MAKERERE UNIVERSITY

ASSESSMENT OF HARDNESS OF WATER SAMPLES FROM SELECTED CLOSED WATER SYSTEM IN KITGUM MUNICIPALITY, KITGUM DISTRICT, NORTHERN UGANDA

BY

OPIRA STEPHEN

21/U/22179/PS

2100722179

BLT III

A RESEARCH PROJECT REPORT SUBMITTED TO THE COLLEGE OF VETERINARY MEDICINE, ANIMAL RESOURCES AND BIOSECURITY IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF BACHELOR OF BIOMEDICAL LABORATORY TECHNOLOGY OF MAKERERE UNIVERSITY

JUNE, 2024

DECLARATION

I **Stephen Opira,** declare that the information presented in this research report is original and has never been used before for any award of any category, where work of other people is used, it is quoted in the reference.

Signature: ……………………………………………… Date: 04th-08/2024

APPROVAL

This research report has been submitted under the guidance, supervision and approval of:

Dr. Saphan Muzoora, (BVM. MSc, PhD Candidate)

Assistant Lecturer,
Department of Biotechnical and Diagnostic Sciences,
School of Biosecurity Biotechnical and Laboratory Sciences,
College of Veterinary Medicine, Animal Resources and Biosecurity,
Makerere University, P. O Box 7062, Kampala

Signature: ……………………………………………… Date: 05/08/2024

DEDICATION

I dedicate this report to my beloved parents and family.

ACKNOWLEDGEMENT

I thank the almighty God who has enabled me this far. Special appreciation to my family and friends. I thank the Area Manager and the Quality Officer National Water and Sewerage Corporation Kitgum for the support they granted to me during my research project. I also thank My Supervisor Dr. Saphan for the support and guidance he gave me during the process of this project. I thank my Colleagues with whom we shared ideas and discussions. May the Almighty God bless them abundantly.

TABLE OF CONTENT

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

ABL	Analytical Biochemistry Laboratory
$CaCO_3$	Calcium Carbonate
COVAB	College of Veterinary Medicine Animal Resources and Biosecurity
EDTA	Ethylene-Diamine-Tetraacetic Acid
HCL	Hydrochloric Acid
mg/L	Milligrams per litre
$MgCO_3$	Magnesium Carbonate
Ppm	Parts per million
SO_4	Sulphate
TCU	True Colour Units
Fe	Iron
NWSC	National Water and Sewerage Corporation
PSP	Public Stand Post
CCP	Central Critical Point
pH	Potential of Hydrogen
SPSS	Statistical Package for the Social Sciences
WHO	World Health Organization

DEFINITION OF OPERATIONAL TERMS

Portable Water: Water that is safe and suitable for human consumption

Drinking Water: Portable water intended for human consumption

Treated Water: Water that has undergone thorough processes such as flocculation, coagulation, sedimentation, filtration and disinfection

Natural portable water: Water that is fit for human consumption without undergoing any form of treatment which will alter its original chemical composition and bacteriological purity.

Conventional treatment: Process involving deliberate coagulation, flocculation, sedimentation, filtration and disinfection to improve the safety and quality of the finished drinking water to consumers.

Water quality: The chemical, physical and bacteriological characteristics of water in respect to suitability for human consumption.

Safe Water: Water that is free from physical, chemical, and/or biological substances in concentrations which could cause illness or injury to consumers.

Surveillance: An independent, continuous, specific measurement, observation and reporting for the purpose of water quality management and operational activities.

Portable water distribution system: Public or private water systems providing consumers with tap water suitable for direct consumption.

Approved water supply: Sources of water that has been inspected and approved by the competent authority for human consumption.

Apparent colour of Water: Colour due to dissolved substances and undissolved suspended matter, determined in the original water sample without filtration or centrifugation.

Colour of Water: Optical property that causes the changing of the spectral composition of transmitted visible light.

Specific colour: Ration between the true colour of a sample and its concentration of dissolved organic carbon.

True colour of Water: Colour due only to dissolved substances determined after filtration of the water sample through a membrane of filter of pore size 0.45µm.

Raw Composite: This is a mixture of raw water from different boreholes to make one raw Water samples.

Water hardness: Is the measured content of divalent metal cations (dissolved Ca++ and Mg++) in Water.

Permanent hardness: Hardness due to dissolved Chlorides, Nitrates and Sulfate of Calcium, Magnesium, Iron and other Metals it is not removed by boiling of Water.

Temporary hardness: Hardness caused by bicarbonates of Calcium and Magnesium and it is removed by boiling.

Complexometric titration: is a form of volumetric analysis in which the formation of a colored complex is used to indicate the end point of a titration.

LIST OF TABLES

ABSTRACT

This study conducted in Kitgum Municipality evaluated the water quality of closed water systems, revealing that 96.7% of samples were classified as very hard water. The mean concentrations of calcium, magnesium, and iron were 79.87 mg/L, 48.689 mg/L, and 0.525 mg/L respectively, with varying ranges. These findings were compared against USGS and WHO standards, highlighting consistent classification of very hard water and occasional iron levels exceeding WHO guidelines. Geological factors, including limestone and dolomite deposits, were proposed as contributors to high mineral content, while iron presence could have stemmed from local soil and Rock leaching or infrastructure corrosion.

Implications of these findings span public health and infrastructure domains, with health risks linked to cardiovascular diseases, Kidney stone and other organ damages from prolonged hard water consumption, alongside dermatological issues from elevated iron and iron overload. Infrastructure faces challenges like scaling and system deterioration, escalating maintenance costs and impairing domestic and industrial appliances efficiency. Mitigating strategies such as ion exchange, reverse osmosis and Lime Soda softening were proposed, contingent on application scale, water quality targets, cost-efficiency, and energy use. Comprehensive monitoring and public education on health risks are recommended to ensure sustainable water quality management in Kitgum Municipality.

CHAPTER ONE

INTRODUCTION

1.1 Background

Water is an essential resource that sustains life and ensures the well-being of individuals and communities (WHO, 2022). It plays a vital role in various aspects of life, including drinking, sanitation, agriculture, and industrial processes. However, the quality of Water can vary significantly, and one important characteristic that is often assessed is Water hardness others being pH and turbidity (Abdullah, 2017). Hardness of Water depends on a complex mixture of both the cations and anions, and predominantly contributed by Carbonates and bicarbonates of Calcium and Magnesium (Sumalapao et al., 2017). It is an index of its capacity to precipitate Soap. Water hardness is directly proportional to the concentration of Ca++ and Mg++ ions along with some other polyvalent metal ions like Iron, Barium, and Strontium. Besides Ca++ and Mg++, other cations are usually present in complex form associated with some organic constituents and their role in causing Water hardness is very minimal, negligible and usually difficult to define (WHO, 2012).

Natural Water hardness usually ranges from 10 to more than 500mg/L. Values above 500mg/L are uncommon (EPA, 1976). United States Geological Survey (USGS) has classified the water with hardness ranging from 0-60 mg/L as soft, 61-120 mg/L as moderately hard, and 121-180 mg/L as hard and with values exceeding 180 mg/L as very hard. WHO (1984) standards, 500 mg/L is the maximum permissible limit of hardness in any Water to be used as potable Water. Water with hardness values less than 10 mg/L are not also suitable due to their low buffering capacity and more corrosive ability. Drinking hard Water pose a potential impact on health such as Cardiovascular disease, Kidney disorder, Digestive disorder, Cerebrovascular disorder, cancer and many others. Hard water Magnesium hardness in association with Sulphate ions poses a laxative effect (tending to stimulate or facilitate evacuation of the bowels) (Abbasi 1998.) Variations in the hardness of portable water result in some physiological disorders in Human beings due to variations in the osmotic potential of intestinal blood and body fluid (Kakati, 2010). A significant correlation has been reported between hardness and incidences of Cardiovascular diseases (Tebbutt,1998)., (Porter 1974)

Drinking Water containing Iron (Fe) excessive of quantity above the recommended standard is detrimental to Human health causing Skin conditions such as Acne, iron can clog up Skin pores resulting into breakouts or damage to the Skin cells, exposure to high Iron can also lead to damage to internal Organs such as the Heart, Pancreas, and Liver due to Iron overload (Gopal et al., 2020)

Up until 2013 when National Water and sewerage corporation (NWSC) started its operation in the district, the Population had very limited access to safe Water and other domestic use. There were few Boreholes especially within the Town council then forcing many people to use unsafe Water (Eyasu H Teshale, Christopher M Howard et al., 2010) and heavily contaminated and polluted Water from River Pager and other nearby open Waterwells located very close to the Town which are heavily contaminated by Humans and Animals activities. This has often resulted in serious health concerns of Typhoid fever, Schistosomiasis, Eye infections, Skin infections, dysentery, diarrhea, Amoebiasis, and an outbreak of Cholera and Hepatitis E (Betty Nannyonga, et al., 2012). These problems have resulted in deaths, health complications and financial losses to the affected population. Since the establishment of portable Water distribution systems especially within the Municipality by NWSC, there has been a significant improvement in the conditions of access to safe Water (JK Tumwine, KK Munguti., 2002); however, there is still inadequacy to access and shortages of supply to most areas of the Municipal due to the growing population. Because there is no adequate supply of Water from a big reservoir, NWSC has installed Water Pumps in various Borehole points to form a Raw composite in order to increase the volume supplied to the Population amongst others by putting PSP and CCP. Though there is still a persistence of other associated problems of the Water distributed such as hardness and unpleasant taste. NWSC has a mandate of conducting Water surveillance in the Municipality in order to ensure Water quality management and also approve private Water supply sources to institutions within the Municipal.

The assessment of water hardness involves determining the concentration of Calcium and Magnesium ions in the Water sample through various methods, such as titration with ethylenediaminetetraacetic acid (EDTA). The hardness of water is commonly expressed in milligrams per liter (mg/L) or parts per million (ppm) of calcium carbonate ($CaCO_3$) equivalent. (WHO, 2009).

Previous studies have reported varying levels of Water hardness in different regions of Uganda, with some areas experiencing high hardness levels that exceed the recommended limits set by international standards. For instance, a study conducted by Nabikolo et al. (2020) in Kampala, Uganda, found that the Water hardness ranged from 150 to 422 mg/L, which exceeded the acceptable limit of 200 mg/L set by the World Health Organization (WHO, 2012). This research therefore aimed to assess the hardness of Water samples from selected closed Water systems in Kitgum Municipality, Kitgum District, Northern Uganda. The study employed the EDTA titration method to determine the concentration of Calcium and Magnesium ions in the Water samples.

1.2 Problem statement

In Kitgum Municipality, located in Kitgum District, Northern Uganda, there is a growing concern regarding the water quality issues of hardness and unpleasant taste in drinking water. The municipality primarily relies on closed water systems such as boreholes and piped water to meet the water needs of its population. This reliance is due to unavailability of a large water body and the seasonal and heavily polluted nature of the nearby River Pager, which cannot serve as a reliable water source due to contamination from human and animal activities, as highlighted by Gravity et al. (2023).

Despite the critical role of these closed water systems, there exists a significant knowledge gap regarding the levels of water hardness within them. Water hardness, attributed mainly to high concentrations of minerals like calcium and magnesium, poses potential risks to public health, domestic plumbing systems, electrical appliances, and industrial processes. The absence of comprehensive data on water hardness levels hinders accurate assessment of these risks and impedes the development of targeted interventions to mitigate adverse effects.

Therefore, there is need for a detailed assessment of water hardness levels in selected boreholes and piped water sources across Kitgum Municipality. This assessment should involve systematic sampling and rigorous analysis of water samples to quantify and understand the extent of water hardness issues. By obtaining precise data on water quality parameters, stakeholders can better identify areas of concern, prioritize intervention strategies, and collaborate effectively with local authorities and community stakeholders to improve water quality, safeguard public health, and enhance the sustainability of water supply systems in the municipality."

1.3 Study objectives

1.3.1 General objective

To assess hardness of Water samples from selected closed Water system in Kitgum municipality, Kitgum district, Northern Uganda.

1.3.2 Specific objectives

i. To determine the concentration of Calcium and Magnesium ions in the Water samples obtained from closed Water systems in Kitgum municipality.
ii. To determine the concentration of total Iron in the Water Samples obtained from the closed water points within Kitgum Municipality.

1.4 Research questions

i. What is the concentration of Calcium and Magnesium ions in the Water samples obtained from closed water systems in Kitgum municipality?
ii. What are the observed and reported problems caused by the effect of Water Hardness within Kitgum Municipality.

1.5 Justification

The assessment of Water hardness in Kitgum Municipality is crucial for several reasons. Firstly, understanding the hardness levels of the Water is essential for ensuring the provision of clean and safe drinking Water to the local population. Excessive hardness of Water can have negative health effects, such as contributing to the occurrence of Kidney Stones and Cardiovascular diseases. Therefore, it is vital to assess the Water quality to protect the health and well-being of the residents. In addition, excessive Water hardness can affect the infrastructure and plumbing systems in the region. The presence of high levels of dissolved minerals can lead to scaling in pipes and appliances, reducing their efficiency and lifespan. By assessing and understanding the hardness levels, appropriate measures can be taken to mitigate the negative impacts on infrastructure and reduce maintenance costs.

1.6 Significance

The findings of this research can contribute to the development of Water treatment strategies and interventions such as implementing Lime Soda water softening method, ion exchange, reverse osmosis or applying suitable Water treatment Chemicals, to reduce the hardness and improve the overall quality of the Water supply. In addition to the above, results will contribute to the understanding of the potential risks associated with the presence of high levels of hardness in the closed Water systems. This knowledge can inform decision-making processes and interventions aimed at improving the Water quality and ensuring the provision of clean and safe Water to the residents by the National Water and Sewerage Corporation, the body responsible for the provision of safe Water to the Population of the Municipality.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water

Water is a vital resource for human survival and plays a crucial role in various aspects of life. According to Prüss-Üstün et al. (2019), access to clean and safe Water is a basic human right and essential for humans and Animals health and well-being. Water is used for drinking, sanitation, agriculture, and industrial processes, making it an indispensable resource (Abdullah, 2017). However, elevated levels in hardness of water can impedes human activities.

2.2 Uses of Water

Water serves numerous purposes in society, in terms of domestic use, water is essential for drinking, cooking, and personal hygiene (Tang, Godskesen, et al., 2021). In agricultural activities, Water is necessary for irrigation and livestock watering. Industries rely on Water for manufacturing processes, cooling systems, and cleaning (Walekhwa et al., 2022). Additionally, water is crucial for maintaining environmental integrity, such as in preserving wetlands and supporting aquatic ecosystems (Klosok-Bazan et al., 2018).

2.3 Communal Sources of Water in Kitgum District

In Kitgum District, Northern Uganda, communal sources of Water, such as Boreholes and piped Water systems, are commonly used to meet the Water needs of the population. Boreholes provide groundwater, while piped water systems distribute Water from centralized sources to multiple households and public facilities (Gravity et al., 2023)

2.4 Hardness of Water

Hardness of Water is a phenomenon which occurs when Soap does not lather easily with Water, scales are produced in pipes and Boilers/Kettles. Hardness is caused by metallic salts (ions) of Calcium and Magnesium and sometimes Fe. These salts are usually in the form of bicarbonate, sulphates and chlorides (Saana et al., 2016). The hardness of water is influenced by geological factors, such as the presence of limestone and dolomite rocks, which contain Calcium and Magnesium Carbonates ($CaCO_3$ and $MgCO_3$).

2.4.1 Cause of water hardness

When Water comes into contact with these rocks, it dissolves the minerals, resulting in increased hardness (Gu et al., 1996)

Other factors contributing to Water hardness include the leaching of minerals from soil and rocks, as well as industrial activities that release minerals into Water sources (WHO, 2009). Human activities, such as the use of certain types of detergents and Soaps, can also contribute to increased water hardness (Klosok-Bazan et al., 2018).

2.5 Types of Water Hardness

There are two main types of Water hardness: temporary hardness and permanent hardness. Temporary hardness is caused by the presence of bicarbonate ions (HCO_3^-) in the water, which can be removed by boiling the water or through the addition of lime or soda ash. Permanent hardness, on the other hand, is caused by the presence of sulfate, chloride, and nitrate ions, which cannot be easily removed by boiling (Ramya et al., 2015)

2.6 Effects/Demerits of Hard Water

The presence of excessive hardness in Water can have various negative effects. One of the most common issues is the formation of scale or mineral deposits in plumbing systems, pipes, and appliances. These deposits can reduce the flow rate of Water, clog Pipes, and decrease the efficiency of plumbing systems and appliances (Betz & Noll, 1999). Hard Water can also cause scaling in boilers and cooling systems, leading to decreased efficiency and increased energy consumption (Tang, Rygaard, et al., 2021). Elevated levels of Iron in water can promote the growth of Iron bacteria, which form slimy deposits in plumbing systems and can lead to clogging and corrosion of Pipes (Serrano, M., Suarez, L., Ferrer, I., et al., 2015)

Presence of dissolved substances and undissolved particulate matters in Water can also affect the Colour of Water (apparent colour of Water). The specific Colour of Water when determined should be within the allowable range, however the most important is the true colour units of Water which signifies a direct relationship with the amount of dissolved substances present in the Water. High TCU of Water makes it unpleasant for consumers to use. Colour in underground Water maybe due to the presence of Coloured Organic substances, presence of Metals such as Iron, Manganese and Copper (Onyutha et al., 2022)

In terms of human health, consuming hard Water has been associated with an increased risk of Kidney Stone formation, Cardiovascular diseases, Atherosclerosis, Barceloux, D. G. (2008). The presence of excessive dissolved minerals can also affect the taste and odour of Water (Ikeme et al., 2014). Furthermore, very hard water can be harsh on the skin and hair, leading to dryness, irritation, and exacerbation of conditions like eczema and dermatitis. The mineral deposits in hard water can also leave a residue on the skin and hair, making them feel dry and dull, American Academy of Dermatology. (n.d.). *Eczema.*

2.7 Determination of Water Hardness

The hardness of Water is commonly determined by measuring the concentrations of Calcium and Magnesium ions present in the Water sample (Napacho & Manyele, 2010). Various methods can be used for this purpose, including titration with Ethylenediaminetetraacetic acid (EDTA), flame atomic absorption spectrophotometry, and inductively coupled plasma-optical emission spectrometry (ICP-OES) (Musa et al., 2019)

The EDTA titration method is widely utilized for the determination of Water hardness. In this method, a Calcium indicator dye, Eriochrome black T, was added to the Water sample in a Conical Flask. Then, a standardized solution of EDTA from a Burette was slowly added to solution in the Flask until a complex formed with the calcium and magnesium ions. The point at which the color change occurred indicated the endpoint of the titration, and the volume of EDTA solution used was used to calculate the concentration of calcium and magnesium ions and expressed the hardness in milligrams per liter (mg/L) or parts per million (ppm) of calcium carbonate (CaCO3) equivalent (General Chemistry Lab, 2017).

Description	**Mg/l or ppm**
Soft	0 - 17.1
Slightly hard	17.2 - 60
Moderately hard	61- 120
Hard	121 - 180
Very hard	181 and over

Source: U.S. Department of Interior and the Water Quality Association (Tang, Godskesen, et al., 2021).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Research design

This was an experimental study that assessed the hardness of Water samples from selected closed Water systems in Kitgum Municipality, Kitgum District, Northern Uganda.

3.2 Study area

Kitgum Municipality, located in Kitgum District, Northern Uganda, was the study area for this research. The municipality is the administrative center of the district and is predominantly urban, with a mix of residential, commercial, and industrial areas. The closed Water systems, including Boreholes and piped Water networks, were selected within the municipality for the sample collection.

3.3 Study population

The study population consisted of all closed water systems in Kitgum Municipality.

3.3.1 Inclusion criteria

Only water samples from functioning boreholes and piped Water systems within the municipality.

3.3.2 Exclusion criteria

Closed water sources that were non-functional or inaccessible during the study period.

Open Water sources within the Municipality were excluded.

3.4 Sample size determination and Sampling strategy

The sample size was determined based on the available closed water systems in Kitgum Municipality. A stratified random sampling technique was used to ensure representation from different areas within the municipality. The total sample size of 30 was used based on the central limit theorem (Walekhwa *et al.*, 2022) for estimating unknown proportions, considering a 5% desired level of precision and 95% confidence level.

3.5 Sample collection and transportation

One liter of Water samples was collected from each of the selected closed Water systems in sterile plastic containers. Prior to sample collection, the containers were thoroughly rinsed with deionized Water to minimize any contamination. Samples were collected directly from the outlets of the Water sources to ensure that the Water represents the actual quality of the supply. The samples were labeled and stored in cool and dark containers to prevent any changes in their chemical composition. The samples were then transported to Analytical Laboratory National Water and Sewerage Corporation Kitgum for analysis.

3.6 Sample processing.

Ensured all laboratory equipment (pipettes, burettes, glassware) were clean, calibrated, and ready for use. Wore appropriate PPE (gloves, lab coat, safety glasses) during chemical handling. Prepared standard solutions of EDTA and Ammonia buffer according to established procedures. Included blank samples (distilled water) and standard reference materials for quality control. Filtered the Water samples using Whatman Grade 934-AH effective for removal of suspended solids in Water and removal of turbidity.

Disposed off waste materials following hazardous waste disposal guidelines.

3.6.1 Determination of water hardness using EDTA titration method.

50 ml of each water samples were measured into separate conical flask. 2 ml of Ammonia buffer solution were added to each sample, a small amount of Eriochrome black T added to each sample. The samples were then titrated with a standardized Ethylenediaminetetraacetic (EDTA) up to the observance of a blue colouration. The titre values of both raw and final Water samples were multiplied with (44.892) as the approved conversion factor where the hardness of Water was expressed in mg/L.

3.6.2 Test for Calcium hardness using Complexometric Titration.

To determine concentration of Calcium ions, 50 ml of the water samples was measured into separate conical flasks and 2 ml of 0.1M NaOH added to each sample. A small amount of Meroxide indicator was added to the samples to obtain a violet colouration. The samples were then titrated with Ethylenediaminetetraacetic acid (EDTA) to permanent pink colour. The titre values were multiplied with (18.025) as the standard conversion factor and the concentrations expressed in mg/L.

3.6.3 Test for Magnesium Hardness using Complexometric Titration.

In order to determine the magnesium hardness, immediately after the end point of calcium hardness, to the same samples were added 3ml of 5.0M HCl then 6 ml of concentrated ammonia solution was also added and small amount of Eriochrome black T indicator, titrated with EDTA until a faint blue color appeared. The titre values were multiplied with (18.025) as the standard conversion factor and the concentrations expressed in mg/L.

3.6.4 Test for total Iron

Determination of total Iron in the Water samples was done using Phenanthroline Spectrophotometric technique. In this method, the samples were prepared by adding a reducing agent, hydroxylamine, to convert all iron to the +2-oxidation state. The pH was adjusted to a value between 6.0 and 9.0 using sodium acetate. Iron ions in the Water samples reacted with a reagent (1,10-phenanthroline) to form a Red Coloured complex. The absorbance of the Coloured complex was measured using a UV-Vis Spectrophotometer at a wavelength of 508 nm, which is the wavelength of maximum absorbance. The absorbance data was analyzed to determine the concentration of iron using a calibration curve. The absorbance of the complex formed was directly proportional to the concentration of Iron in the samples.

3.7 Data Analysis

The data collected from the Water samples was analyzed using SPSS version 27. The mean and standard deviation, were calculated to summarize the hardness levels in the Water samples. The results were interpreted in reference to limits set by international standards.

3.8 Quality Control

To ensure the accuracy and reliability of the results, several quality control measures were implemented. These measures included calibrating laboratory equipment regularly, using standardized protocols for sample collection and analysis (US EAS 12), and conducting duplicate analyses for a subset of samples to assess the reproducibility of the results.

The study strictly adhered to protocols for sample handling, storage, and disposal to minimize any potential risks or negative impacts on the environment.

3.9 Ethical Consideration

Approval letter was obtained from College of Veterinary Medicine, Animal Resources and Biosecurity before the commencement of the research.

Permission was obtained from the authorities responsible for the closed water systems in Kitgum Municipality to collect the water samples.

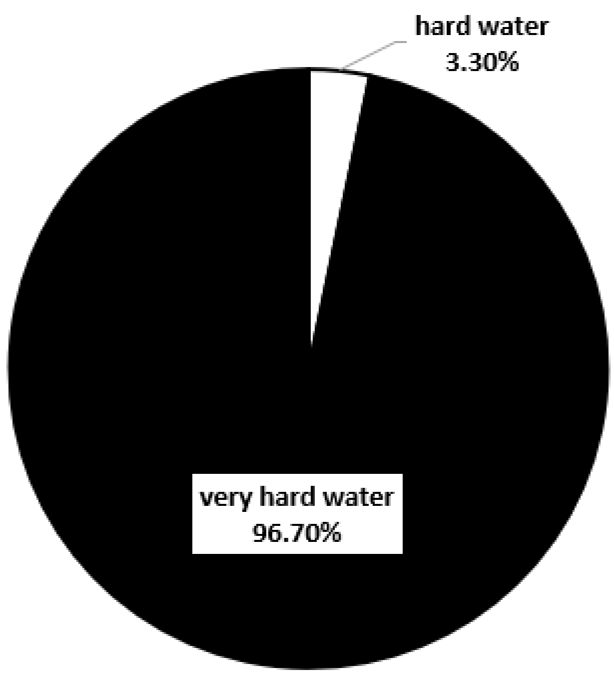
Confidentiality of data and privacy of water sources involved was ensured throughout the study.

CHAPTER FOUR

RESULTS

4.1 Categories of water hardness from water samples obtained from closed water systems in Kitgum municipality.

Out of the 30 Water samples obtained from closed Water systems in Kitgum municipality, 29 (96.7%) were classified as very hard water and only 1 (3.3%) were classified as hard Water. (Figure 1).



Venn diagram showing Classification of water hardness

4.2 Concentration of calcium and magnesium ions in the water samples obtained from closed water systems in Kitgum municipality.

The mean Calcium concentrations in the 30 Water samples obtained from closed Water systems in Kitgum municipality was 79.87 mg/L ranging between 70.571 -179.299 mg/L while the mean Magnesium concentration was 48.689mg/L with a range of 43.012 -54.348 mg/L as shown in table 1.

Table 1: Concentration of calcium and magnesium ions in the water samples

		concentration (mg/L)			
Mineral	**n**	**Mean**	**Std. Error of Mean**	**Minimum**	**Maximum**
Calcium (mg/L)	30	79.87	9.299	70.571	179.299
Magnesium (mg/L)	30	48.68	5.668	43.012	54.348

4.3 Categorizations of calcium and magnesium levels

Using a cut off of 150mg/mL and 100mg/mL for Calcium and Magnesium irons respectively, the mineral concentrations were categorized into normal/ recommended and high levels. Most of the Water samples 27 (90%) had normal calcium levels and normal magnesium levels 28(93.3%) as shown in table 2.

Table 2: Calcium and magnesium levels based on standard cut off points for portable water

Mineral		**Frequency**	**Percent**
Calcium levels	Normal	27	90
	High	3	10
Magnesium levels	Normal	28	93.3
	High	2	6.7

4.4 Concentration of total Iron in the Water Samples obtained from the closed water points within Kitgum Municipality

Out of the 30 water samples collected, the Mean iron concentration was 0.525 with a range of 0.45941-0.59013 mg/L as shown in table 3.

Table 3: Concentration of total Iron in the Water Samples

		Concentration mg/L			
Mineral	**n**	**Mean**	**Std. Error of Mean**	**Minimum**	**Maximum**
Iron (mg/L)	30	0.52477	0.06536	0.45941	0.59013

The mean iron concentration of 0.52477 mg/L exceeds the WHO guideline of 0.3 mg/L. Therefore, based on this standard, the iron level would be categorized as Moderately Polluted. According to WHO guidelines, an iron concentration of 0.52477 mg/L falls within the category of moderately polluted water. This categorization is based on ensuring that drinking Water meets standards that minimize health risks associated with elevated levels of iron, particularly in terms of taste, odor, and potential health effects from long-term consumption.

CHAPTER FIVE

DISCUSSION

This study determined that 96.7% of the water samples obtained from closed water systems in Kitgum Municipality were classified as very hard. The mean concentration of calcium ions in the samples was 79.87 mg/L, with a range from 70.571 - 179.299 mg/L. The mean concentration of magnesium was 48.689 mg/L, ranging from 43.012 - 54.348 mg/L. Additionally, the mean iron concentration was 0.525 mg/L, with values ranging from 0.45941-0.59013 mg/L, occasionally exceeding WHO guidelines. In comparison to findings in central region, the very high hardness levels in Kitgum are outstanding. For instance, studies in Namayumba Sub-county Wakiso District have reported hardness levels up to 79.7 mg/L, which indicates finding well within acceptable limits for consumption in reference to international standards, Musumba, G., Sembatya, J. and Muloogi, D. (2022) as opposed to finding of Kitgum Municipality. Our findings are also consistent with those reported in Ethiopia that showed a high occurrence of Water hardness from Borehole samples (Shigut, Liknew, Irge, & Ahmad, 2017).

Comparing these results with standards established by the United States Geological Survey (USGS) and the World Health Organization (WHO) reveals significant insights. According to the USGS, water hardness exceeding 180 mg/L is categorized as very hard. The WHO recommends a maximum permissible limit of 500 mg/L for total hardness in potable water. The measured concentrations of calcium and magnesium in this study are consistent with the USGS classification of very hard water. Furthermore, the detected iron concentrations in some samples surpass the WHO's recommended limit of 0.3 mg/L for potable water.

The elevated levels of calcium and magnesium ions can be attributed to the geological characteristics of Kitgum Municipality, which likely include substantial deposits of limestone and dolomite. These minerals dissolve into groundwater, contributing to the high concentrations of hardness-causing ions. The presence of significant iron levels in the water samples could be due to the iron-rich soil and rock formations in the area or corrosion from iron-based infrastructure used in the water distribution system.

The implications of these findings are multifaceted, impacting both public health and infrastructure in Kitgum Municipality. Prolonged consumption of very hard water can pose health risks, including an increased incidence of cardiovascular diseases, kidney stones, and digestive issues. Elevated iron levels in drinking water can lead to dermatological problems and, with long-term exposure, potential damage to internal organs due to iron overload. From an infrastructural perspective, hard water contributes to the scaling and deterioration of plumbing systems, leading to increased maintenance costs and decreased efficiency of water-dependent appliances.

These findings underscore the necessity for implementing water treatment and softening technologies, such as ion exchange, Lime Soda softening, and reverse osmosis, to mitigate these risks and ensure safe drinking water for the residents of Kitgum Municipality. However, the choice of water treatment method for hardness depends on factors such as the scale of application (residential, commercial, industrial), water quality goals, cost considerations, and energy efficiency. Combination of methods or sequential treatment steps may also be employed to achieve desired water quality standards effectively. Regular monitoring of water quality and public education on the health risks associated with hard water and iron contamination are also recommended.

CHAPTER SIX

CONCLUSIOS AND RECOMMENDATIONS

6.1 Conclusions

This study has provided a thorough assessment of water hardness in selected closed water systems within Kitgum Municipality, highlighting significant issues with mineral content, particularly calcium, magnesium and iron. The findings indicate a prevalent problem with water hardness that surpasses international standards, reflecting the geological characteristics of the region. The high mineral content poses various challenges for public health, domestic use and industrial applications.

The health implications of consuming water with elevated levels of calcium and magnesium include increased risks of cardiovascular diseases, kidney stones and digestive disorders. Additionally, the excessive iron content in the water samples may lead to conditions such as iron overload, which can cause further health complications. These findings indicate the need for targeted public health interventions and continuous monitoring to mitigate these risks.

From an economic and environmental perspective, the high presence of hardness in Water contributes to scaling in plumbing and industrial systems, resulting in higher maintenance costs and reduced efficiency. Households face increased expenses due to the higher consumption of cleaning agents and potential damage to appliances. Addressing these challenges requires a coordinated effort to implement appropriate water treatment solutions and public awareness campaigns.

In summary, the study emphasizes the urgent need for comprehensive water quality management in Kitgum Municipality. By addressing the issues of water hardness and iron contamination, it is possible to safeguard public health, improve the efficiency of water use in both domestic and industrial settings and reduce the economic burdens associated with water hardness. Future research should focus on developing cost-effective and locally applicable solutions to ensure sustainable access to clean and safe water for the community.

6.2 Recommendations

To address the high levels of water hardness and iron content in Kitgum Municipality, it is essential to implement comprehensive water treatment solutions. Installing water softening systems such as ion exchange units, reverse osmosis, or lime softening can effectively reduce water hardness, while iron filtration systems like oxidation and filtration or catalytic media filters can lower iron concentrations to safe levels. Additionally, regular monitoring and quality control measures should be established, including routine testing of key water parameters and ensuring compliance with WHO and local regulatory standards.

Public awareness and education campaigns are crucial in informing residents about the health risks associated with consuming very hard water and water with high iron content. These campaigns should also promote water conservation practices and the use of treated water for drinking and cooking. Improving the water distribution infrastructure is equally important to minimize pipe corrosion, which contributes to elevated iron levels, and to ensure the longevity and efficiency of plumbing systems through regular maintenance.

Collaboration between local authorities, water utility companies, health agencies, and the community is vital for addressing these water quality issues comprehensively. Advocacy for policy formulation and enforcement aimed at improving water quality and ensuring safe drinking water for all residents of Kitgum Municipality is also essential.

REFERENCES

Abdullah, A. D. (2017). Modelling approaches to understand salinity variations in a highly dynamic tidal river: The case of the Shatt al-Arab river. *Modelling Approaches to Understand Salinity Variations in a Highly Dynamic Tidal River: The Case of the Shatt Al-Arab River*, 1–188. https://doi.org/10.1201/9781315115948

Boadi, N. O., Saah, S. A., Baa-Poku, F., Mensah, E. A., & Addo, M. (2020). Safety of borehole water as an alternative drinking water source. *Scientific African, 10*, e00657. doi:https://doi.org/10.1016/j.sciaf.2020.e00657

Rosen, M. R., & Lapham, W. W. (2008). Introduction to the US Geological Survey National Water-Quality Assessment (NAWQA) of ground-water quality trends and comparison to other national programs. *Journal of environmental quality, 37*(S5), S-190-S-198.

Shigut, D. A., Liknew, G., Irge, D. D., & Ahmad, T. (2017). Assessment of physico-chemical quality of borehole and spring water sources supplied to Robe Town, Oromia region, Ethiopia. *Applied Water Science*, *7*(1), 155-164. doi:10.1007/s13201-016-0502-4

Betz, J. D., & Noll, C. A. (1949). Determination of Total Hardness in Water by Direct Colorimetric Titration. *Journal AWWA*, *41*(11), 982–982. https://doi.org/10.1002/j.1551-8833.1949.tb15173.x

General Chemistry Lab. (2017). *General Chemistry II Lab #4-Determination of the Hardness of Water*. 1–6.

Gravity, O., Piped, F., & Supply, W. (2023). *Ministry of Water and Environment OROM GRAVITY FLOW PIPED WATER SUPPLY AND SANITATION*. *May*.

Gu, W., Garcia, A. E., & Schoenborn, B. P. (1996). Understanding Water. *Neutrons in Biology, March 1993*, 289–298. https://doi.org/10.1007/978-1-4615-5847-7_25

Ikeme, C. H., Dioha, I. J., Olasusi, K. A., & Chukwu, P. U. (2014). Physico-Chemical Analysis of Selected Borehole Water In Umuihi, Town Imo State, Nigeria. *International Journal of Scientific & Engineering Research*, *5*(8), 680–689.

Klosok-Bazan, I., Filipowski, M., & Stojak, M. (2018). Hardness of water analysis at the

Grotowice intake situated near Opole. *E3S Web of Conferences*, *59*, 3–6. https://doi.org/10.1051/e3sconf/20185900004

Musa, D. M., Garba, Y. I., Yusuf, M. S., & Ishaq, A. (2019). Assessment of water quality for selected boreholes and sachets water in Maigatari Town, Jigawa State, Nigeria. *Bayero Journal of Pure and Applied Sciences*, *11*(2), 122. https://doi.org/10.4314/bajopas.v11i2.14

Napacho, Z. A., & Manyele, S. V. (2010). Quality assessment of drinking water in Temeke District (part II): Characterization of chemical parameters. *African Journal of Environmental Science and Technology*, *4*(11), 775–789.

Ramya, P., Jagadeesh Babu, A., Reddy, E. T., & Rao, L. V. (2015). a Study on the Estimation of Hardness in Ground Water Samples By Edta Tritrimetric Method. *International Journal of Recent Scientific Research*, *6*(6), 4505–4507. https://doi.org/10.9790/5736-0910012628

Saana, S. B. B. M., Fosu, S. A., Sebiawu, G. E., Jackson, N., & Karikari, T. (2016). Assessment of the quality of groundwater for drinking purposes in the Upper West and Northern regions of Ghana. *SpringerPlus*, *5*(1), 1–15. https://doi.org/10.1186/s40064-016-3676-1

Sumalapao, D. E. P., Balana, A. J. T., Obias, M. P. E. U., & Reyes, Y. I. A. (2017). Hardness of tap water samples in Manila city, Philippines through complexometric titration. *National Journal of Physiology, Pharmacy and Pharmacology*, *7*(12), 1385–1389. https://doi.org/10.5455/njppp.2017.7.0723613092017

Tang, C., Godskesen, B., Aktor, H., van Rijn, M., Kristensen, J. B., Rosshaug, P. S., Albrechtsen, H. J., & Rygaard, M. (2021). Procedure for calculating the calcium carbonate precipitation potential (CCPP) in drinking water supply: Importance of temperature, ionic species and open/closed system. *Water (Switzerland)*, *13*(1). https://doi.org/10.3390/w13010042

Tang, C., Rygaard, M., Rosshaug, P. S., Kristensen, J. B., & Albrechtsen, H. J. (2021). Evaluation and comparison of centralized drinking water softening technologies: Effects on water quality indicators. *Water Research*, *203*(June). https://doi.org/10.1016/j.watres.2021.117439

Walekhwa, A. W., Ntaro, M., Kawungezi, P., Nimusiima, E., Achangwa, C., Musoke, D., & Mulogo, E. M. (2022). Water quality of improved water sources and associated factors in Kibuku District, Eastern Uganda. *Sustainable Water Resources Management*, *8*(2), 1–13.

https://doi.org/10.1007/s40899-022-00604-5

WHO, (2009). Hardness in drinking-water. Background document for development. *World Health Organisation*, *5*(3), 1–10.

WHO, (2012). Analytical methods and achievability. *WHO Annex 4*, 476–484.

WHO, (2022). Hardness in water is caused by a variety of dissolved polyvalent metallic ions, predominantly calcium and magnesium cations. It is usually expressed as milligrams of calcium carbonate per litre. Hardness is the traditional measure of the capacity of 376. *Chemical Fact Sheets: Hardness*, 376–377.

APPENDICIES

Appendix I: Introductory letter from the Dean College of Veterinary Medicine, Animal Resources and Biosecurity.

MAKERERE UNIVERSITY

COLLEGE OF VETERINARY MEDICINE, ANIMAL RESOURCES AND BIOSECURITY
P.O. BOX 7062 KAMPALA, UGANDA, EAST AFRICAN COMMUNITY
Email: sbls.covab@mak.ac.ug. Tel: +256-772-365060

OFFICE OF THE DEAN
School of Biosecurity, Biotechnical and Laboratory Sciences (SBLS)

Our Ref: **Date:** 20th February 2024

To Whom It May Concern:

Dear Sir / Madam

RE: APPROVAL FOR DATA COLLECTION

I hereby introduce to you Mr. Stephen Opira (Reg. No. 21/U/22179/PS) a finalist student at the College of Veterinary Medicine, Animal Resources and Biosecurity, (CoVAB), Makerere University. He is offering a Bachelor of Biomedical Laboratory Technology (BBLT) programme.

As a finalist student, he proposed to conduct a research study titled; "**ASSESSMENT OF HARDNESS OF WATER SAMPLES FROM SELECTED CLOSED WATER SYSTEMS IN KITGUM MUNICIPALITY, KITGUM DISTRICT, NORTHERN UGANDA**".

This is part of the requirements for the award of the Bachelor of Biomedical Laboratory Technology degree.

The purpose of this communication therefore is in strong support of his application to your office for permission to proceed with his research work.

Your support in this regard will be highly appreciated.

Respectfully yours

Mugasa

DEAN, SCHOOL OF BIOSECURITY, BIOTECHNICAL & LABORATORY SCIENCES (COVAB)
20 FEB 2024
MAKERERE UNIVERSITY P. O. BOX 7062, KAMPALA (U)

Dr. Claire Mack Mugasa, (PhD)
DEAN, SBLS

Appendix II: Acceptance letter to National Water and Sewerage Corporation Kitgum

NATIONAL WATER AND SEWERAGE CORPORATION

KITGUM AREA OFFICE

Telephone 0392551419

Toll free 0800200977/ 0800300977

P.O Box 212

Plot 34, Uhuru Drive

Dated: 26th March 2024

Mr. Opira Stephen,

RE: ACCEPTANCE LETTER

Following your application and request to carry out water analysis for undergraduate dissertation in our laboratory, you are hereby accepted.

You are therefore assigned to Ms. Akongo Vicky; Kitgum Area's Quality Control Officer who shall guide you where necessary. You are also asked to abide by the corporation's rules and regulations while with us.

Kindly share with us your findings when done with your report.

I wish you all the best in your research

Yours faithfully,

Abonyo Caroline Mercy

Area Manager, NWSC-Kitgum Area

Caroline.abonyo@nwsc.co.ug

+256-771822546/751115426

Appendix III: Map of Kitgum Municipality, Kitgum District