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DIRECTORATE OF RESEARCH AND GRADUATE TRAINING

IMPROVING SLOW SAND FILTRATION THROUGH SAND DEPTH OPTIMIZATION AND LEAD REMOVAL USING ZEOLITE: CASE OF KAMULI WATER TREATMENT PLANT

BY

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A DISSERTATION SUBMITTED TO THE DIRECTORATE OF RESEARCH AND GRADUATE TRAINING OF KYAMBOGO UNIVERSITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE IN WATER AND SANITATION ENGINEERING DEGREE OF KYAMBOGO UNIVERSITY

Oct., 2023

DECLARATION

I Okello Emmanuel, hereby declare that this submission is my own work and that to the best of my knowledge and belief, it contains no materials previously published or written by person nor materials which has been accepted for award of any degree of any university or other institute of higher learning except where due to acknowledgement has been made in the text and reference list. The contribution of my supervisor remains quite vital.

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

APPROVAL

The undersigned approved that he has read and hereby recommends for submission to the Directorate of Research and Graduate Training of Kyambogo University, a dissertation entitled improvements of a slow sand filter through filter medium depth optimization and use of zeolite to remove lead from water: a case study of Kamuli water treatment plant in fulfilment of the requirement for the award of a Master of science in Water and Sanitation Engineering Degree of Kyambogo University.

Signature: ………………………………
Dr. Charles Onyutha (Supervisor)
Date………………………………………

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Table of contents

Contents **Page**

DECLARATION i
APPROVAL ii
ACKNOWLEDGEMENT iii
List of Tables vii
List of Figures viii
List of Abbreviations ix
Abstract x
CHAPTER ONE: INTRODUCTION 1
1.1 Background of the study 1
1.2 Problem statement 2
1.3 Objectives 3
1.3.1 Main objective 3
1.3.2 Specific objective 3
1.4 Research questions 3
1.5 Justification 3
1.7 Scope 4
1.8 Conceptual framework 5
CHAPTER TWO: LITERATURE REVIEW 6
2.1 Introduction 6
2.2Guidelines for drinking water 8
2.3 Sources of drinking water and their treatment options 10
2.4 Sand depth optimisation for turbidity removal 14
2.4.2 Synthetic turbidity 14
2.4.3 Turbidity removal 14
2.4.4 Slow sand filtration 15
2.4.5 Filter media depth and hydraulics vs performance 16
2.4.6 Design criteria 16
2.4.7 Filter flow controls 17

2.5 Natural zeolite and its applicability in removal of lead from drinking water 18
2.5.1 Characterization and types of natural zeolite 18
2.5.2 Properties of Zeolite 20
2.5.3 Application of zeolite 21
2.6 Past studies on characteristics of drinking water in Uganda 23
2.7 Challenges of drinking water in developing countries 30
CHAPTER THREE: METHODOLOGY 32
3.1 Introduction 32
3.2.1 Turbidity 32
3.2.2 Colour 33
3.2.3 Hardness 33
3.2.4 Alkalinity 35
3.3 Evaluation of system performance 37
3.3.1 Percentage change of parameters after treatment 37
3.3.2 Statistical and analytical methods 37
3.3.3 Case specific system efficiency 37
3.4 Sand depth optimization 38
3.4.4 Prototype set up 41
3.4.6 Pilot experiments on system hydraulics 42
3.4.8 Actual study experiments for Sand depth optimization 43
3.4.9 Efficiency of sand depth setups in removing turbidity 44
3.5 Applicability of natural zeolite in removal of lead from drinking water 45
3.5.1 Materials 45
3.5.2 Methods 46
CHARPTER FOUR: RESULTS AND DISCUSSION 49
4.1 Comparison of observed water quality parameters against WHO guidelines 49
4.1.1 Turbidity 49
4.2.2 Colour 51
4.3 Testing null hypothesis H_0 (system is not performing) 52
4.4 Case specific System effectiveness 54
4.5 Investigation on heavy metals 54

4.5.2 Removal of lead ions by slow sand filtration 55
4.6 Filter media depth optimization 56
4.6.2 Removal of turbidity 59
4.6.3 Optimum sand depth 62
4.7 Applicability of natural Zeolite in removal of lead ions 64
4.8 Removal efficiency of lead ions by zeolite 64
4.9 Schematic diagram for treatment plant modification 67
CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS 68
5.1 Conclusions 68
5.2 Recommendations 69
References 70
Appendices 84
Appendix 1: Results and system performance evaluation of alkalinity and hardness 84
Appendix 2: Computation of resultant turbidities computed using modal equations 86
Appendix 3 :Model parameters and performance for sand depth optimization 88
Appendix 4: Laboratory activities 89
Appendix 5: Results for water characterization and evaluation of system performance 90
Appendix 6: Results for synthetic turbid water used in sand depth optimization 98
Appendix 7: Results showing effectiveness of natural zeolite in removing lead ions 99
Appendix 8: Additional experimental results of lead removal by zeolite 103

List of Tables

Table 2-1: WHO, EAC and UNBS standard guidelines for physical parameters 8

Table 2-2: Standard guidelines for chemical parameters in drinking water 9

Table 2-3: Standard guidelines for biological parameters in drinking water............................... 10

Table 2-4:Results from the study (Omara et al., 2019)... 25

Table 3-2:Summary of design criteria 41

Table 4-1:Overview of turbidity 50

Table 4-2:Percentage change in min, max and mean turbidity values after treatment 50

Table 4-3:Over view of water colour 51

Table 4-5: Z - tests values with corresponding *p* - values for every month 52

Table 4-6: Student t - test values with corresponding *p* - values for every month 53

Table 4-7:Z - tests values with corresponding *p* - values for combined data 53

Table 4-8: Student t- test values with corresponding *p* - values for combined data..................... 53

Table 4-9: *p* - value of ANOVA one way for the data samples.. 53

Table 4-10: Summary of system effectiveness 54

Table 4-11: Laboratory results for investigated heavy metals against standards 54

Table 4-12: Concentration of lead ions before and after treatment of water 55

Table 4-13:Overview of waiting time and flow rates and various flow depths............................ 57

Table 4-14:Variation of filter depth with flow rate, hydraulic loading rate and turbidity........... 58

Table 4-15: Overview of resultant turbidity from actual experiments 60

Table 4-16: Removal efficiency (%) of synthetic turbidity by the different sand depths............ 61

Table 4-17: Model equations and corresponding optimal sand depth 62

Table 4-18: Model and prototype dimensional and similarity scale up computation.................. 62

Table 4-19: Laboratory results for characterization of Zeolite. 64

Table 4-20:Removal efficiencies, corresponding zeolite dosages and contact time 65

List of Figures

Figure 1-1: Location of Kamuli Municipality…………………………………………..………..4

Figure 1-1: Location of Kamuli Municipality. 4
Figure 1-2: Conceptual framework summary 5
Figure 2-1:Typical slow sand filter configuration, Source:(Bielefeld, 2016).............................. 16
Figure 3-1:Turbidity-concentration regression chart 40
Figure 3-3:Filter depth arrangement set ups 42
Figure 4-1:Min and Max turbidity of raw samples and mean before and after treatment 50
Figure 4-2:Min and max of raw samples and mean values before and after treatment 52
Figure 4-3:Variation of filter depth (m) with a) waiting time b) flow rate(m3/s) 57
Figure 4-4:Efficiency of turbidity removal and resultant turbidity after filtration 61
Figure 4-5:Regression graphs generated for determination of optimal sand depth 63
Figure 4-6: Pattern of removal efficiencies of zeolite dosages and contact time 65
Figure 4-7: Influence of contact time in lead ions removal pattern 66
Figure 4-8: Modified schematic diagram incorporating zeolite in water treatment 67

List of Abbreviations

AC	Activated Carbon
APHA	American Public Health Association
CFUs	Coliform Units
CNTs	Carbon nanotubes
DWD	Directorate of Water Development
EAC	East African Community
EDS	Energy Dispersive Spectroscopy
FAO	Food and Agricultural Organization
FTU	Formazine Turbidity Unit
HDTMA	Hexadecyltrimethyliammonium
IMA	International Mineralogical Association
MDG	Millennium Development Goals
MWE	Ministry of Water and Environment
NEMA	National Environment Management Authority
NTU	Nephelometric Turbidity Unit
NWSC	National WATER and Sewerage Cooperation
SDG	Sustainable Development Goals
TCU	True Colour Units
UBOS	Uganda Bureau of Statistics
UN	United Nations
UNBS	Uganda National Bearau of Standards
UNICEF	United Nations Children’s Fund
WHO	World Health Organization

Abstract

Globally, there are increasing challenges related to physiochemical and bacteriological contamination often met in provision of safe water for human consumption. Eventually, increasing access to portable water ranked high on the United Nation's 2030 agenda. This study focused on improving slow sand filter through optimization of the filter medium depth and the use of zeolite to remove lead from water. Kamuli water treatment plant was considered as the case study. In characterizing raw water from the dam as intake, the minimum and maximum turbidity values recorded during the four months were 3 and 103 NTU before treatment, 1 and 48 NTU were recorded after treatment, respectively. The existing Kamuli water treatment plant exhibited turbidity removal efficiencies in the range of 0 – 26%. To optimize the filter medium for turbidity removal, four different sand depths including 400, 650, 900 and 1150mm were considered in a down scaled physical system setup. Synthetic turbid water with turbidity levels from 5 NTU to 120 NTU were considered to characterize the turbidities recorded from the raw water. The different set ups of sand depths were individually evaluated for system performances. The 400mm and 650mm depths had average removal efficiencies of 81.8% and 85.7%, respectively. However, the 900mm and 1150mm had removal efficiencies of 90% and 93.7%, respectively. Different models in terms of exponential, logarithmic, linear and polynomial functions were used to describe the variation of final turbidity after raw water filtration with sand depths. The models were assessed in terms of mean squared error (MSE) and the cost of the sand to achieve the required 5 NTU based on the World Health Organization guideline for turbidity. The values of MSE for exponential, logarithmic, linear and polynomial models were 0.4758, 0.4078, 0.6535 and 0.3848, respectively. The corresponding costs of sand to achieve the optimal depth based on the models were 2,880, 3,300, 3,235 and 2,915 Uganda shillings, respectively. For a given contact time, efficiency of lead removal increased with increasing mass of zeolite added to water. This was true especially for contact time greater 40 minutes. For instance, the efficiencies of lead removal using zeolite of 1, 3, 5 and 7 grams at a contact time of 80 minutes were 81.8, 90.8, 92.7 and 100%, respectively. However, at a 40-minute contact time, the lead removal efficiency increased as zeolite mass was varied from 1g to 5g and thereafter it decreased. Thus, the optimal removal of lead was at contact time of 40 minutes using zeolite mass of 5g with removal efficiency of 98%. This study therefore, demonstrated potential of zeolite in lead removal.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Water is critical to population for a social, economic, industrial activities and the entire existence both in urban or rural communities (UBOS, 2022; Kiwanuka *et al.*, 2015). Lack of access to clean water is a form of deprivation that endangers life, eliminates opportunities, and diminishes human dignity (Armah *et al.*, 2018). The human right to water and sanitation was recognized by the United Nations (UN) General Assembly in July 2010. Nevertheless, access to safe water is still a challenge (Valcourt *et al.*, 2020). In Uganda, the estimated average national clean water coverage rate is 74.05%, with rural regions having a coverage rate of 69% and urban coverage of 79.1% according to a report by Uganda Wash Resource Centre (UWRC, 2020). There is still a problem with water delivery both in Uganda and world over, and this problem has been linked to a problem with water governance (Katusiime and Schütt, 2020). Infrastructure for drinking water operation and upkeep continue to be quite difficult despite continuous decentralization (Cherunya, Janezic and Leuchner, 2015).

Uganda had a 3.2% population growth rate by 2013 (Wali, Kagoyire and Icyingeneye, 2012) and this produced additional pressure on sanitation for both rural and urban populations but Uganda has ambitious plans of development and one of the developments requirements is safe access to water for rural and urban areas (Kanyesigye *et al.*, 2019), and this means there should be high investments and innovations in water production, supply and sanitation infrastructure so as to achieve the country vision (Uganda Vision 2040). On the other hand, the sixth UN Sustainable Development Goal (SDG) "Ensure availability and sustainable management of water and sanitation for all" is one that the nation is committed to achieving (Brown, Neves-Silva and Heller, 2016).

Uganda therefore has to make studies towards water treatment to identify technologies that improve treatment system efficiency so to deal with prevailing challenges in safe water provision (Harvey and Mukanga, 2020). Some of the urgent challenges met in water production were unrealized recommended standards for various biological and physio-chemical parameters in various parts of the country (Okot-okumu and Otim, 2015). Other research works have also concluded that heavy metals are present in Ugandan water sources (Kulabako, Norrestrom and Bakyayita, 2019).

Kamuli water treatment plant is not spared with the challenges related to water quality met during production. Designed as a slow filtration system, the plant was initially designed with a daily capacity of 1200m^3. Overtime, the water quality and quantity produced has been subdued for reasons observed to be originating from seasonal variations in physio-chemical parameters at the source and the widespread poor disposal of potential heavy metal pollutants (Kwetegyeka *et al.*, 2010).

1.2 Problem statement

According to Kamuli Strategic Plan (KSP, 2016), Water supply in Kamuli Municipality is far below the required capacity, the Municipality's current water treatment plant produces averagely 420 m^3 -500m^3 per day against and this is because the current population of 110,000 (UBOS, 2014), which equals to 3.8 liters per person per day. This is a very small amount of water compared to the global average recommendations of 50 liters per person per day (Brown, Neves-Silva and Heller, 2016). More to that, National Water and Sewerage Cooperation requires 1500m^3 per day to meet a daily demand of customers for municipality of Kamuli. The treatment plant records further indicate that in addition to inadequate water, the water quality also is a major concern as there is an increased unappealing color of the water, and presence of solid particles implying high turbid water is being supplied.

Kamuli treatment plant uses slow filtration process that does not satisfy both quality and quantity water demand from existing population of 110,000 (UBOS, 2014) given that the current water production was designed in 1989 for a town with a population of 20,000. The existing quality and quantity challenges of access to clean and safe water which is a threat to human health will continue to affect the lives of Kamuli municipality dwellers if nothing is done to avert the challenges. The numerous benefits of the slow sand filter process include advantage of low maintenance costs and high efficiency (Bagundol, Awa and Enguito, 2013). The benefits can however be affected by significant changes in physio-chemical parameters at the water source over the years as initial design considerations may be surpassed not forgetting unconsidered issues such as emergency of excessive heavy metals in drinking water. It is against this background that this study intends to characterize, evaluate the performance of the current system and investigate the performance of improvement of the water treatment plant as well as assess the use of natural zeolite in removal of heavy metals in drinking water in Kamuli municipality. An inclusive new system designed to achieve treatment of parameters in question will improve the quality and quantity of clean and safe water for consumption in Kamuli municipality

1.3 Objectives

1.3.1 Main objective

To investigate performance of a slow sand filters for possibility of its improvement in removal of physiochemical parameters and removal of heavy metals using zeolite.

1.3.2 Specific objective

- i) To characterize the quality of raw water from the dam
- ii) To evaluate performance of the water treatment plant
- iii) To optimize slow sand medium depth for turbidity removal
- iv) To evaluate effectiveness of natural zeolite in removal of lead from water

1.4 Research questions

- i) What are the characteristics of raw water from the dam?
- ii) What is the performance efficiency of the water treatment plant?
- iii) What optimal depth of a filter media can efficiently remove turbidity to recommended WHO (2014) limit?
- iv) How effective is natural zeolite in removing lead from drinking water?

1.5 Justification

Kamuli district has an objective and goal to provide a sustainable safe water supply and sanitation facilities within easy reach of 85% of the rural and urban population by 2026, with at least 95% effective use and functionality of infrastructure. Despite the importance of water quality to human health, no such study has been conducted in Kamuli water treatment plant. This research would help in providing information as a guide in reaching this target. Other programs like Uganda vision 2040, Third NDP and African Union Agenda 2063 are among other elements that commit to achieve the SDGs of full access to water and sanitation.

1.6 Significance of the study

i) The study would improve the quality of treated water distributed and consumed by the customers.

ii) The study would ensure that the efficiency of the treatment system is improved to meet the demand from the surging population.

iii) The study would contribute to a common goal of access to clean and safe water which is associated to the UN Sustainable Development Goals and other national development programs.

1.7 Scope

1.7.1 Time scope

The study was executed between January 2022 to February 2023.

1.7.2 Geographical scope

The study used Kamuli treatment plant located in Kamuli municipality, Kamuli district as a case study. Kamuli is approximately 63 kilometers north of Jinja in Busoga Sub-region, the coordinates of Kamuli Municipality are 0 56’42’’N, 3307’30’’E

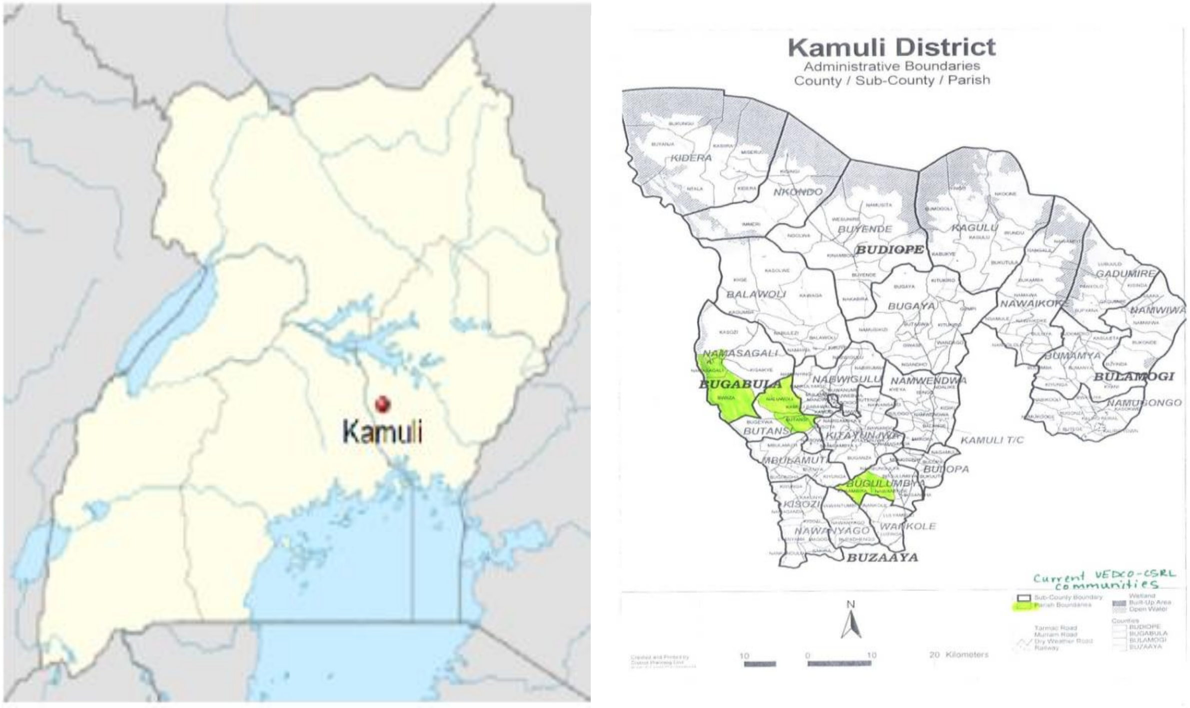


Figure 1-1: Location of Kamuli Municipality.

1.7.3 Content scope

The study involved characterization of physiochemical parameters in both dry and rainy season to account for seasonal weather effects on the physical parameters and treatment processes. Evaluation of treatment plant performance was done using several evaluation tools and following international standards for drinking water requirements. Sand medium depth optimsation for turbidity removal and the applicability of natural zeolite in removal of lead ions as a heavy metal.

1.8 Conceptual framework

The study considered several variables originating from the different factors that governed the study. The variables were linked to each other directly or indirectly in arriving at expected study findings, for example, turbidity removal is measured by the performance of slow sand filters which significantly differs due to seasonal variation as summerised below.

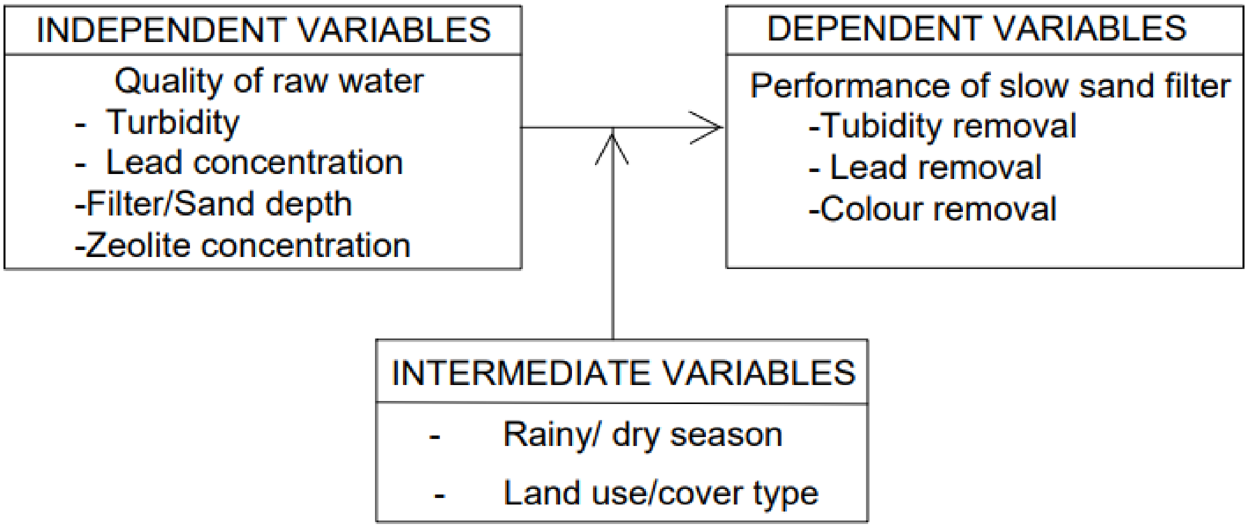


Figure 1-2: Conceptual framework summary

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of documented information in regards to water quality parameters, characteristics of drinking water, guidelines on drinking water requirements, sources of drinking water, past and recent studies in drinking water characteristics and challenges met in providing drinking water. A summary of literature in what has been done so far in connection with this study has been highlighted.

2.1 Characteristics of drinking water

2.1.1 Physical characteristics

Monitoring of physical aspects of water quality essentially determines whether or not the water is polluted (Mitra *et al.*, 2021). Human actions have the potential to negatively impact even the greatest natural water bodies (Omara *et al.*, 2019). Physical characteristics can be determined by;

i) **Turbidity**: This is brought about by water-borne particles like colloidal particles, organic substances in suspension, or microscopic organisms like algae (Hakim, 2018). Suspended matter is commonly observed on surfaces unlike groundwater (Li *et al.*, 2022). Turbidity is normally studied under nephelometry and common unit of measurement is Nephelometric Turbidity Units (NTU) (ISO7027, 2016).

ii) **Colour**: Results from materials dissolved in water (Tchindjang, 2021). Unclean and contaminated are sometimes used interchangeably in relation to water colour. However, the two terms logically have different meanings. A slice of bread dipped in purified water in a glass makes the water unclean but not contaminated. Drinking water should be colourless (Zolnikov, 2013). Coloured water may not be harmless but is unattractive (WHO, 2014). Water colour is measured using platinum-cobalt method with values ranging from 0 (distilled water) to 500 (colour of platinum cobalt solution). Measurement units are Pt/co or True Colour Units.

iii) **Odor and taste**: As a requirement, drinking water should be odorless (WHO, 2011). Odor is usually an indicator material such as hydrogen sulphide and organic material in water. Odor emerges when water from any sources is depleted of oxygen (Lin *et al.*, 2019).

iv) **Temperature**: Its mainly influences the levels of dissolved gasses and minerals. Temperature is commonly measured in degree centigrade. Some studies such as (Lukubye and Andama, 2017) have found that some water sources have beyond the 15℃ temperature value quoted by WHO.

2.1.2 Chemical characteristics

The different minerals and gases in solution describe the chemical composition of both surface and groundwater (Dragon and Marciniak, 2010). Anions are negatively charged minerals and cations are positively charged. The commonest anions *are* Cl, SO_4^{2-}, HCO_3^-, CO_3^{2-}, OH^-, NO_3^- *and* PO_4^{3-} whereas the commonest cations are Ca^{2+}, Na^+, Mg^{2+} and K^+. Other cations such as heavy metals appear in smaller quantities such as Al^{3+}, Fe^{2+}, $Fe^{3+,}$ Mn^{2+}, Pb^{2+}, Zn^{2+}, Sr^{2+}, Ba^{2+}, Li^{2+} and Hg^{2+} (Rajagopal and Wichman 2016) . Notably, high concentration of $Fe^{2+}$and Mn^{2+} indicate depletion of oxygen which affects color (Hamre *et al.*, 2019). Rusty brown colour indicate presence of Fe^{2+} and black indicates presence of Mn^{2+} which both affect aesthetics (Mcfarland and Dozier, 2016). Units or measurement are mg/L or mmol/L.

i) pH and dissolved oxygen: Water can be neutral, acidic or alkaline with pH of 7, less than 7 and greater than 7 respectively (Id *et al.*, 2022). The unit of measurement for the oxygen content of water is dissolved oxygen (DO, mg/L).It is also usually used as an indicator of water quality (Atwebembeire *et al.*, 2018). Water is said to be anoxic when oxygen is depleted to levels less than 1 mg/L or anaerobic when completely without oxygen whereas toxic water is one that has sufficient oxygen quantities (Vo *et al.*, 2022).

ii) **Total Dissolved Solids**: Is a measure of amount of dissolved solids in water. It is the constant total of all components that remain as dry solids in the evaporating dish after a water sample evaporates at 180 °C (Islam *et al.*, 2016).

iii) **Hardness**: Foam from soap cannot easily be produced in hard water(WHO, 2011). Calcium and magnesium salts, together with other minerals found in high amounts, are what form hard water (Mustapha, 2017). Hardness is expressed as calcium carbonate concentration (i.e mg/L as $CaCO_3$).

2.1.3 Micro-Biological/ Bacteriological characteristics

Micro-Biological refers to the presence of algae, micro-organisms, bacteria and viruses (Bacha, Durrani and paracha 2010). Some organisms are pathogenic in nature (Gwimbi, George and Ramphalile, 2019). Ground water is usually clean and clear although it can be prone to microbial contamination especially in urban informal settlements due to presence of pit latrines and indiscriminate solid waste disposal (Kumar *et al*., 2022). Microbial quality concerns bacteria, virus and protozoa. Cholera, typhoid, dysentery and diarrhea are some examples of diseases caused by bacteria (Bwire *et al.*, 2020). Esherichia Coli (or Ecoli) is a specie of bacteria commonly monitored in water sources (Yusnita and Sari, 2020). The presence of Ecoli implies the water may be contaminated with human excreta and may have disease producing organisms including viruses (Galadima *et al.*, 2011). When testing the microbial quality, analyses may focus on Ecoli and other coliforms such as total coliforms and feacal coliforms as indicators of pathogenic organisms (Carrillo-Gómez and García-Rico, 2019). Units of measurement are CFU/100mls (Colony- forming units per 100 mls of water)

2.2Guidelines for drinking water

The WHO, East African Community (EAC) and Uganda as a country all have maximum values set as requirements for the physical aspects of drinking water. **(Table 2-1)** shows quoted values for physical requirements for guidelines from three entities.

2.2.1 Physical aspects

Table 2-1: WHO, EAC and UNBS standard guidelines for physical parameters

Parameter	WHO standard	EAC standard	Uganda standard (UNBS)
Color (TCU max)	15	Colorless	Colourless
Odor	-	Odorless	Unobjectionable
Taste	-	Tasteless	Unobjectionable
pH	6.5-8.5	6.0–8.5	7
Turbidity (NTU max)	5	5	5
Suspended matter	-	Not detectable	Not detectable

Source:(WHO, 2011), (EAC, 2014), (UNBS, 2022)

2.2.2 Chemical aspects

Only after repeated exposure do chemicals present in drinking water start to pose a threat to health (Kim, 2018). Except for pollutants that intermittently discharge or leak into flowing surface waters or groundwater supplies, such as toxic landfill sites, the changes in water quality happen gradually (WHO, 2011). It may not always be required to create criteria for all residual traces for which there are guideline values because some chemical groups, such as disinfection by-products, come from related sources (Ongom, Andama and Lukubye, 2017). WHO sets guidelines for chemicals existing in drinking water quoting occurrence, limit values and reasons for guidelines. The East African Community (EAC) also has guidelines for drinking water at regional level (EAC, 2014) in Tables 1,2,3,4&5 of the guideline. The Uganda National Bureau of Statistics (UNBS) sets drinking water standards at national level. A summary WHO, EAC and UNBS requirements for some chemicals is tabulated in **(Table 2-2)**

Table 2-2: Standard guidelines for chemical parameters in drinking water

Chemical Parameter	WHO standards	EAC standards	UNBS standards
pH	6.5–8.5	6.0–8.5	6.0–8.5
Total Hardness	100-300	300	300
Total Dissolved Solid	600	700	700
Aluminum as Al^{3+}	-	0.2	0.2
Chloride, as Cl^-	-	250	250
Total Iron as Fe	-	0.3	0.3
Manganese, as Mn	-	0.1	0.1
Sodium, as Na^+	-	200	200
Sulphate SO_4	-	400	400
Nitrite	3	45	50
Zinc, as Zn^{2+}	-	5	5
Magnesium, as Mg^{2+}	-	100	100
Calcium, as Ca^{2+}	-	150	150
Lead, as Pb	0.01	0.01	0.01
Cadmium	0.003	0.003	0.003
Chromium Total, as Cr	0.05	0.05	0.05
Residual free Chlorine	0.2	0.2-0.5	0.2

Source: (WHO, 2011; EAC 2014; UNBS, 2022). All units in mg/L except pH

2.2.3 Biological Aspects

The pathogen transmitted through drinking water include; bacteria, viruses, protozoa, helminths (WHO, 2011) **(Table 2-3).**

Table 2-3: Standard guidelines for biological parameters in drinking water

Type of micro-organism	WHO standards	EAC standards	UNBS standards
Total Coliforms in 100 mL	Non detectable	Absent	Absent
E. coli in 100 ml	Non detectable	Absent	Absent
Staphylococcus aureus in 100 ml	Non detectable	Absent	Absent
Sulphite reducing anaerobes in100 mL	Non detectable	Absent	Absent
Pseudomonas aeruginosa fluorescence in 100 ml	Non detectable	Absent	Absent
Streptococcus faecalis in 100ml	Non detectable	Absent	Absent
Shigella in 100 ml	Non detectable	Absent	Absent
Salmonella in 100 ml	Non detectable	Absent	Absent

Source: (WHO, 2011), (EAC 2014) and (UNBS, 2022).

2.3 Sources of drinking water and their treatment options

2.3.1 Surface Water sources

Water resources that supply water to public drinking water supplies and private wells, are rivers, streams, lakes, reservoirs, springs, and groundwater (Ebenebe *et al.*, 2019). Surface water is continuously evaporated, seeped into groundwater supplies, and replenished by rain and snow (Stamm and Mcbride, 2013). Water from streams, rivers, lakes, or reservoirs used in public drinking water systems must be treated before being distributed (Clark, Clark and Dorsey, 2019). 7% of the people in Uganda relies on surface water (lakes, rivers, irrigation canals, and ponds) for drinking water, compared to 144 million people worldwide (Bwire *et al*., 2020).

i) Rivers

There are a lot of variables that affect the quantity and quality of water transported by the river and these are determined by the watershed, so throughout the year, as the seasons change, the river's water level and other characteristics also alter (Putro, 2016). The various climate areas, as well as the river watershed, are intimately connected to the seasons (Mujere and Moyce, 2018). River water level is influenced by large catchments more slowly than by small catchments according Food and Agricultural Organisation (FAO, 1992). Steep slopes in the catchment area increase surface runoff and the amount of soil and silt that enters the river (Wang *et al.*, 2008). When sediments end up in the water, quality is highly compromised leading to more treatment requirements (Nwoye and Ifeoma, 2020).

ii) Lakes

Lakes waters are exposed to the environment and as result of such contact it is at high risk of different categories of contamination (Bhateria and Jain, 2016). The lakes also a natural habitat and encounter other economic activities like fishing, transportation and leisure which all bring about some level of contamination (Aronoff *et al.*, 2021). Weather conditions and existing environmental conditions are responsible for the changes in lake water conditions (Bastaraud *et al.*, 2020), (Mujere and Moyce, 2018). During rainy season for example the physical characteristics are greatly altered which very much dictate the level of treatment requirements (Nsubuga, Namutebi and Nsubuga-ssenfuma, 2014). The Directorate of Water Resources Management has split Uganda's surface water resources into eight main drainage sub-basins i.e Lake Victoria, Lake Kyoga, River Kafu, Lake Edward, Lake Albert, River Aswa, Albert Nile, Kidepo Valley, and 149 more smaller lakes dispersed throughout the nation's 38,500 km^2 are among them (Nsubuga *et al.*, 2014).

iii) Surface run offs

Generated mainly after precipitation when surface infiltration is exceeded. It can also result from A field's irrigation water that drains either as surface flow or as subterranean flow. Little streams form the beginning of runoff, and water is contributed from numerous of these streams. Finally, each of these reaches a lake or stream and merges with it (Balasubramanian, 2017). Surface run offs are characterized by high turbidity, colour and contamination levels which increase the effect of these parameters as run offs recharge lakes, rivers and oceans waters (Ram *et al.*, 2017).

2.3.2 Underground water

Hard rock aquifers with low yields cover much of Uganda (Walekhwa *et al.,* 2022). The world's most significant source of drinking water supply is now groundwater (Katsanou and Karapanagioti, 2017). People living in rural areas and in fast growing urban areas have both increased their consumption of groundwater significantly in both developed and developing countries (Taylor *et al.*, 2013) due to the insufficient supply of surface water and the ongoing decline in its quality (Okot-okumu and Otim, 2015).

2.3.3 Treatment options

A combination of physical, chemical, and biological procedures and processes **(Conventional water treatment)** are used in traditional water treatment (Naser and Abdulrazzaq, 2021). In order of increasing treatment level, the terms preliminary, main, secondary, tertiary, and/or advanced water treatment are all used to designate different stages of treatment (Pakharuddin *et al.*, 2021).

The advanced or non-traditional way of treating water **(non-conventional water treatment)** is less complicated than the traditional method (Fahad *et al.*, 2019). Compared to traditional treatments, non-conventional methods have less of an impact on the environment and can reduce pollutant loads for less money (Ceron *et al*., 2020). If and only if conventional water treatment is no longer practical due to conditions like severe water contamination, non-conventional water treatment is performed (Lever, 2014). Softening, dealkalization, ultrafiltration, demineralization, reverse osmosis, microfiltration, multimedia filtration and nanofiltration are some examples of non-conventional treatment options (Guo *et al.*, 2021). Ion exchange, chemical precipitation adsorption, electrochemical treatment, and the utilization of biosobents are further noteworthy techniques for heavy metal removal (Sarkar and Adhikari, 2018).

a) Surface water treatment options

Surface water sources are those in contact directly to the atmosphere, such as rivers and lakes, the conventional processes are most common mode of purification (Bwire *et al.*, 2020). Processes includes abstraction, screening, the addition of chemicals, coagulation and flocculation, sedimentation and clarification, filtration and disinfection before the water is stored and distributed (Farhaoui and Derraz, 2017). For salty ocean water, treatment is achieved by further desalination ,reverse osmosis to eliminate salts and increase chances of acceptability (Mutai, 2015). Treatment protects the consumer's health. Other reasons are economical for example preventing scaling and corrosion in pipe lines & staining clothes during laundry (Hijnen and Dick Van Der Kooij, 2000; Shinde and Raichurkar, 2019). The level of treatment at each stage is as follows: floating objects (screening), algae (straining or fine screen) iron, manganese, or hardness (precipitation), as well as excessive suspended solids (sedimentation) organic or bacterial contamination, dissolved gases, taste, flavor, or color, and aeration or adsorption (disinfection) (Wang *et al.*, 2020). The processes play different treatment roles and therefor are incorporated or excluded during design depending on prior analysis on the parameters of raw water from the source to maximize treatment costs (Park *et al.*, 2021).

b) Groundwater treatment options

Groundwater reservoir are known to have water with better quality except in areas with highly polluted grounds (Snousy *et al.*, 2022). In developing countries, underground water is extracted and consumed as it is (Carrard, Foster and Willetts, 2019). In some scenarios, groundwater is subjected to some selected processes in the conventional process, mainly aeration to remove or reduce the concentration of iron and manganese which are two common substance affecting the colour of ground water (Swain, Sahoo and Taloor, 2021). Coagulation, flocculation, sedimentation, filtration, and disinfection are by far the most often used processes among the wide range of water treatment procedures (Jayalekshmi *et al.*, 2021).

i) Coagulation, Flocculation and Sedimentation

Certain particles will not sediment, or progressively separate from water over time, despite the fact that many will. To encourage sluggish or non-settling particles to separate more quickly, a soluble chemical or chemical mixture is introduced to the water. Coagulation is the process and these compounds are known as coagulants (Pakharuddin *et al.*, 2021). Larger particles known as flocs are produced when water particles combine with coagulants. These particles settle quickly and can be removed as sludge (Kucera, Hofmanovai and biela 2020). Filtering the water, either before or after sedimentation, using controlled techniques that remove the contaminants as well as the coagulant chemicals can also successfully eliminate flocs (Valentin, Denoeux and Fotoohi, 2017; Shabiimam M A, 2019).

ii) Filtration

Water can be treated in the simplest and most traditional way by passing over a bed of tiny particles, typically sand (Biardzka, 2015). Sand filtration is often used to remove small particles such as larger microorganisms, and fine suspended particulates (Francis *et al.*, 2015).

iii) Disinfection

Although coagulation, flocculation, and filtering can remove a sizable amount of organic matter and bigger bacteria from raw water, some significant pathogens are left behind (Carlen, 2021). Disinfection eliminates potentially dangerous bacteria from the water supply and stops them from re-emerging in the distribution networks since waterborne infections provide a greater threat when they are not disinfected. The most popular disinfectant for drinking water is chlorine. It has a long history of safe use worldwide and is affordable, simple to use, effective at low dose levels against a variety of pathogenic bacteria**.**

2.4 Sand depth optimisation for turbidity removal

2.4.1 Turbidity

This is caused by particles suspended in water such as colloidal and organic matter in suspension or micro-organisms such as algae. Suspended matter is commonly observed in surface water unlike ground water because of the natural filtration that occurs as water percolates through the soil (Seelro *et al.*, 2020). Turbidity is normally studied under nephelometry and common unit of measurement is Nephelometric Turbidity Units (NTU)

2.4.2 Synthetic turbidity

Synthetic turbid water has been used in research to create new methods that use the conventional treatment process of coagulation, flocculation, sedimentation, and filtration under specific circumstances. Using bentonite in varying concentrations—low, medium, and high—synthetic turbid water of different levels is created (Al-sameraiy, 2012).

2.4.3 Turbidity removal

Depending of the investigated turbidity nature of raw water source, the treatment design can be systematized to remove turbidity in a chain processes or unit specific. Design to remove turbidity targets suspended solids to decrease turbidity in return. These procedures are commonly used in water treatment facilities and include coagulation, flocculation, sedimentation, and filtration.

i) Coagulation

Coagulation is commonly achieved by introducing a coagulant which initiates mechanisms for the process. The suspended particles are destabilized and acclimatized to agglomerate and generate larger particles that enhance subsequent removal as the treatment proceeds. Coagulants can be classified as organic and inorganic (Meng and Fu, 2019). Organic coagulants are polymers in nature commonly referred to as polyelectrolytes usually of natural or synthetic origin. Their dosing can be arrived at through pilot experimentation or adaptation of models designed through the years (Muradov et al., 2020). Nowadays, natural coagulants have to a great extent been considered for adaptation owing to their cost effectiveness, safety and environmental friendliness (Ahmed and Mohammed, 2020). Inorganic coagulants are mainly metal salts for example ferric chloride and polyaluminium chloride which are iron and aluminum salts respectively. Studies have shown that aluminum possesses a health risk to human being as its intake in the long run has been linked to brain damage causing dementia and Alzheimer’s disease (Ratnaweera, 2020). For this reason, more interest to develop alternative cheaper, safer and environmentally friendly organic coagulants have been ventured in.

ii) Flocculation

Previously destabilised particles attract each other building into larger sludge sheets known as flocs. The larger sheets develop a more significant weight enabling settling at the subsequent stage of sedimentation prior to filtration.

2.4.4 Slow sand filtration

Slow sand filtration operates primarily through biological process that happens on the surface of the sand bed (Liu *et al.*, 2019). The filter configuration consists of filter units filled with specifically selected and prepared sand that is placed on the gravel located at the underdrain at filter unit. Removal mechanism involves raw water flowing in the filter, pathogens, turbidity and other contaminants are then removed physically (Zaman *et al.*, 2014). Schmutzdecke, a biofilm made of non-hazardous bacteria, grows on top of the shallow layer of water that covers the sand, eliminating infections through predation and competition for food with the water's harmful species (Thomas and Kani, 2016). An animated bio sand filter is shown **Figure 2-1**. Removal of heavy metals from water is efficient at higher filter media depth (Barkouch *et al.*, 2019) and the type or origin of sand used as a filter media (Jumean, Pappalardo and Abdo, 2010). Advanced membrane treatment technologies notable nanofiltration, reverse osmosis, ultrafiltation and electrodialysis have been found to have practical applicability in heavy metal elimination (Qasem and Mohammed, 2021). The use of magnetic fields, electrocoagulation, enhanced oxidation, and adsorption utilizing synthetic and natural adsorbents are further techniques.

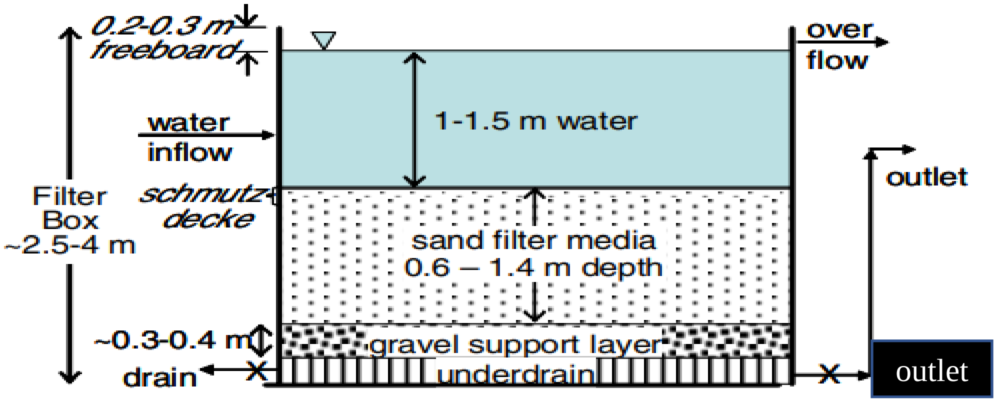


Figure 2-1:Typical slow sand filter configuration, Source:(Bielefeld, 2016)

2.4.5 Filter media depth and hydraulics vs performance

Filter media depth is the main element in design of bio retention systems such as rapid and slow sand filters but the effective ranges of media depths when dealing with the system hydraulics and performance remain questionable. Past studies have revealed that as sedimentation begin to occur on the filter surface, clogging occurs and therefore the hydraulic conductivity generally decreases (Grace, Healy and Clifford, 2016). In sand filtration, factors that affect hydraulic conductivity include grain size and shape, homogeneity, the size and distribution of voids (measured by void ratio and porosity), layering and fissuring, and the degree of saturation (Rather *et al*., 2021),viscosity, temperature, fissuring, compression or stress level, and particle loading are examples of fluid properties (Søborg and Breda, 2015). Efficiency of turbidity removal improves with increase in filter media depth, however, hydraulic conductivity decreases with depth (Takaijudin et at., 2015 ; Ncube, Pidou and Jarvis, 2018; Sze *et al.*, 2021).

2.4.6 Design criteria

Over the years many researchers have found effective values for slow sand filter design criteria that ensures efficient operation, economy and easy maintenance (Fuchs et al., 2015). The design period can range between 5 to 20 years or more, period of operation is twenty-four hours per day, hydraulic loading rate between 0.1m/h to 0.4m/h, initial thickness of sand bed between 0.8m to 1.5m and minimum depth between 0.4 to 0.8, sand specification of effective size D_{10} between 0.15 to 0.35, coefficient of uniformity between 1.5 to 5, height of underdrain including gravel layer between 0.3m to 0.8m and height of supernatant layer, 1.0m to 3m (Liu *et al.*, 2020; Clark *et al.*, 2012; IS, 1990; MWE, 2013).

2.4.7 Filter flow controls

Controlling the flow in, within and out of the filter units influence the level of treatment achieved abundantly. To ensure the removal procedures, operating variables, particularly the hydraulic loading rate, must be kept within the right range (Scott and Darin, 2016). Either the filter's inlet or outlet can be used to regulate the proper hydraulic loading rate (Kiky, 2018).

i) Inlet filter controls

The raw water inlet valve controls the hydraulic loading rate. This raw water entrance valve enables a steady flow of water to the filter unit, which results in a steady hydraulic loading rate. A flow indicator is positioned inside the system to continuously measure the flow. Since the supernatant layer is initially shallower, raw water has a shorter retention duration in this layer. Supernatant layer will eventually rise to make up for the head loss brought on by Schmutzdecke formation at the filter bed surface (Fitriani, *et al*. 2020). As the supernatant level reaches its peak, the sand surface is cleansed. Controls at the filter's inlet are useful because they make filter operation simpler. Direct evidence of the rise in supernatant layer is brought about by an increase in head loss.

ii) Outlet filter controls

Using this method, the system is designed to keep the supernatant layer at a constant maximum level above the bed surface. The difference in levels between the supernatant layer and the water overflow which is usually positioned equal to the bed surface, creates a pressure allowing the water percolates through the media (Park *et al.* 2014). Along with the removal process, retained particles may increase the head loss, hence, influencing the hydraulic loading rate. In order to maintain the desired hydraulic loading rate, an intermediate valve is gradually opened as a consequence of the head loss increase. This valve opening may cause a slight variation of the hydraulic loading rate. The outlet valve opening is regularly adjusted so that the constant hydraulic loading rate can be maintained during operations (Park., *et al.* 2014).

2.5 Natural zeolite and its applicability in removal of lead from drinking water

Due to their characteristics and widespread occurrence, natural zeolites are increasingly being used for environmental applications. Zeolite has been applied in removal of metal ions from drinking water as demonstrated in the study (Krobba et al., 2012)

2.5.1 Characterization and types of natural zeolite

A crystalline substance called zeolite has a unique structure that is characterized by a network of linked tetrahedra, each of which has four oxygen atoms encircling a cation (Derbe, Temesgen and Bitew, 2021). Water molecules and extra-framework cations that are often exchangeable typically occupy channels and cages (Derbe, Temesgen and Bitew, 2021). Because of their distinct cation-exchange capabilities, natural zeolites are being evaluated for a range of agricultural, industrial and environmental uses and is essential to fully characterize the zeolitic materials prior to their utilization (Jim and Almaz, 2021). By using X-ray diffraction, electron microscopy and infrared spectroscopy, the mineral samples are analyzed, and the cation exchange capacity calculated both before and after the treatment (Vreeswijk and Weckhuysen, 2022).

Natural zeolites are also classified as hydrated alumosilicates with open channel networks in their lattice and exchangeable cations which are made up of endlessly extending networks of SiO_4 and AlO_4 tetrahedra connected by common oxygen atoms (Sinngu *et al.*, 2022). Exchangeable cations can enter the frameworks through voids, cages, or channels that are created (Derbe, Temesgen and Bitew, 2021). A charge deficiency caused by the replacement of tetravalent silicon with trivalent aluminum needs to be balanced by adding loosely bound monovalent and divalent cations of alkali and alkaline earth metals (Wolffis *et al.*, 2019). There are currently more than 50 imidazolium and several different mineral species of natural zeolites which are divided into different framework types (molecular sieves) (Vinaches, Bernardo-Gusmão and Pergher, 2017). One of the most common zeolites among them, clinoptilolite, is widely used in a variety of applications and in a continuous succession of solid solutions, clinoptilolite and heulandite are both members of the HEU structural type. Heulandite has a

Si/Al ratio of 4 while clinoptilolite has a Si/Al ratio of >4 according to IMA (International Mineralogical Association) nomenclature (Stocker *et al.*, 2017).

Clinoptilolite is the most common and widely utilized natural zeolite in the world (Cheng *et al.*, 2016). The aluminosilicate framework, exchangeable cations, and zeolitic water are three largely independent components of zeolite structure (Neolaka *et al*., 2018). Although zeolitic tuffs are mostly used as cement and concrete additives to neutralize excess lime, they can be thermally expanded to generate lightweight insulating materials (Stocker *et al*., 2017). The first large-scale cation-exchange water treatment methods using natural zeolites were introduced in the early 1970s (Stocker *et al*., 2017).

Synthetic zeolites frequently have better cation-exchange capacities than natural zeolites, which makes them an appealing adsorption reagent for nitrogen removal and recovery as natural zeolites exhibit a greater selectivity for ammonium (Yuan *et al.*, 2021). Furthermore, natural zeolites have been carefully investigated for the removal of heavy metals from urban, agricultural, and industrial waste streams, including soil effluents, acid mine drainage, and other waste streams Particularly, natural clinoptilolite exhibits a preferential ion exchange for ammonium, which has led to its usage in fish rearing, soil amendment, and pool construction(Magalhães *et al.*, 2022). The most significant natural zeolites concentrations, however, are found in volcanoclastic and sedimentary rocks and typically appear as low-temperature alteration byproducts depending on the geological location and physio-chemical conditions during mineral formation. Zeolite deposits often consist of a heterogeneous mixture of gangue minerals such as quartz, feldspars, and phyllosilicates together with zeolite minerals (mica, clay minerals) (Poirier, 2022).

The stability of zeolite phases, or which zeolites form, as well as the kind and amount of gangue minerals present, are consequently governed by geological considerations, and these considerations have a substantial impact on the efficiency and applicability in technical processes (Castro, Maia and Rômulo, 2019). It is challenging to compare the results because of the large variety of zeolites as well as the many experimental configurations and characterization techniques, particularly when suggested applications are not standardized (Verboekend *et a*l., 2016). As a result, a characterization scheme using combined mineralogical and chemical approaches is given for technical applications, and the results were demonstrated using one particular zeolite sample (Z-01) from an Austrian source (Fang *et al.*, 2021).

2.5.2 Properties of Zeolite

Zeolites with specific structural and chemical characteristics are produced for commercial purposes in order to make use of the natural zeolite properties. Drying of gases and liquids, hydrocarbon separation, and selective molecule adsorption for pollution management are a few examples of commercial applications (Eduardo, Valencia and Rey, 2022).

2.5.2.1 pH of Zeolite

The value of pH has, however, only been correlated with the excess alkalinity and the parameters of the crystallization process in a few papers (Baradaran *et al.*, 2015). A study by (Kolesnichenko, Natalya and Snatenkova, (2018) showed that the Si/AI ratio of phillipsites depends linearly on the pH between 13.3 and 13.7 for systems with a high silica content. In the systems described the pH value is determined by the alkali content of the batch and the equilibria between the alkali, the silicate and aluminosilicate species formed in the solution phase which create an extended buffering system (Munthali *et al.*, 2014).

2.5.2.2 Porosity of Zeolite

Natural zeolite is defined as a microporous, crystalline mineral with a highly regular structure of pores and chambers that are typically inhabited by extra-framework cations and water molecules that can exchange readily. The shape, size, and connectivity of the pores vary between the various zeolite (Murrieta-rico *et al*., (2022).

2.5.2.3 Metal Ions

Unsynthetic zeolite is composed of a tetrahedral structure (TO_4), where T represents different atoms such as silicon, aluminum, germanium, iron, boron, phosphorus or cobalt. Predominantly, the major structures of zeolites represent tetrahedral configuration of alumina $(AlO_4)^{-5}$ and silica $(SiO_4)^{-4}$. The silicon and aluminum units unite to form tetrahedral sheets, whereas hexagonal structures are constructed every six units oriented in the same direction (Krol, 2020). The zeolite's cation exchange capacity is related to its Si/Al ratio since natural zeolites have impurities that limit their application and as a result people have begun to synthesize zeolites for academic as well as industrial purposes (Montalvan-burbano *et al*., 2021). There are 200 types of synthetic zeolites, for example: A, X, Y, L, F, Mordenite, ZSM-5, ZSM-11 among others. Zeolites can be used to mitigate the environmental impacts caused by greenhouse gas emissions. These synthetic zeolites have larger porosity compared to other types of zeolites (Klunk *et al.*, 2020).

2.5.2.4 Thermal stability

According to X-ray diffraction data, this structure is thermally stable up to a temperature of 600 °C and Faujasite (FAU) structure disintegrates above 800°C (Ali, 2022). The goal of the study on zeolites' thermal stability confirm their resistance and determine the highest temperature at which they can be used for a variety of applications. The degree of structural order is not considerably affected by the thermal stability of zeolites but when heated past the point of dehydration, and that the main stabilizing factor is the crystal lattice geometry (Castro, Maia and Rômulo, 2019).

Zeolite thermal analysis graphs by (Castro, Maia and Rômulo, 2019) shows exothermic peaks, one signifying the recrystallization into a new phase and the other being related with the collapse of the crystalline structure to an amorphous phase. The two exothermic peaks in the instance of zeolite therefore point to the emergence of additional crystalline phases (Wang *et al.*, 2023).

2.5.3 Application of zeolite

Zeolite has been used in water, waste water and municipal wastewater treatment by large-scale cation-exchange procedures, demonstrating the efficiency of clinoptilolite for ammonia ion extraction from municipal and agricultural waste streams (Rahman, El-Kamash, and Hung, 2022). Clinoptilolite which selectively exchanges ammonia ions from wastewater and offers an optimal growth medium for nitrifying bacteria, speeds up the nitrification of sludge (Grifasi *et al.*, 2022). It uses the selective exchange of clinoptilolite with an organic resin to extract Nitrogen and Phosphorous from sewage effluent (Zhang *et al.*, 2022).

Ammonium, phosphorus, heavy metals, inorganic anion, organics, and dye adsorption are some of the pollutants in wastewater and their removal from a gas or wastewater process requires zeolite that has been modified properly (Bajda, 2022). An experiment was conducted and studied the kinetics, isotherms, and mechanism of modified zeolite with magnesium ions to adsorb various substances, including ammonia and E. coli and the outcomes demonstrated that modified zeolite has greater activity because of the special surface of the substance (Radoor *et al.*, 2022).

Higher zeolite composition was found to also increase removal effectiveness and basing on the experiments, temperature was not significantly influencing removal (Budianta, Ardiana and Andriyani, 2020). Effect of reaction time and zeolite dosage was also investigated and they discovered that increasing zeolite dose increased surface area, which successfully reduced the ion exchange sites of the zeolites' unsaturation.

2.5.3.1 Application of zeolite in drinking water treatment

A clinoptilolite-amended slow-sand filtration process for the city of Logan, UT, was examined in light of Sims and colleagues' prior discovery was that the inclusion of clinoptilolite improved nitrification of sewage sludge (Sims and Little, 2019). The filtering rate tripled with the addition of a layer of crushed zeolite, with no negative side effects. Clinoptilolite filtration reduced the ammonia concentration of drinking water at Buki Island, upstream from Budapest, from 15 to 22 parts per million to 2 parts per million (Kumar *et al*., 2021). A low-cost method of eliminating lead from drinking water is suggested by the selectivity of a number of natural zeolites for lead ions (Sljivic et al., 2009).

2.5.3.2 Application of zeolite as an adsorbent

Natural zeolite utilization as a catalyst support for transesterification of palm oil was studied by (Shiferaw *et al*., 2023). They prepared the zeolite catalyst by impregnation with potassium hydroxide and was treated with hydrogen peroxide solution prior to catalyst production. The catalyst was identified and utilized in the manufacturing of biodiesel (Hidayat, Mukti1, Handoko, 2018). The catalyst performed well in terms of high yield, good stability, and repeatability during three reaction cycles, according to the results. Zeolite was employed as a dimethyl ether from methanol catalyst in addition to a biodiesel catalyst. The findings indicate that zeolites have the ability to adsorb water, suggesting that they could serve as an effective and affordable catalyst for the manufacture of DME (Sodha *et al*., 2022).

Natural zeolites often cannot compete with their synthetic counterparts in adsorption or catalytic applications (Shiferaw *et al*., 2023). Compared to synthetic materials, most natural materials have narrower pore apertures. The economics of hardware assembly, activation, and regeneration favor the more expensive synthetics, even at $2.00/kg, for the majority of adsorption applications, notwithstanding the low cost of the natural materials (a few cents per kilogram) (Dusselier and Davis, 2018). Nonetheless, researchers have made progress in the drying and purification of acid gases by using specific natural zeolites. For instance, mordenite and chabazite have been employed to take the water and carbon dioxide out of sour natural gas because they can endure the rigors of repeated cycling in acidic settings.

2.5.3.3 Applications of zeolite as a catalyst

Erionite-clinoptilolite zeolite specie has been applied as a hydrogen-exchanged natural mordenite for the hydromethylation of toluene, a catalyst using cation-exchanged clinoptilolite from Tokaj, Hungary, a catalyst using clinoptilolite for the isomerization of n-butene, a catalyst using clinoptilolite for the dehydration (Li and Yu, 2021).

2.6 Past studies on characteristics of drinking water in Uganda

In a study conducted by Atwebembeire *et al* (2018), the physio-chemical quality of the main branch of the River Rwizi in the Mbarara municipality in South Western Uganda was examined. They considered pH, ammonium, dissolved oxygen, color, turbidity, total suspended solid, total iron, phosphates, alkalinity, magnesium, calcium carbonate, and total suspended solid. The American Public Health Association's standard operating procedures were followed for the analysis of the water samples (1985). The results showed that most streams' downstream sections typically recorded the highest values of the physio-chemical parameters ($p \geq 0.05$), followed by their middle and upstream sections, in that order. Most of the parameters studied were at their highest concentrations in downstream streams sand these were the outcomes: Bus Park stream (27.6 C, color 431.17 TCU, TSS 99.33 mg/l, alkalinity 468.33 mg/l, magnesium 121.89 mg/l, calcium carbonate 588.67 mg/l, and chlorine 333.33 mg/l); Kikutu stream (turbidity 123.58 NTU, EC 698 s/cm, and DO 55. Most of the parameters downstream exceeded both NEMA requirements (color, 300 TCUs; Mg, 100mg/l; DO, 5mg/l; 3 PO4, 10 mg/l; pH, 6.0-8.0) and EPA guidelines (temperature, 25 C; color, 20 - 150 TCUs; TSS, 50 mg/l; alkalinity, 400 mg/l; Cl, 250 mg/l; DO, 5 mg/l; 3 PO4. In contrast, the upstream streams Kibimba (17.28°C), Kasharara (15.17°T, 2.5 mg/l TSS), and Karungu (7.02 mg/l Turbidity, 7.02 mg/l Fe, 0.12 mg/l) recorded the lowest values of the data. Throughout the stream, the calcium carbonate hardness of the waters varied from abnormally mild to firm.

Recommendation: The study advised that extensive steps be made to control the various Human-made activities in the river Rwizi's watershed in light of variations in the parameters observed in the downstream that could reach unfavorable circumstances.

A study by Ongom, Andama and Lukubye (2017) was conducted in 2017. The Kayei, Acholi Inn, Waitumba, and Masindi port landing sites were chosen as the study's focus sites for the impact of human and anthropogenic activities (boat dock, waste site, garden, fishing) on water quality indicators. Temperature, pH, water flow rate, dissolved oxygen (DO), nitrite (NO_2), and phosphate were among the variables. The findings demonstrated that anthropogenic activities caused substantial ($p \geq 0.05$) differences in the mean temperature, pH, DO, NO_2, and PO_4-P

Recommendation: The report suggested that, in order to prevent the flow of untreated sewage into the lake, the National Environmental Management Authority (NEMA) should oversee efficient sewage management in the Lake Kyoga basin. To prevent nutrient (phosphorus) enrichment, the authority should additionally manage trash disposal and farming close to the lake.

A study by Omara *et al* (2019) was conducted in vicinity of Kyambogo University Kampala. Samples were taken from three springs namely; Katalina spring, Airport spring 1 and Airport spring 2. The samples' physical and chemical characteristics, including their temperature, pH, turbidity, electrical conductivity, chlorides, and sulfates, as well as their total coliform and E. coli counts were calculated. A hand-held Jenway 370 pH/mV/Temperature meter was used to measure the pH and temperature of the spring water on-site. A precalibrated Jenway 4520 Conductivity/TDS meter was used to measure the conductivity. The Genesys 10S UV-Visible spectrophotometer was used to quantify turbidity Unit (FTU), and the mercuric thiocyanate technique was used to measure chloride levels, Sulphates were estimated by UV-Visible spectrophotometry. Bacteriological parameters were examined using the McConkey Culture Media Method in accordance with the Bacteriological Analytical Manual's (BAM's) standard procedures, and the findings of the ISO test technique are displayed in **(Table 2-4).**

Table 2-4:Results from the study (Omara et al., 2019)

Spring	Temperature (˚C)	pH	E.C (µS/cm)	Turbidity (FTU)	Cl^- (mg/L)	SO24− (mg/L)
Katalina	20.53 ± 1.23	5.33 ± 0.25	162	<5	6.63 ± 0.20	2.44 ± 0.05
AS 1	1 21.53 ± 0.60	6.30 ± 0.10	201	<5	10.91 ± 0.50	5.31 ± 0.24
AS 2	2 20.33 ± 1.62	7.10 ± 0.46	158	<5	9.24 ± 0.07	3.99 ± 0.11

AS 1 - Airport Spring 1, AS 2 - Airport Spring 2

The water samples from Katalina, Airport springs 1 and 2, and Airport spring 2 had respective mean temperatures of 20.53 C 1.2 C, 21.53 C 0.60 C, and 20.33 C 1.62 C. Their results were 5.33 0.25, 6.30 0.10, and 7.10 0.46 for the statistical mean pH. Total coliforms and E. coli levels were found to be above WHO permitted limits in all of the springs, making them all microbiologically contaminated. In conclusion, the analyzed springs' water is unfit for human consumption.

Study recommendation: Government should set aside funds for routine testing of these water sources in the neighborhood to monitor and assess their bacteriological condition and equip community households with water treatment products like Aqua Safe and Water Guard. It is important to do research to determine whether spring contamination and community clinical status are related. It is important to examine the physicochemical and microbiological characteristics of nearby subsurface water sources.

A study by Nkurunziza *et al.*, (2021) in Kisoro Municipality looked at the following physiochemical parameters; Temperature, turbidity, conductivity, biological oxygen demand, total dissolved solids, dissolved oxygen, total alkalinity, calcium, magnesium, phosphates, iron, copper, arsenic, chlorides, and fluoride content of the water samples. Some of the physical and chemical parameters of water samples taken from Chuho springs and taps were found to be outside the recommended WHO guideline for drinking water. Temperature, dissolved oxygen and fluorides were outside the recommended limits of 15 ℃, 10-12 mg/L and 1.5 mg/L, respectively. Additional research should be done to identify other potential water contaminants of microbiological and radioactive origin, coupled with sanitary assessment of the springs. It is also important to understand how the physicochemical characteristics change throughout the rainy season. The study suggested that artificial intelligence should be used to model and predict water quality in the Chuho springs to enhance water quality monitoring.

Bwire., *et al* (2020) carried out a study in six regions (Central, West, West Nile, Northern, Southern and Eastern) of Uganda in the African Great Lakes basins of the five lakes between February 2015 and January 2016 (Victoria, Albert, Kyoga, Edward and George). The study locations were in the districts of Kampala and Kayunga, in the country's central area; Kasese and Buliisa, in the west; and Nebbi and Busia, in the country's northern and eastern regions, respectively. pH, temperature, dissolved oxygen, conductivity, and turbidity were among the variables analyzed. The methods used involved ISO standards. 318 water samples were tested and analyzed in total. The mean test findings for 26% (36/135) of the examined samples were below the World Health Organization (WHO) recommended range for drinking water. The mean water turbidity readings at all locations (100%, 27/27) were higher than the WHO drinking water recommended criteria, and the temperature was higher than 17 °C. Also, 27% (3/11) of the lake sites and 2/5 of the ponds, respectively, had pH and dissolved oxygen levels that were outside of the WHO-recommended ranges of 6.5 to 8.5 for pH and less than 5 mg/L for dissolved oxygen.

Lukubye and Andama (2017), conducted a study in Mbarara municipality located in Mbarara District, South Western Uganda. In view of the growing human activities in the municipality, the study evaluated the physio-chemical quality of a few drinking water sources (springs, boreholes and shallow wells) in relation to WHO drinking water guidelines and other guidelines. In the Nyamitanga, Kamukuzi, and Kakoba divisions, 70 water samples were gathered from purposefully chosen boreholes, springs, wells, and precipitation. The samples were examined using American Public Health Association (APHA) standard procedures for the physio-chemical parameters of temperature, pH, dissolved oxygen (DO), biological oxygen demand (BOD), total dissolved solids (TDS), electrical conductivity (EC), and total hardness. The pH ranged from 5.74 to 7.54 and the mean temperature ranged from 18.07 to 23.45 degrees Celsius. Whereas the mean BOD values fell between 1.83 and 7.71 mg/l, the mean DO levels varied from 4.84 to 12.86 mg/l. The range of the mean TDS and EC measurements for the water samples was 33.40 to 569.20 mg/l and 29.30 to 1139.90 S/cm, respectively. The mean total hardness ranged from

70.00 to 264.00 mg/l. Each of the water sources had reported mean water temperatures that were higher than the WHO's recommended drinking water threshold (15 C). The mean pH of the boreholes at the secondary schools Nyamitanga and Shuhaddea, the spring in Kiswahili, the well in Kisenyi, and the rainwater from storage tanks at Mbarara University of Science and Technology (MUST) were all below the WHO's minimum recommendation value of 6.5, making them acidic. The WHO range for mean DO concentrations (10–12 mg/l) was not met by the spring in Kisenyi, the shallow well in Nyamitanga, the borehole at the secondary school, or the rainwater in MUST. The well at Kisenyi and the borehole at Shuhaddea Secondary School both had average BOD values that were higher than the range of the European Union's recommended standards (3–6 mg/l). All of the water sources had TDS and EC levels that were below that of the WHO maximum recommended limits of 1000 mg/l and 1500 s/cm, respectively. Moreover, total hardness was under the 1000 mg/l WHO safe limit. The other drinking water sources, on the other hand, displayed moderate to full complete hardness, whereas the rainwater in MUST was fairly soft. Increased human activity, particularly around croplands, latrines, landfills, transportation, animal waste, and municipal garbage, has negatively impacted the physicochemical parameters of a few of the municipality of Mbarara's chosen water sources. In order to prevent additional contamination from human activities, the research advised Mbarara Municipal Council to make sure that these drinking water sources have sufficient sanitation and water safety plans.

The study which was carried out by Okot-okumu and Otim (2015), was to evaluate the adequacy of the drinking water sources used by several communities in Uganda and the dangers associated with their usage. Kampala, Lira, Iganga, Gulu, and Amuru served as the case study locations. Water samples were collected, handled, and analyzed in accordance with the American Public Health Association's recommended practices (APHA). Nitrates, turbidity, total dissolved solids, conductivity, temperature, total coliform, and feacal coliform were among the parameters examined. Results of physicochemical and microbiological parameters were: Nitrates (0.01-4.6 mg/l); turbidity (< 5-97.6NTU); Total dissolved solids (59- 420.9 mg/l); conductivity (28-760 µS/cm); pH (5.3-7.2); temperature (23-25.90 °C), total coliform (0-940 cfu/100ml), feacal coliform (0-200 cfu/100ml). The risk of contamination assessment and the water quality analysis concurred that boreholes were the safest (1 CFU/100mL) source of water, with rainwater, standpipe taps, and protected springs following closely after. Shallow wells, uncovered springs, and surface water (such as streams) were high risk water sources (>100 CFU/100 mL). Most of the water springs and wells had levels of nitrate-nitrogen, feacal coliform, and total coliform that exceeded WHO limits for drinking water.

A study by (Ogoyi *et al.*, 2011) focused on investigating the effect of anthropogenic activities as potential pollution of Lake Victoria especially the heavy metal pollutants which may be toxic to humans and aquatic fauna. The heavy metals investigated included; Zn, Pb, Hg, Cd, Cr. The method adopted was Atomic Absorption Spectrophotometry. The results showed the highest concentrations for Zn, Pb, Hg were; 1.589 ppm, 0.823 ppm, 0.000148 ppm, traces of Cadmium and Chromium were found to be minimal in the samples collected. The study according to the findings recommended the need for continuous monitoring of heavy metal pollution levels in Lake Victoria.

A study by Kulabako, R. N., Norrström, A. C. and Bakyayita, G. K**.** (2019) focused on the levels, toxicity and speciation of elements of certain trace metals and other parameters like pH, dissolve organic carbon, Fluorides, Sulphate, nitrates, chloride, iron, aluminum, manganese from Designated Streams in Lake Victoria Basin, Uganda. The selected metals ions included; Ni^{2+}, Cu^{2+}, Zn^{2+}, and Pb^{2+}. Swedish EPA, Canadian, Ugandan, and WHO standards were all employed in the evaluation. The pH of the shallow groundwater was below 6.5, making it acidic. All springs' pH, dissolved organic carbon, flouride, and sulphate levels were below the recommended ranges, although 52.8% of them were nitrate and 39% chloride ion polluted. Major elements like iron, chromium, aluminum, and manganese were present in several surface water tests at levels that were over the recommended limits. According to speciation studies, 74% of the metal ions in surface water were bound to dissolved organic matter, whereas metal hydroxides or fulvic acid bound species predominated in landfill leachates. In 15.3%-30.8% of surface water samples and 8.3%-62.5% of groundwater samples, the findings of modeling sorption data using the Bio-met tool suggested potential risk to toxicity effects of Cu^{2+}, Ni^{2+}, Zn^{2+}, and Pb^{2+}. At 30%-76% of the sample sites, the risk analysis based on the Swedish EPA revealed a range of risks of adverse effects, from high to increasing risk in surface water.

A study by (Kwetegyeka *et al.*, 2010) was executed based on the evidence of emergency of heavy metals in Lake Victoria probably originating from waste water from both human and anthropogenic activities around Kampala city. The Nakivubo Wetland in to which the water is released was predicted to be ineffective in removing heavy metals due to effluent overloading. The study was conducted and monitored for three years between December 2006 to December 2010. The heavy metals inspected were; zinc, copper, cadmium and lead using atomic absorption spectrophotometry, method. the wetland removal efficiency was found to be ineffective in that it had shrunk from 89.7 – 98.3% in December 2006 to 79.4 – 92.1% in December 2008. When water from the lake some kilometers from the wetland was subjected to heavy metal testing, it was found that in the same period, the concentration elevated from 23 - 31% to 35 - 47% in the which is a danger to both human and aquatic population. According to the report, the appropriate authorities should perform pretreatment at each production site, raise plant management's awareness of environmental issues, and take more drastic steps to prevent wetland encroachment.

A study by Hoang *et al* (2020) was conducted in Vietnam to ascertain turbidity removal using fruit seeds as a natural coagulant. In this study, natural coagulant solutions from rambutan, sugar-apple and jujube seeds were prepared by chopping, grinding, drying and combining with suitable inorganic solvents (NaOH, NaCl, distilled water). Influent factors such as pH of water, dose of fruit seed and solvents to extract were studied to examine the efficiency of turbidity removal with synthetic turbid water by Jar test. The curve of turbidity removal for fruit seeds are rather different compared to that of poly aluminum chloride (PAC). The lower the pH, the higher the efficiencies of three fruit seeds. At pH = 3, 20 mg/L of coagulants from jujube seeds and at pH = 4, 20 mg /L of coagulants from rambutan and sugar-apple seed were the optimal condition for synthetic turbid water treatment. Under optimal condition of coagulants from jujube, rambutan and sugar-apple seeds the turbidity removal efficiency was 83%, 89% and 86%, respectively. This revealed a potential application of these natural coagulants for water treatment.

Conducted by Ahmed and Mohammed (2018), the study investigated how naturally occurring coagulants can complement or totally replace synthetic chemical applied for turbidity removal from surface water. This paper evaluated the turbidity removal efficiency of moringa oleifera pod extracts on synthetic high and medium turbidity raw water. The turbidity removal efficiency was evaluated at 3, 6 and 9% w/v stock solutions of moringa oleifera pod extract using jar test. Results obtained revealed that 6% w/v moringa oleifera pod extract optimally removed turbidity from the synthetic raw water at about 200 mg/L coagulant dose corresponding to a removal efficiency of about 80% in both high and medium. The study demonstrated the potentials in using moringa oleifera pod extract for turbidity removal from surface water. The pod extract discovery can be used to clarify in rural communities.

A study by Krisnandi *et al*. (2018), investigated the performance of other potential natural coagulants other than moringa oleifera. These other natural coagulants included Carica papaya and Leucaena leucocephala seeds. Using seeds from Indonesian native plants such moringa oleifera, leucaena, and papaya, it was discovered that all of the seeds contained active coagulant agents and could be utilized to cure turbid water. Moringa oleifera's ability to remove turbidity was unaffected by the coagulant dosage (g/L) or pH, although there was a difference when leucaena and papaya seed powder was employed as the natural coagulant. This study's turbidity removal was equivalent to the outcomes attained by other researchers. It is necessary to conduct additional research on the effects of initial turbidity, post-coagulation sludge volume, and salt extraction.

2.7 Challenges of drinking water in developing countries

i) **Rising stress and competition for fresh water:** According to UN estimates, 1.8 billion people could reside in nations or territories that lack access to clean water by 2025 (Fadaei and Sadeghi, 2014). As a result of demographic and environmental changes like population expansion, desertification, urbanization, and rising consumption as a result of economic growth, the world's scarce water supplies are coming under growing pressure. Climate change has an impact on the frequency, severity, and variability of rainfall, droughts, and flooding, and it is already transforming the world's water cycle at an unprecedented rate. The impact of climate change on these issues further adds to their complexity. The safety of coastal communities and their reliance on freshwater sources are threatened by the anticipated sea level rise (Hummel, Berry and Stacey, 2018).

ii) **Deteriorating water quality and quantity:** Urbanization and deforestation affect stream flows contaminating water supplies and producing significant sanitation concerns. Human actions have the potential to negatively impact even the greatest natural water bodies

(Kwetegyeka *et al*., 2010). When Lake Victoria's level declined, the Ugandan government was forced to invest more money to move the city's water intake into deeper water.

iii) **Chemical and biological pollution:** Aquifers or drinking water supplies may become saline and worthless as a result of poor groundwater management and natural disasters (Kumar *et al*., 2022).

iv) **Decision making capacity:** Water experts have known for a long time that water is crucial for sustainable development, but they do not control the necessary human and financial resources, nor do they make development decisions (Garfi and Ferre, 2011). A variety of social, political, and economical constraints placed on government officials hinder them from protecting drinking water supplies. Another factor is that there is very little environmental education in many nations (Francis *et al.*, 2015). Perhaps they never had the chance to study environmental management, and they may not know how to manage their water resources.

v) **Financial challenges:** Even though water management is acknowledged as a critical issue and receives strong political support, there is a failure to transfer this into effective action and increasing investment flows (Daniel *et al.*, 2021). Too frequently, the returns on water management and investments are undervalued and as a result, other sectors that are thought to be more productive are given priority with the limited resources available. However, a 2006 study put the economic rate of return for every dollar spent on meeting the Millennium Development Goals' water and sanitation target at $8. In the past, managing water resources has been essential to promoting economic development.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter presents details on the materials, methods used in obtaining and analyzing of data, laboratory procedures, and work programme in response to the objectives. It also includes techniques for data collection, treatment and manual analysis. Achieving specific objective one and two involved conducting experimental investigations for the characterization of water quality parameters. This was done in a phase-wise manner before, during and after the rainy season. For specific objective three, the method involved data sampling, trimming, preparation of a synthetic turbid water, fabrication of a slow sand filtration prototype, investigation of system hydraulics, sand depth optimization and re-examination in the laboratory to evaluate the level of treatment achieved in comparison to standard requirements. The applicability of natural zeolite in removal of lead ions as heavy metal was also investigated.

3.2 Characteristics of drinking water quality

The characteristics considered for this study included;

i) Turbidity,
ii) Colour,
iii) Hardness,
iv) Alkalinity, and
v) Selected heavy metals (arsenic, lead, zinc manganese and cadmium, cobolt, iron, chromium and copper).

3.2.1 Turbidity

This was done in accordance with the (ISO 7027-1, 2016) standards for determination of turbidity of portable water

3.2.1.1 Reagents

Strictly reagents of recognized analytical grade were used. Reagents were prepared in accordance with (ISO7027, 2016), proceeded and stored in hard glass high-density polyethylene (HDPE) bottles. Nephelometry quantitative method procedure for measurement of diffuse radiation was used in for the three phases earlier mentioned. Turbidity was measured in Nephelometric Turbidity Units (NTU).

3.2.1.2 Precaution that was followed during sampling

The following precautions were followed during sampling**;**

i) Maintained that all containers that came into contact with the sample were in a scrupulously clean condition.
ii) Washed with hydrochloric acid or surfactant cleaning solution.
iii) Collected samples in glass or plastics bottles while carrying out the determinations, as soon as possible after collection.
iv) When storage was unavoidable, samples were stored in a cool, dark room but for not longer than 24 hours.
v) Samples were stored under cool conditions, they were left to attain room temperature before measurement.
vi) Prevented contact between the sample and air and avoided unnecessary changes in the temperature of the sample

3.2.2 Colour

This was done in accordance with the (ISO7887, 2011) standards for determination of colour of portable water

Method: Determination of true colour using optical instruments

3.2.2.1 Apparatus

i) Spectrophotometer
ii) Membrane filter assembly
iii) pH Meter

3.2.2.2 Sampling and samples

A spectrophotometer was setup strictly observing the operating manual from the manufacturer. Prior to examination, the water samples were filtered through a membrane filter of pore size 0.45µm in parallel with each colour determination.

3.2.3 Hardness

According to ISO6059 (1996), chemical titration is the conventional method for determining hardness. A water sample's hardness is measured in milligrams per liter of calcium carbonate (mg/l CaCO3), which is equal to parts per million (ppm). The term "calcium carbonate hardness" refers to the overall amount of divalent salts present and does not precisely state whether calcium, magnesium, or another divalent salt is the source of the hardness in the water (Mustapha, 2017).

3.2.3.1 Apparatus/requirements

The following apparatus were required to investigate the hardness levels of water samples;

i) Burette 25-30ml
ii) Glass funnel Pipette 1ml
iii) Flask Dropper
iv) Measuring cylinder

3.2.3.2 Reagents:

The following reagents were used;

i) Magnesium carbonate,
ii) 90% ethyl alcohol,
iii) Chloramine (NH_2CL),
iv) Ethylenediaminetetraacetic acid (EDTA),
v) Eriochrome Black-T,
vi) Ammonia Buffer, and
vii) Distilled Water.

3.2.3.3 Reagent preparation

The following steps were followed in reagent preparation as per the standard;

i) EDTA solution: Dissolved 800 ml of distilled water in 4 grams of EDTA and 0.1 grams of magnesium bicarbonate.
ii) Eriochrome Black-T: 100ml of 95% ethyl alcohol, 4.5 grams of hydroxylamine hydrochloride, and 0.4 grams of eriochrome black.
iii) Ammonia Buffer: Stock A: 16.9 grams of NH4CL in 143 milliliters of concentrated NH4OH; Stock B: 1.25 grams of EDTA magnesium salt dissolved in 50 milliliters of distilled water. Combine the two stock solutions, then use DDW to dilute to 250ml. 10ml of the solution should be diluted with 100ml of Deuterium depleted-water (DDW).

3.2.3.4 Procedure

The following steps were followed in investigating the water hardness levels;

i) The burette was filled with standard EDTA solution to the zero level.
ii) Taken 50ml sample water in flask. For sample having high Calcium content, then taken smaller volume and dilute to 50ml.
iii) Added 1ml Ammonia buffer was added.
iv) Added 5 to 6 drop of eriochrome black – T indicator. The solution turned into wine red colour.
v) The initial reading was noted.
vi) The content was titrated against EDTA solution. At the end point colour changed from wine red to blue colour.
vii) The final reading was noted. The process was repeated till concordant value is obtained.
viii) 50ml sample was taken in another flask and boiled. (Added distilled water to get final volume of water.). iii-vii was then repeated in three separate experiments to estimate the most accurate value

3.2.4 Alkalinity

Water alkalinity is a gauge of how well it can balance acids (IS3025, 2008). Natural waters' alkalinity is mostly caused by the salts of weak acids. Alkalinity primarily takes the form of bicarbonates. One way to describe alkalinity is as follows: Alkalinity (mol/L) is calculated as [HCO3-] + [CO3-] + [OH-] - [H+]. Several natural water and wastewater treatments and uses depend on alkalinity. Since many surface waters contain carbonates, bicarbonates, and hydroxides, alkalinity is thought to be a sign of these substances as well. Alkalinity larger than alkaline earth metal concentrations is a crucial consideration when determining whether water is acceptable for irrigation. Alkalinity measurements are used to assess and coordinate water and wastewater treatment processes (IS3025, 2008). The experimental investigation required the following;

3.2.4.1 Apparatus

i) Burette,
ii) Conical flask,
iii) Pipette, and
iv) Measuring cylinder

3.2.4.2 Reagents

i) H_2SO_4 solution,
ii) Phenolphthalein indicator, and
iii) Methyl Orange indicator.

3.2.4.3 Procedure

The following steps were followed while testing for alkalinity in water samples.

i) The burette was filled with sulphuric acid H_2SO_4 solution.
ii) 100ml water sample was taken in flask. A few drops of Phenolphthalein indicator was added.
iii) The initial reading on burette scale was taken and titrated against H_2SO_4 till the pink colour disappeared. The end point reading was noted and the volume of used H_2SO_4 in ml (P) (Concordant value I) was obtained.
iv) 1-3 drop of Methyl Orange was added in same sample flask.
v) It was titrated till the appearance of light orange colour.
vi) The final reading was noted down and the volume of used H_2SO_4 was obtained.
vii) The steps of using the sample to get concordant value (Concordant value II) was repeated.
viii) The total alkalinity of sample was calculated

Note: The observations involved identification of phenolphthalein end point as concordant value I and identification of methyl orange end point as concordant value II in three parallel experiments

3.2.4.4 Calculation for water alkalinity

Total volume of standard H_2SO_4 used for the titration:

T = Concordant value I + Concordant value II

Thus, Phenolphthalein alkalinity = P*1000/ml sample

Total alkalinity (mg/lit of $CaCO_3$) = T*1000/ml sample

3.2.5 Investigation on heavy metals

Raw water samples were drawn from the dam in sample bottles and delivered to the department of geology and petroleum studies at Makerere University to be analyzed for the presence of the following elements (Arsenic As, Lead Pb, Manganese Mn, Cadmium Cd, Chromium Cr, Cobalt Co, Copper Cu and Iron Fe). Testing was done using an Atomic Absorption Spectroscopy (AAS) machine 200 series following American Public Health Association (APHA) standards. For evaluation of performance of the existing system in removing lead ions, samples were drawn and analysed at the faculty of science chemistry laboratory at Kyambogo University. Results from the investigations are shown in **(Table 4-11)** under the analysis section of this thesis.

3.3 Evaluation of system performance

3.3.1 Percentage change of parameters after treatment

The extent of change in water quality parameters investigated which indicates the level of treatment achieved using the existing system was deduced using **Equation 3-1**below

$Change = \left(\frac{min_B - min_A}{min_B}\right) * 100\%$..Equation 3-1

Where; min_B minimum turbidity value before treatment

min_A minimum turbidity value after treatment

3.3.2 Statistical and analytical methods

The obtained laboratory data has been analyzed using the application such as Microsoft Excel. Z-test and Student t-test were used to anlayse means of data samples within the same months for sample spaces more and less than 30 sample spaces respectively. **ANOVA** was used for comparison with all the 4 months. Relationships have been graphically represented, correlations, statistical analysis was carried out to find the mean and ranges of values which were compared with required standards summarized in tables in analysis section.

3.3.3 Case specific system efficiency

The system efficiency for every month of sampling was arrived at by observing the number of times the specific parameters exceeded the WHO standards and the total number of samples analyzed in a given month. The efficiency **(Table 4-8)**, was calculated as a percentage using the Equation below;

$E = \frac{X_1}{X_2} * 100\%$.. Equation 3-2

$\mathrm{X_1}$ − Number of times the turbidity and colour values were within the WHO standards

E − Efficiency, $\mathrm{X_2}$ − Total number of samples

3.4 Sand depth optimization

To achieve this objective, the pattern of turbidity data obtained from objective one was used as reference going forward. The method involved data sampling, trimming, preparation of a synthetic turbid water, fabrication of a bio sand filtration prototype, investigation system hydraulics, sand depth optimization and re-examination in the laboratory to evaluate the level of treatment achieved in comparison to standard requirements.

3.4.1 Data sampling for turbidity levels

Random sampling was used to determine a range of turbidity levels to prepare synthetic turbid water of similar turbidity levels. The turbidity levels were turbidity values representing ranges of all the turbidities of raw water collected in specific objective one. Randomly selected turbidity levels were 5NTU, 10NTU, 20NTU, 40NTU, 60NTU, 80NTU, 100NTU and 120NTU

3.4.2 Preparation of a synthetic turbid water

Different clay soil masses in (g) were dissolved in 1 L of distilled water to create synthetic turbid water. To achieve a homogeneous dispersion of clay particles, clay soil suspension was re-suspended by quick mechanical agitation, or stirring (300 rpm) for five minutes in a jar test device, followed by 30 minutes of gentle mixing (40 rpm) (Al-sameraiy, 2012). After that it was left to settle for 10 minutes. Turbidity of the supernatant liquors was measured in accordance with (ISO 7027, 2016) and quantified in nephelometric turbidity unit (NTU) and average turbidity readings were recorded and plotted against the clay soil concentration in grams per liter (g/L). A linear equation was fitted to the obtained experimental data, correlation coefficient, (R^2) was determined. A linear model equation was generated and used to prepare levels of synthetic turbid water. These levels included turbidity values randomly selected within the boundary of all turbidity values in objective one. Turbidity-concentration regression is shown in **Figure 3-1** below obtained using results in **(Table 3-1)** collected from experiments.

Table 3-1:Synthetic turbidities used in generation of the regression equation

S/No.	Concentration of clay soil(g)	Measured turbidity (NTU)	S/No.	Concentration of clay soil(g)	Measured turbidity (NTU)
1	0.09	0	26	1.05	81
2	0.1	2	27	1.15	82.6
3	0.15	4	28	1.2	99
4	0.18	4	29	1.25	101.6
5	0.2	4.8	30	1.3	107
6	0.25	5	31	1.35	113
7	0.27	5.5	32	1.4	119
8	0.3	9.8	33	1.45	122
9	0.35	12.3	34	1.5	123.5
10	0.4	17	35	1.55	124
11	0.45	21	36	1.7	128
12	0.48	21	37	1.75	132
13	0.5	25	38	1.85	165
14	0.55	33	39	1.9	190
15	0.6	38	40	2	193
16	0.65	42	41	2.05	193
17	0.68	42.8	42	2.08	194
18	0.7	44.3	43	2.09	195
19	0.75	47.5	44	2.11	198
20	0.8	58	45	2.12	199.8
21	0.85	61	46	2.2	204
22	0.87	61.5	47	2.25	206
23	0.9	63	48	2.27	207
24	0.95	99	49	2.29	209
25	1	77	50	2.3	213

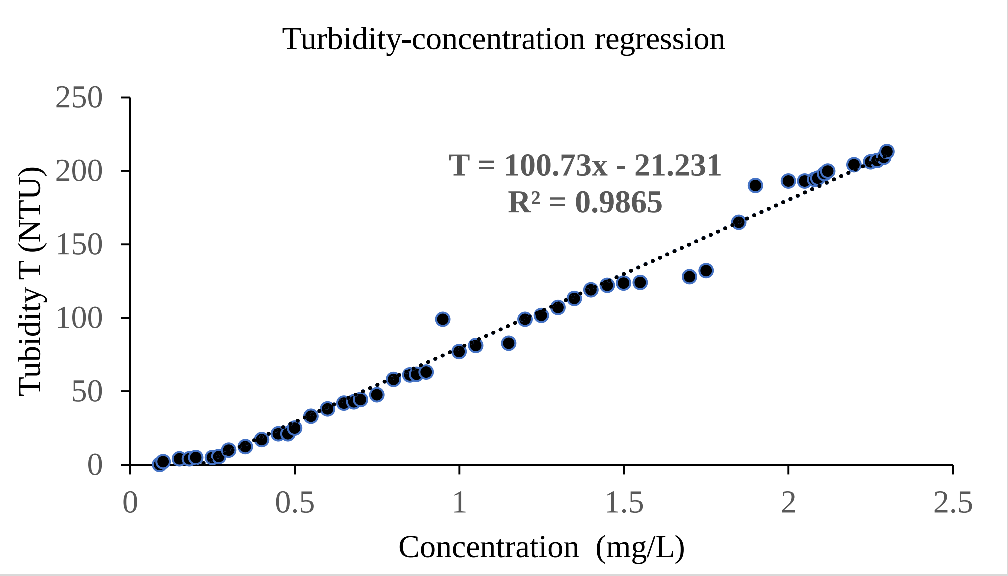


Figure 3-1:Turbidity-concentration regression chart

The regression equation developed in **Figure 3-1** was used to prepare synthetic turbid water of levels randomly selected as 5NTU, 10NTU, 20NTU, 40NTU, 60NTU, 80NTU,100NTU and 120NTU. A regression Equation 3-3 was generated.

$T = 100.73x - 21.231$………………………………………………………... Equation 3-3

T- Turbidity, x- Mass of clay dissolved

3.4.3 Detailed design of the filter

i) **Filter box:** The prototype filter box was fabricated with overall filter depth of 1.7m and an internal effective length of 0.3m by 0.3m opened to atmospheric pressure just like a conventional slow sand filter.

ii) **Underdrain:** The configuration consisted of perforated drain pipes in a matrix with gravel to collect the filtrate which is then drawn by a valve system for sampling and testing

iii) **Filter Media:** Sand was used as the filtration media. The effective size (ES) and Uniformity Coefficient (UC) of sand were determined by sieve analysis and results are summarized in **Table 3-2** below.

Table 3-2:Summary of design criteria

Design Criteria	Standard recommended limits	System values
Hydraulic loading rate	0.1 to 0.2 m^3/h	Determined from pilot experiments (see **Table 4-14)**
Depth of filter sand	0.6 to 1.4 m	0.4 to 1.15m
Specification of sand:		
a. Effective size	(0.15 to 0.35) mm	0.18 to 0.30mm
b. Uniformity coefficient	$1.5 \geq U_c \leq 3$	1.8
Height of underdrain including gravel layer	(0.2 to 0.5) m	0.2m

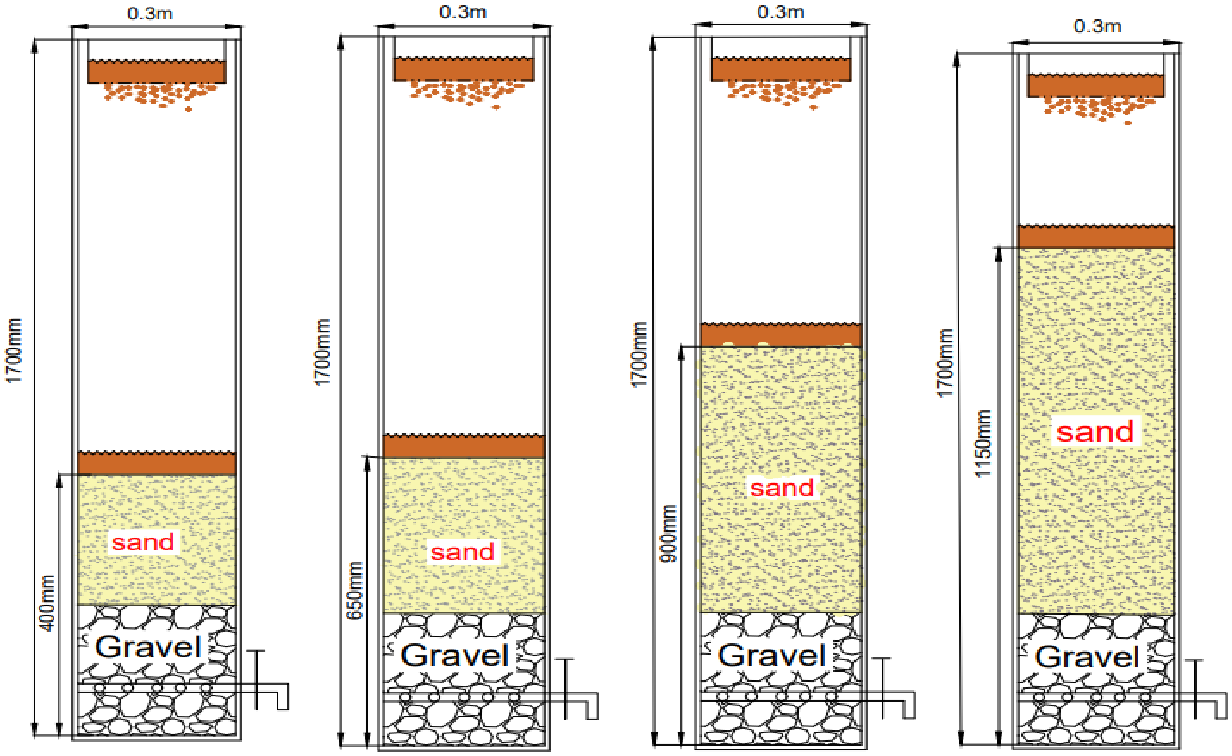
Source: (IS, 1990; MWE, 2013).

3.4.4 Prototype set up

A 0.3m by 0.3m and 1.7m high prototype filters were fabricated by a local welding shop in Bukasa Kirinya Kampala. These filters were fitted with adjustable valve systems that ensure an outlet filter control as well as draining of the filtered water.

3.4.5 Filter media arrangement

Previously washed gravel and sand were parked in batch boxes of dimensions 0.3m by 0.3m by 0.3m shown in **Figure 3-2**. The batch boxes were fabricated with length and with dimensions similar to those of the prototype filter units to ease quantification before filter media placing in the filter boxes. Prior to the experiments, the filter media was washed for three days to further eliminate possible impurities.



Set up 1 **Set up 2** **Set up 3** **Set up 4**

Figure 3-3:Filter depth arrangement set ups

3.4.6 Pilot experiments on system hydraulics

i) **Flow Rates**: Pilot testing on the raw water to be filtered was conducted to establish the suitability of slow sand to establish the maximum allowable flow rate. Flow rates were determined from pilot experiments.

ii) **Filtration-rate Regulation**: Filtration rate may be regulated either at the inlet (inlet control) or at the outlet (outlet control). Outlet control maybe adopted where it will not be difficult to provide daily flow regulation. The later will therefore be adopted.

3.4.7 Depth vs flow rate determination

To determine the flow rate for each sand depth, various pilot experiments were carried out considering the highest level of synthetic turbidity water (120 NTU) in the steps described below;

i) In all the prototype set ups, synthetic turbid water of 120 NTU was introduced in batches

ii) The outlet valves were varied to discharge at a certain rate

iii) Filtrates were drawn to fill a 1litre container and the time taken for each sand depth recorded. The filtrates were thereafter examined for turbidity to ascertain the level of turbidity removal achieved at a particular outlet valve and sand depth in accordance with (ISO 7027, 2016).

iv) The experiment at a given flow regulations were independently terminated when the set ups started producing turbidities of ranges within the WHO standards mainly for higher sand depth set ups. While for lower sand depth set ups, the experiments were terminated when the turbidity values examined from preceding valve regulations returned very closely related or constant values of turbidity on examinations.

v) Procedures i to iv were repeated for different decreasing magnitudes of outflow at the outlet valve

3.4.7.1 Treatment of results from pilot experiments

Variables captured from the experiment have been presented in **(Table 4-14) (**attached to analysis section of this report) and summarized in **(Table 4-13)** under analysis. This included time taken to draw 1litre of filtrates for every outflow regulation, turbidity of filtrates. Hydraulic loading rates and volumetric flow rates were calculated from formulas below;

Volumetric flow rate Q= Volume collected (1L)(V) /Time taken(t) in seconds

$\mathrm{Q} = \frac{\mathrm{V}}{\mathrm{t}}$ ………………………………………………………………… Equation 3-4

Hydraulic loading rate v=Q(m$^{3)}$/Area(A) m^2

$\mathrm{Q} = \frac{\mathrm{Q}}{\mathrm{A}}$ ……………………………………………………………… Equation 3-5

3.4.8 Actual study experiments for Sand depth optimization

The aim of the experiments was to optimize the most effective sand depth for all the synthetic turbidity levels. Experiments were executed following the previously determined hydraulics findings in the pilot study that aimed at determining flow characteristics. For the actual experiment, flow characteristics of pilot experiment three was judged to be the most appropriate because it was at that experiment that the resultant turbidity values in the lower filter media depth started to remain constant and the hydraulic loading rate was within the recommended standards in the deeper filter media setups as per that particular outlet valve adjustment (IS, 1990; MWE, 2013). Following the four prototype set ups 1,2,3 and 4, every synthetic turbidity level prepared was filtered in all the four varying sand depths in three triplicate experiments and results was examined in the laboratory in accordance with (ISO 7027, 2016).

3.4.9 Efficiency of sand depth setups in removing turbidity

The extent of change in water quality parameters investigated which indicates the level of treatment achieved using the existing system was deduced using **(Equation** 3-6**)** below;

$$\text{Efficiency} = \left(\frac{\mathrm{T_s} - \mathrm{T_m}}{\mathrm{T_s}}\right) * 100\% \text{ ………………………………………………. Equation 3-6}$$

Where; $\mathrm{T_s}$ is a specific synthetic turbidity level and $\mathrm{T_m}$ is mean Synthetic turbidity after filtration

3.4.10 Statistical and analytical Methods

The experimental data collected was analyzed using the application such as Microsoft Excel statistical analysis was carried out to find the mean, standard deviation and ranges of values which were compared with required standards summarized in tables in analysis section.

3.4.11 Determination of the optimal sand depth and costs

Several models were fitted into determine the best Microsoft excel model. These various models were in the form of exponential, logarithmic, linear and polynomial equations summarized in (**Table 3-3)**. The model performance was assessed through Mean Squared Error (MSE) and the cost of sand to achieve the required 5NTU based on WHO 2014 guideline for turbidity as summarized in **appendix 2.**

The sand depth that yielded a turbidity value of 5 NTU was computed based on the model and by considering 120 NTU, the model equations were used in the optimization of filter medium depths before deciding on the best model. The costs of the sand medium for various filter depths and optimal depth were computed by application of the principle of dimensional analysis and similarity which relates the dimensions and geometry of the model to that of the prototype in terms of length, area and volume scale ratios to scale up the corresponding cost of various medium depths to that of the actual plant. The market survey showed that the cost of filter sand per ton is Uganda shillings UGX 50,000.00

Table 3-3: Model equations generated for determination of optimal sand depth (y)

Model	Model Form	Model Equation
Exponential	$y = Ae^{Bx}$	y = 26.4848e-0.0023x
Logarithmic	y =A*Ln(x)+B	y = -8.111ln(x) + 58.784
Linear	y =Ax+B	y = -0.0113x + 14.2
Polynomial (2)	$y = Ax^2+Bx+C$	y = 9E-06x2 - 0.0258x + 19.077

3.5 Applicability of natural zeolite in removal of lead from drinking water

To achieve this objective, certain analytical methods and equipment discussed subsequently were used in characterization, preparation of natural zeolite, preparation of test water solution, adsorption experiment and data analysis.

3.5.1 Materials

3.5.1.1 Reagents and solvents

i) Natural zeolite,
ii) Hydrochloric acid (37% Assay, analytical reagent),
iii) Sodium hydroxide (99.95%, analytical reagent),
iv) Lead (II) nitrate (analytical reagent), and
v) Deionized water obtained from Labtech Uganda Ltd.

3.5.1.2 Equipment

i) UV-visible spectrophotometer (Genesys10S),
ii) pH meter (Consort C6010),
iii) Deionized water,
iv) Analytical weighing balance,
v) Programmable oven,
vi) Electrochemical analyzer and muffle furnace (FHP-O3**),**
vii) Ceramic crucibles,
viii) Standard test sieve (0.4-1mm particle size),
ix) Water bath,
x) Glass beakers, and
xi) volumetric flasks (250ml, 100ml, 500ml).

3.5.2 Methods

3.5.2.1 Preparation and characterization of natural zeolite

Natural zeolite samples were extracted from Eastern Uganda, Mbale district particularly Wanale sub-county in the regions of Mt. Elgon. Varying pieces in size of natural zeolite were crushed first by using a hammer mill to a mesh size of <500 mm then followed by dry milling using a ball mill (PM100, Retsch corporation), rotating at 650 rpm for 3 minutes with ball to powder ratio of 2:3 up to a mesh size 75 µm. No chemicals were added to this zeolite.

3.5.2.2 Determination of Metal Oxides (Silica and Alumina)

In a 100 ml beaker, 1g of zeolite was weighed for each sample, it was then mixed with 10 cm^3 of strong hydrochloric acid and dried in a fume hood using an electric hotplate. 30 cm^3 of distilled water and an additional 6 cm^3 of acid were added, respectively. The liquid was then heated to boiling point. The hot solution was filtered through ash-less filter paper, the precipitate was rinsed with 30 cm^3 of hot distilled water and the filtrate was preserved to estimate the iron and aluminum. The precipitate and filter paper were transferred to a clean and weighed crucible. The crucible and its contents were burned to 800°C for 50 minutes and the crucible was let to cool in the dryer and weighed. Calculations were as follows

Percentage of silicon oxide = $\frac{Weight\ of\ SiO_2}{Weight\ of\ sample} \times 100\%$ ……………….. Equation 3-7

3.5.2.3 Determination of mixed oxides (Al_2O_3 & Fe_2O_3)

The filtrate left after precipitation of silica was diluted to around 200ml in a beaker; It was heated to boiling after adding 2g of ammonium chloride and a few drops of methyl red indicator. The color was gradually turned yellow by the use of ammonia solution. Ten minutes were given for the beaker. The solution was filtered through ash-free filter paper, and 2% ammonium nitrate solution was used to wash the precipitate and filter paper. A clean, weighted crucible was used to hold the precipitate and filter paper. 50 minutes were spent burning the crucible and its contents at 800°C. After cooling in the dryer, the crucible was weighted to calculate the mixed oxides.

3.5.2.4 Ferric oxide percentage

5 cm^3 of strong hydrochloric acid was poured to a 100 ml beaker containing about 1g of zeolite. The solution was accurately transferred to a 100 ml volumetric flask, then poured into a beaker

and allowed to settle after being carefully directed until the green color was disappeared. A volumetric flask was filled with 20ml of the clear solution, 5ml of buffer solution, and 1ml of salicylic acid. The mixture was then titrated till the end point against a standard EDTA solution (0.01M). The titration was repeated until two successive readings were consistent. The number of moles and weight in grams were computed from the titration, and the percentage was then computed. As a point of comparison, the same digested solution was also analyzed for iron using a UV visible spectrophotometer, with the results expressed as a percentage of ferric oxide.

3.5.2.5 Aluminum oxide percentage

This was calculated as the difference;

Aluminum oxide percentage = Combined oxides percentage – Ferric oxide percentage.

The ratio of Si:Al was then further computed from the resulting percentages of the respective oxides.

3.5.2.6 Measuring porosity of natural zeolite

Porosity was determined by water displacement method, about 10g of crushed zeolite was measured into falcon tubes in triplicate, about 10ml of deionized water was added to each and gently shaken then left to stand for 24hrs, the displaced volume of air was then determined and the result determined as percentage porosity.

3.5.2.7 Determination of pH of natural zeolite

A known volume of sample after the determination of porosity was used, a pH meter (Consort C6010) was first calibrated using pH 4 and 7 standards and then the probe was dipped in a well agitated water bearing sample of natural zeolite and the resultant pH value recorded in triplicate. The pH of the deionized water used was also determined for comparison.

3.5.2.8 Determination of thermal stability of natural zeolite

About 2g of the zeolite powder was weighed into two different ceramic crucibles, which were then subjected to different temperatures from 200 - 800℃ while weighing after every 1 hour of residence time, the loss in weight was then determined.

3.5.2.9 Preparation and standardization of the Lead test water solution

Samples were prepared by weighing 100mg lead (II) nitrate and dissolved in 1000ml of deionized water. Sample solutions were prepared using a micropipette and were then measured using UV spectroscopy immediately after the sample preparation process. Five calibrations standards of lead ranging from 10 mg/L to 50 mg/L were prepared for preliminary calibration of the spectrophotometer. A quartz cuvette with path length 1 cm was used as the sample container. For every sample, measurement was carried out at 205nm, 211nm and 215nm then the cuvettes were washed thoroughly with distilled water to prevent any left over from previous sample. Both the spectrometer and deuterium lamp were warmed up for at least 30 minutes before starting the measurement. The final concentration of lead in each test solution was then calculated following a method developed by (Tan *et al.*, 2014), using the (**Equation 3-8)** below;

$C_{Pb} = -9.47D_{205} + 18.3D_{211} + 26.4D_{215} + 0.0092$ …………………. Equation 3-9

C_{Pb} – Concentration of lead

3.5.2.10 Computation for removal of Lead ions

The removal was calculated as a percentage of the difference between the initial and final concentrations of lead in the solution before and after adsorption as shown by the (**Equation 3-10)** below. Microsoft excel was used to compute the % removal, averages, standard deviation and performed a student T test to compare the significance of differences.

Removal = $\frac{i_1 - i_2}{i_1} \times 100\%$ …………………………………………………….. Equation 3- 10

Where:

i_1 is initial value of lead concentration

i_2 is the final value of lead concentration

3.5.2.11 Modification of natural zeolite

Crushed natural zeolite was modified based on approach provided in Yong et al. (2021)

CHARPTER FOUR: RESULTS AND DISCUSSION

4.1 Comparison of observed water quality parameters against WHO guidelines

4.1.1 Turbidity

Figure 4-1 shows turbidity before and after treatment. Figure 4-1a shows the ranges of turbidity for the various months before and after filtration. The highest turbidity value was obtained in April. The maximum turbidity values in February and May were 28 NTU. The highest value in April was due to the high rainfall intensities. For all the months, the maximum turbidity values were above the (WHO, 2014) limit **(Table 4-1)**. Thus, treatment was needed to bring the turbidity values below the (WHO 2014) limit. It was only in February that the minimum value was below the (WHO, 2014) limit. This was because February is in a dry season.

In **Figure 4-1b**, results are for comparison of mean turbidity values before and after filtration. The purpose of filtration was to reduce the turbidity to levels below the (WHO, 2014) limit. It is noticeable that the turbidity values in March, April and May (rainy season) were reduced by 45.08%, 60.42%, and 44.08% respectively **(Table 4-2)**. However, the percentage reduction was not substantial. Thus, the turbidity levels were all above the WHO, (2014) limit and this indicates that the sand filtration system was not satisfactorily functioning. In February, the mean turbidity value was reduced by 51.66% **(Table 4-2)** to a value within the acceptable limit however the standard deviation still indicated that there were instances when the WHO, (2014) limits were exceeded. The reduction below the limit in February was because February was a dry season as already seen in **Figure 4-1a**.

The general rise to peak and fall for turbidity before, during and after the rainy season can be related to impact of precipitation on the turbidity of surface water (Bastaraud *et al.*, 2020); Mujere and Moyce, 2018). The mean turbidity values for months that were outside WHO limits relates to results from other studies all over Uganda such as Bwire *et al*. (2020) where turbidity values were 100% outside WHO limits. The mean value for February within the WHO limits is comparable to turbidities of some springs in the proximity of Kyambogo in Kampala (Omara *et al.*, 2019). Mean turbidity values for March to May were beyond those recommended for drinking water (WHO, 2014).

Table 4-1:Overview of turbidity

Before filtration						After filtration			
WHO Standards 5 NTU									
		Min	Max	Mean ± SD	CV%	Min	Max	Mean ± SD	CV%
Period	Feb	3	28	9.61 ± 6.41	66.72	1.00	11	4.65 ± 2.55	54.90
	Mar	9	38	19.14 ± 6.41	38.28	6.00	17	10.51 ± 2.81	26.70
	April	11	103	44.19 ± 29.72	67.25	7.00	48	17.49 ± 11.67	66.71
	May	11	28	15.25 ± 4.00	26.20	6.00	13	8.53 ± 1.54	18.05

Table 4-2:Percentage change in min, max and mean turbidity values after treatment

Period	Min change (%)	Max change(%)	Mean change(%)
Feb	66.67	60.71	51.66
Mar	33.33	55.26	45.08
April	36.36	53.40	60.42
May	45.45	53.57	44.08

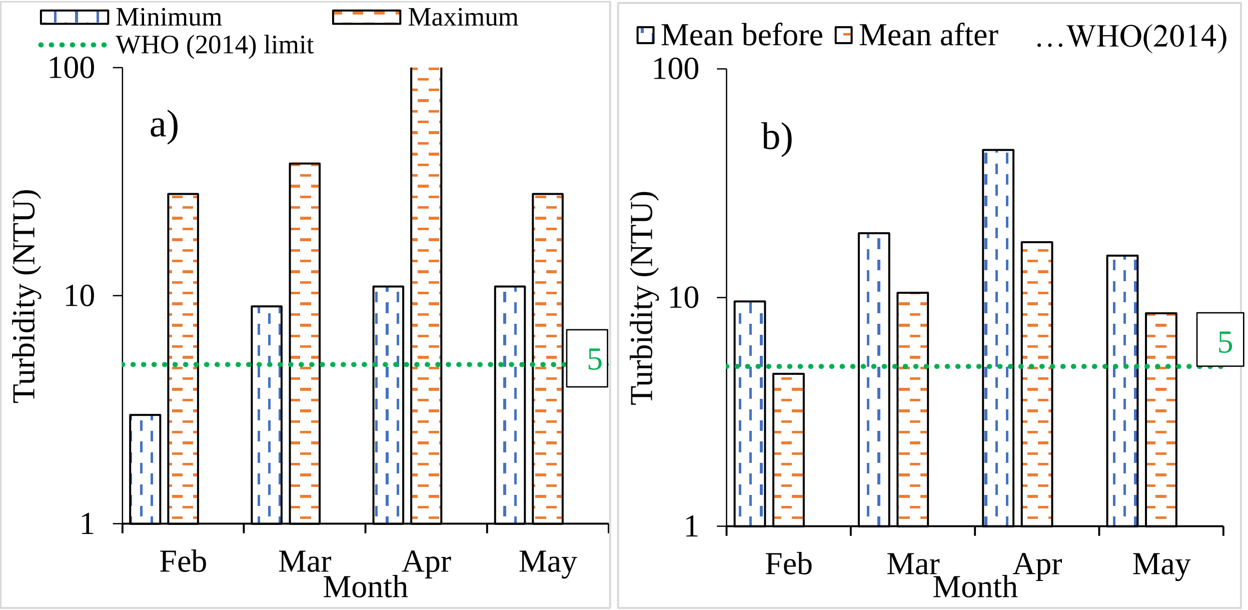


Figure 4-1:Min and Max turbidity of raw samples and mean before and after treatment

4.2.2 Colour

Figure 4-2 shows the results of colour before and after treatment. Figure 4-2a shows the ranges of colour for the sampling period before and after filtration. The highest colour value (considering the metric maximum was obtained in April **(Table 4-3)**. The maximum colour values in February, March and May were comparable. The highest value in April was due to the high rainfall intensities. For all the months, the maximum colour values were above the WHO, (2014) limit of 15TCU. Thus, treatment was needed to bring the colour values below the WHO (2014) limit. It was only in February that the minimum value was below the (WHO, 2014) limit. This was because February is in a dry season.

Figure 4-2b shows the comparison of mean colour values before and after filtration. The purpose of filtration was to reduce the colour to levels below the (WHO, 2014) limit. It is noticeable that the colour values in March, April and May (rainy season) were reduced by 62.41%, 62.99%, and 62.58% respectively **(Table 4-4)**. However, the percentage reduction was not substantial. Thus, the colour levels were all above the WHO, (2014) limit and this indicates that the sand filtration system was not satisfactorily functioning in removing colour. In February, the mean colour value was reduced by 70.52% **(Table 4-4)** to a value (13.56**)** within the acceptable limit. The reduction below the limit in February was because February was a dry season.

The fluctuations in colour values is because the rainy season characterized by high levels of transported and deposited contaminants (Mujere and Moyce, 2018). The results for colour was within the range of colour from a related study in Mbarara municipality Uganda (Atwebembeire *et al.*, 2018)

Table 4-3:Over view of water colour

		Before filtration				After filtration			
		WHO Standards 15 (TCU)							
		Min	Max	Mean ± SD	CV%	Min	Max	Mean ± SD	CV%
Period	Feb	15	100	46.00 ± 21.96	47.75	8.00	18	13.56 ± 2.69	19.85
	Mar	60	417	184.44 ± 98.17	53.22	15.00	158	69.33 ± 2.69	47.08
	April	100	1578	492.56 ± 394.80	80.15	15.00	1264	182.32 ± 2.69	135.64
	May	51	318	73.94 ± 14.63	19.78	11.00	69	27.67 ± 2.69	47.17

Table 4-4:Percentage change in min, max and mean colour values after treatment

		Min change (%)	**Max change(%)**	**Mean change(%)**
Period	Feb	46.67	82.00	70.52
	Mar	75.00	62.11	62.41
	April	85.00	19.90	62.99
	May	78.43	78.30	62.58

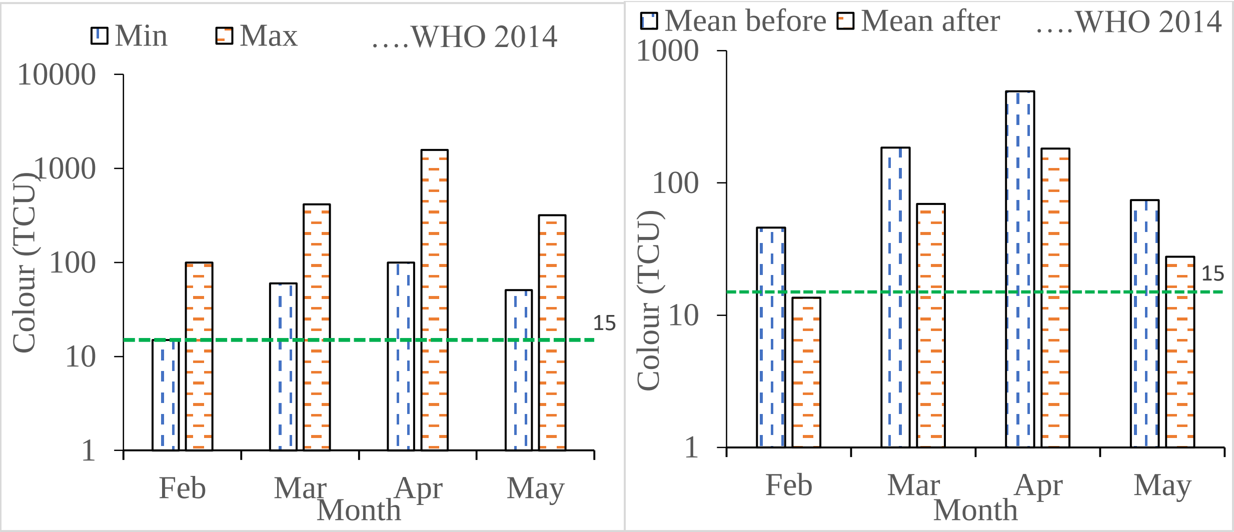


Figure 4-2:Min and max of raw samples and mean values before and after treatment

4.3 Testing null hypothesis H_0 (system is not performing)

a) Z and *t* statistics tests

i. Z and *t* tests for every month of sampling before and after sampling

Table 4-5: Z - tests values with corresponding *p* - values for every month

		Z- test Two (2) sample mean test			
Parameter		**Turbidity**		**Color**	
		Z- value	*p* - value	*Z*- value	*p* – value
Period	Feb	4.0083	6.11E-05	8.2708	2.22E-16
	Mar	7.2103	5.56E-13	7.2968	2.94E-13
	Apr	5.4835	4.35E-08	4.3197	1.56E-05
	May	9.4207	0.E+00	0.8880	4.0E-01

Table 4-6: Student t - test values with corresponding *p* - values for every month

		Student t- test Two (2) sample mean test			
Parameter		**Alkalinity**		**Hardness**	
		t - value	*p* – value	*t* - value	*p* – value
Period	Feb	1.4142	0.2302	-0.3906	0.7160
	Mar	-2.800	0.038	-8.4853	0.0004
	Apr	0.9215	0.3923	-0.1745	0.8672
	May	-4.2164	0.0135	-3.1623	0.0341

ii. Z and t statistics tests for the whole data before and after sampling

Table 4-7:Z - tests values with corresponding *p* - values for combined data

	Z- test- Two (2) sample mean test			
Parameter	**Turbidity**		**Color**	
	Z- value	*p* – value	*Z*- value	*p* – value
Feb-May	6.8172	9.3E-12	5.3136	1.1E-07

Table 4-8: Student t- test values with corresponding *p* - values for combined data

	Student t- test Two (2) sample mean test			
Parameter	**Alkalinity**		**Hardness**	
	t – value	*p* – value	*t* – value	*p* – value
Feb-May	-1.5229	0.1420	-3.1617	0.0045

b) ANOVA

Table 4-9: *p* - value of ANOVA one way for the data samples

	ANOVA F test							
Parameter	**Turbidity**		**Color**		**Alkalinity**		**Hardness**	
	Before	After	Before	After	Before	After	Before	After
	p - value		*p* - value		*p* - value		*p* – value	
Feb-May	1.47E-16	1.67E-13	2.74E-17	6.17E-08	0.0066	0.0752	0.0564	0.0858

The significant p value for all test categories was ($p \geq 0.05$). Both Z test and student t statistics test for the monthly samples were below the significant p - value **(Table 4-5, Table 4-6)**. Z test and student t statistics test for combined data were also below the significant p - value **(Table 4-7, Table 4-8).** A one-way ANOVA as well returned a p - value below the significant p - value

(Table 4-9). The null hypotheses H_0 (system is not performing) can therefore be rejected. In other words, the filtration system is working for turbidity and colour removal and the level of effectiveness is analysed below.

4.4 Case specific System effectiveness

Referring to collected data, the system effectiveness ($E(\%)$) for every month of sampling was arrived at by observing the number of times the specific parameters exceeded the WHO standards and the total number of samples analysed in a given month.

Table 4-10: Summary of system effectiveness

Period	Turbidity			Color		
	X_1NTU)	X_2(NTU)	E(%)	X_1 (TCU)	X_2(TCU)	E(%)
February	8	31	26	3	31	10
March	0	43	0	1	43	2
April	0	43	0	1	43	2
May	0	36	0	7	36	19

4.5 Investigation on heavy metals

4.5.1 Overview of selected heavy metal investigation

From the summary below **(Table 4-11**), arsenic, lead, zinc manganese and cadmium are all above the quoted maximum value for the world health organization for portable water (Ahmed *et al.*, 2021).This therefore calls for treatment options to lower the concentration of the mentioned heavy metals below the required values for consumption. Chromium, copper and iron are all below the recommended WHO maximum values while cobalt has no limits values quoted.

Table 4-11: Laboratory results for investigated heavy metals against standards

Parameter	Result	WHO standard	EAC standard	Uganda standard
As(Mg/l)	0.26	0.010	0.010	0.010
Pb(Mg/l)	0.30	0.010	0.010	0.010
Zn(Mg/l)	4.82	3.000	5.000	5.000
Mn(Mg/l)	3.25	0.100	0.100	0.100
Cd(Mg/l)	0.08	0.003	0.003	0.003
Cr(Mg/l)	0.02	0.050	0.050	0.050
Co(Mg/l)	0.050	-	-	-
Cu(Mg/l)	0.26	2.000	1.000	1.000
Fe(Mg/l)	0.21	0.300	0.300	0.300

4.5.2 Removal of lead ions by slow sand filtration

In **(Table 4-12)**, summaries of the pattern of concentration of lead ions present before and after filtration were drawn. The average values from triplicate test experiments are clearly inconsistent. In other related studies however, removal of heavy metals was found to be effective at high filter media depths (Barkouch *et al.*, 2019) and type or origin of sand filter media used (Jumean, Pappalardo and Abdo, 2010). A student t test used to evaluate the system performance with a null hypothesis H_0 (There is no significant difference in the concentration of lead ions before and after filtration) at a significant *p* - value $p \leq 0.05$ returned a value $p = 0.474$. There was therefore significant difference in a non-coordinated pattern in the concentration of lead ions.

Table 4-12: Concentration of lead ions before and after treatment of water

Sample ID	Sample No	conc. Pb(mg/l)	Average (mg/l)	sample ID	sample No	conc. Pb(mg/l)	Average (mg/l)
D_1	S_1	13.641	13.767	F_1	S_1	16.785	16.806
	S_2	13.827			S_2	16.994	
	S_3	13.834			S_3	16.648	
D_2	S_1	15.004	14.167	F_2	S_1	19.059	19.089
	S_2	13.795			S_2	19.113	
	S_3	13.703			S_3	19.124	
D_3	S_1	16.153	16.119	F_3	S_1	17.668	17.639
	S_2	16.150			S_2	17.623	
	S_3	16.052			S_3	17.606	
D_4	S_1	20.337	20.183	F_4	S_1	19.060	19.039
	S_2	19.986			S_2	19.034	
	S_3	20.228			S_3	19.025	
D_5	S_1	17.129	17.201	F_5	S_1	14.354	14.337
	S_2	17.229			S_2	14.345	
	S_3	17.246			S_3	14.039	

D_x -Samples before treatment

S_{x} - Sample labeling during experiments

F_x- Samples after treatment

4.6 Filter media depth optimization

4.6.1 Overview of waiting time and flow rates from pilot experiments

Figure 4-3 shows the relationship between sand media depth, average waiting time and average flow rate. In **Figure 4-3a**, the waiting time increases with depth. With similar valve regulations, depths of 0.4m, 0.65m, 0.90m and 1.15 required average waiting times of 69.2, 88.0, 142.8 and 154.4 seconds respectively. Depths 0.9m and 1.15m had the longest waiting time but produced filtered water with turbidities within the acceptable range **(Table 4-14)** in accordance with WHO, (2014) standards. More filtration contact time increases physical and biological treatment mechanisms. The 0.4m and 0.65m sand depths had shorter waiting times to draw 1 litre of filtered water. The shorter path within the filter media reduces the contact time used by turbid water to undergo physical and biological treatment mechanisms with the filter media.

In **Figure 4-1b** the volumetric flow rate decreases with increase in depth. The 0.4m and 0.65m depth have higher flow rates indicating reduced cost in time. However, treated water at these flow rates have resultant turbidities outside WHO, (2014) standards. The 0.9m and 1.15m depth have lower flow rates but with resultant turbidity values within the recommended WHO standards.

Table 4-13:Overview of waiting time and flow rates and various flow depths

	Sand media depth (mm)											
	400			650			900			1150		
	Max	Min	Mean± SD	Max	Min	Mean± SD	Max	Min	Mean± SD	Max	Min	Mean± SD
Time (t) (s)	98	40	69.2±24.5	120	60	88.0±23.5	192	66	142.8±57.2	200	78	154.4±52.2
Flow (Q) (m^3/s)	0.09	0.04	0.06±0.02	0.06	0.030	0.04±0.01	0.05	0.02	0.03±0.02	0.05	0.02	0.03±0.01

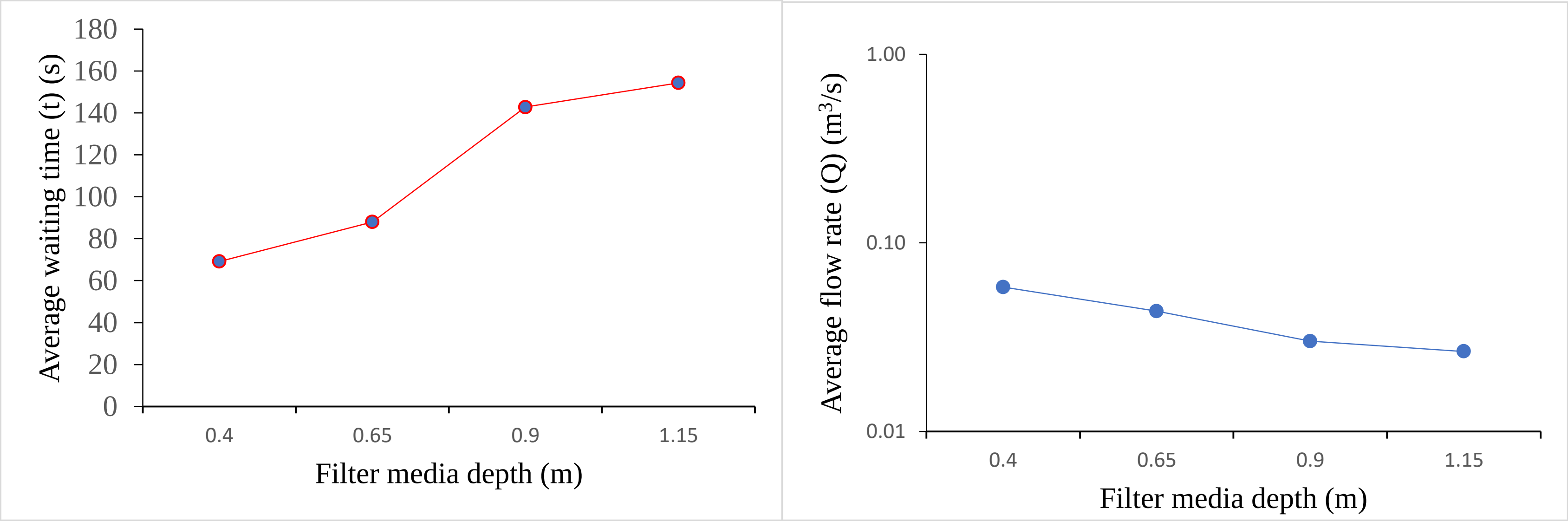


Figure 4-3:Variation of filter depth (m) with a) waiting time b) flow rate(m3/s)

Table 4-14:Variation of filter depth with flow rate, hydraulic loading rate and turbidity

	Sand media depth (mm)															
	1150				900				650				400			
S/N	T (s)	Q (m^3/s)	v ($m^3/h/m^2$)	ATV (NTU)	T (s)	Q (m^3/s)	v ($m^3/h/m^2$)	ATV (NTU)	T (s)	Q (m^3/s)	v ($m^3/h/m^2$)	ATV (NTU)	T (s)	Q (m^3/s)	v ($m^3/h/m^2$)	ATV (NTU)
1	78	0.05	0.51	3	66	0.05	0.61	4	60	0.06	0.67	10	40	0.09	1.00	12
2	120	0.03	0.33	2	98	0.04	0.41	3	72	0.05	0.56	8	50	0.07	0.80	10
3	180	0.02	0.22	2	170	0.02	0.24	3	88	0.04	0.45	7	70	0.05	0.57	10
4	194	0.02	0.21	1	188	0.02	0.21	2	100	0.04	0.40	7	88	0.04	0.45	10
5	200	0.02	0.20	1	192	0.02	0.21	1	120	0.03	0.33	7	98	0.04	0.41	9
T-Time, Q-Volumetric flow rate, v- Hydraulic loading rate, ATV- Average Turbidity Value																

4.6.2 Removal of turbidity

Figure 4-4 shows the efficiency of turbidity removal with the variation of filter media depth. In Figure 4-4a the highest turbidity values after filtration were obtained from the 0.4m and 0.65m sand depth filters with mean removal efficiencies of 81.8% and 85.7% respectively **(Table 4-14)**. The maximum turbidity values in the 0.9m and 1.15 m sand depth filters were below WHO, (2014) with mean removal efficiencies of 90.5% and 93.7% respectively **(Table 4-14)**.

In Figure 4-4b, resultant turbidity values were compared with the WHO, (2014) standards. Filtration was meant to reduce the turbidity to levels below the WHO, (2014) limit. It is noticeable that for the 0.4m and 0.65m sand depth filter systems, some of resultant turbidity values exceeded the maximum WHO turbidity value of 5NTU which meant the percentage reduction was not substantial **(Table 4-15)**. This indicates that the 0.4m and 0.65m sand depth filter systems were not satisfactorily functioning. In the 0.9m and 1.15m sand depth systems, the resultant turbidity values were all within the acceptable limit.

The general reduction in resultant turbidity values on examination across the varying sand depths can be related to impact of increasing filter media depth on turbidity removal in slow sand filters (Ncube, Pidou and Jarvis, 2018). The mean resultant turbidity values for media depths outside WHO, (2014) limits relates to results from other studies where shallow sand depths associated with high hydraulic conductivity give shorter waiting time with filtrates outside recommended turbidity values (Takaijudin et al., 2015). The resultant mean values for deeper media depths within the WHO limits is comparable to turbidities in some past studies that looked at removal efficiencies and mechanisms in slow sand filters (Zaman *et al.*, 2014; Thomas and Kani, 2016).

Table 4-15: Overview of resultant turbidity from actual experiments

		Sand media depth (mm)											
		400			650			900			1150		
		Max	Min	Mean± SD	Max	Min	Mean± SD	Max	Min	Mean± SD	Max	Min	Mean± SD
SYTHETIC TURBIDITY LEVELS	5	2	1	1.67±0.58	2	1	1.33±0.58	2	0	1.00±1.00	1	0	0.67±0.58
	10	4	3	3.33±0.58	4	2	3.00±1.00	3	1	2.00±1.00	3	0	1.33±1.53
	20	5	4	4.33±0.58	5	3	3.67±1.16	4	2	3.00±1.00	3	0	1.67±1.53
	40	6	5	5.67±0.58	6	4	4.67±1.16	4	2	2.00±1.00	3	1	2.00±1.00
	60	9	8	8.67±0.58	6	4	5.00±1.00	4	3	3.33±0.58	4	1	2.33±1.53
	80	10	8	9.00±1.00	7	4	5.67±1.53	3	2	2.33±0.58	3	1	2.00±1.00
	100	12	9	9.33±0.58	8	5	6.33±1.53	4	2	3.00±1.00	3	2	2.33±0.58
	120	12	8	10.00±2.00	9	5	7.00±2.00	4	2	2.67±1.16	3	1	2.00±1.00

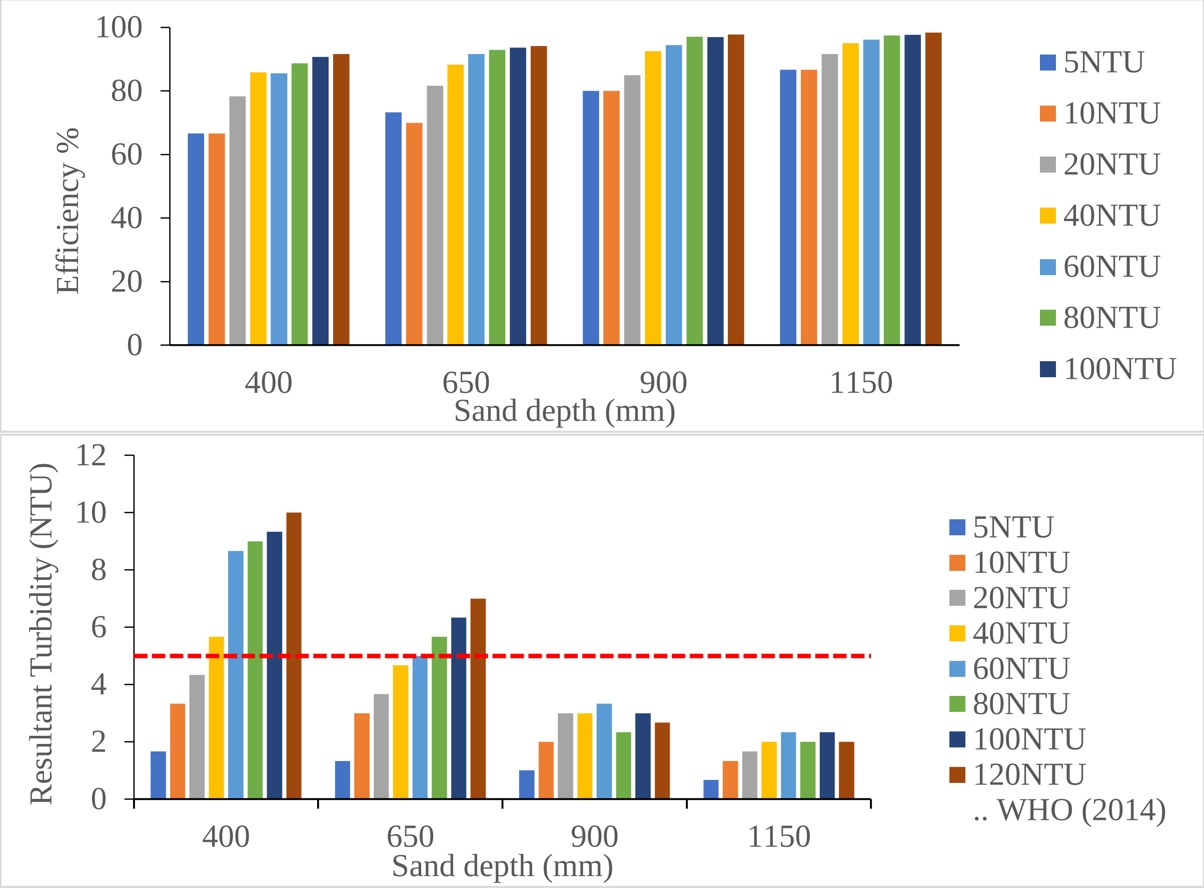


Figure 4-4:Efficiency of turbidity removal and resultant turbidity after filtration

Table 4-16: Removal efficiency (%) of synthetic turbidity by the different sand depths

ST(NTU)	400(mm)	650(mm)	900(mm)	1150(mm)
5	66.67	73.33	80.00	86.67
10	66.67	70.00	80.00	86.67
20	78.33	81.67	85.00	91.67
40	85.83	88.33	92.50	95.00
60	85.56	91.67	94.44	96.11
80	88.75	92.92	97.08	97.50
100	90.67	93.67	97.00	97.67
120	91.67	94.17	97.78	98.33
Average (%)	**81.77**	**85.72**	**90.48**	**93.70**

ST-Synthetic Turbidity

4.6.3 Optimum sand depth

Figure 4-5(a-h) shows the pattern of model equations. **(Table 4-17)** below summarizes the model equations and the depths that yielded a turbidity value of 5 NTU. The multi criteria model evaluation produced optimal sand depth that can treat turbidity even for a worst case scenario of 120NTU as 725mm, 831mm, 814mm, and 733mm for various models. Exponential model gave the optimal sand depth of 725mm based on the MSE.

Table 4-17: Model equations and corresponding optimal sand depth

Model	Model Equation	Sand depth (mm)
Exponential	y = 26.4848e-0.0023x	725
Logarithmic	y = -8.111ln(x) + 58.784	831
Linear	y = -0.0113x + 14.2	814
Polynomial (2)	y = 9E-06x2 - 0.0258x + 19.077	733

4.6.4 Scale up costs for various sand depths

Different models in terms of exponential, logarithmic, linear and polynomial functions were used to describe the variation of final turbidity after raw water filtration with sand depths. The models were assessed in terms of mean squared error (MSE) and the cost of the sand to achieve the required 5NTU based on the World Health Organization guideline for turbidity. The values of MSE for exponential, logarithmic, linear and polynomial models were 0.4758, 0.4078, 0.6535 and 0.3848, respectively. The corresponding costs of sand to achieve the optimal depth based on the models were 2,880.00, 3,300.00, 3,235.00 and 2,915.00 UGX shillings, respectively as shown in **(Table 4-18)** below.

Table 4-18: Model and prototype dimensional and similarity scale up computation

	Sand depth(mm)	Sand Volume (Cubic meter)	Sand volume (ton)	Cost (Ugx.)
Prototype Depth	400	0.0360	0.0318	1,590.00
	650	0.0585	0.0516	2,580.00
	900	0.0810	0.0715	3,575.00
	1150	0.1035	0.0914	4,570.00
Model Equations	Exponential (725)	0.0653	0.0576	2,880.00
	Logarithmic (831)	0.0748	0.0660	3,300.00
	Linear (814)	0.0733	0.0647	3,235.00
	Polynomial (733)	0.0660	0.0583	2,915.00
	Actual Plant	177.6889	156.8305	7,841,522.00

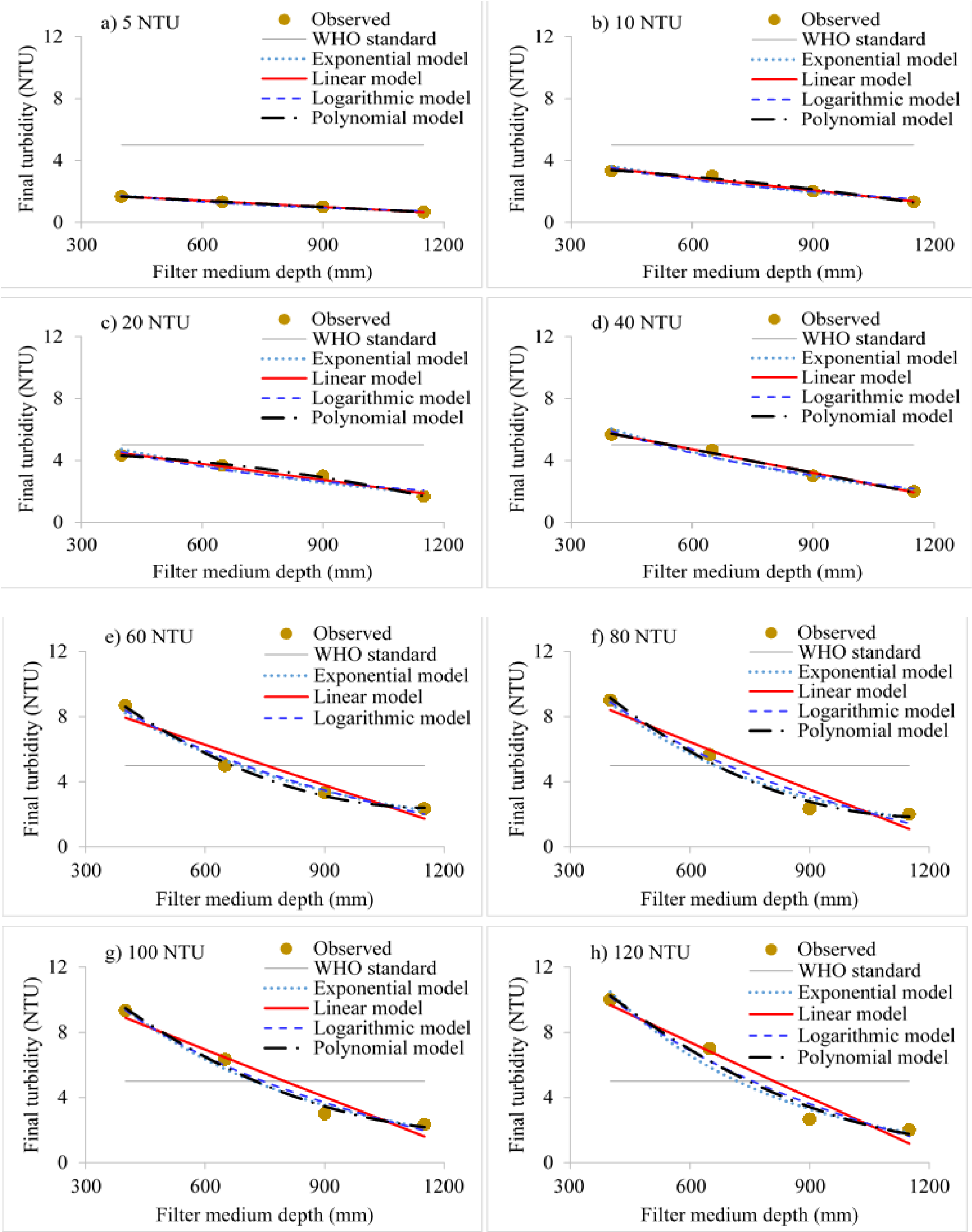


Figure 4-5:Regression graphs generated for determination of optimal sand depth

4.7 Applicability of natural Zeolite in removal of lead ions

4.7.1 Characterization results for Zeolite

The zeolite was found to have a mean pH of 8.38±0.03 **(Table 4-19)**, which implied that it was slightly alkaline and therefore also well suited for the removal of Pb-ions in solutions by adsorption. This is in agreement with a similar study by (Khan *et al.*, 2018) on adsorption of lead which noted that the process was strongly pH dependent, with adsorption increasing as pH rose. The zeolite was also found to be thermally stable up to 800℃ as shown by the fairly constant and very minimal change in weight with increasing temperature, this is of significant importance for adsorption applications that involve temperature as a variable factor, since elevated temperatures have been known to decompose inorganic materials.

Table 4-19: Laboratory results for characterization of Zeolite.

Sample ID	pH	Porosity/%	Alumina/%	Silica/%	Si:Al ratio	Thermal stability (Initial weight 2g)
Z1	8.39	40.00	33.67	43.50	1.29	200℃, 1.98g
Z2	8.40	41.00	33.00	43.00	1.30	400℃, 1.97g
Z3	8.35	40.00	33.60	43.38	1.29	600℃, 1.97g
Mean	8.38±0.03	40.33±0.58	33.42±0.37	43.29±0.26	1.30±0.01	800℃, 1.96g

4.8 Removal efficiency of lead ions by zeolite

Figure 4-6 shows the removal efficiencies of different zeolite dosages of 1,3,5 and 7 grams with contact times of 40, 60 and 80 minutes. With a contact time of 40 minutes, removal efficiencies gradually increased with increase in zeolite mass to 98% until its peaks at 5 grams and slightly drops to 95.3% for zeolite masses above 5grams **(Table 4-20)**. For contact times of 60 and 80 minutes, showed that the removal efficiency increased with increase in zeolite mass dosage.

Generally, increasing the zeolite mass increases the adsorption mechanism because as the masses are increased, a large surface area is achieved which in turn increases the accumulation of the pore surface area and canals where removal takes place. In related studies, increasing the mass of zeolite will increase cation exchange sites because of the greater surface area (Khan *et a*l., 2018).

Other studies found out that higher adsorption capacity values occurred with specific composition of natural zeolite for example higher concentration of clinoptilite and mordenite showed more effectiveness in removal of lead ions (Budianta, Ardiana and Andriyani, 2020). Results in Figure 4-6 suggests that zeolite mass of about 6grams yields an optimal condition for removal of lead ions regardless of the contact time. Further investigation is required to explain this phenomenon

Table 4-20:Removal efficiencies, corresponding zeolite dosages and contact time

	Zeolite mass dosages (g)			
Contact time (mins)	1	3	5	7
40	95.3%	97%	98%	95.3%
60	88.5%	95.5%	95.5%	96.8%
80	81.8%	90.8%	92.7%	100%

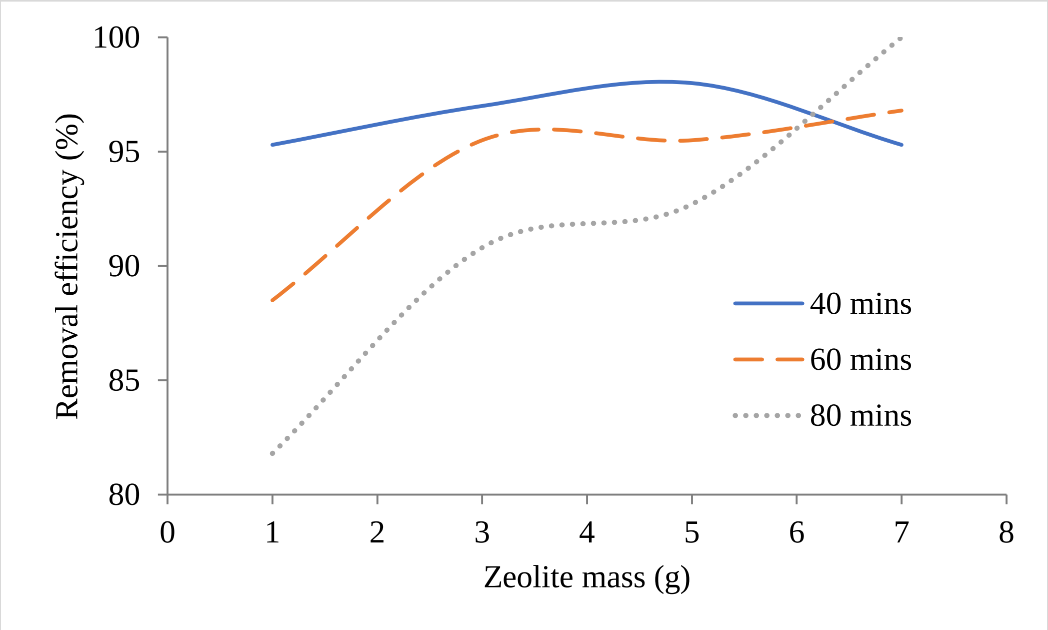


Figure 4-6: Pattern of removal efficiencies of zeolite dosages and contact time

Figure 4-7 shows the removal pattern of varied contact times of 40, 60 and 80 minutes. The trend generally showed there were higher removal efficiencies as the zeolite masses were increased at specific contact times considered in the study. A favorable condition under the studied experiment showed removal efficiencies of 95.3%, 96.8% and 100% at contact times of 40, 60 and 80 minutes respectively under a zeolite mass of 7 grams

Inin comparison to past studies done on adsorption of lead ions using zeolite at a room temperature but varying the contact time and keeping constant the other parameters such as the metal concentration, the pH of the solution and the mass of the adsorbent. The kinetics of elimination of Pb^{2+} ions is a two-step process. At the beginning of sorption at the surface sites, as well as the highest motive force for mass transfer which caused the rapid sorption of Pb^{2+} as seen in similar studies where zeolite was used to remove Cu^{2+} (Sljivic *et al.*, 2009). This rapid sorption phase was followed by a slow increase in the amount of sorbed cations due to the progressive occupation of the active sites leading to decrease in concentration of Pb^{2+} in the liquid phase (Krobba *et al.*, 2012).

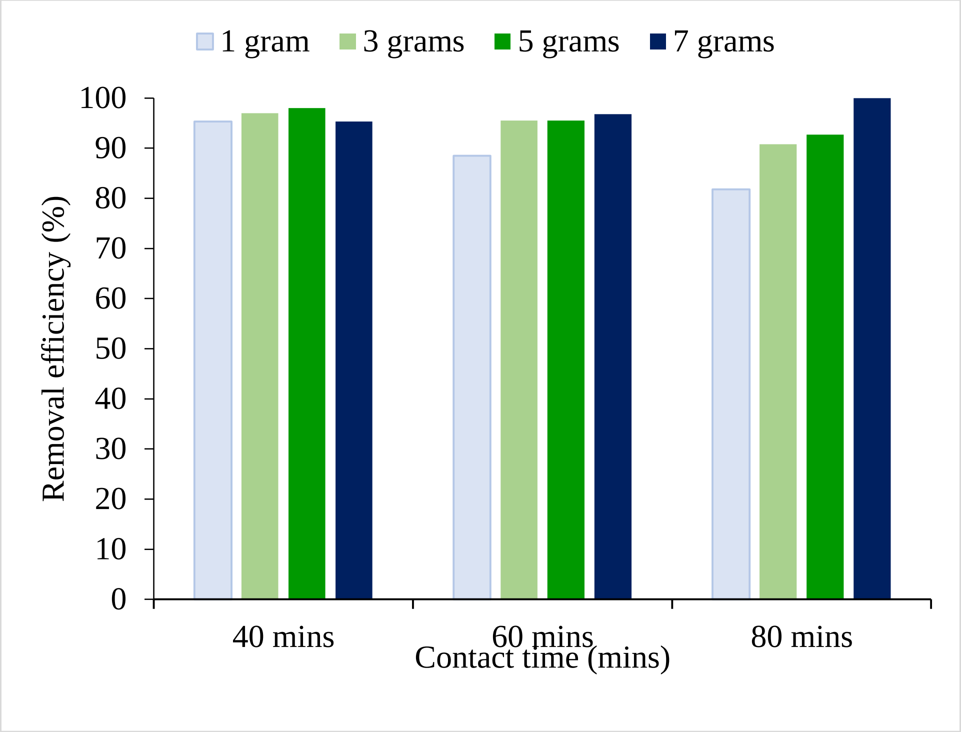


Figure 4-7: Influence of contact time in lead ions removal pattern

4.9 Schematic diagram for treatment plant modification

Raw water from the dam is abstracted and transmitted for 3.6km to the water treatment plant in Kamuli town. The water is then aerated before slow sand filtration. A Zeolite treatment process has been incorporated between the filtration process and contact tank where chlorination is done. Treated water is then high lifted to the overhead reservoirs of 120 and 180 cubic meter and distributed by gravity to customers.

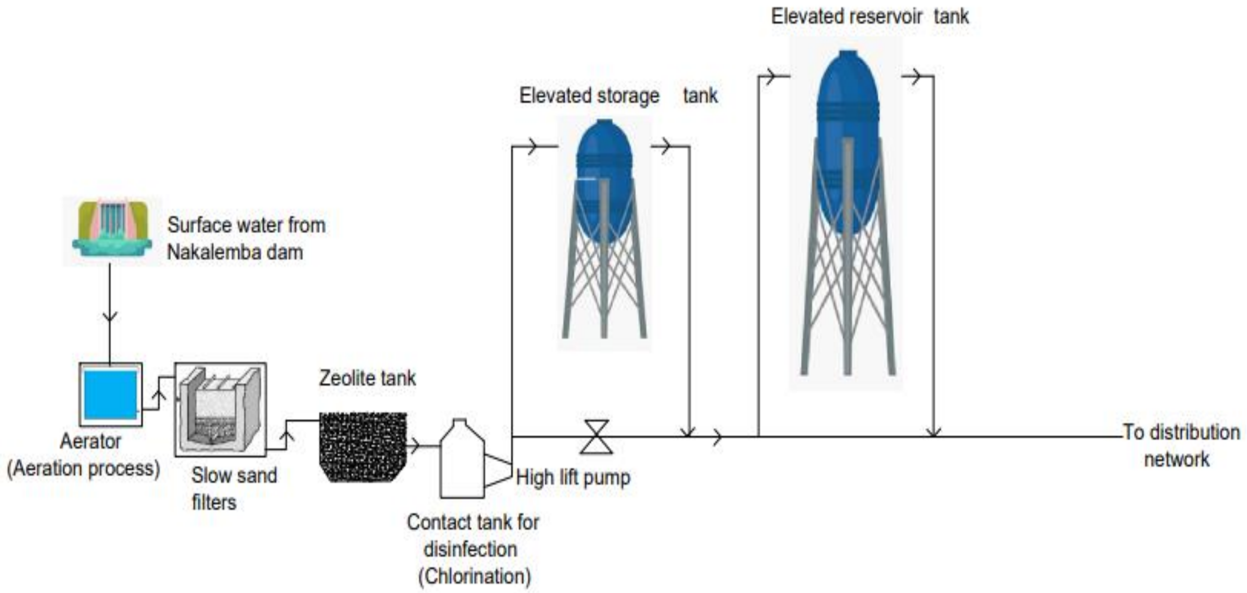


Figure 4-8: Modified schematic diagram incorporating zeolite in water treatment

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The physiochemical characterization of parameters was done in both the dry and wet seasons. Average turbidity values were observed in the dry seasons in February, March and May. The highest turbidity values were recorded in April. The minimum and maximum turbidity values recorded during the four months were 3 and 103 NTU before treatment, 1 and 48 NTU were recorded after treatment, respectively. It can be concluded that turbidity increases during the rainy season as sediments get transported to the intake source by runoffs.

Evaluation of system performance showed that the existing Kamuli water treatment plant exhibited turbidity removal efficiencies in the range of 0 – 26%. Filter medium optimization removed turbidity as a physical parameter sufficiently to maximum average of 90.5% and 93.7% in 900mm and 1150mm respectively. The optimum sand medium depth of 725mm was deduced by determining the values of MSE and cost for exponential, logarithmic, linear and polynomial models as 0.4758, 0.4078, 0.6535 and 0.3848, respectively. The corresponding costs of sand to achieve the optimal depth based on the models were 2,880.00, 3,300.00, 3,235.00 and 2,915.00 Uganda shillings, respectively.

In testing for the effectiveness of natural zeolite in removing lead from drinking water, for a given contact time, efficiency of lead removal increased with increasing mass of zeolite added to water. This was true especially for contact time greater than 40 minutes. For instance, the efficiencies of lead removal using zeolite of 1, 3, 5 and 7 grams at a contact time of 80 minutes were 81.8, 90.8, 92.7 and 100%, respectively. However, at a 40-minute contact time, the lead removal efficiency increased as zeolite mass was varied from 1g to 5g and thereafter it decreased. Thus, the optimal removal of lead was at contact time of 40 minutes using zeolite mass of 5g with removal efficiency of 98%. This study therefore, demonstrated potential of zeolite in lead removal.

5.2 Recommendations

The study investigations indicated that optimization of filter medium depth is effective for removal of turbidity as a physical parameter. On the other hand, further investigation and evaluation found natural zeolite to be effective in removing lead ions from drinking water. The study therefore recommends further studies to focus on treatment systems that combine both filter medium and natural zeolite that remove other physical parameters and other heavy metals simultaneously.

Further research and studies should be carried out to establish removal potential of other toxic heavy metals like arsenic, chromium, cadmium and others using natural zeolite as well as incorporating other underlying factors such as particle size, type of adsorbent, varying temperature and pH.

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Appendices

Appendix 1: Results and system performance evaluation of alkalinity and hardness

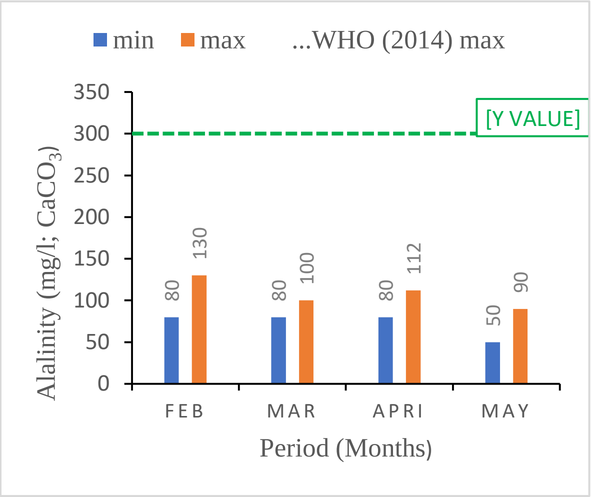
1) Alkalinity

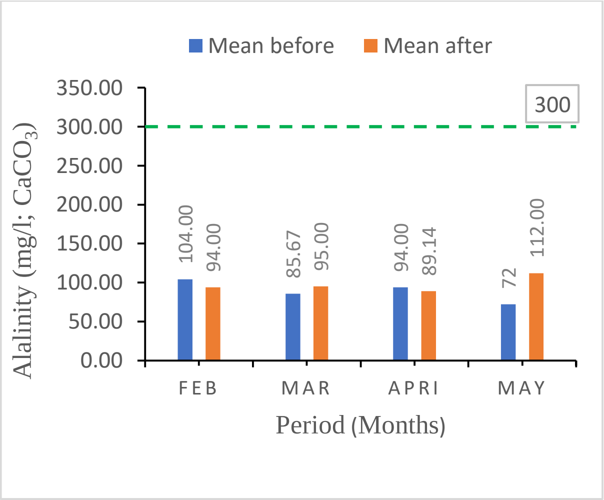
WHO Standards	100-300 (mg/l of $CaCO_3$)				100-300 (mg/l of $CaCO_3$)			
	Before filtration				After filtration			
	Min	Max	Mean ± SD	CV%	Min	Max	Mean ± SD	CV%
Feb	80	130	104.00 ± 18.17	17.47	90.00	100	94.00 ± 5.48	5.83
Mar	80	100	85.67 ± 8.04	9.39	80.00	100	95.00 ± 8.37	8.81
Apri	80	112	94.00 ± 10.71	11.39	80.00	96	89.14 ± 6.72	7.54
May	50	90	72 ± 14.83	20.60	90.00	160	112.00 ± 27.75	24.78

Change %

$$Change = \left(\frac{min_B - min_A}{min_B}\right) * 100\%$$

Period	Min change (%)	Max change(%)	Mean change(%)
Feb	-12.50	23.08	9.62
Mar	0.00	0.00	-10.89
April	0.00	14.29	5.17
May	-80.00	-77.78	-55.56





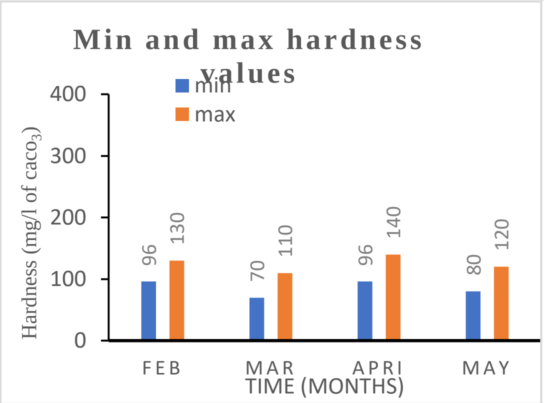
2) Hardness

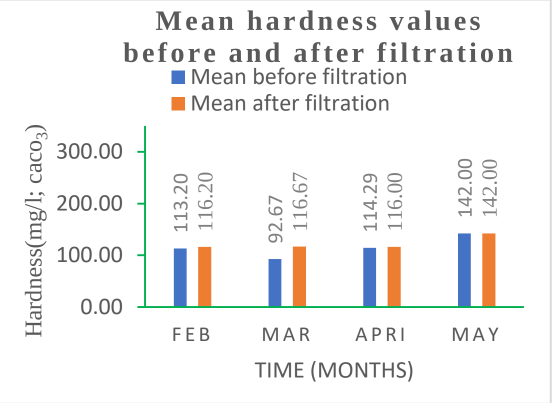
WHO Standards	- mg/l; $CaCO_3$				- mg/l; $CaCO_3$			
	Before filtration				After filtration			
	Min	Max	Mean ± SD	CV%	Min	Max	Mean ± SD	CV%
Feb	96	130	113.20 ± 14.53	12.84	96	140	116.20 ± 18.23	15.69
Mar	70	110	92.67 ± 13.37	14.42	100	140	116.67 ± 13.66	11.71
Apri	96	140	114.29 ± 38.10	33.34	100	152	116.00 ± 17.85	15.39
May	80	120	142.00 ± 14.83	10.45	120	180	142.00 ±23.87	16.81

Change %

$$\boldsymbol{Change = \left(\frac{min_B - min_A}{min_B}\right) * 100\%}$$

Period	**Min change (%)**	**Max change(%)**	**Mean change(%)**
Feb	0.00	-7.69	-2.65
Mar	-42.86	-27.27	-25.90
April	-4.17	-8.57	-1.50
May	-50.00	-50.00	0.00





Appendix 2: Computation of resultant turbidities computed using modal equations

Model 1									
Exponential		$y = 2.8281e^{-0.0012x}$	$y = 6.0418e^{-0.0013x}$	$y = 7.7261e^{-0.0012x}$	$y = 10.7212e^{-0.0014x}$	$y = 16.4623e^{-0.0017x}$	$y = 20.9455e^{-0.0022x}$	$y = 20.6398e^{-0.0020x}$	$y = 26.4848e^{-0.0023x}$
	Depth	5NTU	10NTU	20NTU	40NTU	60NTU	80NTU	100NTU	120NTU
	400	1.75	3.59	4.78	6.12	8.34	8.69	9.27	10.55
	650	1.30	2.60	3.54	4.32	5.45	5.01	5.63	5.94
	900	0.96	1.88	2.62	3.04	3.56	2.89	3.41	3.34
	1150	0.71	1.35	1.94	2.14	2.33	1.67	2.07	1.88
MSE		0.0030	0.0617	0.1085	0.0887	0.0912	0.2368	0.1861	0.4758
R²		0.9820	0.9485	0.9030	0.9767	0.9897	0.9414	0.9669	0.9524

Model 2									
Logarithmic		$y = -0.932\ln(x) + 7.2962$	$y = -1.918\ln(x) + 15.036$	$y = -2.362\ln(x) + 18.71$	$y = -3.532\ln(x) + 27.069$	$y = -6.041\ln(x) + 44.579$	$y = -7.07\ln(x) + 51.267$	$y = -7.006\ln(x) + 51.345$	$y = -8.111\ln(x) + 58.784$
	Depth	5NTU	10NTU	20NTU	40NTU	60NTU	80NTU	100NTU	120NTU
	400	1.71	3.54	4.56	5.91	8.38	8.91	9.37	10.19
	650	1.26	2.61	3.41	4.19	5.45	5.47	5.97	6.25
	900	0.96	1.99	2.64	3.04	3.49	3.17	3.69	3.61
	1150	0.73	1.52	2.06	2.18	2.00	1.44	1.97	1.62
MSE		0.0033	0.0572	0.1003	0.0790	0.1036	0.2662	0.1849	0.4078
R²		0.9764	0.9095	0.8969	0.9610	0.9821	0.9670	0.9765	0.9618

Model 3									
Linear		y = -0.0013x + 2.2	y = -0.0028x + 4.5867	y = -0.0035x + 5.8533	y = -0.0051x + 7.76	y = -0.0083x + 11.24	y = -0.0097x + 12.293	y = -0.0097x + 12.793	y = -0.0113x + 14.2
	Depth	5NTU	10NTU	20NTU	40NTU	60NTU	80NTU	100NTU	120NTU
	400	1.68	3.47	4.45	5.72	7.92	8.41	8.91	9.68
	650	1.36	2.77	3.58	4.45	5.85	5.99	6.49	6.86
	900	1.03	2.07	2.70	3.17	3.77	3.56	4.06	4.03
	1150	0.71	1.37	1.83	1.90	1.70	1.14	1.64	1.21
MSE		0.0008	0.0194	0.0341	0.0230	0.4674	0.6757	0.4535	0.6535
R^2		1.0000	0.9692	0.9657	0.9890	0.9196	0.9164	0.9424	0.9389

Model 4									
Poly (2)		y = 2E-20x^2 - 0.0013x + 2.2	y = -1E-06x^2 - 0.0007x + 3.89	y = -3E-06x^2 + 0.0007x + 4.46	y = 5E-20x^2 - 0.0051x + 7.76	y = 1E-05x^2 - 0.0248x + 16.813	y = 1E-05x^2 - 0.0283x + 18.563	y = 9E-06x^2 - 0.0242x + 17.67	y = 9E-06x^2 - 0.0258x + 19.077
	Depth	5NTU	10NTU	20NTU	40NTU	60NTU	80NTU	100NTU	120NTU
	400	1.68	3.45	4.26	5.72	8.49	8.84	9.43	10.20
	650	1.36	3.01	3.65	4.45	4.92	4.39	5.74	6.11
	900	1.03	2.45	2.66	3.17	2.59	1.19	3.18	3.15
	1150	0.71	1.76	1.30	1.90	1.52	-0.76	1.74	1.31
MSE		0.0008	0.1001	0.0644	0.0230	0.3124	2.6371	0.1850	0.3848
R^2		1.0000	0.9802	0.9943	0.9890	0.9962	0.9861	0.9857	0.9708

Appendix 3 :Model parameters and performance for sand depth optimization

MODEL PARAMETERS								
	5NTU	10NTU	20NTU	40NTU	60NTU	80NTU	100NTU	120NTU
Exponential model								
A	2.8281	6.0418	7.7261	10.7212	16.4623	20.9455	20.6398	26.4848
B	-0.0012	-0.0013	-0.0012	-0.0014	-0.0017	-0.0022	-0.002	-0.0023
Logarithmic model								
A	-0.932	-1.918	-2.362	-3.532	-6.041	-7.07	-7.006	-8.111
B	7.2962	15.036	18.71	27.069	44.579	51.267	51.345	58.784
Linear model								
A	-0.0013	-0.0028	-0.0035	-0.0051	-0.0083	-0.0097	-0.0097	-0.0113
B	2.2	4.5867	5.8533	7.76	11.24	12.293	12.793	14.2
Polynomial model								
A	2.00E-20	-1.00E-06	-3.00E-06	5.00E-20	1.00E-05	1.00E-05	9.00E-06	9.00E-06
B	-0.0013	-0.0007	0.0007	-0.0051	-0.0248	-0.0283	-0.0242	-0.0258
C	2.2	3.89	4.46	7.76	16.813	18.563	17.67	9.077
MODEL PERFORMANCE								
	5NTU	10NTU	20NTU	40NTU	60NTU	80NTU	100NTU	120NTU
MSE								
Exponential	0.0030	0.0617	0.1085	0.0887	0.0912	0.2368	0.1861	0.4758
Logarithmic	0.0033	0.0572	0.1003	0.0790	0.1036	0.2662	0.1849	0.4078
Linear	0.0008	0.0194	0.0341	0.0230	0.4674	0.6757	0.4535	0.6535
Polynomial (2)	0.0008	0.1001	0.0644	0.0230	0.3124	2.6371	0.1850	0.3848
R^2								
Exponential	0.9820	0.9485	0.9030	0.9767	0.9897	0.9414	0.9669	0.9524
Logarithmic	0.9764	0.9095	0.8969	0.9610	0.9821	0.9670	0.9765	0.9618
Linear	1.0000	0.9692	0.9657	0.9890	0.9196	0.9164	0.9424	0.9389
Polynomial (2)	1.0000	0.9802	0.9943	0.9890	0.9962	0.9861	0.9857	0.9708

Appendix 4: Laboratory activities

Activities during Characterisation of water parameters in the laboratory

Activities involving application of natural zeolite in lead ion removal

Appendix 5: Results for water characterization and evaluation of system performance

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NATIONAL WATER AND SEWERAGE CORPORATION
3 1 MAY 2022
THE CENTRAL LABORATORY

Name of Student: Emmanuel Okello
Address: Kyambogo University, Kampala
Date of Report: 31/05/2022

Reg. No: 19/U/GMEW/18845/PD

Date	Lab. NO.	Turbidity of raw water (Dam)	Turbidity after filtration	Color of Raw water	Color after filtration	Alkalinity of raw water	Alkalinity after treatment	Hardness of raw water	Hardness after treatment
		NTU (A)	NTU (B)						
01/02/2022	2201	9	5	40	15	100	100	120	140
02/02/2022	2202	8	4	45	12				
03/02/2022	2203	5	2	60	18				
04/02/2022	2204	5	3	35	15				
05/02/2022	2205	5	2	20	14				
06/02/2022	2206	5	3	15	10	110	90	130	105
07/02/2022	2207	5	3	20	14				
08/02/2022	2208	3	[illegible]	15	10				
09/02/2022	2209	5	2	25	8				
10/02/2022	2210	8	5	40	15				
11/02/2022	2211	9	5	15	10				
12/02/2022	2212	7	5	40	15				
13/02/2022	2213	7	4	35	15				
14/02/2022	2214	8	4	25	13	80	90	100	110
15/02/2022	2215	9	5	22	10				
16/02/2022	2216	5	4	5[illegible]	12				
17/02/2022	2217	4	1	[illegible]7	13				
18/02/2022	2218	7	5	84	15				
19/02/2022	2219	5	2	57	13				
20/02/2022	2220	9	6	70	17				

Page 1 of 9

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21/02/2022	2221	8	4	55	15	100	90	96	96
22/02/2022	2222	4	2	57	12				
23/02/2022	2223	5	3	60	15				
24/02/2022	2224	16	8	55	14				
24/02/2022	2225	15	7	70	12				
25/02/2022	2226	15	5	30	8				
26/02/2022	2227	15	6	35	19				
27/02/2022	2228	21	8	70	15	130	100	120	130
27/02/2022	2229	25	10	75	18				
28/02/2022	2230	28	11	40	10				
28/02/2022	2231	18	9	100	15				
01/03/2022	2232	15	8	60	27				
02/03/2022	2233	12	6	78	35				
03/03/2022	2234	13	7	112	74				
04/03/2022	2235	12	8	118	78	80	100	90	120
05/03/2022	2236	14	9	124	58				
06/03/2022	2237	18	11	179	91				
07/03/2022	2238	14	10	149	63				
08/03/2022	2239	12	8	126	122				
09/03/2022	2240	12	7	151	118				
10/03/2022	2241	11	8	131	158				
11/03/2022	2242	12	9	95	40	100	100	110	140
12/03/2022	2243	9	6	101	48				

Page 2 of 9


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13/03/2022	2244	11	8	123	78				
14/03/2022	2245	10	8	112	74				
15/03/2022	2246	13	7	128	65				
16/03/2022	2247	14	10	180	66				
17/03/2022	2248	19	11	231	70	90	100	90	110
17/03/2022	2249	24	14	288	133				
18/03/2022	2250	21	13	252	99				
18/03/2022	2251	19	11	249	95				
19/03/2022	2252	23	11	246	83				
20/03/2022	2253	20	12	231	79				
21/03/2022	2254	27	15	308	86				
21/03/2022	2255	25	14	300	98				
22/03/2022	2256	33	13	389	87	80	90	100	120
22/03/2022	2257	36	15	397	99				
23/03/2022	2258	36	14	417	95				
24/03/2022	2259	38	16	410	93				
25/03/2022	2260	29	17	318	66				
25/03/2022	2261	27	12	287	110				
26/03/2022	2262	20	12	167	59	80	80	70	100
26/03/2022	2263	21	11	98	42				
27/03/2022	2264	19	9	140	48				
27/03/2022	2265	17	8	102	2[illegible]				
28/03/2022	2266	16	8	140	31				

Page 3 of 9


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28/03/2022	2267	20	9	108	15				
29/03/2022	2268	18	11	134	33				
29/03/2022	2269	16	10	126	29				
30/03/2022	2270	20	11	100	27				
30/03/2022	2271	26	15	114	33	84	100	96	110
31/03/2022	2272	17	9	130	38				
31/03/2022	2273	16	10	180	72				
31/03/2022	2274	18	11	102	41				
01/04/2022	2275	19	9	100	15				
02/04/2022	2276	16	7	150	40				
03/04/2022	2277	11	8	131	33				
04/04/2022	2278	20	11	210	20	100	80	120	100
04/04/2022	2279	18	8	222	40				
05/04/2022	2280	15	7	206	43				
06/04/2022	2281	17	10	210	52				
07/04/2022	2282	20	12	225	41				
08/04/2022	2283	16	8	150	40				
09/04/2022	2284	19	10	201	70	100	80	140	110
09/04/2022	2285	22	11	280	136				
10/04/2022	2286	20	10	194	88				
11/04/2022	2287	11	7	149	63				
12/04/2022	2288	26	13	252	83				
12/04/2022	2289	23	9	246	43				

Page 4 of 9

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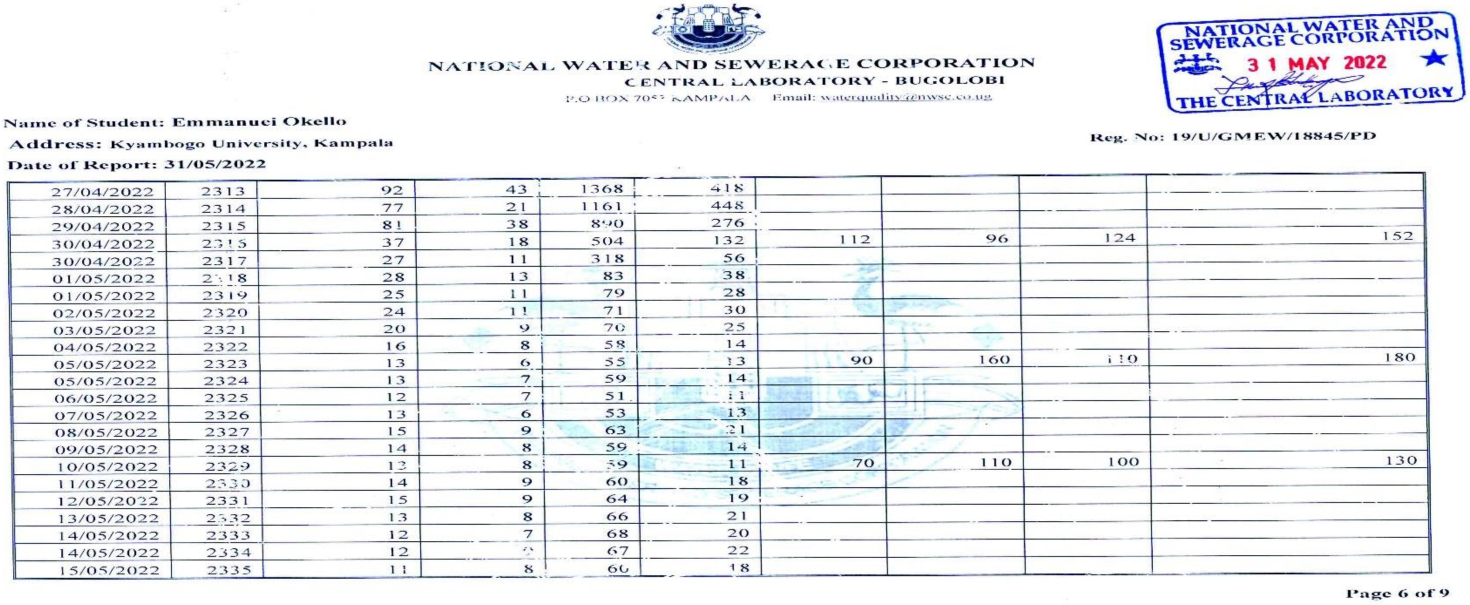
13/04/2022	2290	19	8	339	89				
13/04/2022	2291	20	9	175	92				
14/04/2022	2292	21	11	154	66	86	90	96	108
14/04/2022	2293	20	10	211	71				
15/04/2022	2294	55	18	464	101				
15/04/2022	2295	49	15	434	98				
16/04/2022	2296	60	14	556	121				
16/04/2022	2297	61	14	544	123				
17/04/2022	2298	48	11	367	96	90	92	110	120
17/04/2022	2299	43	12	366	106				
18/04/2022	2300	37	13	287	110				
19/04/2022	2301	27	11	318	35				
19/04/2022	2302	30	13	389	87				
20/04/2022	2303	35	14	407	85				
20/04/2022	2304	63	17	471	147	90	90	110	100
21/04/2022	2305	81	31	576	197				
21/04/2022	2306	103	39	890	516				
22/04/2022	2307	92	34	1264	418				
23/04/2022	2308	88	32	1041	317				
24/04/2022	2309	83	31	898	347				
25/04/2022	2310	95	37	1311	979	80	96	100	120
25/04/2022	2311	97	48	1578	1264				
26/04/2022	2312	86	39	993	341				

Page 5 of 9



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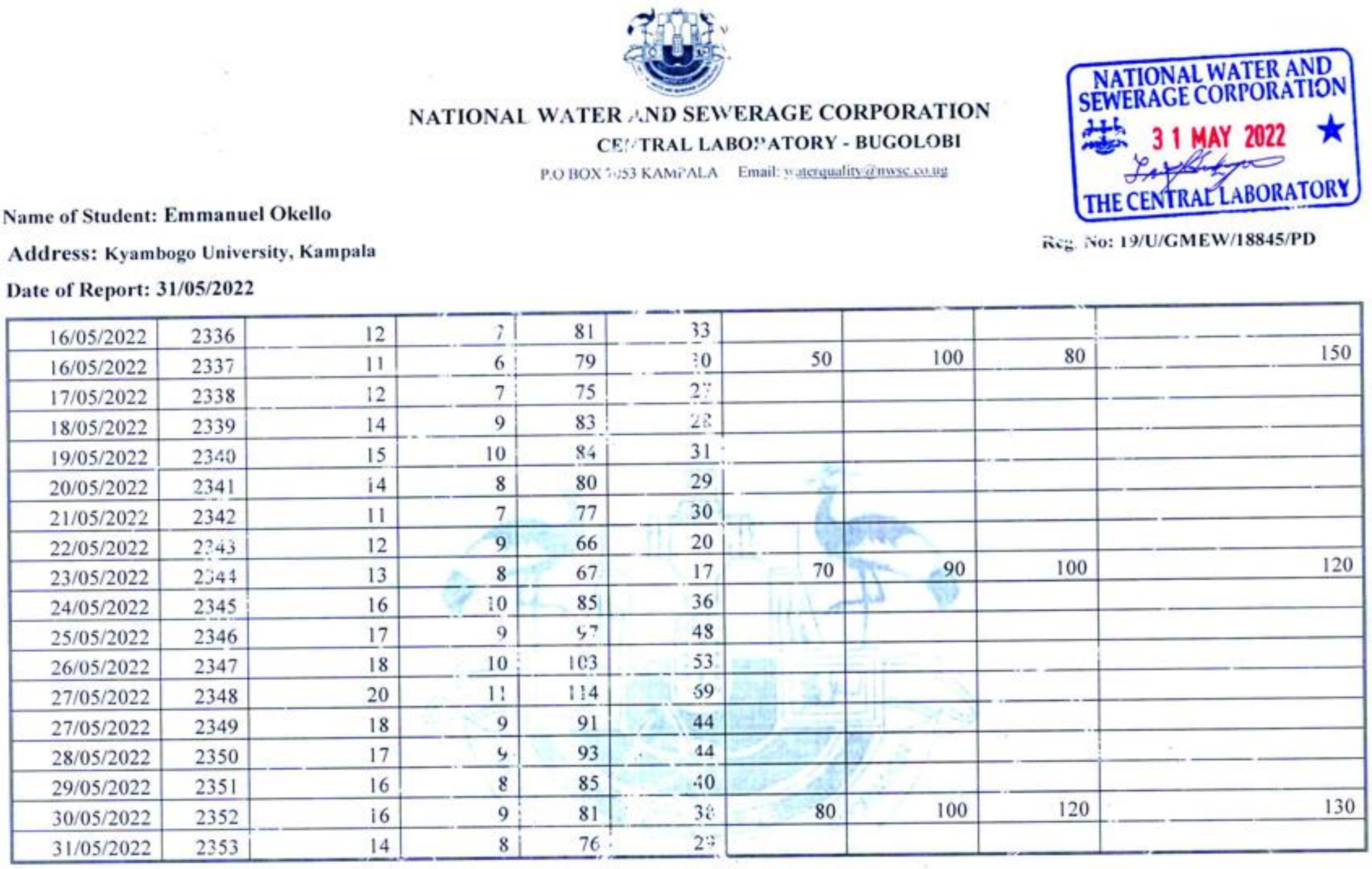
27/04/2022	2313	92	43	1368	418				
28/04/2022	2314	77	21	1161	448				
29/04/2022	2315	81	38	890	276				
30/04/2022	2316	37	18	504	132	112	96	124	152
30/04/2022	2317	27	11	318	56				
01/05/2022	2318	28	13	83	38				
01/05/2022	2319	25	11	79	28				
02/05/2022	2320	24	11	71	30				
03/05/2022	2321	20	9	70	25				
04/05/2022	2322	16	8	58	14				
05/05/2022	2323	13	6	55	13	90	160	110	180
05/05/2022	2324	13	7	59	14				
06/05/2022	2325	12	7	51	11				
07/05/2022	2326	13	6	53	13				
08/05/2022	2327	15	9	63	21				
09/05/2022	2328	14	8	59	14				
10/05/2022	2329	12	8	59	11	70	110	100	130
11/05/2022	2330	14	9	60	18				
12/05/2022	2331	15	9	64	19				
13/05/2022	2332	13	8	66	21				
14/05/2022	2333	12	7	68	20				
14/05/2022	2334	12	9	67	22				
15/05/2022	2335	11	8	60	18				

Page 6 of 9



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31 MAY 2022
THE CENTRAL LABORATORY

Name of Student: Emmanuel Okello

Address: Kyambogo University, Kampala

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16/05/2022	2336	12	7	81	33				
16/05/2022	2337	11	6	79	30	50	100	80	150
17/05/2022	2338	12	7	75	27				
18/05/2022	2339	14	9	83	28				
19/05/2022	2340	15	10	84	31				
20/05/2022	2341	14	8	80	29				
21/05/2022	2342	11	7	77	30				
22/05/2022	2343	12	9	66	20				
23/05/2022	2344	13	8	67	17	70	90	100	120
24/05/2022	2345	16	10	85	36				
25/05/2022	2346	17	9	97	48				
26/05/2022	2347	18	10	103	53				
27/05/2022	2348	20	11	114	59				
27/05/2022	2349	18	9	91	44				
28/05/2022	2350	17	9	93	44				
29/05/2022	2351	16	8	85	40				
30/05/2022	2352	16	9	81	38	80	100	120	130
31/05/2022	2353	14	8	76	29				

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Tel: + 256 - 414 - 541258
Fax: + 256 - 414 - 531061

College of Natural Sciences
School of Physical Sciences
DEPARTMENT OF GEOLOGY AND PETROLEUM STUDIES

Friday 8th July 2022

OKELLO EMMANUEL

Dear Sir,

RE: ANALYSIS OF WATER SAMPLE

In the Departmental we received One water sample to be analysed for the following elements (As, Pb, Zn, Mn, Cd, Cr, Co, Cu and Fe). The sample was acidified and later aspirated using AAS machine Agillent 200 series, the following results were obtained in Mg/l.

Table of results,

Water sample	Mg/l
As	0.26
Pb	1.30
Zn	4.82
Mn	3.25
Cd	0.08
Cr	0.02
Co	0.05
Cu	0.26
Fe	0.21

Analyst........Sessanga Robert..........................
Sessanga Robert

For! Sessanga
....
Dr. A.G. Batte
HEAD OF DEPARTMENT

MAKERERE UNIVERSITY
DEPARTMENT OF GEOLOGY & PETROLEUM STURDIES
COLLEGE OF NATRUAL SCIENCES
08 JUL 2022
HEAD
P. O. BOX7062, KAMPALA

```
Method:                 Test.mfx    (Wavelength(s))
Last modified:          03-Mar-23 4:39:26 PM by John KYU-CHEMISTRY DEPT
Spectrophotometer:      GENESYS 10S UV-Vis
Serial number:          2L9U082211
Firmware:               4.006
Autozero:               03-Mar-23 4:47:46 PM
Autozero:               03-Mar-23 4:48:37 PM after sample D5
Autozero:               03-Mar-23 4:49:40 PM after sample D5
Autozero:               03-Mar-23 4:59:53 PM after sample D5
Autozero:               03-Mar-23 5:01:19 PM after sample F5
Autozero:               03-Mar-23 5:02:19 PM after sample F5
Autozero:               03-Mar-23 5:03:57 PM after sample F5
Measured:               03-Mar-23 5:04:35 PM by John KYU-CHEMISTRY DEPT
Result filename:        Okello Pb1.rfx


Sample: D1
    215 nm    211 nm    205 nm
   0.422 A   0.191 A   0.106 A

Sample: D2
    215 nm    211 nm    205 nm
   0.458 A   0.228 A   0.134 A

Sample: D3
    215 nm    211 nm    205 nm
   0.493 A   0.246 A   0.145 A

Sample: D4
    215 nm    211 nm    205 nm
   0.628 A   0.299 A   0.182 A

Sample: D5
    215 nm    211 nm    205 nm
   0.529 A   0.251 A   0.152 A

Sample: D1
    215 nm    211 nm    205 nm
   0.425 A   0.203 A   0.118 A

Sample: D2
    215 nm    211 nm    205 nm
   0.423 A   0.200 A   0.110 A

Sample: D3
    215 nm    211 nm    205 nm
   0.495 A   0.244 A   0.147 A

Sample: D4
    215 nm    211 nm    205 nm
   0.621 A   0.292 A   0.186 A

Sample: D5
    215 nm    211 nm    205 nm
   0.530 A   0.254 A   0.150 A

Sample: D1
    215 nm    211 nm    205 nm
   0.421 A   0.204 A   0.108 A

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```
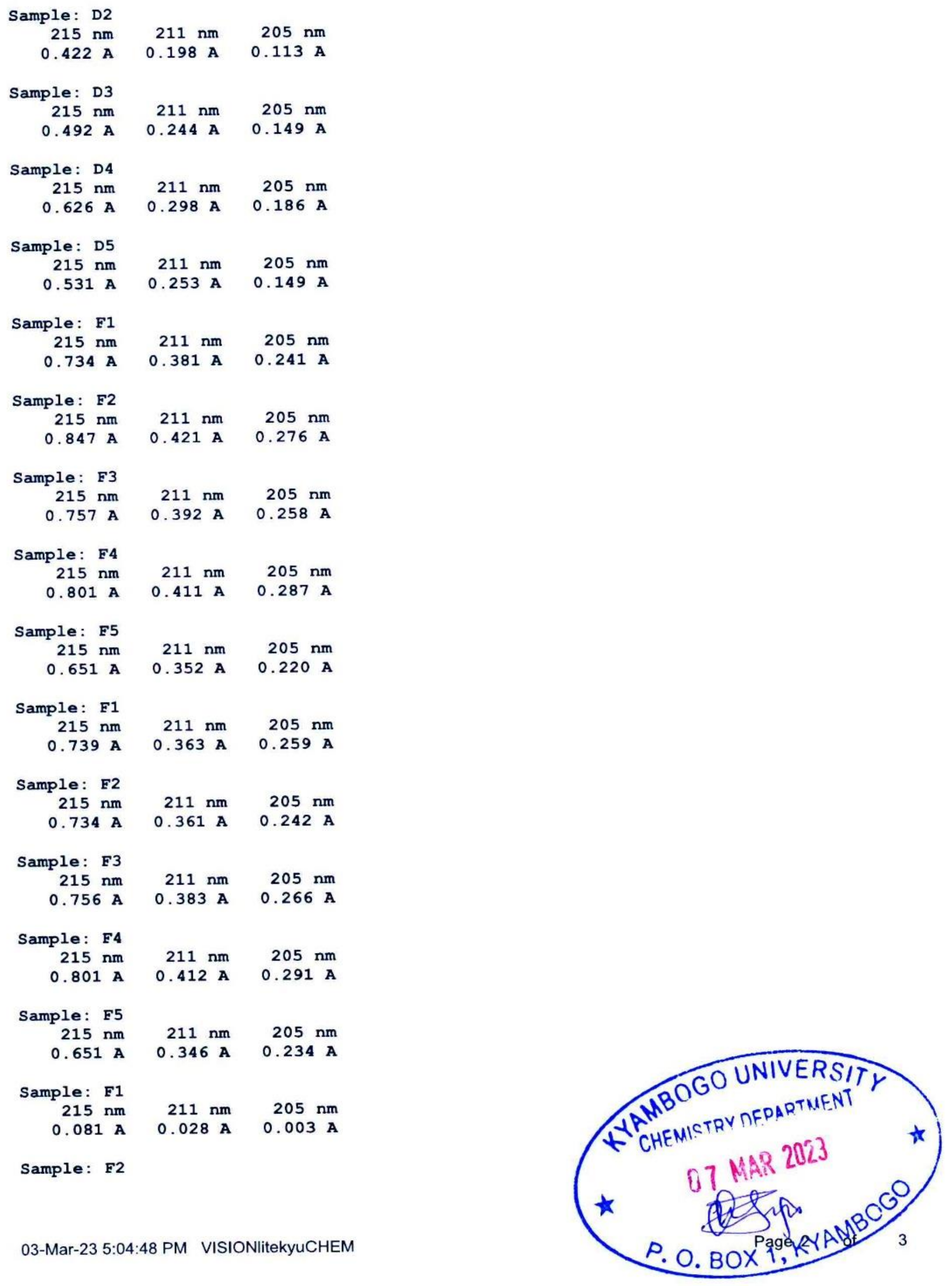

07 MAR 2023



```
Sample: D2
     215 nm      211 nm     205 nm
    0.422 A    0.198 A    0.113 A

Sample: D3
     215 nm      211 nm     205 nm
    0.492 A    0.244 A    0.149 A

Sample: D4
     215 nm      211 nm     205 nm
    0.626 A    0.298 A    0.186 A

Sample: D5
     215 nm      211 nm     205 nm
    0.531 A    0.253 A    0.149 A

Sample: F1
     215 nm      211 nm     205 nm
    0.734 A    0.381 A    0.241 A

Sample: F2
     215 nm      211 nm     205 nm
    0.847 A    0.421 A    0.276 A

Sample: F3
     215 nm      211 nm     205 nm
    0.757 A    0.392 A    0.258 A

Sample: F4
     215 nm      211 nm     205 nm
    0.801 A    0.411 A    0.287 A

Sample: F5
     215 nm      211 nm     205 nm
    0.651 A    0.352 A    0.220 A

Sample: F1
     215 nm      211 nm     205 nm
    0.739 A    0.363 A    0.259 A

Sample: F2
     215 nm      211 nm     205 nm
    0.734 A    0.361 A    0.242 A

Sample: F3
     215 nm      211 nm     205 nm
    0.756 A    0.383 A    0.266 A

Sample: F4
     215 nm      211 nm     205 nm
    0.801 A    0.412 A    0.291 A

Sample: F5
     215 nm      211 nm     205 nm
    0.651 A    0.346 A    0.234 A

Sample: F1
     215 nm      211 nm     205 nm
    0.081 A    0.028 A    0.003 A

Sample: F2
```

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Page 2 of 3

```
    215 nm     211 nm     205 nm
   0.194 A    0.078 A    0.048 A

Sample: F3
    215 nm     211 nm     205 nm
   0.106 A    0.060 A    0.018 A

Sample: F4
    215 nm     211 nm     205 nm
   0.157 A    0.085 A    0.052 A

Sample: F5
    215 nm     211 nm     205 nm
   0.001 A    0.007 A    0.000 A

Sample: F1
    215 nm     211 nm     205 nm
   0.731 A    0.369 A    0.248 A

Sample: F2
    215 nm     211 nm     205 nm
   0.732 A    0.371 A    0.244 A

Sample: F3
    215 nm     211 nm     205 nm
   0.754 A    0.389 A    0.262 A

Sample: F4
    215 nm     211 nm     205 nm
   0.801 A    0.411 A    0.283 A

Sample: F5
    215 nm     211 nm     205 nm
   0.652 A    0.341 A    0.232 A
```

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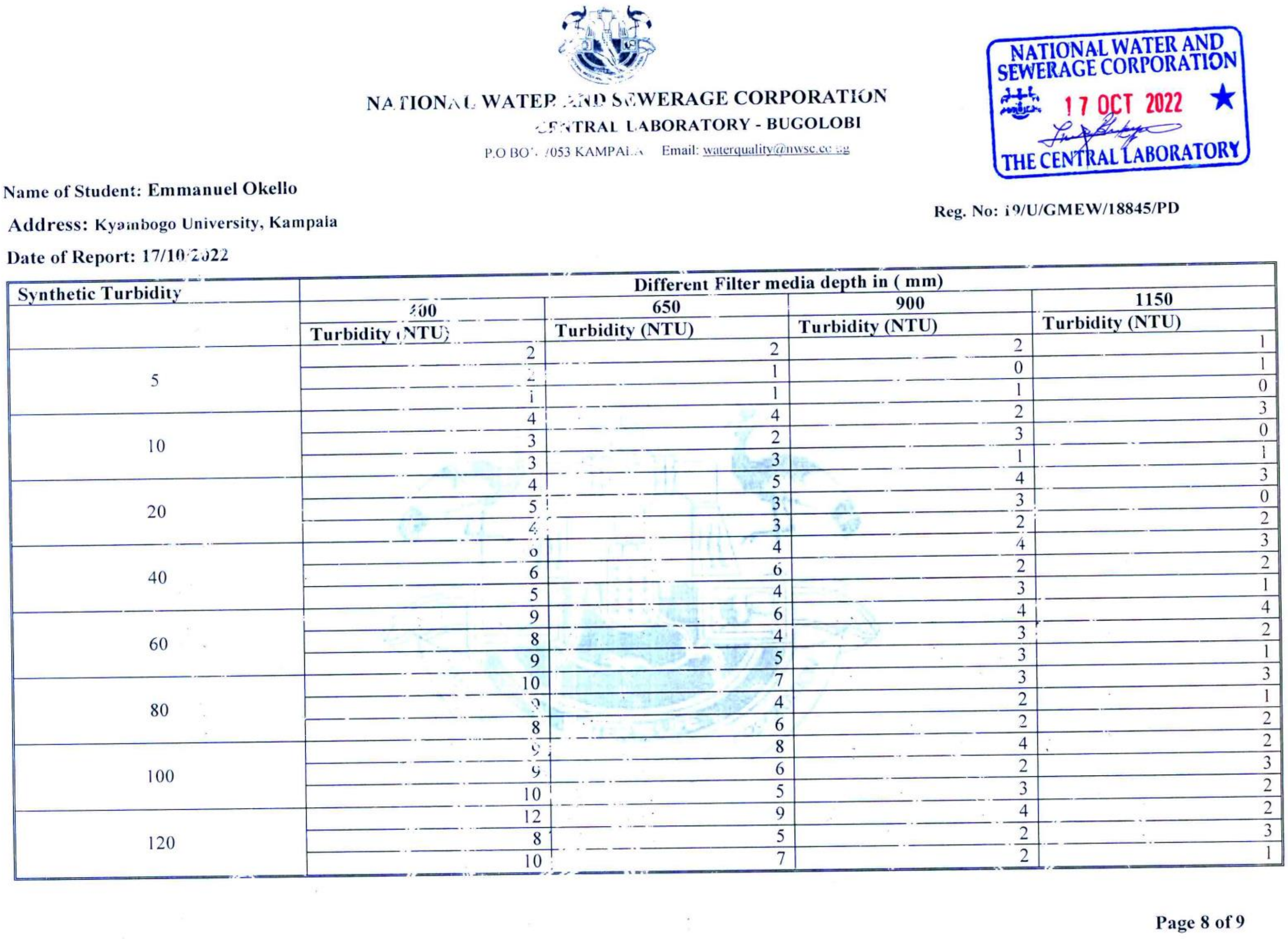
Appendix 6: Results for synthetic turbid water used in sand depth optimization



NATIONAL WATER AND SEWERAGE CORPORATION
CENTRAL LABORATORY - BUGOLOBI
P.O BOX 7053 KAMPALA Email: waterquality@nwsc.co.ug

NATIONAL WATER AND SEWERAGE CORPORATION
17 OCT 2022
THE CENTRAL LABORATORY

Name of Student: Emmanuel Okello

Address: Kyambogo University, Kampala

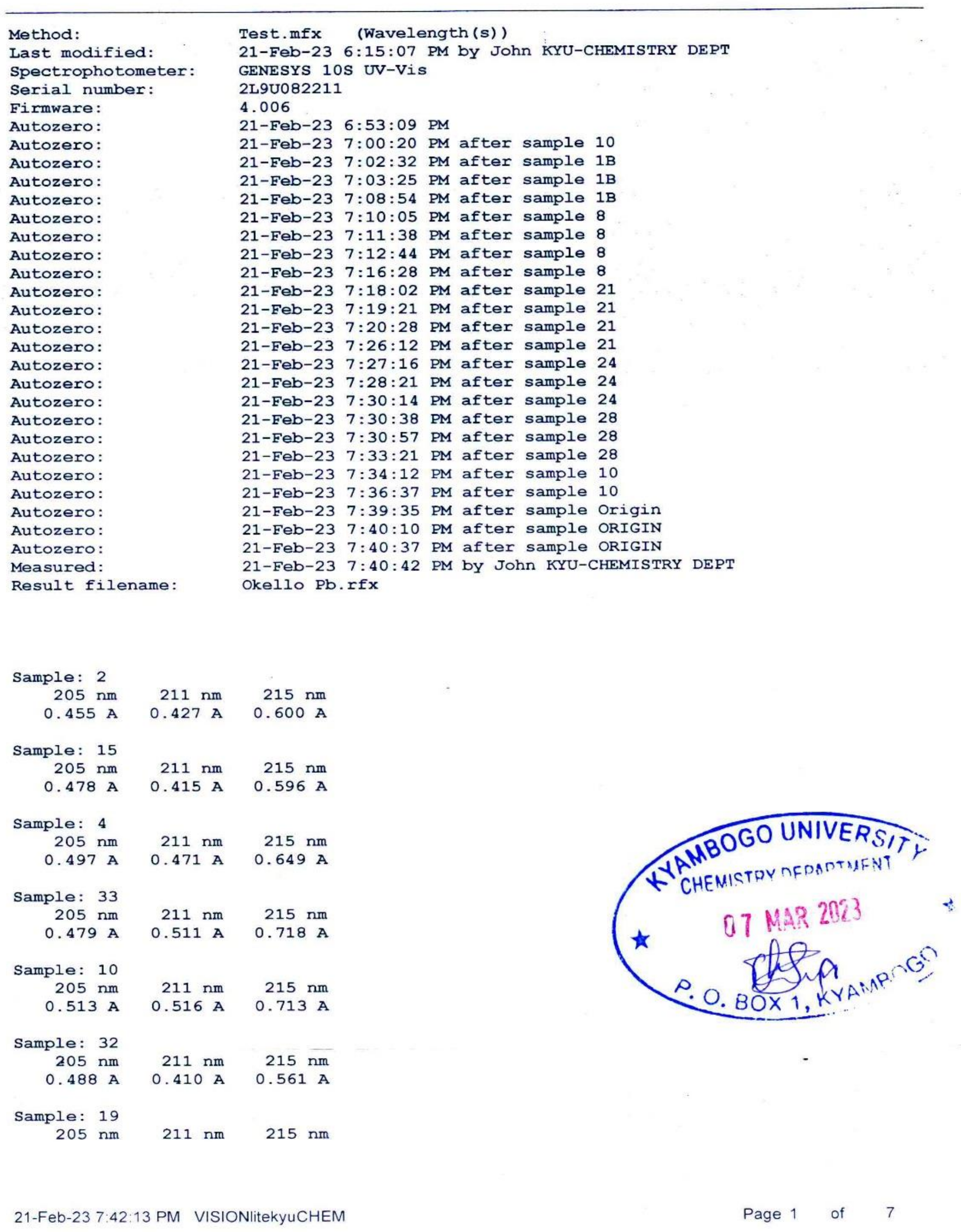
Date of Report: 17/10/2022

Reg. No: 19/U/GMEW/18845/PD

Synthetic Turbidity	Different Filter media depth in (mm)			
	400	650	900	1150
	Turbidity (NTU)	Turbidity (NTU)	Turbidity (NTU)	Turbidity (NTU)
5	2	2	2	1
	2	1	0	1
	1	1	1	0
10	4	4	2	3
	3	2	3	0
	3	3	1	1
20	4	5	4	3
	5	3	3	0
	4	3	2	2
40	6	4	4	3
	6	6	2	2
	5	4	3	1
60	9	6	4	4
	8	4	3	2
	9	5	3	1
80	10	7	3	3
	9	4	2	1
	8	6	2	2
100	9	8	4	2
	9	6	2	3
	10	5	3	2
120	12	9	4	2
	8	5	2	3
	10	7	2	1

Page 8 of 9

Appendix 7: Results showing effectiveness of natural zeolite in removing lead ions



```
Method:                Test.mfx    (Wavelength(s))
Last modified:         21-Feb-23 6:15:07 PM by John KYU-CHEMISTRY DEPT
Spectrophotometer:     GENESYS 10S UV-Vis
Serial number:         2L9U082211
Firmware:              4.006
Autozero:              21-Feb-23 6:53:09 PM
Autozero:              21-Feb-23 7:00:20 PM after sample 10
Autozero:              21-Feb-23 7:02:32 PM after sample 1B
Autozero:              21-Feb-23 7:03:25 PM after sample 1B
Autozero:              21-Feb-23 7:08:54 PM after sample 1B
Autozero:              21-Feb-23 7:10:05 PM after sample 8
Autozero:              21-Feb-23 7:11:38 PM after sample 8
Autozero:              21-Feb-23 7:12:44 PM after sample 8
Autozero:              21-Feb-23 7:16:28 PM after sample 8
Autozero:              21-Feb-23 7:18:02 PM after sample 21
Autozero:              21-Feb-23 7:19:21 PM after sample 21
Autozero:              21-Feb-23 7:20:28 PM after sample 21
Autozero:              21-Feb-23 7:26:12 PM after sample 21
Autozero:              21-Feb-23 7:27:16 PM after sample 24
Autozero:              21-Feb-23 7:28:21 PM after sample 24
Autozero:              21-Feb-23 7:30:14 PM after sample 24
Autozero:              21-Feb-23 7:30:38 PM after sample 28
Autozero:              21-Feb-23 7:30:57 PM after sample 28
Autozero:              21-Feb-23 7:33:21 PM after sample 28
Autozero:              21-Feb-23 7:34:12 PM after sample 10
Autozero:              21-Feb-23 7:36:37 PM after sample 10
Autozero:              21-Feb-23 7:39:35 PM after sample Origin
Autozero:              21-Feb-23 7:40:10 PM after sample ORIGIN
Autozero:              21-Feb-23 7:40:37 PM after sample ORIGIN
Measured:              21-Feb-23 7:40:42 PM by John KYU-CHEMISTRY DEPT
Result filename:       Okello Pb.rfx


Sample: 2
    205 nm    211 nm    215 nm
   0.455 A   0.427 A   0.600 A

Sample: 15
    205 nm    211 nm    215 nm
   0.478 A   0.415 A   0.596 A

Sample: 4
    205 nm    211 nm    215 nm
   0.497 A   0.471 A   0.649 A

Sample: 33
    205 nm    211 nm    215 nm
   0.479 A   0.511 A   0.718 A

Sample: 10
    205 nm    211 nm    215 nm
   0.513 A   0.516 A   0.713 A

Sample: 32
    205 nm    211 nm    215 nm
   0.488 A   0.410 A   0.561 A

Sample: 19
    205 nm    211 nm    215 nm

21-Feb-23 7:42:13 PM   VISIONlitekyuCHEM                          Page 1    of    7
```

```
   0.507 A   0.505 A   0.733 A

Sample: 25
    205 nm    211 nm    215 nm
   0.475 A   0.386 A   0.520 A

Sample: 1A
    205 nm    211 nm    215 nm
   0.469 A   0.535 A   0.792 A

Sample: 1B
    205 nm    211 nm    215 nm
   0.479 A   0.435 A   0.604 A

Sample: 32
    205 nm    211 nm    215 nm
   0.471 A   0.400 A   0.566 A

Sample: 19
    205 nm    211 nm    215 nm
   0.490 A   0.508 A   0.727 A

Sample: 25
    205 nm    211 nm    215 nm
   0.486 A   0.403 A   0.536 A

Sample: 1A
    205 nm    211 nm    215 nm
   0.485 A   0.537 A   0.790 A

Sample: 1B
    205 nm    211 nm    215 nm
   0.492 A   0.430 A   0.586 A

Sample: 32
    205 nm    211 nm    215 nm
   0.468 A   0.413 A   0.566 A

Sample: 19
    205 nm    211 nm    215 nm
   0.505 A   0.513 A   0.723 A

Sample: 25
    205 nm    211 nm    215 nm
   0.478 A   0.407 A   0.532 A

Sample: 1A
    205 nm    211 nm    215 nm
   0.471 A   0.542 A   0.787 A

Sample: 1B
    205 nm    211 nm    215 nm
   0.474 A   0.422 A   0.577 A

Sample: 14
    205 nm    211 nm    215 nm
   0.489 A   0.416 A   0.559 A

Sample: 29
    205 nm    211 nm    215 nm
   0.479 A   0.459 A   0.632 A
```

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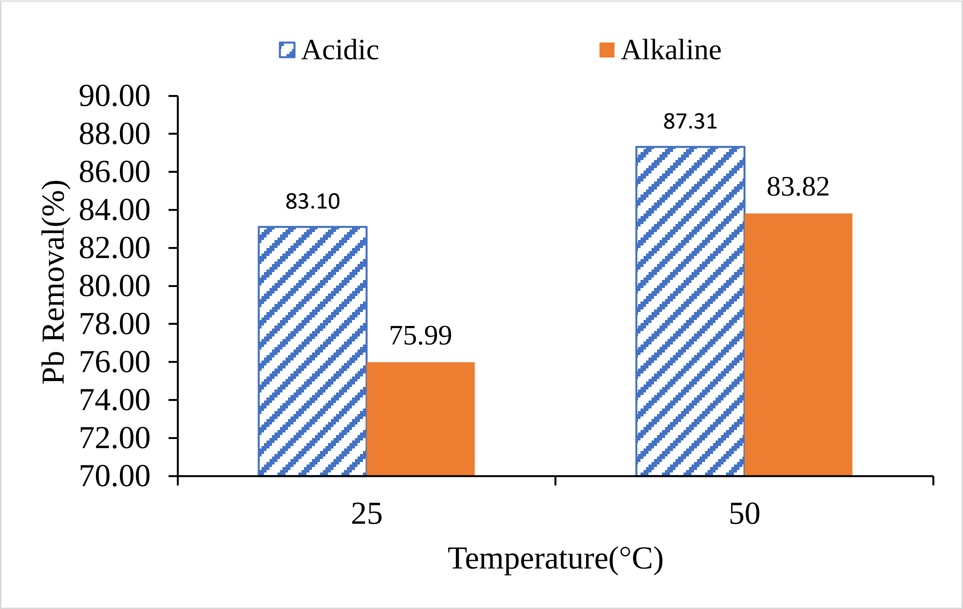
```
    205 nm     211 nm     215 nm
   0.522 A    0.579 A    0.884 A

Sample: 24
    205 nm     211 nm     215 nm
   0.466 A    0.326 A    0.437 A

Sample: 16
    205 nm     211 nm     215 nm
   0.475 A    0.423 A    0.575 A

Sample: 26
    205 nm     211 nm     215 nm
   0.484 A    0.424 A    0.576 A

Sample: 11
    205 nm     211 nm     215 nm
   0.486 A    0.386 A    0.500 A

Sample: 30
    205 nm     211 nm     215 nm
   0.502 A    0.589 A    0.884 A

Sample: 24
    205 nm     211 nm     215 nm
   0.463 A    0.335 A    0.441 A

Sample: 28
    205 nm     211 nm     215 nm
   0.480 A    0.366 A    0.494 A

Sample: 28
    205 nm     211 nm     215 nm
   0.494 A    0.389 A    0.535 A

Sample: 28
    205 nm     211 nm     215 nm
   0.486 A    0.393 A    0.536 A

Sample: 2
    205 nm     211 nm     215 nm
   0.466 A    0.416 A    0.598 A

Sample: 15
    205 nm     211 nm     215 nm
   0.503 A    0.478 A    0.655 A

Sample: 4
    205 nm     211 nm     215 nm
   0.490 A    0.378 A    0.473 A

Sample: 33
    205 nm     211 nm     215 nm
   0.477 A    0.514 A    0.743 A

Sample: 10
    205 nm     211 nm     215 nm
   0.486 A    0.446 A    0.598 A

Sample: 2
    205 nm     211 nm     215 nm
   0.457 A    0.425 A    0.595 A
```

```
Sample: 15
   205 nm    211 nm    215 nm
  0.471 A   0.421 A   0.597 A

Sample: 4
   205 nm    211 nm    215 nm
  0.479 A   0.385 A   0.468 A

Sample: 33
   205 nm    211 nm    215 nm
  0.498 A   0.500 A   0.731 A

Sample: 10
   205 nm    211 nm    215 nm
  0.496 A   0.465 A   0.624 A

Sample: Origin
   205 nm    211 nm    215 nm
  0.499 A   0.402 A   0.520 A

Sample: ORIGIN
   205 nm    211 nm    215 nm
  0.131 A   0.303 A   0.889 A

Sample: ORIGIN
   205 nm    211 nm    215 nm
  0.137 A   0.304 A   0.889 A

Sample: ORIGIN
   205 nm    211 nm    215 nm
  0.137 A   0.301 A   0.889 A
```

Appendix 8: Additional experimental results of lead removal by zeolite

i) Percentage removal of lead ions at constant contact time of 20 minutes

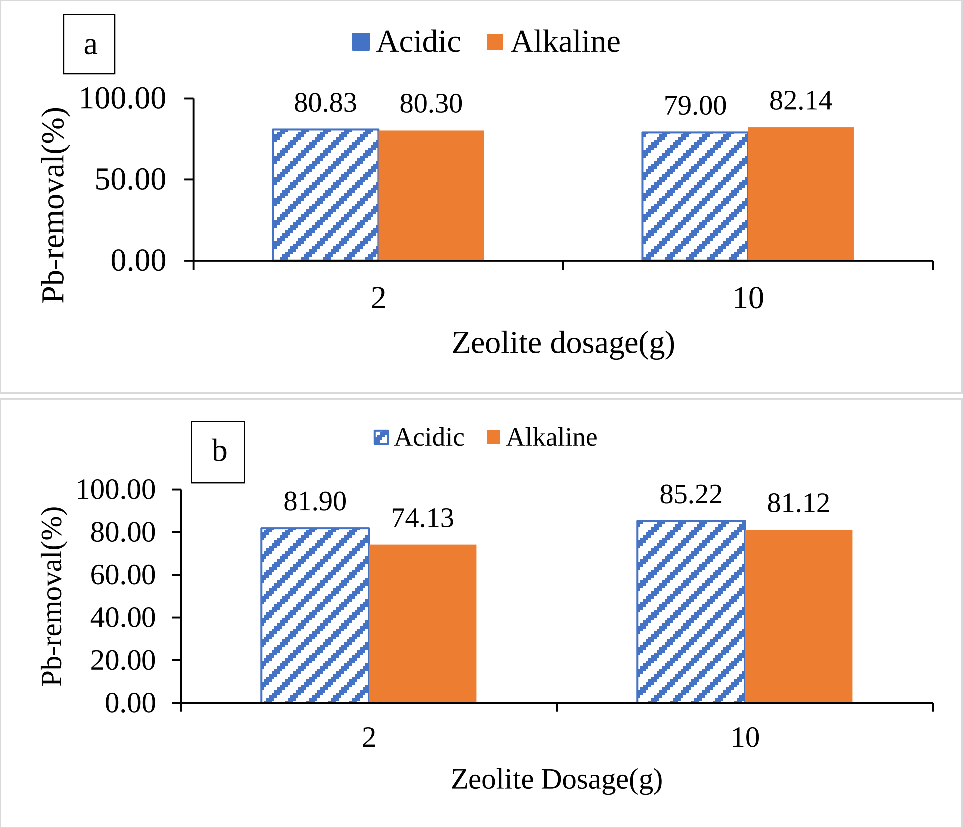
RUN B	RUN A	Temp. (°C)	Contact time (Min.)	Zeolite Dosage (Grams)	pH	Removal (%)-A	pH	Removal (%)-B
33	4	25	20	6	Acidic	83.10	Alkaline	75.99
14	27	37.5	20	2	Acidic	68.45	Alkaline	82.45
20	29	37.5	20	10	Acidic	80.73	Alkaline	83.29
28	24	50	20	6	Acidic	87.31	Alkaline	83.82



Variation of percentage removal with temperature at constant contact time of 20 minutes

ii) Percentage removal of lead ions at constant contact time and temperature

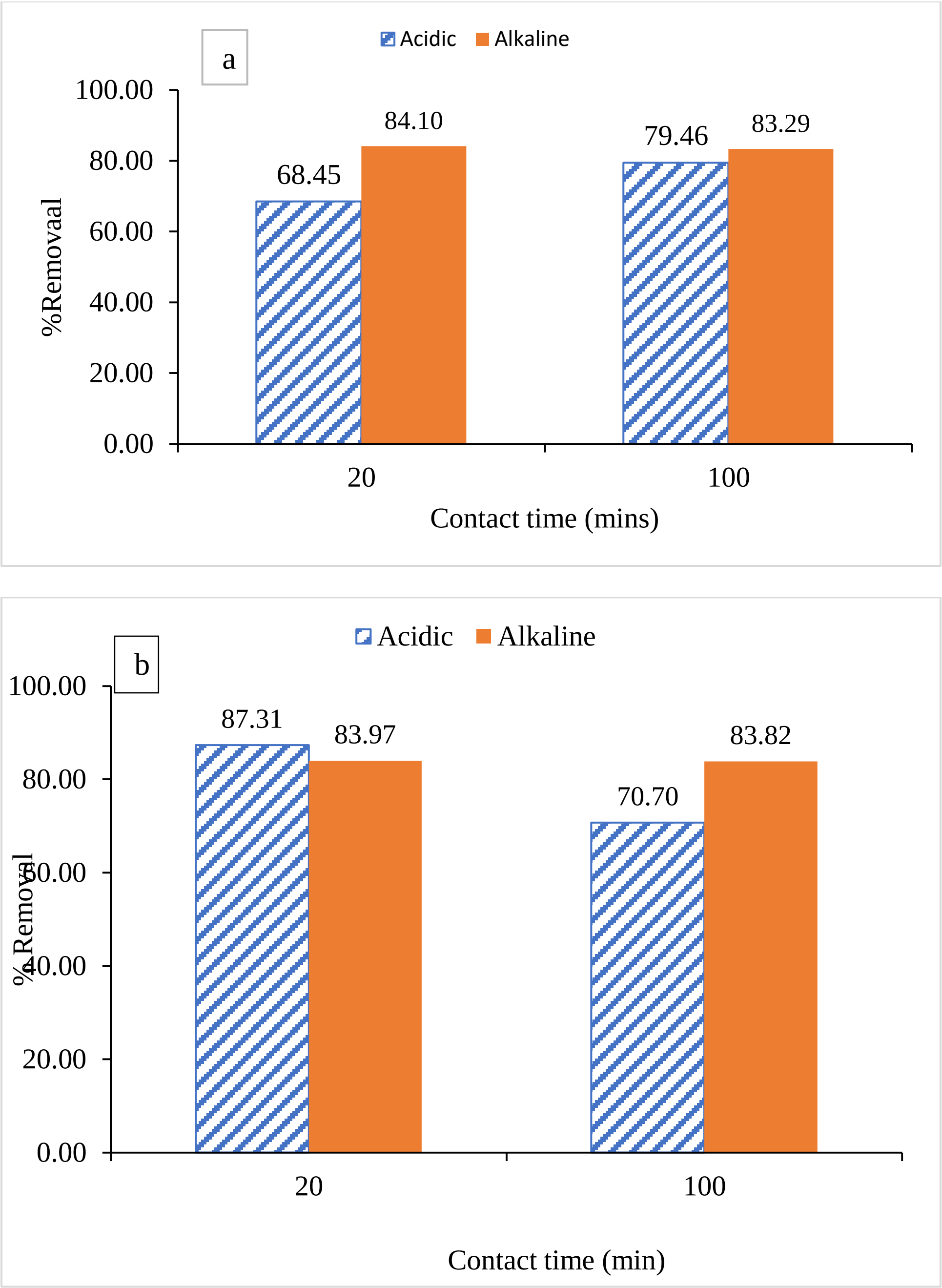
RUN B	RUN A	Temp (°C)	Contact time (Min.)	Zeolite Dosage (Grams)	pH	Removal (%)-A	pH	Removal (%)-B
15	2	25	60	2	Acidic	80.83	Alkaline	80.30
32	10	25	60	10	Acidic	79.00	Alkaline	82.14
13	6	37.5	60	6	Acidic	73.80	Alkaline	81.15
3	16	50	60	2	Acidic	81.90	Alkaline	74.13
26	21	50	60	10	Acidic	85.22	Alkaline	81.12



Variation of removal with varying zeolite dosage, constant temperature and contact time

iii) Removal of lead ions at constant temperature (37.5 & 50)°C contact Zeolite dosage of 2grams

RUN B	RUN A	Temp (°C)	Contact time (Min.)	Zeolite Dosage (Grams)	pH	Removal (%)-A	pH	Removal (%)-B
15	2	25	60	2	Acidic	80.83	Alkaline	80.30
12	27	37.5	20	2	Acidic	68.45	Alkaline	84.10
20	31	37.5	100	2	Acidic	79.46	Alkaline	83.29
26	16	50	60	2	Acidic	81.90	Alkaline	81.12
25	4	25	20	6	Acidic	83.10	Alkaline	83.29
33	19	25	100	6	Acidic	76.21	Alkaline	75.99
34	1	37.5	60	6	Acidic	73.80	Alkaline	81.15
11	24	50	20	6	Acidic	87.31	Alkaline	83.97
28	30	50	100	6	Acidic	70.70	Alkaline	83.82
32	10	25	60	10	Acidic	79.00	Alkaline	82.14
9	8	37.5	100	10	Acidic	83.11	Alkaline	80.35
14	29	37.5	20	10	Acidic	80.73	Alkaline	82.45
3	21	50	60	10	Acidic	85.22	Alkaline	74.13



Removal of lead at constant temperature (37.5 & 50) °C contact Zeolite dosage of 2grams