KYAMBOGO UNIVERSITY

FACULTY OF ENGINEERING

DEPARTMENT OF CIVIL AND BUILDING ENGINEERING

QUALITY OF PACKAGED DRINKING WATER ALONG ITS PRODUCTION AND DISTRIBUTION CHAIN: A CASE OF CENTRAL AND EASTERN UGANDA

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

OCTOBER, 2019

DECLARATION

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

Sign………………………………………..

Mr. AGONZA DEOGRATIOUS

Date…………………………………………

APPROVAL

The undersigned acknowledge that they have read and hereby approve the submission acceptance by Kyambogo University, a report entitled: Quality of packaged drinking water along its production and distribution chain: Case of Central and Eastern Uganda, in fulfillment of the requirements for the award of a degree of Master of Science in Water and Sanitation Engineering of Kyambogo University.

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ACKNOWLEDGEMENTS

First and foremost, I thank God for His Grace that has seen me this far. It has not been easy but by his strength I have managed to reach this stage. My special thanks go to my supervisors Dr. Charles Onyutha and Eng. Dr. Anne Nakagiri for the knowledge and skills they passed on to me right from the topic formulation up to research conclusion. Without them it would not have been possible to reach this far.

My thanks go to my lovely wife Mrs. Winnie K. Agonza and our five lovely children; Kabalungi Juliana, Agonza Jeremiah, Kugonza Reinhard, Agonza Morris and Kamanyire Emmanuel. Mr. David Eboku (Manager Standards Department) Mr. Deus Mubangizi (Manager Laboratory Services) and other UNBS staff thanks a lot for your support without which it would be impossible to reach this far.

DEDICATION

I hereby dedicate this report to my lovely family; Mrs. Winnie K. Agonza and our five lovely children; Kabalungi Juliana, Agonza Jeremiah, Kugonza Reinhard, Agonza Morris and Kamanyire Emmanuel.

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LIST OF ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of Variance
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EAS	East African Standards
EC	Electric Conductivity
EU	European Union
FC	Faecal Coliform
FS	Fecal streptococci
GDWQ	Guidelines For Drinking Water Quality
ISO	International Organization for Standardization
MWE	Ministry of Water and Environment
NDWS	National drinking water standards
NTU	Nephelometric Turbidity Unit
NWSC	National Water & Sewerage Corporation
PH	Percentage Hydrogen
SLL	Standard Lower Limit.
SPSS	Statistical Package for Social Sciences
SUL	Standard Upper Limit
TBS	Tanzania Bureau of Standards

TC	Total Coliforms
TCU	True Colour Unit
TDS	Total Dissolved Solids
TH	Total Hardness
UIRI	Uganda Industrial Research Institute
UV	Ultraviolet
UNBS	Uganda National Bureau of Standards
WHO	World Health Organization
WQS	Water Quality Strategies
WSP	Water Safety Plan

ABSTRACT

Access to safe and affordable drinking water is one of core targets under Sustainable Development Goals: 6. Bottled water is a path way for such safe access as from 1990, with currently more than 40 registered brands amidst the high demand for it, mainly at functions and events in spite of the varying consumer perception. This study aimed at assessing packaged drinking water quality along its production and distribution chain. The study focused on; assessing consumer perception on bottled water quality, its quality during production processes and on local markets in Central and Eastern Regions of Uganda. Findings from the study showed that majority of the respondents from the consumer perception survey, 86% agreed to bottled water being tasty, 42% agreed that it has odour and 13% agreed that it has colour. Furthermore, during sample testing, evident results of appearance, aroma, texture and taste confirmed were recorded and guided selection of study case factories of the study. All the tested 24 samples from production and 60 samples from market for the 3 bottled water brands tested met National Drinking Water Standards. However, they all showed differences in key parameters in the four towns. The parameters also showed degree of changes depending on storage facilities. The difference mainly differed by; location; market avenue; storage all attributed to probably, travel distance, temperature difference and expiry dates. Bottled water is; safe for consumption, not coloured but bears taste and odour as related to consumer's perception.

Key words; Bottled water, Taste, Odour, Colour, parameter, quality.

CHAPTER ONE: INTRODUCTION

1.1 Background

Water is a very important resource for humans as it forms 50% to 60% of our body weight and plays a vital role in the body metabolic processes (Kawther and Alwakeel, 2007). This makes access to safe drinking water essential to health and personal development. It is one of the basic human rights and a component of effective policy for health protection (WHO, 2011: Kassenga, 2007). One way in which humans can access water is thorough bottled water. Packaged water is any potable water that is manufactured or processed for sale that is sealed in food-grade bottles, sachets, or other containers and intended for human consumption (Warburton, 2000).

Bottled drinking water consumption is on increase in different parts of the world and the trend has been steadily growing in the world for the past 30 years (Adel et al., 2012). People choose bottled water because of health concerns, or as a substitute for other beverages. Aesthetics reasons such as an unacceptable taste and an unpleasant appearance of tap water resulting from residual chlorine, convenience and fashion have been found to influence consumption of bottled water (Halage et al., 2015, Abd El-Salam et al., 2008).

In addition, nutritional benefits associated with bottled water make it a better alternative than taking boiled or tap water (Sasikaran et al., 2012). The advantages of consuming bottled water, economic development, rising population, consumer-spending patterns, life style trends and growing levels of health consciousness, are driving the rise in bottled water industry. The world bottled water market is estimated to be over $70bn. This has sparked an interest in ensuring the bottled water is adequate for consumption thus regulation of its production.

1.2 Problem Statement

Because of high demand for bottled water, the industry and consumers are faced with a problem of counterfeits. Unscrupulous people have penetrated the production industry and market with substandard counterfeits that do not meet the drinking water quality standards hence exposing the consumers to healthy risks of out breaks of water borne diseases like cholera, typhoid among others. To ensure that bottled water is acceptable for human consumption, it is mandatory to register brands of bottled water for quality monitoring and control purposes. Worldwide, manufacturers involved in processing and packaging water are doing so under the radar of their respective governments. There is also The International Bottled Water Association (IBWA) that not only unifies the bottled water industry, but represents an uncompromising commitment to the safety and availability of bottled water worldwide. In Uganda, the Uganda National Bureau of Standards (UNBS) using the EAS 214 packaged drinking water specification, 2014 regulates all producers of water through a comprehensive range of measures that include auditing the production process, product testing and post market monitoring programs (UNBS, 2013).

The stringent requirements and standardization of bottled water processes would imply satisfactory quality. However, this is not the case. Studies worldwide have found variations in the quality of bottled water on the market. There is thus a need to understand the causes of the variations in the quality of bottled water.

1.3 Research Objectives

1.3.1 Main Objective

The main objective of the study was to assess packaged drinking water quality along its production and distribution chain.

1.3.2 Specific Objectives

i. To assess consumers' perception on bottled water quality;
ii. To assess packaged drinking water quality at production processes;
iii. To assess packaged drinking water quality on local market.

1.4 Research Questions

i. What perception do consumers have on bottled water in terms of taste, odour and colour?
ii. What is the quality of water along the bottled water production chain?
iii. What is the quality of bottled water on local market?

1.5 Research Justification

Bottled drinking water quality has been of increasing concern worldwide. Therefore, any effort to have such concerns (i.e. the different public perceptions on aesthetic characteristics of water, Media-doubts and fears about drinking water may be exacerbated by stories in the media or by commercial advertisements featuring alternative drinking water options or treatment devices) addressed is highly appreciated. For a level of complete physical, mental and social health, consumers should have access to safe packaged water for drinking. From a health promotion perspective, it is important to understand what water sources consumers are using and why, and to address any potential health problems relating to public and alternative water sources before they experience negative health outcomes relating to water-borne contaminants. This upstream approach to health involves identifying risk factors and at-risk populations. This study was to give the public an understanding of the sources and quality of bottled water being consumed in central and eastern regions of Uganda as is required by UNBS drinking water quality standards hence justifying the need for the proposed study.

1.6 Significance

In Uganda, especially in urban centres, a number of people have complained most especially on the unacceptable taste of some of bottled water brands on market. Technically, the taste of water is just an indicator of underlying quality issues that these consumers cannot easily identify and might result in long term health issues if not addressed (Gangil et al., 2013). Establishing the quality of bottled water along its production chain and on market will help to address this by identifying what these issues might be.

Academically this research will serve as a tool for knowledge building and learning facilitation. It will also serve as a way to prove lies and support truths. It will also serve as means to understand more about water quality issues, guide in identifying gaps and need for further research especially on water bottled water quality issues not forgetting being used as a reference while conducting such researches.

In a long run, the study is to raise public awareness on the quality of bottled water on market and therefore make informed decisions for example either to keep on consuming (in a situation that the quality requirements are met) or to fore go and opt for other options (in a situation that the quality requirements are not met) therefore reducing public health risks related to consumption of bottled drinking water that does not meet the quality requirements.

Furthermore, the study is to inform the drinking water quality regulating body precisely UNBS about its effectiveness as it does its work as mandated. In case the study finds out that some of the brands do not meet the quality requirements, then it is upon (UNBS) to devise more effective and stringent means of addressing the challenge. In a fortunate event that indeed all the quality requirements are met by the brands on market in Uganda then it is expected to aim at maintaining the status quo or even better improve it.

1.7 Study Scope

The study focused on three bottled drinking water manafucturing factories located in Nakawa Division, Kampala and assessed both physical, chemical and biological parameters at three locations (key sites) along the production chain; Abstraction, after treament, and storage. Assessments followed the distribution process of bottled water from the factory to the local market in Central region (Kampala and Mityana towns) and Eastern (Mbale and Soroti towns) Region of Uganda. pH, $CaCO_3$ and Total coliform were the main focus of the assessement at market grounds, specifying the market avenue (Suppermarket or shop), and storage (boxes, shelves, fridges), between January and November, 2019. The criteria used to come up with the four towns and the two regions is clearly explined in chapter three under the three speficific objectives for the conducted study.

1.8 Conceptual Framework

A conceptual framework is an analytical tool with several variations and contexts. It can be applied in different categories of work where an overall picture is needed. It is used to make conceptual distinctions and organize ideas, strong conceptual frameworks capture something real and do this in a way that is easy to remember and apply.

Conceptual framework explains the path of a research and grounds it firmly in theoretical constructs. The overall aim of the conceptual framework is to make research findings more meaningful, acceptable to the theoretical constructs in the research field. When combined with theoretical concept, conceptual framework assists in stimulating research while ensuring extension of knowledge by providing both direction and impetus to the research inquiry. It also enhances the empirical and rigor of a research. A research without the theoretical or conceptual frameworks makes it difficult for readers in ascertaining the academic position and the under laying factors to the researcher's assertions and /or hypothesis Adom et al., (2018).

Figure. 1-1 is the adopted conceptual framework that was adopted for this study. The independent variables were the chemical, physical and biological components of bottled water, methods of processing, raw water source, handling, transportation and storage. The intervening variables were the water quality standards, UNBS guidelines, bottling companies and quality regulatory bodies. The independent being water quality for this

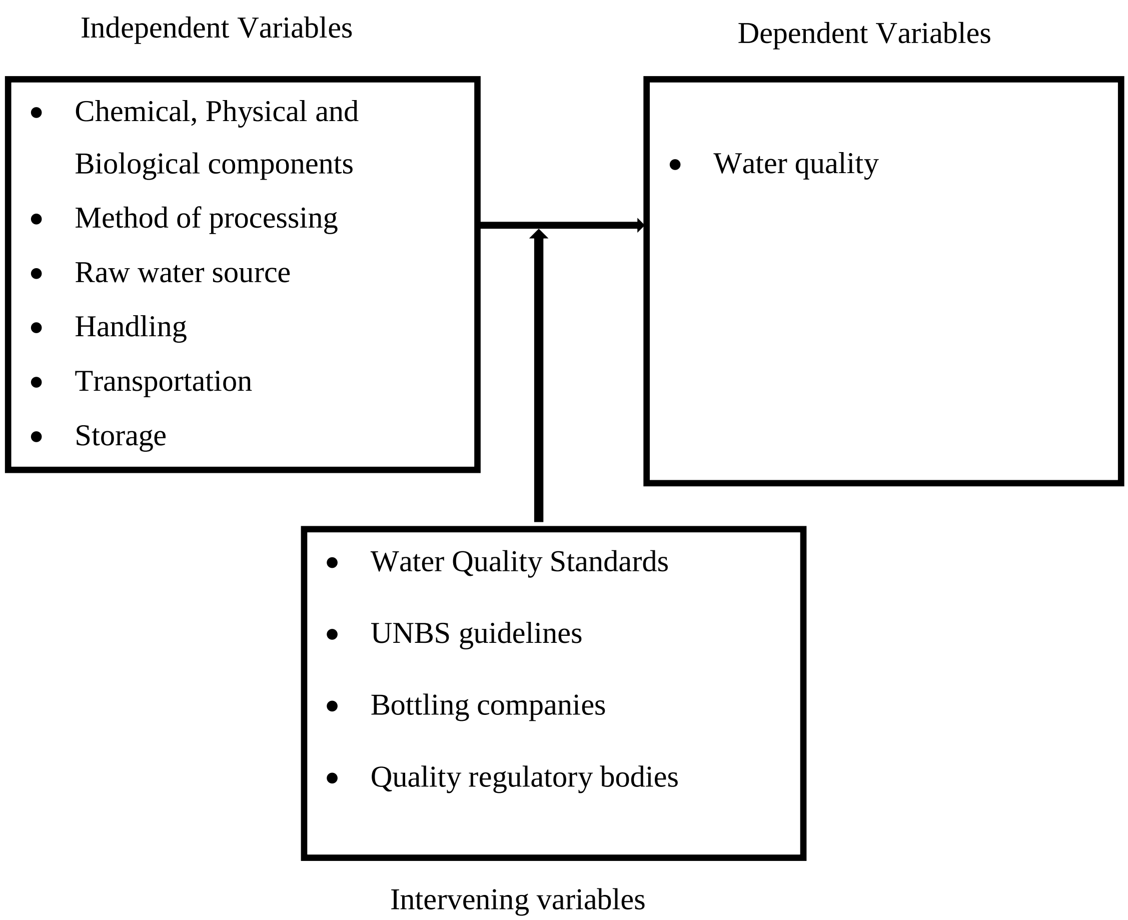


Figure 1-1: **Adopted conceptual framework of the study**

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This topic brings out some of previously done works by scholars related to the topic, the conceptual literature and not forgetting the empirical literature giving snapshots of the works of other people that are related to the research topic.

2.2 Definitions

For purposes of this study the following terms and definitions were applied.

Water quality refers to the basic physical, chemical and biological characteristics of water that determine its suitability for life or for human uses (Pooja, 2017).

Natural mineral water in accordance with European legislation natural mineral water is defined as microbiologically wholesome water from an underground aquifer tapped via one or more natural or drilled wells. The only treatment allowed prior to bottling is to remove unstable components such as iron and sulphides and to (re)introduce carbon dioxide.

Packaged water is any potable water that is manufactured or processed for sale which is sealed in food-grade bottles, sachets, or other containers and intended for human consumption (Warburton, 2002). Also defined as water that has been suitably treated for human consumption, filled and sealed in containers. It may contain minerals naturally occurring or intentionally added; it may contain carbon dioxide naturally occurring or intentionally added but does not contain sugars, sweeteners, flavouring or other food stuffs.

Artesian well water: Water from a well tapping a confined aquifer in which the water level stands at some height above the top of the aquifer.

Glacial water: Water which is derived from an approved source originating from and collected within a watershed containing a glacier, and is not derived from a public water system.

Spring water: Water derived from an underground formation from which water flows naturally to the surface of the earth.

Well water: Water from a hole bored, drilled, or otherwise constructed in the ground which taps the water of an aquifer.

Purified water or demineralized water: Water which has been processed by distillation, deionization, reverse osmosis, or other suitable process, and contains no added substance.

Alternatively, this water may be called:

a) **Deionized water** if it is processed by deionization.

b) **Distilled water** if the water has been processed by distillation; and

c) **Reverse osmosis water** if the water has been processed by reverse osmosis.

Sterilized water: Water that has been processed to meet the "Test for sterility"

Enriched water: Water with added minerals.

Prepared waters: Water that originates from other types of water supply suitably prepared before packaging.

Potable water: Water that is safe and suitable for human consumption.

Drinking water: Potable water intended for human consumption.

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

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

Safe water: Water that is free of 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.

Disinfection: Reduction by means of chemical agents and/or physical methods, of the number of micro-organism to a level that does not compromise public health.

Container: Any bottle, carton, can or other container to be filled with water, properly labeled and intended for sale.

2.3 Conceptual Review

Water quality refers to the basic physical, chemical and biological characteristics of water that determine its suitability for life or for human uses (Pooja, 2017). In accordance with European legislation natural mineral water is defined as microbiologically wholesome water from an underground aquifer tapped via one or more natural or drilled wells. The only treatment allowed prior to bottling is to remove unstable components such as iron and sulphides and to (re)introduce carbon dioxide.

2.4 Theoretical Review

Clean, safe and sufficient freshwater is vital for the survival of all living organisms and smooth functioning of ecosystems, communities and economies. Because of this, most people today depend on bottled water as a major source of their drinking water. This means that ensuring that this water is safe is vital (UNBS, 2013).

The characteristics of water can be classified into three broad categories: Physical, chemical and biological characteristics (Pooja, 2017). Physical characteristics of water (temperature, colour, taste, odour and etc.) are determined by senses of touch, sight, smell and taste. The chemical constituents of water that can lead to health problems resulting from even a single exposure include PH, Electrical Conductivity, Salinity, Alkalinity Hardness, Heavy Metals, Dissolved oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand. The health concerns associated with chemical constituents of drinking-water arise mainly from the ability of chemical constituents to cause adverse health effects after extended exposure time (WHO, 2017).

Under biological characteristics, microbial contamination caused by many types of micro-organisms naturally present in the water such as Protozoa, Bacteria, Viruses, Helminths is one of the major concerns of water quality (WHO, 2017).

2.4.1 Physical Characteristics

Physical characteristics of water (temperature, colour, taste, odour and etc.) are determined by senses of touch, sight, smell and taste. For example, temperature by touch, colour, floating debris, turbidity and suspended solids by sight, and taste and odor by smell.

Temperature is a measure of the average energy (kinetic) of water molecules and is a basic water quality parameter. It is measured on a linear scale of degrees Celsius or degrees Fahrenheit and dependent on atmospheric temperature. Temperature affects a number of water quality parameters such as dissolved oxygen which is a chemical characteristic. Oxygen solubility is less in warm water than cold water.

Color in water is primarily a concern of water quality for aesthetic reason. Colored water gives the appearance of being unfit to drink, even though the water may be perfectly safe for public use. Color of a water body can indicate the presence of organic substances such as algae. In recent times, color has been used as a quantitative assessment of the presence of potentially hazardous or toxic organic materials in water. Color is reduced or removed from water through the use of coagulation, settling and filtration techniques.

Taste and odour are human perceptions of water quality. Human perception of taste includes sour (hydrochloric acid), salty (sodium chloride), sweet (sucrose) and bitter (caffeine). Relatively simple compounds produce sour and salty tastes.

However, sweet and bitter tastes are produced by more complex organic compounds. Odour is produced by gas production due to the decomposition of organic matter or by substances added to the wastewater. Odour is measured by special instruments such as the Portable H_2S meter which is used for measuring the concentration of hydrogen sulphide.

Turbidity is a measure of the light-transmitting properties of water and is comprised of suspended and colloidal material. It is important for health and aesthetic reasons. Turbidity provides an inexpensive estimate of Total Suspended Solids (TSS) concentration.

Solids; Total Dissolved Solids (TDS) is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. The principal constituents are usually Calcium, Magnesium, Sodium, and Potassium cations and Carbonate, Hydrogen Carbonate, Chloride, Sulphate, and Nitrate Anions. The total solids content of water is defined as the residue remaining after evaporation of the water and drying the residue to a constant weight at 103°C to 105°C.

Solids are classified as settle-able solids, suspended solids and filterable solids. Settle-able solids (silt and heavy organic solids) are the one that settle under the influence of gravity. Suspended solids and filterable solids are classified based on particle size and the retention of suspended solids on standard glass-fibre filters.

The significance of suspended solids in water is great, on a number of grounds. The solids may in fact consist of algal growths leading to severe eutrophic conditions in any water.

2.4.2 Chemical Characteristics

The health concerns associated with chemical constituents of drinking-water arise mainly from the ability of chemical constituents to cause adverse health effects after extended exposure time (WHO, 2006). There are few chemical constituents of water that can lead to health problems resulting from even a single exposure. The major chemical properties of water are discussed below: -

pH is a measure of how acidic or basic (alkaline) the water is. It is defined as the negative log of the hydrogen ion concentration. The pH scale is logarithmic and ranges from 0 (very acidic) to 14 (very alkaline). For each whole number increase (i.e. 1 to 2) the hydrogen ion concentration decreases tenfold and the water becomes less acidic. The range of natural pH in fresh waters extends from around 4.5, for acid, peaty upland waters, to over 10.0 in waters where there is intense photosynthetic activity by algae. However, the most frequently encountered range is 6.5-8.0.

Changes in pH may alter the concentrations of other substances in water to a more toxic form. Ammonia toxicity, chlorine disinfection efficiency, and metal solubility are all subjective to changes in pH value.

Electrical Conductivity; The conductivity of water is an expression of its ability to conduct an electric current as a result of breakdown of dissolved solids into positively and negatively charged ions. The major positively charged ions are sodium (Na^{+}), calcium (Ca^{+2}), potassium (K^{+}) and magnesium (Mg^{+2}). The major negatively charged ions in water include chlorides (Cl^{-}), sulphates (SO_4^{-2}), carbonates (CO_3^{-2}), and bicarbonates (HCO_3^{-}). Nitrates (NO_3^{-2}) and phosphates (PO_4^{-3}) are minor contributors to conductivity, although they are very important biologically. Conductivity in itself is a property of little interest but it is an invaluable indicator of the range of hardness, alkalinity and the dissolved solids content of the water.

Salinity; is a measure of the amount of salts in the water. Because dissolved ions increase salinity as well as conductivity, the two measures are related. Saline waters owe their high salinity to the presence of dissolved ions including sodium, chloride, carbonate and sulphate. The presence of a high salt content may make water unsuitable for domestic, agricultural or industrial use. Moreover, the ionic composition of the water can be critical. For example, Cladocerans (water fleas) are far more sensitive to potassium chloride than sodium chloride at the same concentration.

Alkalinity; It is a measure of the capacity of the water to neutralize acids and it reflects its buffer capacity. It is attributed to the presence of carbonates and hydroxides.

Hardness; It is a natural characteristic of water which can enhance its palatability and consumer acceptability for drinking purposes. The hardness of water is due to the presence of Calcium and Magnesium minerals that are naturally present in the water. The common signs of a hard water supply are poor lathering of soaps and scum. The hardness is made up of two parts: temporary (carbonate) and permanent (noncarbonate) hardness. The temporary hardness of water can easily be removed by boiling the water. Table 2.1 shows the measure of hardness (expressed in mg/l as $CaCO_3$).

Table 2.1: Measure of Water Hardness

Degree of Hardness	**Concentration of $CaCO_3$(mg/l)**
Soft	0-100
Moderate	100-200
Hard	200-300
Very Hard	300-500
Extremely Hard	500-1000

(Source: WHO, 2017)

Heavy metal; refers to any metallic chemical element that has a relatively high density and is toxic or poisonous at low concentration. The major examples of heavy metals are mercury (H_g), cadmium (C_d), arsenic (A_s), chromium (C_r), nickel (N_i), copper (C_u), cobalt (C_o) and lead (P_b) etc. Some heavy metals (e.g. copper, selenium, zinc) are necessary to keep up the metabolism of the human body as trace elements. However, they can be poisonous at higher concentrations leading to various serious diseases.

Dissolved oxygen (DO); is the amount of gaseous oxygen (O_2) dissolved in an aqueous solution. It gets into water by diffusion from the surrounding air, by aeration (rapid movement), and as a waste product of photosynthesis. The oxygen in dissolved form is needed by most aquatic organisms to survive and grow.

Biochemical Oxygen Demand (BOD); is the amount of dissolved oxygen required by aerobic biological organisms to degrade the organic material present in a water body at certain temperature over a specific time period. It is widely used as an indication of the organic quality of water and thus representing the pollution load. It is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days (BOD_5) of incubation at 20°C. When organic matter decomposes, micro-organisms (such as bacteria and fungi) feed upon this decaying material and eventually the matter becomes oxidized. The harder the micro-organisms work, the more oxygen will be used up giving a high measure of BOD, leaving less oxygen for other life in the water.

Chemical Oxygen Demand (COD); determines the quantity of oxygen required to oxidize the organic matter present in water body under specific conditions of oxidizing agent, temperature and time. COD is an important water quality parameter as it provides an index to assess the effect discharged wastewater will have on the receiving environment. Higher COD levels represent the presence of greater amount of oxidizable organic material in the sample, the degradation of which will again lead to hypoxic conditions in the water body. The ratio of BOD to COD indicates the percent of organic material in water that can be degraded by natural micro-organism in the environment.

2.4.3 Biological Characteristics

Microbial contamination; is one of the major concerns of water quality. Many types of microorganisms are naturally present in water such as Protozoans (such as Amoeba, cryptosporidium, giardia), Bacteria (such as Salmonella, typhus, cholera, shigella), Viruses (such as Polio, hepatitis A, meningitis, encephalitis) and Helminths (such as Guinea worm, hookworm, roundworm).

Total Coliform and Faecal Coliform; Total coliform bacteria, faecal coliform bacteria, and E. coli are all considered indicators of water contaminated with faecal matter. Contaminated water may contain other pathogens (micro-organisms that cause illness) that are more difficult to test for. Therefore, these indicator bacteria are useful in giving us a measure of contamination levels. E. coli is a bacterial species found in the faecal matter of warm-blooded animals (humans, other mammals, and birds). Total coliform bacteria are an entire group of bacterial species that are generally similar to and include the species E. coli. There are certain forms of coliform bacteria that do not live in faecal matter but instead live in soils. Faecal coliform bacteria are coliform bacteria that do live in faecal matter, including, but not limited to, the species E. coli. Most of the faecal coliform cells found in faecal matter are E. coli. Untreated sewage, poorly maintained septic systems, un-scooped pet waste and farm animals with access to water bodies can cause high levels of faecal coliform bacteria to appear in and make the water unhealthy.

2.5 The Existing Quality Standards

There are set standards worldwide for purposes of ensuring that safe water is supplied to the respective consumers. There are WHO, European Union standards, ISO among others. In Uganda, both WHO and East African Standards, UNBS regulates all producers of bottled water. Tables 2-2 & 2-3 show the UNBS physical, chemical and biological requirements for packaged drinking water.

Table 2.2: UNBS Physical Requirements for Safe Packaged Drinking Water

Characteristic	**Packaged drinking water**	**Method of test**
Colour (TCU max)	15	ISO 7887
Turbidity (NTU)	1 max. (NTU)	ISO 7027
pH	6.5 – 8.5	ISO 10523
Taste	Not objectionable	-
Odour	Odourless	-
Conductivity (µS/cm)	2500	ISO 7887

(Source: US EAS 153, 2014)

Table 2.3: UNBS Chemical and Biological Requirements for Packaged Drinking Water

Substance or characteristic	Packaged drinking water (mg/L max.)	Method of test
Suspended matter	Not detectable	
Total dissolved solids	1500	ASTM D 5907
Total organic matter	0.003	ISO 8245
Total hardness, as CaCO3,	300	ISO 6059
Aluminum, as Al+++,	0.2	ISO 12020
Chloride, as Cl-	250	ISO 9297
Iron Fe	0.3	ISO 6332
Sodium, as Na+	200	ISO 9964-1
Sulphate	400	ISO 22743
Zinc, as Zn++	5	ISO 8288
Magnesium, as Mg++	100	ISO 7980
Calcium, as Ca++	150	ISO 7980
Residual free chlorine	Not detectable	ISO 7393

(Source: US EAS 153, 2014)

2.6 Empirical Review

Varga (2011) carried and examined the bacteriological quality of bottled natural mineral waters sold in Hungary. The findings of this study highlight the need for a more stringent self-control by some producers of mineral water and therefore recommended a more systematic surveillance by the official authorities of food control. Many bottled waters can be obtained from natural sources such as springs or can also be manufactured from tap water (Addo, 2009). De-mineralized water or distilled water is simply tap water that has undergone processes to lower mineral content and remove chemicals such as chlorine (Health Canada, 2001).

Bottled drinking water is processed from various sources where the taste and quality may vary from place to place, so too does bottled water's taste and quality vary among and even within brands (Warburton and Austin, 2000). However, the presence of contaminants does not necessarily indicate that the water poses a health risk for example; minerals such as magnesium and calcium give water a distinctive flavor and essential to the body. It is only at their high levels that these and other contaminants such as pesticides or microbes from human waste can cause adverse effects or illness.

Generally, Physical, chemical and biological characteristics of water are considered as a main health controlling factor and the state of disease in the living organisms (Kazi et al., 2009). The appearance, taste and odour of drinking water should be acceptable to the consumer as they build the confidence of consumers, avoid complaints and, more importantly, prevent consumers from the use of water from sources that may be unsafe. Also, some chemicals and microbes cause adverse health effects in humans (EAS 12: 2013).

Mihayo and Mkoma (2012) carried out a study to determine the physico-chemical quality of bottled drinking water brands available in retail shops in Mwanza city Tanzania. On comparing with drinking water standards, the results showed that, water type for different bottled water brands had their TDS ranging from very high concentrations (brands A and B) to low concentrations (brands C, D, E, and F). For total hardness, most brands were considered to have soft water except for brand E which had moderately hard water. The dominant component to all bottled water brands were Sulphates (SO_4^-), Chlorides (Cl^-), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) Ferrous (Fe^{2+}) and Nitrates (NO_3^-). When compared with Tanzania Bureau of Standards (TBS) and World Health Organization (WHO) guidelines for drinking water, analysed parameters in all brands were within TBS and WHO limit values for drinking water. The study, therefore, concluded that the analysed bottled water brands are safe for human consumption. However, it recommends other water quality parameters such as microbiological and heavy metal be studied in future.

Adel et al., (2012) carried out a study to determine the Physical, chemical and microbial properties of bottled water in Baghdad, Iraq. The parameters considered included pH, Electrical conductivity (EC), Total dissolved salts (TDS), Phosphate, Nitrate, Sulphates, Chlorides, Total hardness (TH), Calcium, Magnesium, Total coli forms (TC), Faecal streptococci (FS) and Clostridium spp. The results of the study showed that the majority of the analysed physical and chemicals properties were below their respective bottled drinking water standards for maximum admissible concentrations except Magnesium ion. In addition, of a total of 42 water samples examined four samples were contaminated with total coli forms and three samples were contaminated with genus Clostridium spp, with large numbers exceeding the allowable limits for bottled drinking water. While no faecal streptococci bacteria was found in other tests of microbiological investigations. The study also showed there is no match in physical and chemical properties for large proportion of tested water with those characteristics mentioned in the labels on the bottles.

In a study to investigate the physico-chemical properties of the bottled drinking water available in the Dhaka city of Bangladesh by Alam et al., (2017), it was observed that the concentration of same parameter is quite different from sample to sample. The findings indicated that except the pH, DO and Fe^{2+} values, all other parameter values were quite low and appeared within the World Health Organization (WHO) and Bangladesh Drinking Water Quality Standard (BDWQS) limit.

Salih et al., (2015) while analyzing some physicochemical parameters and the heavy metals of Cr, Co, Ni and Cu in samples of plastic bottled drinking water of seven brands in Iraqi Kurdistan Region found out that the said parameters exceeded the WHO drinking water standard.

A study conducted by Eman et al., (2014) to demonstrate the suitability of bottled water used in Kirkuk city - Iraq and Tap water processed by the Directorate of Kirkuk's water for human consumption had results showing discrepancies between the data obtained in the samples with what is listed on brands label. It also found out that water supplied by the Water Directorate of Kirkuk is not suitable to drink.

Muhammad et al., (2009) in a study to examine the bacteriological quality of carbonated soft drinks sold in Bangladesh markets found out that most samples were not in compliance with microbiological standards set by organizations like the World Health Organization. Pseudomonas aeruginosa is the predominant species with an incidence of 95%. Streptococcus spp. and Bacillus stearothermophilus were the next most prevalent with numbers ranging from 6 to 122 and 9 to 105 cfu/100 ml, respectively. Fifty-four percent (54%) of the samples yielded Salmonella spp. at numbers ranging from 2 to 90 cfu/100 ml. Total coliform (TC) and faecal coliform (FC) counts were found in 68–100% and 76–100% of samples of individual brands, at numbers ranging from 5 to 213 and 3 to 276 cfu/ 100 ml, respectively. Basing on WHO standards 60–88% of samples from six brands and 32% and 40% of samples from two other brands belonged to the intermediate risk group with FC counts of 100–1000 cfu/ 100 ml. Heterotrophic plate counts, however, were under the permissible limit in all 225 samples. These findings suggest that carbonated soft drinks commercially available in Bangladesh posed substantial risks to public health.

While examining the bacteriological and physical quality of locally packaged drinking water in Kampala, Uganda (Halage et al.,2015), it was found out that some bottled water and sachet water brands were contaminated with faecal coli form. Seventy percent 70% of the sachet water analysed exceeded acceptable limits of 0 total coliforms per 100mL set by WHO and the national drinking water standards. The physical quality (turbidity and pH) of all the packaged water brands analysed was within the acceptable limits. However, there was statistically significant difference between the median count of total coliform in both sachet water and bottled water brands. However, only three of the five municipalities in the city, namely, Lubaga, Makindye, and Kawempe, were randomly selected for involvement in the study.

Lisa et al., (2015) while assessing the microbiological quality of bottled water and protected spring water in Bushenyi district, Uganda found out that bottled water sold in Ishaka, Bushenyi District had high quality standards while protected spring water showed significant level of contamination with E. coli which could potentially cause diseases to the consumers. Basing on discussion, it is clear that not all bottled water on market meet the requirements. One of the ways to assure and protect the public is to carry out such studies so that people are kept informed.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter explains the methods and procedures that were used to conduct the study, including the research design, study population, sample size, sampling techniques, data collection procedures, data collection methods, data collection instruments.

Packaged drinking water was observed to undergo various sequential sub processes to be transformed into finished product for consumption. The quality of bottled water was categorized by chemical (pH, Electrical Conductivity, $CaCO_3$), physical (Temperature, Colour, Taste, Odor, Turbidity, TDS), and biological (E. coli, fecal matter), Pooja (2017).

3.2 Research Design

A cross sectional research design was used for the study. The study was carried out in four (4) towns of the two (2) administrative regions of Uganda i.e. Kampala City and Mityana town in Central, Mbale and Soroti in Eastern regions of Uganda.

3.3 Research approach

The study focused on numerical and descriptive variables hence justifying use of quantitative and qualitative research approaches for assessing packaged drinking water quality along its production and distribution chain.

3.4 Sources of Data

3.4.1 Primary Data Sources

The primary sources of data for this study were sample units of the different bottled water brands/categories, field observations, interviews of stake holders and filled questionnaires.

3.4.2 Secondary Data Sources

Secondary sources of data utilized in the study included: text books, journals, published and government agencies such as MWE, UNBS and NWSC among others.

3.5 Data Collection Tools

Tools used in the study included: -Reagents, pH meters, conductivity meters, dissolved CO_2 meter, dissolved O_2 meter for laboratory tests. Interview guides, observation check lists and questionnaires were used for qualitative data collection.

3.6 Data collection

Focusing on the three specific objectives of the study: i) To assess consumers' perception on 3 selected bottled water quality. ii) To assess packaged drinking water quality at production processes. iii) To assess packaged drinking water quality on local market, this section covers and gives details on the different procedures and methods that were used to collect both qualitative and quantitative data that the study relied on to come up with the findings.

3.7 Attainment of Specific objectives

3.7.1 Specific objective 1; To assess consumers' perception on bottled water quality

From the pool of bottled water companies, selection was made for the brands to be used for the research. The criteria used to select brands for the study considered the brands with the biggest proportion of the market shared and on production processes that are common to bottled water manufacturing. The three brands selected cover about 70% of the total market shared with other bottled water brands. Basing on this criteria the selected X, Y and Z brands cover about 70% of the Uganda bottled water shared market and all use the common methods of bottled water production processes that involve raw water abstraction, treatment which involves raw water reception, sand filtration, activated carbon treatment, micro filtration, UV-treatment, ozonation, cleaning and sanitation, inspection, labeling, sealing, batch coding, finished product storage and distribution, packaging, final product inspection, storage and distribution to market for consumption as shown in appendices I and 11.

After brands selection, consumers' perception on the three aspects of water i.e. odour, taste and smell was sought. A questionnaire was developed /designed based on whether bottled water is tasty, has colour or odour?

Samples of the three brands of bottled water (X, Y and Z) were bought with hidden identity of the brands to remove bias to test for taste, smell and odour. The 100 randomly chosen respondents (25 from each of the four towns) using the designed questionnaire were requested to give their views on taste, odour and colour for the selected brands.

3.7.2 Specific objective 2: Assessing packaged drinking water at production process

At the three factories premises (Factories X, Y and Z) assessment of what actually happens in these factories was carried out. Areas /aspects of interest while carrying the assessment were; Do these factories have water safety plans in place? Do they have in place facilities like water quality monitoring and testing laboratories? Qualified water quality staff? Etc. all aimed at producing and supplying safe, clean and adequate packaged drinking water to the public appendix III. Other areas of interest included the type and quality of water source i.e. underground, spring, NWSC, the different treatment processes, their flows and their effectiveness on treating water to the acceptable drinking water standards, storage facilities within the factory premises.

3.7.2.1 Sampling

During each of the three sampling regimes, water samples were collected in clean bottles from factories raw water abstraction point, after treatment collection tank and treated water storage tank at each of the 3 selected (X, Y and Z) bottled water manufacturing factories premises, collected samples were well labeled and stored in a cooler box, then transported to Uganda Industrial Research Institute (UIRI) laboratory in Nakawa-Kampala for analysis.

3.7.2.2 Tests conducted

Tests and read off meter were conducted for the key physical parameters (turbidity, PH, conductivity) chemical parameters ($CaCO_3$, Ka^+, Ca^{2+}, Mg^{2+}, PO_4^{2-}, SO_4^{2-}, Cl^-, F) and biological parameters (Total coliform), Pooja (2017).

3.7.2.3 Production Process

Observations were also made on the different practices (handling, packaging, storage, etc.) and sequential processes that water undergoes to be transformed into finished product ready for consumption on market.

3.7.3 Specific objective 3: Assessing bottled water quality on local market

After getting consumers views and assessing the production processes/chain for the three (3) factories (X, Y and Z) it was necessary to move to the local market as a follow up on quality issues on bottled water and for purposes of getting enough data for the study.

3.7.3.1 Sampling

Kampala, Mityana and Mbale, Soroti towns in Central and Eastern regions were selected for the study. The purposive selection of the four towns was based on a number of criteria that considered consumption (the 4 towns consume not less than 70% of the three (3) bottled water brands produced in the country), location of factories (the 3 brands processing factories are all located in these two regions), study budget and other costs related issues also had to be considered (easy to access and fund).

During the sampling process in each of the four (4) towns a total of five (5) samples of each of the three (3) brands were picked from shelves, boxes and fridges of supermarkets, shops and kiosks. The picked samples were well labeled for easy identification purposes. The label would reflect the town, brand and a serial number. Details of where the samples were picked i.e. (from fridge, box or shelf) whether from a shop, kiosk or super market including expiry dates were recorded on a separate sheet/note book during the sampling exercise (Appendix IV).

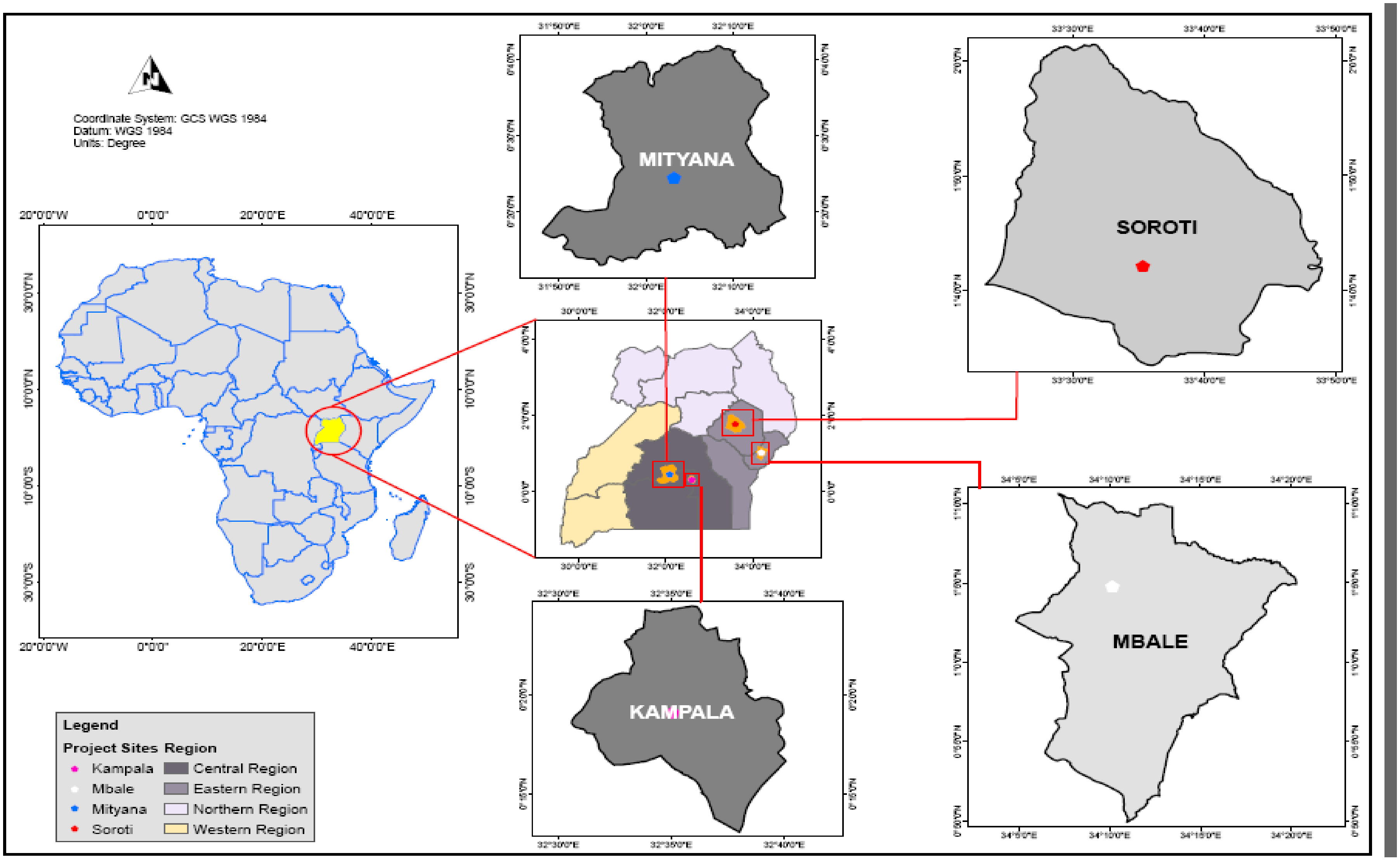


Figure 3-1 Map of study area

3.7.3.2 Tests

The samples were taken to UIRI laboratory in Nakawa and tests conducted to assess the physical, chemical and biological characteristics of the three (3) bottled water brands on market. The tests aimed at ascertaining whether the brands meet the permissible and set UNBS/WHO standards for packaged drinking water.

3.8 Data Analysis and Presentation

Tabulations were used for descriptive statistics using Microsoft excel. The different outcomes expected were laboratory test results of biological, physical and chemical of specific parameters for bottled water as stipulated in the bottled drinking water guide (UNBS, 2014). Charts and graphs; histograms, box plots were also used to present and generate meaningful data interpretation for the study.

3.9 Assessing changes in parameters values

To assess the extent of changes for same parameter for within each brand, among brands and for different locations/towns, Average bias was computed and data analysed using graphs.

3.10 Checking Quality Consistency

To check if the water quality in the market was consistent with that in the factory, the Average Bias (AB) for PH and $CaCO_3$ parameters for water quality at factory and market was computed using the equation

AB (%) = $(Q_m - Q_f)/Q_f \times 100$

Where Q_m= is the quality parameter from the bottled water from the market

Q_f= is the quality parameter of the water from the factory

3.11 Ethical Consideration

Ethical issues provide standards and norms of behavior that outline the moral relationship between the researcher and the respondent (Copper and Shindler 2008). During this study approaches were undertaken to ensure that there was no potential risk connected to the study and respondents, ensuring confidentiality and smooth data collection process whereby;

- An introduction letter from Kyambogo University to UNBS (Government parastatal body responsible for quality assurance) was given (Appendix: VII).
- Provisions for consent to participate in the study were catered for in the interview guide and questionnaire design for data collection at factory premises and on market (Appendices: VIII and IX).

- During the data collection process also verbal confirmation and assurance was given to respondents and bottled water manufacturers that the research done was for academic purposes and that information given was to be treated with utmost confidentiality.

CHAPTER FOUR: ANALYSIS, DISCUSSION AND PRESENTATION OF RESULTS

4.1 Introduction

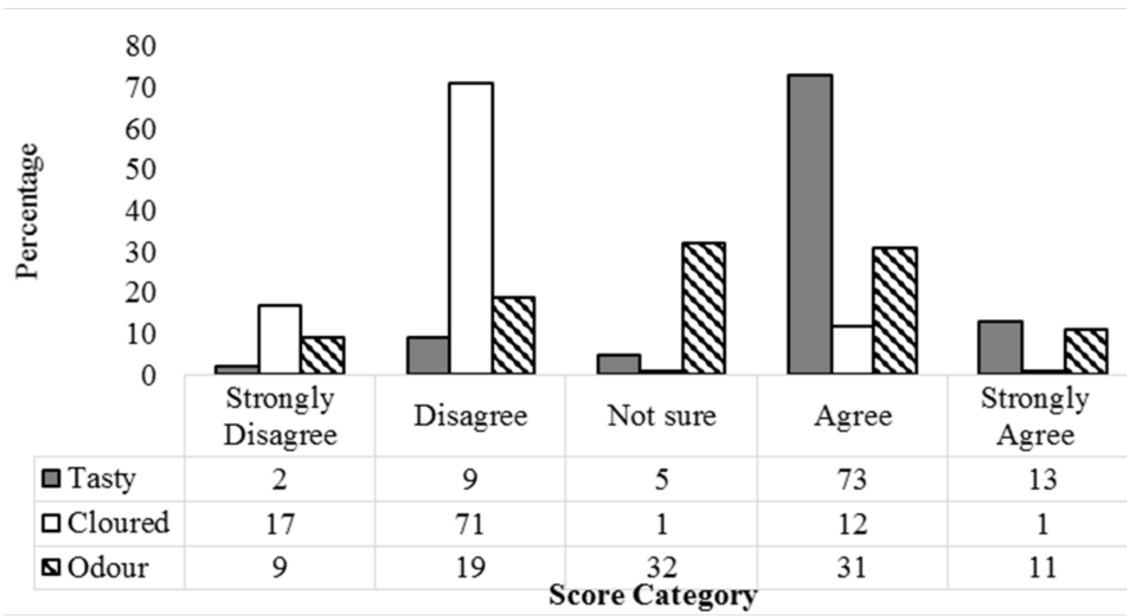
This chapter presents the results, analysis interpretation, and discussions of the research findings in line with the study objectives as regards to assessing the quality of bottled drinking water along the production chain, local market and establishing strategies for any improvement.

4.2 Objective 1: Assessing consumer perception on bottled water quality

Referring to Figure. 4-1 when response was sought on consumers' perception on bottled water being tasty, 86% agreed. 9% disagreed and 2% strongly disagreed and 5% were not sure. For odour, 32% were not sure and 42% agreed with 28% disagreeing. Bottled water being with colour 13% agreed, 71% disagreed, 17% agreed and 1% was not sure Fig. 4-1.

From the given responses results indicate deviation to some extent from the UNBS/WHO set and acceptable standards of bottled drinking water characteristics. Packaged drinking water is supposed to be colourless, tasteless and odourless. The deviation from the UNBS acceptable standards for bottled drinking water (refer to Table 2-2 and Table 2-3) could be attributed to poor or inefficient treatment processes, the presence of contaminants like organic matter can also be a source for bad odour in water

(Pooja, 2017). Odour could also be attributed to presence of excess residual chlorine in case of a factory relying on NWSC as source for raw water in its production process (NWSC, 2018). Excess iron also gives water a funny odour (Warburton, 2000). Acidic water (PH<6.0) is also at times associated with funny taste (Warburton and Austin, 2000). Excessive mineral contents i.e. excess Calcium and Magnesium Carbonates can also be sources of funny and unpleasant tastes of bottled water. Excess Fe^{3+} ions, H_2S and other elements in water can also be sources of foul smell (WHO, 2017). Odour, taste and smell in most cases are drinking water indicative characteristics for an under-laying problem that requires being investigated (Adel et al., 2012).



	Strongly Disagree	Disagree	Not sure	Agree	Strongly Agree
Tasty	2	9	5	73	13
Cloured	17	71	1	12	1
Odour	9	19	32	31	11

Figure 4-1: Survey results of whether bottled water has odour, taste and colour

The study results of 86% of respondents agreeing with bottled water has taste, 42% agreeing with bottled water has odour and 13% agreeing to bottled water has colour indicate that there is a water quality problem that has to be addressed. The consumer perception results strongly supported the need to carry out further research or investigation in areas of production processes, handling, packaging and investigating the product being sold on market.

4.3 Objective 2: Assessing packaged drinking water quality at production processes

The study established that all the three factories treated water to the required UNBS set standards (Appendix (VIII). This is witnessed by the laboratory tests results of the bottled water quality parameters all of which were within the acceptable set limits for packaged drinking water as per National drinking water standards (NDWS and WHO). However, factory Z was the best of the three factories in bottled quality requirements achievement (37%) at treatment, followed by Y (35%), then X (27%) as indicated in Figure 4-2. The difference could be attributed to a number of factors that may include among others; different degree to adherence to water safety plans, treatment processes, type of source and pollutants loading at source, etc.

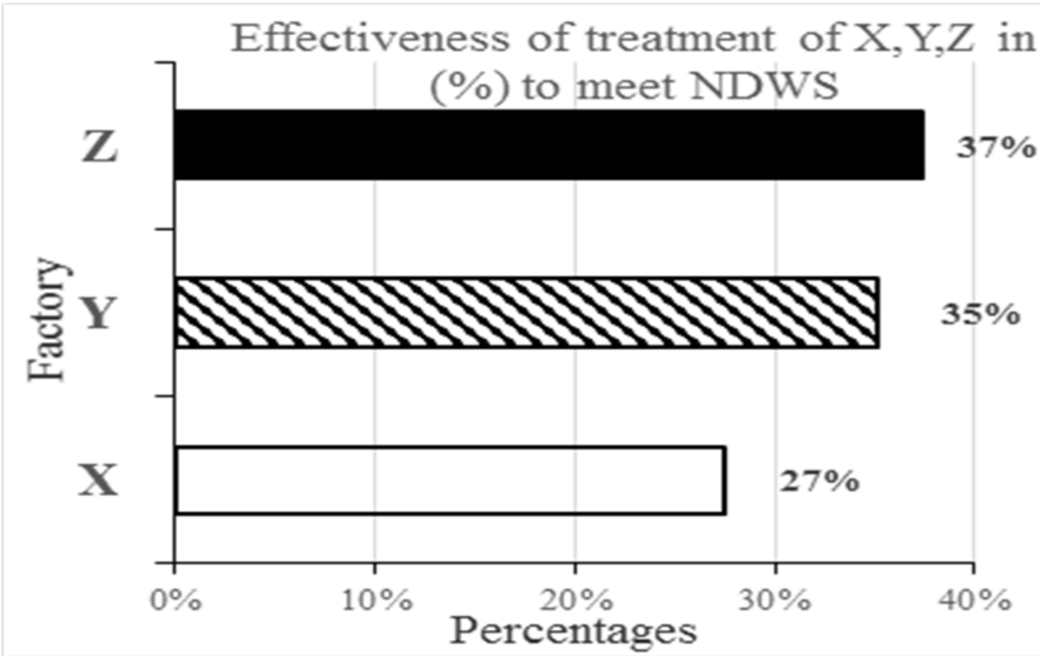


Figure 4-2: Effectiveness of factories production process in treatment

4.3.1 Sodium (Na^+) and Potassium (K^+)

Figure 4-3: i) and ii) show laboratory tests results for Sodium (Na^+) and Potassium (K^+) at source, after treatment and storage for factories X, Y, Z. It can be seen that the tests results values for the two parameters Na^+ with (20.2, 11.3) mg/l and K^+ with (7.9, 3.6) mg/l being the highest and lowest readings respectively are less than the UNBS Standard Upper Limit SUL) of 200mg/l hence within the acceptable limits. Source for factory X had the highest value for Na^+ and K^+. Values for both Na^+ and K^+ at the three sources reduced after treatment. The reduction in value of Na+ and K+ could be due to treatment processes.

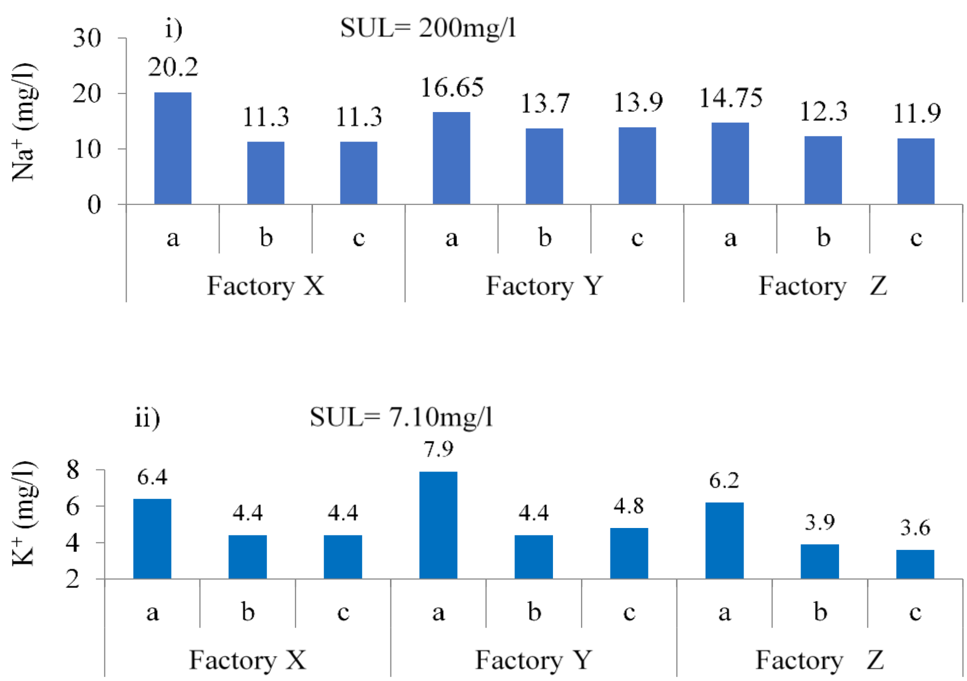


Figure 4-3: Values of tests results for i) Na+ and ii) K+

4.3.2 Calcium (Ca^{2+}) and Magnesium (Mg^{2+})

Figure 4-4: i) and ii) show laboratory tests results for Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) at source, after treatment and storage for factories X, Y, Z. The tests results indicate that the highest reading for Ca^{2+} and Mg^{2+} of 93.25mg/l and 37 mg/l are within acceptable limits compared to SUL of 150mg/l and 100mg/l for Ca and Mg^{2+}, respectively. It can also be seen that values do differ for the three sources X, Y and Z. The difference could be due to the difference in mineral content of the rock formation through which the water with its dissolving effect for the factories do infiltrate.

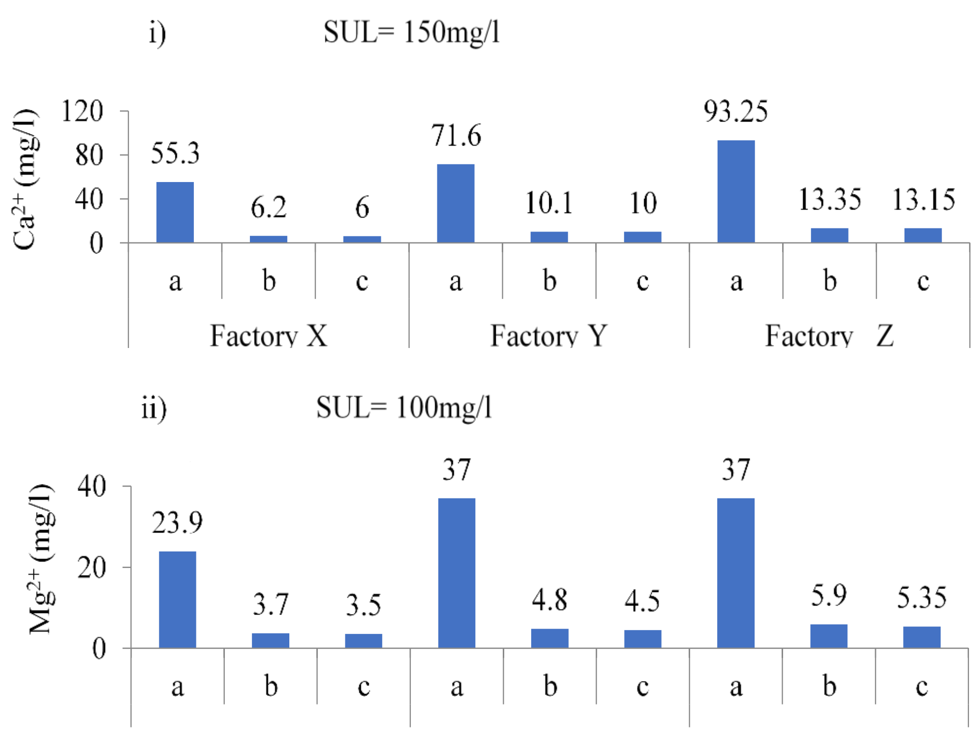
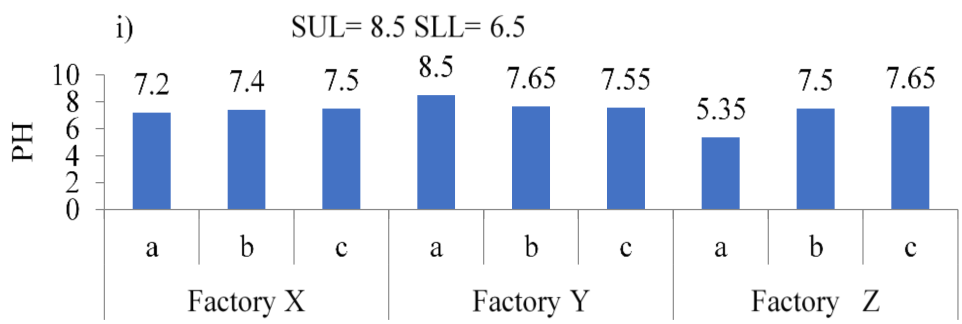


Figure 4-4: Values of tests results for i) Ca^{2+} and b) Mg^{2+}

4.3.3 PH and Total Dissolved Solids (TDS)

Figure 4-5: i) and ii) show laboratory tests results for PH and Total Dissolved Solids (TDS). The tests results with PH and TDS readings of (7.2-8.5) range and maximum of 183mg/l compared to (6.5-8.5) and 1500mg/l SUL values are within acceptable limits for bottled drinking water. The changes of test values between the sources and storage is attributed to the treatment processes.



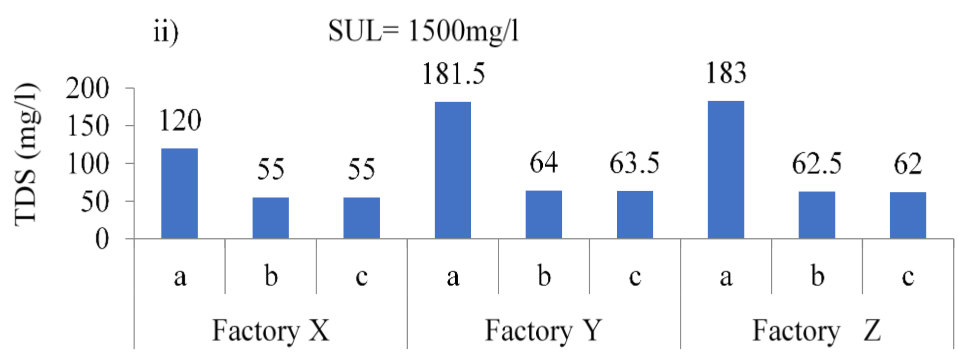


Figure 4-5: Values of tests results for a) PH and b) TDS (Note: SUL is Standard Upper Limit and SLL is Standard Lower Limit)

4.3.4 Nitrates (NO_3) and Nitrites (NO_2)

Figure 4-6: i) and ii) show laboratory tests results for Nitrates (NO_3) and Nitrites (NO_2) at source, after treatment and storage for factories X, Y and Z. All tests values for Nitrates (NO_3) are within acceptable limits. The Nitrite (NO_2) tested values of 0.005mg/l for sources Y and Z are noted to be above the acceptable upper limit of 0.003mg/l. However, after treatment processes the nitrite values (< 0.003) for all three factories are observed to be within the acceptable limits for bottled drinking water.

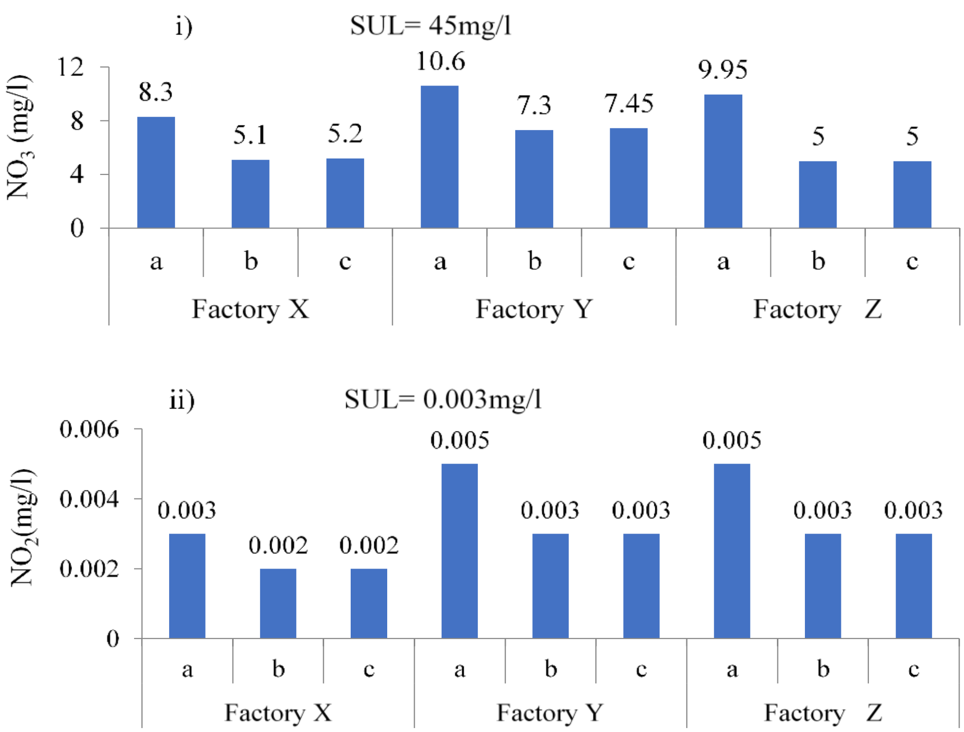


Figure 4-6: Values of tests results for i) NO_3 and ii) NO_2

4.3.5 Phosphates (PO_4) and Sulphates SO_4)

Figure 4-7: i) and ii) show laboratory tests results for Phosphates (PO_4) and Sulphates SO_4) at source, after treatment and storage for factories X, Y and Z. The tests results show that the Phosphates test values of source Y (4.45mg/l) and source Z (4.35mg/l) were above the acceptable limit of 2.2 mg/l. However, after treatment all the Phosphates test values of (<1.3mg/l) are noted to be within the acceptable limits with SUL of 2.2mg/l. All Sulphates tests value (<15.2mg/l) are noted to be within the acceptable limits with SUL of 2.2mg/l.

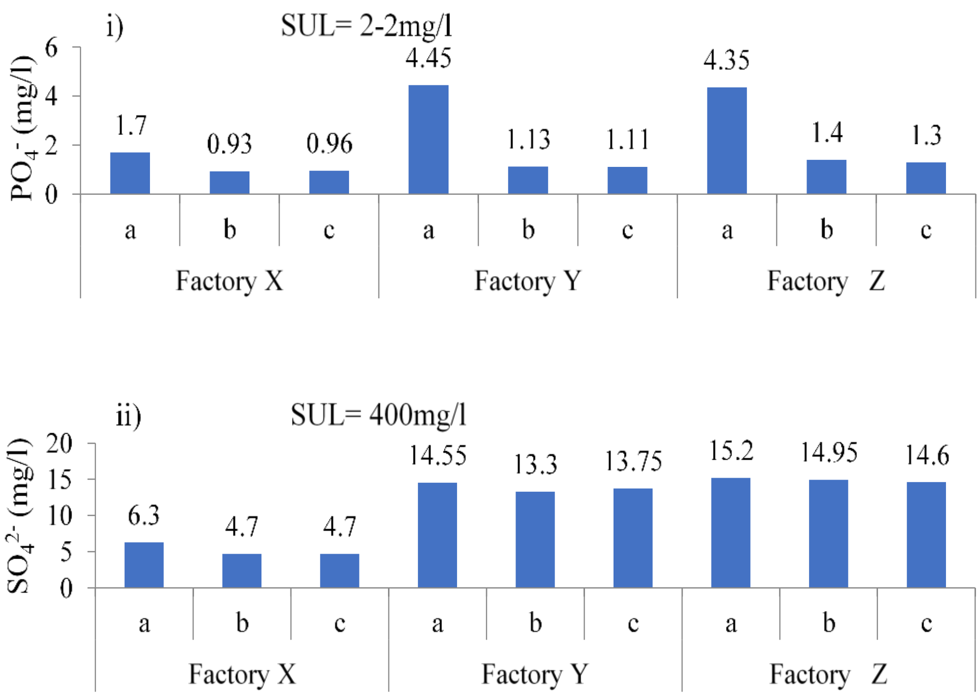


Figure 4-7: Values of tests results for a) PO_4^- and b) SO_4^{2-}

4.3.6 Chlorides (Cl^-) and Flourides (F^-)

Figure 4-8: i) and ii) show laboratory tests results. The tests results show that Chlorides with maximum test value of 46.6mg/l and SUL of 250mg/l are within acceptable limits. The fluorine test values for source X (7mg/l), source Y (10.2mg/l) and source Z (9.9mg/l) are above the SUP value of 1.5mg/l. After treatment all fluorine values are observed to be less than 1.15mg/l hence within acceptable limits indicative of effective treatment processes as regards to the fluorine levels of drinking water.

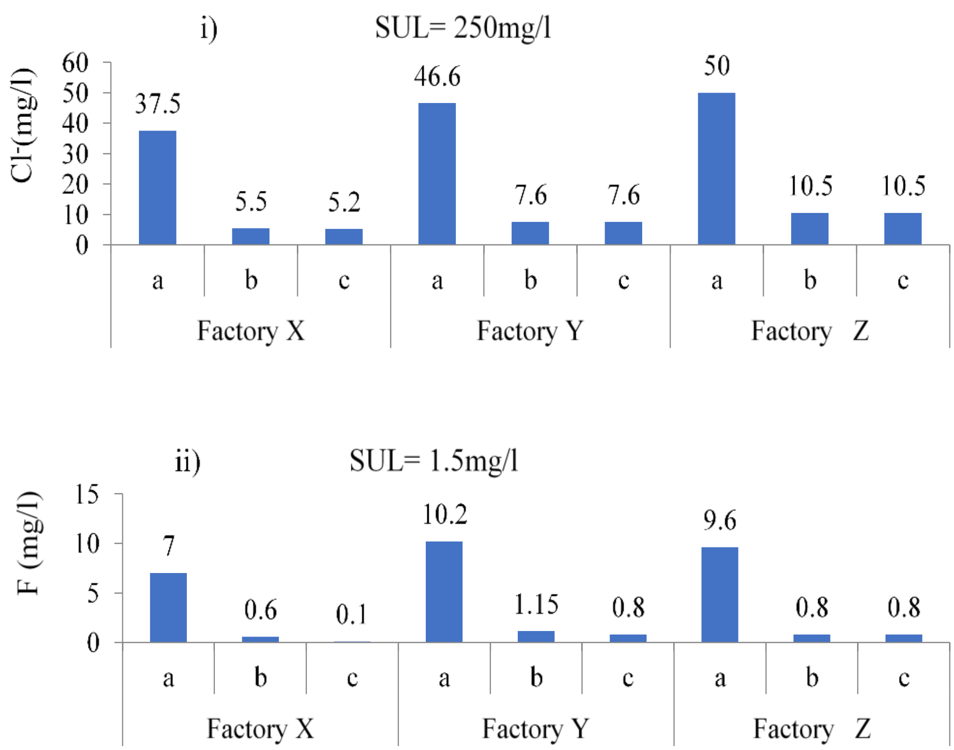
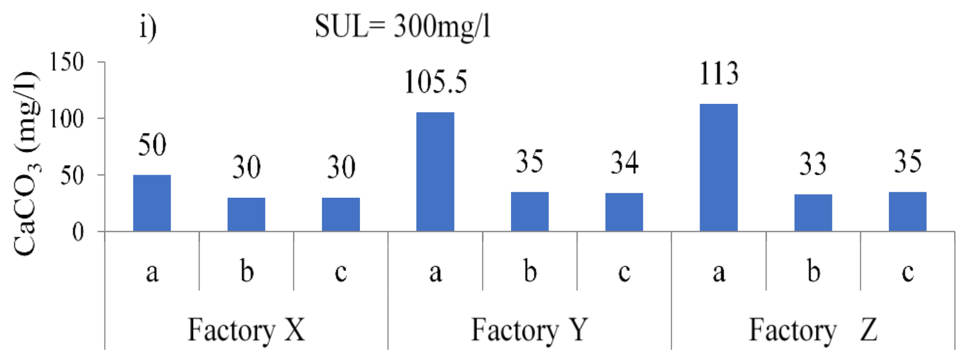


Figure 4-8: Values of tests results for i) Cl^- and ii) F

4.3.7 Calcium Carbonates ($CaCO_3$) and Turbidity

Figure 4-9: i) and ii) show laboratory tests. All tests values for Calcium Carbonate with maximum reading of 113mg/l and SUL 300mg/l are within acceptable limits for bottled drinking water. Turbidity values for the three factories sources (X-18mg/l), (Y-27.5), (Z-27) are all above acceptable limits with SUL of less than 1. However, after treatment the values are reduced to acceptable values a good indicator for an effective treatment process for turbidity removal during production.



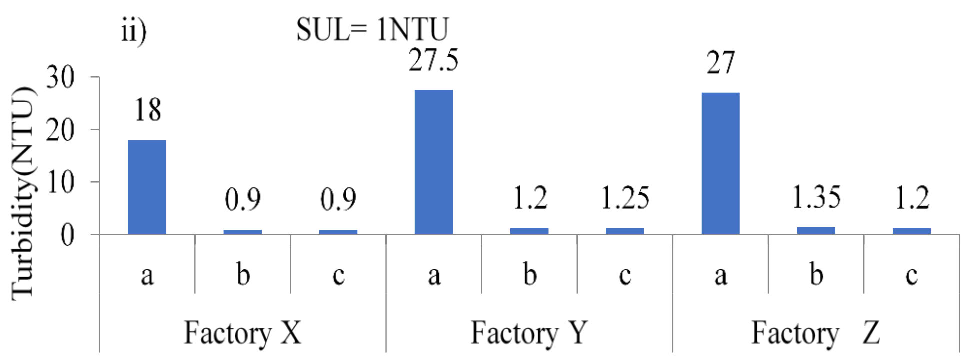
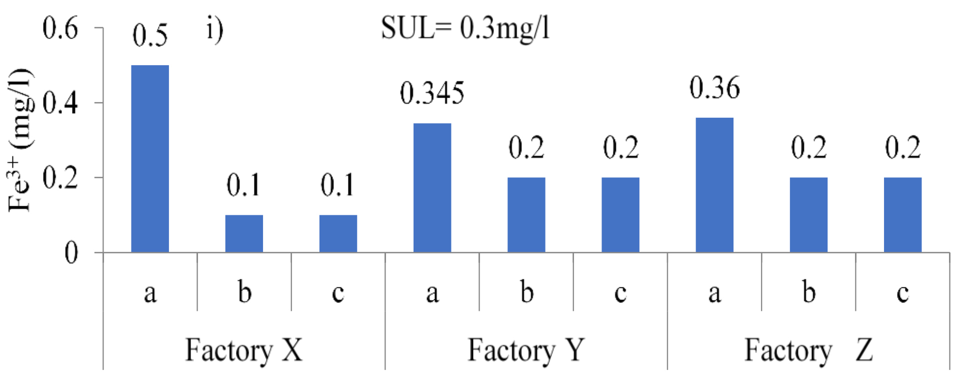


Figure 4-9: Values of tests results for i) $CaCO_3^{2-}$ and ii) Turbidity

4.3.8 Iron (Fe^{3+}) and Electric conductivity (EC)

Figure 4-10: i) and ii) show laboratory tests. It can be seen that the test values for three factories sources (X-0.5mg/l), Y-0.345mg/l), (Z-0.36mg/l) are all above the SUL (0.3mg/l). However, after treatment, the values are all reduced to acceptable limits with SUL of 0.3mg/l which is a good indicator for the treatment processes as regards to reduction of iron content to acceptable standards. Electric conductivity tests values for the three factories SUL of 2500mg/l are within acceptable range for drinking water.



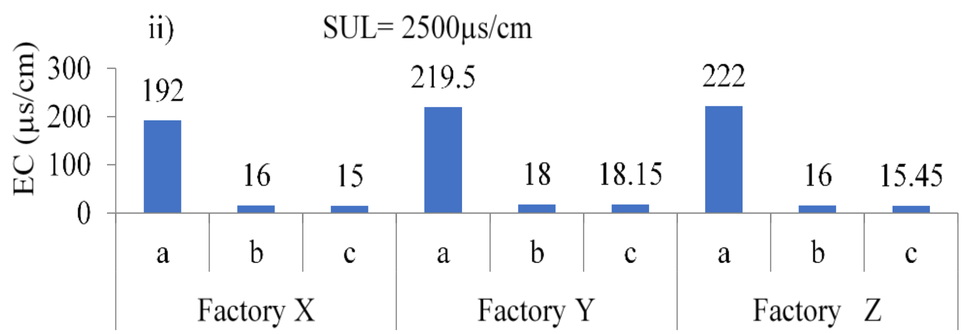


Figure 4-10: Values of tests results for i) Fe^{3+} and ii) EC

Both X and Z, water abstraction sources (ground water) could have been exposed to underground rocky formations with different mineral contents, hence the high nutrient, metal content and Electrical conductivity in) source water compared to factory Y. This may be attributed to the fact that Y abstracted from National water system, that is already pre-treated (hence the high chlorine, $CaCO_3$ content and pH).

In spite pre-treatment of received water by factory Y, the study indicated that Z was the best at treatment of abstracted water against NDWS, since its source water was filtered by the great nature in the different layers of soil as evidenced by the low Fe and nitrate content. This is in agreement to the findings under the study, by Mi-Jung established that 60% of the Pusan residents took untreated underground water (springs, wells) and was safe (Mi-Jung et al., 2002).

Findings by Parihar in analysis of underground water established that 1% of the ground water level is threatened either directly or indirectly by pollution, which ascertains the high salinity levels (concentration of cations) in factory X abstracted water (Parihar. et al., 2012). Aggregated with low frequency of flashing the sand beds, opening Quartz column and replacing and cleaning the micro filter (10µ and 5µ), this could be why factory X performed below Y and Z.

Findings on biological parameter by this study indicated that E-Coli was zero (0) in all three brands of products, which was within the industry standard (<1). This indicates absence of pathogenic microorganisms that cause water borne diseases like cholera, dysentery and typhoid fever in the water supplies, thus guarantee bottled water quality.

4.3.9 Objective 2 conclusion

Although all the three factories water products met the set UNBS standards for safe clean bottled water, factory Z performed better than X and Y. This could be due to varying degrees of efficiency in the treatment processes for the three factories. It could also be attributed to poor maintenance practices contrary to the recommended schedules and practices by the plants manufacturers. It can also be due to partial treatment where some key steps /processes are avoided among other reasons. However, at time of factories visit all the required processes to ensure that the water quality issues are properly addressed were observed to be operational for each of the three factories. Further ranking shows X being the second Y being last for the three bottled water manufacturing factories.

4.4 Objective 3: Assessing bottled quality water on local market

4.4.1 Bias on water quality based on production and market

The study based on analysis of PH and Calcium Carbonate ($CaCO_3$) content established that there was bias (production vs market) in quality of same brand bottled water i.e. quality immediately after production and quality of same brand on local market. The magnitude of the bias in quality of the brands at production ready for market and same brand on market ready for consumption was found out to be more pronounced in Mityana town, followed by Soroti town, Mbale town with Kampala having minimal variations Figure 4-11).

The bias could be probably due to short transportation distance or proper handling of the products compared to other towns. Also, the bias may be attributed to the fact that Mityana and Mbale towns compared to Soroti and Kampala had the highest number (28%) of bottled water closer to expire dates ((01-02)/2020) compared to other two towns. The bias within same brand for the different factory's products (X, Y and Z) was noted to vary differently at the 4 (four) market locations, with Y varying most in Kampala and Mbale whereas Z varied most in Mityana and Soroti in comparison to other brands.

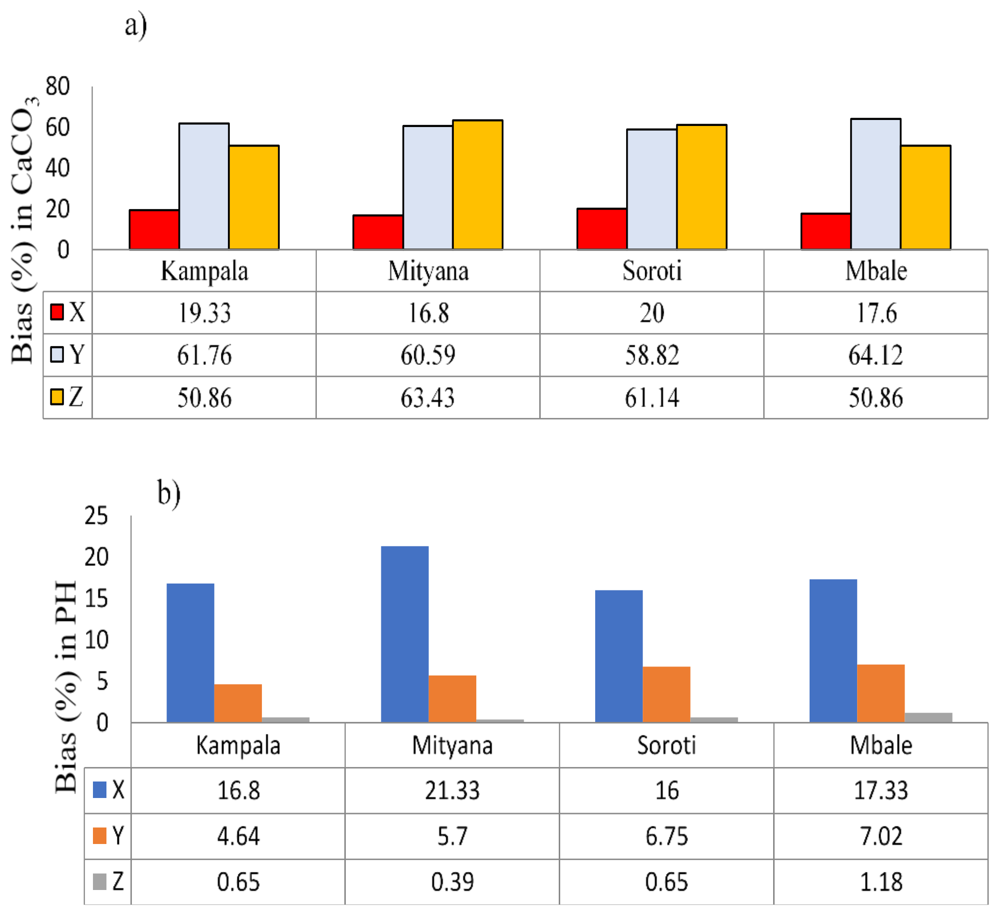


Figure 4-11: Average bias for a) $CaCO_3$ and b) PH in water quality on market

4.4.2 Bias of PH and $CaCO_3$ at location and storage

Figure 4-12 a) and b) show test results of bias in % for $CaCO_3$ and PH for fridge storage in the four (4) towns. It can be seen that water quality in terms of $CaCO_3$ differed differently for the different brands in the four towns. Z had the highest bias in Soroti town. Y had the highest bias in Mbale and Kampala towns. X had a minimal bias in all the four towns. For PH Brand X recorded the highest bias in all the four (4) towns followed by brand Y. Z had the least bias in the four (4) towns.

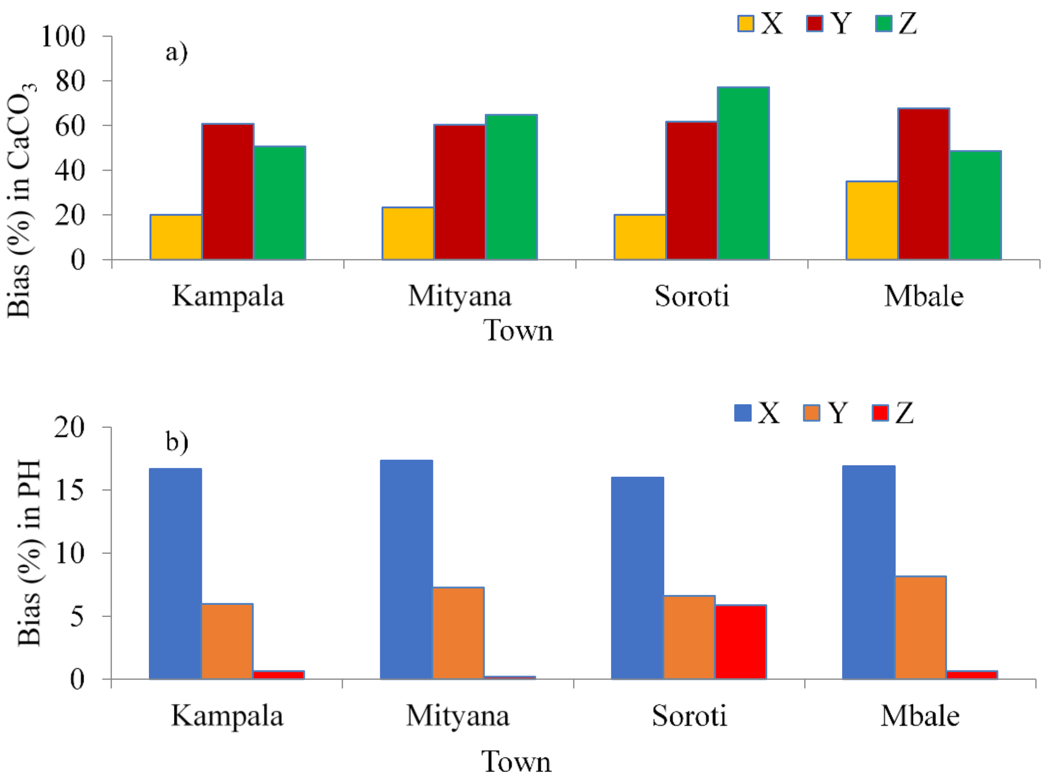


Figure 4-12: Fridge-based bias (%) for $CaCO_3$ and b) PH

Figure 4-13 a) and b) Show bias % in $CaCO_3$ and PH for shelf storage. It can be seen that brand Y in Kampala had the highest bias in the four towns for $CaCO_3$. Brand Y is also on the lead in Mbale and Mityana towns. Brand X had the lowest $CaCO_3$ bias in all the four (4) towns for shelf storage. For PH bias, Y in Mbale town had the highest bias for the four towns. Brand X had the highest bias in Kampala. Z had the lowest bias in each of the four (4) towns.

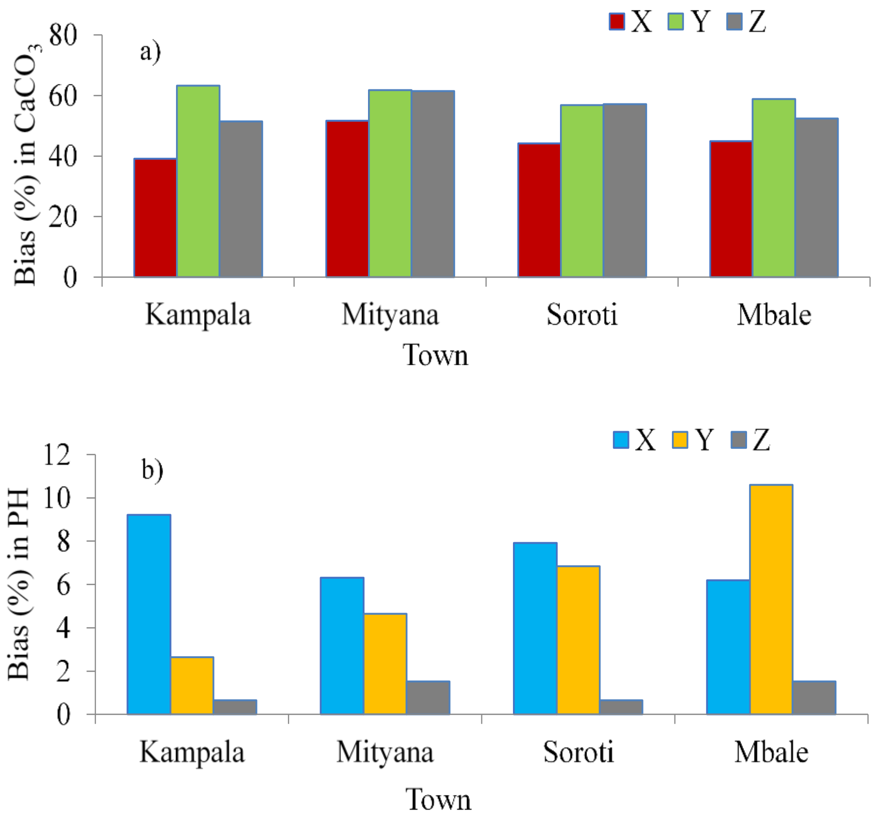


Figure 4-13: Location-based bias (%) in a) $CaCO_3$ and b) PH

Figure 4-14 a) and b) Show a comparison of bias in $CaCO_3$ and PH for Fridge and shelf storage in the four towns for the three (3) brands. It can be seen that $CaCO_3$ bias for brand Y and Z was in the lead for the three brands in fridge storage. Brand X had the least bias in $CaCO_3$ bias in fridge storage. For PH brand X in fridge showed the highest bias. Brand Z had the least bias at shelf and fridge storage for the three (3) brands.

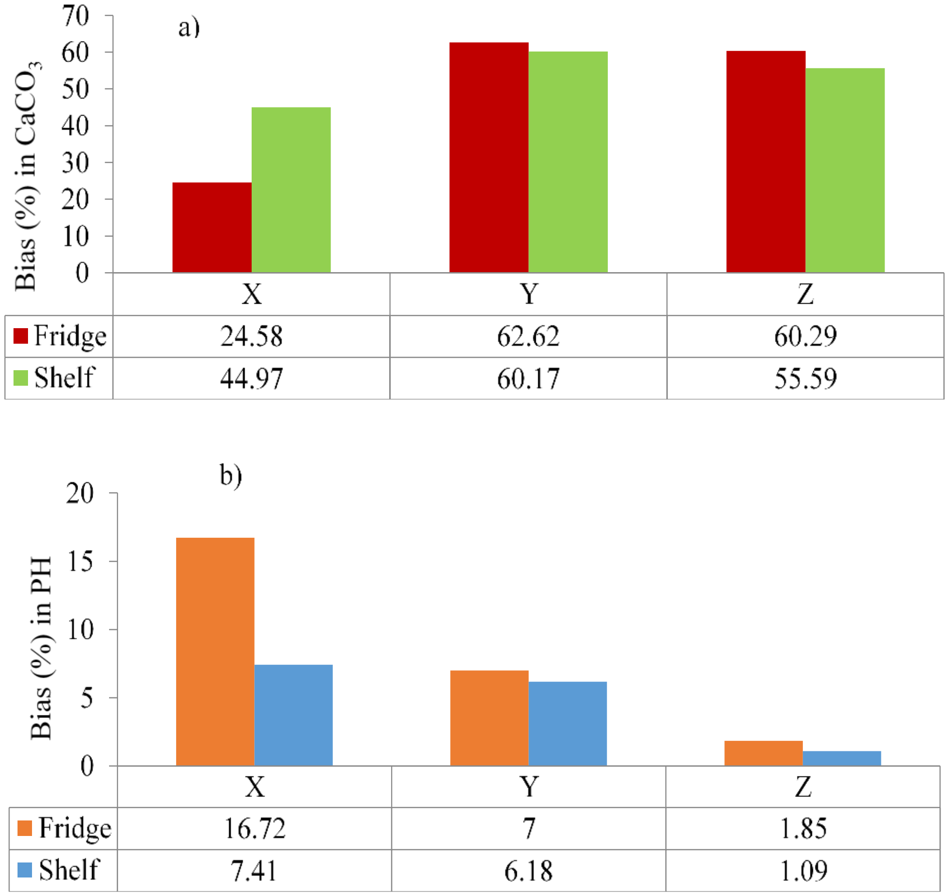


Figure 4-14: Storage-based bias (%) in a) $CaCO_3$ and b) PH

4.4.3 Objective 3 conclusion

Bottled water quality is affected by other factors other than production/treatment processes. This is confirmed by the study results that clearly show that the quality of bottled brand at production is not the same as at market. Results also show that even water quality at market could differ depending on the type of brand, location and storage facilities.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter describes a summary of the study findings, conclusions of the study and the suggested recommendations for the conducted study and not forgetting areas of further research.

5.2 Conclusions

The analysis of a total of 24 samples from production and 60 samples from market for the 3 bottled water brands in Kampala and Mityana Central and Mbale and Soroti in Eastern regions of Uganda revealed that bottled water after production processes and on market for the brands was within normal limits prescribed by both Who and UNBS (NDWG) guidelines. Na+, K+, Ca2+, Mg^{2+}, PH, TDS, NO_3^-, NO_2^-, PO_4^-, SO_4, F, Cl^- $CaCO_3$, Turbidity, EC, Fe^{3+} after treatment were all within permissible.

The tested $CaCO_3$, PH, Turbidity and Ecoli for samples picked from local market were also all within the acceptable limits. However, the consumer perception survey of this study established that bottled water had taste, odour and colour in spite the fact that potable water is expected to have none. Furthermore, during sample testing, evident results of appearance, aroma, texture and taste confirmed to the latter.

On following up the distributed bottled water to market, differences in $CACO_3$ content and PH were observed on comparison of same brands $CaCO_3$ and PH content at

Factories and after the brands leaving the factories. The differences were noted based on different locations, premises and storage facilities. On market premises (supermarkets performing better than shops); storage (minimal difference in boxes, followed by shelf's, then fridge) all attributed to probably temperature difference and expiry dates. In spite of the noted differences in $CaCO_3$ and PH as indicated, the study concluded that bottled water from the 3 brands is; safe for consumption, not coloured but bears taste and odour as related to consumer's perception.

5.3 Recommendations

5.3.1 Action by stakeholders in bottled/packaged drinking water manufacturing

As a good practice bottled water manufacturer should always recommend on storage conditions for bottled water. This is based on the findings of water quality changing with conditions of storage i.e. whether in shelves, ridges or boxes.

The issue of shelf-life i.e. stating clearly the time for which bottled water will remain usable or fit for consumption (both manufacturing and expiry dates should be indicated on bottled water during the brands labeling processes).

UNBS and other stake holders responsible for regulating water quality issues should devise more effective and stringent means of addressing the challenge and maintaining bottled water quality standards for the safety of the public. In a fortunate event that indeed all the quality requirements are met by the brands on market in Uganda then it is expected to aim at maintaining the status quo or even better improve it.

5.3.2 Future research

Future research should be carried out to establish the different factors, the extent and under what conditions they do affect bottled water quality.

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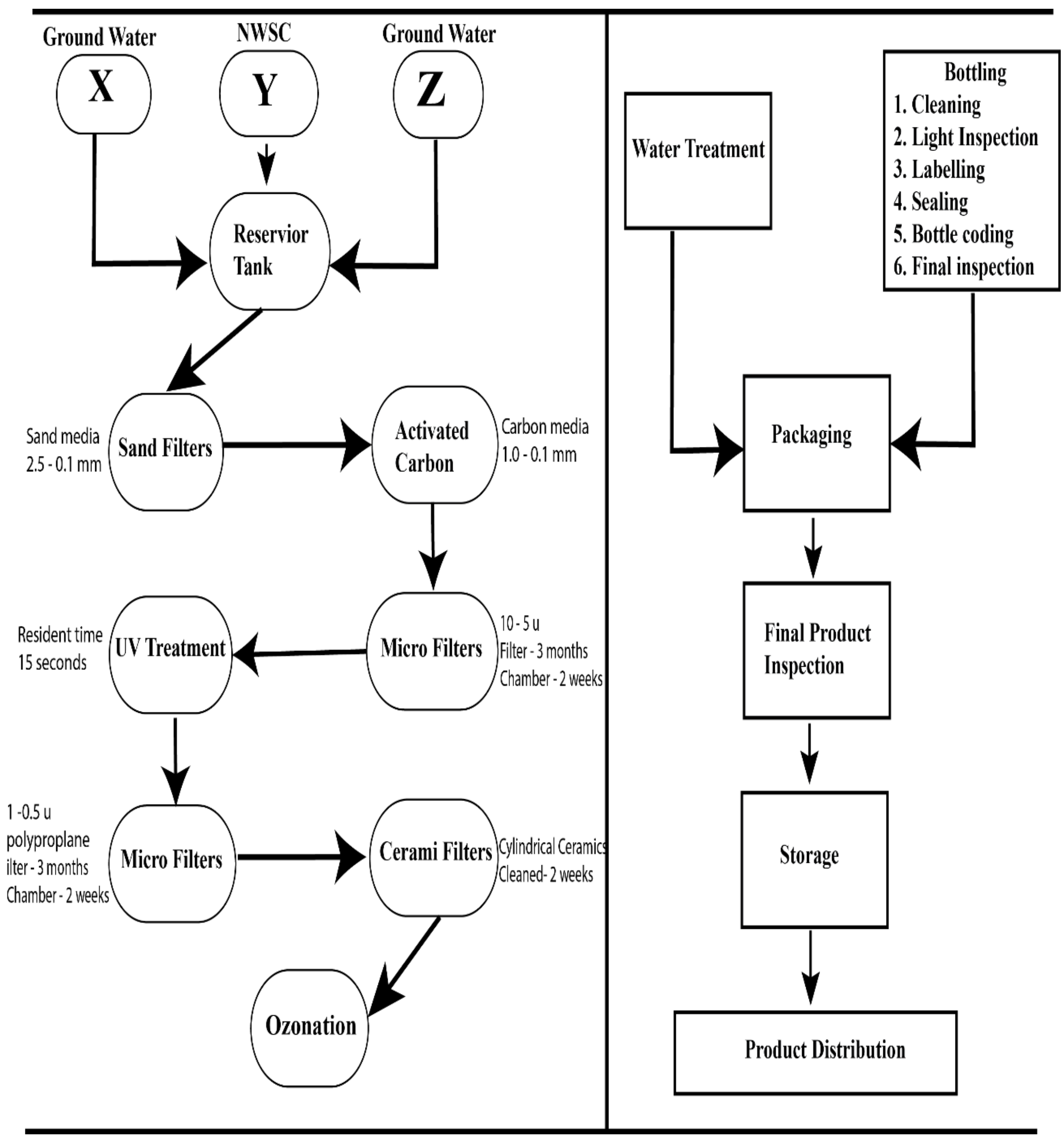
APPENDICES

Appendix I: Summary of bottled water manufacturing (production) processes



Appendix II: Details of the bottled water factory treatment processes

Potable Water Reception	Raw water or partially treated water is obtained from an underground water source (spring or drilled borehole/production well) or National Grid of National Water and Sewage Corporation (NWSC), by way of hygienically closed pumping system. The water is conveyed to a Reservoir Tank where inspection to ascertain its suitability for processing is made. This tank is cleaned and sanitized on a monthly basis and records maintained.
Sand Filtration	Potable water is then made to pass through Quartz sand media. This is a column of small stones of different sizes arranged in layers. The arrangement starts with big sizes of 2.5 mm to 0.1mm from top to bottom. Water flows from top to down with positive pressure and in process water filtration is done by holding big suspended matter in the potable water. These stones are flashed daily before start of every production shift. The sand media is generally cleaned by way of opening Quartz column once in a year during the annual shut down and

	the entire media is replaced every after two years. Water then goes into the activated carbon.
Activated Carbon Treatment	Water is then flown to a column of activated carbon arranged in layers in the carbon filter chamber. The carbon media consists of black chalk in nature ranging from 1.0 mm to 0.1mm. This media sometimes is referred to as absorber filter which attracts; segments, colour, toxins and chlorine odour hence improving the; colour, odour and taste of the in-process water.
Micro Filtration (10µ & 5µ)	Water is then passed through a series of synthetic fibre micro filters arranged from 10µ, and then 5µ and the filters in the chamber are arranged in parallel. 10µ filters remove the particles that remain in the in-process water after sand and carbon filtration/ treatment. 5µ filters also known as absolute filters remove particles that remain after sand, activated carbon and 10µ filters' filtration, microorganisms that are bigger than 10µ & 5µ are removed from the in-process water. The filters are changed every three (3) months and chambers cleaned every two (2) weeks unless clogged earlier. The record on cleaning the chamber and change of filters is be maintained.
U.V. Treatment 1	Water is then passed through a column of U.V. rays with a

	resident time of 15 seconds. These rays sterilize the water by striking the cells. UV energy penetrates the outer cell membrane of microorganism, passes through the cell body and disrupts its DNA preventing reproduction. UV treatment does not alter water chemically (i.e. no dissolved organics, in-organics or particles are removed) and nothing is being added except energy. The sterilized microorganisms are not removed from the water. It's noted that UV does not effectively disinfect some organisms (most moulds, protozoa, and cysts of *Giardia lamblia* and Cryptosporidium) since they require a higher dose.It is possible to achieve 99.9% reduction in certain applications of UV treatment but with proper maintenance.
Micro Filtration (1µ and 0.5µ)	Water is then passed through a series of polypropylene micro filters arranged from 1µ, and then 0.5µ and the filters in the chamber are arranged in parallel. 1µ and 0.5µ filters successively remove the killed microorganisms and any other contaminants in the in-process water that escaped the previous filtration. These filters are changed every three (3) months and chambers cleaned every two (2) weeks unless clogged earlier. Pressure within the filtration chambers is monitored and in case of clogging of filters, the pressure increases beyond normal

	which signifies the need to replace the filters. The record on cleaning the chamber and replacement of filters is be maintained.
Ceramic Filters Micro Filtration (0.9µ)	Water is then pumped through the ceramic filters also referred to as water polishers, they are columns of ceramic cylindrical arranged in series within the chamber and columns arranged in parallel. These filters and chamber are cleaned every two (2) weeks unless clogged earlier. Pressure within the filtration chambers is monitored and in case of clogging, the pressure increases beyond normal which signifies the need to clean filters and sanitize the chamber. Records are maintained on these operations.
Ozonation	Water is then ozonated to achieve further microbial treatment and post capping disinfection of all the product contact surfaces. The Ozone system is comprised of four basic parts: Oxygen concentrator, Ozone generator, Ozone contacting, and Off-gas disposal. Ambient air at 21 % oxygen is be taken in by the Oxygen concentrator and then the O_2 is concentrated to 96%. The concentrated oxygen gas is then be fed into the ozone generator which converts the oxygen to ozone gas. Ozone at concentration 0.2-0.4 ppm interferes with the metabolism of

	bacterium cells, most likely through inhibiting and blocking the operation of the enzymatic control system. Ozone destroys viruses by diffusing through the protein coat into the nucleic acid core, resulting in damage of the viral RNA. At higher concentrations, ozone destroys the capsid or exterior protein shell by oxidation so DNA (deoxyribonucleic acid) or RNA (ribonucleic acid) structures of the microorganism are affected.
Bottle Cleaning & Sanitization	Disposable bottles are cleaned and rinsed with ozonated water for disinfection. The returnable bottles are inspected, sorted, cleaned inside and out, rinsed and disinfected with oxonia solution and finally with ozonated product water. The cleaning and rinsing is by automatic systems where bottles are ished, disinfected before filling and capping. The caps are also pre-rinsed and sanitized with ozonated product water.
Rinsing, Filling & Capping	The cleaned bottles are further rinsed out with pressurized ozonated water by rinsing nozzles oriented inside bottles at 90^0. The rinsed bottles are then filled with product water and capped automatically within the enclosed rinsing, filling and capping machines.
Candling/ Light	This is done by exposing the individual packaged bottle on a light back ground to check any presence of foreign particles or

Inspection	any other defects on the products. Products that are found to be defective are separated immediately and labeled as non-conforming. These products are later analyzed for rework or disposal.
Labeling	The products are labeled in accordance to the UNBS labeling requirements and product information. This is as per US EAS 38:2014. For the returnable bottles, pale/ faded and torn labels are replaced with new ones. The labels are properly and firmly stuck on the bottles.
Sealing	Sleeves are fixed and the auto steamer used to secure them firmly. The bottle caps are sealed to prevent any contamination and as evidence of no tampering has been done on the product as it riches the customer. The sleeves are properly and firmly stuck on the bottles.
Batch Coding	The packaged products are coded at the neck with; batch number, expiry date, and production time for product traceability. The batch is a working day date, and it consists of 6 digits for instance B# YYMMDD. The expiry date as; BB DD. MM. YY and time the individual bottle has been produced as;

	mm: ss.
Final Product Inspection	The packaged products are finally inspected to ascertain that all the physical product characteristics are fulfilled before dispatch or storage is done. Records are maintained.
Finished product storage	The final products are stored under conditions that do not compromise/ alternate the quality of the products.
Products Distribution	Distribution vehicles are inspected to ascertain that they are; free from contaminants and good mechanical condition before they are loaded. During on loading, proper stacking of products is ensured to avoid damages during distribution. Box boded vehicles is be used and whenever open carriers is be used tarpaulins is employed to cover and protect the products. Records on product inspection, product details, product destination is be maintained for product traceability.

Appendix III: Guide survey questionnaires

Dear Respondent, I am a student of Kyambogo University pursuing a Master's degree in Water & Sanitation Engineering. I am conducting a study on **Assessment of Packaged Drinking Water Quality Along its Production Chain to Consumer: Determinants and Implications in Uganda.** I would be grateful if you avail me with the information relating to the above topic for research purposes. Be assured that the information you provide will be used for this study and will be treated with maximum confidentiality.

Section A: General Questions

The following section contains general questions necessary for classification purposes.

1. Gender:

   Male ☐ Female ☐

2. Age (Years):

   18-25 ☐ 26-35 ☐ 36-45 ☐ Above 46 ☐

3. Marital Status

   Single ☐ Married ☐ Divorced/Separated ☐

   Others (Specify)…………………………………….

4. Highest Academic Qualification:

Diploma ☐ Degree ☐ Masters ☐ PhD ☐

Others (Specify)…………………………………

5. Duration of Employment:

Below 1 Year ☐ 1-4 Years ☐ 5-9 Years ☐ Above 10 Years ☐

Are you ready to be part of this research?

Yes ☐ No ☐

Interviewee signature..

Using Likert scale 1-5; express your Disagreement /Agreement with statements below by ticking the number of your choice:

1. Strongly disagree (SD)

2. Disagree (D)

3. Not sure (NS)

4. Agree (A)

5. Strongly agree (SA)

Section B: Odour

No.	Statement	SD	D	NS	A	SA
1.	Brand **X** has odour.	**1**	**2**	**3**	**4**	**5**
2.	Brand **Y** has odour	**1**	**2**	**3**	**4**	**5**
3.	Brand **Z** has odour	**1**	**2**	**3**	**4**	**5**

Section C: Taste

No.	Statement	SD	D	NS	A	SA
1.	Brand **X** has a taste.	**1**	**2**	**3**	**4**	**5**
2.	Brand **Y** has a taste	**1**	**2**	**3**	**4**	**5**
3.	Brand **Z** has a taste	**1**	**2**	**3**	**4**	**5**

Section C: Colour

No.	Statement	SD	D	NS	A	SA
1.	Brand **X** has a colour	**1**	**2**	**3**	**4**	**5**
2.	Brand **Y** has a colour	**1**	**2**	**3**	**4**	**5**
3.	Brand **Z** has a colour	**1**	**2**	**3**	**4**	**5**

Appendix IV: Interview Guide and Observation Check list

Quality Manager/Analyst/Controller

Interviewer/Researcher name..

Interviewer/Researcher Supervisor..

Main Interviewee Name... Gender........Age…..

Marital Status…………………Qualification…………………. Duration………………..

Main Interviewee Designation..

Name of Factory..Location..

Date of Interview...

Name and Signature of the respondent……………………………………………………….

Sn	Question	Response/Observation
1	How is the General cleanness?	
2	What type of Source?	
3	What are the yields of the source?	
4	Are there alternate sources?	
5	Is protection adequate?	
6	Are there measures for corrective actions in response to deviation from limits?	
7	Is there a verification plan to ensure that individual components of the production and the entire system as a whole is operating safely?	
8	Is the infrastructure adequate to ensure water safety?	
9	Is there in place an independent surveillance system to ensure safety of the packaged drinking water?	

10	Are there measures to ensure undertaking of appropriate treatment and safety of packaged water to the consumer in place?	
11	Does the company have a water safety plan in place?	
12	If the water safety plan is in place does it have the 3 key components?	
13	Are the workers in factory sensitized on importance of water quality?	
14	Are the workers provided with safety gears?	
15	What type of packaging materials are used by the company?	
16	What is the source of packaging materials?	
17	Are there measures in place to address and minimize contamination due to packaging materials and processes?	
18	How is packaged drinking water transported?	
19	Is the company registered with UBOS?	
20	Are there policies/guidelines regarding packaged water quality control in factory?	
21	Is there evidence to prove 3 above?	
22	Is the laboratory fully equipped?	
23	At what points /stages are samples picked for testing?	
24	Does the company have a sampling programme that takes into consideration appropriate international recommendations?	
26	Is the sampling regular?	
27	If sampling is regular what are the factors that determine	

	its frequency?	
28	How often is the testing done?	
29	What are the parameters used to monitor water quality?	
30	Does the company have a budget line for water quality testing and monitoring?	
31	Who does the water quality monitoring and testing?	
32	What are the qualifications of the water quality monitoring personnel?	
33	What are the challenges faced by the water quality analyst while handling assignments	
34	What technology does the company use to treat water?	
35	What are the challenges faced by this kind of technology?	
36	How often does UNBS check on quality?	
37	What is involved in routine maintenance (cleaning) of the plant?	
37	On what basis and how often is this done?	
38	Is there evidence, i.e a log book, checklist to confirm?	
39	Other than the usual parameters does the company go a step ahead to consider other parameters like heavy metals etc in the testing process?	
40	Is the manufacturer a member of any packaged water manufacturers association?	

Appendix V: Market Samples Remarks

SOROTI TOCOM

EXPIRY DATE	SAMPLE LABEL	REMARKS
17/01/2020	SX1	Shop-Shelf.
30/01/2020	SX2	Supermarket (Om)-Fridge
15/01/2020	SX3	Super market (Pooran)-Shelf.
22/02/2020	SX4	Supermarket (Om) - Box
20/12/2019	SX5	Lockup - shelf.
29/08/2019	S21	Funeral-box
30/08/2020	S22	market - shelf
15/07/2020	S23	Super market - Box
28/04/2020	S24	Super market - shelf
19/12/2020	S25	Super market-fridge

EXPIRY DATE	SAMPLE	REMARKS
26/06/2020	SY_1	Shop – Shelf.
27/06/2020	SY_2	Super market ~~ff~~ – Shelf.
26/06/2020	SY_3	Shop – Shelf.
26/06/2020	SY_4	Supermarket – Fridge
18/06/2020	SY_5	Super market – Fridge

KAMPALA

29/01/2020	KX_1	—	Shelf supermarket
3/03/2020	KX_2	—	Supermarket fridge
21/02/2020	KX_3	—	Shop Shelf
29/03/2020	KX_4	—	Shop Shelf
24/02/2020	KX_5	—	
8/07/2020	KY1	—	Supermarket fridge.
8/07/2020	KY2	—	Supermarket shelf
12/08/2020	KY3	—	Supermarket fridge
12/08/2020	KY4	—	Shop - Shelves
8/07/2020	KY5	—	Shop - fridge

19/12/19	K21 –	Supermarket fridge
6/6/20	K22 –	Supermarket Shelf
6/6/20	K23 –	R. Shop ~~Shelf~~ Fridge
6/6/20	K24 –	Kiosk fridge
6/6/20	K25 –	Supermarket fridge

MITYANA TOWN

21/02/2020	MTX1	— Supermarket shelf.
21/02/2020	MTX2	— Supermarket fridge
10/02/2020	MTX3	— Supermarket fridge
19/02/2020	MTX4	— Shop shelf.
11/02/2020	MTX5	— lockup fridge

AQUA – Y

21/11/19	MTY1	— Supermarket shelf
25/11/19	MTY2	— Supermarket fridge
26/05/20	MTY3	— R. Shop fridge
26/05/20	MTY4	— R Shop shelf.

26/05/20 MT45 – Kiosk Shelf

31/03/20 MT21 — Super market fridge

19/12/19 MT22 – Shop Shelf

5/09/20 MT23 – Shop fridge

20/12/20 MT24 – Shop fridge

19/12/19 MT24 – Super market Shelf

Date	Sample label	MBALE TOWN	Remarks-mbale
~~MX1~~ 18/01/2020	MX1	Mbale	Haus Supermarket Fridge
18/02/2020	MX02	Mbale	Shop ~~Self~~ Shelve
11/02/2020	MX3	"	Shop fridge
15/01/2020	MX4	"	Supermarket fridge
02/02/2020	MX5	"	Supermarket Shelve
6/04/2020	MY1	"	Supermarket - Shelve
3/07/2020	MY2	"	Shop - fridge
6/04/2020	MY3	"	Supermarket fridge
16/08/2020	MY4	"	Retail Shop - fridge
20/08/2020	MY5	"	Retail Shop Shelfs

19/ 12/ 2019 M21 – Supermarket fridge

19/12/ 2019 M22 – Super market shelf

3/08/ 2020 M23 – Super market fridge

21/08/ 2020 M24 – Supermarket shelf

19/12/ 2020 M25 – Shop (Retail) shelf

Appendix VI: Introductory letter from Kyambogo University

KYAMBOGO UNIVERSITY
Department of Civil and Building Engineering
P. O. BOX 1, KYAMBOGO – KAMPALA, UGANDA
Website: www.kyu.ac.ug, Email: civil@kyu.ac.ug
TEL: +256-41-4287340, FAX: +256-41-4289056/4222643

30th April 2019

The Executive Director, UNBS - Headquarters,
P.O Box 6329,
Kampala, Uganda.

Dear Eng. Dr.,

RE: INTRODUCTION LETTER FOR AGONZA DEOGRATIOUS

Mr. Agonza Deogratious is a student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Building Engineering. He is conducting a research study on "Assessment of Packaged Drinking Water Quality along its Production Chain: Determinants and Implications in Uganda". He is being supervised and co- supervised by Dr. Charles Onyutha and Eng. Dr. Anne Nakagiri, respectively.

In his research, Deogratious will require support on a number of occasions for the various specific objectives of his study (see next page). He will need authorization from the UNBS to:

1) Allow him go to some companies that process and package drinking water; here, the researcher is required to assess the various processes that packaged drinking water goes through with respect to quality aspects, and
2) Conduct water quality tests from the UNBS laboratory.

In some cases, the UNBS may need to avail the researcher with some of information relevant for the research study. Such information includes, the most recent list of certified water companies, list accredited laboratories for conducting water quality tests, guidelines for monitoring quality in the various stages of processing and packaging of drinking water, etc.

I shall be grateful for any assistance rendered to Mr. Deogratious Agonza to allow him conduct his research study timely.

Yours Sincerely,

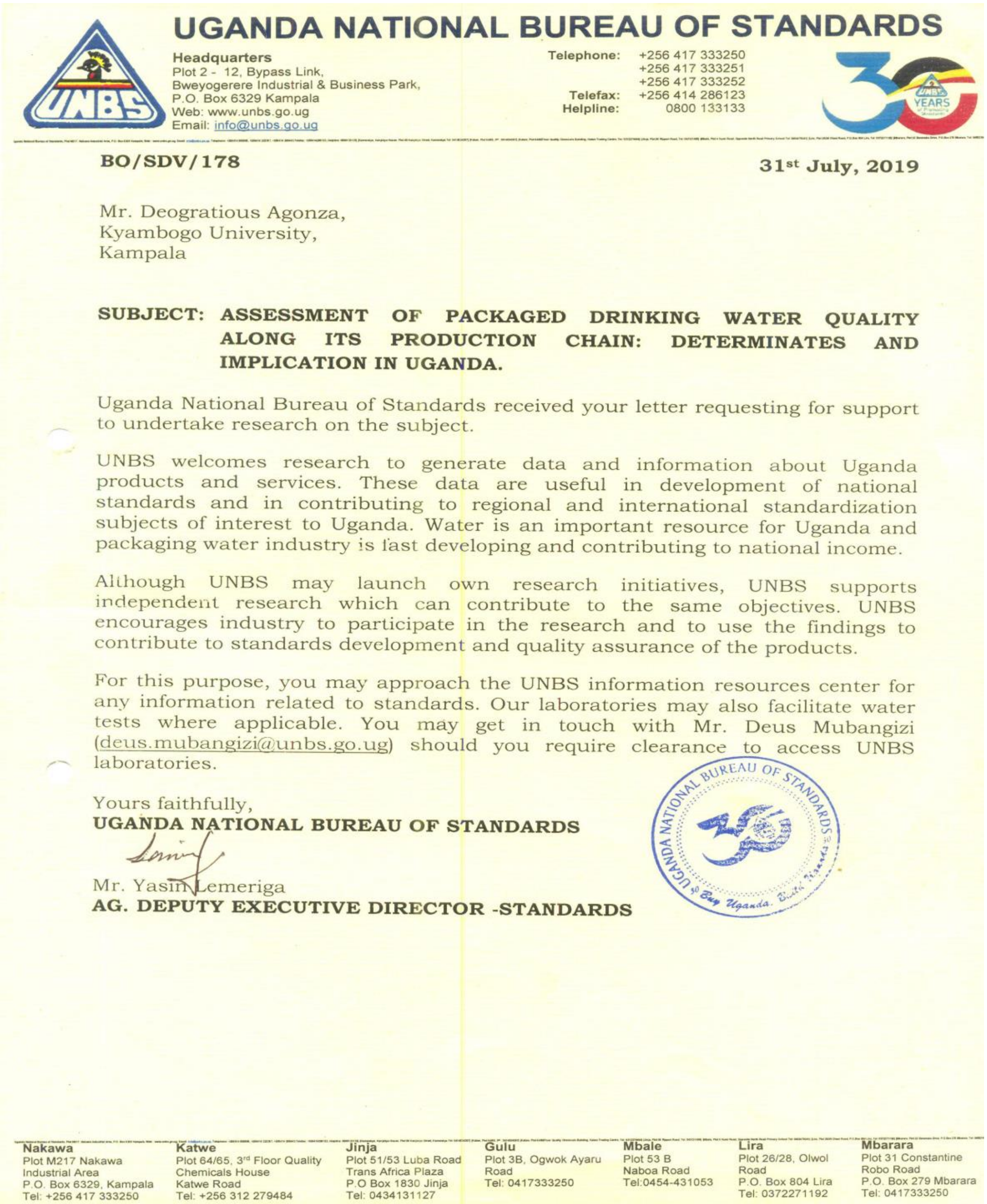
THE HEAD OF DEPARTMENT
CIVIL AND BUILDING ENGINEERING
KYAMBOGO UNIVERSITY

UGANDA NATIONAL BUREAU OF STANDARDS
08 MAY 2019
RECEIVED
STANDARDS HOUSE BWEYOGERERE

Jacob Nyende (PhD)
Head of Department Civil & Building Engineering

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

Appendix VII: Acceptance letter from UNBS.



UGANDA NATIONAL BUREAU OF STANDARDS

Headquarters
Plot 2 - 12, Bypass Link,
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Telefax: +256 414 286123
Helpline: 0800 133133

BO/SDV/178

31st July, 2019

Mr. Deogratious Agonza,
Kyambogo University,
Kampala

SUBJECT: ASSESSMENT OF PACKAGED DRINKING WATER QUALITY ALONG ITS PRODUCTION CHAIN: DETERMINATES AND IMPLICATION IN UGANDA.

Uganda National Bureau of Standards received your letter requesting for support to undertake research on the subject.

UNBS welcomes research to generate data and information about Uganda products and services. These data are useful in development of national standards and in contributing to regional and international standardization subjects of interest to Uganda. Water is an important resource for Uganda and packaging water industry is fast developing and contributing to national income.

Although UNBS may launch own research initiatives, UNBS supports independent research which can contribute to the same objectives. UNBS encourages industry to participate in the research and to use the findings to contribute to standards development and quality assurance of the products.

For this purpose, you may approach the UNBS information resources center for any information related to standards. Our laboratories may also facilitate water tests where applicable. You may get in touch with Mr. Deus Mubangizi (deus.mubangizi@unbs.go.ug) should you require clearance to access UNBS laboratories.

Yours faithfully,
UGANDA NATIONAL BUREAU OF STANDARDS

Mr. Yasin Lemeriga
AG. DEPUTY EXECUTIVE DIRECTOR -STANDARDS

UGANDA NATIONAL BUREAU OF STANDARDS

Nakawa Plot M217 Nakawa Industrial Area P.O. Box 6329, Kampala Tel: +256 417 333250
Katwe Plot 64/65, 3rd Floor Quality Chemicals House Katwe Road Tel: +256 312 279484
Jinja Plot 51/53 Luba Road Trans Africa Plaza P.O Box 1830 Jinja Tel: 0434131127
Gulu Plot 3B, Ogwok Ayaru Road Tel: 0417333250
Mbale Plot 53 B Naboa Road Tel:0454-431053
Lira Plot 26/28, Olwol Road P.O. Box 804 Lira Tel: 0372271192
Mbarara Plot 31 Constantine Robo Road P.O. Box 279 Mbarara Tel: 0417333250

Appendix VIII: AVERAGE VALUES OF TESTED PARAMETERS FOR FACTORIES X, Y and Z

	Parameter	pH	EC	TDS	Turb	Na^{+}	K^{+}	F^{-}	SO_4^{2-}	PO_4	Cl^{-}	Cac o3	NO_3^{-}-N	NO_2^{-}	Fe3+	Mg2+	T -Coli	Ca++
	STANDARD VALUES	6.5-8.5	2500	1500	1	200	7.10	1.5	400	2.2	250	300	45	0.003	0.3	100	<1	150
FACTORY X	SOURCE	7.2	192	120	18	20.2	6.4	7	6.3	1.7	37.5	50	8.3	0.003	0.5	23.9	0	55.3
	AFTER TREATMENT	7.4	16	55	0.9	11.3	4.4	0.6	4.7	0.93	5.5	30	5.1	0.002	0.1	3.7	0	6.2
	STORAGE	7.5	15	55	0.9	11.3	4.4	0.1	4.7	0.96	5.2	30	5.2	0.002	0.1	3.5	0	6.0
FACTORY Y	SOURCE	8.5	219.5	181.5	27.5	16.65	7.9	10.2	14.55	4.45	46.6	105.5	10.6	0.005	0.345	37	0	71.6
	AFTER TREATMENT	7.65	18	64	1.2	13.7	4.4	1.15	13.3	1.13	7.6	35	7.3	0.003	0.2	4.8	0	10.1
	STORAGE	7.55	18.15	63.5	1.25	13.9	4.8	0.8	13.75	1.11	7.6	34	7.45	0.003	0.2	4.5	0	10
FACTORY Z	SOURCE	5.35	222	183	27	14.75	6.2	9.6	15.2	4.35	50	113	9.95	0.005	0.36	37	0	93.25
	AFTER TREATMENT	7.5	16	62.5	1.35	12.3	3.9	0.8	14.95	1.4	10.5	33	5	0.003	0.2	5.9	0	13.35
	STORAGE	7.65	15.45	62	1.2	11.9	3.6	0.8	14.6	1.3	10.5	35	5	0.003	0.2	5.35	0	13.15