USE OF FERRIC CHLORIDE ZEOLITES IN GROUND WATER TREATMENT AT HOUSEHOLD LEVEL A CASE STUDY OF KYABALOGO VILLAGE, NAKISUNGA SUB-COUNTY

IVAN JOSEPH LUBULWA

M22B32/050

A DISSERTATION SUBMITTED TO THE FACULTY OF ENGINEERING, DESIGN AND TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF SCIENCE IN CIVIL AND ENVIRONMENTAL ENGINEERING OF UGANDA CHRISTIAN UNIVERSITY

February, 2026

UGANDA CHRISTIAN
UNIVERSITY
A Centre of Excellence in the Heart of Africa

ABSTRACT

The issue of access to clean drinking water continues to be a great struggle in various rural locations where the sources of groundwater are becoming more and more polluted with heavy metals and other inorganic substances. At the same time, heavy metals such as lead (Pb^{2+}) and copper (Cu^{2+}) are classified as hazards of the highest order due to their toxic nature, persistence, and bioaccumulation (Tchobanoglous et al., 2014). A study on water quality in Kyabalogo Village, Nakisunga Sub-county, Mukono District, Uganda, indicated the existence of Pb and Cu in the spring water exceeding the tolerable limits for drinking water. Therefore, the water cannot be used in households without prior purification.

The current work is focused on the application of natural zeolite as an inexpensive and effective adsorbent to purify the spring groundwater by removing Pb^{2+} and Cu^{2+} at the household level. Previous literature shows that divalent heavy metals can be taken away by zeolites by 80–95% via ion-exchange processes, where the ions of the heavy metals Pb^{2+} and Cu^{2+} in the solution replace the cations (e.g., Na^+, K^+, Ca^{2+}) that are in the zeolite lattice (Misaelides, 2011). The results of this research work are expected to provide a cheap and an eco-friendly approach solution for the rural water treatment community. (Wang & Peng, 2010).

DECLARATION

I, **LUBULWA IVAN JOSEPH** hereby declare that this final year research project entitled; Use of modified zeolites in ground water treatment at household level a case study of Kyabalogo Village, Nakisunga Sub-County is mine. I personally typed this report on my own and it has never been forwarded to any institution or organization for an award of any qualification. I therefore strongly confirm without any doubt and in my right state of mind, that this is my original work.

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

LUBULWA IVAN JOSEPH.

M22B32/050

APPROVAL

I certify that this report is for LUBULWA IVAN JOSEPH Registration Number M22B32/050. I fully accept that he has been under my supervision and so submitted to the Faculty of Engineering, Design and Technology in partial fulfillment of a Bachelor of Science Degree in Civil and Environmental Engineering from Uganda Christian University.

Mr. Baagala Brian Sempijja

Academic Supervisor (Uganda Christian University)

Signature:.....................................

Date:..

ACKNOWLEDGEMENT

“It is impossible to accomplish anything significant without the tireless input of dedicated people” First of all, I acknowledge the lord my heavenly father for bestowing upon me a unique combination of gifts, talents as well as resourceful people who have enabled me to reach this far. “He lifted me out of miry clay and set my feet upon rocks and established my steps in the most troubling time” (psalms 40:2)

I extend my appreciation to my lecturers at the Department of Engineering and Environment for their positive criticism that has constantly helped me refine my project concept and most importantly my supervisor Mr. Brian Sempijja for his extensive contribution in giving me guidance during all the engagements and works done throughout the entire project period.

I am profoundly grateful to all respondents, especially the local people that use the Springs for domestic use and I also cannot forget to thank my Project Partner Mr. Mukizi Octave for all his support and guidelines that I needed for the success of this training practice. Great appreciation goes to my parents for their financial support, prayers and continuous career guidance towards my academic journey.

Finally I would like to express my utmost and sincere gratitude to the management of Uganda Christian University particularly Faculty of Engineering, Design and Technology for giving us this opportunity to carry out research and gain more expertise in the education field.

MAY GOD BLESS YOU ALL.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

APHA	American Public Health Association
Pb	Lead
US/EAS	Uganda Standard/East African Standard
Cu	Copper
EC	Electrical Conductivity
FAAS	Flame Atomic Absorption Spectroscopy
CEC	Cation Exchange Capacity
AF	Adsorption Frequency
FTIR	Fourier Transforms Infrared Spectroscopy
MWE	Ministry of Water and Environment
NBL	Nile Breweries Limited
NWSC	National Water and Sewerage Corporation
TDS	Total Dissolved Solids

ICP-MS	Inductively Coupled Plasma–Mass Spectrometry
UBOS	Uganda Bureau of Statistics
UNBS	Uganda National Bureau of Standards
US: EAS	Uganda Standards East Africa Standards
GIS	Geographical Information System
WHO	World Health Organization

CHAPTER ONE: INTRODUCTION

This chapter includes the background, problem statement and geographical scope and justification of this research project.

1.1 BACKGROUND

Pollution from both point and non-point sources still continue to pollute essential water resources on a global scale. Major contributors to the pollution of both surface water and groundwater are industrial discharges, domestic sewage, agricultural runoff, and changes in the environment (WHO, 2024). In many parts of the world that are still developing, groundwater that people rely on for drinking purposes is slowly discovered to contain harmful inorganic pollutants and especially heavy metals such as lead (Pb), copper (Cu), iron (Fe), and cadmium (Cd). These metals are unyielding, non-degradable, and their presence even in minuscule amounts causes a very serious health risk (Tchobanoglous et al., 2014).

By the year 2035, the global population increase is estimated to be around 7.9 billion, and consequently, the water crisis is to be more severe than it is now, particularly in rural areas where the supply of water treatment facilities is limited (WHO, 2024). The conventional use of filtration by households such as plain sand filtration, membrane filters, and biochar filters has been found to be inadequate as poor adsorption capacity and large variation in maintaining the level of metals below that of the drinking water standard have been cited as the causes.

Among the various treatment methods available, the one based on adsorption has gained recognition as the most efficient and at the same time the least expensive solution to heavy metals removal. Natural zeolites in particular are the most popular ones, boasting the property of having the highest cation-exchange capacity, micropore structure, and strong affinity for the divalent metal ion such as Pb^{2+} and Cu^{2+} (Wang & Peng, 2010). In this manner, zeolites can swap their cations (Na^{+}, Ca^{2+}, K^{+}) for those of toxic metals, significantly reducing the concentration of metals in contaminated water within minutes (Misaelides, 2011).

This research focuses on the purification of Kyabalogo Village, Nakisunga Sub- by using modified zeolites as an adsorbent for household drinking water.

1.2 PROBLEM STATEMENT

The major sources of water in Uganda are underground, and in addition to that, natural springs are also used for domestic purposes, drinking water, and small-scale economic activities. In Kyabalogo village, Nakisunga sub-county, the spring water is the main source of water since it is free, easy to access, and available all year round. However, human activities such as improper waste disposal, agricultural runoff, and unregulated land use around these water sources have deteriorated the quality of the water significantly (WHO, 2024).

Water quality monitoring from community springs in central Uganda indicates the presence of heavy metals and pathogenic microorganisms in large quantities (Nzanzu et al., 2022) The heavy metals Pb, Cu, and Cd are listed among the ones that are very toxic and detrimental to the health of living organisms at very low concentrations (Tchounwou et al., 2012). Furthermore, with the presence of pathogens in the water, the risk to public health is even greater, with fecal coliforms being detected in the range of 1000 CFU/100 mL (Nzanzu et al., 2022).

A good number of the Kyabalogo Village residents are elderly or low-income and thus cannot afford the piped water from the National Water and Sewerage Corporation (NWSC). They, therefore, rely on spring water that is likely to be contaminated by human activities and groundwater infiltration of heavy metals. Hence, the need for developing inexpensive household-scale treatment systems is very critical.

Popular household filtration systems like sand filters, membrane filters, and cloth filtration have not shown high efficiency in the removal of dissolved heavy metals. On the other hand, natural zeolites are known for their high cation-exchange capacity and great attraction to divalent heavy metals like Pb^{2+} and Cu^{2+}, which makes the

1.3 OBJECTIVES OF STUDY

1.3.1 Main objective

To use modified zeolites in water treatment at household level a case study of Kyabalogo village, Nakisunga Sub-County

1.3.2 Specific objectives

1. To determine the physicochemical properties of three selected springs in Kyabalogo village, Nakisunga Sub-County

2. To determine the removal efficiency of natural zeolites in water treatment
3. To design a simple household water treatment system.

1.4 Research questions

1. What are the current heavy metal concentrations in the water of the three selected springs in Kyabalogo Village, Nakisunga Sub-County?
2. How to determine the removal efficiency of natural zeolites in water treatment?
3. What are the specifications of the household treatment system to be designed?

1.5 JUSTIFICATION

Zeolites are regarded as the most efficient crystalline aluminosilicates minerals for water-treatment media applications, thanks to their remarkable capability of removing heavy metals such as lead (Pb^{2+}) and copper (Cu^{2+}) from water. The main reasons for their high efficiency are their high cation-exchange capacity, porous structure, and excellent affinity for divalent metal ions. Clinoptilolite, a natural zeolite, is the most commonly used mineral as it is regarded as a very low-cost, eco-friendly, and selective adsorbent for toxic metals in drinking water (Sprynskyy et al., 2006; Wang & Peng, 2010).

Ion exchange occurs mainly as a mechanism of sorption whereby metal ions in solution displace the weaker cationic exchangeable ones (Na^{+}, K^{+}, Ca^{2+}) of the zeolite. This phenomenon can be illustrated as follows:

$2(Z{-}Na)+Pb2+ \rightarrow (Z)2{-}Pb+2Na+$

$2(Z-Na)+Cu2+\rightarrow(Z)2-Cu+2Na+$

Zeolites additionally eliminate heavy metals through surface adsorption and complexation, thus making them multifunctional. As a result of their high efficiency, simplicity, low operational cost, and compatibility with household water treatment, adsorption has been identified as the preferred method over such treatments as membrane filtration, precipitation, and solvent extraction (Foo & Hameed, 2010).

Among the possible adsorbents, zeolites win due to their very large specific surface area, permanent negative framework charge, natural occurrence, and water resistance. It has been proven on many occasions that zeolites possess an extremely strong selection for Pb^{2+} and Cu^{2+} ions even when the competing ions are Ca^{2+} and Mg^{2+} (Inglezakis & Zorpas, 2012). Thus, they could very well be applied in the treatment of natural groundwater in rural areas like Mukono, where heavy metals may be above the stipulated limits.

To sum up, zeolites, with their combination of low cost, selectivity, and high efficacy, become the ideal option for household water treatment. They are distinguished by their dual Roman Catholic and Orthodox mechanisms of ion-exchange and adsorption with natural availability, which are the best choice for Pb^{2+} and Cu^{2+} removal from spring groundwater and as a natural resource that is readily available in the rocks of Mbale proven performance.

1.6 GEOGRAPHICAL SCOPE

The study focused on three springs located in Kyabalogo village, Nakisunga Sub-County, Central Region (0034/40.0// N, 60000/30.0// E). The presence of many springs (both protected and unprotected) is a characteristic of the area, but the researchers chose to study only three springs which are most likely to get contaminated because of their location.

1.6.1 CONTENT SCOPE

This research study is mainly focused on;

1. Determining the physicochemical properties of three selected springs in Kyabalogo village, Nakisunga Sub-County
2. Determining the removal efficiency of natural zeolites in water treatment
3. Designing a simple household water treatment system.

1.6.2 TIME SCOPE

This research project commenced in May 2024 and will be completed in December 2025.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

This chapter comprises of details of current academic literature, reviews, theories and general information specific to this research project from existing published information in peer reviewed articles, books, conference papers and others.

2.1 Heavy metals

There are definitions that dictate heavy metals according to their toxicity meaning that they are very harmful even if present in very small concentrations and thus arsenic, lead, and mercury have been said to be more dangerous than iron, copper, and zinc which are considered to be the body's allies or have very limited effects in the amounts set as non-lethal for the most toxic elements. Nevertheless, the scientific community has come to the conclusion that heavy metals are those elements with a density greater than 5g/cm3 (Ali & Khan, 2018). With respect to this investigation, copper with an estimated density of around 8.9g/cm3 and iron with 7.9g/cm3 can definitely be classified as heavy metals.

2.2 Copper

Copper (Cu) is an indispensable trace element that functions as a cofactor for various enzymes, participates in the formation of connective tissues, strengthens the immune system, and takes part in the processing of nervous impulses (ICA, n.d). Its occurrence in food as well as the low levels in many water sources makes copper deficiency rare, if not impossible, in the general population, the exception being individuals with defective copper metabolism.

It is the case that copper is essential in minute quantities, but when it is present in large amounts, it becomes a contaminant of drinking water. To prevent health issues like gastrointestinal irritation, nausea, and complications in patients with Wilson's disease (WHO, 2017), the WHO sets a limit of 2.0 mg/L as the maximum allowable concentration in drinking water. Furthermore, copper at concentrations exceeding 2.5 mg/L will alter the taste and color of the water, making it less acceptable.

Copper contamination in groundwater systems is a common issue caused by not only geological sources but also leaching of contaminated soils, agricultural chemicals, and improper waste disposal. In contrast to the corroding copper pipes being the main source of contamination in piped distribution systems, rural groundwater pollution may come from weathered rocks, mining residues and human wastes (Zhou et al., 2024).

Household water with excessive copper has the potential to cause laundry staining at the concentration of more than 1 mg/L and pipe discoloration (WHO, 2017). Traditional methods of household filtration do not remove dissolved Cu^{2+} ions, as copper is not easily removed through simple sand filtration or chlorination. While more advanced techniques like chemical precipitation, coagulation, membrane and ion exchange have been proven effective, they also tend to be expensive and complicated for low-income rural households.

Adsorption, particularly the application of natural zeolites, is a cheap and an efficient alternative. The high cation-exchange capacity of zeolites and their ability to selectively bind Cu^{2+} ions make them ideal for the purification of contaminated groundwater in the home setting.

2.3 Lead

Lead is a metal that is very toxic and has no beneficial role in the human body. The case of lead is different from that of trace elements: Even the least exposure might lead to huge health impacts, and this is especially so for vulnerable groups like children and pregnant women (WHO, 2021). According to the WHO, lead is a Group 2A probable human carcinogen, and it is very strictly stated that no amount of lead exposure is considered to be safe (WHO, 2021). Thus, the WHO guideline value for lead in drinking water is fixed at 0.01 mg/L.

A vast pool of scientific studies has all pointed to the same conclusion that the consumption of lead-contaminated water even at levels of less than 0.1 mg/L can have extreme effects on brain development, general health, and even physiology of the organism. Lead diminishes the amount of hemoglobin made, disrupts enzyme activity and builds up in the bones and soft tissues of the body with time (Tchounwou et al., 2012). In children, lead presence in drinking water below the level of 0.05 mg/L is blamed for lowering IQ, hindering cognitive skills, creating behavior series, and causing growth to stop (Lanphear et al., 2018). Adults suffering from the similar case might face the problems of high blood pressure, kidney malfunction, infertility, and heart attack (Flora et al., 2012).

Even higher amounts of lead in drinking water, and say, those found in rural groundwater and city outskirts, springs, are huge risks. Rahman et al. (2023) mention fatigue, abdominal pain, memory loss, muscle weakness, and anemia as symptoms of chronic lead exposure. The long-term lead deposit causes neurodegeneration, seizures, and organ failure. Health risks depend on various factors like age, nutrition, socio-economic status, and exposure time (WHO, 2021).

Groundwater percolation varies a lot, nevertheless, the major contributors are the geological weathering, lead plumbing corrosion, wrong batteries and paints disposal, and agricultural or industrial runoff (Kumar et al., 2017; Zhou et al., 2024). For example, a rural Ugandan community like Kyabalogo Village in Nakisunga Sub-County frequently experiences lead pollution through geological layers, soil leaching contamination. These sources usually cause contamination that is more direct and persistent than contamination resulting from isolated human activities.

As per the Uganda Standards (US EAS 2014), the maximum allowable limit for lead in potable water is 0.01 mg/L, which is in line with WHO recommendations. Lead levels beyond this point are not only harmful to health but also signify that the groundwater has been contaminated on a larger scale.

Considering the great health risks of lead even at low levels in drinking water, it is critical that proper treatments are implemented. Among the adsorption-based methods, one especially using natural zeolites has the potential to remove Pb^{2+} from the water selectively, and that is due to its high cation-exchange capacity and strong affinity for divalent heavy metals (Wang & Peng, 2010; Misaelides, 2011).

2.4 Methods of removing heavy metals from water.

Heavy metals have been removed or at least reduced to acceptable levels through a variety of methods that have been developed and implemented. These ways of removal include; Coagulation, Ion exchange, Adsorption, Chemical precipitation/neutralization, Membrane filtration, ion floatation which covers reverse osmosis, micro/nano/ultra-filtration, evaporation and electrochemical methods (Lupa et al, 2023; Senanu et al, 2023).

Such methods are considered to be impractical particularly in developing nations because of the enormity of the costs involved (operation, maintenance, education/skilling) that would be incurred for the continuous use of the techniques, particularly, to treat the large quantities of water or over-contaminated water in order to provide water just adequate enough for the growing populations in vast regions with very little or no access to clean water for consumption (Joseph et al, 2019). Thus, the search is on for more affordable methods in the removal of heavy metals from water in places like Uganda.

Other limitations of the conventional methods according to Gahrouei, (2024) and Senanu (2023) are in Table 1 below.

Table 1: Limitations of the conventional methods of heavy metal removal in water (Source: Senanu, 2023; Gahrouei, 2024; Wang et al,2025

Method of treatment	**Limitations**
Membrane filtration: This involves the passage of water that is pressurized through membranes. The membranes extract the heavy metal ions allowing water to go through.	High operation costs from energy usage to pressurize water Expensive membranes/membrane material Heavy metal species with smaller size than the membrane cannot be filtered
Chemical precipitation: This involves chemical reagents being added to aqueous solutions with heavy metals and the reagents react to form insoluble solids easily precipitated out of the water and filtered out eventually.	Some heavy metals have optimum pH points & may form water soluble compounds in both base and acidic conditions. Thus, pH adjustment is needed. Toxic chemical by products from the reactions. Large amounts of chemicals required for efficient precipitation leading to high operational costs. Large amounts of sludge produced.
Floatation: Just like dissolved air floatation, air bubbles are incorporated into water from the bases of their chambers binding heavy metal ions as	High energy costs for constantly pumping pressurized

they move upwards. Scum is formed at the top of the water surface containing the heavy metal ions and is skimmed off.	
Coagulation: Chemicals(coagulants) are added to destabilize charges on heavy metal ions forming dense colloids that are sedimented or filtered from the water.	Chemicals cannot be reused Large amounts of sludge formed daily
Ion exchange: Solid like polymers with a similar ion to the heavy metals are used for exchange of ions removing heavy metal ions from the aqueous solution.	Polymers required not readily available for all metals. Suspended materials in the water Have to first be removed before ion exchange method can be used.
Electrochemical technique: Use of electric potential and ion exchange membrane to remove the heavy metal ions/species.	High energy costs Skilled personnel for operation Large amounts of sludge produced Clean feed required hence other treatment methods should first be used.

2.5 Adsorption

Adsorption is one of the methods used in which heavy metal ions are fixed on the surface of the adsorbent, hence, the elimination of heavy metals through adsorption (Lupa et al, 2023). The process of separation here involves removing ions from the liquid by either physical or chemical adsorption of the dissolved heavy metal ions.

Physical adsorption means that the ions get trapped in the adsorbent's porous surface. Hence, adsorbents with large pore size and high surface area among others are expected to be good ones (Akhtar et al, 2024). In contrast, chemical adsorption refers to the use of the chemical compounds such as functional groups that serve as binding sites to which the ions exhibit high affinity.

The research on the use of waste materials in particular has been focused on the availability of these materials locally, thus, environmental sustainability due to the regeneration of the biochar (Carrasco et al, 2022). Therefore, water treatment with bio-sorbent waste materials. The adsorption process is also regarded as a heavy metal removal technique that is two in one, as it inherently involves the filtration process due to the media used and hence is sometimes called activated carbon filtration when activated carbon is used (Pillai, 2024).

Numerous researches have explored the employment of both natural and altered zeolites for the decontamination of water, especially by the extraction of heavy metals like Pb^{2+} and Cu^{2+} from aquifers. The main mechanisms of zeolites are adsorption and cation-exchange, where the ions of metals in water are trapped and substituted by ions that are on the zeolite surface. The combination of their porous crystalline structure, high specific surface area, and strong affinity for divalent metal ions makes zeolites highly efficient in household-scale treatment applications.

2.6 Use of natural zeolite in treatment.

Natural zeolites have been the subjects of extensive research owing to their ability to purify water by removing heavy metals and other toxic ions, especially in the case of groundwater contaminated with Pb^{2+} and Cu^{2+}. The unique feature of zeolites which contributes to their effective performance is their solid structure of aluminosilicate that has connected micropores where metal ions can be readily adsorbed by cation exchange (Fernandes et al., 2022). Through the use of zeolites as a filtration or adsorption medium, water containing heavy metals can be treated to obtain a very low concentration of these metals due to the large surface area of the zeolite and the very strong affinity of the zeolite for divalent cations.

Zeolites are natural minerals formed from the volcanic eruptions, and their primary location is usually in the cracks and pores of the volcanic rocks. The development of zeolites is associated with the destruction of volcanic glazes, feldspars, and clay minerals under the specific conditions of hydrothermal areas (Fernandes et al., 2022). Although there are more than sixty types of natural zeolite identified across the globe, only a few clinoptilolite, mordenite, chabazite, and heulandite are found in sufficient amount and with the right quality to be applied for water treatment.

Natural zeolites are, in contrast to synthetic zeolites, more versatile in the sense that they have a wider range of chemical compositions, pore structures, and mineralogies. This variability, however, is a double-edged sword and may sometimes limit their performance to a certain degree. But on the other hand, it is a significant advantage that natural zeolites are much cheaper and easier to obtain than synthetic ones; therefore, they can be used for rural water purification systems and household filtration solutions (Fernandes et al., 2022). Their use in these situations has resulted in a growing interest in their ability to remove toxic metals from drinking water in low-income areas, e.g. Kyabalogo Village.

2.6.1 Adsorption

Zeolites have a very large specific surface area and a very large cation-exchange capacity, which allow them to effectively adsorb metal ions that are dissolved in water. Their open framework of three-dimensional pores allows for the presence of a large number of active sites where metal ions with positive charges like Cu^{2+} and Pb^{2+} can be captured and held by means of surface adsorption and ion-exchange processes. Thus, zeolites are appropriate for the removal of heavy metals from groundwater in treatment applications.

2.6.2 Ion Exchange

Zeolites are crystalline aluminosilicates with negatively charged lattice sites that can exchange their native cations (such as Na^{+}, K^{+}, Ca^{2+}) with dissolved metal ions in water. Through this ion-exchange mechanism, zeolites can selectively remove heavy metals such as Pb^{2+} and Cu^{2+} by replacing their internal exchangeable ions with the contaminant ions present in the groundwater.

2.7 Catalytic Oxidation

Zeolites of some types may also show catalytic properties based on the active surface sites and the composition of the framework. Such a catalytic character, in heavy-metal removal, can give a boost to the adsorption process by assisting in the reactions that take place at the surface between the zeolite and the dissolved metal ions. Therefore, the binding strength of the metals like Pb^{2+} and Cu^{2+} onto the zeolite surface may be strengthened which would lead to an increase in the removal efficiency.

2.7.1 pH Adjustment

At the time of treatment, zeolites have the ability to alter as well as stabilize the pH level of the water that has been contaminated. A suitable pH level must be maintained because the adsorption efficiency of heavy metals, like Pb^{2+} and Cu^{2+}, is highly pH-dependent. During the adsorption process, zeolites can function as a mild buffering medium, which would generally assist in controlling sudden alterations of pH in the treated water and thus, increase the metal uptake efficiency.

2.8 Modification of natural zeolites for use.

Natural zeolite modification, a necessary process, comes first in the list of the steps to be taken for improving its power as an adsorbent for heavy metals, like Pb^{2+} and Cu^{2+}, in groundwater. Impurities, blocked pores, and a limited number of active sites usually accompany raw zeolite, the presence of which could hinder the latter's adsorption efficiency. Therefore, it is necessary to apply physical and chemical modification methods not only to increase the surface area and porosity of the zeolite but also to improve its cation-exchange capacity.

With acid or base chemicals, one can effectively remove mineral impurities, dissolve carbonates and open up blocked pore channels and thus, enjoy improved ion-exchange performance as well as the higher affinity for metal ions (Fernandes et al., 2022). HCl, for example, acid treatment, can effectively lead to the exposure of more active sites and hence, a better binding of Pb^{2+} and Cu^{2+} ions from water.

Furthermore, besides mineral acid treatments, the polarity and surface charge of zeolites have also been changed by using organic surfactants for surface modification. Surfactants, such as quaternary ammonium compounds, form a monolayer on the external surface of zeolite and this, in turn, results in better metal adsorption and interaction with the dissolved contaminants (Fernandes et al., 2022).

Thermal activation, salt impregnation, and particle-size reduction are some of the other enhancement techniques that may come under the umbrella of household-scale filtration applications, whereby adsorption kinetics would be improved and, consequently, removal efficiency increased.

CHAPTER THREE: METHODOLOGY

3.0 Introduction

This chapter explains the methods and materials used to achieve the objectives of the research. It contains details of sampling procedures, test methods for key parameters on water, material samples, material preparation and attaining specifications for an efficient household system.

The assessment of the removal of heavy metals (Cu and Pb) using natural Zeolites followed a quantitative experimental procedure. From the analysis of collected raw water samples to the design of the treatment system.

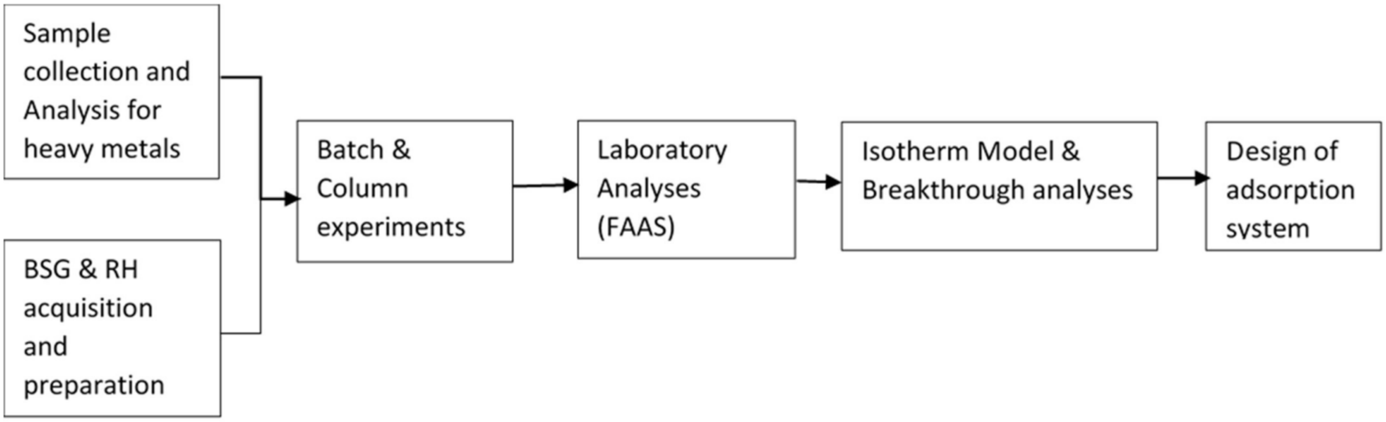


Figure 1 : Research design flow chart

3.1 Sampling and Sample Storage

3.1.1 Area of study

The research is focusing on the area Kyabalogo Village, which is located in Nakisunga Sub-County of Mukono District in Central Uganda (approximately at the latitude and longitude coordinates of (0°17′24″N, 32°46′48″E). The research is concentrated on three springs that are situated in the village and are the major sources of groundwater for the local community's domestic use. Among the three springs, one is well protected but still hazardous for direct human use without prior treatment; the other two springs are not protected which makes them more vulnerable to contamination and hence, the safe drinking water supply for the local community is at risk.

The groundwater from these springs is the main source of water for the local people who consume it for drinking, cooking, cleansing and bathing, irrigation of small areas, etc. The reason for this heavy reliance on springs is that most households cannot afford tap water from the National Water and Sewerage Corporation (NWSC). The unprotected springs are surrounded by humans and their activities—such as washing clothes, bathing, vehicles washing, watering animals, and disposing of household refuse—which definitely raise the contamination risk. Along with this, the nearby agricultural fields contribute to the problem through runoff, fertilizers, and leaching from soils giving rise to heavy metals and other pollutants in the groundwater.

The sampling points were strategically chosen to reflect the differences in exposure:

- Spring A (Protected) – Approx. 0°25′05″N, 32°45′10″E, situated upstream in a sheltered area.
- Spring B (Unprotected) – Approx. 0°24′58″N, 32°45′20″E, midpoint close to domestic activities.
- Spring C (Unprotected) – Approx. 0°24′52″N, 32°45′35″E, downstream, near areas for agricultural and waste disposal.

The groundwater quality in the village is represented by these springs and also the effectiveness of zeolite-based treatment for heavy-metal removal under household conditions is made possible to be assessed through these springs.

3.1.2 Sampling procedure

During a month-long period, water samples from three springs in Kyabalogo Village, Nakisunga Sub-County were collected on three different days: 8th, 15th, and 21st September. The laboratory then received the samples where they were going to conduct heavy metals (Pb^{2+} and Cu^{2+}) analysis and assess several other physicochemical parameters. Besides this, the pH, electrical conductivity (EC), total dissolved solids (TDS), and temperature were also measured in situ at each spring during the sampling.

The sampling method was designed according to the WHO (2017) and APHA (2017) standard guidelines for heavy-metal water sampling. The borosilicate glass bottles to be used were conditioned by being washed with 1:1 nitric acid 24 hours before sampling this will remove any contaminants that may be left from the previous use and also protect the metal ions.

The spring water was collected by dipping the bottles into the water at a depth of about 20 centimeters, with the mouths angled toward the springs to prevent the intake of any surface debris. To maintain the quality of the samples, nitric acid (1:1) was added immediately after collection until the sample pH fell below 2. The sample was then labeled with the sample number, spring location, date, time, temperature, and pH, and then kept in a cooling box with ice at 4–8°C for transport to the laboratory.

This systematic sampling allowed for the continuous monitoring of groundwater quality changes and at the same time the reliable evaluation of the zeolite's adsorption capability for heavy metals removal.

3.2 Objective I: Determination of the Physico-Chemical Characteristics of Raw Groundwater from Three Selected Springs in Kyabalogo Village, Sub-County

3.2.1 Introduction

The water quality indicators that will be examined in this goal are pH, electrical conductivity (EC), Total Dissolved Solids (TDS), Temperature, and the concentrations of heavy metals (Pb and Cu) in the unprocessed water of the three chosen springs in Kyabalogo village, sub-county.

In the case of heavy metal evaluation of unprocessed groundwater, the parameters that are most susceptible to pollution and thus their values will be decreased or increased are pH, electrical conductivity (EC), total dissolved solids (TDS), and the concentrations of the dissolved metals like Pb^{2+} and Cu^{2+}. These parameters are very important for the determination of water quality and also play a significant role in the evaluation of the treatment methods, such as zeolite adsorption, (Lu, 2021).

3.2.2 Measuring In-situ Parameters

At the same time, in-situ trials for the other parameters pH, electrical conductivity (EC), Total Dissolved Solids (TDS), Temperature, etc. were done several times at that location where the sample was taken by a multimeter (Model eXact pH+). The probe of the multimeter was rinsed with distilled water, and then it was plunged into the sample to ensure that the entire sensor was submerged. The values that were on the screen of the multimeter were allowed to stabilize for 1–2 minutes before reading and recording the values of the respective parameters.

3.2.3 Determining the concentration of (Cu) and (Pb) in the water samples

The amounts of Pb^{2+} and Cu^{2+} in the spring water samples collected were determined by Flame Atomic Absorption Spectrometry (FAAS), according to the procedures laid out in APHA 3111B (APHA, 2017). The analyses were carried out after the samples ($pH < 2$) were very carefully adjusted to the original pH values which had been measured during collection.

Each sample was fed to the spectrometer via a thin tube and subjected to a flame at specific wavelengths for lead and copper. The FAAS device quantified the light absorption by the atoms in the sample, and the software derived the absorbance values to determine the amount of Pb^{2+} and Cu^{2+} in mg/L based on the concentration. This technique allowed for accurate measurement of the heavy metals in the groundwater and at the same time made possible the assessment of the zeolite adsorbent's effectiveness for the removal of these pollutants.

Determining the removal efficiency of natural zeolites in water treatment

The study used natural zeolite rocks from Mbale in Eastern Uganda. After mining, the zeolites were cleaned first and then crushed and sieved into different particle sizes before use in adsorption experiment.

3.3 Objective II: Determination of removal efficiency of Zeolites.

3.3.1 Material Preparation

The natural zeolite rocks sourced from Mbale in Eastern Uganda were initially subjected to a rigorous washing process with distilled water to eliminate any dirt, dust, and other impurities. The zeolite materials were then subjected to a drying process in the oven at 105°C for 24 hours to evaporate any water present. After the drying process, the zeolite rocks were pulverized and screened to acquire a consistent particle size of 0.6–2 mm, which allowed for uniformity in flow and perfect interaction during the adsorption testing of heavy-metal removal from spring water.

3.3.2 Preparation and Modification of Zeolite

The first natural zeolite rocks were hammered to break them into smaller pieces, after which a manual aggregate crushing machine was used to make them even smaller. The crushed zeolite was later screened to get particle sizes ranging from 0.15 to 0.3 mm. Moreover, in order to eliminate impurities, the washed zeolite was packed in oven-dried polythene bags at 70°C for 12 hours and then stored in polythene bags to avoid contamination by dust.

To gain higher heavy-metal adsorption, chemical alteration of the zeolite took place. An 800 g amount of prepared zeolite was combined with a 1000 cm^3 solution of anhydrous ferric chloride ($FeCl_3$) in water at the concentration of 21.36 g/dm^3 under the temperature of 25°C. The mixture was subjected to stirring for 15 minutes and then allowed to stand for 24 hours to enable ion exchange properly. Then the modified zeolite was filtered and washed with distilled water until no chloride ions were detected (this was confirmed with the silver nitrate test). After that, the iron(III)-modified zeolite was dried at 70°C for 12 hours and stored in sealed polythene bags, which were then placed in a plastic container to shield against contamination (Turyasingura & Kantuntu, 2023).

This alteration increases the cation-exchange capacity of the zeolite and its affinities for Pb^{2+} and Cu^{2+}, thus making the zeolite more effective for treating household groundwater.

Figure 2 ***ferric Chloride***

Figure 3 ***sieve analysis***

Figure 4 ***process of sieve analysis***

3.3.3 Percentage determination for the removal efficiency of Zeolites.

The removal efficacy of zeolites was established through the determination of lead (Pb^{2+}) and copper (Cu^{2+}) concentrations in spring water before and after its treatment. Along with these, pH, electrical conductivity (EC), total dissolved solids (TDS), and temperature were measured, in-situ, to gauge water quality. The treatment outcomes were labeled as C_e (effluent concentration) and the starting concentrations in the unprocessed water as C_i.

The zeolite adsorption efficiency (%) is determined through the following formula:

Adsorption capacity = $Ci - Ce \times 100$ (Reagan, 2019)

A preliminary column experiment was done to investigate the best particle size and packing method for the zeolite to be used in a household-scale filtration system. The columns were placed in containers of a 6 cm diameter (D1, D2, D3) and filled randomly with zeolite of the same particle size (0.6–2 mm), and at the bottom was a small layer of cotton to support the adsorbent and prevent washout.

Throughout the experiment, certain volumes of water from the three chosen springs were run through the columns, and samples were taken at the outlet for Pb^{2+} and Cu^{2+} analysis by FAAS. The removal rates of each zeolite column were then compared to find the best-performing configuration for heavy-metal adsorption from spring groundwater.

3.4 Objective III: Designing an adsorption system

The design of the zeolite column adsorption system was based on the average day water requirement of a typical domestic unit in Kyabalogo Village, Nakisunga Sub-County, following the guidelines by the Uganda Water Supply Design Manual (MWE, 2013), the World Health Organization (2020), and the Uganda Bureau of Statistics (2024).

The dimensions of the adsorption column were designed based on the flow rate needed to satisfy the daily water requirement in the household to ensure the required interaction time between the water and the zeolite for effective elimination of the Pb^{2+} and Cu^{2+} ions from the spring water. The design was meant to be suitable for domestic application and thus made from the natural zeolites available in the country.

3.4.1 Design of simple household treatment system.

The estimated output of the spring water was expected to fit in the limit of the household zeolite adsorption column design. The best height of the zeolite in the test column was determined to be 30cm through initial experimentation to establish the correct time for the removal of Pb^{2+} and Cu^{2+} ions.

The method that was applied in determining the speed of the spring water was a basic timing technique. The bottle was dropped to fall through a known distance of 50m and the time taken to fall through the known distance was recorded three times. The average velocity (v) was then determined by the equation:

$v = = S/t$

DISTANCE = S

The discharge/flow rate is derived from;

$Q= V \times A$

Where;

v = velocity

A = area

The values measured above were employed to design the domestic zeolite column in order to provide an optimal contact area for the efficiency of the Pb^{2+} and Cu^{2+} ions while also taking into consideration a reasonable flow rate for domestic applications.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.0 Introduction

The findings from each objective are presented in this chapter and the corresponding in-depth discussion and analysis that are in line with the scope of the study.

Physicochemical properties of raw water sourced from the three springs in KYABALOGO VILLAGE, NAKISUNGA SUB-COUNT

The figures in this section depict the average value of the pH, EC (μS/cm), TDS (ppm), and concentrations of the Cu and Pb parameters at each of the sample points based on the description in section 3.1.1.

Table 2: Summary of results

PARAMETER	UNITS	THREE DIFFERENT DAYS (8th,15th and 21st)			EAS STANDARDS
		A (n=3)	B (n=3)	C (n=3)	
pH		6.64 ± 0.49	6.95 ± 0.48	6.24 ± 0.79	
Electrical Conductivity (EC)	μS/cm	57.45±4.52	61.30±9.99	55.65±3.12	
Total Dissolved Solids (TDS)	Ppm	39.85±2.00	43.60±5.01	40.25±2.76	
Lead, Pb	mg/L	0.006±0.002	0.2±0.06	0.20±0.02	0.01 MAX
Copper, Cu	mg/L	0.72±0.08	1.2±0.28	1.2±0.05	1.00 MAX

4.0.1 pH

The pH levels of the raw water from the three springs in Kyabalogo Village recorded a slightest variation for the three days of collection (8th, 15th, and 21st September). The pH levels ranged from 6.24 to 6.94, and the pH levels are still within the recommended pH levels for natural potable water in the Uganda Standard US EAS 12:2014 guidelines, where the pH ranges from 5.5 to 9.5.

The second sampled day, A (protected spring), recorded the lowest average pH value of 6.24, followed later by the gradual increase in Spring B (6.82), followed again by a slight decrease in Spring C (6.67). All these changes occur due to the natural fluctuating processes in the springs, since the springs are fed by groundwater.

The variation in the pH level, according to Zhang et al. (2021), in the short-term periods is because of changes in rainfall infiltration, interaction of the groundwater with the surface, and biogeochemical reactions in the aquifer.

The possible increase in pH in Spring B relatively might be a resultant effect of the activities conducted by the people believed to be the primary cause of the pH rise. The sampling activity period in the area involved observing the number of houses in the area surrounding the spring where people wash, bath, and wash the Jerry Can water nearby in the order listed above. The activity conducted involves the use of domestic detergents and soap that increase the pH levels temporarily when the by-products are discharged into the water in spring sources (Goel and Kaur, 2012). The mean values recorded in point A, B, and C were 6.64 ± 0.49, 6.95 ± 0.48, and 6.24 ± 0.79 respectively, showing an increase in the pH levels from point A to C in the springs studied.

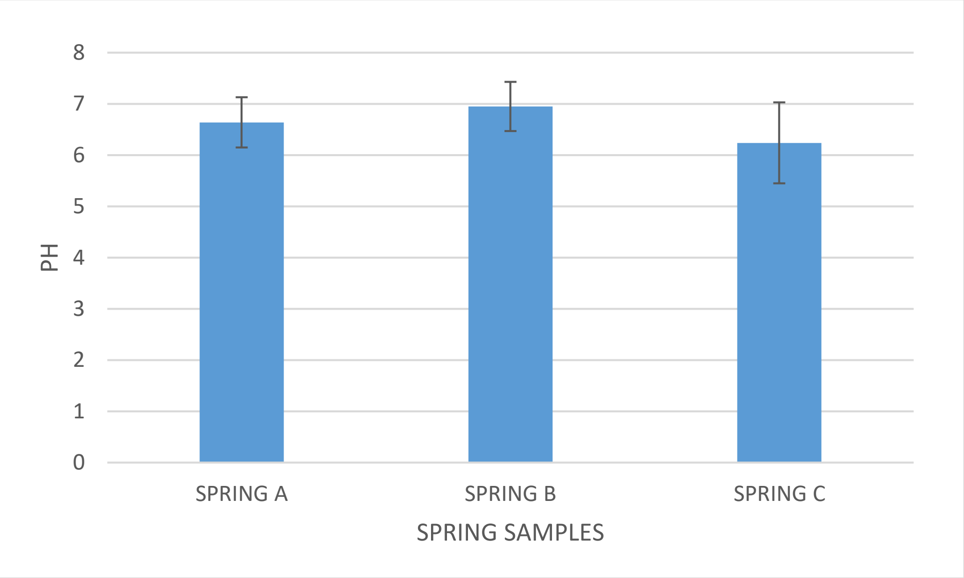


Figure 5 **: Mean pH values for samples of A, B and C *n* = *3*.**

4.1 Electrical Conductivity (EC)

The values for Electrical Conductivity (EC) measured in the three days of sampling also stayed well within the maximum limits allowed by the Uganda Standards US EAS 12:2014, at a maximum of 2500 µS/cm for EC in drinking water. The average values measured for EC rose marginally from Spring A (54.87 ± 4.52 µS/cm) to Spring B (57.30 ± 9.99 µS/cm), then marginally fell at Spring C (54.53 ± 3.12 µS/cm), but the slight increase recorded at Spring B indicates a natural effect and does not form part of the source water quality impairment.

The rise in Spring B is mostly due to human activities surrounding the spring. Various human activities such as washing clothes, bathing, jerry-can washing, and motorbike washing, among other domestic activities, occur directly near the spring site and contribute greywater characterized by the presence of dissolved ions such as phosphates and chlorides present in washing soap and detergent to the spring. Various studies carried out earlier have demonstrated that the presence of such chemical compounds in domestic wastewater is responsible for the rise in the electrical conductivity levels in the spring and ground water sources, as more charged particles are added to the water column (QMUL, n.d.).

Overall, in spite of the slight change in the EC values in Spring B, the levels in the other two springs are well below the national standards. This implies that the springs are less affected by the contamination due to salinity and that the slight changes are due to the input of grey water in the area.

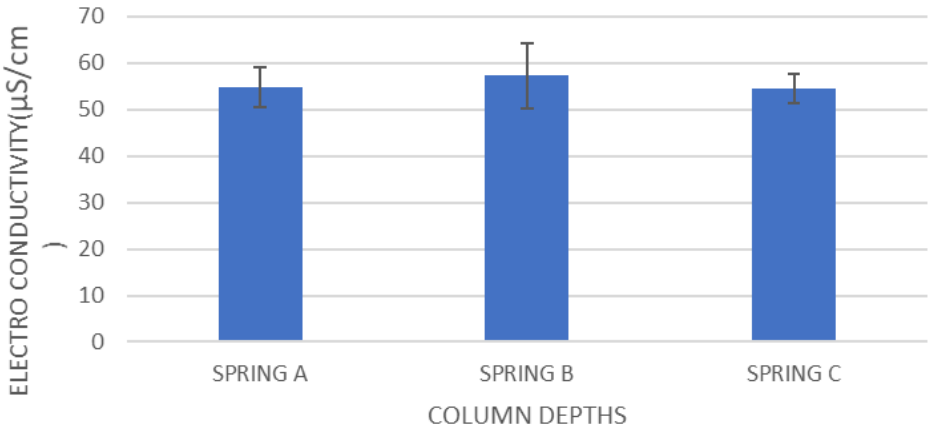


Figure 6: Average values of EC for the three sampling springs points A, B and C

4.1.1 Total Dissolved Solids (TDS)

Total Dissolves Solids (TDS) are those total solids in water that pass through a filter with a pore size of 2.0 µm (APHA, 1999).

TDS gives an approximate value of the quality of the groundwater because the total dissolve solids affect the turbidity, taste, and conductivity of the water (APHA, 1999).

For naturally occurring groundwaters, TDS values are mostly due to the dissolution of ions such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, and trace levels of ions such as Cu^{2+} and Pb^{2+}.

The results of the mean TDS concentrations also validate the stability of the springs, with Spring A registering an average of 39.51 ± 2.00 mg/L, Spring B registering an average of 43.62 ± 5.06 mg/L, and Spring C registering an average of 41.04 ± 2.77 mg/L. Notably, each average is well within the acceptable limit of the US Environmental Assessment Strategy 12:2014 guideline of 1500 mg/L in drinkable water. The minor variations in the concentrations across the springs are understandably a result of the variations in the geology and recharge mechanisms but are instead stable and do not pose any issues of salinity to the water sources

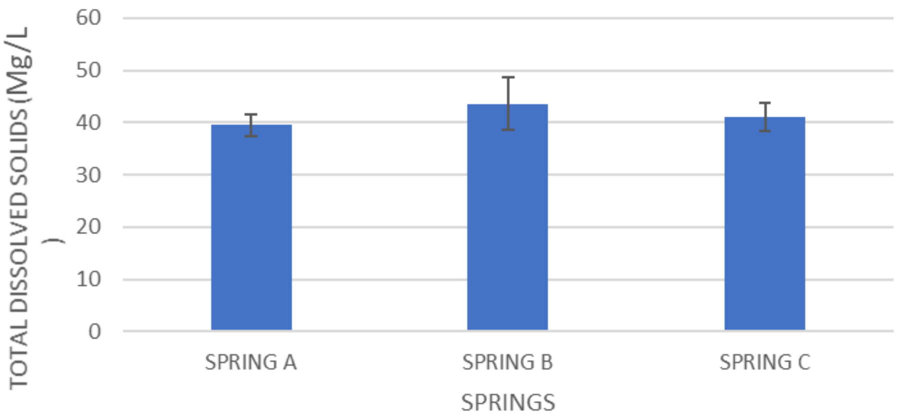


Figure 7: Average values for TDS for the three different springs A, B and C

4.1.2 Heavy metal concentrations (Cu and Pb)

The results of the analysis of the levels of Copper (Cu) and Lead (Pb) released from the sampled springs on the 8th, 15th, and 21st of September clearly indicated the presence of spatial variation across the area studied. The maximum permissible limits of Cu and Pb in drinking water according to the Uganda Standard for Drinking Water Quality US EAS 12:2014 are given by 1.0 mg/L and 0.01 mg/L, respectively.

Table 3 : Average Heavy Metal Levels at Sampling Points A, B and C

Heavy Metal	**Sampling Point**	**Mean Concentration (mg/L)**	**EAS Standards (mg/L)** (MWE, 2020)
Pb	**A**, n = 3	0.006± 0.0008	0.O1
	B, n = 3	0.22 ± 0.022	
	C, n = 3	0.21 ± 0.042	
Cu	**A**, n = 3	0.79 ± 0.10	I.0
	B, n = 3	1.22 ± 0.12	
	C, n = 3	1.32 ± 0.17	

When taking into consideration the total number of sampling periods, the lowest levels of both metals in Spring A (protected spring) are observed. For the Copper level, the values fluctuated from 0.65 to 0.82 mg/L, while the average value reached 0.73 mg/L, while the Lead ranged from 0.006 to 0.009 mg/L, with a mean of 0.006 mg/L. The average concentration of the analyzed metals is wthin the limits of the safe concentration of drinking water specified by the US EAS 12:2014 standard, indicating that spring A is safe from contamination. Even though the concentration of the heavy metals is not alarming, the fact that they are present suggests that the ‘protected’ spring is not completely insulated from the effects of environmental factors such as surface runoff.

The spring with the highest concentrations of metals came from Spring B. The results in the analysis illustrate that the levels of Copper ranged from 1.10 to 1.30 mg/L while the average value is approximately 1.2 mg/L, and Lead was ranging from 0.20 to 0.24 mg/L with an average of 0.20 mg/L. The concentrations of both Cu and Pb in Spring B and C exceeded the recommended levels for safe drinking water. The substantially high concentrations of the two metals in Spring B could be linked to the uncontrolled human activities taking place in and around the source such as bathing, washing clothes, washing cars/bodas, and drainage from the settlements that form the spring surroundings, thus resulting in the scattering of the metal-containing sediments and dust into the springs.

The Spring C recorded a moderate to high level of metal content characterized by the presence of Copper at a level of 0.99 to 1.34 mg/L (approx. 1.2 mg/L) and Lead at a concentration of 0.19 to 0.22 mg/L (approx. 0.20 mg/L). However, this was still lower than the recorded concentrations in Spring B but higher than the permissible levels. The slight drop in the values recorded on the final day might be attributed to dilution and incorrect calibration. The water from the two Springs is also harmful for human consumption but only safe after treatment.

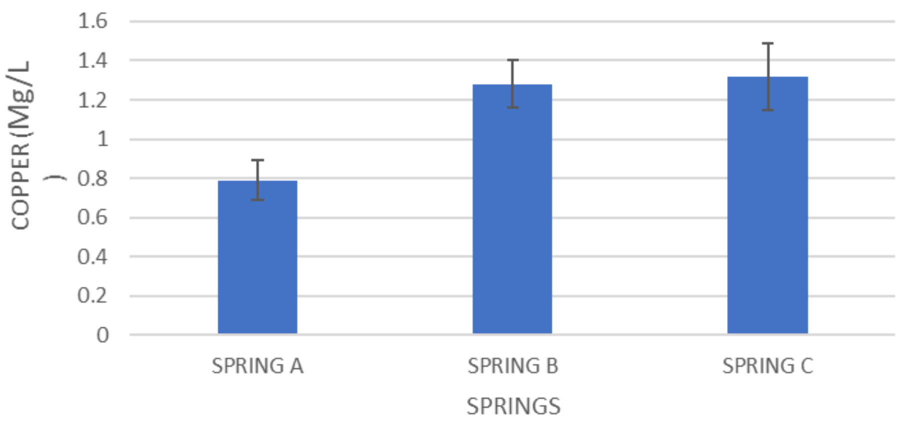


Figure 8: Average concentration of Copper in Springs A, B and C

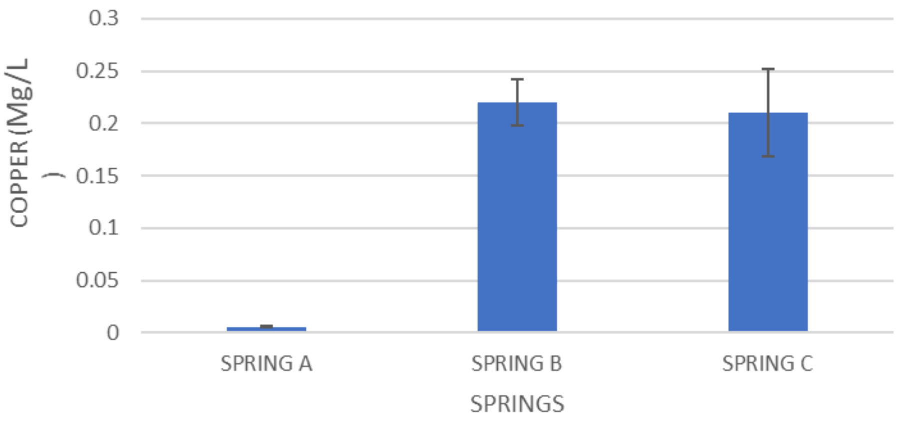


Figure 9 : Average concentration of Lead in Springs A, B and C

4.2 DETERMINATION OF PERCENTAGE REMOVAL FOR ZEOLITES.

4.2.1 Percentage Removals at different depths

PH

The resulting effect on the pH of the spring water samples, following treatment with the natural and modified zeolite beds of varying depths, was a marked increase in pH values due to the chemical composition and interaction of zeolite minerals and the spring water. The exchangeable alkaline earth elements in zeolites include calcium, magnesium, sodium, and potassium, which migrate to the water in the process of ion exchange. The replacement of the hydrogen ions in the water with the weakly alkaline ions resulted in an increase in pH values, an effect that was accelerated by the size of the zeolite bed in contact with the water.

The first treatment phase was represented by the sample taken on 8th September, with a pH value of 6.58 ± 0.10. Upon treatment with a 10 cm layer of natural zeolite on 10th October, the pH rose to 6.98 ± 0.12. This is typical for natural zeolite media, whose relatively low number of active binding sites and relatively low surface activity make them less effective than modified zeolites. Also, the short contact time of two minutes in this treatment was a factor in the moderate ion exchange and slight neutralization of the slightly acidic raw water sample.

Higher pH increase was recorded in the second stage, where the sample collected on the 15th September (raw pH value of 6.62 ± 0.12) received treatment on the 16th October with a bed of modified zeolite measuring 20 cm in height. The pH of the treated water increased to 7.32 ± 0.15, showing a higher buffering capacity. Surface modification is known to improve the ion exchange capacity of zeolite by accentuating the surface functional groups, pore volume, and the availability of active adsorption sites. The deeper bed and the larger contact time of five minutes gave a higher chance of hydrogen ion exchange with the alkaline cations, resulting in higher pH levels than in the natural zeolite sample processed in a shallow bed.

The last treatment process, applied to the sample of the 21st September (raw pH of 6.65 ± 0.11), performed on the 23rd of October, consisted of a modified zeolite with a bed height of

30 cm and an extended contact time of approximately ten minutes. It produced the highest pH value in the treated solution, averaging 7.52 ± 0.18 at a depth where the higher quantity of zeolite present, along with its larger surface area and longer interaction time with the water, enabled the maximum utilization of the ion-exchange capacity of the modified zeolite. The pH of the resultant effluent shows a considerable neutralization process, resulting in an optimally well-buffered pH suitable for drinking quality.

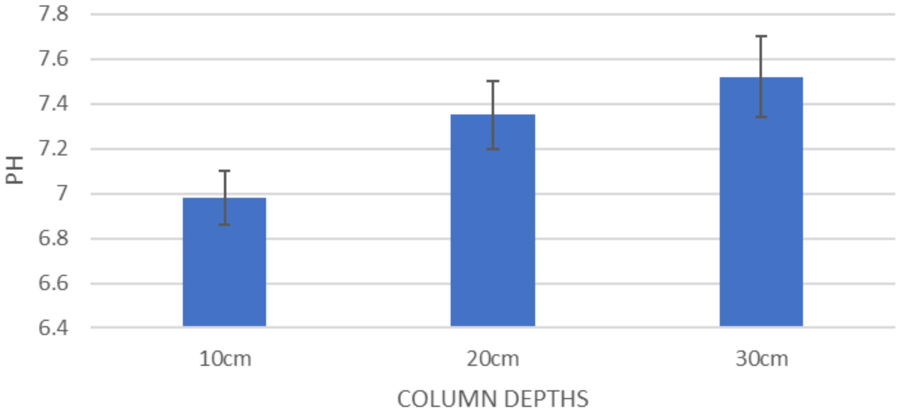


Figure 10 **: Mean pH values for samples of A, B and C at different depths *n* = *3*.**

4.2.2 Electro Conductivity

The Electrical Conductivity (EC) of the raw groundwater samples taken from the springs on the 8th, 15th, and 21st of September ranged from 54 to 57 µS/cm, with Spring B recording higher amounts because of the grey water discharge from bathing, washing, and motorbike washing practices. The EC value of the water reduced systematically following the treatment process involving natural and modified zeolite beds of various depths, representing the process where the ions in solution are removed through adsorption and ion exchange processes. The modified zeolite has a high cation exchange capacity, making it capable of removing ions such as Na^+, Ca^{2+}, Mg^{2+}, and trace amounts of heavy metals responsible for the conductivity in the water.

For the 8th September samples, following treatment on the 10th of October with a 10 cm bed of natural zeolite and a contact period of approximately two minutes, EC reduced slightly from the raw levels (54.9-57.3 µS/cm) to an average treatment value of 50-52 µS/cm. For the 15th September samples, treatment on the 16th of October with a 20 cm bed of modified zeolite and an average contact period of five minutes resulted in a considerable decrease in EC from the raw levels to an average treatment value of 44-47 µS/cm in the springs. The maximum decrease in EC was measured in the 21st September samples treated on the 23rd of October with a 30 cm bed of modified zeolite and an average contact period of ten minutes, resulting in EC values ranging from 40-42 µS/cm. This depicts the highest level of efficiency in the removal of dissolved ions.

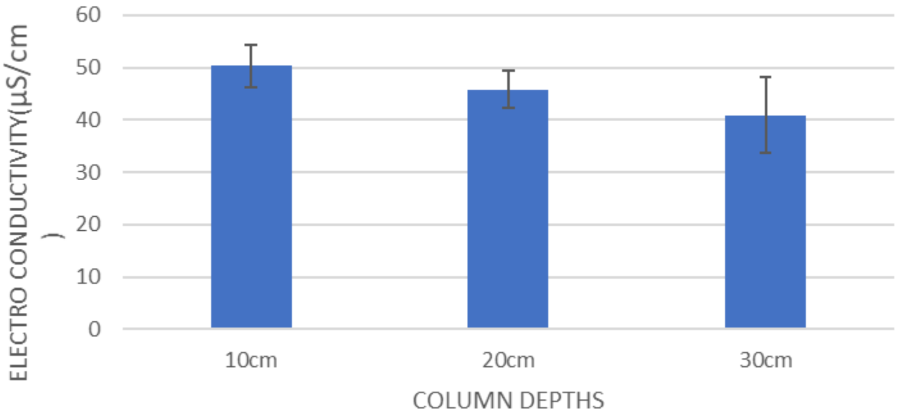


Figure 11 : Average values of EC for the three springs at different depths with treated and natural zeolite

4.2.3 Total Dissolved Solids

After treatment with the natural and modified zeolite beds of varying depths, the Total Dissolved Solids (TDS) in the spring water samples decreased consistently in each of the three springs. The initial TDS levels in the untreated groundwater samples ranged from 38.34 to 43.23 mg/L, owing to the natural presence of ionized species Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and trace amounts of heavy metals such as Pb^{2+} and Cu^{2+}. The treatment with a natural zeolite bed of a height of 10 cm (with a treatment duration of ~2 minutes) resulted in a moderate decrease in TDS to a value of 32.90 to 40.96 mg/L, recording a removal efficiency of 40% to 60%. The moderate decrease in TDS is due to the low surface area and ion exchange capacity of the natural zeolite.

The increase in the bed height to a depth of 20 cm employing the modified zeolite (contact time ~5 minutes) resulted in the further decrease in TDS to approximately 27.07-33.71mg/L, due to the enhanced adsorption capacity and ion exchange efficiencies of the modified zeolite. The maximum decrease in TDS was noted in the 30 cm bed height of modified zeolite (contact time ~10 minutes), in which the values of TDS reduced to approximately 18.87-20.07 mg/L, thereby exhibiting a removal efficiency of more than 90%. The average values of TDS in the post-treated samples from the three springs ranged approximately from 28.67-32.54 mg/L.

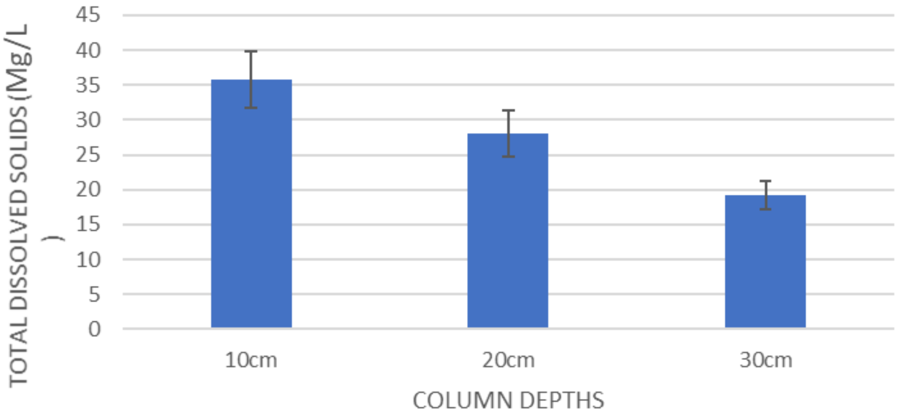


Figure 12 **: Average values of TDS at different removal depths for the three different springs**

Copper

After the treatment process using natural and modified beds of increasing depths, the copper concentrations in the groundwater of springs A, B, and C diminished progressively. For the initial samples taken on the 8th September and treated on the 10th October, employing a bed height of 10 cm natural zeolite and a contact period of approximately two minutes, the copper concentrations of the samples from springs A, B, and C contained 0.005, 0.75, and 1.07 mg/L, respectively. Though reduced from the raw values, the concentrations of springs B and C were still higher than the standard value of 1.0 mg/L, thus pointing towards the low efficacy of the shallow natural beds in removing copper ions from the water. The percentage removal in this case was in the range of 40 to 60% and clearly indicated the inefficiency of the shallow natural zeolite beds in bringing the levels required by the standards for domestic utilization.

There was an improvement in the copper removal efficiency in the second samples, taken on the 15th September and processed on the 16th October with a bed height of modified zeolite measuring 20 cm. For the three springs, the copper levels reduced to 0.245, 0.13, and 0.268 mg/L for Springs A, B, and C, respectively, corresponding to an efficiency of 80-90% of the maximum permissible limit of 1.0 mg/L. The improvement in the efficiency is due to the higher surface area and contact time of approximately 5 minutes due to the modified zeolite in a larger bed height.

The highest removal was recorded in the third set of samples, taken on the 21st September and treated on the 23rd October with a bed height of 30 cm and modified zeolite. With a contact time of approximately ten minutes, copper levels were reduced to 0.213, 0.11, and 0.198 mg/L for Springs A, B, and C, respectively. This is a removal efficiency of well above 90%, and approximately 95%, respectively, and clearly shows that an increase in bed height and a modification in zeolite significantly enhance the efficiency of copper adsorption to levels well within the acceptable limit.

The impact of zeolite type and the height of the treatment bed in the elimination of copper in domestic-scale groundwater treatment has been adequately illustrated by the following results.

The water was passed through zeolites of depths of 15cm, 20cm, and 25cm to give variation in contact period. Three separate trials were conducted and the average of the values measured was derived. The efficiency in the removal process was then measured based on the peak hour values of the effluent. The values above were derived.

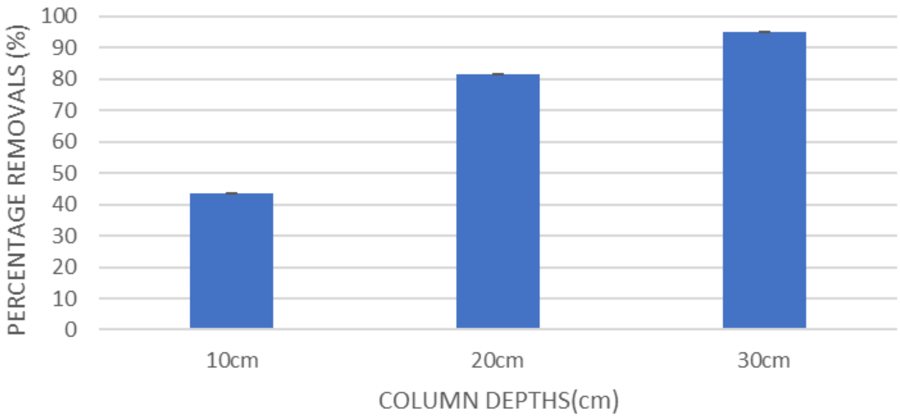


Figure 13 **: Percentage removal for Copper at different depths**

Lead

The lead levels in the spring water from springs A, B, and C reduced progressively after the treatment processes involving natural and modified zeolite beds of varying depths. The initial samples taken on the 8th September and treated on the 10th October with a natural zeolite bed of 10 cm and a contact period of two minutes resulted in a lead level of 0.003, 0.028, and 0.044 mg/L in springs A, B, and C, respectively. Though the value in spring A was less than the permissible level of 0.01 mg/L, springs B and C exceeded the limit, thereby confirming the ineffectiveness of the shallow natural zeolite beds in meeting the required standards. The percentage removal of the contaminants at this point was between 40 and 60%, depending on the capacity of the shallow natural zeolite beds, which has a low surface area and ion-exchange capacity.

The improvement in the efficiency of lead removal was noted in the second batch of samples, taken on the 15th September and treated on the 16th of October with a bed height of 20 cm of modified zeolite media. The levels of lead in the samples taken from Springs A, B, and C after treatment stood at 0.001, 0.005, and 0.008 mg/ L, respectively, recording a removal efficiency of 80-90%. The higher bed height and the higher cation exchange capacity of modified zeolite facilitated the reduction of the concentrations of the samples to below the permissible levels in all the springs.

The third batch of samples, taken on the 21st September and treated on the 23rd October with a bed height of modified zeolite at 30 cm, recorded the highest efficiency of lead removal. The lead levels reduced to 0.003, 0.004, and 0.008 mg/l in springs A, B, and C, respectively, recording a removal efficiency of more than 90%, or about 95%. The fact that the treatment involved a higher bed height and a modified surface of the zeolite, thus prolonging the contact period to about 10 minutes, resulted in the achievement of the required standards in the spring water samples.

The third batch of samples collected on the 21st September and treated on the 23rd October with a bed height of modified zeolite of 30cm recorded the highest efficiency of lead removal. Lead levels reduced to 0.003, 0

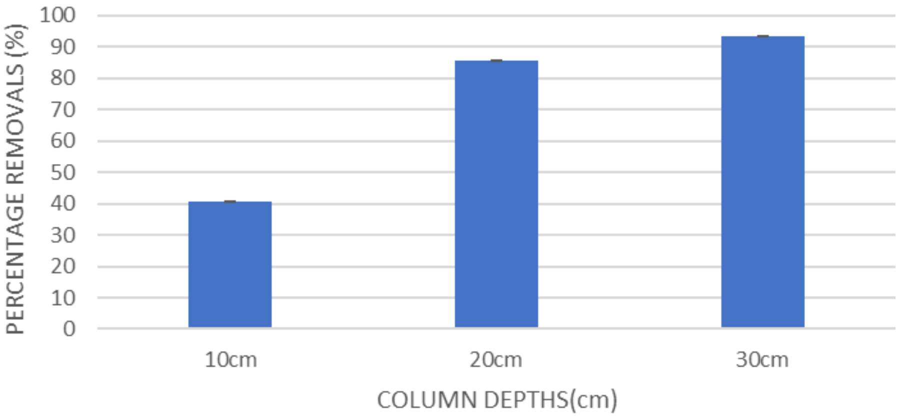


Figure 14: **Percentage removal for Lead at different depths**

4.3 Design of Packed Bed Adsorption Column for Spring Water Treatment Using Natural and Modified Zeolites

1. Treatment Objectives and Influent Characteristics

a) Target Contaminant: Lead (Pb^{2+})

Lead (Pb^{2+}) was chosen as the target contaminants to be reduced in the packed bed column design because it consistently represented the highest hazard to human health out of the six measured heavy metals in the three springs (A, B, and C). Though copper was high in some samples, the choice was made based on its higher toxicity, its tendency to be present in groundwater, and the fact that the raw concentrations in springs B and C were close to, or actually above, the drinking water guideline value in Uganda of 0.01 mg/L (US EAS 12:2014). Compared to copper, the levels of lead contamination in springs, especially in the September sampling campaign, were less constant and represented an active source of contamination in the springs, possibly due to interaction with soil moisture and plumbing and human deposition.

Based on the results of the observations, the choice of the design basis for the packed bed adsorption column using natural and modified zeolites was lead because of its lower permissible limit in water, higher toxicity, and bioaccumulation properties, making it the most challenging species to remove. The design of the column to remove Pb^{2+} to less than 0.01 mg/L will ensure effectiveness in the treatment of other metals such as Cu^{2+}, whose percentage removal was similar to or higher than that of Pb^{2+} in the treatment studies. The removal of Pb^{2+} thus served as the basis for scaling the design of the column system for the treatment of groundwater at the community level based on the adsorption bed depths, EBCT values, and breakthrough curves.

a) Desired Effluent Quality

The design of the packed bed adsorption column was based on the quality of the effluent that was required according to the US EAS 12:2014 standard for drinking water quality. The target contaminant of concern in this work was the lead (Pb^{2+}), followed by the copper (Cu^{2+}) ions.

For the treated spring water to meet the national standards of drinking water quality, the following performance objectives were established:

4.3.1 MAXIMUM ALLOWABLE LEAD CONCENTRATION (Pb^2

This limit is the regulatory requirement in the country to ensure safe drinking water and was the design limit that was used. (0.01mg/l)

4.3.2 MAX ALLOWABLE CONCENTRATION OF COPPER (Cu^{2+}

Although copper was not the primary design contaminant, concentrations in the effluent were measured against this guide to assess the effectiveness of the system. (1.0mg/l)

•Target removal efficiencies based on laboratory column performances:

•Natural zeolite (10 cm bed height): 40-60

Initial post-treated samples demonstrated some percentage of lead removed but failed to meet the standardized value of 0.01mg/L, thereby gauging the effectiveness of natural zeolite with the shallow bed depth.

•Modified zeolite (bed depth: 20 cm) - Removal

The increase in the height of the bed and the modifications to the surface significantly improved the removal efficiency of Pb^{2+} ions, and most samples fell below the regulatory limit.

•Modified zeolite (bed height of 30 cm): > 95%

At the longest contact time (10 minutes), a safe level of lead was reached in the effluent in each of the post-experiment samples, making this system the most effective.

These effluent limits served as the basis for the calculation of the bed height, empty bed contact time (EBCT), breakthrough, and design parameters of the resultant prototype adsorption column.

b) Influent Characteristics

Experimental results of raw water sampling (8th, 15th, and 21st September) gave the following results;

- Leads raw ranges: 0.003 to 1.32
- pH: 6.24 – 6.95
- Electrical Conductivity: 54.87-57.30
- TDS: 39.51-43.62

The values suggest mild mineralization, low salinity index, and heavy copper and lead contamination that demands adsorptive polishing.

2. Adsorbent Material: Natural and Modified Zeolites

Adsorption Capacity

The zeolite employed in the study has a high affinity to heavy metals, especially to Pb^{2+} and Cu^{2+} ions, owing to its high CEC and micro porous structure.

- Natural zeolite capacity: Moderate (40-60% removal at 10cm)
- Modified capacity: High (80-95% at 20-30 cm

Physical and Chemical Properties

Density:

- Particle size: 0.75 -2 mm
- Density:
- Porosity

2. Breakthrough Characteristics Based on Experimental EBCT

For domestic-scale adsorption systems employing zeolite, breakthrough is considered to occur at the point where the treated water shows a level of the influent constituent of 5%, implying that the column is removing a total of 95% of the constituent, while exhaustion happens when the concentration in the effluent reaches a total of 95% of the influent level, implying the saturated state of the zeolite column (Metcalf & Eddy/AECOM, 2003).

Based on the current study, the breakthrough and exhaustion properties in removing Pb^{2+} ions from the spring water sources were investigated through a small column laboratory experiment to simulate a typical domestic water treatment system involving natural and modified zeolites. The breakthrough curves for the experiments enabled the assessment of the effectiveness of the zeolite bed dimensions of 10 cm, 20 cm, and 30 cm in the removal process.

The breakthrough time for the zeolite columns was then estimated based on important design parameters such as: influent and effluent concentrations of lead, flow rate corresponding to a domestic scale, bulk density of zeolite, Freundlich constants of adsorption ((Kf and 1/n)), and the Empty Bed Contact Time (EBCT). The above parameters helped in the design of an effective domestic treatment unit that could remove lead to a safe level in drinking water.

Three column depths (10, 20, and 30 cm) were employed to assess the breakthrough and exhaustion characteristics:

Three column depths (10, 20, 30 cm) were used to determine breakthrough and exhaustion behavior:

Breakthrough occurred at:

Column Depth	Zeolite Type	EBCT (min)	% Removal Pb
10 cm	Natural	2 min	40–60%
20 cm	Modified	5 min	80–90%
30 cm	Modified	10 min	~95%

- Natural zeolite (10 cm): early breakthrough
- Modified zeolite (20 cm): delayed breakthrough
- Modified zeolite (30 cm): no breakthrough observed within 10 minutes

These EBCTs guided scale-up design.

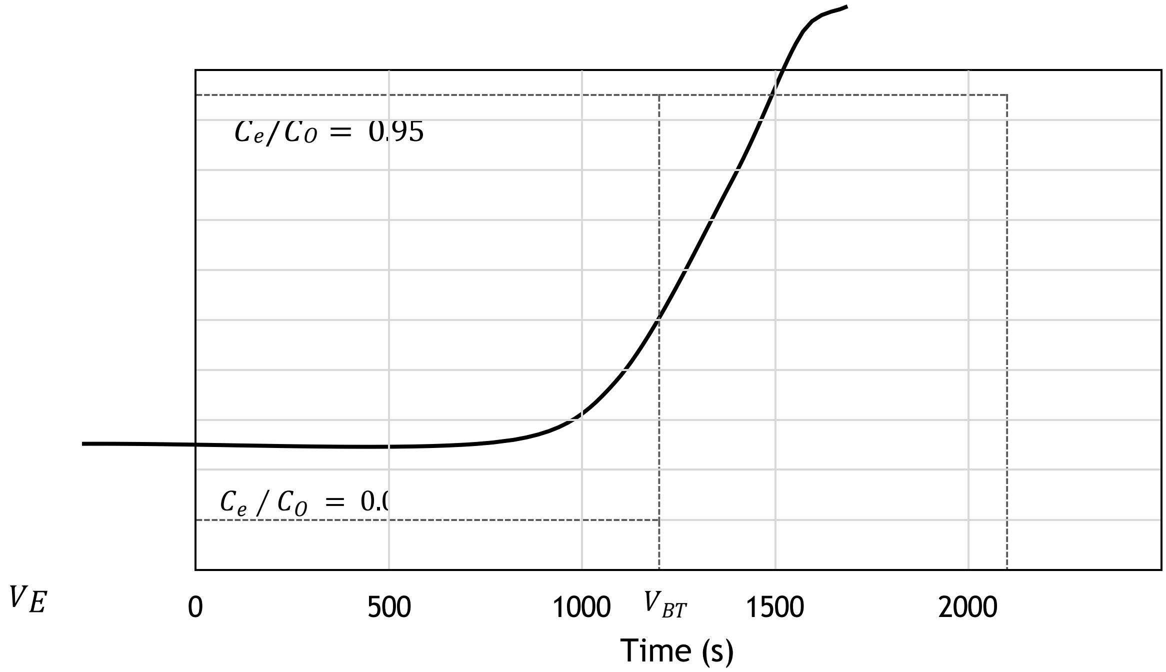


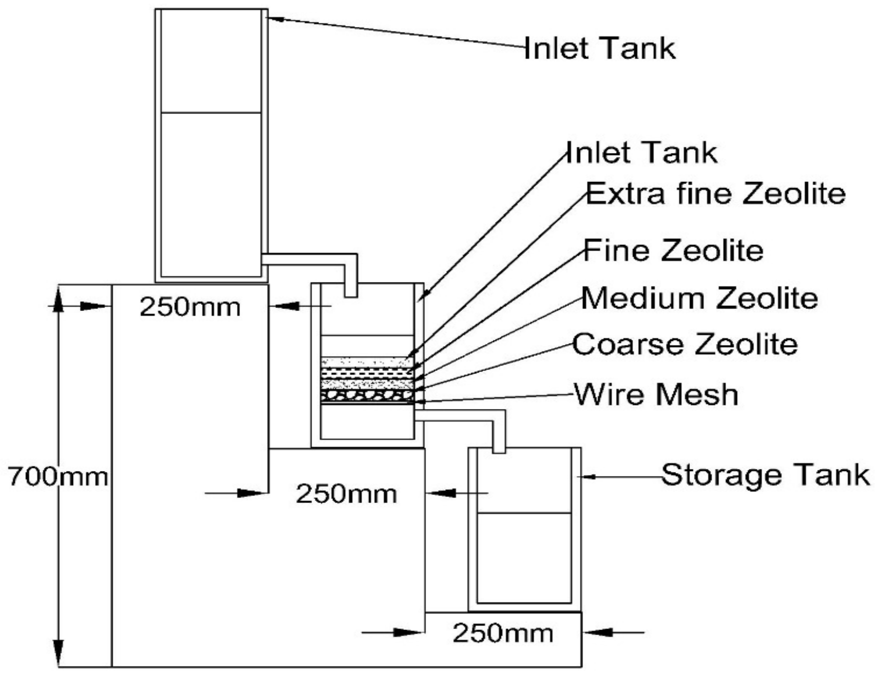
Figure 15: **Breakthrough Curve for the Small-Scale Column Test**

4.4 Summary of Column Design for Full-Scale Implementation

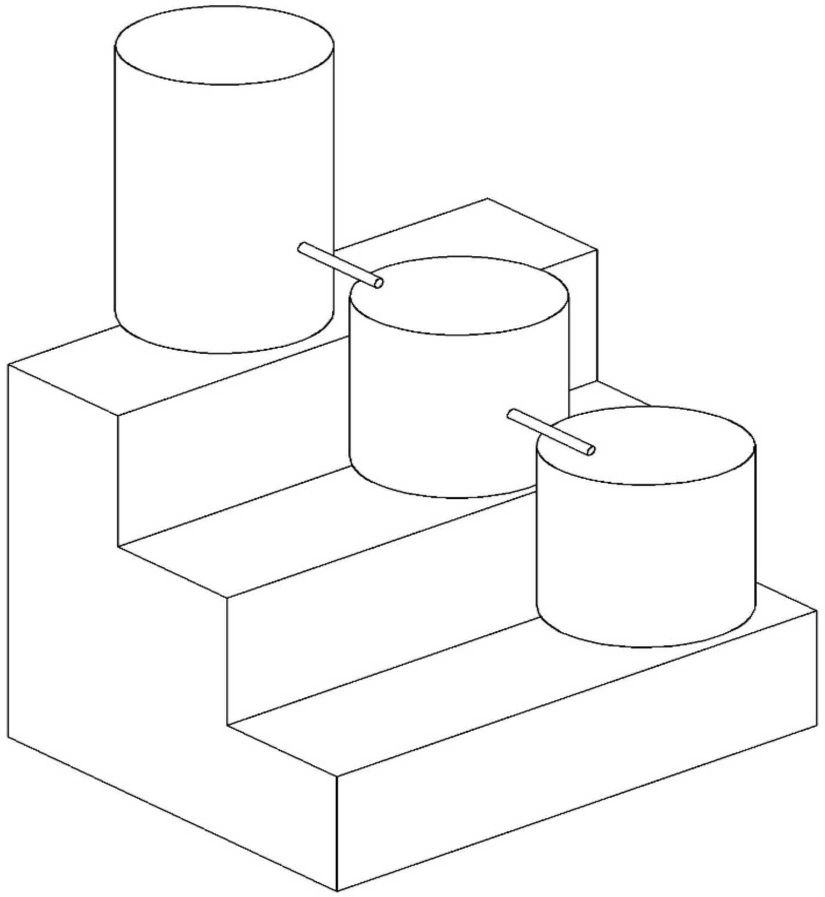
A complete system based on the modified zeolite should employ:

- Column height: ≥ 30 cm
- EBCT: >10 minutes
- Flow rate: ≤ 1.5 L/hr./unit
- Mass of zeolite: 6 to 8 kg/unit for
- Average life: 3 to 6 months based upon the raw metal content

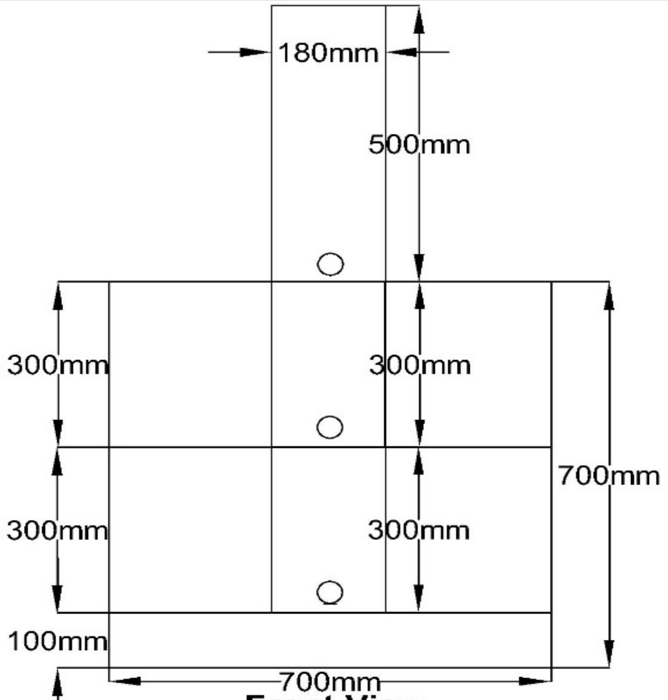
SYSTEM DIMENSIONS			
	Zeolite tank	**Inlet tank**	**Storage tank**
Height	30cm	50cm	50cm
Diameter	18cm	18cm	18cm
Material	Plastic	Plastic	Plastic
FILTER MEDIA			
Type	Clinoptilolite zeolite		Contact time 10 mins
Particle size	0.075-2mm		
CONNECTIONS			
Inlet tap	15mm		Desired quality 0.08 mg/l for Pb 0.8 mg/l for Cu
Flow rate	1.5l/min		
Daily capacity	15L/day		



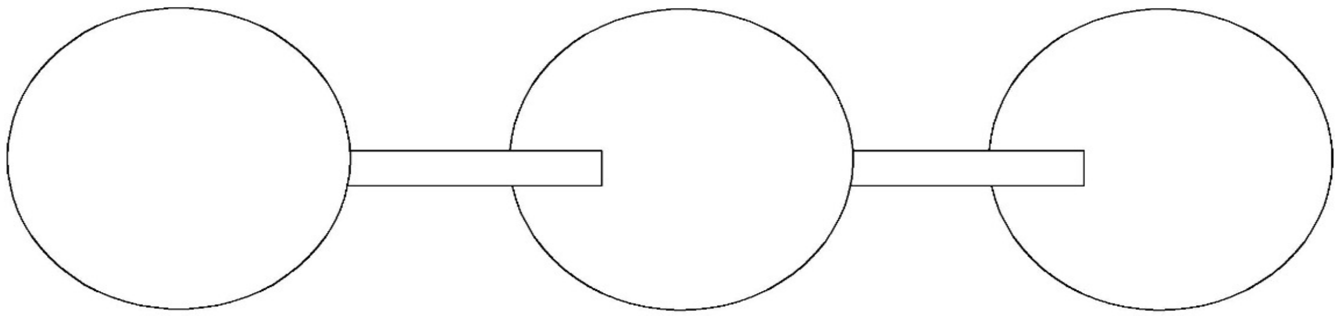
Section View



Isometric View



Front View



Plan View

TITLE:	**ZEOLITE FILTER SYSTEM**
SCALE:	**1:50**
AUTHOR:	**LUBULWA IVAN JOSEPH**
REG NUMBER:	**M22B32/050**

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study aimed to assess the suitability of natural and modified zeolites for the removal of copper (Cu^{2+}) and lead (Pb^{2+}) from groundwater collected from three springs (A, B, and C) in Kyabalogo Village, Nakisunga Sub–County. Samples were collected on three campaigns 8th, 15th, and 21st September—to characterize raw water quality. The first objective was achieved by determining the physicochemical characteristics of the springs, including pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), turbidity, and concentrations of Cu^{2+} and Pb^{2+}. Results showed slight spatial variations, with Spring B generally exhibiting higher EC, TDS, and heavy metal concentrations, likely due to nearby domestic activities such as laundry, bathing, grey water discharge, and jerry can washing.

The second aim, concerning the assessment of the efficiency of natural and modified zeolites in the removal of heavy metals, was realized through column adsorption studies done at higher depths of the bed (10 cm, 20 cm, and 30 cm). Natural zeolite at a 10 cm depth recorded relative efficiencies of 40 to 60%, but in some instances, the copper and lead concentrations in the effluent did not comply with the national drinking water standards (US EAS 12:2014). Nevertheless, modification of the zeolite and the higher depths recorded higher efficiencies in the process. At a 20 cm column using modified zeolite, efficiencies crossed the 80 to 90% mark, while at a higher depth of 30 cm, efficiencies were in excess of 95%, recording concentrations well within the permissible limits of copper (2.0 mg/L) and lead (0.01 mg/L) in the effluent water.

The third target concerning the optimization of the operation conditions of the adsorption columns was also realized. Raising the EBCT values from 2 minutes (10 cm) to 5 minutes (20 cm) and finally to 10 minutes (30 cm) demonstrated a notable increase in the efficiency of the adsorption process and the point of breakthrough. The optimization of the adsorption process is thus important in the polishing of ground water.

Finally, the work proved the efficacy of modified zeolite as a low-cost adsorbent that has the capability to remove contaminants in the groundwater in rural areas where spring water is the main source of drinking water.

5.2 Recommendations

Based on the results, the modified zeolite with a bed height of 20 to 30 cm sustained an efficiency rate of more than 90% in the removal of Lead (Pb^{2+}) and Copper (Cu^{2+}) ions in the water. The modified zeolite is recommended to be incorporated in the gravity flow columns for domestic water treatment in Kyabalogo Village. The modified zeolite will provide safer water than the natural zeolite at a height of 10 cm, whose efficiency was below the minimum required in the protected and unprotected springs in the village.

For efficient heavy metal removal, the domestic column should be designed to provide a suitable bed height or EBCT value of ideally 5 to 10 minutes. The design should involve the use of packed beds measuring 20 to 30 cm high, thereby ensuring a reasonable contact capacity for the water and zeolite combination. The domestic users should be able to regulate flow rates and replace zeolite in case of breakthrough.

Future works should be conducted to investigate the regeneration and reusability of modified zeolite to minimize the cost associated with operations, for instance, saline back-washing and mild acid treatment processes. Other topics of investigation should include the impacts of co-existing ions in the groundwater, such as Ca^{2+}, Mg^{2+}, and Na^{+} ions, on the efficiency of adsorption capacity of Cu^{2+} and Pb^{2+} ions in real domestic settings. Other possible methods of modifying zeolite to make the system more environment-friendly and sustainable in a low-cost manner, for instance, through the process of acid activation, surfactant treatment, and heating, should be investigated.

References

Andres, A.-B., Alfredo, C. T., & Mario, O.-M. (2022). Adsorption Isotherms: Enlightenment of the Phenomenon of Adsorption. In *Wastewater Treatment* (p. 15). Chihuahua, Mexico: Intech Open.

Annelie, H., & Lea, R. (2006). Methodological Aspects of Using Blast Furnace Slag for ssWastewater Phosphorus Removal. *JOURNAL OF ENVIRONMENTAL ENGINEERING*,

Anubhav, S., Sharma, A., Verma, R. K., & Chopade, R. l. (2022). *Heavy Metal Contamination of Water and Their Toxic Effect on Living Organisms.*

APHA . (1999). American Public Health Association,. In A. W. American Public Health Association, *Standard Methods for the Examination of Water and Wastewater* (p. 541).

APHA . (1999). American Public Health Association,. In A. W. American Public Health Association, *Standard Methods for the Examination of Water and Wastewater* (p. 541).

Ariffin, N., Abdullah, M. M., Mohd, M. R., Zainol, A., Mohd Fared Murshed3, H.-Z. ,., & Bayuaji, R. (2017). Review on Adsorption of Heavy Metal in Wastewater by Using Geopolymer . *EDP Sciences*, 8.

Ariffin, N., Abdullah, M. M., Mohd, M. R., Zainol, A., Mohd Fared Murshed3, H.-Z. ,., & Bayuaji, R. (2017). Review on Adsorption of Heavy Metal in Wastewater by Using Geopolymer . *EDP Sciences*, 8.

Askeland, D., Pradeep, P. F., & Wendelin, J. W. (2010). *THE SCIENCE AND ENGINEERING OF MATERIALS. 6TH ED.* Cengage Learning Ltd.

Askeland, D., Pradeep, P. F., & Wendelin, J. W. (2010). *THE SCIENCE AND ENGINEERING OF MATERIALS. 6TH ED.* Cengage Learning Ltd.

Athar, H., Sangeeta, M., & Richa, M. (2021). Removal of Heavy Metals from Wastewater by Adsorption. *IntechOpen*, 25.

Athar, H., Sangeeta, M., & Richa, M. (2021). Removal of Heavy Metals from Wastewater by Adsorption. *IntechOpen*, 25.

Auerbach, S. M., 2003. *Handbook of zeolite science and technology.* s.l.:s.n.

Aziz, S. Q. & Mustafa, J. S., 2019. Step-by-step design and calculations for water treatment plant units. *Advances in envronmental Biology,* Volume 13, p. 16.

BCWCID2. (2021). *Request for Proposals (RFP) for Granular Activated Carbon Adsorption System* . Texas.

BCWCID2. (2021). *Request for Proposals (RFP) for Granular Activated Carbon Adsorption System* . Texas.

Bedmohata, M., Chaudhari, A., Singh, S., & Choudhary, M. (2015). Adsorption Capacity of Activated Carbon Prepared by Chemical Activation of Lignin for the Removal of Methylene Blue Dye. *International Journal of Advanced Research in Chemical Science (IJARCS), Volume 2*(Issue 8), PP 1-13.

Bedmohata, M., Chaudhari, A., Singh, S., & Choudhary, M. (2015). Adsorption Capacity of Activated Carbon Prepared by Chemical Activation of Lignin for the Removal of Methylene Blue Dye. *International Journal of Advanced Research in Chemical*

Science (IJARCS), Volume 2(Issue 8), PP 1-13.

Bekkum, H. v., 2001. Introduction to Zeolite Science and Practice. *Elsevier*.

Blanca, G., Belén, M.-P., & Magna, M. (2020). Chemical and microstructural characterization of blast furnace slag. *Revista de la Sociedad Científica del Paraguay, Vol. 25*(No. 2), 4.

Blanca, G., Belén, M.-P., & Magna, M. (2020). Chemical and microstructural characterization of blast furnace slag. *Revista de la Sociedad Científica del Paraguay, Vol. 25*(No. 2), 4.

Busulwa, R., 2023. *Investigating the effectiveness of using natural zeolite as an adsorbent for removing chromium from tannery wastewater*. Tororo: Busitema University.

Čabanová, K., Jozef, V., Jana, S., Vlastimil, M., Pavlína, P., Iveta, M., & Jana, K. (2018). Chemical and phase composition of metallurgical slags and their effects on freshwater green algae. *Elsevier Ltd, 5*(210), 9.

Čabanová, K., Jozef, V., Jana, S., Vlastimil, M., Pavlína, P., Iveta, M., & Jana, K. (2018). Chemical and phase composition of metallurgical slags and their effects on freshwater green algae. *Elsevier Ltd, 5*(210), 9.

Cantinho, P, Matos, M., Trancoso, M. A., & dos Santos, M. M. (2015). Behaviour and fate of metals in urban wastewater treatment plants: a review. *Int. J. Environ. Sci. Technol*, 28.

Cantinho, P, Matos, M., Trancoso, M. A., & dos Santos, M. M. (2015). Behaviour and fate of metals in urban wastewater treatment plants: a review. *Int. J. Environ. Sci.*

Technol, 28.

Cejka, J., 2010. *Zeolites and Catalysis: Synthesis, Reactions and Applications,* s.l.: s.n.

Chen, C., Hu, J., & Luo, S. (2017). Adsorption of Heavy metal ions from wastewater onto Biochar. *Environmental science and technology* , 512-523.

Chen, C., Hu, J., & Luo, S. (2017). Adsorption of Heavy metal ions from wastewater onto Biochar. *Environmental science and technology* , 512-523.

Commission .

D.Olson, W. M. a., 1992. *Details of structures of 85 of the zeolites.* s.l.:International Zeolite association.

Elias, J. A. (2008). *Introduction to Ironmaking and Steelmaking*. Society of Manufacturing Engineers. .

Elias, J. A. (2008). *Introduction to Ironmaking and Steelmaking*. Society of Manufacturing Engineers. .

Fernandes , L. d. M., Rodrigues da Silva, G. & Clark Peres, A. E., 2022. Zeolite Application in Wastewater Treatment. *Adsorption Science & Technology,* Volume 2022,

for the removal of industrial dyes: A review. *R SC Adv*, 24571–24587 .

Fuhrimann, S., Stalder, M., Winkler, M. S., Niwagaba, C. B., Babu, M., Godfrey, M., . .

Fuhrimann, S., Stalder, M., Winkler, M. S., Niwagaba, C. B., Babu, M., Godfrey, M., . .

Gabson, B., Andrew, M., Hannington, T., Allan, G., Caroline, K. N., Patrick, O., . . . Timothy, O. (2022). Heavy Metal Contamination of Sediments from an Exoreic African Great Lakes’ Shores (Port Bell, Lake Victoria), Uganda. *MDPI*, 15.

Gabson, B., Andrew, M., Hannington, T., Allan, G., Caroline, K. N., Patrick, O., . . . Timothy, O. (2022). Heavy Metal Contamination of Sediments from an Exoreic African Great Lakes' Shores (Port Bell, Lake Victoria), Uganda. *MDPI*, 15.

Gautam, R. K., Sharma, ,. S., Mahiya, S., & Chattopadhyaya, M. (2015). Contamination of Heavy Metals in Aquatic Media Transport, Toxicity and Technologies for Remediation. *ResearchGate*, 25.

Gautam, R. K., Sharma, ,. S., Mahiya, S., & Chattopadhyaya, M. (2015). Contamination of Heavy Metals in Aquatic Media Transport, Toxicity and Technologies for Remediation. *ResearchGate*, 25.

George, E., Kiyoshi, F., & Lin, X. (2004). *Handbook of Metallurgical Design.* NEW YORK

George, E., Kiyoshi, F., & Lin, X. (2004). *Handbook of Metallurgical Design.* NEW YORK

Ghosh, A. (2016). *Treatise on Process Metallurgy, Volume 3: Ironmaking and Steelmaking (1st ed.).* . Elsevier.

Gina, P., & Hannes, J. (2018). *EFFECTS OF REDUCTION OF WASTEWATER VOLUMES ON SEWERAGE SYSTEMS AND WASTEWATER TREATMENT PLANTS.* Water Research

Hassan, E.-C. (2020). self compacting concrete; Materials,Properties and applications.

Imran, R. C., Chowdhury, S., Abu, M., & Mazumd, J. (2021). Removal of lead ions from water and waste water; a review on low cost adsorbents. *Applied Water Science.* INTO WATER OR LAND) REGULATIONS, 2020. The Ministry for Water and Environment. *The Uganda Gazette*, 28.

Isabella, L., Federica, P., Katja, T., Mark, C., Vilma, D., & Cristina, L. (2021). Alkali Activation of Metallurgical Slags: Reactivity, Chemical Behavior, and

Environmental Assessment. *Materials, 14*(639), 19.

James, M., Elias, M., Mark, S., & Geoffrey, S. S. (2020). Ironmaking and Steelmaking Slags as Sustainable Adsorbents for Industrial Effluents and Wastewater Treatment: Acritical Review of Properties, Perfomance, Challenges and Opportuities. *sustainability*, 46.

Javadian, H., Ghorbani, F., Tayebi, H., & Asl, S. (2015). Study of the Adsorption of Cd

Jolocam, M., Kwetegyeka, J., Ntale, M., & Wasswa, J. (2020). Efficiency of the Nakivubo wetland as a filter forheavy metal pollutants of Kampala urban effluent into Lake Victoria, Uganda. *International Scholars Journal*, 9.

Jyothi, N. R. (2020). Heavy Metal Sources and Their Effects on Human Health. In *Heavy Metals - Their Environmental Impacts and Mitigation* (p. 23). Andhra Pradesh: The Author(s).

Kadirevelu, k., Thamaraiselvi, K., & Namasivayam, C. (2001). Removal of heavy metal ions from waterwater by activated carbon. *Bioresource Tecnology*, 263.

Khan, A. R., Mohammad, R. R., & Yousef, A. A.-R. (2000). A thermodynamic model for liquid adsorption isotherms. *Separation and Purification Technology , 18*(20), 237-250.

Kristina, Č. B., Jozef, V., Jana, S., & Vlastimil, M. (2017). Chemical and phase composition of metallurgical slags and their effects on freshwater green algae. *Elsevier Ltd* , 9.

Kumar KY, M., HB, Y., Nayaka, J., Balasubramanyam, H., & Hanumanthappa. (2013). Low-cost synthesis of metal oxide nanoparticles and their application in adsorption of commercial dye and heavy metal ion in aqueous solution. *Powder Technology*.

Kumar, A., Singha, S., Sengupta, B., Dasgupta, D., Datta, S., & and Mandal, T. (2016). Intensive insight into the enhanced utilization of rice husk ash: abatement of rice mill wastewater and recovery of silica as a value added product. *Ecological Engineering*, 270–281.

Kyambadde, J., F Kansiime, L. G., & G, D. (2010). Hydraulic loading, stability and water quality of Nakivubo wetland, Uganda. *African Journal of Aquatic Science* , 213-220.

Lars, H., Ashantha, G., & Godwin, A. A. (2005). Understanding heavy metal and suspended solid relationships in in Urban stormwater using simulated rainfall. *Environmental management*, 149-158.

Manases, M., Marvie, C. B., Nurul, A. J., Chriztian, J. R., Marvin, R., A. G., & Erison, R. (2019). The removal of copper (II) and lead (II) from aqueous solution using Fuller's earth and Fuller's earth-immobilized nanoscale zero valent iron (FE-NZVI) by adsorption. *EDP Sciences, 268*(10510), 6.

Mbabazi, J., Kwetegyeka, J., Wasswa, J., & Ntale, M. (2010). Ineffectiveness of Nakivubo wetland in filtering out heavy metals from untreated Kampala urban effluent prior to discharge into Lake Victoria, Uganda. *African Journal of Agricultural Research, 5*(4), 10.

Metcalf & Eddy / AECOM. (2003). *Wastewater Engineering; Treatment and Resource Recovery*. New York: McGraw-Hill Education.

Metcalf & Eddy, 2004. *Wastewater Engineering treatment and Reuse*. s.l.:s.n.

Miedaner, M. M., Weerasooriya, R., & Tobschall, H. J. (2006). Chapter 17-1-pK modeling strategies for the adsorption of some trace elements onto gibbsite. In J. (. Lützenkirchen (Ed.), *Interface Science and Technology* (pp. 469-490). Elsevier (Surface Complexation Modelling).

Miyamoto, T., Koichi, T., Kenichi, A., & Sachiko, H. (2015). *Production and Use of Blast Furnace Slag Aggregate for Concrete*. Tokyo: NIPPON STEEL & SUMITOMO METAL.

MODELS. *ACTA TECHNICA CORVINIENSIS – Bulletin of Engineering*, 86 - 95.

Mohammed, S., Mahdi, B., & in. (2022). Handbook of Sustainable Concrete and industrial waste management. *ScienceDirect*, 21.

Mona, A. A., Saud, R., Abdulla, A., & Ahmed, A. E.-F. (2023). synthesis and characterisation of biodegradable poly(vynl alcohol)-chitosan/cellulose hydrogel beads for efficient removal of Pb, Cd, Zn and Co from water.

MWE. (2020). THE NATIONAL ENVIRONMENT (STANDARDS FOR DISCHARGE OF EFFLUENT

NEMA, 1999. Standards for Discharge of Effluent into Water or on Land Regulations. *The National Environment.*

NEMA, 1999. *Standards of Discharge of effluent into water on land.* s.l.:s.n.

p. 26.

Precious, E., Israel, I. A., & Isiguzo, E. A. (2022). REVIEW OF ADSORPTION ISOTHERMS

Qasem, N. A., Mohammed, R. H., & Lawal, D. U. (2021). Removal of heavy metal ions from wastewater: a comprehensive and critical review. *Clean Water*, 16.

Rađenović, A., Jadranka, M., Tahir, & Sofilić. (2013). Characterization of Ladle Furnace Slag from Carbon Steel Production as a Potential Adsorbent. *Advances in Materials Science and Engineering*, 7.

Reagan, A., 2019. *Investigating Biosorption using cofffee husks as a method of removing chromium from tannery waste water,* Mukono: UCU.

Ruhma, R., Iqrash, S., Parveen, A., Muhammad, J. I., & Murid, H. (2021). A state-of-the-art review on wastewater treatment techniques: the effectiveness of adsorption method. *Environmental Science and Pollution Research*, 28.

Saverio, L., Riccardo, B., M. I., Bianca, M., Silvia, M., Roberto, S., . . . Cinzia, (2021). Wastewater Treatment Using Alkali-Activated-Based Sorbents Produced from Blast Furnace Slag. *Applied Sciences, 11*(2985), 15.

ScienceDirect, 15.

Sels, B., 2016. *Zeolites and Zeolite like materials.* s.l.:s.n.

Shahadat, M., & Isamil, S. (2018). Regeneration performance of clay-based adsorbents

Srivastava, S. K., Gupta, V. K., & Mohan, D. (1997). Removal of Lead and Chromium by Activated Slag- A Blast Furnace Waste. *Journal of Environmental Engineering*, 9.

Sudir, M., Asha, R., & Mehra, R. (2017). Assessment of heavy metals in correlation with physio-chemical properties of drinking water of northern rajasthan, India. *international journal of pure and applied physics*, 102-106.

Sukmana, H., Naoufal, B., Fernanda, P., & Cecilia, H. (2021). Adsorption and coagulation in wastewater treatment – Review. *AKJournals*, 49 - 68.

Tamirat, D. C., & Tariku, N. (2019). Removal Methods of Heavy Metals from Laboratory Wastewater. *Journal of Natural Sciences Research*, 7.

Technology Networks. (2020). *Atomic Absorption Spectroscopy, Principles and Applications.* Retrieved November 26, 2023, from https://www.technologynetworks.com/analysis/articles/atomic-absorption-spectroscopy-principles-and-applications-356829.

Touraj, N., Hermann, R., Zahra, Z. S., & Marc, S. (2016). using total suspended solids and turbidity as proxies for evaluation of metal transport in river . *Applied geochemistry*, 68.

Turyasingura, M. & Kantuntu, J., 2023. Optimisation of eggshell-zeolite composite as a potential surfactant adsorbent for handwashing wastewater. *case studies in chemical and environmrntal engineering,* Volume 7.

U.S Department of Transportation Federal Highway Administration. (2016). *User Guidelines for Waste and Byproduct Materials in Pavement Construction, Blast Furnace Slag.* Office of Research, Development, and Technology, Office of Safety, RDT.

UN Water, 2019. *Water development report*. s.l.:UN.

UNBS. (2016). composition, specification and conformity creteria for common cements.

Usman, M. O., Aturagaba, G., Muhammad, N., & George, W. N. (2022). A review of adsorption techniques for removal of phosphates from wastewater. *Water Science & Technology*, 20.

Vito, I., Maria, C. S., Maria, L. S., Concetta, L., & Vincenzo, M. (2018). Impact of

Wastewater Treatment Plant Effluent on Downstream Water Quality.

Waleed, J., & Hamad, M. (2023). Heavy Metals – Definition, Natural and Anthropogenic Sources of Releasing into Ecosystems, Toxicity, and Removal Methods – An Overview Study. *Journal of Ecological Engineering*, 23.

Walter, J. J. (1972). ADSORPTION PROCESSES. *The University of Michigan, College of Engineering*, 18.

Yahya, J. (2022). Adsorption: A Cost-Effective Wastewater Treatment Technology for Removal of Conventional and Emerging Organic Contaminants. In J. Yahya, *Cost-efficient Wastewater Treatment Technologies* (pp. pp 17–33).

Yali, W., Huining, L., Suping, C., & Qi, W. (2021). Adsorption Behavior of Lead Ions fromWastewater on Pristine and Aminopropyl-Modified Blast Furnace Slag. *Water, 13*(2735), 19.

Younas, F., Adnan, M., Zia, U. R., Xiukang, W., Sadia, Y., Waqas, M.-U.-D., . . . Muhammad, M. H. (2021). Current and Emerging Adsorbent Technologies for Wastewater Treatment: Trends, Limitations, and Environmental Implications. *water*, 25.

Zarifeh, R., Ahasanul, K., Antoine, K., & Seddik, K. (2023). Adsorption of Heavy Metals: Mechanisms, Kinetics, and Applications of Various Adsorbents in Wastewater Remediation—A Review. *waste*, 31.

Appendix A.PICTORIAL

Figure 16 : 2mm zeolite particles

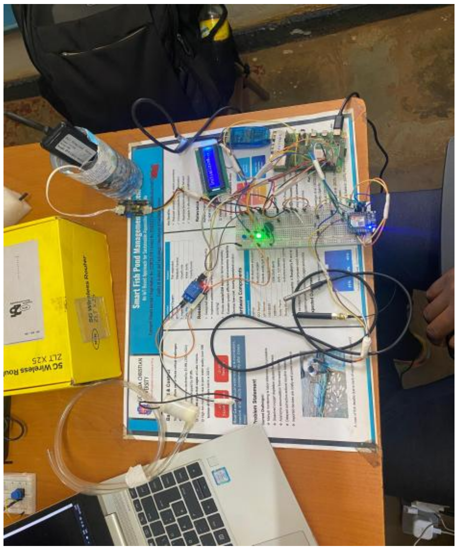


Figure 17: Automated system for testing jeavy metals indicators in water

Figure18:Household prototype

Figure 19: Different layers of prepared zeolites

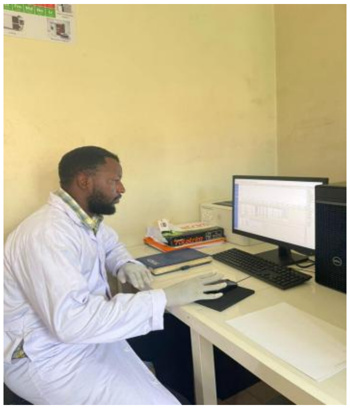


Figure20: Anaylsing raw data from the heavy metal analysis

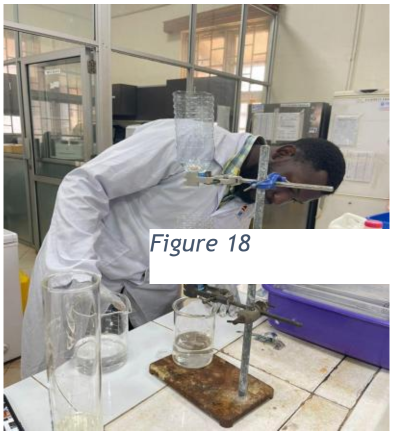
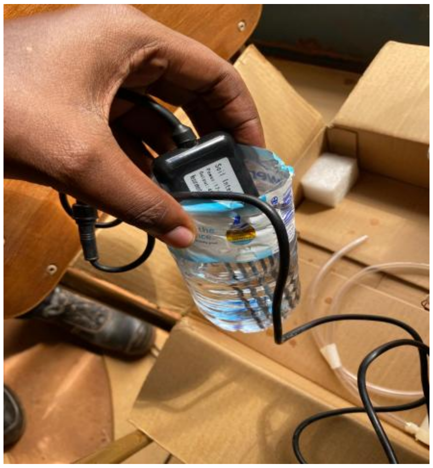
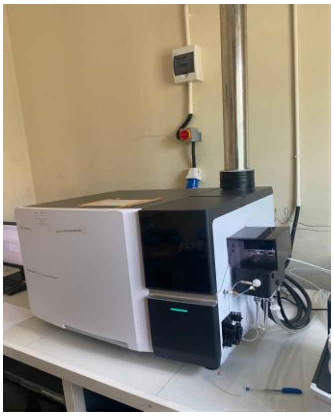


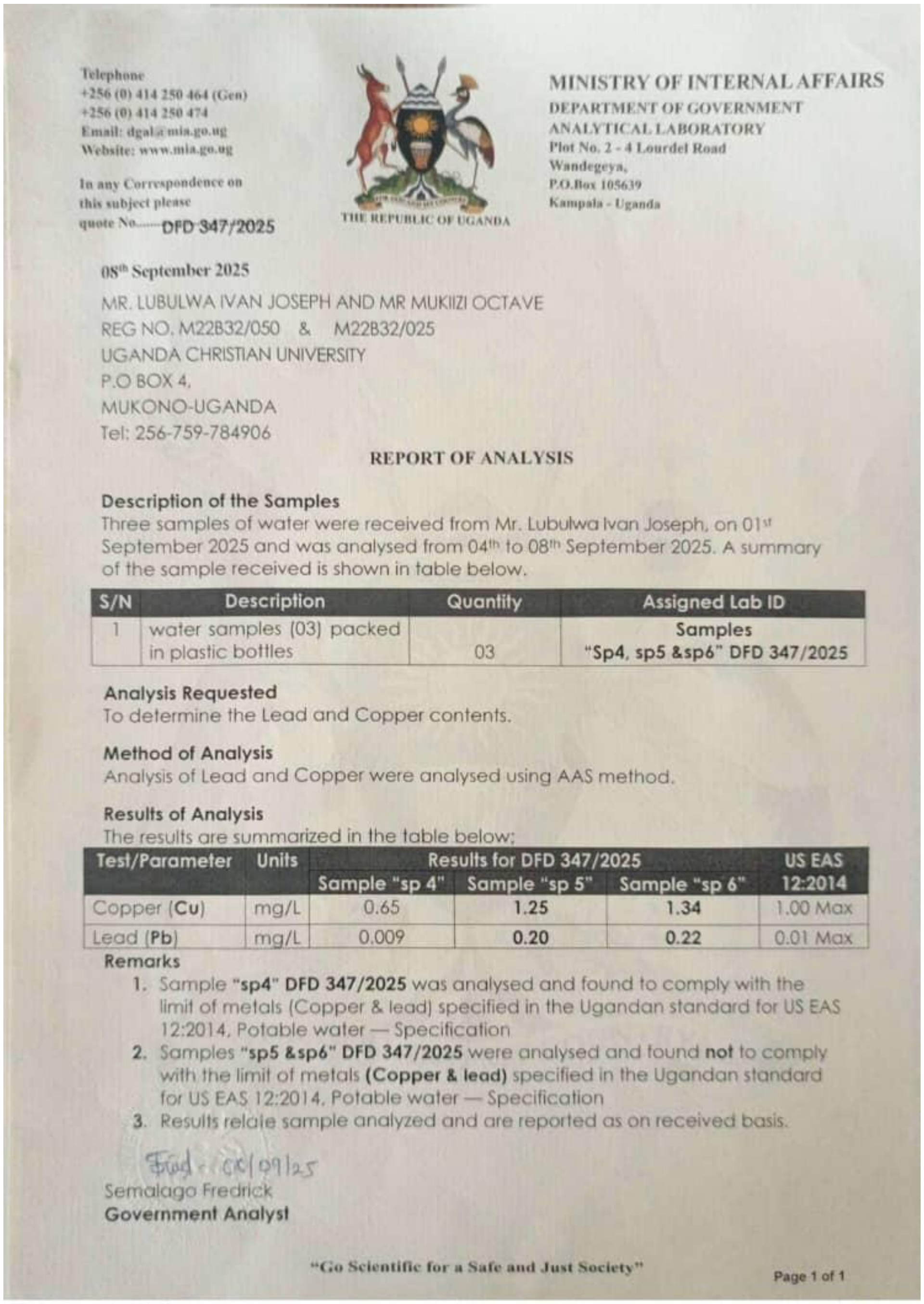
Figure 18

Figure 21: column test experiment

 Figure 22: Zeolite rocks obtained from Mbale	 igure 22: Testing the utomated system I develop uring the project	 Figure 23: Ferric chloride
 Figure 24: Zeolite rocks sorted to obtain the ones with high zeolite concentration		 Figure 25: Sieve analysis

Appendix B: laboratory results



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

In any Correspondence on
this subject please
quote No.......DFD 347/2025

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

08th September 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 01st September 2025 and was analysed from 04th to 08th September 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	**Samples "Sp4, sp5 &sp6" DFD 347/2025**

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below;

Test/Parameter	Units	Results for DFD 347/2025			US EAS 12:2014
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	
Copper (**Cu**)	mg/L	0.65	**1.25**	**1.34**	1.00 Max
Lead (**Pb**)	mg/L	0.009	**0.20**	**0.22**	0.01 Max

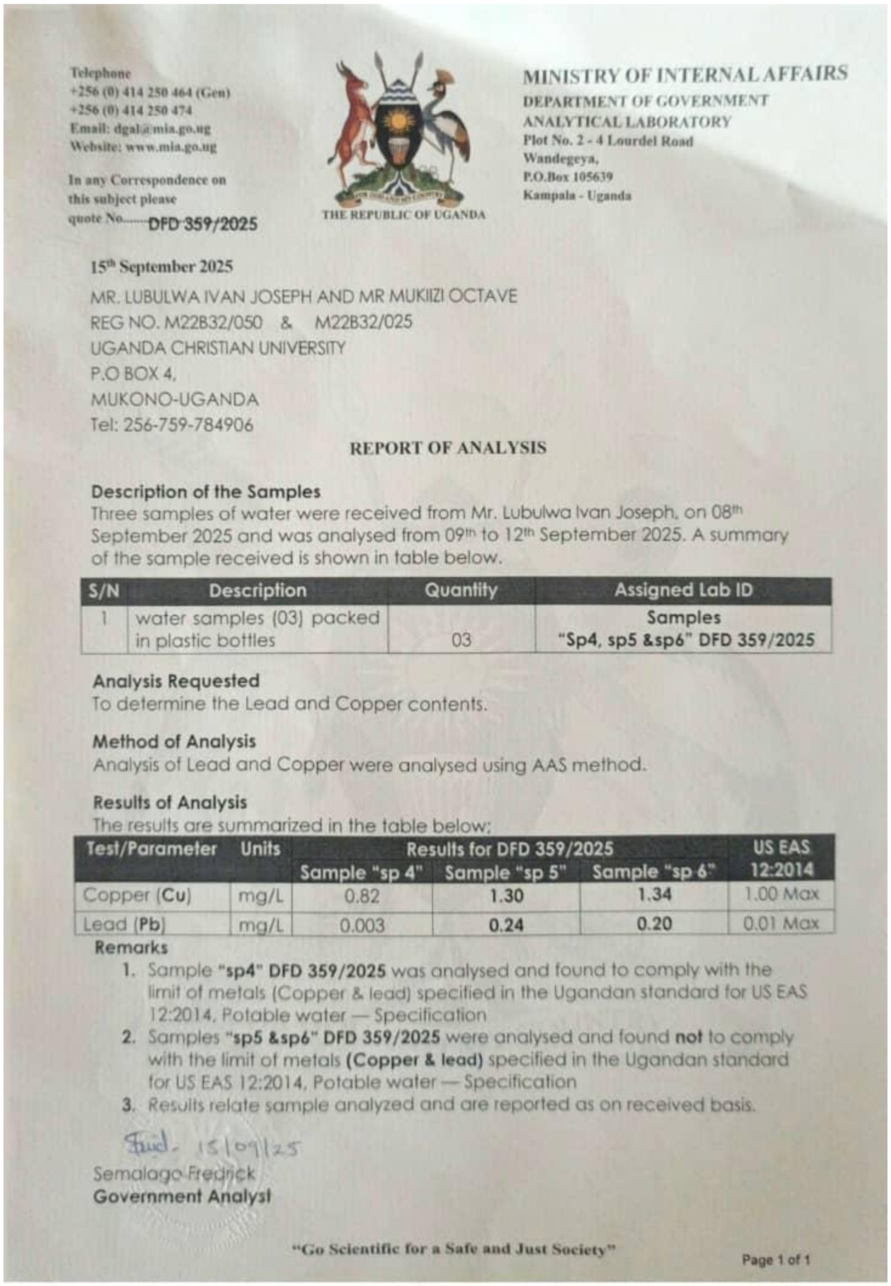
Remarks

1. Sample **"sp4" DFD 347/2025** was analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Samples **"sp5 &sp6" DFD 347/2025** were analysed and found **not** to comply with the limit of metals **(Copper & lead)** specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
3. Results relate sample analyzed and are reported as on received basis.

Fred - 08/09/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

In any Correspondence on
this subject please
quote No.......DFD 359/2025

15th September 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 08th September 2025 and was analysed from 09th to 12th September 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	Samples **"Sp4, sp5 &sp6" DFD 359/2025**

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below:

Test/Parameter	Units	Results for DFD 359/2025			US EAS 12:2014
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	
Copper (**Cu**)	mg/L	0.82	**1.30**	**1.34**	1.00 Max
Lead (**Pb**)	mg/L	0.003	**0.24**	**0.20**	0.01 Max

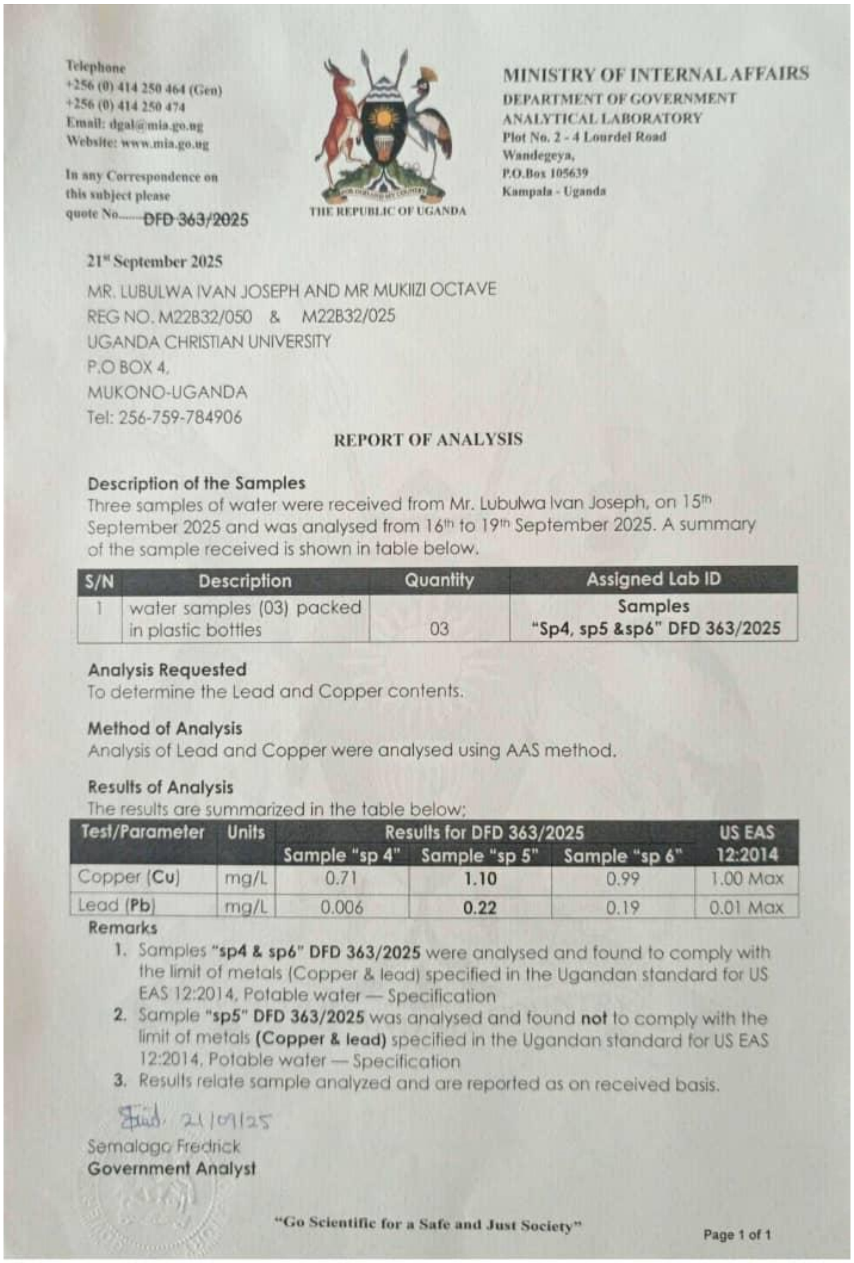
Remarks

1. Sample **"sp4" DFD 359/2025** was analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Samples **"sp5 &sp6" DFD 359/2025** were analysed and found **not** to comply with the limit of metals **(Copper & lead)** specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
3. Results relate sample analyzed and are reported as on received basis.

Fred. 15/09/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

In any Correspondence on
this subject please
quote No....... DFD 363/2025

21st September 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 15th September 2025 and was analysed from 16th to 19th September 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	**Samples "Sp4, sp5 &sp6" DFD 363/2025**

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below;

Test/Parameter	Units	Results for DFD 363/2025			US EAS 12:2014
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	
Copper (**Cu**)	mg/L	0.71	**1.10**	0.99	1.00 Max
Lead (**Pb**)	mg/L	0.006	**0.22**	0.19	0.01 Max

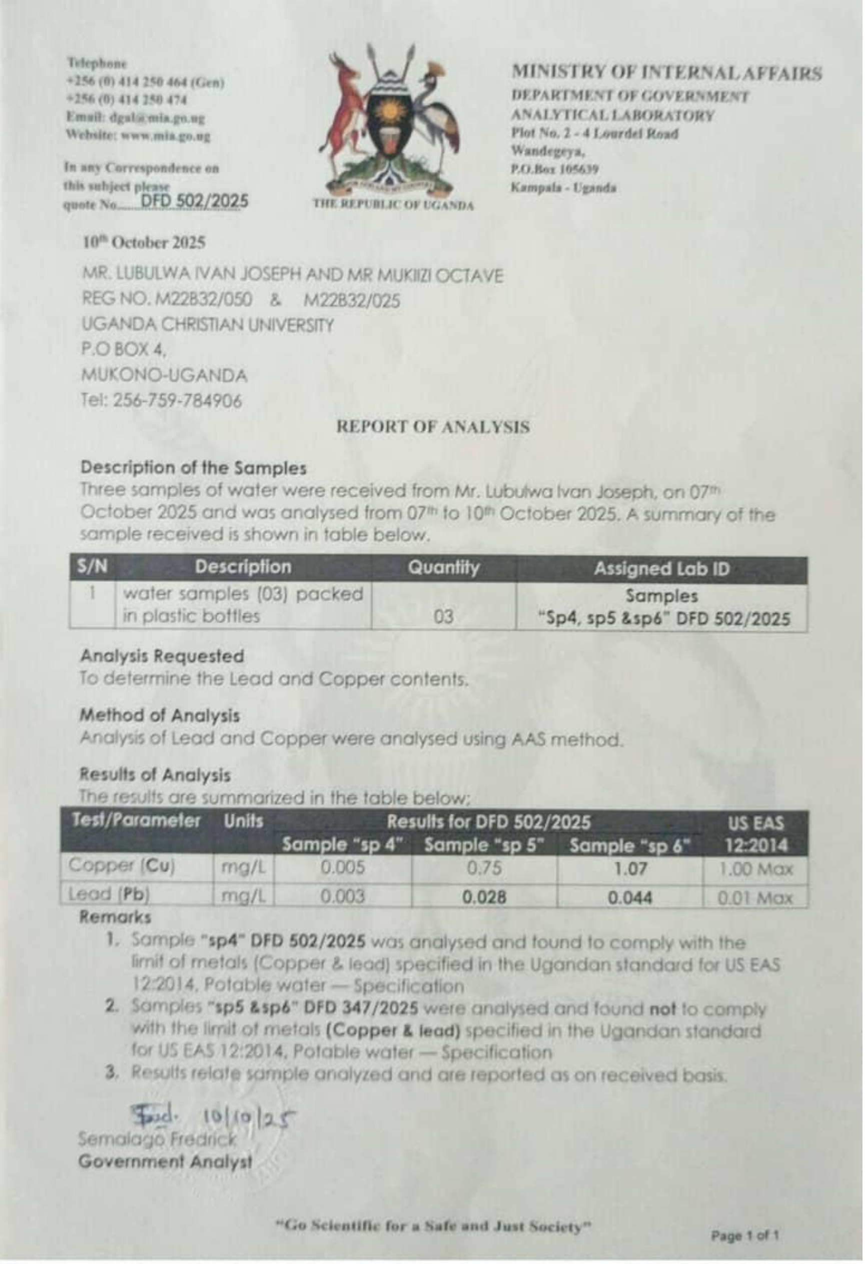
Remarks

1. Samples **"sp4 & sp6" DFD 363/2025** were analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Sample **"sp5" DFD 363/2025** was analysed and found **not** to comply with the limit of metals **(Copper & lead)** specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
3. Results relate sample analyzed and are reported as on received basis.

21/09/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

In any Correspondence on
this subject please
quote No...... DFD 502/2025

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

10th October 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 07th October 2025 and was analysed from 07th to 10th October 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	Samples "Sp4, sp5 &sp6" DFD 502/2025

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below;

Test/Parameter	Units	Results for DFD 502/2025			US EAS 12:2014
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	
Copper (**Cu**)	mg/L	0.005	0.75	**1.07**	1.00 Max
Lead (**Pb**)	mg/L	0.003	**0.028**	**0.044**	0.01 Max

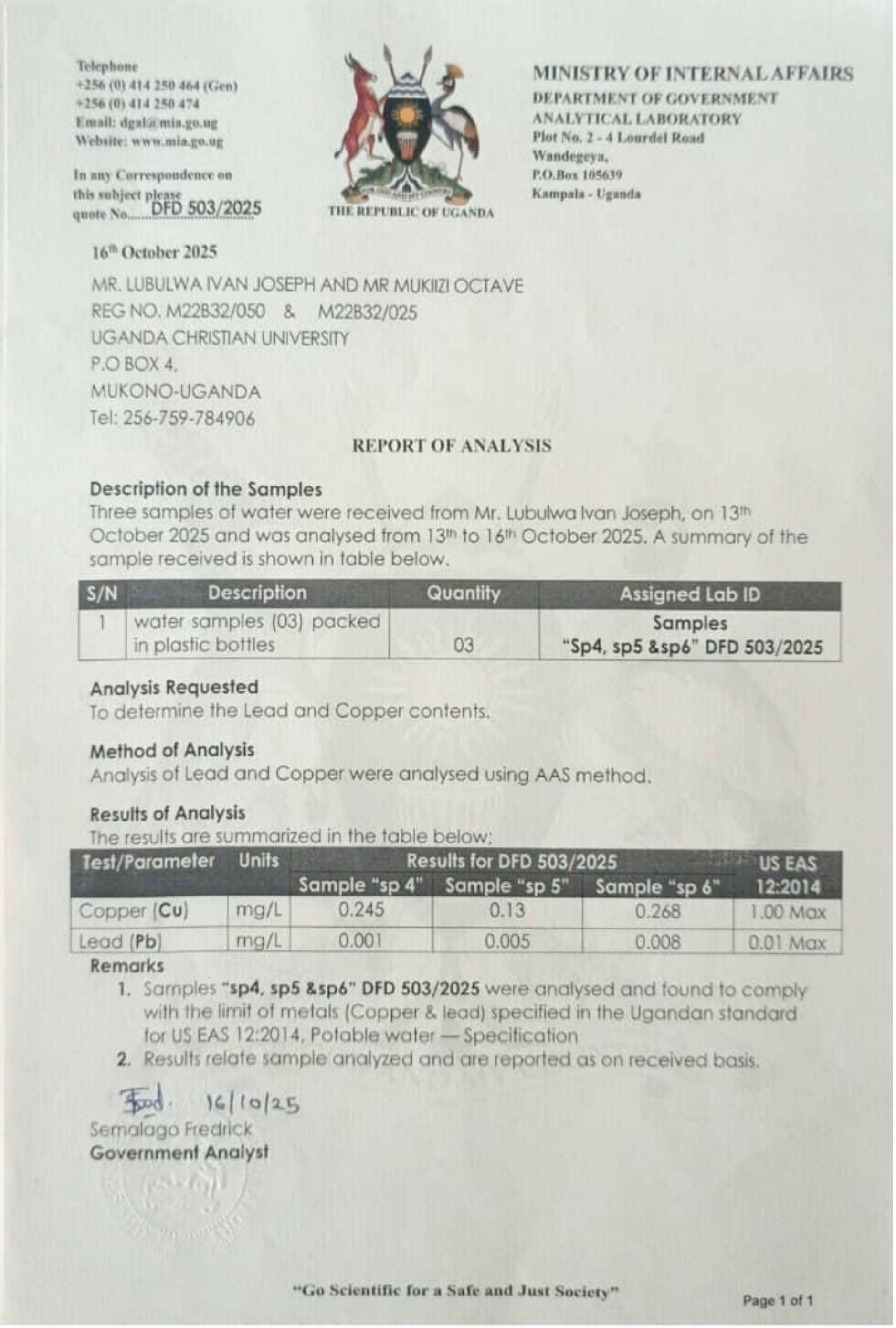
Remarks

1. Sample **"sp4" DFD 502/2025** was analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Samples **"sp5 &sp6" DFD 347/2025** were analysed and found **not** to comply with the limit of metals **(Copper & lead)** specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
3. Results relate sample analyzed and are reported as on received basis.

Fred. 10/10/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

In any Correspondence on
this subject please
quote No. DFD 503/2025

16th October 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 13th October 2025 and was analysed from 13th to 16th October 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	Samples **"Sp4, sp5 &sp6" DFD 503/2025**

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below;

Test/Parameter	Units	Results for DFD 503/2025			US EAS 12:2014
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	
Copper (**Cu**)	mg/L	0.245	0.13	0.268	1.00 Max
Lead (**Pb**)	mg/L	0.001	0.005	0.008	0.01 Max

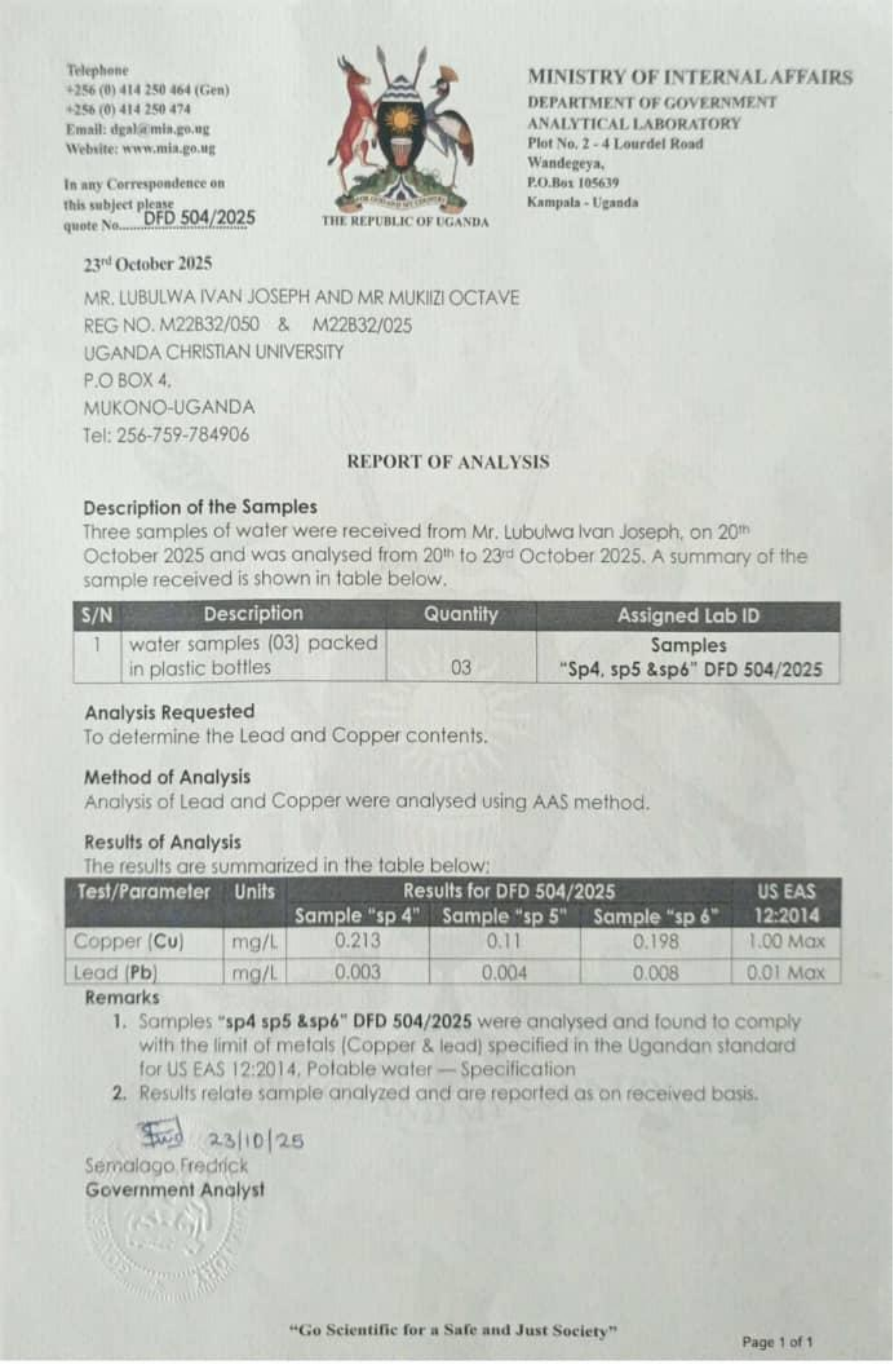
Remarks

1. Samples **"sp4, sp5 &sp6" DFD 503/2025** were analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Results relate sample analyzed and are reported as on received basis.

16/10/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

In any Correspondence on
this subject please
quote No. DFD 504/2025

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

23rd October 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 20th October 2025 and was analysed from 20th to 23rd October 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	Samples **"Sp4, sp5 &sp6" DFD 504/2025**

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below:

Test/Parameter	Units	Results for DFD 504/2025			US EAS 12:2014
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	
Copper (**Cu**)	mg/L	0.213	0.11	0.198	1.00 Max
Lead (**Pb**)	mg/L	0.003	0.004	0.008	0.01 Max

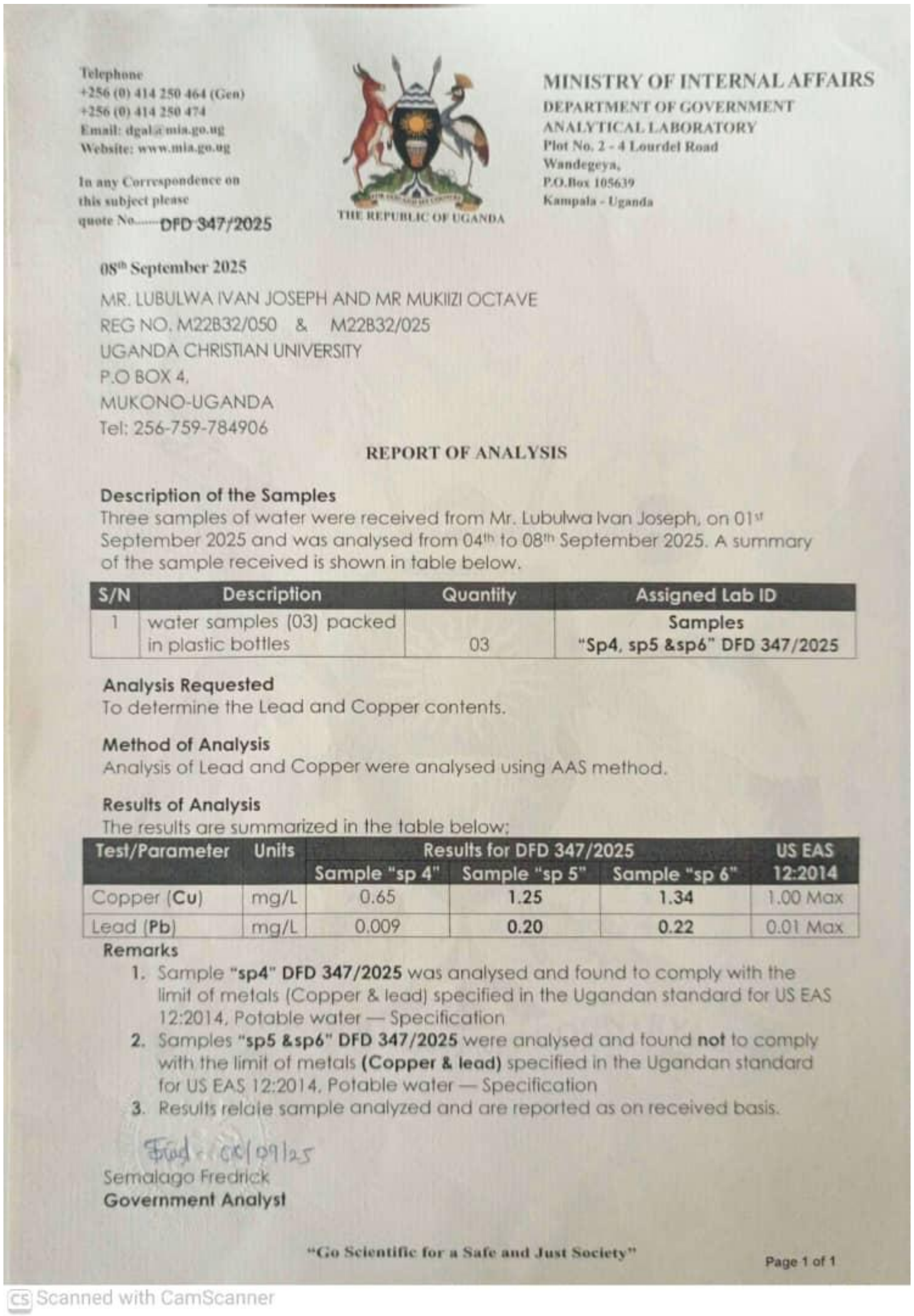
Remarks

1. Samples **"sp4 sp5 &sp6" DFD 504/2025** were analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Results relate sample analyzed and are reported as on received basis.

23|10|25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

In any Correspondence on
this subject please
quote No……DFD 347/2025

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

08th September 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 01st September 2025 and was analysed from 04th to 08th September 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	**Samples "Sp4, sp5 &sp6" DFD 347/2025**

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below;

Test/Parameter	Units	Results for DFD 347/2025			US EAS 12:2014
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	
Copper (**Cu**)	mg/L	0.65	**1.25**	**1.34**	1.00 Max
Lead (**Pb**)	mg/L	0.009	**0.20**	**0.22**	0.01 Max

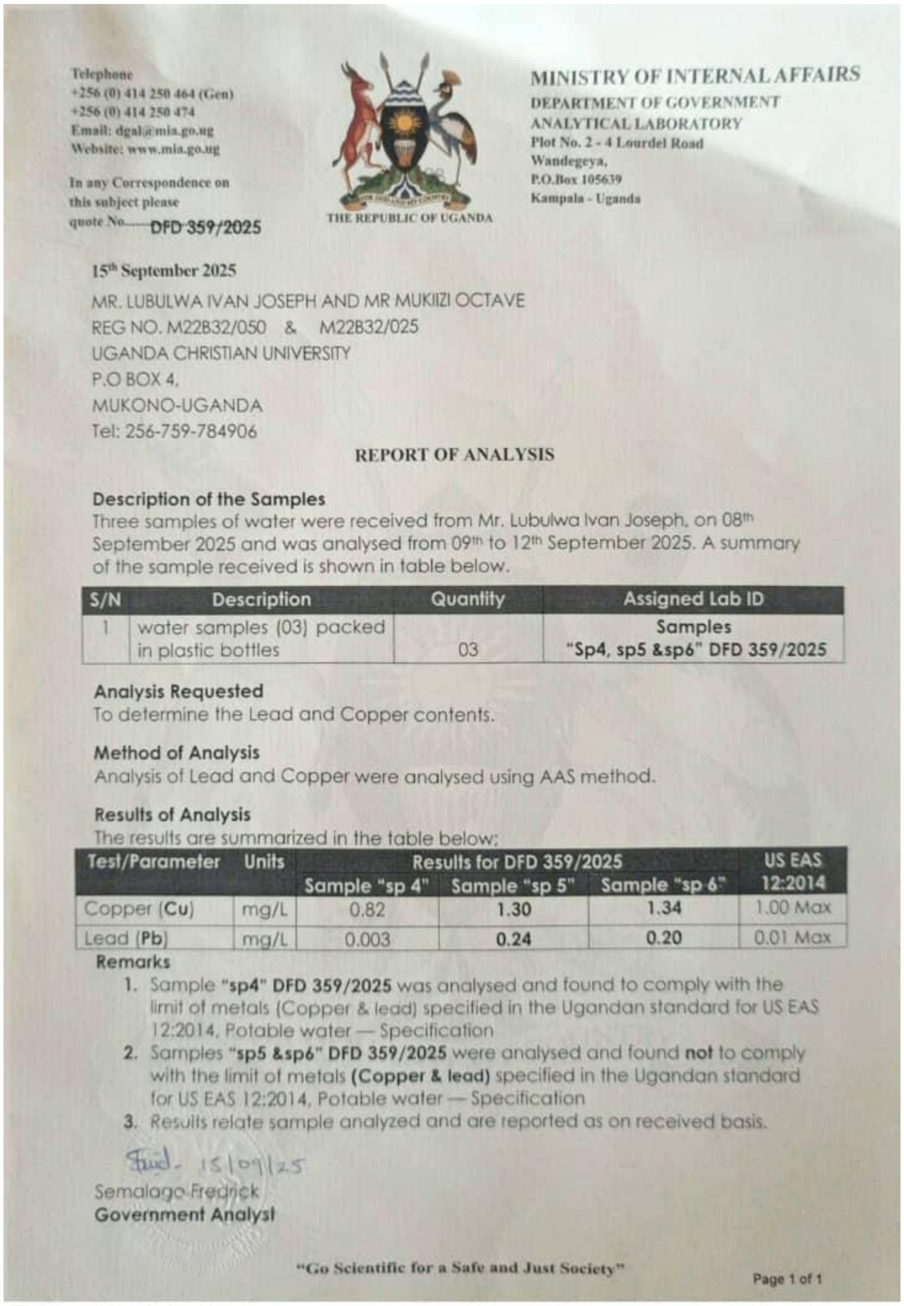
Remarks

1. Sample **"sp4" DFD 347/2025** was analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Samples **"sp5 &sp6" DFD 347/2025** were analysed and found **not** to comply with the limit of metals **(Copper & lead)** specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
3. Results relate sample analyzed and are reported as on received basis.

Fred - 08/09/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

In any Correspondence on
this subject please
quote No........DFD 359/2025

15th September 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 08th September 2025 and was analysed from 09th to 12th September 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	**Samples "Sp4, sp5 &sp6" DFD 359/2025**

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below;

Test/Parameter	Units	Results for DFD 359/2025			US EAS 12:2014
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	
Copper (**Cu**)	mg/L	0.82	**1.30**	**1.34**	1.00 Max
Lead (**Pb**)	mg/L	0.003	**0.24**	**0.20**	0.01 Max

Remarks

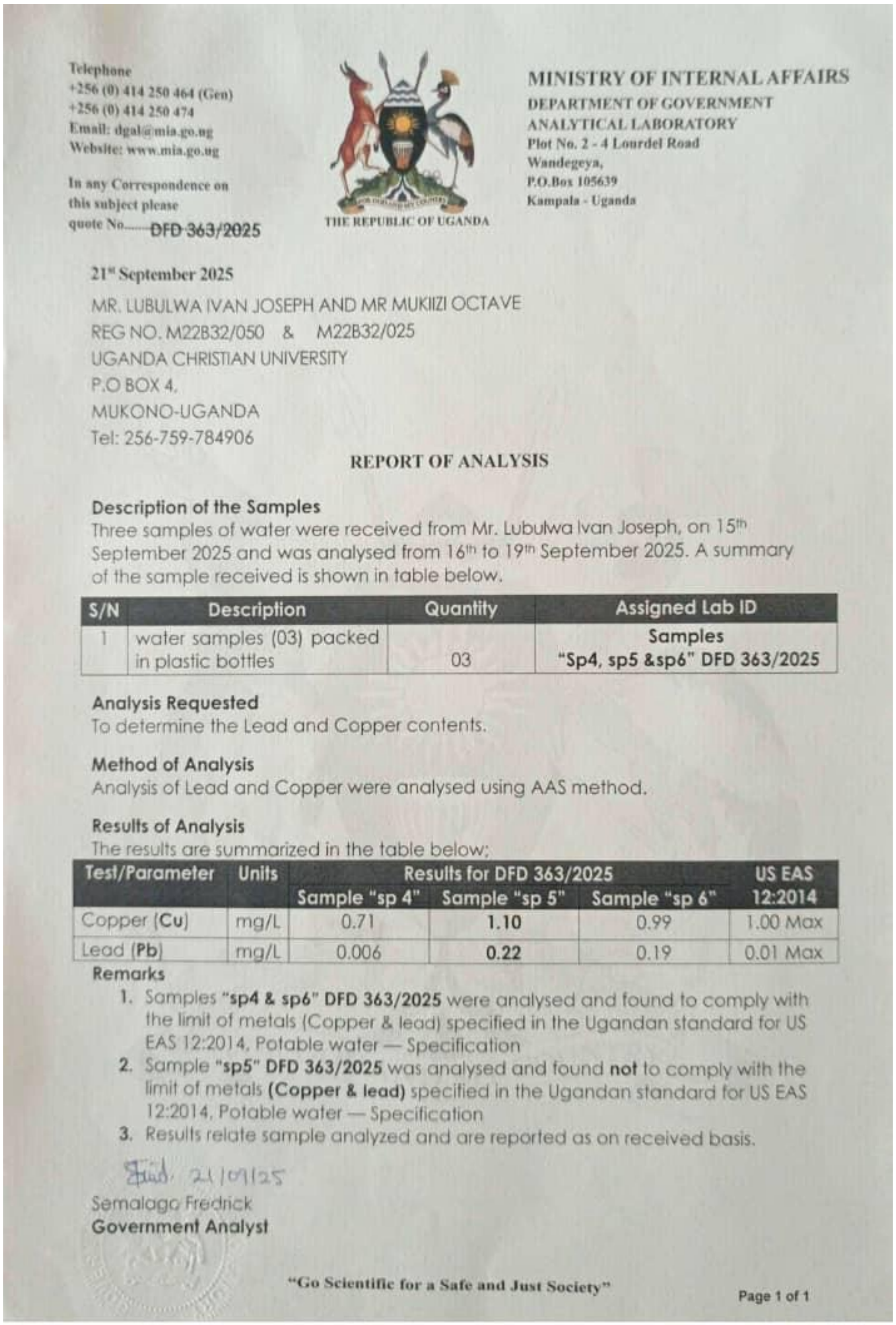
1. Sample **"sp4" DFD 359/2025** was analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Samples **"sp5 &sp6" DFD 359/2025** were analysed and found **not** to comply with the limit of metals **(Copper & lead)** specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
3. Results relate sample analyzed and are reported as on received basis.

Fred. 15|09|25

Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

In any Correspondence on
this subject please
quote No.......DFD 363/2025

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

21st September 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 15th September 2025 and was analysed from 16th to 19th September 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	**Samples "Sp4, sp5 &sp6" DFD 363/2025**

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below;

Test/Parameter	Units	Results for DFD 363/2025			US EAS
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	12:2014
Copper (**Cu**)	mg/L	0.71	**1.10**	0.99	1.00 Max
Lead (**Pb**)	mg/L	0.006	**0.22**	0.19	0.01 Max

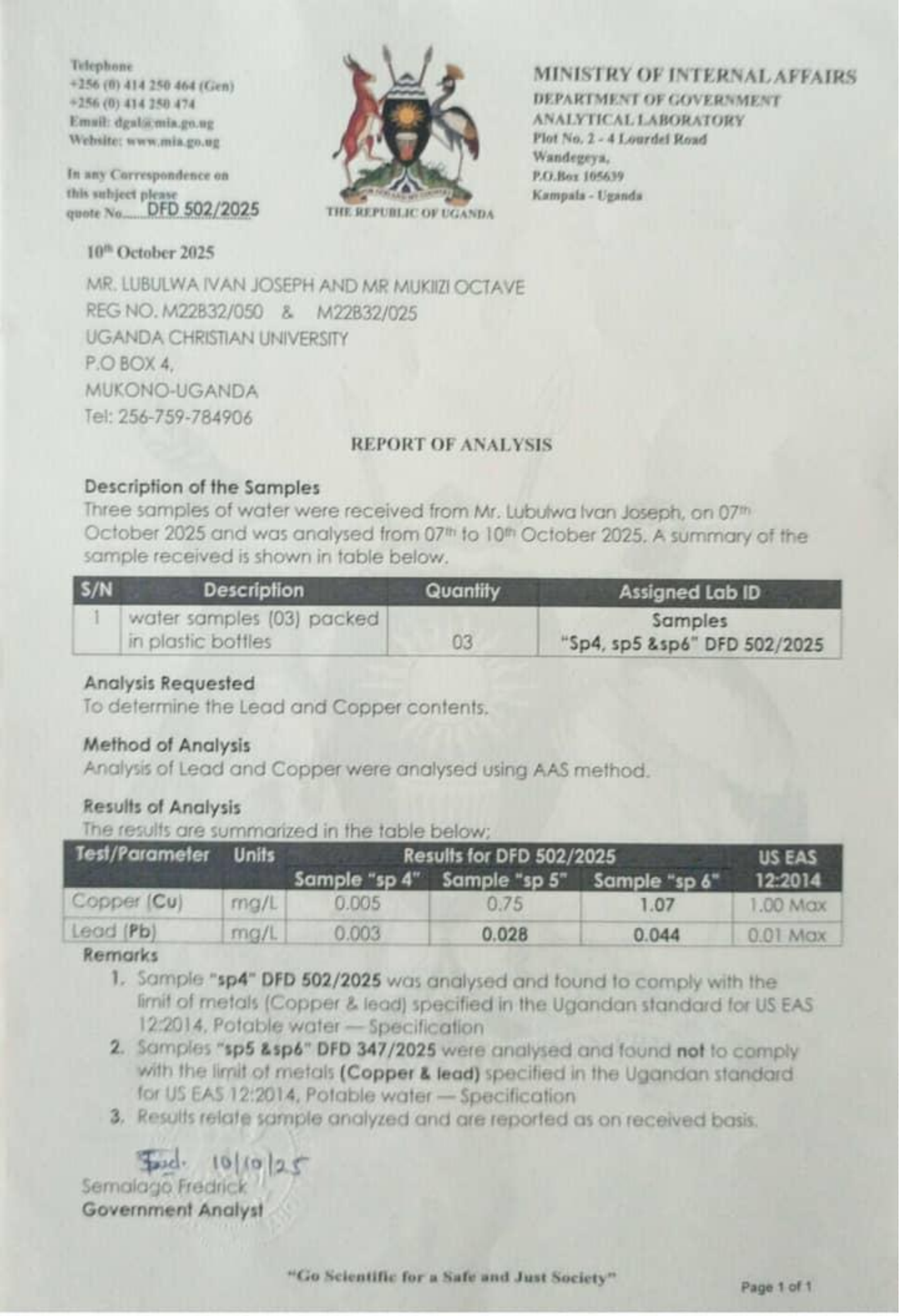
Remarks

1. Samples **"sp4 & sp6" DFD 363/2025** were analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Sample **"sp5" DFD 363/2025** was analysed and found **not** to comply with the limit of metals **(Copper & lead)** specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
3. Results relate sample analyzed and are reported as on received basis.

21/09/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

In any Correspondence on
this subject please
quote No......DFD 502/2025

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

10th October 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 07th October 2025 and was analysed from 07th to 10th October 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	Samples **"Sp4, sp5 &sp6" DFD 502/2025**

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below;

Test/Parameter	Units	Results for DFD 502/2025			US EAS 12:2014
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	
Copper (**Cu**)	mg/L	0.005	0.75	**1.07**	1.00 Max
Lead (**Pb**)	mg/L	0.003	**0.028**	**0.044**	0.01 Max

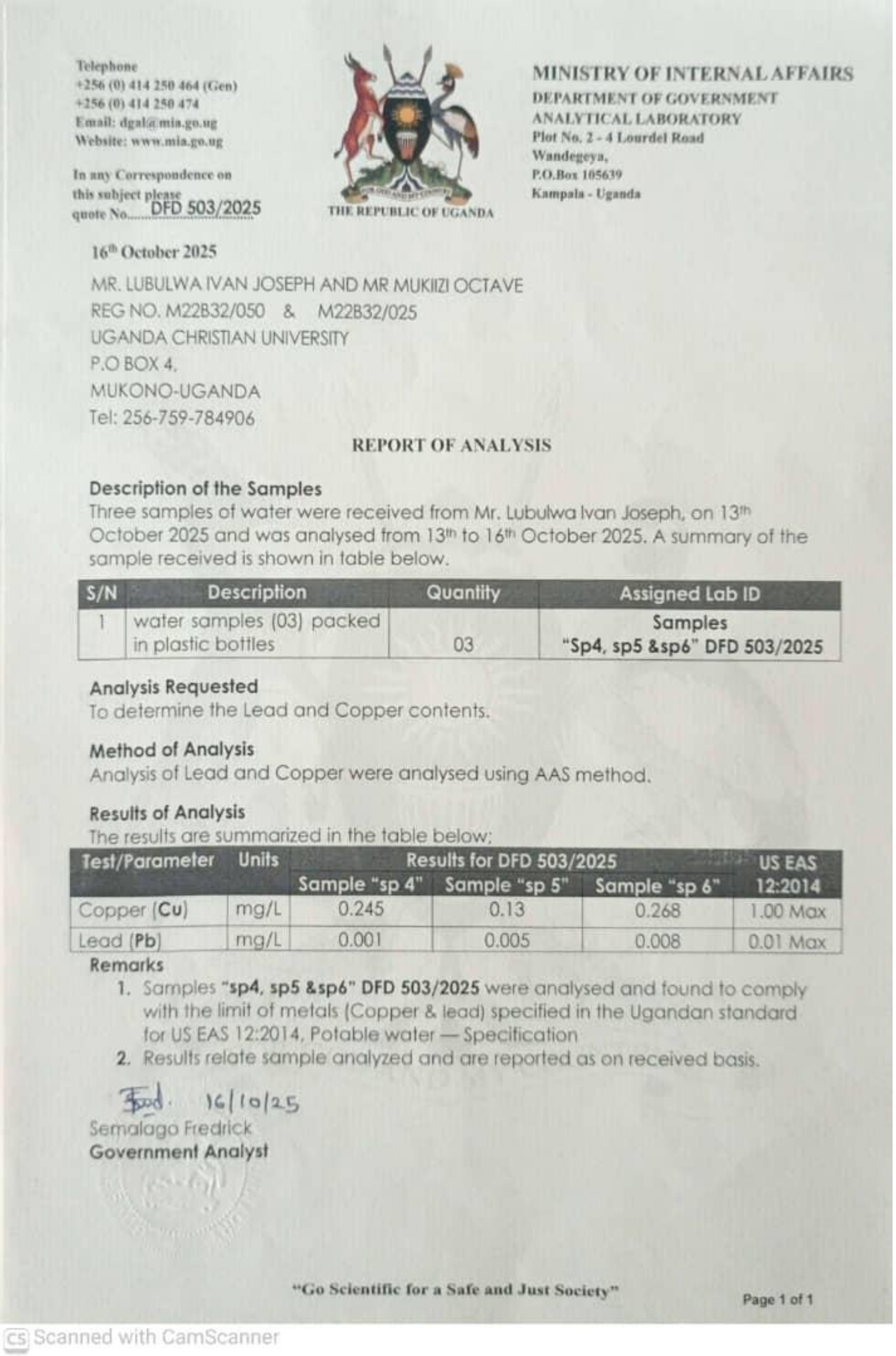
Remarks

1. Sample **"sp4" DFD 502/2025** was analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Samples **"sp5 &sp6" DFD 347/2025** were analysed and found **not** to comply with the limit of metals **(Copper & lead)** specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
3. Results relate sample analyzed and are reported as on received basis.

Fred. 10/10/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

In any Correspondence on
this subject please
quote No.......DFD 503/2025

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

16th October 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 13th October 2025 and was analysed from 13th to 16th October 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	Samples **"Sp4, sp5 &sp6" DFD 503/2025**

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below;

Test/Parameter	Units	Results for DFD 503/2025			US EAS 12:2014
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	
Copper (**Cu**)	mg/L	0.245	0.13	0.268	1.00 Max
Lead (**Pb**)	mg/L	0.001	0.005	0.008	0.01 Max

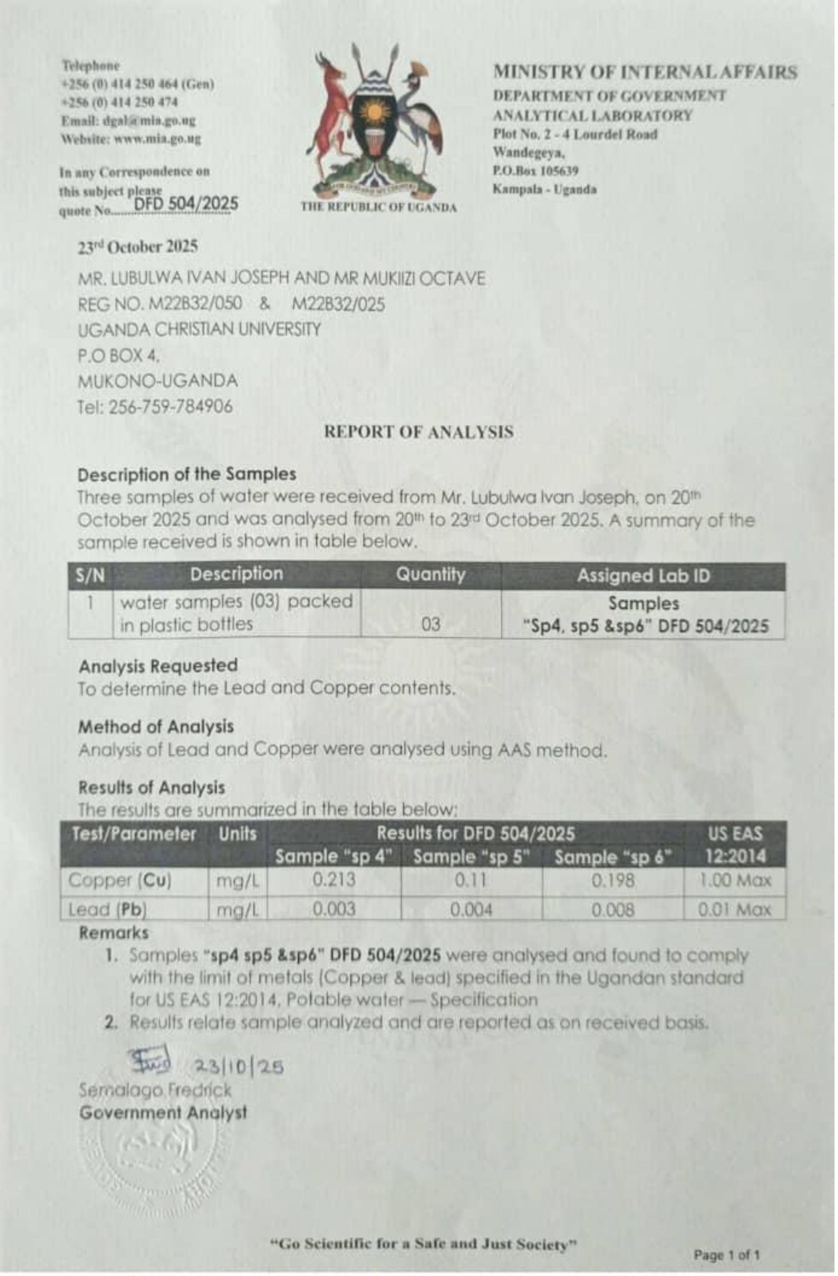
Remarks

1. Samples **"sp4, sp5 &sp6" DFD 503/2025** were analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Results relate sample analyzed and are reported as on received basis.

Fred. 16/10/25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1



Telephone
+256 (0) 414 250 464 (Gen)
+256 (0) 414 250 474
Email: dgal@mia.go.ug
Website: www.mia.go.ug

THE REPUBLIC OF UGANDA

MINISTRY OF INTERNAL AFFAIRS
DEPARTMENT OF GOVERNMENT
ANALYTICAL LABORATORY
Plot No. 2 - 4 Lourdel Road
Wandegeya,
P.O.Box 105639
Kampala - Uganda

In any Correspondence on
this subject please
quote No. DFD 504/2025

23rd October 2025

MR. LUBULWA IVAN JOSEPH AND MR MUKIIZI OCTAVE
REG NO. M22B32/050 & M22B32/025
UGANDA CHRISTIAN UNIVERSITY
P.O BOX 4,
MUKONO-UGANDA
Tel: 256-759-784906

REPORT OF ANALYSIS

Description of the Samples

Three samples of water were received from Mr. Lubulwa Ivan Joseph, on 20th October 2025 and was analysed from 20th to 23rd October 2025. A summary of the sample received is shown in table below.

S/N	Description	Quantity	Assigned Lab ID
1	water samples (03) packed in plastic bottles	03	Samples **"Sp4, sp5 &sp6" DFD 504/2025**

Analysis Requested

To determine the Lead and Copper contents.

Method of Analysis

Analysis of Lead and Copper were analysed using AAS method.

Results of Analysis

The results are summarized in the table below:

Test/Parameter	Units	Results for DFD 504/2025			US EAS 12:2014
		Sample "sp 4"	Sample "sp 5"	Sample "sp 6"	
Copper (**Cu**)	mg/L	0.213	0.11	0.198	1.00 Max
Lead (**Pb**)	mg/L	0.003	0.004	0.008	0.01 Max

Remarks

1. Samples **"sp4 sp5 &sp6" DFD 504/2025** were analysed and found to comply with the limit of metals (Copper & lead) specified in the Ugandan standard for US EAS 12:2014, Potable water — Specification
2. Results relate sample analyzed and are reported as on received basis.

23|10|25
Semalago Fredrick
Government Analyst

"Go Scientific for a Safe and Just Society"

Page 1 of 1