively in table 4.12. These concentrations significantly exceed the NEMA limit of 0.100 mg/L for arsenic. The high levels of arsenic pose a significant concern as it is a toxic element with potential health risks to humans and the environment. The statistical analysis shows that there is significant (*p-value 0.118* as shown in Table 4.13) influence of abattoir activities on the arsenic levels of River Rwizi. Arsenic in water bodies leads to increase in microbes and cause cancer and skin diseases (Adesiyan *et al.* 2018).

**Table 4.12:** Student t-test of paired two sample for means for arsenic downstream and upstream levels.

| | *DOWNSTREAM* | *UPSTREAM* |
|---|---|---|
| Mean | 5.512 | 5.648 |
| Variance | 9.800 | 7.824 |
| Observations | 5 | 5 |
| Pearson Correlation | 0.940 | |
| Hypothesized Mean Difference | 0 | |
| df | 4 | |
| t Stat | -0.283 | |
| P(T<=t) one-tail | 0.396 | |
| t Critical one-tail | 2.132 | |
| P(T<=t) two-tail | 0.791 | |
| t Critical two-tail | 2.776 | |

**Table 4.13:** Results of ANOVA for downstream and upstream levels.

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| ABATTOIR | 5 | 12.540 | 2.508 | 0.755 |
| DOWNSTREAM | 5 | 27.560 | 5.512 | 9.800 |
| UPSTREAM | 5 | 28.240 | 5.648 | 7.824 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 31.504 | 2 | 15.752 | 2.571 | 0.118 | 3.885 |
| Within Groups | 73.514 | 12 | 6.126 | | | |
| Total | 105.017 | 14 | | | | |

Where; SS =sum of squares, df=degrees of freedom, MS=mean square

### *4.4.4 Comparison of Chromium for downstream and upstream levels*

The water quality analysis of River Rwizi indicates the presence of chromium (Cr) upstream, and downstream locations. The concentrations of chromium reported are 0.385 mg/L, and 0.339 mg/L, respectively in tables 4.14 and 4.15. These concentrations are all below the (NEMA, 2020) discharge limit of 0.050 mg/L for chromium. Therefore, the chromium levels in River Rwizi, as indicated by the analysis, meet the regulatory standards. This suggests that the water quality in terms of chromium content in River Rwizi is relatively good. However, based on the given data, it can be inferred that the chromium concentrations at the abattoir, upstream, and downstream locations are within acceptable limits according to the NEMA guidelines. This suggests that the water quality in terms of chromium content in River Rwizi is relatively good.

**Table 4.14:** Student t-test of paired two sample for means for chromium downstream and upstream levels.

| | ***DOWNSTREAM*** | ***UPSTREAM*** |
|---|---|---|
| Mean | 0.348 | 0.385 |
| Variance | 0.018 | 0.009 |
| Observations | 5 | 5 |
| Pearson Correlation | 0.919 | |
| Hypothesized Mean Difference | 0 | |
| df | 4 | |
| t Stat | -1.409 | |
| P(T<=t) one-tail | 0.116 | |
| t Critical one-tail | 2.132 | |
| P(T<=t) two-tail | 0.232 | |
| t Critical two-tail | 2.776 | |

**Table 4.15**: Results of ANOVA for Chromium downstream and upstream levels.

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| ABATTOIR | 5 | 2.296 | 0.459 | 0.045 |
| DOWNSTREAM | 5 | 1.742 | 0.348 | 0.018 |
| UPSTREAM | 5 | 1.927 | 0.385 | 0.009 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 0.032 | 2 | 0.016 | 0.668 | 0.531 | 3.885 |
| Within Groups | 0.286 | 12 | 0.024 | | | |
| Total | 0.318 | 14 | | | | |

Where; SS =sum of squares, df=degrees of freedom, MS=mean square

### *4.4.5 Comparison of iron for downstream and upstream levels*

The water quality analysis of River Rwizi indicates that the concentrations of iron (Fe) at the abattoir, upstream, and downstream locations was not detected. Comparing these findings with the NEMA limit of 3.500 mg/L for iron, it is evident that the iron concentrations in River Rwizi are well below the regulatory threshold. Based on the given data, it can be concluded that the iron concentrations at the Abattoir, Upstream, and Downstream locations are below the NEMA limit. This suggests that the water quality in terms of iron content in River Rwizi is satisfactory and does not pose any immediate concerns in relation to iron contamination. Whereas Ofomatah *et al*. (2023) reported high iron levels in abattoir effluent of 61.17 to 596.89 mg/L, the water samples from boreholes next to the abattoir reported lower levels with mean values of 0.183 mg/L. This is attributed to high nutritional usefulness of iron to animals and high solubility of its salts in water.

### *4.4.6 Comparison of Mercury for downstream and upstream levels*

The water quality analysis of River Rwizi reveals the presence of mercury (Hg) at the abattoir, upstream, and downstream locations and the concentrations of mercury reported are 7.260 mg/L, 0.480 mg/L, and 1.580 mg/L, respectively in tables 4.16 and 4.17 as NEMA, 2020 limit of 0.010 mg/L for mercury. It was evident that the abattoir pollutes River Rwizi with mercury.

**Table 4.16:** Student t-test of paired two sample for means for mercury downstream and upstream levels.

| | ***DOWNSTREAM*** | ***UPSTREAM*** |
|---|---|---|
| Mean | 1.58 | 0.48 |
| Variance | 3.392 | 1.037 |
| Observations | 5 | 5 |
| Pearson Correlation | -0.484 | |
| Hypothesized Mean Difference | 0 | |
| df | 4 | |
| t Stat | 0.984 | |
| P(T<=t) one-tail | 0.190 | |
| t Critical one-tail | 2.132 | |
| P(T<=t) two-tail | 0.381 | |
| t Critical two-tail | 2.776 | |

**Table 4.17:** Results of ANOVA for mercury for downstream and upstream levels.

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| ABATTOIR | 5 | 36.300 | 7.260 | 69.923 |
| DOWNSTREAM | 5 | 7.900 | 1.580 | 3.392 |
| UPSTREAM | 5 | 2.400 | 0.480 | 1.037 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 132.401 | 2 | 66.201 | 2.671 | 0.110 | 3.885 |
| Within Groups | 297.408 | 12 | 24.784 | | | |
| Total | 429.809 | 14 | | | | |

Where; SS =sum of squares, df=degrees of freedom, MS=mean square

### *4.4.7 Comparison of Chemical Oxygen Demand (COD) for abattoir, upstream and downstream levels*

The water quality analysis of River Rwizi includes the measurement of Chemical Oxygen Demand (COD) at the abattoir, upstream, and downstream locations. The COD concentrations was 604.910 mg/L, 252.280 mg/L, and 83.048 mg/L, respectively. Comparing these results with the NEMA limit of 70.000 mg/L for COD, it is evident that the COD concentrations in River Rwizi are below the regulatory threshold at all three locations. The upstream and downstream values for the COD were in agreement with findings of Elemile *et al.* (2019) who reported COD of the ground water ranging between 44.67 and 16.67 mg/L in Omu-Aran, Nigeria. The COD at the abattoir was higher than ever reported (Ihekweme et al., 2021).

Based on the given data, it can be concluded that the COD concentrations at the abattoir, upstream, and downstream locations are below the NEMA limit. This suggests that the levels of chemically oxidizable substances in the water are relatively low. However, it is important to note that COD concentrations can fluctuate due to various factors, including seasonal variations, land use practices, and the presence of specific pollutants. Continuous monitoring and assessment are necessary to ensure the long-term sustainability of water quality in River Rwizi, and to identify and address any potential sources of chemical pollution.

**Table 4.18:** Student t-test of paired two sample for means for COD abattoir, downstream and upstream levels t-Test: Paired Two Sample for Means.

| | *UPSTREAM* | *DOWNSTREAM* |
|---|---|---|
| Mean | 83.048 | 252.280 |
| Variance | 14.73052 | 3772.538 |
| Observations | 5 | 5 |
| Pearson Correlation | -0.674 | |
| Hypothesized Mean Difference | 0.05 | |
| df | 4 | |
| t Stat | -5.9084 | |
| P(T<=t) one-tail | 0.0024 | |
| t Critical one-tail | 2.132 | |
| P(T<=t) two-tail | 0.004 | |
| t Critical two-tail | 2.776 | |

**Table 4.19:** Results of ANOVA for COD for downstream and upstream levels.

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| ABATTOIR | 5 | 3024.550 | 604.910 | 23536.480 |
| DOWNSTREAM | 5 | 1261.400 | 252.280 | 3772.538 |
| UPSTREAM | 5 | 415.24 | 83.048 | 14.731 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 708878.890 | 2 | 354439.4 | 38.91554 | 5.68E-06 | 3.885 |
| Within Groups | 109294.976 | 12 | 9107.915 | | | |
| Total | 818173.866 | 14 | | | | |

Where; SS =sum of squares, df=degrees of freedom, MS=mean square

### *4.4.8 Comparison of Biochemical Oxygen Demand (BOD) for downstream and upstream levels*

In tables 4.20 and 4.21 average BOD concentrations were 2530, 1520, and 2650mg/L, at abattoir, upstream, and downstream respectively. Comparing these results with the NEMA limit of 50.000 mg/L for BOD, it is evident that the BOD concentrations in River Rwizi are significantly higher than the regulatory threshold. Elemile *et al.* (2019) reported BOD values ranging from 12 to 26 mg/L in a monthly analysis of water quality of a river receiving abattoir effluent. The reported value is very high; this could be attributed to indifference in water speed, volume and sources of water to the river.

**Table 4.20:** Student t-test of paired two sample for means for BOD downstream and upstream levels.

| | *UPSTREAM* | *DOWNSTREAM* |
|---|---|---|
| Mean | 1520 | 2650 |
| Variance | 557000 | 2780000 |
| Observations | 5 | 5 |
| Pearson Correlation | 0.58463256 | |
| Hypothesized Mean Difference | 0 | |
| df | 4 | |
| t Stat | -1.8418474 | |
| P(T<=t) one-tail | 0.06964985 | |
| t Critical one-tail | 2.13184679 | |
| P(T<=t) two-tail | 0.13929969 | |
| t Critical two-tail | 2.77644511 | |

**Table 4.21:** Results of ANOVA for BOD downstream and upstream levels.

| Groups | Count | Sum | Average | Variance | | |
|---|---|---|---|---|---|---|
| ABATTOIR | 5 | 12650 | 2530 | 792000 | | |
| DOWNSTREAM | 5 | 13250 | 2650 | 2780000 | | |
| UPSTREAM | 5 | 7600 | 1520 | 557000 | | |
| ANOVA | | | | | | |
| Source of Variation | SS | df | MS | F | P-value | F crit |
| Between Groups | 3852333.333 | 2 | 1926167 | 1.399491 | 0.284247 | 3.885294 |
| Within Groups | 16516000 | 12 | 1376333 | | | |
| Total | 20368333.33 | 14 | | | | |

Where; SS =sum of squares, df=degrees of freedom, MS=mean square

### *4.4.9 Comparison of Total Phosphorus for abattoir, downstream and upstream levels*

It was observed in tables 4.22 and 4.23 that the total phosphorus levels in all locations (abattoir, upstream, and downstream) were significantly lower than the NEMA limit of 5.000 mg/L. This suggests that the phosphorus content in the water from River Rwizi near the abattoir is within acceptable limits and does not pose a significant risk to the environment or water quality. The presence of high levels of nutrients like phosphorus in water can lead to eutrophication, a process in which excessive nutrients promote the growth of algae and aquatic plants. This can disrupt the balance of the aquatic ecosystem and deplete oxygen levels, negatively influencing the water quality and aquatic life. However, in the case of River Rwizi, the total phosphorus levels near the abattoir (0.855mg/L) are considerably lower than the NEMA limit (5.000mg/L), suggesting that the phosphorus contribution from the abattoir is currently within acceptable limits. In a study by Yilmaz and Koç (2014), it was reported that, orthophosphate of river Akcay which receives effluent from a dairy farm was 0.12 mg/L which is lower than 0.798 mg/L.

**Table 4.22:** Student t-test of paired two sample for means for Total Phosphorus downstream and upstream levels.

| | *DOWNSTREAM* | *UPSTREAM* |
|---|---|---|
| Mean | 0.076 | 0.052 |
| Variance | 0.005 | 0.001 |
| Observations | 5 | 5 |
| Pearson Correlation | 0.42 | |
| Hypothesized Mean Difference | 0 | |
| df | 4 | |
| t Stat | 0.863 | |
| P(T<=t) one-tail | 0.219 | |
| t Critical one-tail | 2.132 | |
| P(T<=t) two-tail | 0.437 | |
| t Critical two-tail | 2.776 | |

**Table 4.23:** Results of ANOVA for Total Phosphorus abattoir, downstream and upstream levels.

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| ABATTOIR | 5 | 4.274 | 0.855 | 0.280 |
| DOWNSTREAM | 5 | 0.378 | 0.076 | 0.005 |
| UPSTREAM | 5 | 0.261 | 0.052 | 0.001 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 2.086 | 2 | 1.043 | 10.973 | 0.002 | 3.885 |
| Within Groups | 1.141 | 12 | 0.095 | | | |
| Total | 3.227 | 14 | | | | |

Where; SS =sum of squares, df=degrees of freedom, MS=mean square

### *4.4.10 Comparison of Total Nitrogen for abattoir, downstream and upstream levels*

Table 4.25 shows total nitrogen results for water quality analysis of River Rwizi indicate varying concentrations of total nitrogen at different locations. The abattoir location shows a significantly high concentration of 82.743 mg/L, surpassing the NEMA limit of 10.000 mg/L. Neboh *et al.* (2013) found high levels of total nitrogen in the river than uncontaminated river water. In Table 4.24 illustrates the mean value concentration for Upstream and downstream of 2.835 and 4.200mg/L respectively. The abattoir has *p-value* = 0.004 table table 4.25 indicating a significant impact of the total nitrogen in the water according to the statistical analysis carried out.

**Table 4.24:** Student t-test of paired two sample for means for Total Nitrogen abattoir, downstream and upstream.

| | *DOWNSTREAM* | *UPSTREAM* |
|---|---|---|
| Mean | 4.200 | 2.835 |
| Variance | 8.255 | 5.840 |
| Observations | 5 | 5 |
| Pearson Correlation | -0.381 | |
| Hypothesized Mean Difference | 0 | |
| df | 4 | |
| t Stat | 0.693 | |
| P(T<=t) one-tail | 0.2631 | |
| t Critical one-tail | 2.1312 | |
| P(T<=t) two-tail | 0.526 | |
| t Critical two-tail | 2.776 | |

**Table 4.25:** Results of ANOVA for total nitrogen for abattoir, downstream and upstream.

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| ABATTOIR | 5 | 413.716 | 82.743 | 3412.805 |
| DOWNSTREAM | 5 | 21.001 | 4.200 | 8.255 |
| UPSTREAM | 5 | 14.175 | 2.835 | 5.840 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F critical* |
|---|---|---|---|---|---|---|
| Between Groups | 20926.986 | 2 | 10463.493 | 9.160 | 0.004 | 3.885 |
| Within Groups | 13707.598 | 12 | 1142.300 | | | |
| Total | 34634.584 | 14 | | | | |

| | | | |
|---|---|---|---|
| Within Groups | 16516000 | 12 | 1376333 |
| Total | 20368333.33 | 14 | |

Where; SS =sum of squares, df=degrees of freedom, MS=mean square

## 4.5. Exploring a cheaper water treatment using rice husks

Based on the finding the abattoir pollutes River Rwizi water. For the community using water from River Rwizi need to improve water treatment and at low cost hence exploring use of rice husks to treat water before use. The researcher explored both raw and activated carbon rice husks to treat water and compared their efficiencies at different dosages and contact time

### *4.5.1 COD removal with raw rice husks*

The results in Table 4.26 shows the effectiveness of using raw rice husks for removing COD from wastewater. Generally, the COD removal rate increases with increasing contact time and dosage of raw rice husks. At each contact time, higher dosages of raw rice husks tend to result in higher COD removal rates. For example, at 5 minutes' contact time, the COD removal rate increased from 35.0% for 1 gram to 55.0% for 5 grams, indicating that the removal rate increased with increasing dosage.

Contact time is a critical factor in adsorption efficiency. The results demonstrated a positive correlation between contact time and COD removal percentage for both raw and activated rice husks across all dosages. For instance, with a 5 grams dosage of activated rice husks, the COD removal increased from 79% at 5 minutes to 91% at 20 minutes. This trend occurs because a longer contact time provides more opportunity for the organic pollutant molecules to diffuse through the solution, reach the adsorbent surface, and navigate the pore network to bind to active sites (Mortada et al., 2023). The initial rapid removal (within the first 5-10 minutes) is due to the abundance of vacant surface sites, which gradually saturated over time, leading to a slower rate of removal until equilibrium is reached.

**Table 4.26:** Summary of the twenty duplicate synthetic wastewater treatment experiment for removal of COD with raw and carbonized activated rice husks.

**Raw rice husks**

| Contact Time (minutes) | 1 g | 2 g | 3 g | 4 g | 5 g |
|---|---|---|---|---|---|
| 5.0 | 35.0 | 44.0 | 48.0 | 52.0 | 55.0 |
| 10.0 | 37.0 | 46.0 | 50.0 | 55.0 | 58.0 |
| 15.0 | 38.0 | 49.0 | 51.0 | 59.0 | 62.0 |
| 20.0 | 41.0 | 51.0 | 53.0 | 62.0 | 65.0 |

**Activated Carbonized Rice husks**

| Contact Time (minutes) | 1 g | 2 g | 3 g | 4 g | 5 g |
|---|---|---|---|---|---|
| 5.0 | 47.0 | 54.0 | 64.0 | 65.0 | 79.0 |
| 10.0 | 48.0 | 58.0 | 67.0 | 69.0 | 84.0 |
| 15.0 | 51.0 | 63.0 | 69.0 | 73.0 | 88.0 |
| 20.0 | 52.0 | 65.0 | 72.0 | 74.0 | 91.0 |

Where g means gram

These findings are consistent with previous studies on the use of agricultural waste materials, such as rice husks, for wastewater treatment. For instance, Tchamango *et al.* (2017) demonstrated the potential of rice husks as an adsorbent for the removal of COD from textile wastewater. In a similar study by Ahmaruzzaman and Gupta (2011) the adsorption capacity of rice husk for selected organic dyes was reported to vary from 99.4 mg/g to 155 mg/g. This is in agreement with reported effective removal of COD from wastewater in this study.

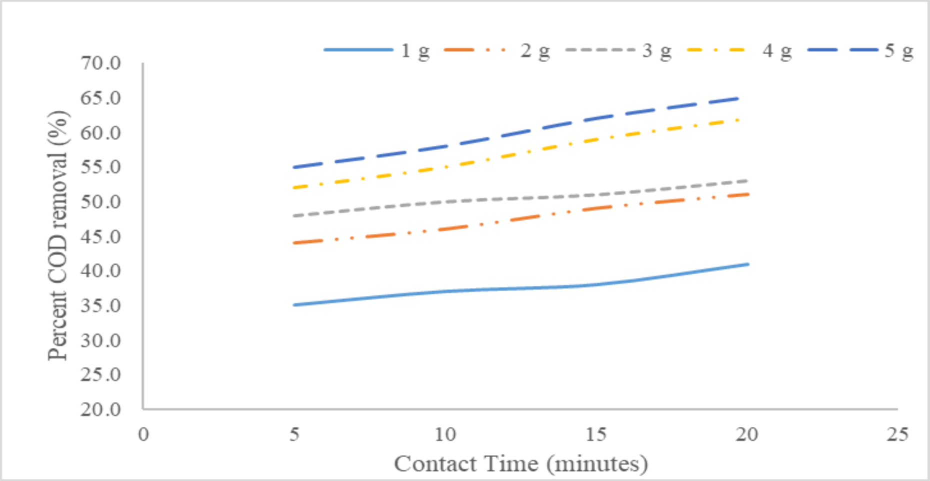

**Figure 4.15:** Effect of contact time on COD removal for different dosages.

The removal takes s-shape for all dosages. The removal increases gradually between 5 and 10 minutes then slight increase between 10 and 15 then resume with slight increase in COD removal at contact time of 20 minutes. All experiments were carefully and accurately carried with least correlation coefficient of 0.9627 and a highest correlation as 0.9966 at 1, and 5g dosage respectively. From the figure 4.16, the higher the dosage, the higher the COD removal from water with longer contact time.

### *4.5.2 COD removal with activated carbonized rice husks*

The removal of COD using rice husks primarily occurs through adsorption, a process where pollutant molecules accumulate on the surface of the adsorbent. The mechanism differs between raw and activated carbonized rice husks: Removal is primarily due to physical adsorption (physisorption) and the presence of surface functional groups like silanol (Si-OH) and cellulose hydroxyls (-OH). These groups can form weak Van der Waals forces and hydrogen bonds with organic molecules present in the wastewater, thereby removing them from solution (Ahmaruzzaman and Gupta, 2011). The relatively lower surface area of raw husks limits their efficiency. The carbonization and activation process dramatically increases the surface area and creates a microporous structure. This enhances two mechanisms: Enhanced Physical Adsorption: The vast network of pores provides more sites for organic molecules to be trapped and Chemical Adsorption (Chemisorption): The activation process introduces oxygen-containing functional groups (e.g., carboxyl, lactone, phenol) on the carbon surface. These groups can form stronger, often covalent, bonds with specific organic pollutants, leading to higher removal efficiency (Blachnio et al., 2020). The superior performance of the activated carbon, as shown by the 91% COD removal, is directly attributable to this synergistic effect of high surface area and surface chemistry."

Based on the given result, it shows increasing the dosage of activated carbonized rice husks leads to an increasing in COD removal with increasing contact time. For each contact time, the COD removal increased as the dosage of activated carbonized rice husks increased. For example, at a contact time of 5 minutes, the COD removal increased from 47.0% for 1 gram to 79.0% for 5 grams.

Similarly, at a contact time of 20 minutes, the COD removal increased from 52.0% for 1 gram to 91.0% for 5 grams. These findings are consistent with previous studies that have demonstrated that increasing the dosage of activated carbon can improve COD removal in wastewater treatment processes (Mortada *et al*., 2023).

Furthermore, the increasing trend in COD removal with increasing contact time for each dosage level suggests that longer contact times is more effective in removal of COD, likely due to increased opportunity for chemical reactions to occur between the activated carbonized rice husks and the wastewater. This finding is supported by a study conducted by Rahman *et al.* (2017) which demonstrated that increasing the contact time in wastewater treatment using activated carbon improve COD removal efficiency.

In addition, table 4.26 shows an increase in both contact time and dosage of activated carbonized rice husks. For instance, at 5 minutes contact time, the COD removal rate increased from 47.0% for 1 gram to 79.0% for 5 grams, indicating that the removal rate increased with increasing dosage. Similarly, at 20 minutes contact time, the COD removal rate increased from 52.0% for 1 gram to 91.0% for 5 grams, indicating that the removal rate increased dosage.

These findings are consistent with previous studies on the use of activated carbon in wastewater treatment. Sivakumar *et al.* (2020) demonstrated that higher doses of activated carbon led to higher COD removal rates in the treatment of textile wastewater. Similarly, Abdel-Ghani *et al.* (2007) showed that increasing the dose of activated carbon improved the removal of COD from industrial wastewater.

The results also suggests that there may be an optimal dosage and contact time for achieving maximum COD removal rates. This is because while increasing the dosage and contact time generally leads to higher COD removal rates, there may be a point beyond which additional increases do not result in significant additional removal rates. Thus, it is important to optimize the dosage and contact time to achieve the best possible COD removal rates.

Overall, the results suggest that increasing the dosage of activated carbonized rice husks and extending the contact time can improve COD removal in wastewater treatment processes. This agrees with findings of (Mortada *et al*., 2023) who concluded that chemically activated carbonized rice husks are effective for the elimination of COD from wastewater with longer contact time of 100 minutes.

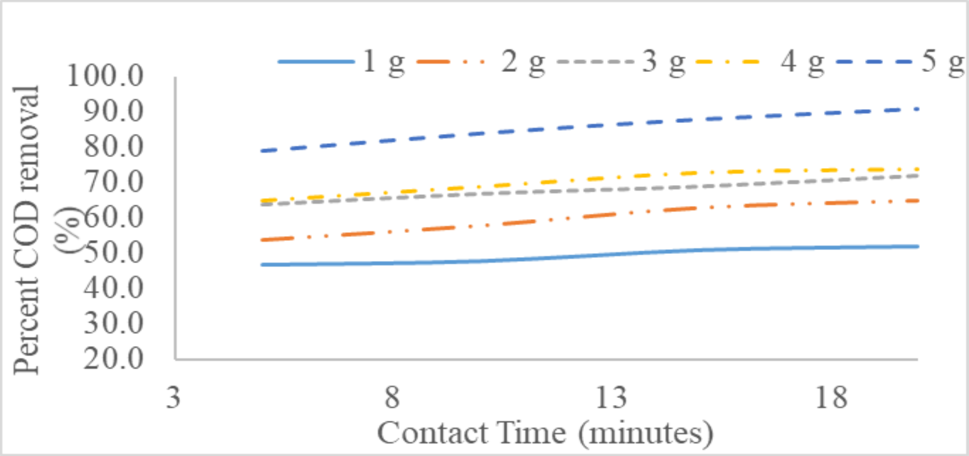

**Figure 4.16:** Variation of COD removal by activated carbonized with contact time at different dosages.

COD removal is directly proportional to adsorbent dosage for 1-5grams of the activated carbon. Figure 17 shows that longer contact times allow for more effective removal of COD, likely due to increased opportunity for chemical reactions to occur between the treatment agent and the wastewater. However, it was important to note that this trend may not continue indefinitely, as there was a point where additional contact time does not result in significant additional COD removal.

### *4.5.3 Comparison of removal efficacy of raw and carbonized rice husks*

Generally, COD removal varies linearly with contact time. Figures 4.17 a and b show higher COD removal by carbonized rice husks than raw rice husks for the same contact time and different dosages. Figure 4.17 (c) show that the difference in COD removal for the same dosage and contact time increases as contact time increases. When comparing the data for activated carbonized and raw rice husks for COD removal, several studies have found that activated carbonized rice husks generally exhibit higher removal rates than raw rice husks.

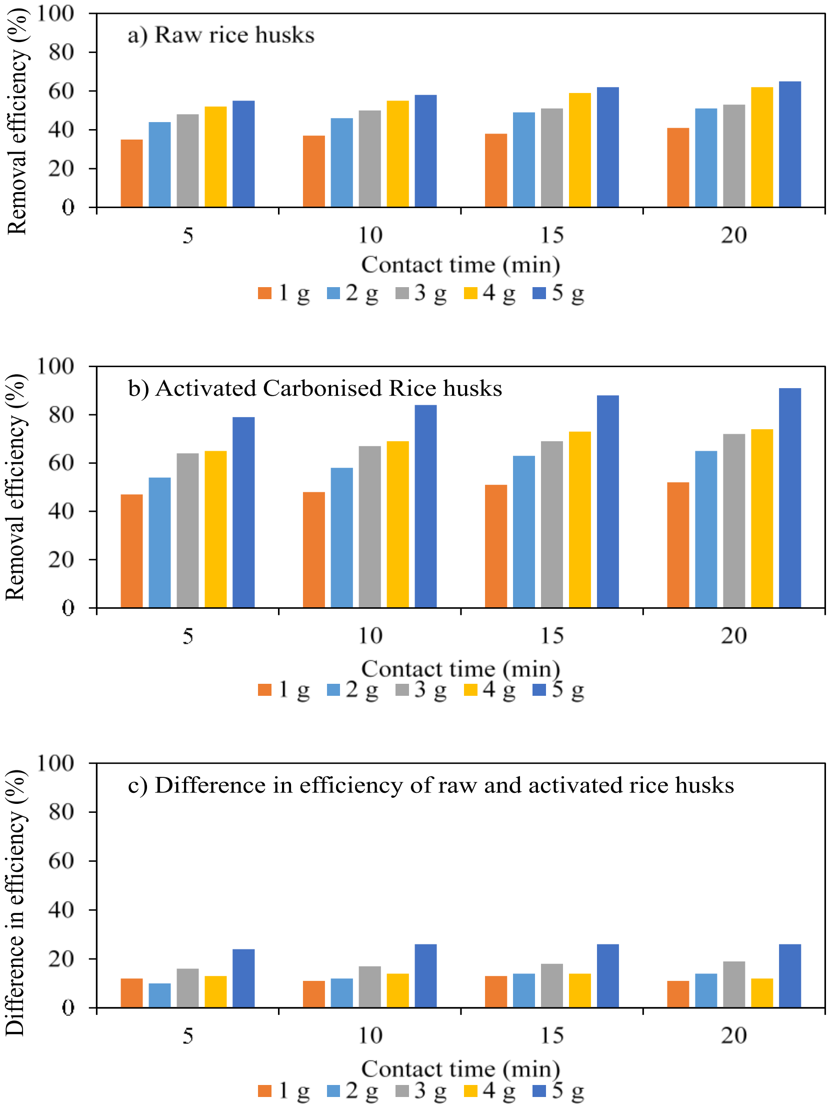

**Figure 4.17:** Comparison of removal efficacy of raw and carbonized rice husks.

Here are some examples of research supporting this comparison:

Hussain *et al*. (2017) investigated the use of activated carbonized rice husk and raw rice husk for the removal of COD from textile wastewater. They reported that activated carbonized rice husk had a higher COD removal efficiency than raw rice husk, with removal rates of up to 93% and 66%, respectively. The authors attributed this to the higher surface area and porosity of the activated carbonized rice husk, which allowed for greater adsorption of COD.

Zhang *et al*. (2020) studied the use of rice husk biochar for COD removal from landfill leachate and found that activated carbonized rice husk had a higher COD removal efficiency than raw rice husk. At a dosage of 5 g, the COD removal rates for activated carbonized rice husk and raw rice husk were 92% and 77%, respectively. The authors noted that the higher removal efficiency of activated carbonized rice husk was due to its larger surface area and microporous structure.

Ahmed *et al*. (2016) compared the COD removal efficiency of activated carbonized and raw rice husk in the treatment of dye wastewater. They reported that activated carbonized rice husk had a higher COD removal efficiency than raw rice husk, with removal rates of up to 95% and 72%, respectively. The authors attributed this to the higher surface area, porosity, and specific surface groups of activated carbonized rice husk.

Overall, these studies suggest that activated carbonized rice husk is generally more effective than raw rice husk for the removal of COD from wastewater due to its higher surface area and porosity. However, it is important to note that the effectiveness of each material can be influenced by several factors, such as the type and concentration of pollutants in the wastewater, the dosage and contact time of the adsorbent, and the pH and temperature of the system.

In conclusion, the data suggests that raw rice husks can be used for the removal of COD from wastewater, but their effectiveness is limited compared to activated carbonized rice husks. Nonetheless, using raw rice husks as an alternative adsorbent material for wastewater treatment could be a sustainable and cost-effective solution, particularly in regions where activated carbon is not readily available or affordable.

# CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

## 5.1. Conclusion

### *5.1.1 What are the wastewater effluent management practiced at Ruti abattoir?*

The abattoir generates a large quantity of wastewater during its operation collected from cleaning processes. The floor of the abattoir slaughtering section is cemented and having drainage channels where wastewater flows to the septic tank outside. The available septic tank is small and cannot contain the amount of generated wastewater and during the study, a hidden outlet discharging wastewater to open environment in the nearby bush. Blood generated during abattoir operation is boiled on site below the penstock. In addition, there is rainwater harvest systems in place at the facility and during rainy season storm; water carries away dropping from penstock holding area downstream to the River Rwizi

### *5.1.2 What are the characteristics of the Ruti abattoir wastewater effluent?*

The wastewater generated from the abattoir flow to river, then river water upstream and downstream of River Rwizi. The heavy metals element characterized are Copper, Nickel, Arsenic, Chromium, Mercury and Iron and other elements are Total Phosphorus (TP), Total Nitrogen (TN), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD).

The heavy metals found present in three abattoir wastewater and River Rwizi water were Chromium, nickel, copper, mercury. Iron was tested and was not present in all water samples collected. In addition to heavy metals, other elements characterized were COD, BOD, TN and TP. These elements deplete dissolved oxygen, posing the greatest threat to aquatic life and rendering the water unsafe for human use. The abattoir effluent had high concentration of BOD and COD compared to the River Rwizi water.

### *5.1.3 How is the impact of abattoir wastewater effluent on quality of River Rwizi?*

The abattoir activities have a significant effect on the water bodies and from the wastewater treatments. There significantly high concentration of COD contained in the abattoir wastewater generated flowing to River Rwizi with p-value of $5.1x10^6$ indicating (*p-value* <0.05). The elements with *p-value* <0.05 are copper, nickel, TP and TN significantly impacting the River Rwizi water quality. However, arsenic, chromium, mercury, BOD their *p-values* >0.05 These elements influence negatively River Rwizi water quality for human use and consumption.

### *5.1.4 To what extent can raw and activated rice husks treat wastewater from abattoir?*

The data demonstrates that increasing the dosage and contact time of rice husks can lead to higher COD removal rates in water treatment. The dosage 1, 2, 3, 4 and 5 grams of raw and activated carbon rice husks at contact time of 20 minutes increased efficiency in COD removal of 41, 51, 53, 62, 65% and 52, 65, 72, 74 and 91%, respectively. The efficiency is directly proportional with increase contact time of 5, 15 and 20 minutes at dosage of 5 g of raw and activated carbon rice husks of 55, 62, 65 and 79, 88, 91%, respectively.

Activated carbon demonstrated high efficiency in COD removal compared with raw rice husks at different dosages and contact time. These findings are consistent with previous studies and suggest that activated carbon can be an effective treatment agent for COD removal.

## 5.2 Recommendations

### *5.2.1 Policy recommendation*

i) The abattoir management and developers should adhere to effluent discharge limits of National Environment Management Authority when operating the abattoir.

ii) The National Environmental Management Authority as the regulator need to periodically monitor abattoir wastewater discharge levels

iii) The abattoir management need to develop wastewater management plan for containment of effluent generated

### *5.2.2 Further research recommendation*

i) Further research should investigate the efficacy of other locally available agricultural wastes (e.g., banana peels, coffee husks) as adsorbents for treating abattoir wastewater

ii) Apart from chemical components, assessing abattoir wastewater discharge microbiological impact on River Rwizi water quality needs to be carried out

iii) The effect of seasonality should be investigated regarding the impact of Ruti abattoir on quality of River Rwizi.

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# APPENDICES

## Appendix A 1: Administrators Interview Guide

Atugasha Den is a student of Kyambogo University pursuing Master of Science in Water and Sanitation Engineering.

The purpose of this interview guide is to acquire data about Ruti abattoir in Mbarara City wastewater handling which will be used in the current research or study being conducted by the researcher

The data provided will be used strictly for academic purposes and treated with extreme confidentiality.

The data provided will be used strictly for academic purposes and treated with extreme confidentiality.

| | | | |
|---|---|---|---|
| Consent | YES ☐ | | NO ☐ |
| Date of Survey | | | |
| Time of Survey | | | |
| Interviewee Details | Gender | Male ☐ | Female<br>☐ |
| Name | | | |
| Contact | | | |
| Signature | | | |

**Instructions: Tick the option you think is appropriate**

1. Does the abattoir have an Environmental policy statement?

Yes ☐

No ☐

If yes, please state it below

………………………………………………………………………………………

………………………………………………………………………………………

………………………………………………………………………………

Has the abattoir carried out EIA, monitoring and auditing?

Yes ☐

No ☐

If yes, please specify the time of carrying out EIA and the results of the audit.

………………………………………………………………………………

………………………………………………………………………………

Does the abattoir have an Environmental Management System?

Yes ☐ No ☐

If yes, please explain the Environmental Management System details.

………………………………………………………………………………

What are the existing treatment methods for the abattoir waste water in place?

a) Biological treatment only ☐

b) Chemical treatment only ☐

c) Biological and chemical treatment ☐

d) Physical treatment only ☐

Others specify ……………………………………………………………

Where are the treatment gaps in the abattoir waste water treatment system?

a) The inefficient unit process technology currently being used

☐

b) The maintenance schedule of the treatment system

☐

c) Administrative concern and compliance with effluent standards ☐

d) Financial funding of the treatment system

☐ Others specify

…………………………………………………………………………

What administrative measures can be put in place to reduce the treatment gaps?

e) Develop a revised effective abattoir waste water treatment system

☐

f) Place more funds for the improvement of the current treatment system

☐

g) Revise the maintenance schedule for the treatment system ☐

h) Improve company compliance with waste water treatment standards ☐

Others specify ……………………………………………………………

What are the future administrative prospects towards the waste water treatment?

Acquire more land to commission a new waste water treatment plant ☐

Formulate a new environmental policy and regulations towards the abattoir wastewater ☐

Carry out EIA, monitoring and auditing of the improved treatment system

Others specify…………………………………………………………

### *Appendix A 2: Technical Staff Interview Guide*

Atugasha Den is a student of Kyambogo University undertaking Master of Science in water and Sanitation Engineering.

The purpose of this interview guide is to acquire data about Ruti abattoir wastewater handling which will be used in the current research or study being conducted by the researcher

The data provided will be used strictly for academic purposes and treated with extreme confidentiality.

| | | |
|---|---|---|
| Consent | Yes ☐ | No ☐ |
| Date of Survey | | |
| Time of Survey | | |
| Interviewee Details | Gender | Male ☐<br>Female ☐ |
| Name | | (Optional) |
| Contact | | |
| Signature | | |

**Instructions: Tick the option you think is appropriate**

1. What is the average total tonnage of meat processed per day abattoir?

   a) Over 10 tons per day ☐

   b) Over 5 tons per day ☐

   a) Less than 5 tons per day ☐

   Other specify ……………………………………………………………

In terms of litres, how much water does each cow processing use per day?

- a) Over 100 litres ☐
- b) Less than 100 litres ☐

Others specify ……………………………………………………

Are there chemical food additives or cleaning chemicals used in the processing section?

1 Chemical food additives ☐

2 Cleaning chemicals like acoustic soda, sodium chloride ☐

3 Disinfectants like chlorine, alcohol ☐

4 Please specify any other chemical additives and cleaning chemicals.………………………………………………………

Does the technical staff have a maintenance schedule? If yes how often is it carried out?

- a) Daily ☐
- b) Weekly ☐
- c) Monthly ☐
- d) Not at all ☐

Others specify below …………………………………………………

What are the existing treatment methods for the abattoir waste water in place?

- a) Biological treatment only ☐
- b) Chemical treatment only ☐

c) Biological and chemical treatment ☐

d) Physical treatment only ☐

Others specify ……………………………………

Where are the treatment gaps in the abattoir waste water treatment system?

a) The existing technology currently being used ☐

b) The maintenance schedule of the treatment system ☐

c) Administrative concern and compliance with effluent standards ☐

d) Financial funding of the treatment system ☐

Others specify………………………………………

Which technical measures can be employed to reduce the treatment gaps?

a) Develop an improved effective abattoir waste water treatment system ☐

b) Revise the maintenance schedule for the abattoir waste water treatment system ☐

Others specify…………………………………………

Does the abattoir have any occupational health and safety regulations?

Yes ☐ No ☐

If yes is there any documentation regarding health and safety

a) Provision and proper use of PPE

b) Provision and compliance with occupational health posters and signage

c) Occupational health and safety training Others specify

……………………………………………………………………………………

…………………………………………………………………………………

Which documents can be provided for consultation?

Yes ☐ No ☐

If yes

a) proper use of PPE ☐

b) compliance with occupational health posters and signage

☐

c) Occupational health and safety training ☐

Others specify ……………………………………………

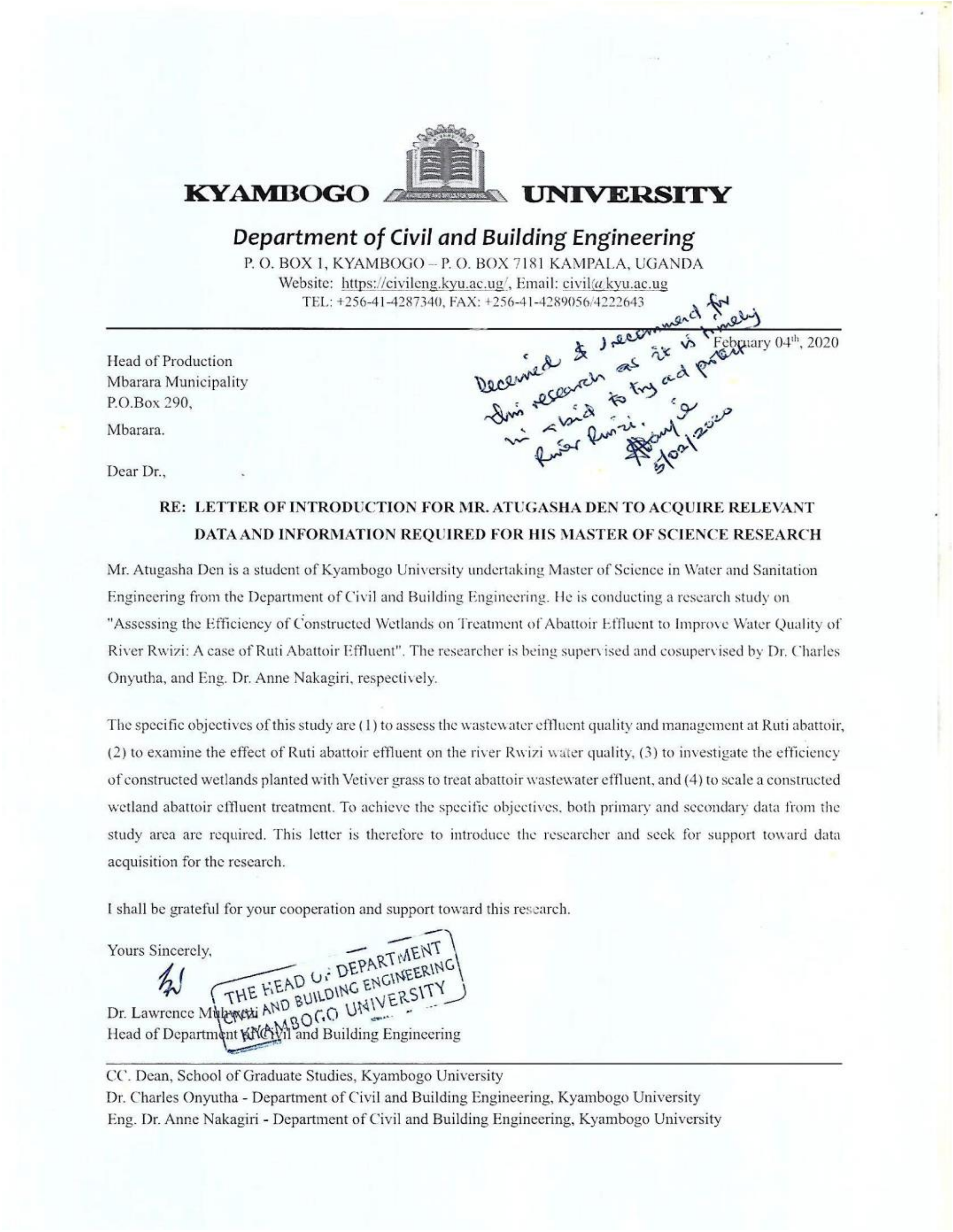
## **Appendix A 3:** Summary of the Twenty Duplicate Synthetic Wastewater Treatment Experiment for Removal of Total Nitrogen with Raw Rice Husks.

| Run | Temp. (ºC) | Contact Time (mins) | Rice husk dosage (g) | Raw Rice Husks | | | Activated carbonized Rice Husks | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean TP Removal % | Mean TN Removal % | Mean COD Removal % | Mean TP Removal % | Mean TN Removal % | Mean COD Removal % |
| 1 | 25.0 | 20 | 0.85 | 88.287 | 36.299 | 55.267 | 71.069 | 51.507 | 86.007 |
| 2 | 47.7 | 10 | 2.36 | 88.711 | 100.000 | 57.544 | 76.099 | 77.017 | 64.601 |
| 3 | 60.0 | 20 | 0.85 | 64.299 | 92.183 | 18.734 | 78.450 | 79.692 | 65.312 |
| 4 | 39.1 | 20 | 1.68 | 39.462 | 100.000 | 50.040 | 56.011 | 98.351 | 69.235 |
| 5 | 25.0 | 16 | 2.36 | 87.932 | 100.000 | 93.840 | 73.596 | 84.579 | 75.251 |
| 6 | 39.1 | 14 | 0.85 | 90.457 | 67.711 | 23.723 | 69.427 | 84.633 | 74.843 |
| 7 | 60.0 | 20 | 0.85 | 95.161 | 88.215 | 22.473 | 78.450 | 88.144 | 65.312 |
| 8 | 60.0 | 14 | 1.68 | 81.567 | 94.496 | 39.574 | 67.188 | 98.351 | 58.044 |
| 9 | 60.0 | 20 | 2.36 | 70.621 | 99.087 | 36.375 | 68.581 | 77.966 | 54.437 |
| 10 | 25.0 | 16 | 1.68 | 93.946 | 97.669 | 78.621 | 70.904 | 87.171 | 74.422 |
| 11 | 25.0 | 10 | 2.36 | 69.359 | 89.211 | 42.813 | 75.933 | 80.042 | 76.041 |
| 12 | 39.1 | 14 | 0.85 | 74.764 | 67.711 | 60.664 | 69.427 | 88.144 | 74.843 |
| 13 | 60.0 | 20 | 2.36 | 85.504 | 100.000 | 42.220 | 68.581 | 87.171 | 54.464 |
| 14 | 60.0 | 10 | 0.85 | 80.742 | 100.000 | 23.815 | 67.359 | 74.176 | 69.445 |
| 15 | 25.0 | 20 | 0.85 | 78.443 | 81.199 | 52.226 | 55.934 | 62.456 | 82.676 |
| 16 | 60.0 | 10 | 0.85 | 72.896 | 94.992 | 20.551 | 67.359 | 74.176 | 69.445 |
| 17 | 47.1 | 10 | 1.68 | 73.183 | 100.000 | 52.765 | 61.435 | 70.475 | 72.210 |
| 18 | 38.8 | 14 | 1.68 | 82.028 | 77.272 | 54.951 | 82.673 | 57.972 | 72.500 |
| 19 | 25.0 | 10 | 1.68 | 59.662 | 100.000 | 75.040 | 70.101 | 53.393 | 78.898 |
| 20 | 58.4 | 19 | 1.68 | 86.446 | 100.000 | 34.005 | 71.539 | 77.960 | 61.178 |

## Appendix A 4: TN results for Raw Rice Husks

| Run | Temperature (ºC) | Contact Time (mins) | Rice husk dosage (g) | Dilution factor | Ordinate (A) | Concentration (mg/L) | N% Removal | Mean Removal % | Stdev.S. % |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 25 | 20 | 0.9 | 1 | 0.529 | 62.716 | 37.284 | 36.299 | 1.393 |
| **1** | 25 | 20 | 0.9 | 1 | 0.545 | 64.686 | 35.314 | | |
| **2** | 47.7 | 10 | 2.4 | 1 | -0.006 | 0.000 | 100.000 | 100.000 | 0.000 |
| **2** | 47.7 | 10 | 2.4 | 1 | -0.002 | 0.000 | 100.000 | | |
| **3** | 60 | 20 | 0.9 | 1 | 0.064 | 7.592 | 92.408 | 92.183 | 0.318 |
| **3** | 60 | 20 | 0.9 | 1 | 0.068 | 8.043 | 91.957 | | |
| **4** | 39.1 | 20 | 1.7 | 1 | -0.025 | 0.000 | 100.000 | 100.000 | 0.000 |
| **4** | 39.1 | 20 | 1.7 | 1 | -0.026 | 0.000 | 100.000 | | |
| **5** | 25 | 16 | 2.4 | 1 | -0.067 | 0.000 | 100.000 | 100.000 | 0.000 |
| **5** | 25 | 16 | 2.4 | 1 | -0.068 | 0.000 | 100.000 | | |
| **6** | 39.1 | 14 | 0.9 | 1 | 0.27 | 32.040 | 67.960 | 67.711 | 0.353 |
| **6** | 39.1 | 14 | 0.9 | 1 | 0.274 | 32.539 | 67.461 | | |
| **7** | 60 | 20 | 0.9 | 1 | 0.099 | 11.779 | 88.221 | 88.215 | 0.008 |
| **7** | 60 | 20 | 0.9 | 1 | 0.099 | 11.791 | 88.209 | | |
| **8** | 60 | 14 | 1.7 | 1 | 0.053 | 6.311 | 93.689 | 94.496 | 1.140 |
| **8** | 60 | 14 | 1.7 | 1 | 0.04 | 4.698 | 95.302 | | |
| **9** | 60 | 20 | 2.4 | 1 | 0.004 | 0.486 | 99.514 | 99.087 | 0.603 |
| **9** | 60 | 20 | 2.4 | 1 | 0.011 | 1.340 | 98.660 | | |
| **10** | 25 | 16 | 1.7 | 1 | 0.02 | 2.313 | 97.687 | 97.669 | 0.025 |
| **10** | 25 | 16 | 1.7 | 1 | 0.02 | 2.349 | 97.651 | | |
| **11** | 25 | 10 | 2.4 | 1 | 0.093 | 11.044 | 88.956 | 89.211 | 0.360 |
| **11** | 25 | 10 | 2.4 | 1 | 0.089 | 10.534 | 89.466 | | |
| **12** | 39.1 | 14 | 0.9 | 1 | 0.27 | 32.040 | 67.960 | 67.711 | 0.352 |
| **12** | 39.1 | 14 | 0.9 | 1 | 0.274 | 32.539 | 67.461 | | |
| **13** | 60 | 20 | 2.4 | 1 | -0.002 | 0.000 | 100.000 | 100.000 | 0.000 |
| **13** | 60 | 20 | 2.4 | 1 | -0.014 | 0.000 | 100.000 | | |
| **14** | 60 | 10 | 0.9 | 1 | -0.007 | 0.000 | 100.000 | 100.000 | 0.000 |
| **14** | 60 | 10 | 0.9 | 1 | -0.023 | 0.000 | 100.000 | | |
| **15** | 25 | 20 | 0.9 | 1 | 0.159 | 18.849 | 81.151 | 81.199 | 0.067 |
| **15** | 25 | 20 | 0.9 | 1 | 0.158 | 18.754 | 81.246 | | |
| **16** | 60 | 10 | 0.9 | 1 | 0.047 | 5.528 | 94.472 | 94.992 | 0.734 |
| **16** | 60 | 10 | 0.9 | 1 | 0.041 | 4.489 | 95.511 | | |
| **17** | 47.1 | 10 | 1.7 | 1 | 25 | 0.000 | 100.000 | 100.000 | 0.000 |
| **17** | 47.1 | 10 | 1.7 | 1 | -0.006 | 0.000 | 100.000 | | |
| **18** | 38.8 | 14 | 1.7 | 1 | 0.189 | 22.372 | 77.628 | 77.272 | 0.503 |
| **18** | 38.8 | 14 | 1.7 | 1 | 0.195 | 23.084 | 76.916 | | |
| **19** | 25 | 10 | 1.7 | 1 | -0.063 | 0.000 | 100.000 | 100.000 | 0.000 |
| **19** | 25 | 10 | 1.7 | 1 | -0.076 | 0.000 | 100.000 | | |
| **20** | 58.4 | 19 | 1.7 | 1 | -0.005 | 0.000 | 100.000 | 100.000 | 0.000 |
| **20** | 58.4 | 19 | 1.7 | 1 | -0.006 | 0.000 | 100.000 | | |

# Appendix A 5: Introductory letter



KYAMBOGO UNIVERSITY

*Department of Civil and Building Engineering*

P. O. BOX 1, KYAMBOGO – P. O. BOX 7181 KAMPALA, UGANDA
Website: https://civileng.kyu.ac.ug/, Email: civil@kyu.ac.ug
TEL: +256-41-4287340, FAX: +256-41-4289056/4222643

February 04th, 2020

Received & I recommend for this research as it is timely in a bid to try and protect River Rwizi.
5/02/2020

Head of Production
Mbarara Municipality
P.O.Box 290,
Mbarara.

Dear Dr.,

**RE: LETTER OF INTRODUCTION FOR MR. ATUGASHA DEN TO ACQUIRE RELEVANT DATA AND INFORMATION REQUIRED FOR HIS MASTER OF SCIENCE RESEARCH**

Mr. Atugasha Den is a student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Building Engineering. He is conducting a research study on "Assessing the Efficiency of Constructed Wetlands on Treatment of Abattoir Effluent to Improve Water Quality of River Rwizi: A case of Ruti Abattoir Effluent". The researcher is being supervised and cosupervised by Dr. Charles Onyutha, and Eng. Dr. Anne Nakagiri, respectively.

The specific objectives of this study are (1) to assess the wastewater effluent quality and management at Ruti abattoir, (2) to examine the effect of Ruti abattoir effluent on the river Rwizi water quality, (3) to investigate the efficiency of constructed wetlands planted with Vetiver grass to treat abattoir wastewater effluent, and (4) to scale a constructed wetland abattoir effluent treatment. To achieve the specific objectives, both primary and secondary data from the study area are required. This letter is therefore to introduce the researcher and seek for support toward data acquisition for the research.

I shall be grateful for your cooperation and support toward this research.

Yours Sincerely,

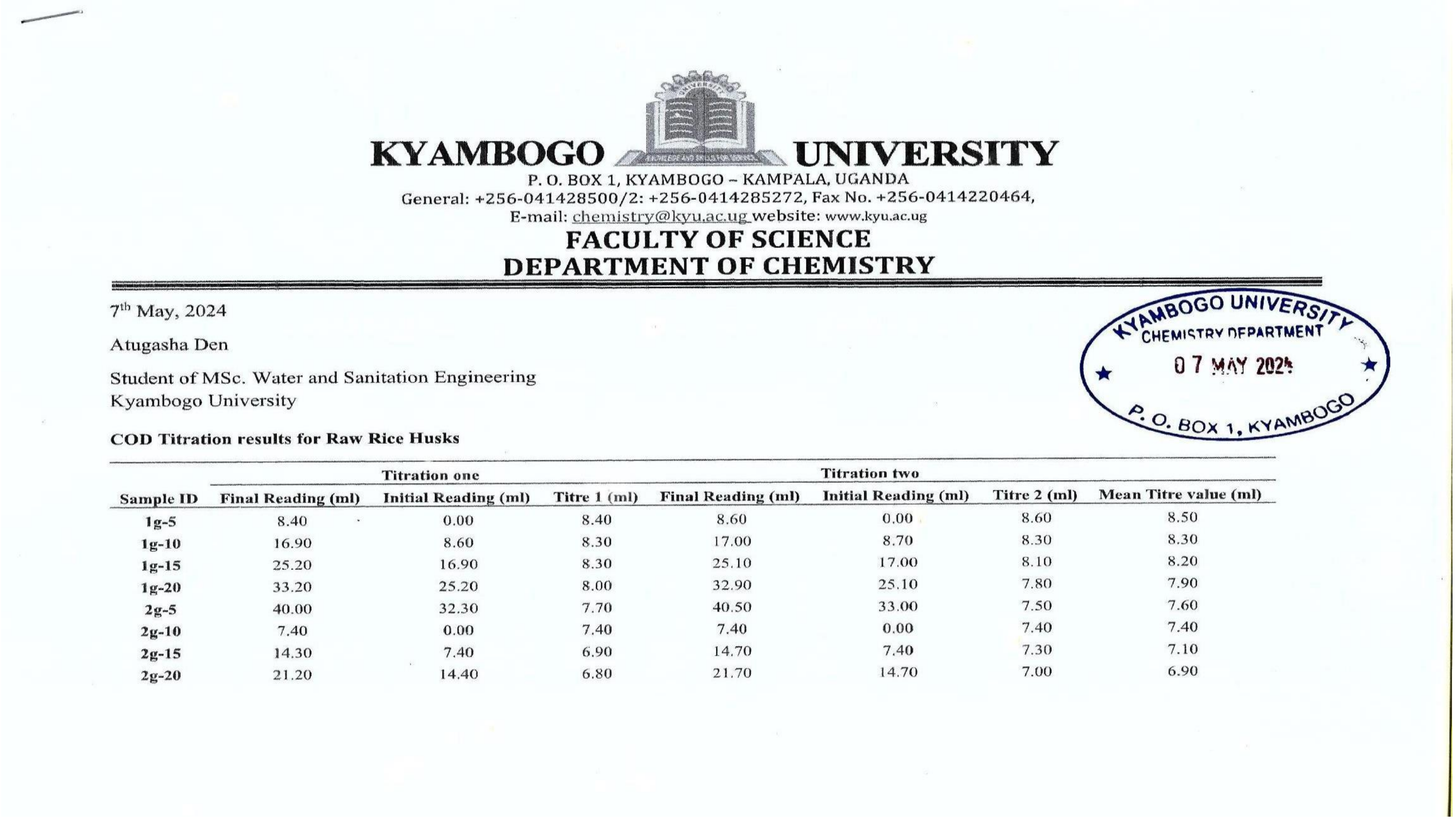
THE HEAD OF DEPARTMENT
CIVIL AND BUILDING ENGINEERING
KYAMBOGO UNIVERSITY

Dr. Lawrence Muhwezi
Head of Department of Civil and Building Engineering

---

CC. Dean, School of Graduate Studies, Kyambogo University
Dr. Charles Onyutha - Department of Civil and Building Engineering, Kyambogo University
Eng. Dr. Anne Nakagiri - Department of Civil and Building Engineering, Kyambogo University

## Appendix A 6: Certified Laboratory Results



**KYAMBOGO UNIVERSITY**
P. O. BOX 1, KYAMBOGO – KAMPALA, UGANDA
General: +256-041428500/2: +256-0414285272, Fax No. +256-0414220464,
E-mail: chemistry@kyu.ac.ug website: www.kyu.ac.ug

### FACULTY OF SCIENCE
### DEPARTMENT OF CHEMISTRY

7th May, 2024

07 MAY 2024

Atugasha Den

Student of MSc. Water and Sanitation Engineering
Kyambogo University

**COD Titration results for Raw Rice Husks**

| | Titration one | | | Titration two | | | |
|---|---|---|---|---|---|---|---|
| **Sample ID** | **Final Reading (ml)** | **Initial Reading (ml)** | **Titre 1 (ml)** | **Final Reading (ml)** | **Initial Reading (ml)** | **Titre 2 (ml)** | **Mean Titre value (ml)** |
| **1g-5** | 8.40 | 0.00 | 8.40 | 8.60 | 0.00 | 8.60 | 8.50 |
| **1g-10** | 16.90 | 8.60 | 8.30 | 17.00 | 8.70 | 8.30 | 8.30 |
| **1g-15** | 25.20 | 16.90 | 8.30 | 25.10 | 17.00 | 8.10 | 8.20 |
| **1g-20** | 33.20 | 25.20 | 8.00 | 32.90 | 25.10 | 7.80 | 7.90 |
| **2g-5** | 40.00 | 32.30 | 7.70 | 40.50 | 33.00 | 7.50 | 7.60 |
| **2g-10** | 7.40 | 0.00 | 7.40 | 7.40 | 0.00 | 7.40 | 7.40 |
| **2g-15** | 14.30 | 7.40 | 6.90 | 14.70 | 7.40 | 7.30 | 7.10 |
| **2g-20** | 21.20 | 14.40 | 6.80 | 21.70 | 14.70 | 7.00 | 6.90 |

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| **3g-5** | 28.40 | 21.30 | 7.10 | 29.00 | 21.70 | 7.30 | 7.20 |
| **3g-10** | 35.40 | 28.50 | 6.90 | 36.10 | 29.00 | 7.10 | 7.00 |
| **3g-15** | 42.30 | 35.40 | 6.90 | 43.00 | 36.10 | 6.90 | 6.90 |
| **3g-20** | 6.50 | 0.00 | 6.50 | 6.90 | 0.00 | 6.90 | 6.70 |
| **4g-5** | 13.20 | 6.50 | 6.70 | 13.80 | 6.90 | 6.90 | 6.80 |
| **4g-10** | 19.70 | 13.20 | 6.50 | 20.30 | 13.80 | 6.50 | 6.50 |
| **4g-15** | 25.90 | 19.70 | 6.20 | 26.30 | 20.30 | 6.00 | 6.10 |
| **4g-20** | 31.90 | 25.90 | 6.00 | 32.00 | 26.40 | 5.60 | 5.80 |
| **5g-5** | 38.30 | 31.90 | 6.40 | 38.60 | 32.00 | 6.60 | 6.50 |
| **5g-10** | 44.30 | 38.30 | 6.00 | 6.40 | 0.00 | 6.40 | 6.20 |
| **5g-15** | 5.90 | 0.00 | 5.90 | 12.10 | 6.40 | 5.70 | 5.80 |
| **5g-20** | 11.30 | 5.90 | 5.40 | 18.30 | 12.70 | 5.60 | 5.50 |

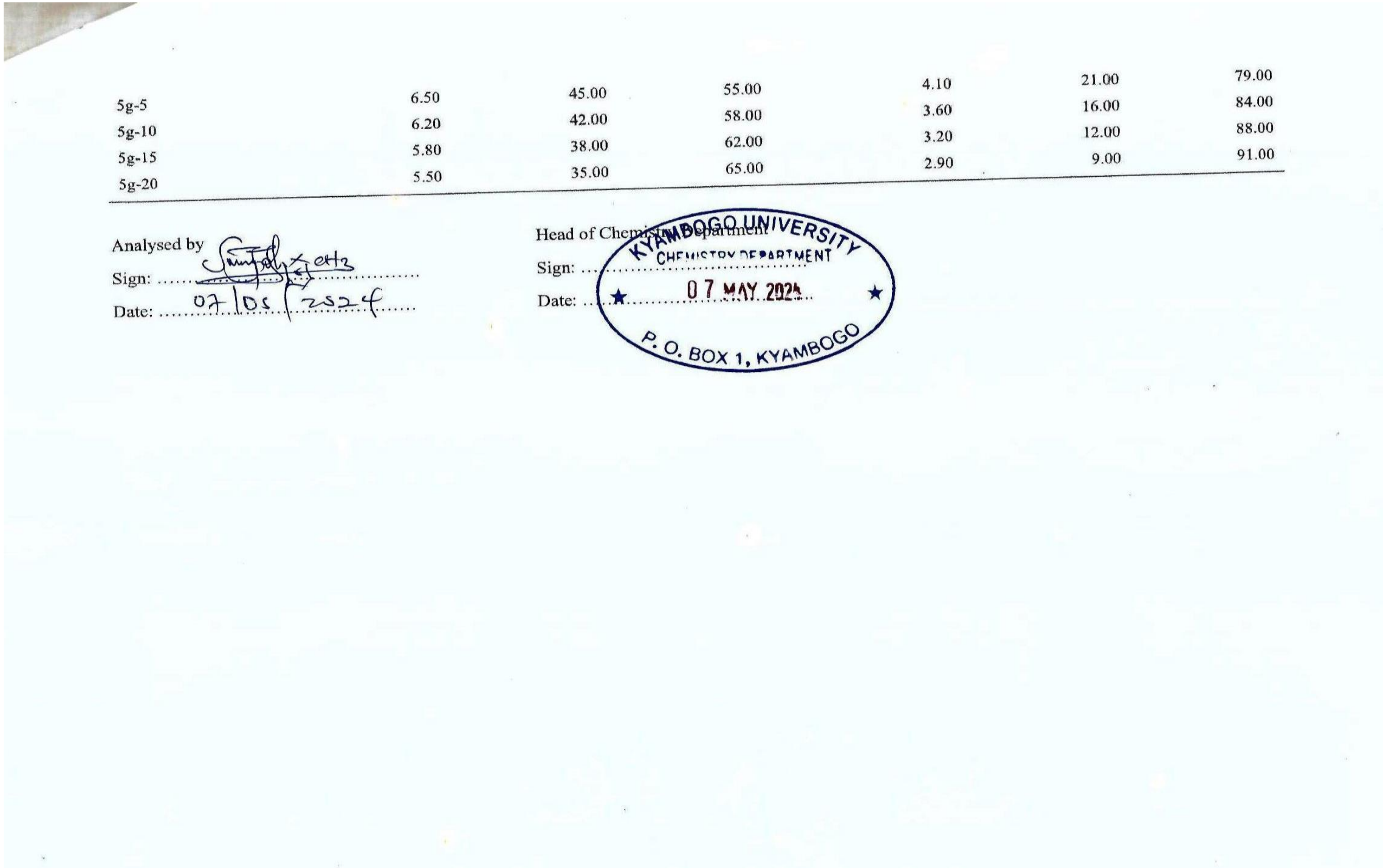
**COD Titration results for Carbonised activated Rice Husks**

| Sample ID | Final Reading 1 (ml) | Initial Reading 1 (ml) | Titre 1 (ml) | Final Reading 2 (ml) | Initial Reading 2 (ml) | Titre 2 (ml) | Mean Titre value (ml) |
|---|---|---|---|---|---|---|---|
| **1g-5** | 7.20 | 0.00 | 7.20 | 7.40 | 0.00 | 7.40 | 7.30 |
| **1g-10** | 14.30 | 7.20 | 7.10 | 14.70 | 7.40 | 7.30 | 7.20 |
| **1g-15** | 21.60 | 14.40 | 7.20 | 21.30 | 14.70 | 6.60 | 6.90 |
| **1g-20** | 28.20 | 21.70 | 6.50 | 28.40 | 21.30 | 7.10 | 6.80 |
| **2g-5** | 34.70 | 28.20 | 6.50 | 6.70 | 0.00 | 6.70 | 6.60 |
| **2g-10** | 40.00 | 33.70 | 6.30 | 12.80 | 6.70 | 6.10 | 6.20 |
| **2g-15** | 5.80 | 0.00 | 5.80 | 18.50 | 12.90 | 5.60 | 5.70 |
| **2g-20** | 11.40 | 5.80 | 5.60 | 23.90 | 18.50 | 5.40 | 5.50 |
| **3g-5** | 17.30 | 11.60 | 5.70 | 29.00 | 23.50 | 5.50 | 5.60 |
| **3g-10** | 23.00 | 17.40 | 5.60 | 36.10 | 31.10 | 5.00 | 5.30 |
| **3g-15** | 28.30 | 23.00 | 5.30 | 43.00 | 38.10 | 4.90 | 5.10 |
| **3g-20** | 33.20 | 28.30 | 4.90 | 6.90 | 2.20 | 4.70 | 4.80 |
| **4g-5** | 38.80 | 33.20 | 5.60 | 12.30 | 6.90 | 5.40 | 5.50 |
| **4g-10** | 43.90 | 38.90 | 5.00 | 17.50 | 12.30 | 5.20 | 5.10 |

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| **4g-15** | 4.80 | 0.00 | 4.80 | 22.10 | 17.50 | 4.60 | 4.70 |
| **4g-20** | 9.40 | 4.80 | 4.60 | 26.70 | 22.10 | 4.60 | 4.60 |
| **5g-5** | 13.60 | 9.40 | 4.20 | 30.70 | 26.70 | 4.00 | 4.10 |
| **5g-10** | 17.10 | 13.60 | 3.50 | 34.40 | 30.70 | 3.70 | 3.60 |
| **5g-15** | 20.60 | 17.40 | 3.20 | 37.60 | 34.40 | 3.20 | 3.20 |
| **5g-20** | 23.60 | 20.60 | 3.00 | 40.40 | 37.60 | 2.80 | 2.90 |

**COD calculation with titre values**

|  | **Raw Rice Husks** |  |  | **Activated** |  |  |
|---|---|---|---|---|---|---|
| Sample ID | Titre value (ml) | COD (mg/L) | % Removal | Tire value (ml) | COD (mg/L) | % Removal |
| 1g-5 | 8.50 | 65.00 | 35.00 | 7.30 | 53.00 | 47.00 |
| 1g-10 | 8.30 | 63.00 | 37.00 | 7.20 | 52.00 | 48.00 |
| 1g-15 | 8.20 | 62.00 | 38.00 | 6.90 | 49.00 | 51.00 |
| 1g-20 | 7.90 | 59.00 | 41.00 | 6.80 | 48.00 | 52.00 |
| 2g-5 | 7.60 | 56.00 | 44.00 | 6.60 | 46.00 | 54.00 |
| 2g-10 | 7.40 | 54.00 | 46.00 | 6.20 | 42.00 | 58.00 |
| 2g-15 | 7.10 | 51.00 | 49.00 | 5.70 | 37.00 | 63.00 |
| 2g-20 | 6.90 | 49.00 | 51.00 | 5.50 | 35.00 | 65.00 |
| 3g-5 | 7.20 | 52.00 | 48.00 | 5.60 | 36.00 | 64.00 |
| 3g-10 | 7.00 | 50.00 | 50.00 | 5.30 | 33.00 | 67.00 |
| 3g-15 | 6.90 | 49.00 | 51.00 | 5.10 | 31.00 | 69.00 |
| 3g-20 | 6.70 | 47.00 | 53.00 | 4.80 | 28.00 | 72.00 |
| 4g-5 | 6.80 | 48.00 | 52.00 | 5.50 | 35.00 | 65.00 |
| 4g-10 | 6.50 | 45.00 | 55.00 | 5.10 | 31.00 | 69.00 |
| 4g-15 | 6.10 | 41.00 | 59.00 | 4.70 | 27.00 | 73.00 |
| 4g-20 | 5.80 | 38.00 | 62.00 | 4.60 | 26.00 | 74.00 |



| | | | | | | |
|---|---|---|---|---|---|---|
| 5g-5 | 6.50 | 45.00 | 55.00 | 4.10 | 21.00 | 79.00 |
| 5g-10 | 6.20 | 42.00 | 58.00 | 3.60 | 16.00 | 84.00 |
| 5g-15 | 5.80 | 38.00 | 62.00 | 3.20 | 12.00 | 88.00 |
| 5g-20 | 5.50 | 35.00 | 65.00 | 2.90 | 9.00 | 91.00 |

Analysed by

Sign: ……………………………………

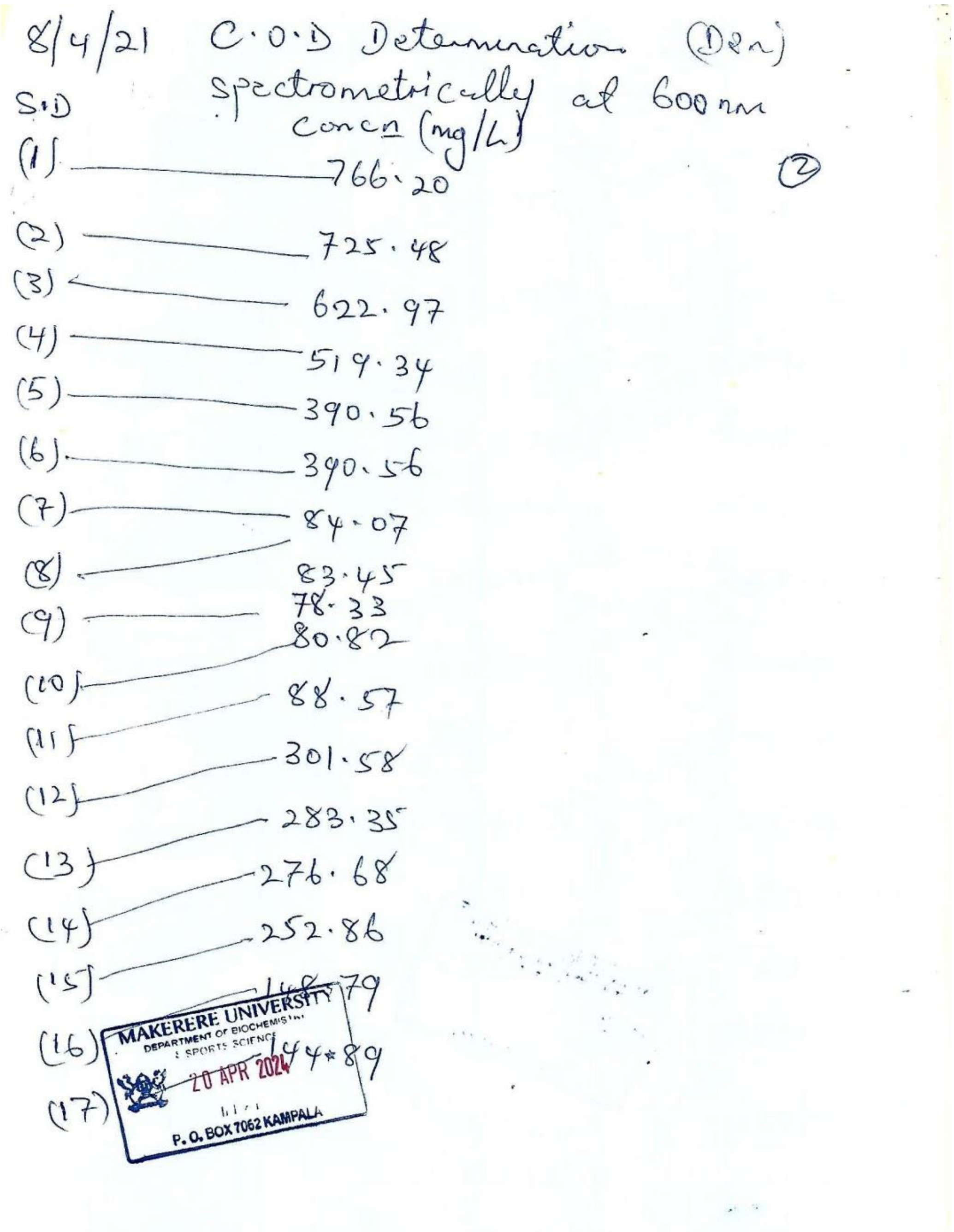
Date: 07/05/2024

Head of Chemistry Department

Sign: ……………………………………

Date: 07 MAY 2024

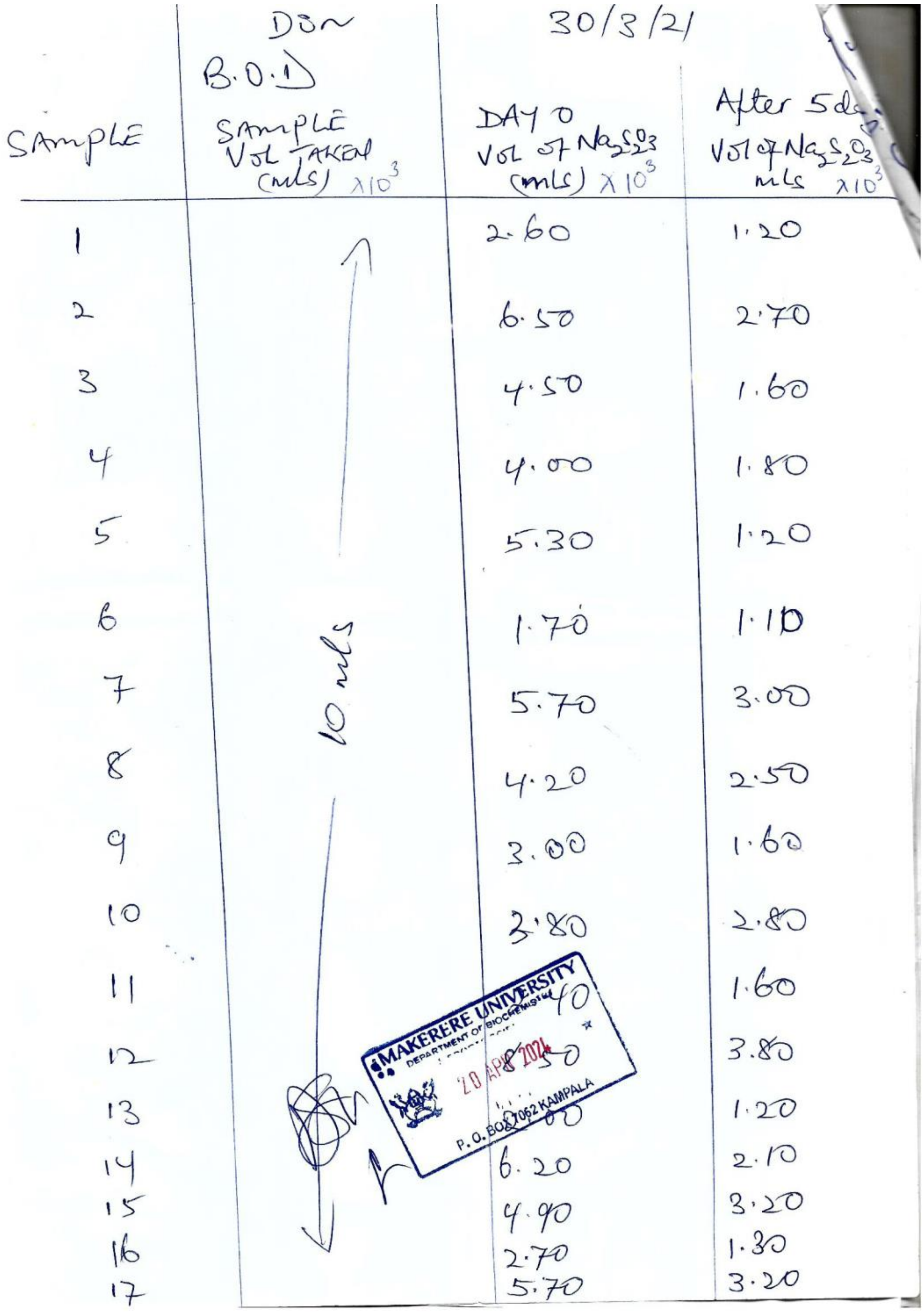
KYAMBOGO UNIVERSITY
CHEMISTRY DEPARTMENT
P. O. BOX 1, KYAMBOGO



8/4/21 C.O.D Determination (Den)
spectrometrically at 600 nm
S.D
Concn (mg/L)

②

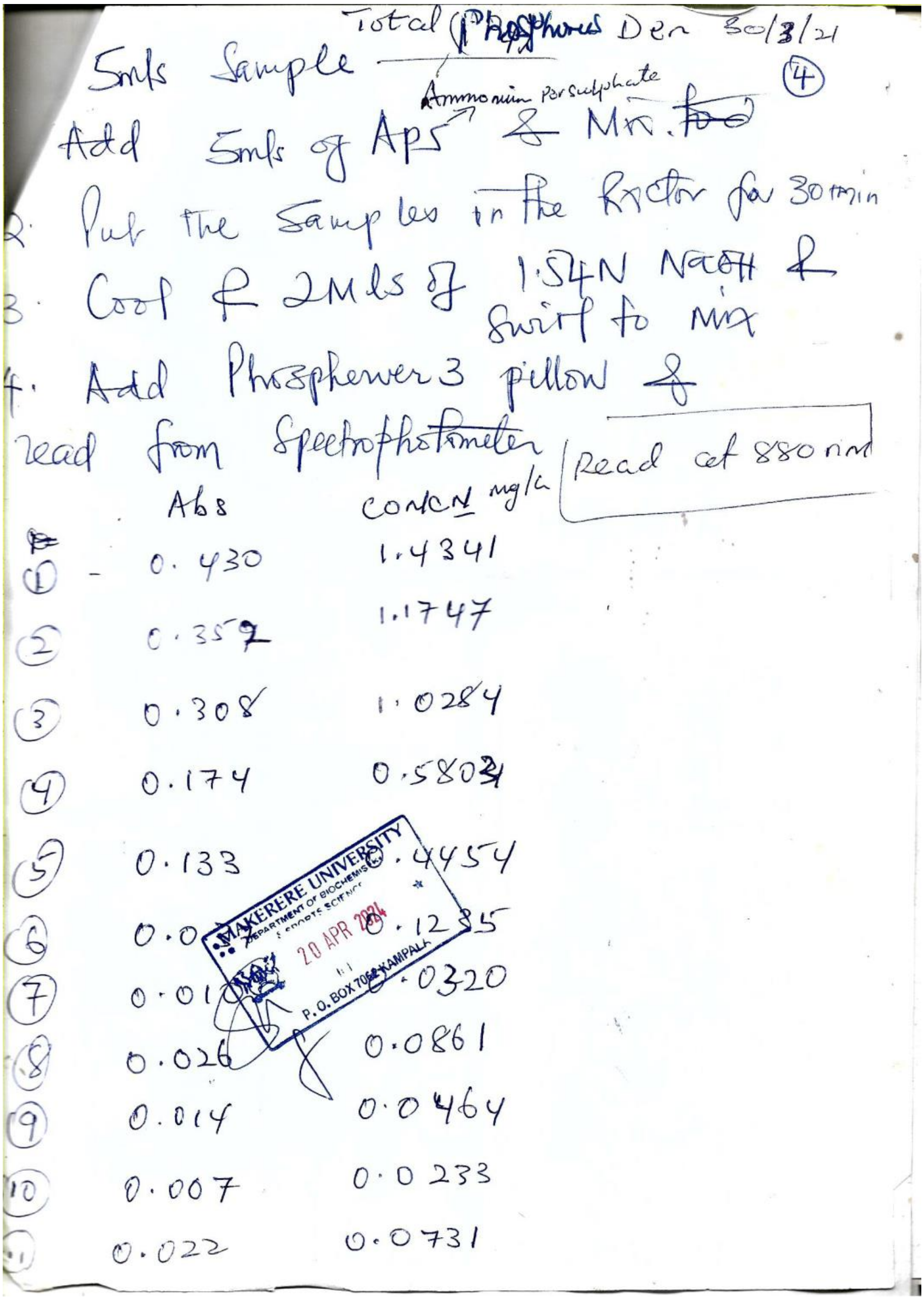
(1) 766.20
(2) 725.48
(3) 622.97
(4) 519.34
(5) 390.56
(6) 390.56
(7) 84.07
(8) 83.45
78.33
(9) 80.82
(10) 88.57
(11) 301.58
(12) 283.35
(13) 276.68
(14) 252.86
(15) 148.79
(16) 144.89
(17)



D3N 30/3/21

B.O.D

| SAMPLE | SAMPLE VOL TAKEN (mls) x$10^3$ | DAY 0 VOL of $Na_2S_2O_3$ (mls) x$10^3$ | After 5 da VOL of $Na_2S_2O_3$ mls x$10^3$ |
|---|---|---|---|
| 1 | 10 mls | 2.60 | 1.20 |
| 2 | | 6.50 | 2.70 |
| 3 | | 4.50 | 1.60 |
| 4 | | 4.00 | 1.80 |
| 5 | | 5.30 | 1.20 |
| 6 | | 1.70 | 1.10 |
| 7 | | 5.70 | 3.00 |
| 8 | | 4.20 | 2.50 |
| 9 | | 3.00 | 1.60 |
| 10 | | 3.80 | 2.80 |
| 11 | | [illegible] | 1.60 |
| 12 | | 8.50 | 3.80 |
| 13 | | 2.00 | 1.20 |
| 14 | | 6.20 | 2.10 |
| 15 | | 4.90 | 3.20 |
| 16 | | 2.70 | 1.30 |
| 17 | | 5.70 | 3.20 |



Total Phosphorus Den 30/3/21

5mls Sample ④

Ammonium persulphate

Add 5mls of APS & Mix. ~~too~~

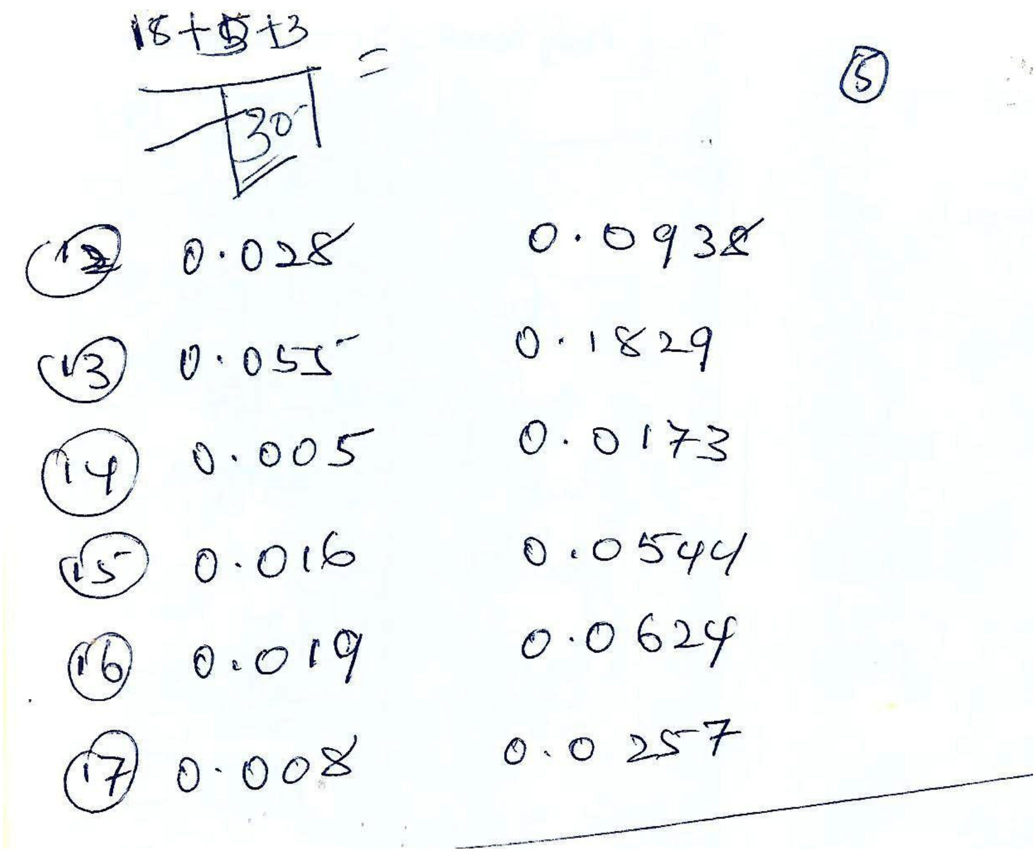
2. Put the samples in the Reactor for 30min

3. Cool & 2Mls of 1.54N NaOH & swirl to mix

4. Add Phosphower 3 pillow & read from Spectrophotometer

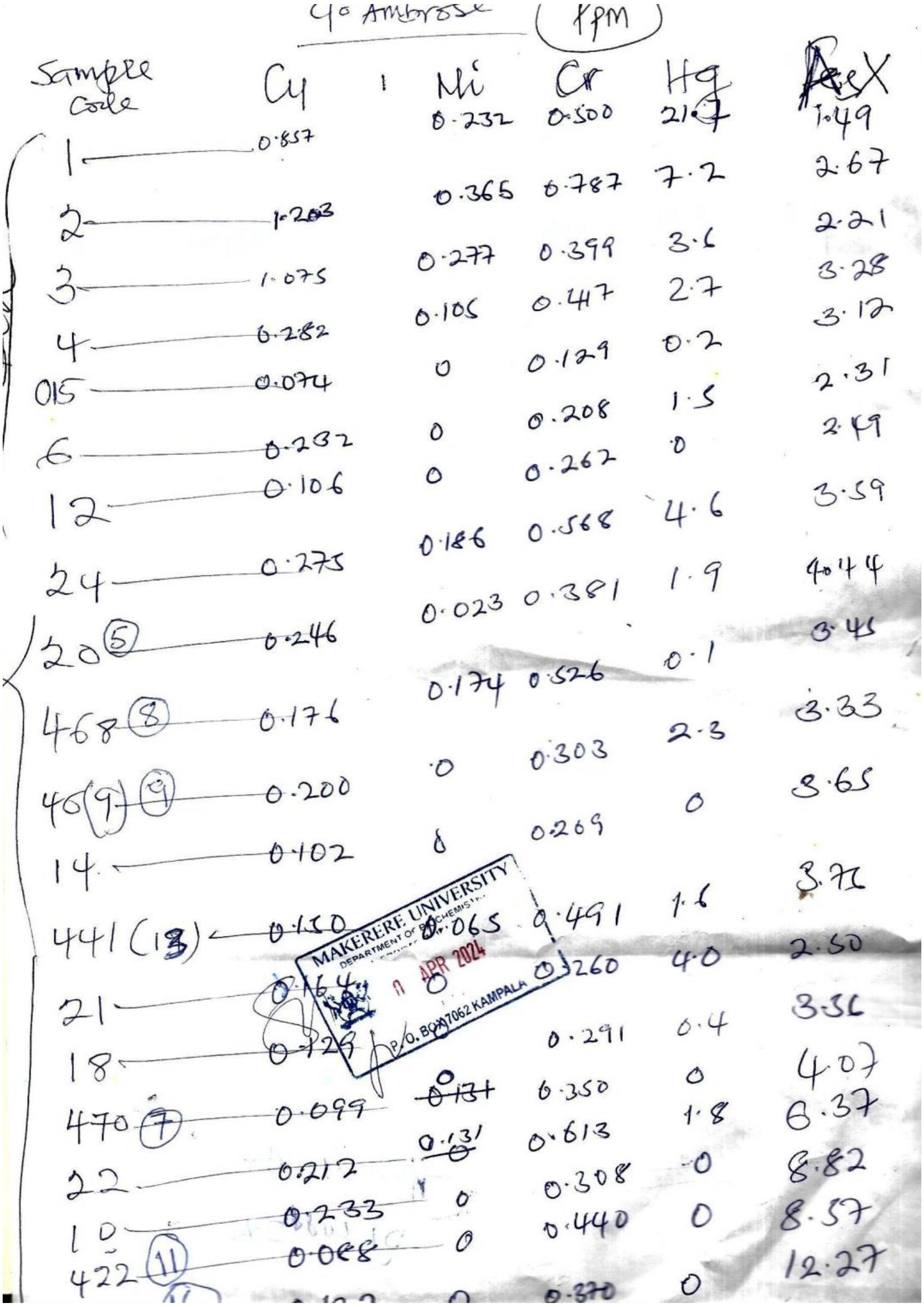
Read at 880nm

| | Abs | CONCN mg/L |
|---|---|---|
| ① | 0.430 | 1.4341 |
| ② | 0.357 | 1.1747 |
| ③ | 0.308 | 1.0284 |
| ④ | 0.174 | 0.5803 |
| ⑤ | 0.133 | 0.4454 |
| ⑥ | 0.0[illegible] | 0.1285 |
| ⑦ | 0.01[illegible] | 0.0320 |
| ⑧ | 0.026 | 0.0861 |
| ⑨ | 0.014 | 0.0464 |
| ⑩ | 0.007 | 0.0233 |
| ⑪ | 0.022 | 0.0731 |



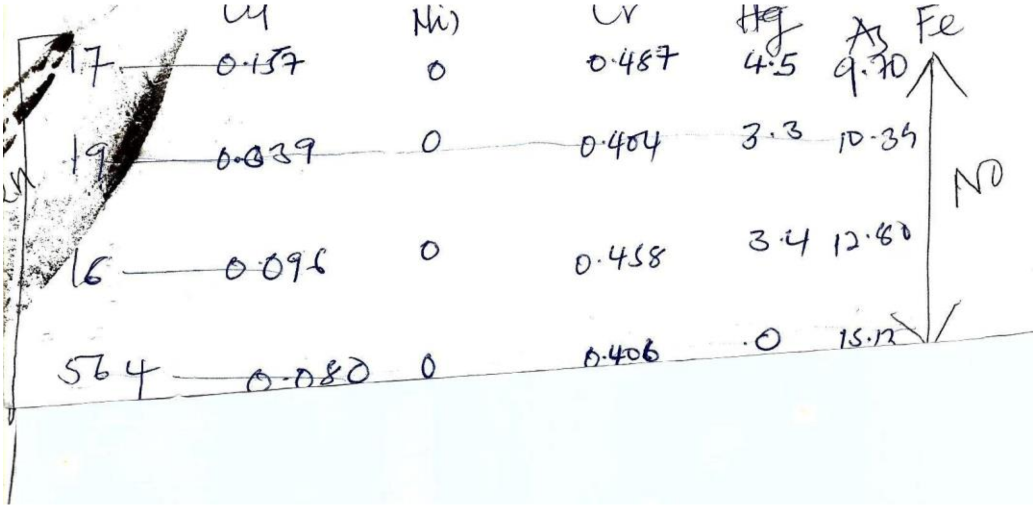
$\frac{18+5+3}{\boxed{30}} =$ ⑤

| | | |
|---|---|---|
| ⑫ | 0.028 | 0.0938 |
| ⑬ | 0.055 | 0.1829 |
| ⑭ | 0.005 | 0.0173 |
| ⑮ | 0.016 | 0.0544 |
| ⑯ | 0.019 | 0.0624 |
| ⑰ | 0.008 | 0.0257 |

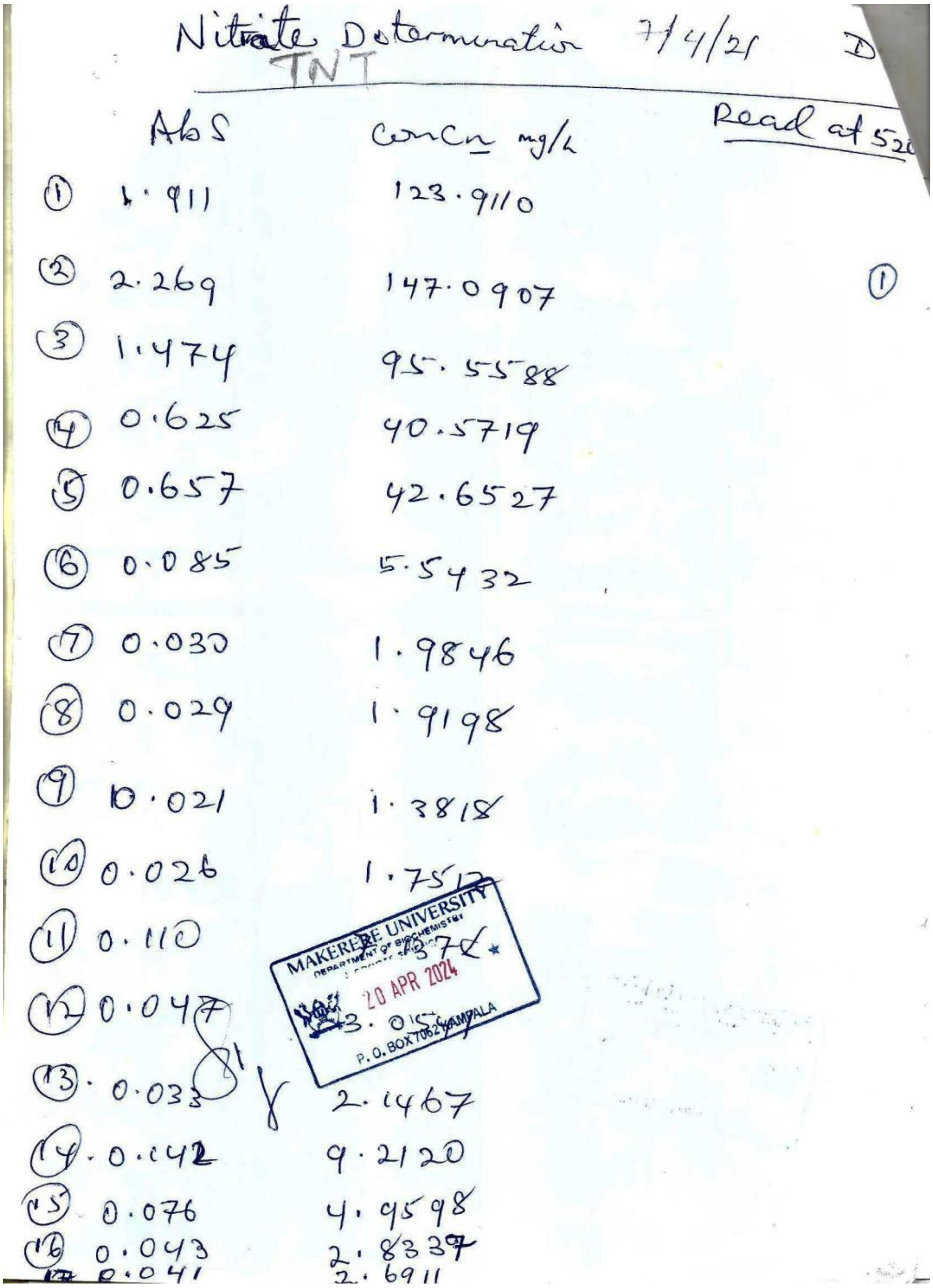


4° Ambrose (PPM)

| Sample Code | Cu | Ni | Cr | Hg | AsX |
|---|---|---|---|---|---|
| 1 | 0.857 | 0.232 | 0.500 | 21.7 | 1.49 |
| 2 | 1.203 | 0.365 | 0.787 | 7.2 | 2.67 |
| 3 | 1.075 | 0.277 | 0.399 | 3.6 | 2.21 |
| 4 | 0.282 | 0.105 | 0.447 | 2.7 | 3.28 |
| 015 | 0.074 | 0 | 0.129 | 0.2 | 3.12 |
| 6 | 0.232 | 0 | 0.208 | 1.5 | 2.31 |
| 12 | 0.106 | 0 | 0.262 | 0 | 2.49 |
| 24 | 0.275 | 0.186 | 0.568 | 4.6 | 3.59 |
| 20 (5) | 0.246 | 0.023 | 0.381 | 1.9 | 4.44 |
| 468 (8) | 0.176 | 0.174 | 0.526 | 0.1 | 3.45 |
| 46(9) (9) | 0.200 | 0 | 0.303 | 2.3 | 3.33 |
| 14 | 0.102 | 0 | 0.269 | 0 | 3.65 |
| 441 (13) | 0.150 | 0.065 | 0.491 | 1.6 | 3.71 |
| 21 | 0.164 | 0 | 0.260 | 4.0 | 2.50 |
| 18 | 0.129 | 0 | 0.291 | 0.4 | 3.36 |
| 470 (7) | 0.099 | ~~0.131~~ 0 | 0.350 | 0 | 4.07 |
| 22 | 0.212 | 0.131 ~~0~~ | 0.613 | 1.8 | 6.37 |
| 10 | 0.233 | 0 | 0.308 | 0 | 8.82 |
| 422 (11) | 0.068 | 0 | 0.440 | 0 | 8.57 |
|  | 0.1 | 0 | 0.370 | 0 | 12.27 |



|  | Cu | Ni | Cr | Hg | As | Fe |
|---|---|---|---|---|---|---|
| 17 | 0.157 | 0 | 0.487 | 4.5 | 9.70 | NO |
| 19 | 0.039 | 0 | 0.404 | 3.3 | 10.34 |  |
| 16 | 0.096 | 0 | 0.458 | 3.4 | 12.80 |  |
| 564 | 0.080 | 0 | 0.406 | .0 | 15.12 |  |



Nitrate Determination 7/4/21 D

TNT

Read at 52

|  | Abs | Concn mg/L |
|---|---|---|
| ① | 1.911 | 123.9110 |
| ② | 2.269 | 147.0907 |
| ③ | 1.474 | 95.5588 |
| ④ | 0.625 | 40.5719 |
| ⑤ | 0.657 | 42.6527 |
| ⑥ | 0.085 | 5.5432 |
| ⑦ | 0.030 | 1.9846 |
| ⑧ | 0.029 | 1.9198 |
| ⑨ | 0.021 | 1.3818 |
| ⑩ | 0.026 | 1.7512 |
| ⑪ | 0.110 | [illegible] |
| ⑫ | 0.047 | 3.015[illegible] |
| ⑬ | 0.033 | 2.1467 |
| ⑭ | 0.142 | 9.2120 |
| ⑮ | 0.076 | 4.9598 |
| ⑯ | 0.043 | 2.8337 |
| 17 | 0.041 | 2.6911 |

①