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Presented by

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ASSESSMENT OF THE QUALITY OF BOTTLED DRINKING WATER PRODUCED IN AFRICAN CITIES: A CASE STUDY OF Kigali, Rwanda.

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ASSESSMENT OF THE QUALITY OF BOTTLED DRINKING WATER PRODUCED IN AFRICAN CITIES

A CASE STUDY OF Kigali, Rwanda.

BY

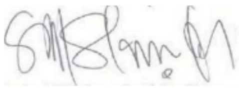
Adeline ICYIMPAYE

A Research Thesis Submitted in Partial Fulfilment of the Requirements for the Award of the Degree of Master of Science in Water Policy of Pan African University Institute of Water and Energy Science (including climate change) Tlemcen, Algeria

September, 2019

CERTIFICATION

This thesis has been submitted for examination with my approval as the university supervisor

Signature: 

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DEDICATION

This work is dedicated to my family and my unconditional friends. You have been cordial to me in a very unique way.

DECLARATION

I, **Adeline ICYIMPAYE**, hereby declare that this thesis represents my personal work, realized to the best of my knowledge and has never been presented for a degree in any other University. I also declare that all information, material and results from other works presented herein, have been fully cited and referenced in accordance with the academic rules and ethics.

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BIOGRAPHICAL SKETCH

Adeline is a Rwandese masters' holder in Water Policy from Pan African University - Institute of Water and Energy Sciences (including climate change)-PAUWES in Tlemcen, Algeria. Adeline has a Bachelors' degree in Soil and Water Management from University of Rwanda-College of Agriculture, Animal Sciences and Veterinary Medicine (UR-CAVM), preceded by a solid background of Physics, Chemistry and Mathematics. She is passionate about conservation of all natural resources especially water and soil.

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ABBREVIATION AND ACRONYMS

Al: Alminium

AOV: Analysis of Variance

Ca: Calcium

Cl^-: Chloride

EAC: East African Community

EAS: East African Standards

EC: Electrical Conductivity

E-coli: Escherichia coli

EPA: Environmental Protection Agency.

F^-: Fluoride

Fe: Iron

HACH: Housing Authority of the City of Houston

ISO: International Organization for Standardization

IWRM: Integrated Water Resources Management

K: Potassium

LSD: Least Significant Differences

Ltd: Limited.

MINIFRA: Ministry of Infrastructure

Mg: Magnesium

Na: Sodium

$NO3^-$: Nitrate

NQTL: National Quality Testing Laboratories

NTU: Nephelometric Turbidity Units

p: Probability

PAUWES: Pan African University Institute for Water and Energy Sciences (incl. Climate Change)

pH: Power of Hydrogen

QMS: Quality Management System

RS EAS: Rwanda Standards identical to East African Community Standards

RS ISO: Rwanda Standards identical to International Organization for Standardization

RSB: Rwanda Standards Board

SDG: Sustainable Development Goals

$SO4^{2-}$: Sulphate

TA: Total Alkalinity

TDS: Total Dissolved Solids

UNICEF: United Nations International Children's Emergency Fund

UR-CST: University of Rwanda-College of Science and Technology

WASAC: Water and Sanitation Corporation

WCL: Water Central Laboratory

WTP: Water Treatment Plant

WHO: World Health Organization

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ABSTRACT

The primordial role of water in the survival of all living organisms is well known. Unfortunately, in most of developing countries including Rwanda, many people still lack access even to basic drinking water services. Consequently, demand in bottled water, which may also come from sources exposed to pollution, keeps on increasing where tap water's safety is doubted. People are afraid of health problems including death which may be linked to consumption of unsafe water.

In that regard, this research was conducted to assess the physicochemical quality of bottled drinking water and tap water produced in Kigali. Hence, seven (7) representative samples of seven certified bottled water brands plus an additional sample of tap water were collected. Samples were subjected to laboratory analysis in triplicates by using standard methods. Spectrophotometer method was used for analysis of nitrate (NO_3^-), iron (Fe), sulfate (SO_4^{2-}), chloride (Cl^-), potassium (K^-), Fluoride (F^-), and aluminum (Al^{3-}); titration for total alkalinity (TA), calcium (Ca^{2+}), magnesium (Mg^{2+}); and direct reading on appropriate equipment for pH, turbidity, total dissolved solids (TDS), sodium (Na+) and electrical conductivity (EC).

An Analysis of Variance (AoV) was conducted using Statistix 10.0 software. Results showed that the concentration of some parameters were significantly different ($p \leq 0.05$) among water brands, those were: pH, TDS, (Fe), (Na), SO4, Cl, TA, Al and EC. In contrast, Turbidity, NO3, Ca, Mg, K, and F were not significantly different ($p \geq 0.05$) among brands. Furthermore, all physical and chemical parameters investigated fell within the ranges of Rwanda Standards Board (RSB) and World Health Organization (WHO) permissible limits for safer drinking water, except for pH which violated the lower permissible limit in three brands and the tap water. The results also showed that tap water had good quality as compared to bottled drinking water. However, the research discovered that the concentrations of parameters provided on bottle labels did not match with laboratory results in most of the cases. Companies were recommended to update their labels periodically. The study finally concluded that the overall quality of bottled drinking water produced in Kigali and tap water supplied by WASAC meet the standards of safety for human consumption.

Keywords: Physicochemical parameters, Bottled drinking water, Drinking Water Quality standards, WHO guidelines**.**

RESUME

Le rôle primordial de l'eau dans la survie de tous les organismes vivants est bien connu. Malheureusement, de nombreuses personnes n'ont toujours pas accès aux services de base d'approvisionnement en eau potable dans la plupart des pays en développement, y compris le Rwanda. Par conséquent, la demande en eau embouteillée, qui provient également de sources exposées à la pollution, ne cesse de croître là où la sécurité de l'eau du robinet est mise en doute par crainte de problèmes de santé, notamment de décès liés à la consommation d'eau insalubre. À cet égard, cette recherche visait à évaluer la qualité physico-chimique de l'eau de boisson en bouteille et de l'eau du robinet produites à Kigali. Ainsi, 7 échantillons représentatifs de sept marques d'eau embouteillée certifiées ont été achetés et un échantillon d'eau du robinet a été prélevé. Les échantillons ont été soumis à des analyses de laboratoire en triple exemplaire en utilisant des méthodes standard. Des méthodes de spectrophotomètre ont été utilisées pour le nitrate, le fer, le sulfate, le chlorure, sodium; le potassium, le fluorure et l'aluminium; titrage pour alcalinité totale, calcium, magnésium, et lecture directe sur les équipements appropriés pour le pH, la turbidité, le total des solides dissous et la conductivité électrique. L'AoV dans le logiciel de Statistix a montré que la concentration de certains paramètres était significativement différente ($p \leq 0,05$) parmi les marques d'eau, à savoir pH, TDS, (Fe), (Na), SO4, Cl, TA, Al et EC. En revanche, les concentrations de turbidité, NO3, Ca, Mg, K et F n'étaient pas significativement différentes ($p \geq 0,05$) en termes de concentration entre toutes les marques, ce qui explique pourquoi les résultats du test de comparaison de paires de LSD ont montré des groupes de moyenne homogènes différents pour chaque paramètre. En outre, tous les paramètres physiques et chimiques étudiés se situaient dans les limites permises du Rwanda Standards Board (RSB) et de l'Organisation mondiale de la Santé (OMS), à l'exception de 4 marques (y compris l'eau du robinet) qui dépassaient la limite inférieure autorisée du pH. L'étude a conclu que la qualité globale de l'eau potable en bouteille produite à Kigali et de l'eau du robinet fournie par WASAC était conforme aux normes de sécurité pour la consommation humaine. En outre, les résultats ont montré que l'eau du robinet était de bonne qualité en tant qu'eau potable en bouteille. Cependant, la recherche a révélé que les concentrations de paramètres indiquées sur les étiquettes des bouteilles ne correspondaient pas aux résultats de laboratoire dans la plupart des cas. Il a été recommandé aux entreprises de mettre à jour leurs étiquettes périodiquement.

Mots-clés: Paramètres physicochimiques, Eau potable en bouteille, Normes de qualité de l'eau potable, Directives de l'OMS.

IMPORTANT TECHNICAL DEFINITIONS

Drinking / Potable Water: *water either in its original state or after treatment, intended for human drinking, cooking, food preparation or other domestic purposes, food production, regardless of its origin whether it is supplied from a distribution, from a tank or in bottles* (WHO, 2011).

Treated water: *Water that has undergone through processes such as flocculation, coagulation, sedimentation, filtration and disinfection* (WHO, 2011).

Natural potable water: *Water that is from natural sources that is fit for human consumption without undergoing any form of treatment which will alter its original chemical composition and bacteriological purity* (WHO, 2011).

Natural mineral water: *Water clearly distinguishable from ordinary drinking water because:*

a) It is characterized by its content of certain mineral salts and their relative proportions and the presence of trace elements or of other constituents,
b) It is obtained directly from natural or drilled sources from underground water bearing strata for which all possible precautions should be taken within the protected perimeters to avoid nay pollution of, or external influence on, the chemical and physical qualities of natural mineral water.
c) Of the constancy of its composition and the stability of its discharge and its temperature, due account being taken of the cycles of minor natural fluctuations (RSB, 2011).

Mineral Water: *Water as defined previously and that may include permitted treatment such as Ozonation, UV sterilization, decantation filtration and permitted selective removal of fluoride.*

Bottled/Packaged Drinking *Water**:** Water filled into hermetically sealed containers of various compositions, forms, and capacities that is safe and suitable for direct consumption without necessary further treatment. Bottled drinking water is considered as food* (EAC, 2018).

Water Quality: *The chemical, physical and biological characteristics of water in respect to suitability for an intended use/purpose (RSB, 2011).*

Safe water: *Water that is free of chemical substances & micro-organisms in concentrations which could cause illness or body disorders in any form (RSB, 2011).*

Guidelines for drinking Water Quality: *recommendations provided by the World Health Organization (WHO) for managing the risk from hazards that may compromise the safety of drinking-water. They provide values of optimum concentration of a constituent which does not result in any significant health risk over a lifetime of consumption* (WHO, 2011)

1. INTRODUCTION

1.1.Background of the Study

Eight hundred forty four (844) million people, just 1 in 10 of the global population in 2015 were still living without access even to basic drinking water services (UNW-DPAC, 2015), only 71% were using safely managed drinking water service (UN, 2018), and sadly 58% of 159 million people who were still collecting drinking water directly from surface water lived in sub-Saharan Africa (WHO-UNICEF-JMP, 2017) and the situation is still the same 1 in 3 people do not have access to safe drinking water (WHO, 2019).

Water as a vital nutrient, our organs needs it for their normal functioning and also to keep the water balance in our body (Mihayo.I, Mkoma.S, 2012). On average, Water accounts 60% of the body weight for an adult human being (Je´quier & Constant, 2010). The average water intake of 2 liters per day for adults is needed as commonly used by the World Health Organization (WHO) and regulators in computing drinking water guidelines and standards (WHO, 2005).

Different initiatives have been established in all regions and countries; in which among their targets included this one of ensuring that drinking water supply from improved water source will be achieved at 100%, and that water should be safe and accessible for all population by a specific time frame. The Sustainable Development Goals (SDGs); goal 3 (target 9), goal 6 (target 1 and 3); Rwanda‘s Vision 2020; Nation Water Supply Policy of Rwanda; and African Union’s Agenda 2063, all seek to achieve, within their respective timelines, full access to drinking water that should be safe, affordable, and free of chemicals as well as other hazardous contamination (AUC, 2015); (UN-SDGs, 2015) (ECA, 2018).

The availability and quantity of drinking water are nothing without quality, because poor quality of drinking water leads to health problems which can even cause death (WHO, 2017); (MININFRA, 2016). Therefore, several companies are involved in purification and packaging water in bottles for direct drinking where tap water is inaccessible or when the quality of tap water can‘t be trusted (Janan, 2015.).

Bottled drinking water is currently a popular but expensive source of drinking water (Toma, 2015) in Rwanda like elsewhere in Africa, especially in cities where the majority of rich peoples are concentrated because they believe that it is safe as it undergoes further treatment before being packaged (Oyebog.S & al, 2012) (AF Shahaby, 2015).

Kigali, capital city of Rwanda like some other African cities is experiencing a rapid development, population growth, fastest urbanization, and increasing industrial activities (UN-RWanda, 2017) (AfricaGrowthInitiative, 2019); (UNDP, 2018), if coupled with insufficient maintenance of distribution pipes, both may alter the ground water quality (Ton Dietz, 2014)It is obvious that even bottled water may not be safe if performed purification process was not done carefully to meet quality standards of drinking water because Bottled water comes from sources such as wells, springs, artesian wells, and the municipal water supply which may not be far from a city where pollution is a problem (Oyebog.S & al, 2012). Moreover, the variation in prices for different packaged drinking water brands also threatens people's trust of quality when they find themselves in a situation where they have to drink the cheapest water. In this regard, it was very important to conduct this study that assessed the quality of bottled drinking water produced and sold in Rwanda.

1.2. Problem Statement

Rwanda like other countries striving to achieve SDGs has incorporated the goal number 6 of SDGs in its Vision 2020's targets, and is clearly elaborated in the National Water Supply Policy where the safety of drinking water is highlighted among key conditions for all sources of drinking water (SDGCA, 2018) (MININFRA, 2016). The current trends of pollution of natural water resources has great impact on the quality of water supplied to public population, hence the global consumption of bottled drinking water was increased by an average of 12% per year because people believe that it is safer than tap water (Alam.M & al, 2017).

The Rwanda Standards Board (RSB), which is an agency in charge of quality verification, certification and standardization of all products in Rwanda, has to ensure that bottled drinking-water produced by all water bottling companies in Rwanda is safe before giving them the standardization mark. Hence, hence WHO guidelines for drinking-water quality are considered while adopting international standards like the East African Standards (EAS) which are useful for quality control of most of the products in the region.

Despite the certification of brands by RBS, water analysis results are valid once at a time, the quality may not be maintained in time due to different factors, like climate change which can alter the chemical composition of water sources, the type; status; and calibration of the equipment, method and technics of treatment (WHO, 2011).

In addition, the fact that the Rwanda is experiencing a rapid urbanization and increasing industrial activities, when coupled with insufficient maintenance of distribution pipes they affect the quality of water sources and drinking water as well, and thus may also alter the quality of bottled drinking-water in case the purification done by bottling companies is not satisfactory or once performed carelessly. Moreover, it has been observed that some bottled water brands do not bear the standardization mark of approval which is given by RSB. It was therefore of paramount importance to assess the quality of bottled drinking water produced and sold in Kigali.

1.3. Main Objective:

To Assess the Physicochemical Quality of Bottled Drinking Water produced in Kigali.

1.4. Specific Objectives:

- ✓ To test the physicochemical parameters of bottled water and tap water,
- ✓ To compare the physicochemical parameters of bottled water and tap water with concentration presented on bottle labels,
- ✓ To compare the quality of bottled and tap water with RSB and with WHO drinking water quality standards and brand among themselves.

1.5. Research Questions

i. What is the level of concentration of physicochemical parameter in tested bottled drinking water brands and tap water?

ii. Is there any difference in concentration between bottled and tap water in terms of physicochemical quality?

iii. How good are our tap and bottled drinking water compared to RSB and WHO standards?

iv. Is the concentration of parameters labelled on bottles matching with laboratory findings?

1.6. Justification of the Study

Rwanda is experiencing a fastest urbanization and increasing industrial activities, when coupled with insufficient maintenance of distribution pipes they may affect the quality of drinking water and water sources. Water as a vital nutrient, human beings need it not only in quantity but also in quality to survive.

Poor quality of drinking water leads to health problems which can even cause death, reason why nowadays many people are committed to buy bottled drinking Water because they believe that the quality in enhanced compared to tap water. Bottled drinking water companies are business entities, if by any chance the purification done by bottling companies is not satisfactory, performed carelessly, or a single mistake in calibration of equipment, the quality of produced water will also be affected as bottled water comes from sources which may not be far from the source of contamination.

It was therefore needed to assess the physicochemical quality of bottled drinking water which is being produced and sold in Kigali and compare it with tap water, RSB standards and WHO guidelines for drinking water quality as well to clear the doubt.

1.7. Limitation of the Study

Some physical, chemical and all microbiological test were not covered due to the unavailability of funds and limited time, the research was limited to physicochemical quality analysis by considering 15 important parameters which, if not controlled, can basically affect the overall quality of water directly or indirectly by interference with other parameters. Targeted bottled drinking water brands were only those manufactured in Rwanda even if there were other brands from neighboring countries which are available on market inside Kigali because it should have been difficult to collect detailed information about their manufacturing companies as well as the source of their raw water.

It is important to note that not all chemicals present in drinking water are harmful to human life, through drinking-water few of them may contribute to their overall intake in the body which sometimes prevent diseases for example the effect of fluoride (with minimum desirable concentrations) in drinking-water by protecting against dental caries, while others occurs in drinking-water at concentrations well below those at which toxic effects may occur, and for some others are unlikely to be present in drinking-water at all (WHO, 2008); (WHO, 2011) , another example is presence of trace elements like sodium, potassium and chloride which are mostly found in water by small quantities and play a role in body metabolism (RBS, 2014), (WHO, 2017). That is also another reason why this research focused on some parameters rather than others.

2. LITERATURE REVIEW

2.1. Introduction

2.1.1. The Importance of Water Quality

Good physicochemical and bacteriological quality of drinking water is considered as a gatekeeper preventing harmful entities to enter our body. Even if some elements and organisms are harmless to human health but their presence in drinking water still have to be monitored because of their interference with others which might complicate the removal of others and/or enhance microbial growth. Physicochemical parameters in drinking water need a serious attention because a slight difference out of permissible limit for some hazardous elements may result into death or several form of disabilities on consumers.

Bacteriological quality of drinking water give information about the presence or absence of coliforms and e-coli which are always related to fecal contamination. Therefore, knowing that water is pathogens free plays a very important role to control the mortality of vulnerable persons like children under 5 years old as they are the mostly affected by gastrointestinal disorder such as diarrhea, vomiting, cholera, typhoid, dysentery, etc.

2.1.2. The Consequences of Poor Quality of Drinking Water

Poor quality of drinking water lead to health risks because that water may contains pathogens and harmful chemicals, as a daily per capita consumption of water for an adult assumed to be two (2) liters it means that by drinking unsafe water uncountable number of hazardous chemicals and Pathogens might get introduced in the body and weaken the immunity system (WHO, 2019). Water-related diseases remain a major concern in most of the developing countries due to massive use of unimproved water sources that are still the only available source of water for many households, Therefore, pathogens such as Salmonella species, Shigella species, Vibrio cholera and Escherichia coli being shed in human and animal feces ultimately find their way into water supply source through seepage, erosion and poor hygiene practices while doing domestic activities. Thus lead to the outbreak of diseases like typhoid, hepatitis A and tropical diseases including trachoma, intestinal worms and schistosomiasis (WHO, 2019).
Beside water-related diseases, the presence of chemicals in drinking water such as nitrates and fluoride beyond recommended permissible limits may cause chronic health effects including cancer, liver and kidney damage, disorders of the nervous system, birth defects like underweight baby and so on, depending on the type and concentration of chemicals (Prüss-Ustün, 2019).

Therefore, the chemical quality of drinking water has to be verified in all potable water before it is given to consumers whether it is supplied from WTP or from a natural source and in packaged water as well. Physical quality of drinking water affect its aesthetic value and acceptability which often goes with sociocultural beliefs of consumers. Parameters like odor, color, and taste if they are not in range, they compromise the palatability of water.

2.2. Empirical Review

2.2.1. Bottled Drinking Water Versus Tap Water

Consumers of bottled drinking water have various reasons for purchasing packaged drinking-water, such as taste, convenience (especially for travelers) or fashion (WHO, 2008), but in most of the cases they tend to think that bottled drinking water is always rich in minerals and safer than tap water but it does not necessarily has to be better, all depend on circumstances like treatment process/ technique(s) applied during production or raw water composition; otherwise both tap and bottled water may fall in the same range of drinking water quality standards after treatment (WHO, 2008), such findings have be obtained by a researcher in Mwanza city – Tanzania after determining physical and chemical quality parameters of both tap and bottled drinking water brands available in that city (Mihayo.I, Mkoma.S, 2012).

2.2.2. Overview on Quality of Bottled Drinking Water

Quality assessment of bottled drinking water in different cities has demonstrated that not all brands of bottled drinking water are safe to human consumption like the case of Vauban bottled water brand sold in Erbil city – Iraq (Toma, 2015), that was exactly the same for bottled drinking water sold in Kirkuk city - Iraq where the results on chemical and physical properties analysis showed that water processed in three regions of Kirkuk was not suitable for drinking and also there was discrepancies between the data obtained in vitro and what was listed on brands label (Hussein.E & al, 2014), for the case of Kathmandu valley - Nepal where 90% of the 27 brands of bottled water sampled by researcher had heterotrophic bacterial count that were above the acceptable range and the total coliform count that also crossed the WHO guidelines (Timilshina.M & al, 2012), another study was done for the qualitative and bacteriological assessment of bottled drinking water available on market in the city of Mymensingh - Bangladesh and its results showed that most of the bottled water studied were out of their safety guidelines (Sharmin.S & al, 2012), similar research was done in Dhaka city of Bangladesh to analyze physical and chemical parameters in bottled drinking water and the findings revealed that some parameters like pH, DO, and $Fe2+$ were out of permissible limits (Alam.M & al, 2017).

The chemical composition of water is highly dependent of the geology of where the source is located, the type of rocks; geological formation; and weathering process occurred in the region dictate the quality of water especially ground water which mostly serves as a reliable source of drinking water in rural areas as well as in arid and semi-arid regions in form of boreholes, wells, and springs (Oyebog.S & al, 2012).Moreover the current speed in development, expansion of industrial generated waste, population growth, deforestation, mining, climate change, and land degradation by extensive use chemicals in agriculture are worsening the pollution status of natural water resources which serve as drinking water source (Mohsin & al, 2013); (Ako.A & al, 2012). Consequently, the global consumption of bottled drinking water was increased by an average of 12% per year because people believe in its safety than tap water (Alam.M & al, 2017).

Therefore, the quality of bottled water is worth questionable because the changes in water quality occur progressively. Changes may occur during storage and/or transportation, especially due to the effect of sunlight in case bottles are directly exposed to sunlight (Mihayo.I, Mkoma.S, 2012); moreover, large bacterial populations may be developed from small initial populations just in short time after production (Sharmin.S & al, 2012).

Most of the time it is only the poor peoples who are vulnerable of different microbial infections and waterborne diseases resulting to the consumption of contaminated or unsafe drinking water available in their vicinity (WHO, 2019) because they are unable to buy safe drinking water (from public water kiosks, Public standpipe or packaged water) as it happened to workers of garment industries in Dhaka the capital city of Bangladesh who are used to drink water supplied by the supply factory near the capital city containing total coliforms, fecal coliforms, and total aerobic bacteria count which were higher than the standard limits (Hassan.M & al, 2016).

The SDGs goal 3 (target 9), goal 6 (target 1 and 3); and African Union's Agenda 2063, all seek to achieve, within their respective timelines, full access of drinking water that should be safe, affordable, and free of chemicals as well as other hazardous contamination, and they also do recognize the role of quality water in reducing the number of deaths and illnesses (UN-SDGs, 2015). In this regard, Rwanda like many other countries is striving to provide adequate and safe water to her citizens (WASAC, 2019).

Rwanda's Vision 2020; and its National Water Supply Policy both highlight the safety of drinking water as an important parameter (MININFRA, 2016); with reference to the report of the Joint Monitoring Program of WHO /UNICEF for Water Supply and Sanitation, in Rwanda, in 2012, 81% of the urban population and 68% of the rural population had access to improved drinking water sources means from protected sources (WHO-UNICEF-JMP, 2017); (MININFRA, 2016). This could lower the demand of bottled water in the country.

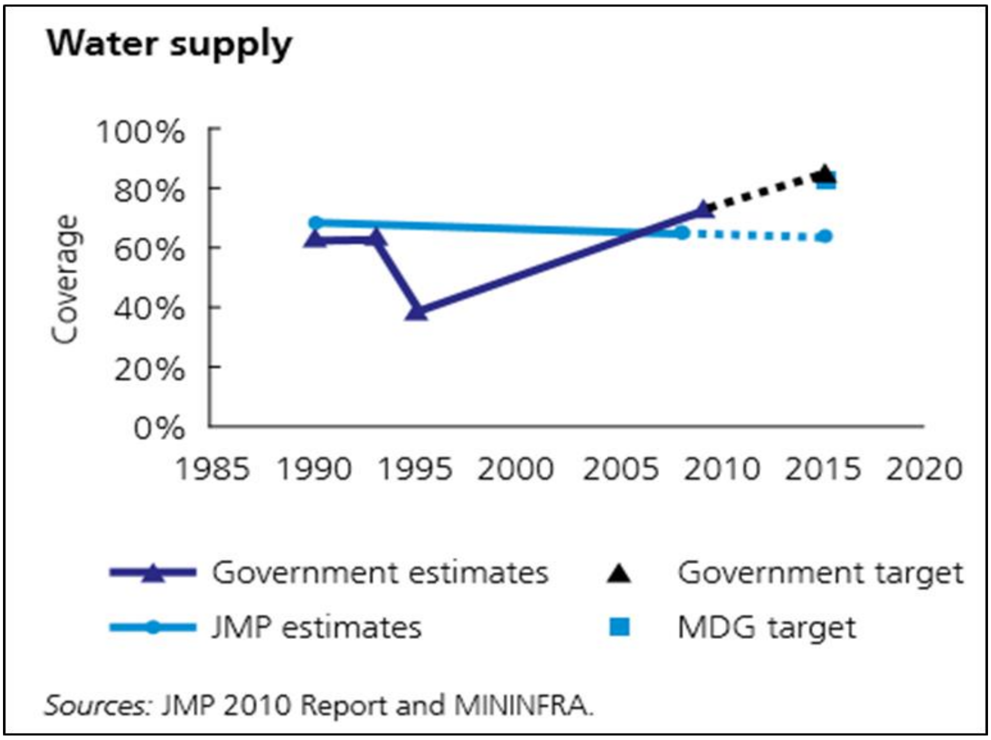

Figure 2.1: Water Accessibility in Rwanda

However; some people can't stop questioning about the quality of drinking water by taking into consideration insufficient maintenance of distribution pipes and the impact of industrial activities on ground water quality (Ton Dietz, 2014), as the country is experiencing a fastest urbanization and development (UNDP, 2018), which are always connected to environmental pollution (Toma, 2015). In addition, the extended periods of dry pipe and increased water tariff are also hindering water access in the country (RTV, 2019).

According to WHO, most chemicals arising in drinking water are of health concern only after extended exposure of years, rather than months, the principal exception is nitrate (WHO, 2011). In situations where short-term exposure is not likely to lead to health impairment, it is often most effective to concentrate the available resources for remedial action on finding and eliminating the source of contamination, rather than on installing expensive drinking-water treatment for the removal of the chemical constituent.

WHO Guidelines are applicable on both packaged water and ice intended for human consumption, large metropolitan and small community piped drinking-water systems, to non-piped drinking-water systems in communities and in individual dwellings, and other range of specific circumstances. It provides standards for microbial aspects, chemical aspects, radiological aspects, and acceptability aspects.

2.3. Theoretical Concerns

The poor quality of water leads to a continual decline of humans' well-being through water borne diseases, neurological problems, and various forms of physical disability depending on the type and/or concentration of contamination (Eawag, 2015). Unfortunately statistical data shows that 1 in 10 people who had no access to basic water services (PACN, 2010) are currently including 144 million of people who drink untreated surface water (WHO, 2019), and thus compromise the accessibility of safe water as a human right (AF Shahaby, 2015); (RBS, 2014), without forgetting its vital role of sustaining life (Toma, 2015).

Drinking water should be safe, free from concentration of chemicals (Alam.M & al, 2017), and other hazardous contaminants of health concern as stated in the WHO Guidelines for drinking quality (WHO, 2017). Reason why the global consumption of bottled drinking water keeps on increasing because people know the impact of consuming unsafe water and they don't trust the quality of water supplied by service providers in their municipality (Alam.M & al, 2017).

The United Nations member countries have pledged to achieve sustainable development goals (SDGs) by 2030 (UN-SDGs, 2015), raison why countries tried to incorporate SDGs goals in their national policies and strategies (UN, 2018). In addition to that all African countries also are committed to achieve the Agenda 2063 (AUC, 2015).Those two above mentioned initiatives have in their targets to ensure at 100% the coverage of improved water supply source with full access, safety, and affordability.

2.3.1. Drinking Water Quality Standards

The WHO Guidelines for drinking water describe reasonable minimum requirements of safe practice to protect the health of consumers and derive numerical "guideline values" for constituents of water or indicators of water quality. However, WHO recognizes the context of local or national environmental, social, economic and cultural conditions that may dictate other mandatory limits and thus result in national, local, or regional standards. Hence, the diversity of drinking water standards is obvious because there is no single approach that is universally applicable for drinking-water standards (WHO, 2011). Unfortunately, WHO does not promote the adoption of international standards for drinking-water quality, because those conditions that push the adoption of other standards may dictate even the quality which is not satisfactory.

Thus, Rwanda has her own standard, Rwanda Standards (RS), which is used together with the adopted international and regional standards applicable on different particular specifications of test and analysis in drinking water domain such as Rwanda Standard identical to East African Standards (RS EAS), Rwanda Standard identical to International Organization for Standardization (RS ISO), Rwanda Standards based on American Society for Testing and Materials (RS ASTM), Rwanda Standards incorporating Codex Alimentarius Commission (RS CAC/RCP) standard for bottled/packaged waters which describes quality factors, limits for certain chemicals, hygiene, packaging and labelling and so on. Note that CAC is under WHO and the FAO.

2.3.2. Drinking Water Quality Standards in Rwanda

The Rwanda Standards Board (RSB), former Rwanda Bureau of Standards, is the agency in charge of quality verification, certification, and standardization. RSB through National Quality Testing Laboratories (NQTL) carries out tests of bottled drinking water to ensure its safety for consumption and usage. The standards used by RBS for water quality are in line with WHO water quality guidelines as well as the East African Standards (EAS). The EAS provide regional solutions and set harmonized technology and terminology and offer good practice, allowing industries and companies in the region to comply with required standards to remove trade barriers encountered when exchanging goods and services. The following are some of EAS adopted by RSB to become RS:

• EAS 153 for Packaged Drinking Water

• EAS 13 for Packaged Natural Mineral Water

• EAS 12 for Potable Water

Drinking water or potable water itself is water which is safe enough to be consumed by humans or used with low risk of immediate or long term harm (EAC, 2018). According to their source and purification, drinking water is typically mineral, purified, sparkled or, bottled water, etc (RBS, 2014).

Parameters for drinking water quality which are tested by RSB typically fall under three categories: Physical, Chemical and Microbiological. Physicochemical parameters of interest to RSB in packaged drinking water include color, turbidity, total suspended and dissolves solids, pH, trace compounds like total hardness, aluminum, Sulfates, iron, sodium, zinc, magnesium, calcium, free residual chlorine, potassium, inorganic mineral and Heavy metals as fluoride, nitrates, Chlorides, arsenic, lead, copper, manganese, and so on (appendix.4).

2.3.3. Improved and Unimproved Water Supply Systems

According to WHO's 3rd edition of guidelines for drinking-water quality; public, improved and unimproved water supply include the following;

• Improved water supply technologies:
—Household connection
—Public standpipe
—Borehole
—Protected dug well
—Protected spring
—Rainwater collection
• Unimproved water supply technologies:
—Unprotected well
—Unprotected spring
—Vendor-provided water
—Bottled water
—Tanker truck provision of water (WHO, 2008),

2.4. Physicochemical Indicators of Packaged Drinking Water Quality

This section include only parameters that have been analyzed within the present research. Bottled water falls into this category of packaged drinking water which include also water packaged in cans, laminated boxes, glass and plastic bags. WHO Guidelines for bottled waters recommend that certain chemical constituents may be more readily controlled than in piped distribution systems, and stricter standards may therefore be preferred in order to reduce overall population exposure and same measures apply when selecting the source of the water. However, some substances become more difficult to manage in bottled water than in tap water such as hazards associated with the nature of the bottle, higher temperatures and longer period of storage both may even favor the growth of some microorganisms to higher levels (WHO, 2008).

2.4.1. pH of Drinking Water

This is the potentiality of concentration of H ions in water. Although pH usually has no direct impact on consumers (EPA, 2018 Edition of the Drinking Water Standards and Health Advisories Tables, 2018), its range still very important in Water Treatment Plants (WTP) as an operational parameter, particularly in terms of the efficacy of chlorination or optimizing coagulation. At pH levels above 8.0, there is a progressive decrease in the efficiency of the chlorine disinfection process and soda taste in water. At pH less than 7 the more acidic the water become, and the higher the pH value the more alkaline is the water. When pH levels of water is less than 7.0, corrosion of metallic water receptacles may occur, releasing metals into the drinking water. However, the toxicity of metals depend on their solubility and on the presence of different types of anions and other cations but still it is undesirable as it may cause health concerns if concentrations of such metals exceed recommended limits (WHO, 2011).

From the pH scale that varies from 0 to 14, the acceptable range of pH in packaged drinking water as recommended by both WHO's first edition of the Guidelines for Drinking-water Quality and RS EAS is between 6.5 and 8.5 (EAC, 2018).

2.4.2. Turbidity

The turbidity of water is a measure of how water is transparent by measuring its capacity to scatter light considering the effect of suspended and colloidal materials. Turbidity is commonly used as an indicator for the general condition of the drinking water because particles suspended in drinking water may serve as shields for pathogenic microorganisms and many toxic chemicals such as pesticides and heavy metals are selectively adsorbed on suspended particulate matter. Moreover, high turbidity reduce the efficiency of disinfection and that may lead to possibility of gastrointestinal irritation, thus complete disinfection may require high volume of chlorine which may bring other interference problems in return such as objectionable odor which can affect the palatability of water to consumers. Hence, the guideline maximum value (permissible limit) for turbidity in drinking water as recommended by WHO is five (5) NTU (Nephelometric Turbidity Units) but preferably less than one for effective removal of chlorine-resistant pathogens such as Cryptosporidium during disinfection (WHO, 2011) and 1 NTU for RSB recommendation for packaged drinking water (EAC, 2018).

2.4.3. Total Dissolved Solids (TDS)

Normally, TDS found in drinking water is not of health concern but at high levels it may affect the acceptability of drinking-water. TDS comprise inorganic salts principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates; and small amounts of organic matter that are dissolved in water. In the first edition of the Guidelines for Drinking-water Quality, published in 1984, a guideline value of 1000mg/liter was established for TDS, based on taste considerations (WHO, 2011). Unfortunately, the fourth edition of WHO's guidelines for drinking water quality didn't recommend a fixed range for TDS in drinking water, but a maximum level of 1000mg/l has been recommended by RSB.

2.4.4. Nitrate

Nitrate (NO_3^-) is found in the natural environment where it comes from agricultural fertilizers both organic (manure) and inorganic (nitrogenous inputs) and also in wastewater and then find its way to join surface water or ground water by means of erosion and seepage phenomenon, its microbial reduction can lead to nitrite (NO_2^-) and this can usually happens inside of water distribution pipes when chloramination has been used as disinfectant (WHO, 2011).

The primary health hazard from nitrate-nitrogen occurs when nitrate is transformed to nitrite in the digestive system and this particularly happens in individuals with low gastric acidity or with gastrointestinal infections. The nitrite oxidizes iron in the hemoglobin of the red blood cells to form methaemoglobin, which block the oxygen-carrying capacity of hemoglobin. Hence this creates the condition known as methaemoglobinaemia (sometimes referred to as "blue baby syndrome"). For adults, their body has the ability to convert methaemoglobin to oxyhaemoglobin but for infants under six months they still lack enzyme to reduce methaemoglobin back to oxyhaemoglobin. However, nitrate and nitrite have other beneficial physiological roles such as the protection of the gastrointestinal tract against a variety of gastrointestinal pathogens by nitrate and the antibacterial properties of nitrite (WHO, 2011). Other studies revealed that high levels and long-term expose to nitrate can inhibit iodine uptake, with the potential for an adverse effect on the thyroid.

Therefore, it is very important to balance their potential risks with their potential benefits by keeping their levels within the recommended permissible limits. Nitrate guideline value for drinking water of 50mg/l has been recommended by WHO, and 45mg/l in packaged drinking water recommended by RS EAS.

2.4.5. Iron (Fe)

Naturally found in fresh waters at levels ranging from 0.5 to 50mg/liter, it may also exist in drinking-water as a result of the use of iron coagulants or the corrosion of steel and cast iron pipes during water distribution. In drinking-water supplies, Iron (II) salts are unstable and are precipitated as insoluble Iron (III) hydroxide, which settles out as a rust-colored silt. Iron also promotes undesirable bacterial growth ("iron bacteria") within a waterworks and distribution system, resulting in the deposition of a slimy coating on the piping (WHO, 2003) According to WHO Iron is not of health concern at concentrations normally observed in drinking-water, moreover, taste and appearance of water are affected below the health-based value as the minimum daily requirement for iron depends on age, sex, physiological status. However, high concentration of Fe in drinking water can cause staining and taste that harm its acceptability (GEMS/Water, 2007) reason why a maximum limit of 0.3mg/l has been recommended in RS and WHO’s first edition of the Guidelines for Drinking-water Quality as well.

2.4.6. Sulphate (SO4)

The ingestion of water containing high concentrations of sulphate can have a laxative effect, which is enhanced when the sulphate is consumed in combination with magnesium. Ingestion of large quantities of sulphate has a major physiological effects such as catharsis, dehydration, and gastrointestinal irritation, and other effects like noticeable taste and the corrosion of distribution systems (WHO, 2011). Maximum permissible limit set by WHO and RSB for sulphate content in drinking water is 400mg/l.

2.4.7. Chloride (Cl^-)

Chloride in drinking-water originates from natural sources, sewage, industrial effluents, urban runoff containing de-icing salt and saline intrusion but the main source of human exposure to chloride is the addition of salt to food. Excessive chloride concentrations increase rates of corrosion of metals in the distribution system as well as the detectable salty taste in water, moreover it has been suspicious of causing High blood pressure (WHO, 2011), and hence a guideline value of 250mg/l has been recommended by both WHO and RSB. However, till today there is no health-based guideline value for chloride in drinking-water because there is no known evidence that chlorides constitute to any human health hazard.

2.4.8. Total Alkalinity (TA)

The alkalinity of water is a measure of its capacity to neutralize acids which is also known as buffering capacity.

The alkalinity of natural waters is mainly due to the presence of carbonates, bicarbonates and hydroxide compounds in soil and bedrock where water passes. However, the ratio of these ions is a function of pH, mineral composition, dissolved solids, temperature and ionic strength. Alkalinity is preferable to be high in order to lower the acidity and its importance in preventing rapid pH change because low Alkalinity (i.e. high acidity) causes deterioration of plumbing fixtures thus increases the chance for the presence of many heavy metals in water. Even if it is not considered detrimental to humans but too much alkalinity in drinking waters may also have a distinctly flat, unpleasant taste. Unfortunately there is no guideline value proposed by the WHO but as the desirable pH for drinking water has to be around 7 (neutral), the desirable alkalinity in some other national standard has been set between 20-200 mg/L and a permissible limit of 600 mg/L in the absence of Alternate Source (BIS, 2012).

2.4.9. Calcium (Ca^{2+})

Calcium has many positive effects compared to its minor adverse effects. It is the main responsible of water hardness, and may influence toxicity of other compounds because elements like copper, lead and zinc are much more toxic in soft water.

Calcium carbonate has a positive effect on lead water pipes, because it forms a protective lead (II) carbonate coating, this prevents lead from dissolving in drinking water, and thereby prevents it from entering the human body. Calcium phosphate is a supporting substance and it causes bone and tooth growth, together with vitamin D. Bones decalcify (osteoporosis) and fractures become more likely if a body is not getting enough calcium. Since a guideline value is proposed for total hardness, no WHO guideline value proposed for calcium concentration in drinking water however a maximum permissible limit of 200mg/l and a desirable level of 75mg\l has been adopted in other standards like Indian Standards (BIS, 2012) and 150mg/l as a maximum limit by RSB.

2.4.10. Magnesium

Magnesium salts are important contributors to the hardness of water which break down when heated and forming scale in boilers. Apart from that, water hardness has been suspected to have a link with cardiovascular disease, growth retardation, and reproductive failure (Sengupta, 2013). Too much Magnesium can result in detectable taste and gastrointestinal irritation in the presence of sulfate. Magnesium concentrations greater than 125 mg/l may result in a laxative effect on some people (Johnson, 2019).

Magnesium ion is important for the regulation of muscle contractions and the transmission of nerve impulses, and it activates energy producing enzymes. Nervousness, lack of concentration, dizziness, and headaches or migraines may result from magnesium deficiency. Since a guideline value were proposed for total hardness, there is no WHO guideline value proposed for magnesium concentration in drinking water. However, in Indian Standard it ranges between 30-100 mg\l and a maximum limit of 100mg\l is recommended by RSB.

2.4.11. Sodium

Normally Sodium in drinking water does not exceed the limit but its levels may become even higher due to some water softeners, or in the shore region where salt intrusion may be taking place. Excessive concentration of Na in water results in unacceptable taste whose threshold also depends on associated anion and the temperature.

Despite suspicion of linkage between Sodium and hypertension, cancer and reproductive effects in some animal species (EPA, 2003), there is no clear evidence that it may be that much harmful to humans (WHO, 2003), hence a there is no health based guideline value proposed by WHO. Simply, a guideline value of 200mg/liter for sodium content in drinking water was established by WHO based on taste or acute effects such as nausea, vomiting, inflammatory reaction in the gastrointestinal tract, thirst, muscular twitching and convulsions considerations, and same value is recommended by RSB.

2.4.12. Potassium

Potassium is an essential element in biological functioning of humans' body as an electrolyte, regulator of water balance and the acid-base balance in the blood and tissues, and it is very helpful in transmission of electrical impulses in the heart (Kowey.P.R, 2002). Potassium is rarely found in drinking water on concentration of concerns for health. Hence, it was not considered necessary by WHO to establish a health-based guideline value for potassium in drinking-water. Higher potassium concentration in water can originate from treatment by water softeners using potassium chloride, and such water may cause some health effects in susceptible individuals like people with kidney dysfunction, heart disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkalaemia; people taking medications that interfere with normal potassium-dependent functions in the body; and older individuals or infants (Ringer & Bartlett, 2007). Hence, a standard value of 50mg\l is recommended by RSB for packaged drinking water (WHO, 2011).

2.4.13. Fluoride

Fluorine is a common element widely distributed in the earth's crust and exists in the form of fluorides in a number of minerals, it is also found in vegetation especially in tea. The fluoride in final water is always present as fluoride ions, whether from natural sources or from artificial fluoridation. The presence of fluoride in water, food products, soil, atmosphere, industrial, pharmaceutical products and other beverage like tea lead to human exposure on higher levels of its daily intake (WHO, 2011).

A number of positive and negative effects have been attributed to Fluoride presence in water, but the most important are the following;

- The presence of fluoride in drinking water at low concentrations (≈ 1.0 mg/L) prevents dental caries by demineralization and remineralization.
- At intermediate concentrations it causes mottling of teeth
- At high concentrations (> 4.0 mg/L) it causes dental fluorosis and skeletal fluorosis, which can damage bones and joints.

Consequently, guideline maximum value of 1.5 mg/liter of naturally occurring fluoride in drinking water has been recommended by WHO (WHO, 2011), and RSB, and 0.8 mg/l for fluoridated water supplies (EuropeanCommunities, 2010).

2.4.14. Aluminum

The primary sources of aluminum in drinking-water is either natural or comes from coagulants used in treatment of water, high concentrations of Al in drinking water results in deposition of aluminum hydroxide floc which often leads to consumer complaints. There is little indication that orally ingested aluminum is acutely toxic (neurotoxicity) to humans despite the widespread occurrence of the element in foods, drinking-water and many antacid preparations, it has been suspected that aluminum exposure bring risks for the development of Alzheimer disease. Hence, a standard value of 0.2mg/l has been recommended by WHO and adopted by RSB.

2.4.15. Electrical Conductivity

Electrical Conductivity is the property of water to conduct electricity which is related to the total concentration of the ionized substances in water. This property is affected by many factors like temperature of water, the nature and concentration of dissolved substances, and so on, that is why it has a close and positive relationship to TDS. However, there is no guideline value proposed by WHO for conductivity but RSB recommended a maximum value of 1500 µS\cm for potable water.

3. METHODOLOGY

This section indicates how data for the study were collected, processed, analyzed and interpreted in order to answer the research questions. It describes how the research objectives were achieved all along the research. This chapter, therefore, comprises the description of the research area, geographical location, country profile, hydrological situation and geology, research design, location of bottled drinking water producer companies under study, data collection methods and instruments, and data analysis.

3.1. Study Area

Rwanda is located in Central East Africa between latitudes 1004' and 2051' South, longitudes 28045' and 31015'East. Neighboring countries are Democratic Republic of Congo to the West, Uganda to the North, Tanzania to the East, and Burundi to the South. It has a surface area of 26348 sq.km with a population size of 12 163 917 (MINECOFIN, 2014). Rwanda has a hilly mountainous relief with an altitude ranging between 900 m and 4507 m and average rainfall of 1400 mm per year.

Rwanda has sufficient natural water resources consisting of lakes covering 149,487 ha, marshland covering a total surface of 278,536 ha, and several rivers. The country water drains into two hydrological basins: the Nile basin covers 67% of national territory and drain 90% 0f water whereas the Congo basin occupies the remaining (NISR, 2014).

Actually, there are several companies in Rwanda that produce packaged drinking water but some of them are not yet certified with S-mark (standardization mark) of RSB, by the time of sampling only 7 of them were having a validated certification mark (RSB, 2019). The existing bottled drinking water companies are located in different provinces and Districts of Rwanda but the majority are in Kigali city (RSB, 2019).

3.1.1. Geographical Location of Water Companies

Below is the Administrative map of Rwanda showing Kigali city which is the case study area; and the localization of companies producing bottled drinking water and tap water under study.

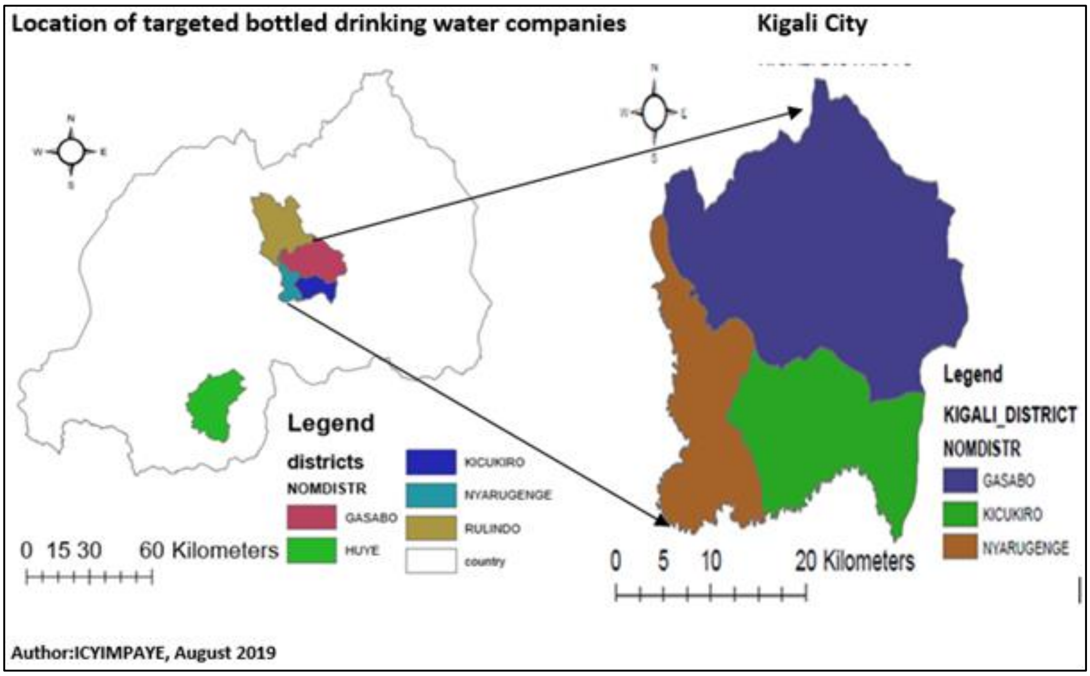

Figure 3.1. Administrative Map of Rwanda, Kigali city (NISR, 2014).

3.1.2. Geological Outline of Rwanda

The geology of Rwanda is composed by some oldest rocks of migmatites, gneisses, metamorphosed sediments, mainly schists and quartzites intruded by granites that covers most of Rwanda. It consists of Middle (Meso) Proterozoic formations, with Tertiary age, East African Rift, volcanic cover in South Kivu, Cyangugu and in the northwestern Birunga mountains (Dewaele, 2009). Cenozoic to Recent volcanic rocks occur in the northwest and west. Some of these volcanics are highly alkaline and are extensions from the Birunga volcanic area of southwestern Uganda. Tertiary and Quaternary sediments fill parts of the Western Rift in the western part of the country. Agrominerals like Phosphates occurrence has been found not significant in level however dolomitic limestones with MgO contents up to 17% have been found in Precambrian rocks in the Western province (MINECOFIN, 2010).

3.2. Research Design

The present research used a completely randomized research design while collecting water samples. However other methods have been also in this research, both qualitative and quantitative research methods. Primary data were collected by carrying out laboratory tests. Bottled water samples of all targeted brands under study were bought from random supermarkets in all districts of Kigali city, the same random method has been used to collect samples of tap water.

After collection of samples and subject them to laboratory analysis, chemical content (values) of targeted parameters were determined. Secondary data have been collected by using desk method through reviews of different water quality standards and guidelines, programs and policy related to quality of drinking water.

3.3. Sampling

The procedures for collection of water samples, transport and storage have been done by following WHO guidelines recommendations as provided in the Third Edition of International Standards for Drinking-Water (WHO, 1971). A total number of 21 bottled water samples representing 7 brands of drinking water bottling companies were purchased in different supermarkets at random basis, after checking the caps and protective seal intact, parameters content on labels as well as the dates of expiration; an additional triplicates sample of tap water was also collected in sterile glass bottles. They were transported after sampling to the Environmental Engineering Laboratory of the University of Rwanda-College of Science and Technology (UR-CST), located in Kigali's central city. They have been then subjected to physical and chemical quality analyses. Samples of bottled water brand and tap water have been assigned codes from letter A to H all along the research.

3.4. Quality Assurance

In order to ensure the accuracy of results quality assurance measures were implemented as follows:

- Methods for transport and storage of water samples complied with standards (the use of cooler box for sample the transport of samples, preservation where necessary and minimization of time between sample collection and analysis, storage of samples at 4°C before analysis.
- Use of calibrated instruments according to the manufacturer's instruction.
- Samples were analyzed based on standard methods and equipment for examination of water quality certified by ISO that also comply with WHO's 3rd edition of guidelines for International Standards for Drinking-Water (WHO, 1971).
- Preparation and use of blank solutions that were appropriate to the method under use.
- The average value of three triplicate for each sample was taken for each determination of final concentration of each parameter.
- All materials were thoroughly cleansed with appropriate detergent and rinsed with distilled water, otherwise disinfection with 70% ethanol was done when necessary.

3.5. Physicochemical Analysis

A total number of 15 parameters [the pH, Turbidity, TDS, Nitrate (NO_3^-), Iron (Fe^{2+}), Sulfate ($SO4^{2-}$), Chloride(Cl^-), Total Alkalinity ($CaCO_3$), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^+), Potassium (K^+), Fluoride (F^-), Aluminum (Al^{3+}) and Electrical Conductivity (EC)] have been tested from each one of the 8 samples in a triplicate, which means that a total number of 360 laboratory tests were undertaken. The pH, TDS, Turbidity and EC values were read directly from the appropriate kits/equipments, while NO^-_3, Fe^{2+}, Cl^-, F^-, Al^{3+}, and K^+ have been analyzed with spectrophotometric method and/or others by undertaking titration ($Ca^{2+,}$ $CaCO_3$, Total Alkalinity, Sodium and Mg^{2+}). Only the average of replications of tests for a single parameter has been considered for comparison whereas all results have been used in statistical analysis for further interpretation. Laboratory test results have been compared among brands, information written on bottle's label and with the prescribed Rwanda and WHO drinking water quality standards, the statistical analysis was undertaken to test the significance of the analyzed treatments. Lastly, the conclusion and recommendations with a policy brief have been provided according to the status of research outcomes.

3.5.1. Determination of pH

Electrometric method has been used to measure pH values in our samples. In the laboratory, a pH meter (HANNA model 209) was used to determine the pH of water samples. Buffer solutions of pH 4.0, 7.0 and 9.0 were prepared to calibrate the instrument.

Procedure:

A volume of about 50ml has been taken from each sample and poured into a clean glass beaker and the electrode inserted into it (after being calibrated and rinsed by distilled water), the button selector of the pH meter was turned and the value of pH was directly read from the instrument and recorded. This was repeated three times for all samples.

3.5.2. Determination of Turbidity

Turbidity was determined with HACH method by using a turbidimeter (model CO 150). The turbid meter was first calibrated with Formazin standard solutions of 0.2 NTU, 10 NTU, 100 NTU and 1000 NTU by filling consecutively 4 clean sample cells with well mixed standard solutions. It was then returned to the measurement mode and used.

Procedure:

A clean dry sample cell was rinsed with the water from the sample to be tested, then the sample cell was filled with sample to be analyzed and then covered with light shield cap. The outer surface of the cell was wiped with a clean and dry tissue/paper. It was then inserted into the optical well and the lid closed. After pressing the read button, NTU value was recorded after the display has stopped flashing.

3.5.3. Determination of TDS

A multifunctional HANNA meter (model HI 98360W) was used to determine the Total Dissolved Solids (TDS) of water samples in the laboratory after calibration the instrument.

Procedure:

About 50ml of water sample was poured into a clean glass beaker and stirred to ensure uniform mixture, then the electrode of the instrument was immersed into the sample. After the reading became stabilized the value was read and recorded in mg/L.

3.5.4. Determination of Electrical Conductivity

The same multifunctional HANNA meter (model HI 98360) was used to determine the Electrical Conductivity of our samples (EC).

Procedure:

About 50ml of water sample was poured into a clean glass beaker and the conductivity meter electrode was then inserted into the beaker. The value was read and recorded in µS/cm unit after it indicated a fixed value.

3.5.5. Determination of Nitrate

To determine nitrate-nitrogen in our samples a spectrophotometer (model DR 6000) has been used. SPADNS Spectrophotometric method is one of the HACH Methods useful in water quality testing. That powder pillow test consists of Cadmium reduction phenomenon as it reduces nitrate in sample into nitrite. The later one reacts in an acidic medium with sulfanilic acid to form an intermediate diazonium salt which couples with gentisic acid to form an amber colored solution. Test results are measured at 400 nm (HACH, 2005).

Procedure:

The machine was turned on first and we selected the test program. The multi-cell adapter was installed according to the shape of the sample cells we were using for them to face the direction of light. With a Pipet, a volume of 10.0 mL of water from the sample was measured and put into a clean sample cell (raw water) where a content of one Nitra Ver 5 Nitrate Reagent Powder Pillow was added in the sample and the stopper was closed and shaken vigorously for one minute. After the mixture was allowed to rest for 5 minutes, in that time an amber color started to develop proportionally to the content of nitrate content.

The blank were prepared by putting another volume of about 10.0 mL of water sample into another clean empty sample cell. After wiping the sample cell containing blank with a suitable clean tissue we inserted it into the cell holder and covered the place with instrument’s cap and pressed zero for the display to show zero (zeroing), then after the showing up of reading 0 mg/l the following was the sample cell containing the sample to be introduced in the cell holder of the machine for reading of Nitrate content which was displayed in mg/l which came after pressing read button. Where nitrate concentration was very low to the point that the machine can’t read it (not in between 0.1 and 10.0 mg/l), Nitra Ver 6 reagent powder pillow was used instead of Nitra Ver 5, because with Nitra Ver 6 we could read the concentration between 0.01 and o.50 mg/l (HACH, 2005).

Figure 3.2. Sample Cells and Spectrophotometer Machine

3.5.6. Determination of Potassium

The determination of potassium has been done also by using spectrophotometric method with means of spectrophotometer (model DR 6000) fig.3.2. In the spectrophotometer which has been used, the method number for potassium is 905 from stored program.

This method consists on reaction potassium in sample with sodium tetraphenylborate to form potassium tetraphenylborate which is an insoluble white solid. Hence the amount of turbidity produced becomes proportional to potassium concentration in sample. Test results were measured to 650nm (HACH, 2005).

Procedure:

For all spectrophotometric methods procedures are almost similar, the difference lies in method number to be used from stored program, the type of reagent to be used and the reaction time. Three (3) different reagents of potassium powder pillow were used (potassium reagent 1 powder pillow, potassium reagent 2 powder pillow, potassium reagent 3 powder pillow). Water sample has been introduce in a graduated cylinder up to 25ml and potassium reagent 1 powder pillow and potassium reagent 2 powder pillow were added respectively. After closing the cylinder and mixing for few seconds, the content of potassium reagent 3 powder pillow has been also added in the cylinder then closed and shaken for 30 seconds and then left for 3 minutes reaction time. A sample cell containing 10ml of black which was taken from sample has been introduced in the cell holder and press zero for zeroing. After 7 minutes we introduced 10ml of prepared sample in another samples cell that we inserted in the cell holder then to read the concentration of potassium in mg/l.

3.5.7. Determination of Calcium

Calcium concentration has been determined by titration method, by precipitating Ca^{2+} with a strong base

Procedure:

Using a clean pipette, 50ml of the water sample was poured into a clean conical flask. About 1ml of aqueous solution of 1.0M NaOH was added in the flask, followed by 0.2g of powdered Ammonium murexide indicator as it is only sensible to Ca^{2+} ions. The mixture in the flask was titrated with 0.01M EDTA (Ethylene Diamine Tetra Acetic acid) solution while mixing gently until the color changed from pink to purple that indicated the endpoint. Then, the volume of titre was read and recorded.

Calculation:

Formulae 1: $\text{Calcium hardness as CaCO3 (mg/L)} = \frac{\text{Average Titre} \times 1000}{\text{Sample Volume (ml)}}$

To obtain the concentration of calcium ion we also used the results of our titration as follows:

Formulae 2: $Ca2 + \ (mg/L) = \text{Calcium hardness} \times 0.40$

3.5.8. Determination of Magnesium

The concentration of Magnesium ions has been determined by titration method as done for Calcium. Based on the total hardness that was determined by adding 1.0 ml of 0.5M Ammonium buffer solution (pH = 10.0) and 2 ml (3 drops) of Eriochrome Black T indicator into 50ml volume of water sample, followed by titration with 0.01M EDTA solution and calculations. The value of total hardness was used to calculate magnesium hardness.

Procedure:

The magnesium hardness was determined as the difference between the total hardness and calcium hardness.

Calculation:

Formulae 3: $Magnesium\ Hardness = [\text{Total hardness}] - [\text{Calcium hardness}]$

The concentration of magnesium ion was then obtained from the magnesium hardness as follows:

Formulae 4: $Mg2 + \ (mg/L) = \text{Magnesium hardness} \times 0.243$

3.5.9. Determination of Iron

The concentration of iron has been determined by means of spectrophotometer using FerroVer method. When FerroVer Iron reagent is added in water, it converts all soluble iron and most of insoluble forms of iron to soluble ferrous iron. Then the ferrous iron reacts with 1,10 phenanthroline indicator in the reagent to form an orange color which is proportional to the concentration of iron. The results of this test are measured at 510 nm in the range of 0.02 to 3.00mg/l (HACH, 2005).

Procedure:

The blank was prepared by putting 10ml of water sample into a square sample cell. In a second sample cell we prepared the sample by adding FerroVer Iron reagent into 10ml of sample water and swirled, then we allowed the mixture to react from 3 to 5 minutes. Lastly, the blank was placed in the machine for zeroing (0.00mg/l) and that was followed by introduction of sample in the cell holder to find the concentration of iron in the sample which was displayed in mg/l.

3.5.10. Determination of Alminium

Spectrometric method has been used to determine Alminium concentration in water samples by means of spectrophotometer machine (model DR 6000). When HACH 8012 method is used, alminium indicator combines with alminium in the sample to form red-orange color which is proportional to the concentration of alminium in the sample. Apart from alminium reagent, ascorbic acid is added to remove iron interference and the test results are measured at 522 nm. With this method alminium concentration is detected from 0.008 to 0.800 mg/l (HACH, 2005).

Procedure:

To prepare our sample, we poured 50ml of water sample in a cylinder and added one ascorbic acid powder pillow. After we closed and mixed the sample, one Aluver3 aluminium reagent powder pillow has been added which changed the sample's color from an orange to orange-red as a proof of alminium presence in sample. The sample was kept on agitation for mixing in one minute. Then the blank was prepared by putting 10ml of mixture from the cylinder into the sample cell in which we added one bleaching 3 reagent powder pillow, the stopper was closed and the mixture swirled for 30 seconds and the solution turned a light to medium orange. The mixture was posed for 15 minutes reaction period. After posing the blank for 15 minutes, we took 10ml from the mixture in cylinder (prepared sample) and introduced in the second sample cell. Lastly. The blank was wiped and introduced in the cell holder for zeroing and followed by prepared sample for the machine to display alminium concentration in mg/l Al^{3+}.

Figure 3.3. Aluminum Reagents Powder Pillow

3.5.11. Determination of Fluoride

Fluoride was determined by SPADNS Spectrophotometric Method which relies on the fact that when fluoride reacts with certain zirconium dyes, it forms a colorless complex anion which is proportional to the fluoride concentration and a dye. The resulting colored complex anion is measured in a spectrophotometer at 570 nm. The spectrophotometer can read from 0 to 2.00 mg/L F^- in the water sample (HACH, 2005).

Procedure:

The volume of10.0 mL was pipetted from the water sample and introduced into a clean & dry 10-mL sample cell (raw water). Another sample cell containing 10.0 mL of deionized water was prepared as a blank. 2ml of SPADNS Reagent solution was added into each one of the above prepared sample cells and swirled to mix, then waited for one minute recommended reaction time. As the machine was set, we introduced into the cell holder our sample cell containing blank after wiping the cell with a suitable clean tissue, the place was covered with instrument's cap. We clicked on zero for the display to show zero (0.00mg/l). Then the prepared sample was inserted into the cell holder, covered with instrument cap and the instrument operated to obtain a reading of the concentration fluoride displayed in mg/l.

3.5.12. Determination of Chloride

Chloride concentration in samples has been determined by means of spectrometric method that consist on the reaction between mercuric thiocyanate and the chloride in the sample where they liberate thiocyanate ion. Thiocyanate ions in turn react with ferric ions to form an orange ferric thiocyanate complex and the amount of that formed complex is always proportional to the concentration of chloride in sample. The same spectrophotometer (model DR 6000) was used (HACH, 2005).

Procedure:

When the preliminaries were done, a sample of 10ml was poured in a square sample cell. Another sample cell was also filled with 10ml of deionized water (blank). By using a pipet, 1ml of mercuric thiocyanate solution was added in each sample cell and the mixture was swirled. After mixing we added 0.5ml of ferric ion solution in each sample cell and swirled again to realize a formation of orange color if chloride was present. After 2 minutes of reaction time, the sample cell containing the blank was wiped and inserted in the cell holder for zeroing. The last step was to insert the sample cell containing water sample and press read when the instrument cap was closed in order to read the concentration of our parameter that was displayed on the screen of the machine.

3.5.13. Determination of Sulfate

We used spectrophotometer (model DR 6000) to measure sulphate by SulfaVer 4 method. The test is based on a single SulfaVer 4 reagent powder pillow containing barium that react with sulfate ions in the sample to form a precipitate Barium sulfate. The resulting turbidity is proportional to the concentration of sulfate in sample. Results are measured at 450 nm (HACH, 2005).

Procedure:

The sample was prepared by filling a clean sample cell with water sample to the 10ml mark. A content of one of SulfaVer 4 reagent powder pillow was added to the water in the cell and swirled vigorously to dissolve powder. The mixture was allowed to stand undisturbed for five minutes reaction period. Then after, a blank was prepared by pouring 10ml of water sample in the square sample cell, wiped and inserted in the cell holder for zeroing. Zeroing was followed by inserting the prepared sample into the chamber and pressed read to display the concentration of sulfate in mg/l.

3.5.14. Determination of Total Alkalinity

By titrimetric method total alkalinity was determined. We used 0.01N H_2SO_4 as titrant solution, phenolphthalein and methyl orange as indicators.

Procedure:

A volume of 50ml was taken from water sample by using pipette and poured into a clean conical flask, two drops of phenolphthalein indicator were added. The sample turns to pink color if pH is greater than 8.3. Titration continues against 0.01N H_2SO_4 solution by swirling gently until the pink color just disappeared. Then titre volume (Tv) was read and recorded. When the sample remained colorless after the addition of the phenolphthalein indicator, it means that pH is less than or equals to 4.5, then three drops of methyl orange indicator need to be added, that one turns the sample to yellow and titration continued with H_2SO_4 which changed the yellow color to orange at the end of titration.

Calculation:

Formulae 5: $Total\ Alkalinity\ as\ CaCO3\ (mg/L)\ = \frac{\text{A} \times \text{T} \times 1000}{\text{Sample volume (ml)}}$

Where A = Titre of standard acid at phenolphthalein end point

T = Titre of standard acid at methyl orange end point

3.5.15. Determination of Sodium

Sodium concentrations were determined by using flame photometer PFP 7 JENWAY. By means of standards solutions with known concentrations to give their absorbance. Then, from the calibration curve, the equation gave the concentration of sodium solution.

Procedures:

Sodium Standard Solution was prepared of 1000mg/l (1000ppm). By using deionised water, dilution of standard solution were done to have small volume with lower concentrations of standard solution up to 1.0mg Na/100ml. the selection of sodium filter was done and aspirate to adjust sensitivity control in order to obtain a reading of 100. After obtaining 100 on the standard, deionised water was aspirated and adjusted the zero control to obtain zero reading.

Once the standard is fixed to 100 and deionised water to 0, the last step is to aspirate the other sample solutions and record the readings to plot a calibration curve.

Calculation:

Suppose that x was the sample, L the low standard and H the high standard, then formulae below was generated:

Formulae 6: $Conc\ x\left(\frac{mg}{L}\right) = \text{Conc L} + \frac{\text{(Reading X − Reading L)}}{\text{(Reading H − Reading L)}} \times (Conc\ H\ -\ Conc\ L)$

3.6. Statistical Analysis

In order to determine whether differences existed concentrations of determined parameters among brands, data were then subjected to statistical analysis by conducting Analysis of Variance (AoV) in Statistix 10 Analytical Software and then statistical significance of concentrations between water brands was carried out at 95% confidence level ($\alpha \leq 0.05$), the mean comparison test was also performed on all parameters whose treatments were found significant, the Least Significant Differences (LSD) was performed to test if there is significances among means. Moreover, Microsoft excel has been used for graphical representation of comparison between laboratory results showing concentration in each brand, WHO & RSB standards values and concentration written on labels of water bottles. The summaries of analyzed data are attached on Appendix 6.

4: RESULTS AND DISCUSSION

4.1. Physical and Chemical Characteristics of Tap and Packaged Drinking Water

The physical and chemical quality of tap and bottled drinking water produced in Kigali city were examined in this study. Results obtained have shown that bottled drinking water produced in Rwanda under different brand names and the tap water supplied by WASAC in public network from different water treatment plants exhibited relatively similar characteristics in most of their physicochemical quality parameters especially dissolved ions (Appendix 2).

4.1.1. pH

The pH values of all bottled water brands ranged from 6.13 to 7.13 as shown in (Fig. 4.1). All the 7 brands of bottled drinking water and 1 representative sample of tap water (coded as a brand) had their pH values below the RSB and the WHO upper permissible limit of 8.5, though 4 brands including tap water violated the lower permissible limit of 6.50. According to WHO low pH levels are objectionable because of the corrosive effect on metallic water receptacles and thus may be even more problematic on tap water if the distribution pipe are made in metals. Moreover, all the pH values found in laboratory were slightly different to those indicated on labels of bottles where provided, pH values found in laboratory were smaller than what was marked on labels except for one brand where we had the inverse.

Low pH especially in tap water could have resulted in the aluminum sulfate used by some WTP during coagulation and flocculation process and/or more dissolved anions in raw water used as source. The pH difference recorded among all treatments (brands and tap water) was very significant with p (0.0000) $\leq$ 0.05 (Appendix 7). By running out LSD All-Pairwise Comparisons Test we found 5 groups (A, B, C, D and E) of pH in which the means were not significantly different from one another, in which brand H was in group A; brands C and G shared same group B; brand B and D in group C, brand F in group D, and brands A and E have been classified in group E. It meant that even though we had different pH values in our samples (replications) but still the average pH values of brands were closer to each other, not big differences in pH quality.

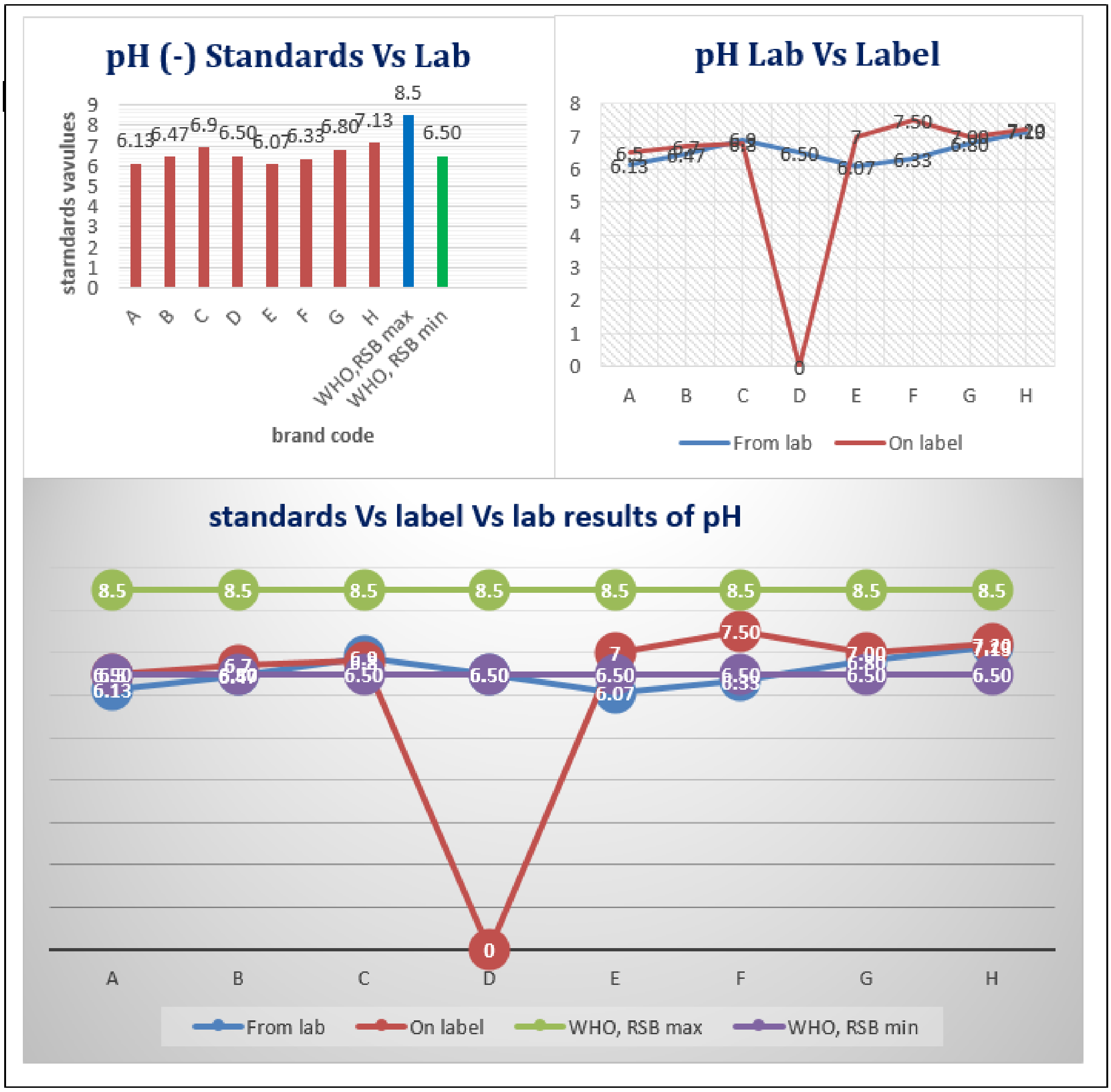

Figure 4.1.pH Results

4.1.2. Turbidity

Turbidity values found ranged from 0.22 NTU to 1.26 NTU for all brands. All turbidity values read were below the WHO permissible limit of 5.0 NTU. Regarding RSB standards, The half of brands (B, C, D, F) were above the limit and the other remaining half (A, E, G, H) including tap water were below the RSB maximum limit of turbidity for packaged drinking water which is 1NTU as shown below on (Fig. 4.2).

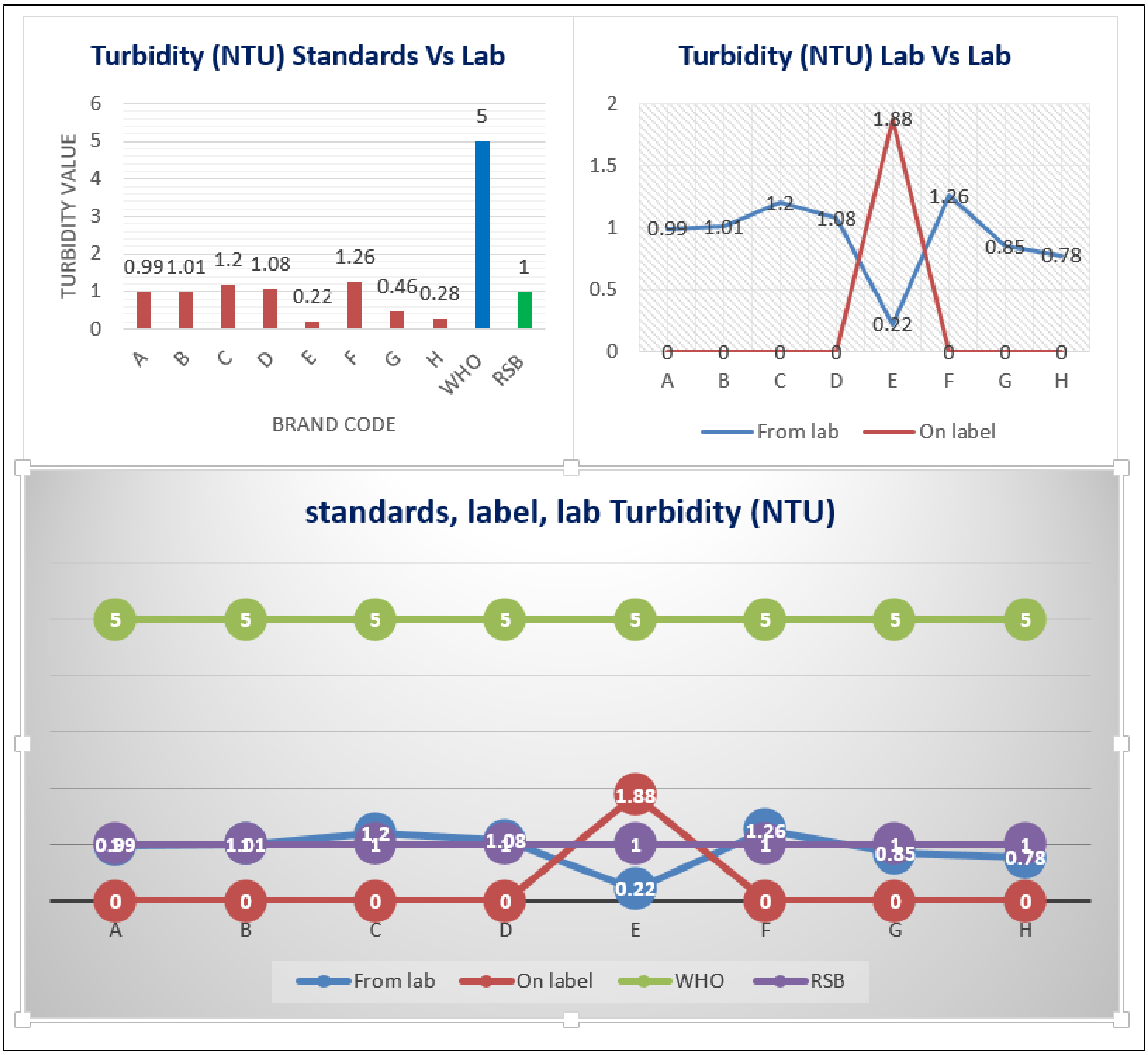

Figure 4.2 Turbidity Results

These results mean that the filtration process in some bottled water manufacturing companies is not as effective as it is in others. Highly turbid drinking water may result in health risks as excessive turbidity can protect pathogenic microorganisms from the effects of disinfectants, and also stimulate the growth of bacteria during storage which may even become worse for bottled water because it may spend a couple of months in the market processes.

The majority of brands didn't provide turbidity content on label and the one provided was lower than laboratory findings which was a good thing. Even though 4 brands exceeded the RSB recommendation value of turbidity, all brands were below the WHO guideline limit. Hence, all brands still had satisfactory quality in terms of turbidity.

The Analysis of Variance has shown that the difference in turbidity among all treatments was not significant because their p values of 0.0640 was ≥ 0.05. Based on LSD All-Pairwise Comparisons Test, we only found 3 groups (A, B, and C) however some brands were belonging to more than one groups. Thus brand F, C, D, B, A, G belonged to the group **A**; brand D, B, A, G, H had same characteristics of Group **B**; brands B, A, G, H, E were in group C. In other words, brand D can be classified as **AB**, brands B, A, G as **ABC**, and brand H as **BC**. That kind of groups means that the means also were not significantly different from one another.

4.1.3. TDS

Total dissolved solids results ranged between 9.4 and 100 mg/l. The diversity in TDS was attributed to natural sources of water and/or manufacturer, this indicated that all the brands of packaged water contained varied concentrations of dissolved mineral elements for the mineral nutrition of consumers. It also made sense that TDS values found on labels, even though are not equal to laboratory results but both had same orientation. The highest TDS in brand A may be due to the fact that it is a natural mineral water coming from a natural spring hence many minerals as its chemical composition was not altered. Lowest TDS content in brand H can also be assigned to the automated processes of purification and filtration which is undertaken before packaging that lower the content of minerals. Lower TDS means softer drinking water. However, water with extremely low concentrations of TDS may also be unacceptable to some consumers because of its flat insipid taste and make it not advisable to people with high nutrient diet.

Even though WHO did not provide any limit for TDS content in its fourth edition (which is the latest) of guidelines for drinking water quality, our results were evaluated based on the RSB recommendation limit of 1000 mg/l and all TDS values for all brands were lower than the standard value. Hence, all brands had good quality water in terms of TDS, details are presented in (figure 4.3) below.

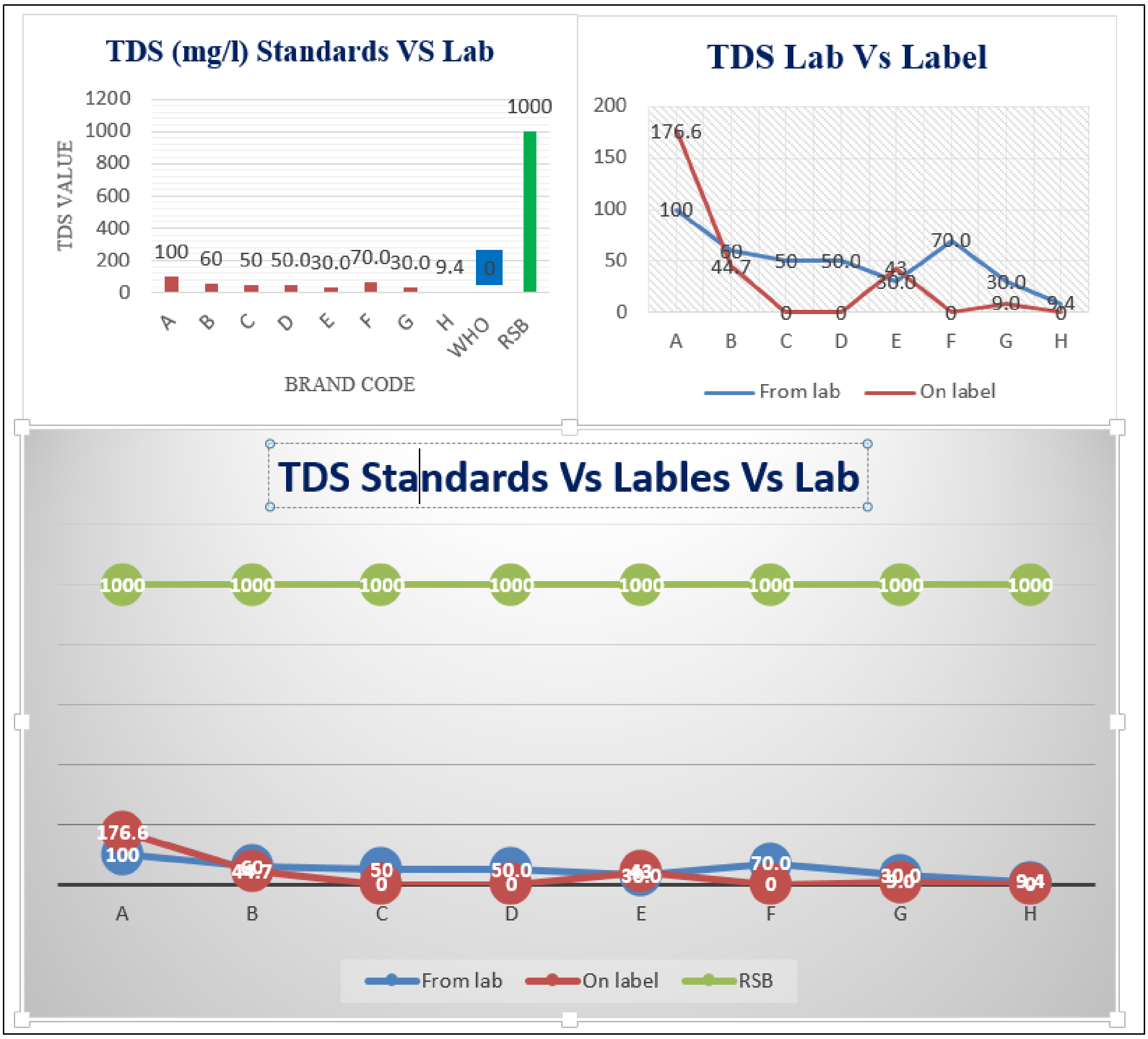

Figure 4.3.TDS Results

The Analysis of Variance has shown that the difference in TDS values among treatments was very significant with p (0.0000) ≤ 0.05. However, the results of LSD All-Pairwise Comparisons Test have classified all brands into 6 groups in which the means were not significantly different from one another where brand A was in group **A**, brand F in group **B**, brand B in group **C**, brands C and D in group **D**, brands E and G in group **E**, brand H in group **F**.

4.1.4. EC

Electrical Conductivity measurements found in laboratory ranged from 14.33 µS/cm to 220 µS/cm. It is directly related to the concentration of salts dissolved in water and the T DS as well. Hence, highest EC was observed in brand A and the lowest in brand H.

However, all values of EC found were below the RSB standard limit which is 1500 µS/cm. Refer to fig 4.4 below for details on comparisons. Only one value of EC was present on label and it was lower than both the laboratory result and the standard. Almost all bottled water companies do not provide the EC value on bottle labels.

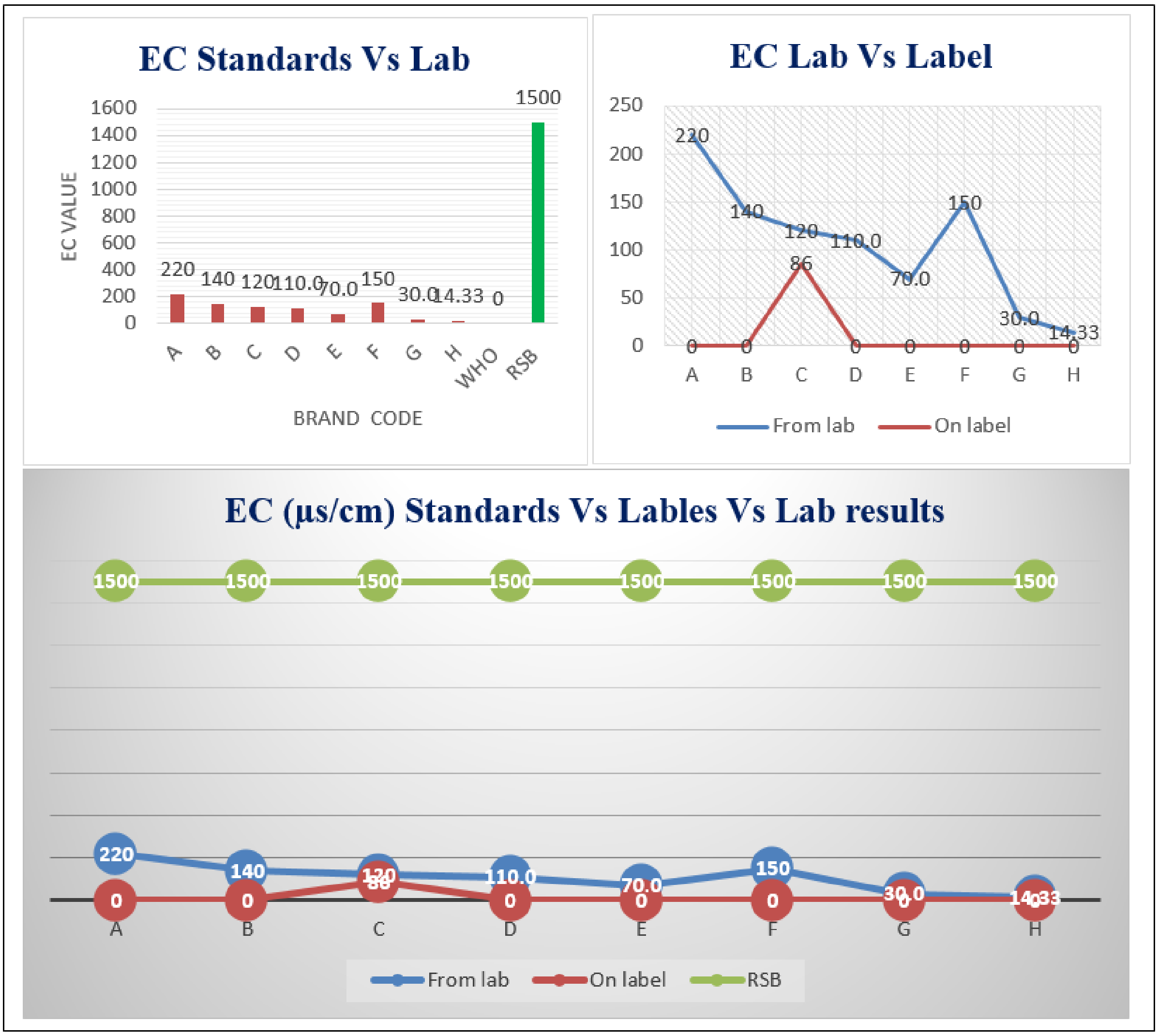

Figure 4.4. Electrical Conductivity Results

By carrying out LSD All-Pairwise Comparisons Test, the means have been classified into 8 different groups that were significantly different from one to another and they have been ordered from **A to H** for brand A, F, B, C, D, E, G and H respectively, which means that the capacity of brand A to conduct electricity is higher than the capacity of brand F, and so on up to brand H which was classified as the worse conductor of electricity i.e Many dissolved salts in brand A and few dissolved salts in brand H.

4.1.5. Nitrate

The laboratory results on Nitrate (NO3) were far below the limit of both standards 50mg/l for WHO recommendations and 45mg/l for RSB. Only brans E had a remarkable concentration of nitrate which was 4.08 mg/l but other remaining brands were having NO_3 concentration below 1mg/l ranging from 0.01 to 0.44 mg/l. The completely randomized AOA on Nitrate has shown that the difference between treatments is not significant with a p value equals to $0.4895 \geq 0.05$. The results of LSD All-Pairwise Comparisons Test has classified all brand's means in a single group **A**, in which there was no significant pairwise differences among them. Brands in group were ordered on a descending order from E, G, D, H, F, C, B and A.

Among the 8 brands under study, only 2 of them (A and E) provided the concentration of NO3 on label and one of those values was higher than the laboratory result on brand A but that was not the case on brand E. Even though high Nitrate in drinking water has related health risks especially for infants, its small concentration has a beneficial physiological roles such as the protection of the gastrointestinal tract against a variety of gastrointestinal pathogens and the antibacterial properties of nitrite. Nitrite can occur from the reduction of nitrate in distribution pipe or inside the digestive system. Hence, it is good to have nitrate in our drinking water on smaller concentration.

The highest concentration of nitrate in brand E with respect to others can be attributed to source of its drinking water because it is the only one brand whose raw water came from surface water (river) which is vulnerable to pollution from the excessive application of fertilizers, leaching of wastewater and other organic wastes.

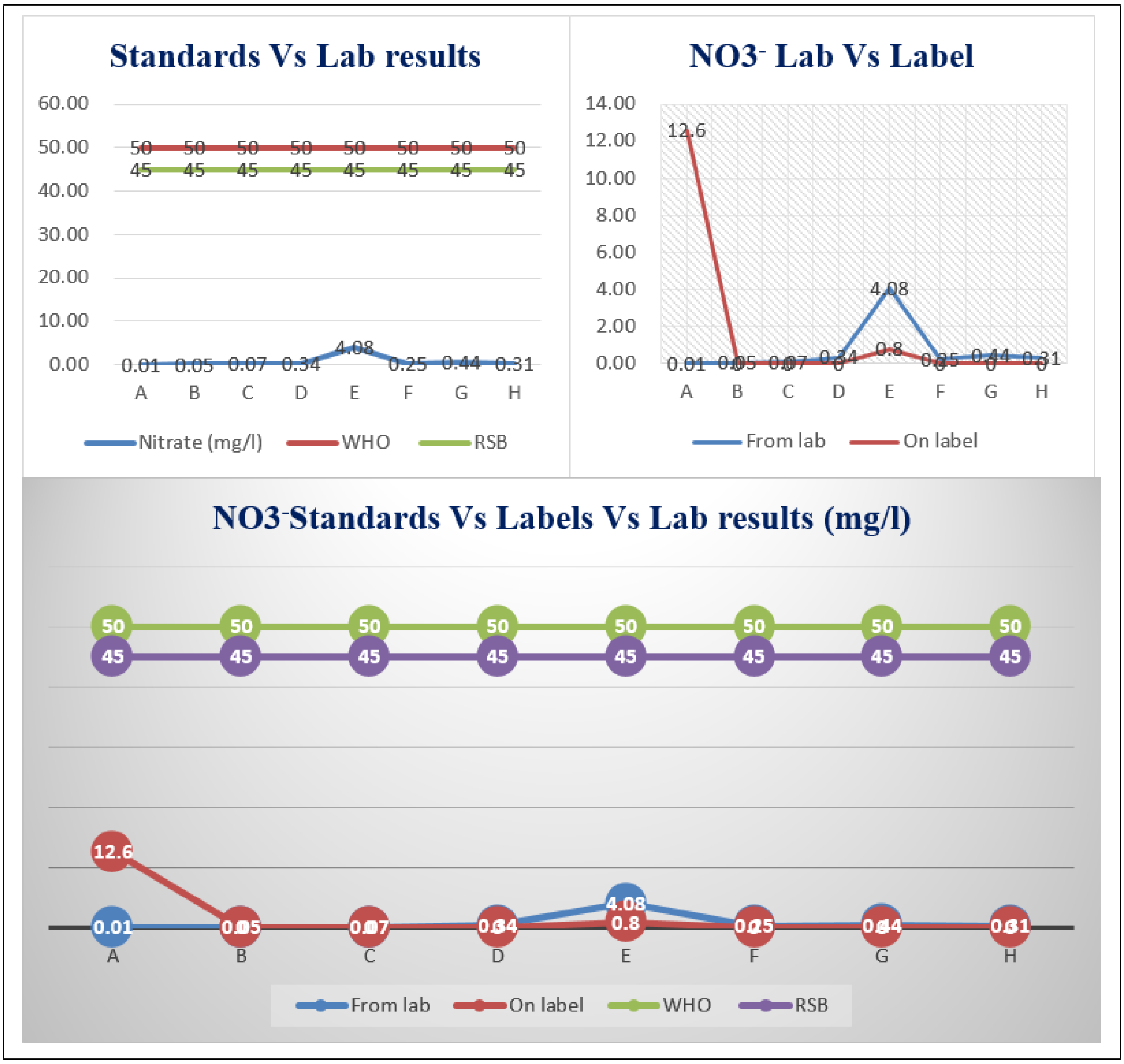

Figure 4.5. Results of Nitrate

4.1.6. Potassium

The present research found that Potassium (K) concentrations were very far below 50mg/l which is the RSB maximum standard limit of K concentration in drinking water. Laboratory results on the analysis of K concentration in all brands were almost equal to 0.1mg/l for each brand. Hence, the completely randomized AOA on Potassium has shown that the difference between treatments was not significant with p value of $0.4369 \geq 0.05$. Nevertheless, the results of LSD All-Pairwise Comparisons Test have classified all brands in 2 homogeneous groups (**A** and **B**) of means, in which there was no significant pairwise differences among them. Brands in group A were brand F, H, D, C, G, B, and E, then brand in group B were H, D, C, G, B and A which means that brand H, D, C, G, B and E had properties of both group A and B i.e. their group has been recognized as **AB** group.

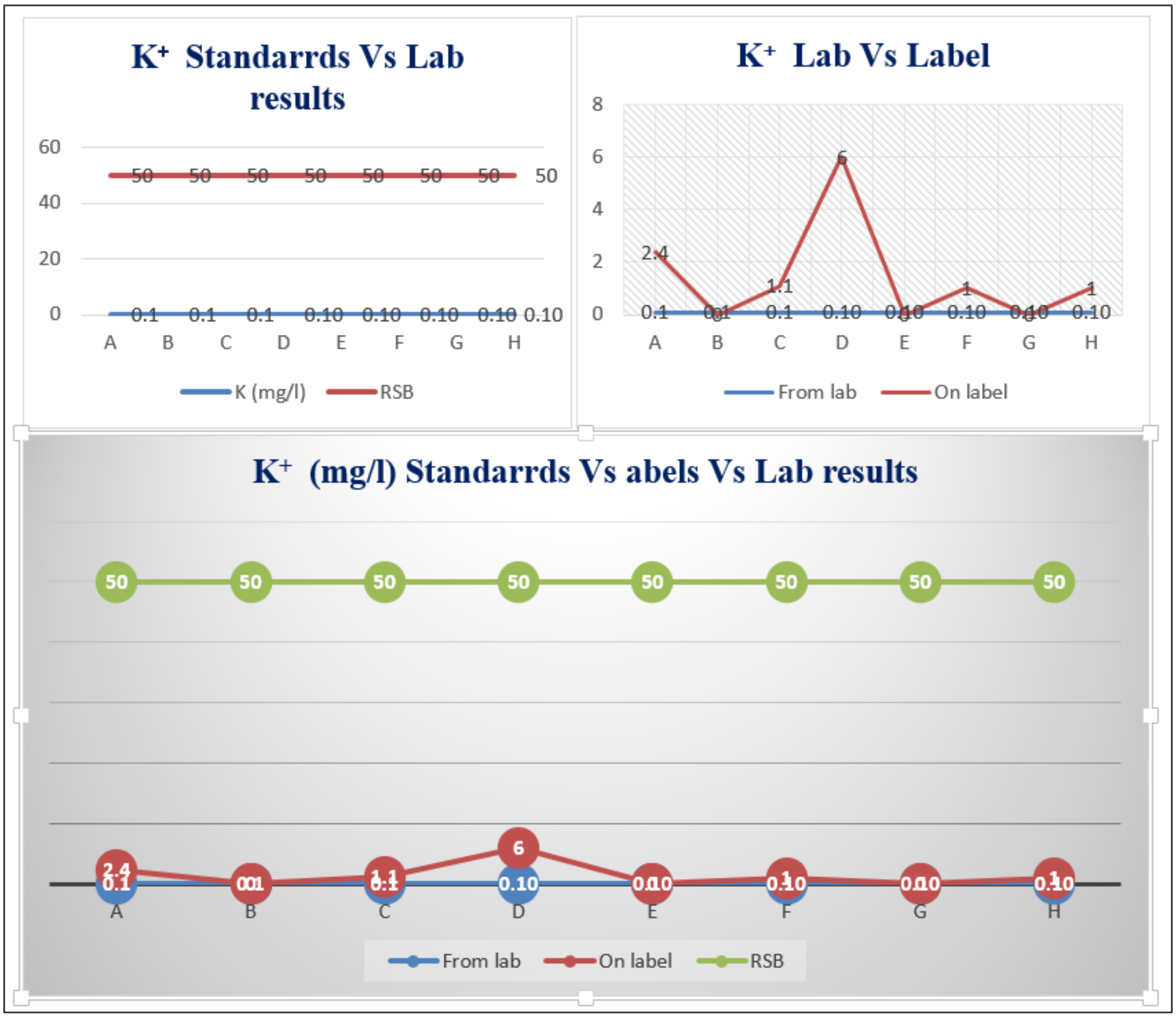

Figure 4.6. Potassium Results

Low concentration of K in our brands of bottled drinking water is normal, it is rarely found in drinking water even though it has a crucial role in different biological processes inside our body, a variety of food products supply the required amount. Moreover, high potassium in human body is not good especially for people with kidney dysfunction, heart disease, hypertension, and so on. Thus, the quality of bottled water in all brands have been found good in terms of potassium concentration.

4.1.7. Calcium

The concentration of Calcium in the brands of bottled water under study have been found minimal in all brands, it ranged from 0.067 to 0.10 mg/l and all of them were very far below the RSB standard of 150mg/l. The completely randomized AOA on Calcium has shown that the difference between treatments was not significant as their p value of 0.4414 was ≥ 0.05. Nevertheless, the results of LSD All-Pairwise Comparisons Test have classified all brands in 2 homogeneous groups of means **A** and **B**. Brand E, D, H, B, G, and F were classified in group A whereas brand D, H, B, G, F, A, and C have been having characteristics of group B. Hence, brand D, H, B, G, and F had similar particular characteristics putting them in group **AB**. The content of calcium provided by companies on bottle labels (where given) has been higher than laboratory findings for 4 brands.

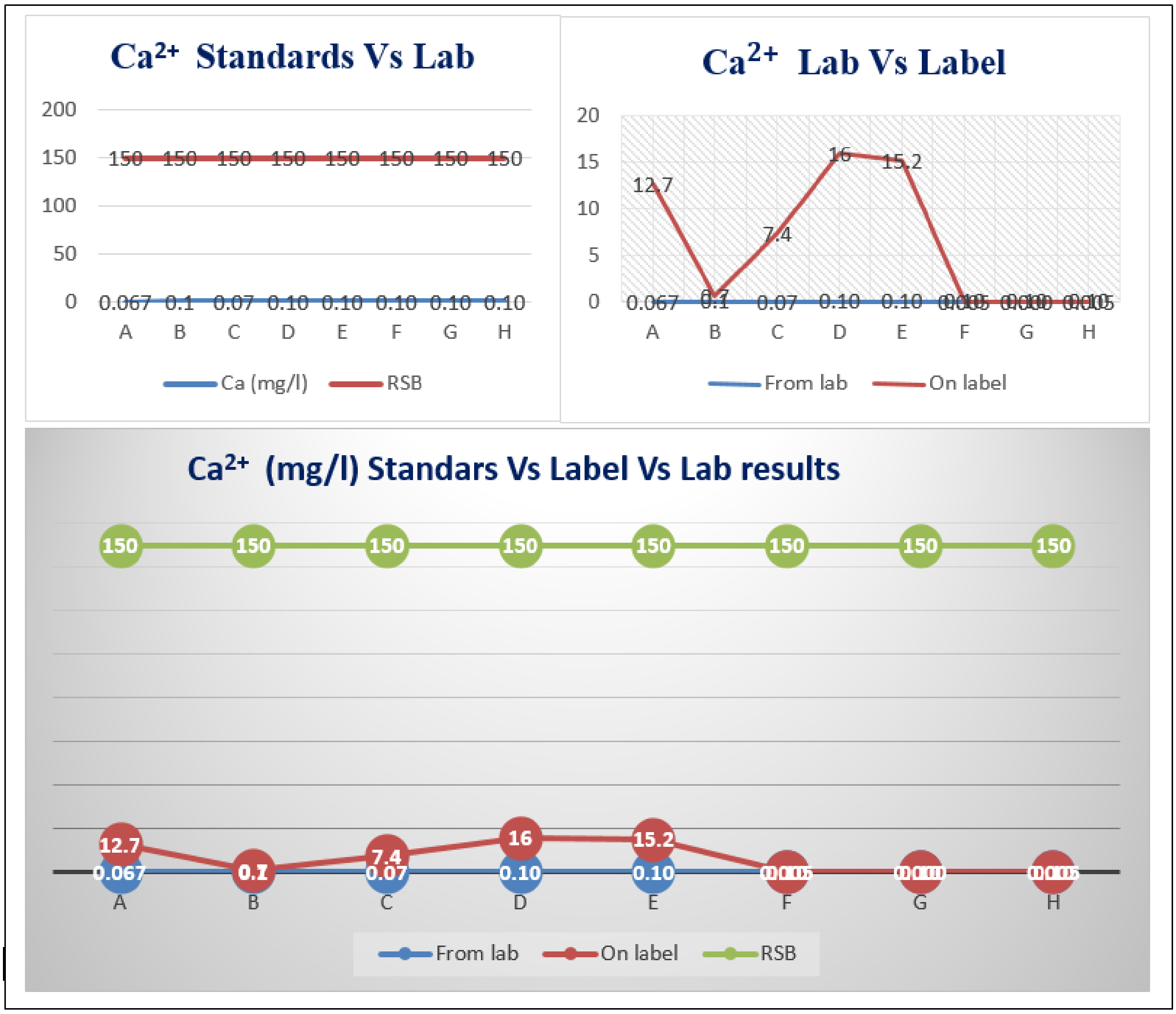

Figure 4.7. Calcium Results

Calcium like Potassium play a crucial role in several biological functions in human's body. Calcium is very important especially for children as it supports bone and tooth growth, muscle contraction, and the transmission of nerve impulse. Its deficiency results in structure deformation for children and increased risk of fracture for adults. At higher concentration it becomes one of the responsible of water hardness that has been suspected to have a link with cardiovascular problems like blood pressure, growth retardation, and cancer.

4.1.8. Magnesium

The brands of bottled water recorded relatively lower concentrations of Mg ions ranging from 0.099 to 0.10 mg/l with respect to RSB standard which is 100 mg/l.

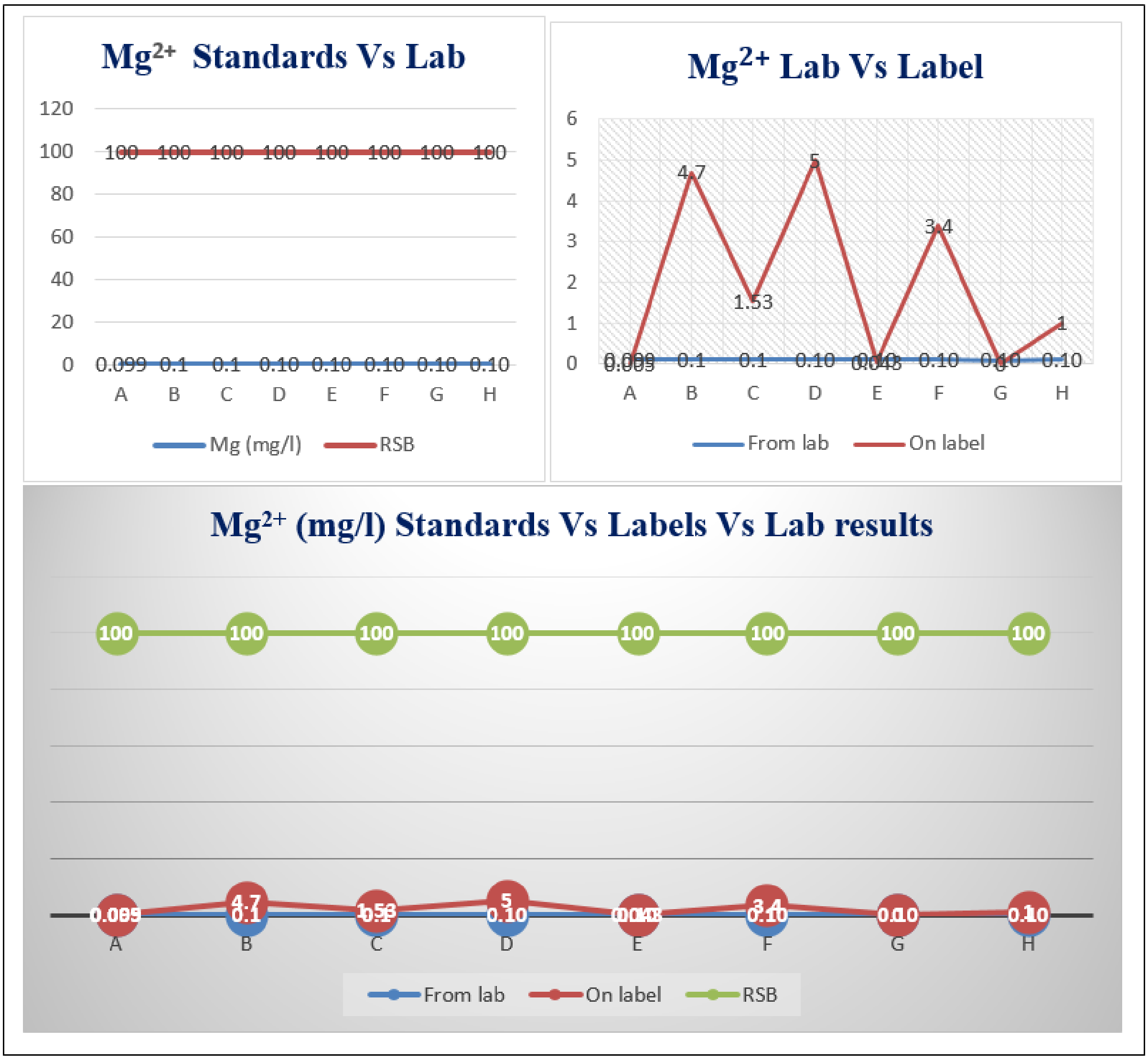

Figure 4.8. Results of Mg2+

We didn't find any significant difference in concentration of magnesium ions between brands ($p \geq 0.0980$). Fortunately, the LSD All-Pairwise Comparisons Test have classified brands in 2 homogeneous groups of means A and B in in which the means were not significantly different from one another. Group **A** covered brand F, A, H, D, E, C, and G whereas group **B** was mad by brand D, E, C, G, and B. However, brand D, E, C, and G were having characteristics of both groups, literally they have been classified in group **AB**. 7 out of 8 brand had magnesium content on bottle labels, The value provided on label of A and E were lower than the laboratory findings while the inverse was has been observed on brand B, C, D, F, and H. Magnesium deficiency affects neurological and neuromuscular function, resulting in anorexia, muscular weakness, lethargy and unsteady gait. Magnesium like Calcium plays an important role in blood clotting and cell signaling. Too much or too low concentrations of Magnesium in human body both cause health struggles but still the quality of our water is good as the laboratory results didn't exceed the standard limit. Food diet is the main source of Magnesium content in the body and medicine can supply more magnesium if needed. Its concentration in drinking water is just a small supplement.

4.1.9. Iron

Iron (Fe^{+}) concentration ranged from 0.0 mg/L to 0.1 mg/L in all brands of packaged drinking water as shown below (Fig. 4.9.) and all the results were below the standard value of both WHO and RSB. The completely randomized AOV on concentration of Iron ions between brands recorded significant difference with p value of $0.0001 \leq 0.05$. Nevertheless, the LSD All-Pairwise Comparisons Test gave us 2 groups (A and B) in which the means were not significantly different from one another. Group **A** included brand A, E, and C while group **B** included brand D, B, H, F, and G. The result of laboratory analysis have been found higher than the concentration marked on labels of brand A, and C, both values were equals on brand G, and laboratory content was lower than label content on brand E,F and H.

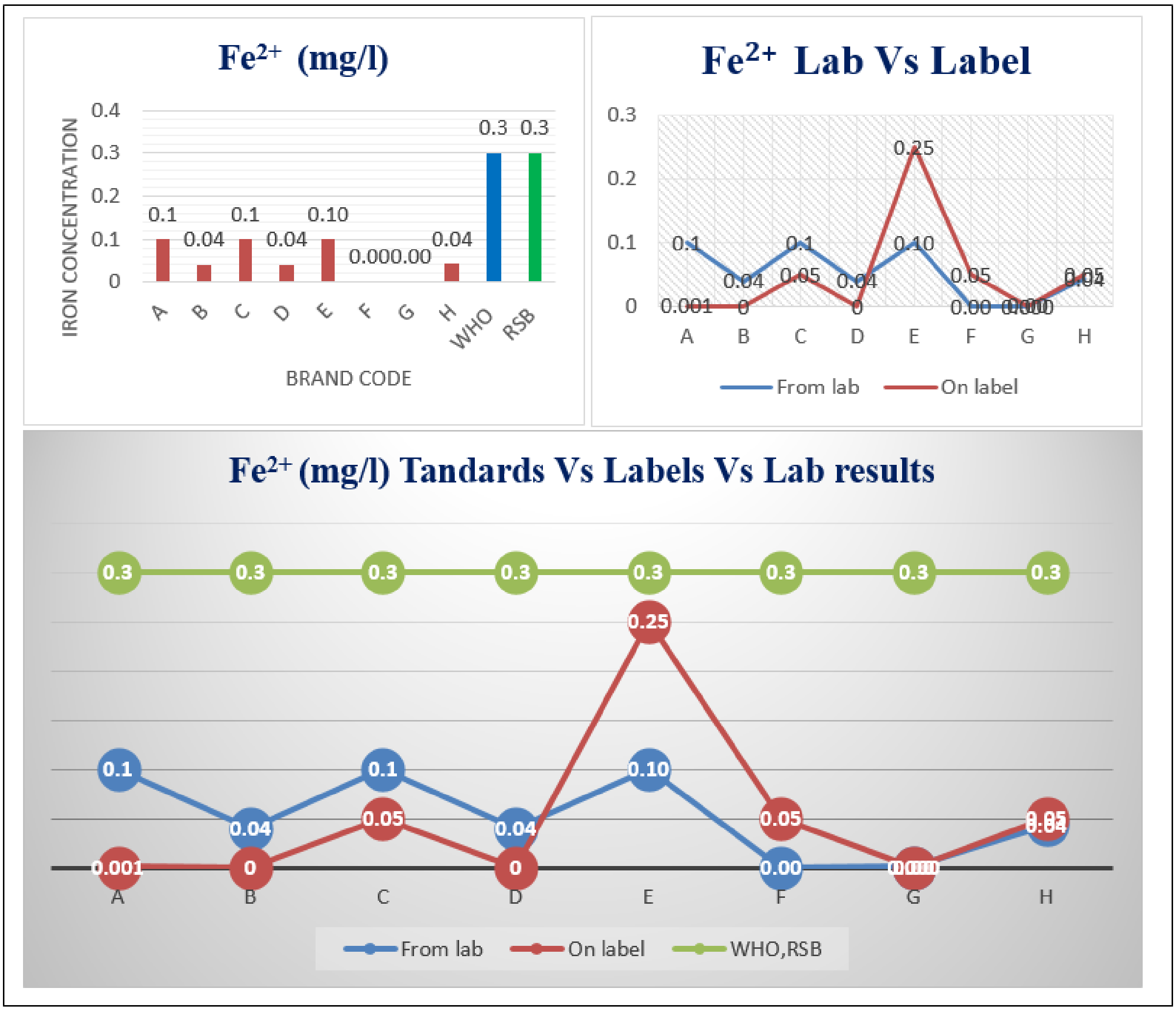

Figure 4.9. Results of Iron

The Iron concentration in all brand of analyzed bottled water when compared to WHO guideline and RSB standard value which are both equal to 0.3 mg/l, brought us to the conclusion that the quality of our bottled water is good. Consumers are protected against negative effect of drinking water with excess Iron ions such as unacceptable taste.

4.1.10. Alminium

The concentration of Aluminum (Al) in brands of bottled water under study ranged from 0.097 to 0.10 mg/l and all of them were below the WHO and RSB standard limit of 0.2 mg/l. The completely randomized AOA of Alminium concentrations has shown that the difference between treatments was significant as their p value of 0.0163was ≤ 0.05. However, the results of LSD All-Pairwise Comparisons Test classified all brands in 3 homogeneous groups (**A**, **B**, **C**) in which the means were not significantly different from one another.

Brand C, A, and D were classified in group **A**; brand A, D, H, B, G, and F in group **B**; whereas brand B, G, F, and E were in group **C**. Many brands had characteristics of more than one group. Hence, the apparition of new groups like **AB** for brand A and D, and group BC for brand B, G and F. Water bottling companies did not provide the concentration of Aluminum on bottle labels at all, even the one available was higher than laboratory results.

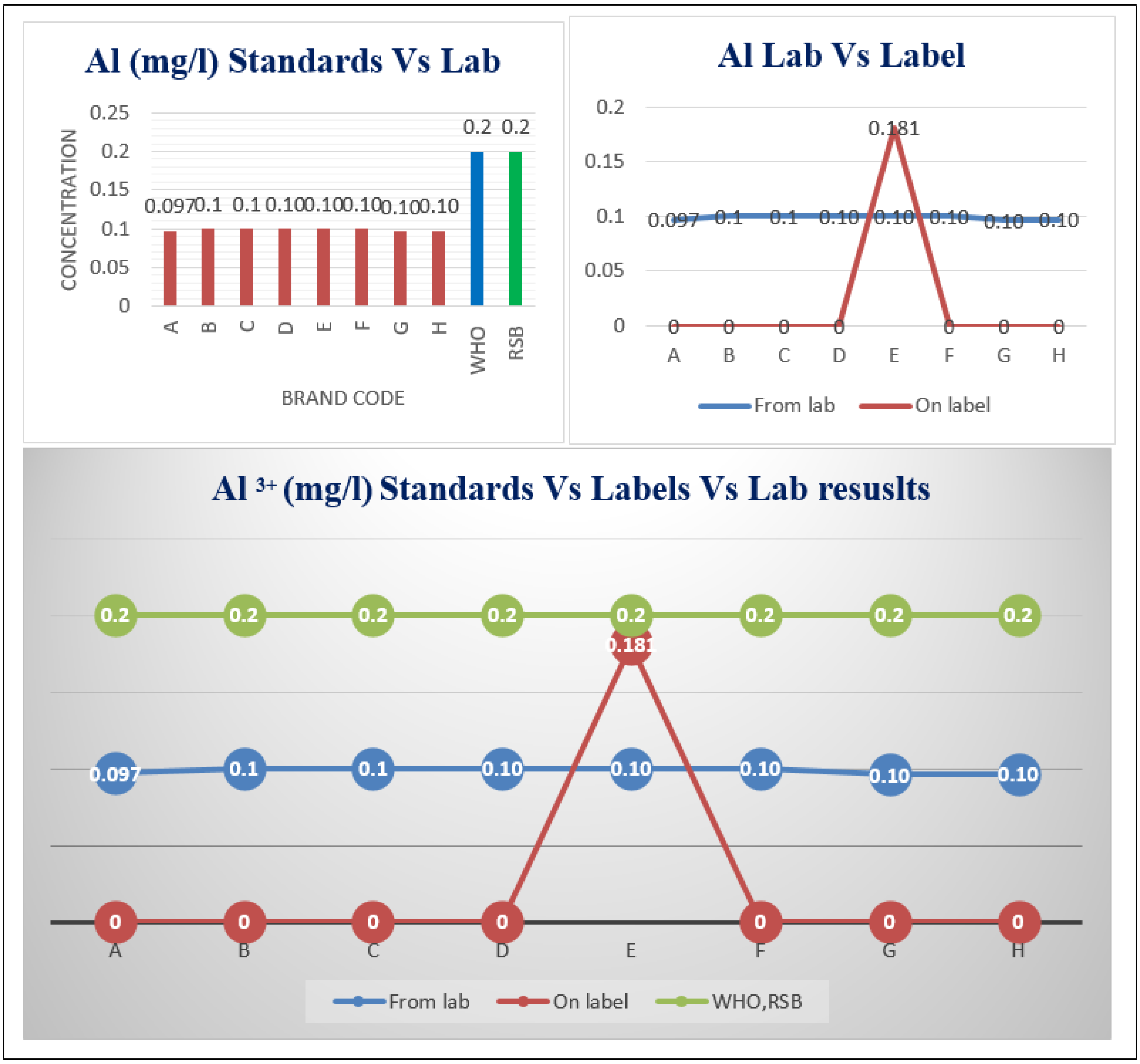

Figure 4.10. Alminium Results

Actually there is no indication that orally ingested Aluminum is acutely toxic (neurotoxicity) to humans. Moreover, the concentration on which it is found in drinking water is well below the recommended standard limit which means that all drinking water brands under study are safe for human consumption and had good quality.

4.1.11. Fluoride

All brands of bottled water recorded relatively lower concentrations of Fluoride ranging from 0.01 to 0.40 mg/l with respect to RSB standard which is 1.5 mg/l. The highest concentration was observed in H and the lowest in C (Fig.4.11.). We didn't find any significant difference in concentration of magnesium ions between brands p (0.3489) ≥ 0.05. Fortunately, the LSD All-Pairwise Comparisons Test have classified brands in 2 homogeneous groups of means A and B in in which the means were not significantly different from one another. Group **A** covered brand H, G, E, F and B whereas group **B** was made by brand G, E, F, B, D, A and C. However, brand G, E, F, and B were having characteristics of both groups, literally they have been classified in group **AB**. Brand B and E had Fluoride content on bottle labels, and their values (provided on label) were lower than the laboratory results of F^-concentration.

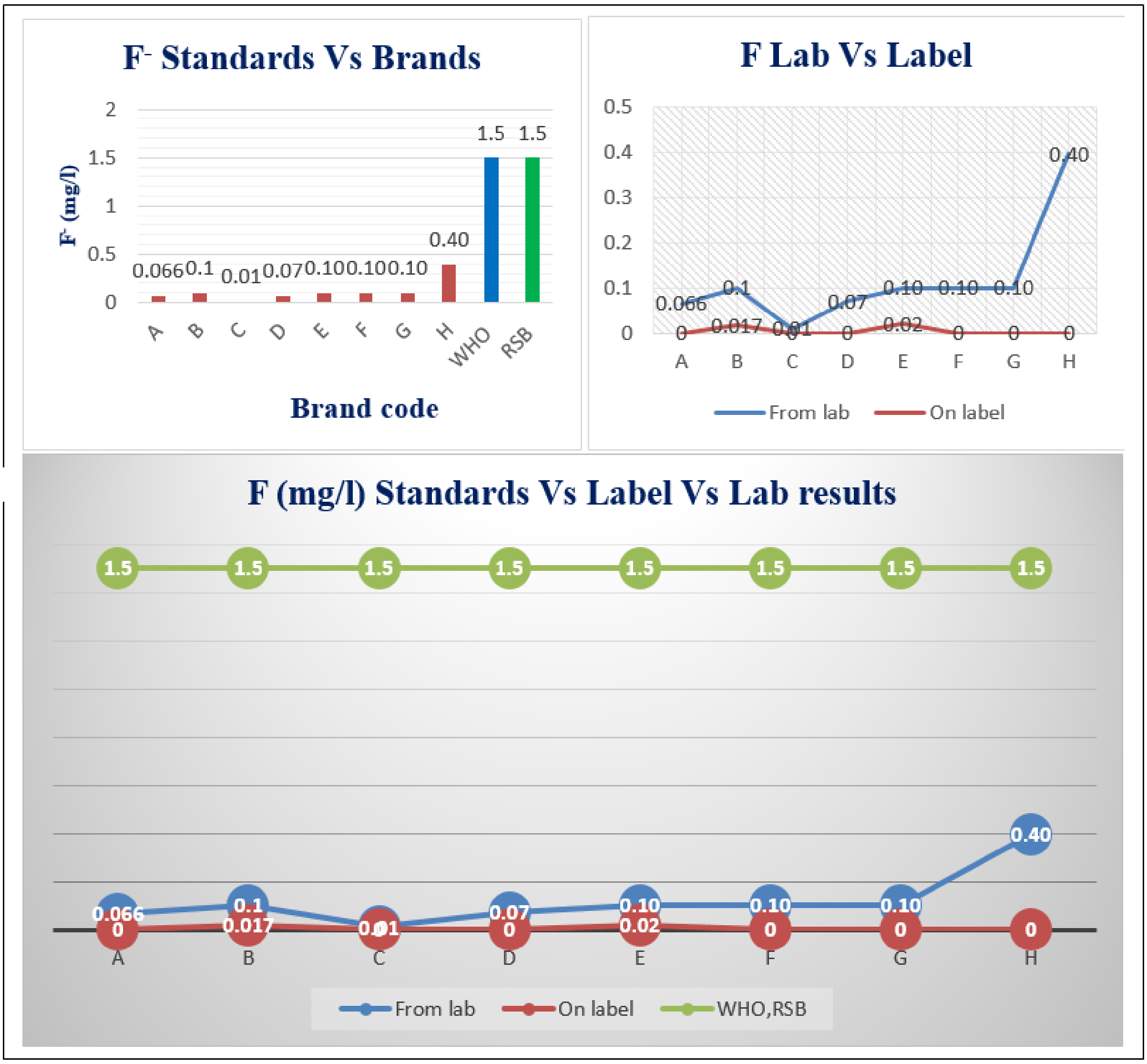

Figure 4.11. Fluoride Results

Based on our results which were all below maximum permissible limit provided by both WHO and RSB standards, all brands are safe for consumption, no effect of high Fluoride contamination (mottling of teeth, dental fluorosis, and skeletal fluorosis). However, when considering the positive impact of little concentration of Fluoride in drinking water (≈ 1.0 mg/L) such as prevention of dental caries, all brands can't be counted on to supply the supplement of Fluoride, if needed another brand of drinking water out of those covered in the research can be considered if it has about 1 mg/l fluoride content.

4.1.12. Chloride

Chloride concentrations ranged from 0.090 mg/L to 0.373 mg/L for our bottled water brands (Fig. 4.12). These concentrations were much lower than the WHO and the RSB permissible limit of 250 mg/L.

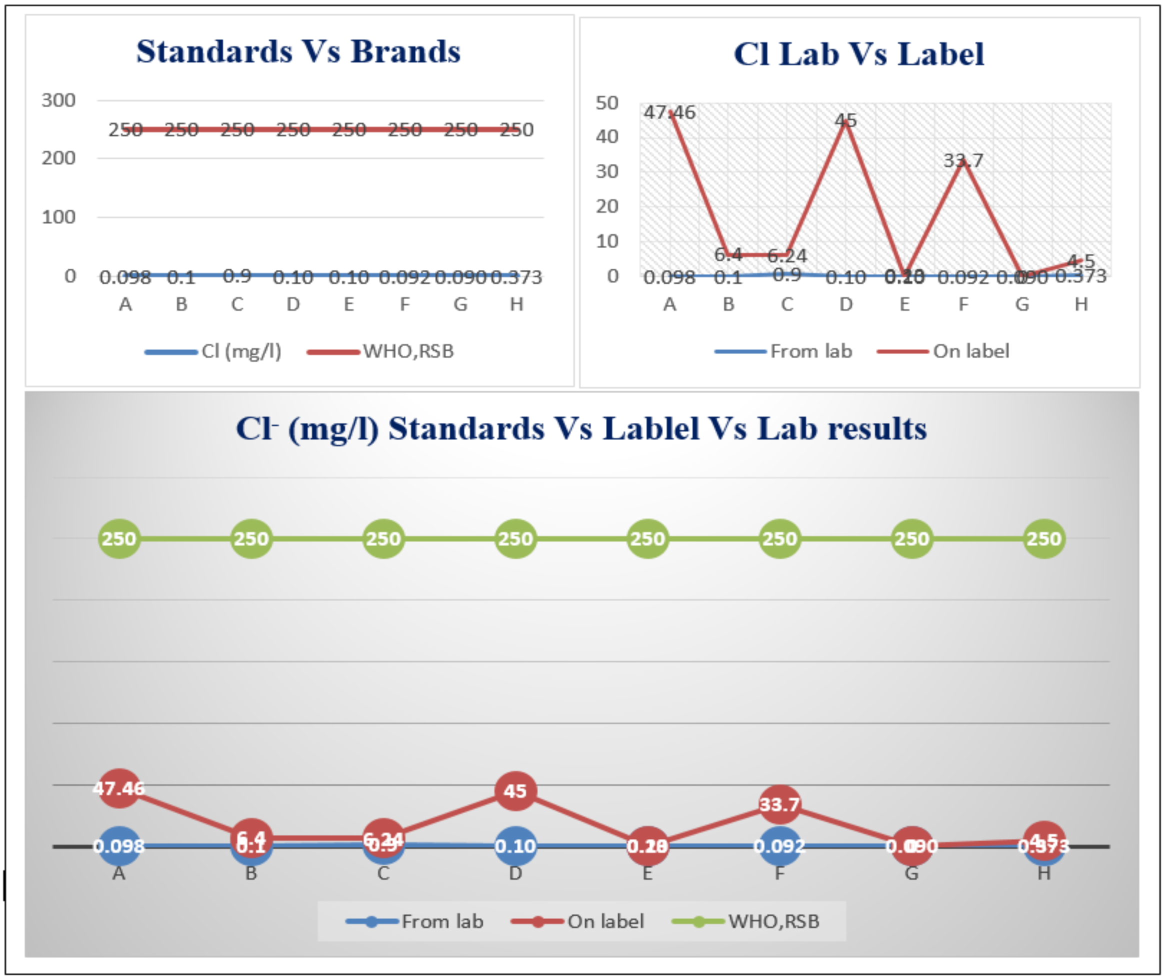

Figure 4.12. Chloride Results

Statistically, the AOV has shown that the difference in concentrations of chloride among treatments was significant because their p (0.0005) was ≤ 0.05 but LSD All-Pairwise Comparisons Test have classified brands in 2 homogeneous groups of means (A and B) in which the means were not significantly different from one another. Brand C was found in group **A** while others (H, D, A, B, E, G, and F) were in group **B**. All brand provided Chloride concentration on labels except G, and those provided concentrations were higher than the laboratory results. According to the WHO (2011), there was no known evidence that chloride has a health effect, the main operational issue for chloride is its ability to increase the corrosiveness of water, particularly in low alkalinity waters. Although high concentrations (above the guideline) of chloride may result in a detectable taste in water. Hence, the quality of bottled drinking water under study have been all found good in terms of Chloride concentration.

4.1.13. Sulfates

The concentration of sulphate ranged from 0 mg/L to 8.0 mg/L in all brands of packaged water as shown (Fig. 4.13).

Statistically, the AOV has shown significant differences in concentrations of sulfate among treatment with p value of 0.0001 which is less than 0.05. LSD All-Pairwise Comparisons Test gave us 4 groups (A, B, C, and D) in which the means were not significantly different from one another. Brand C was included in Group **A**, brand D, G, H in group **B**, brand G, H, E in **C** , and brand E, B, A, F in **D**. Thus means that we has derivative groups like **BC** (for brand G and H) and **CD** (for brand E). The results from laboratory were higher than the concentration marked on labels in some cases but lower in others.

Brand F recorded the lowest concentration whereas brand C recorded the highest but still even the highest was far away below the WHO and RSB standard limit of 400 mg/L which means that our brand are good in terms of $SO4^{2-}$ content. Actually, the natural presence of sulfate in drinking water result from the presence of some dissolved minerals like gypsum (CaSO4·2H2O) and it normally found in small concentration. Increased concentrations of sulfate in drinking water comes as a result of using sulfates-based coagulants in WTP.

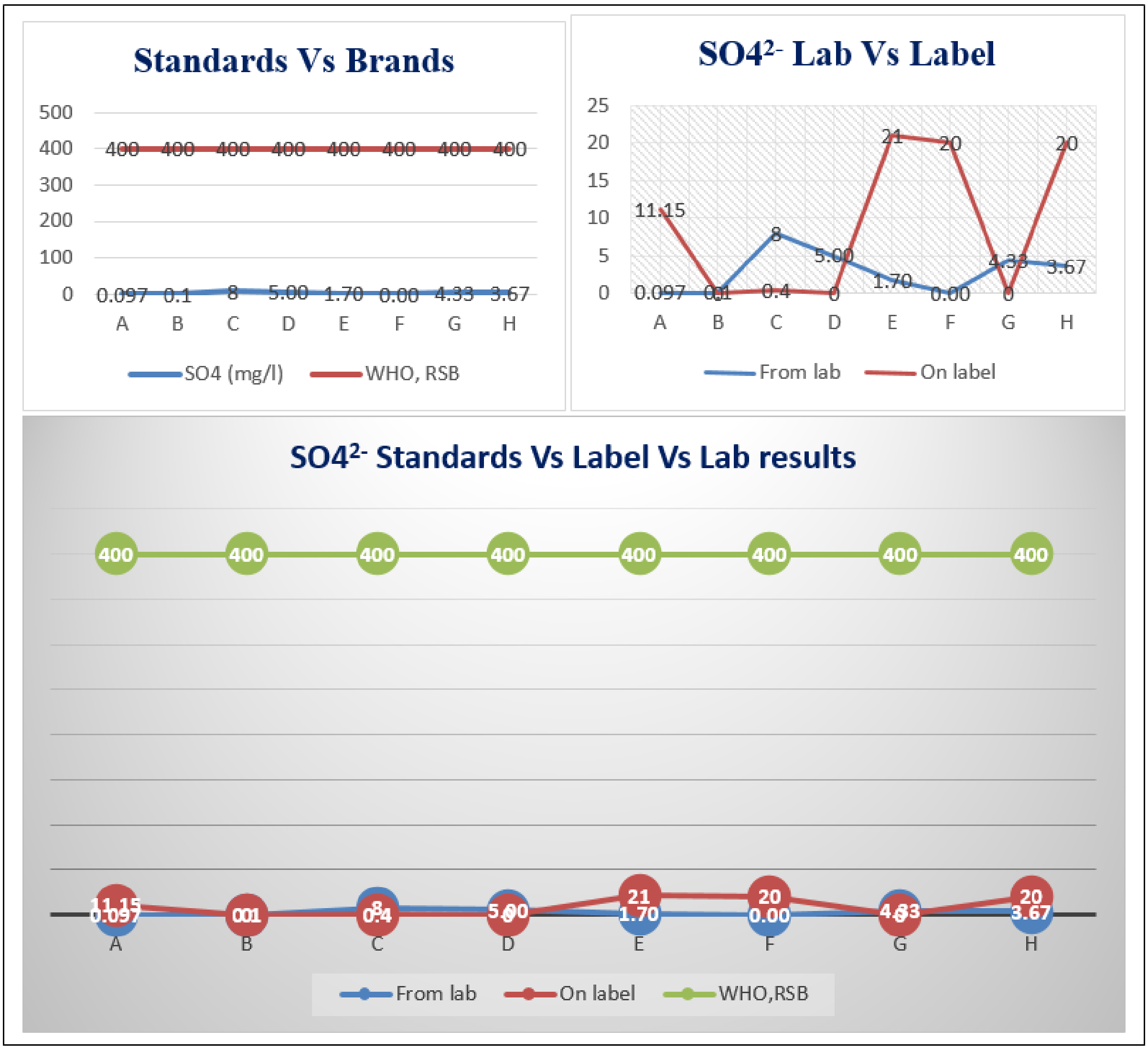

Figure 4.13. Sulfate Results

4.1.14. Total Alkalinity

Total Alkalinity values ranged from 10.00 mg/L to 26.67 mg/L. Higher alkalinity was recorded in brand F which was the one having higher turbidity and the lowest alkalinity was found in H as it used to have lowest TDS and turbidity (fig.4.14).

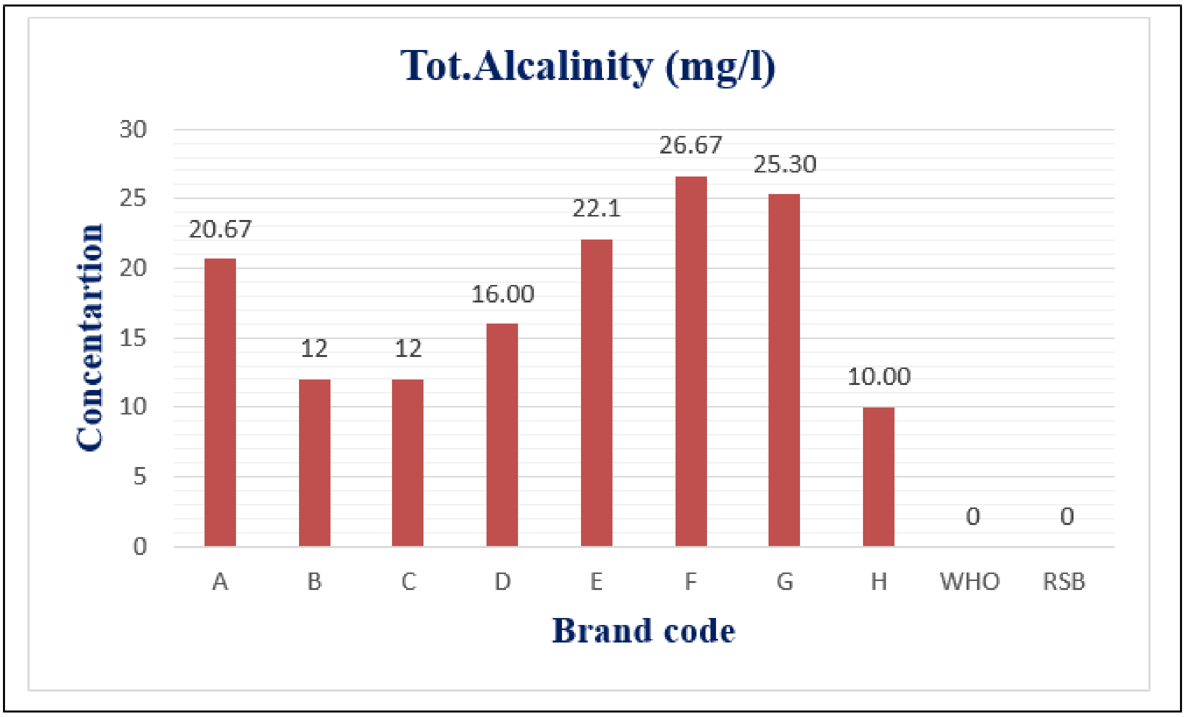

Figure 4.14. Total Alkalinity Results

The constituents of alkalinity in natural systems include mainly carbonate, means that F had more dissolved carbonates salts than others. By running a completely randomized AOV on treatments, significant difference in total alkalinity concentration p (0.0015) $\leq$ 0.05 was recorded. Moreover, LSD All-Pairwise Comparisons Test gave us 3 groups (A, B, C) in which the means were not significantly different from one another. Brand F, G, E, and A have been classified in group **A**; brand E, A, D in group **B**; and brand D, B, C, and H in **C**. Thus, the apparition of subgroup **AB** for brand E and A, and subgroup **BC** for brand D.

Although Alkalinity is generally associated with high TDS and water hardness but it is not considered detrimental to human health, reason why there is no standard limit provided by both WHO and RSB.

4.1.15. Sodium

Lower concentrations of Sodium ions were recorded in all brand of bottled water with respect to the standard maximum permissible limit of 200 mg/l for both WHO and RSB. Laboratory results of the concentration ranged from 0.74 to 1.36 mg/l.

Figure 4.15. Sodium Results

Brand D recorded the highest concentration than others while brand E recorded the lowest.

Long-term exposure to high levels of Sodium has been suspected to be linked to high blood pressure or hypertension, acute effects for infants, cancer and reproductive effects in some animal species. Moreover, very high dose of Sodium Chloride may cause nausea, vomiting, inflammation of the gastrointestinal tract, thirst, muscular twitching, convulsions, and possibly death. Considering the results gotten from the laboratory and the maximum permissible limit of Sodium ions concentration in our drinking water samples, all brands under study had good quality drinking water in terms of Sodium concentration.

5. CONCLUSION AND RECOMMENDATIONS

This research was carried out in Kigali city aiming to assess the physicochemical quality of bottled drinking water sold in Kigali. After laboratory testing of selected 15 parameters in samples collected from 7 brands of bottled and 1 tap water, results have been compared with RSB and WHO standards to evaluate the suitability of our drinking water to human consumption. In addition, concentrations of each parameter in brands have been compared among themselves and also with concentration provided on labels of the bottles.

5.1. Conclusion

The research revealed that the brands of bottled drinking water and tap water produced in Kigali were in line with standards even though the concentration of 2 parameters in 4 brands mismatched with standards, but the general quality of all brands under study has been concluded to be good because even those that mismatched were closer to the limits.

The Results of pH were found within permissible limits for brands C, D, G, H while others were found below the minimum permissible limit. The same for Turbidity all brands met WHO guideline but 4 of them (A, B, E and F) were slightly higher than the recommended maximum limit of RSB. TDS, EC, Nitrate, Potassium, Calcium, Magnesium, Iron, Alminium, Fluoride, Chloride, Sulfate, Total Alkalinity and Sodium met both RSB and WHO recommended permissible limits. Tap water (coded as brand) produced by WASAC company, like other 3 brands, violated only the minimum limit of pH. Hence, tap water is as good in quality as bottled drinking water because even the LSD All-Pairwise Comparisons Test in statistix analytical software revealed that there was no significant differences in means of parameters that were showing discrepancies after running the AoV. Apart from pH and turbidity, there is no brand which is best than others because they are all in recommended ranges. Thus means that consumers can decide which brand of bottled water to drink or tap water depending on their respective taste or diet requirement as brands did not have same concentrations for all parameters.

Even thought, few discrepancies were observed on pH and Turbidity, it is not a big deal as those parameters do not even have an approved scientific direct health concern apart from the palatability. The research concluded that bottled drinking water and tap water produced in Kigali city are safe and suitable for drinking purpose in terms of physical and chemical quality. However, other researches are still needed to assess the bacteriological and radiological quality of that water.

5.2. Recommendations

To water companies

Water bottling companies and WASAC are recommended to monitor the quantity of coagulants/flocculants used in water treatment process by adding lime in case they are using Aluminum Sulfate or by using an alternative product like sidifloc in order to maintain the pH of treated water within permissible the ranges.

Since the majority of brands did not provide (or just provided few) concentrations of even basic parameters on labels of bottle, manufacturer companies were recommended to provide those information on labels for consumers to choose which brand to take according to their diet requirements. Same recommendation goes to WASAC as a water service provider in urban areas, public stand pipe and water kiosks need to have a scripture graved on the wall showing the concentration of basic elements of water quality.

Moreover, the research revealed that the difference in concentration written on bottle labels and laboratory results is remarkable on some parameters, manufacturer companies should update bottle labels periodically without generalization because the concentration of quality parameters may change in treated water due to the status of raw water which goes with season, time and/or climate change.

To Readers

Take actions, it’s your time to contribute to the achievement of SDGs, sustain lives by ensuring that basic needs such as water are accessible and safe in order to cut off illness and deaths that could come up from bad quality of water. Other researches need to be undertaken to ensure that the Bacteriological and Radiological (heavy metals concentration) quality of tap water and bottled water produced in Kigali are in line with standards.

To RSB

Quality control need to be enhanced, and the process of getting the standardization mark should be made easier so that all water bottling companies can be able to afford it for all consumers’ to drink their water without doubting the quality.

To PAUWES

After realizing that same research topics can be really demanding on financial basis, the team of experts in charge of evaluating students’ research proposal should also work on the budgets and ensure that the project will be supported by available research grant otherwise students can be advised to change topic beforehand.

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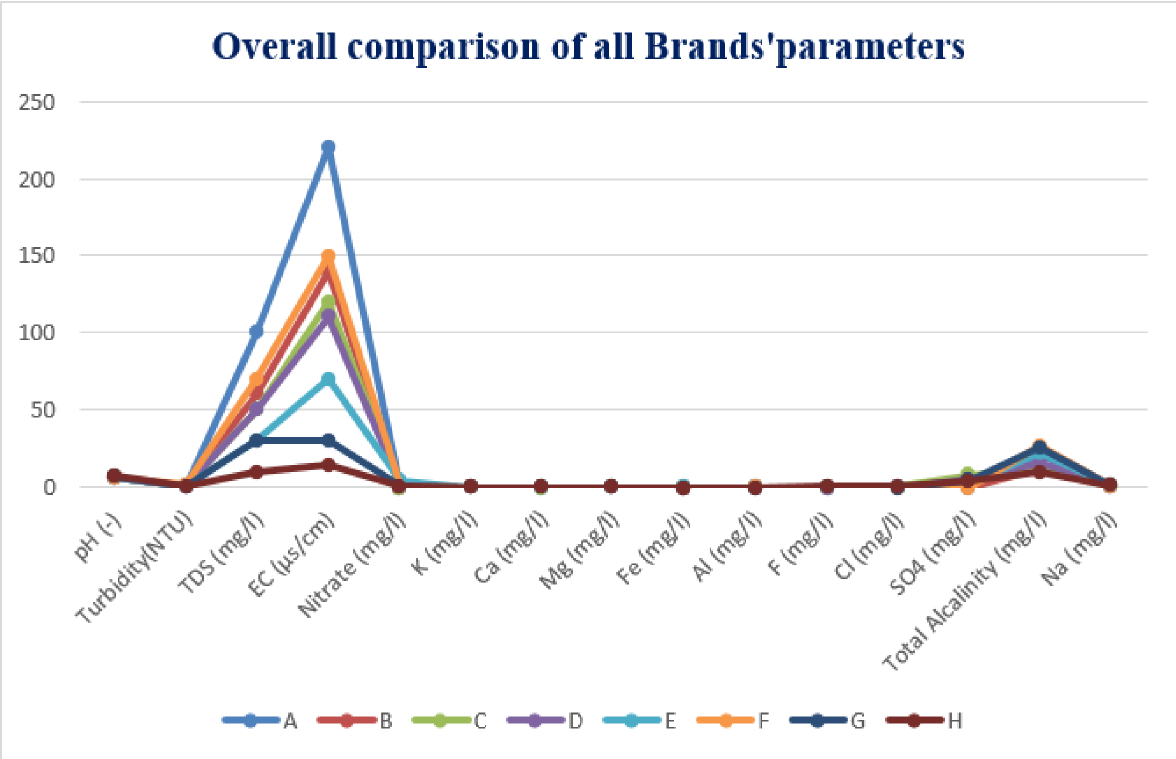
7. APPENDIX

Appendix 1 : Research Budget

S/ No	Item	Item number	Total Amount in $	Rate (unit Price)	Amount in local currency	Comment and Link to Research Activity
1	Flight (Tlemcen-Kigali)	Round-trip ticket	1136.08896	134487 DA	134487 DA	Paid purposely to go and conduct research study for the case study Rwanda
2	Sample Analysis	24 samples	2120.75258	Detailed in appendix 7.4.	1,888,000. RWF	For Laboratory test of water quality parameters.
Total		**3256.84**		That was the minimum amount possible for the last options.		
Overall Comment		The amount of grant provided for Research Thesis was not enough to cover all research expenditures as it was initially designed in the budget. Additional activities, charges and a part of laboratory cost have been taken into charges by the researcher.				

Appendix 2: Overall Brands Comparison



Appendix 3: Laboratory results

TRT	Rep	pH (-)	Turbidity	TDS (mg/l)	EC (µs/cm)	Nitrate (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Fe (mg/l)	Al (mg/l)	F (mg/l)	Cl (mg/l)	SO4 (mg/l)	TA (mg/l)	Na (mg/l)
1	1	6.3	1	100	220	0.01	0.1	0	0.099	0.1	0.098	0.002	0.099	0.093	20	1.01
1	2	6	1.1	100	220	0.01	0.1	0.101	0.098	0.098	0.098	0.098	0.098	0.099	20	0.92
1	3	6.1	0.88	100	220	0.01	0.09	0.101	0.1	0.102	0.095	0.097	0.098	0.098	22	0.9
2	1	6.4	0.95	60	140	0	0.099	0.099	0.098	0.097	0.097	0.098	0.097	0.095	10	1.09
2	2	6.5	0.95	60	140	0.04	0.099	0.099	0.098	0.01	0.095	0.098	0.098	0.098	10	0.92
2	3	6.5	1.13	60	140	0.1	0.098	0.1	0.097	0.01	0.096	0.097	0.098	0.1	16	0.8
3	1	6.9	1.4	50	120	0.12	0.1	0	0.098	0.096	0.098	0.01	1	9	10	1.18
3	2	6.8	1.1	50	120	0.05	0.099	0.102	0.098	0.097	0.099	0.002	1	8	10	1.12
3	3	7	1.11	50	120	0.05	0.1	0.1	0.099	0.098	0.098	0.003	0.7	7	16	1
4	1	6.50	0.89	50.0	110.0	0.34	0.100	0.100	0.098	0.100	0.096	0.098	0.099	6.00	20.00	1.43
4	2	6.50	1.13	50.0	110.0	0.51	0.100	0.101	0.099	0.010	0.098	0.099	0.099	7.00	16.0	1.43
4	3	6.50	1.20	50.0	110.0	0.16	0.100	0.101	0.099	0.010	0.097	0.009	0.098	2.00	12.00	1.22
5	1	6.00	0.17	30.0	70.0	0.23	0.098	0.098	0.098	0.099	0.095	0.100	0.100	0.10	20.0	0.67
5	2	6.10	0.10	30.0	70.0	0.00	0.099	0.990	0.099	0.099	0.095	0.100	0.095	2.00	26.00	0.84
5	3	6.10	0.38	30.0	70.0	12.00	0.099	0.097	0.099	0.099	0.095	0.100	0.094	3.00	20.4	0.71
6	1	6.30	2.69	70.0	150.0	0.14	0.099	0.098	0.099	0.003	0.096	0.100	0.093	0.00	30.0	0.92
6	2	6.30	0.29	70.0	150.0	0.23	0.102	0.098	0.100	0.000	0.095	0.100	0.091	0.00	30.0	0.92
6	3	6.40	0.81	70.0	150.0	0.37	0.101	0.098	0.099	0.002	0.096	0.100	0.092	0.00	20.0	0.90
7	1	6.80	0.26	30.0	30.0	0.74	0.100	0.099	0.098	0.001	0.096	0.101	0.094	2.00	16.00	1.18
7	2	6.80	0.67	30.0	30.0	0.23	0.099	0.099	0.099	0.002	0.096	0.100	0.092	7	26.00	1.26
7	3	6.80	0.45	30.0	30.0	0.35	0.100	0.099	0.098	0.000	0.096	0.100	0.091	4.00	34.00	1.10
8	1	7.20	0.17	10.5	18.00	0.39	0.101	0.099	0.099	0.007	0.096	0.096	0.091	2.00	10.0	1.3
8	2	7.10	0.26	8.6	10.00	0.21	0.100	0.100	0.099	0.003	0.096	0.100	0.093	5.00	10.0	1.2
8	3	7.10	0.41	9.0	15.00	0.32	0.100	0.100	0.099	0.003	0.098	0.990	0.934	4.00	10.0	1.2

Appendix 4: Method and Parameters' Concentration for Tap water

Sampling date	12/03/2019						
Date of analysis	13/03/2019						
District	Muhanga						
Parameters /site	**Unit**	**Gihuma RW**	**Gihuma TW**	**Ifatima Tank**	**Binunga Network**	**Requirement STDs**	**Method used**
Total coli-forms	MPN/100 ml	>200.5	<1	**<1**	**<1**	**Not detected**	**EPA 9223**
Feacal coli-forms	MPN/100 ml	1	<1	<1	<1	**Not detected**	**EPA 9223**
E. coli	Cfu/100 ml	>200.5	<1	<1	<1	**Not detected**	**EPA 9223**
Turbidity	NTU	41.5	1.19	1.88	2.14	**5**	**EPA 180.1**
Residual chlorine	mg/l	-	2.20	0.23	0.06	**0.2-0.5**	**HACH 8021**
PH		6.5	7.0	7.0	7.0	**6.5 -8.5**	**EPA 150.1**
Color	mgPtCo	215	8	12	17	**15**	**HACH 8025**
Sulfates	Mg/l	<2	21	21	20	**400**	**HACH 8051**
Calcium	mg/l	9.6	17.6	15.2	9.6	**150**	**HACH 8338**
Iodine	mg/l	1.73	6.52	1.07	0.26	**5**	**HACH 8031**
Aluminum	mg/l	0.295	0.186	0.181	0.200	**0.2**	**HACH 8012**
TH	mg/l	40	58	42	42	**300**	**HACH 8226**
TA	mg/l	0.0	0.0	0.0	0.0	**300**	**HACH 8338**
TAC	mg/l	18	22	22	16	**300**	**HACH 8338**
Tca	mg/l	24	44	38	24	**300**	**HACH 8338**
TMg	mg/l	22	36	20	26	**300**	**HACH 8338**
Bromine	mg/l	1.07	4.04	0.70	0.19	**5**	**HACH 8016**
Nitrates (NO_3-N)	mg/l	0.0	1.1	0.8	0.6	**45**	**HACH 8039**
Nitrites (NO_2-N)	mg/l	0.008	0.014	0.019	0.025	**0.9**	**HACH 8507**
Ammonia nitrogen	mg/l	0.03	0.00	0.02	0.01	**0.5**	**HACH 8155**
Ammonium	mg/l	0.03	0.00	0.02	0.01	**0.5**	**HACH 78155**
Suspended matter	mg/l	14	0	0	0	**Not detected**	**HACH 8006**
Iron	mg/l	3.65	0.16	0.25	0.30	**0.3**	**HACH 8008**
Manganese	mg/l	0.407	0.125	0.043	0.044	**0.1**	**HACH 8149**
Copper	mg/l	0.04	0.04	0.04	0.00	**1**	**HACH 8506**
Phosphates	mg/l	1.25	0.85	0.52	0.52	**2.2**	**HACH 8048**
Fluorides	mg/l	0.02	0.08	0.02	0.02	**1.5**	**HACH 8029**
Sulfide	mg/l	0.018	0.001	0.002	0.003	**0.05**	**HACH 8131**
Cyanide	mg/l	0.011	0.001	0.004	0.005	**0.01**	**HACH 8027**
Conductivity	µs/cm	100.8	88.2	86	102	**1500**	**HI 98360**
Total dissolved solids	mg/l	50.4	44.1	43	51	**1000**	**HI 98360**
Silica	mg/l	<2	21	21	20	**ND**	**HACH 80185**
Chromium	mg/l	0.205	0.169	0.167	0.134	**0.05**	**HACH 8023**

Appendix 5: Proforma Invoice

UNIVERSITY of RWANDA

COLLEGE OF SCIENCE AND TECHNOLOGY
SCHOOL OFENGINEERING
P.O.Box 3900, Kigali, Rwanda
Email: dpt_cege.cst@ur.ac.rw

UR CONSULTANCY SERVICES
P.O. Box 4285, Kigali, Rwanda
Email: consultancy@ur.ac.rw
TIN: 103365480

Bank Details: National Bank of Rwanda, Account Name: UR CONSULTANCY SERVICES, Account No: 1000041102 (FRW)

DEPARTMENT OF CIVIL, ENVIRONMENTAL AND GEOMATICS ENGINEERING

«ENVIRONMENTAL ENGINEERING LABORATORY»

PROFORMAINVOICE

Our Ref.No: UR/CST/CEGE/EE/ 039

Date: 20thMay, 2019

To:

Company Name : **Miss Adeline ICYIMPAYE**
Project Name : Assessment of Physicochemical Quality of Bottled Drinking Water in Kigali
Tel : +250788728458
E-mail : icyampadeline@gmail.com
Address : Nyamasheke District
Source of Sample : Supermarkets
Water use purpose: Potable Water

PART A: QUOTATION ON WATER TESTING

S.N	Test Descriptions/Parameters	Unity	N° of Samples	Unity Price (per one parameter in one sample (Rwf))	Total Price (Rwf)
1	PH	--	8	10,000.0	80,000.0
2	Turbidity	NTU	8	10,000.0	80,000.0
3	Electrical Conductivity	µS/Cm	8	10,000.0	80,000.0
4	Total Alkalinity	mg/L	8	10,000.0	80,000.0
5	Total Dissolved Solids (TDS)	mg/L	8	10,000.0	80,000.0
6	Potassium	mg/L	8	15,000.0	120,000.0
7	Aluminium, as Al^{+++}	mg/L	8	15,000.0	120,000.0
8	Chloride, as Cl^-	mg/L	8	10,000.0	80,000.0
9	Iron as Fe^{2+}	mg/L	8	15,000.0	120,000.0
10	Sodium, as Na^+	mg/L	8	15,000.0	120,000.0
11	Sulphate SO_4^{2-}	mg/L	8	15,000.0	120,000.0
12	Magnesium, as Mg^{++}	mg/L	8	15,000.0	120,000.0
13	Calcium, as Ca^{++}	mg/L	8	15,000.0	120,000.0

Testing carried out by College of Science & Technology (CST), University of Rwanda, under organized working procedures correlating to international standards. Information contained herein is believed to be true and accurate, however all statements are made without warranty, expressed or implied, regarding accuracy of the information. In general, the concluded results conforming that for all materials and field tests conform to all references given in this report and to the General Technical Requirement

Bank Details: National Bank of Rwanda, Account Name: UR CONSULTANCY SERVICES, Account No: 1000041102 (FRW)

14	Nitrate, as NO_3^-	mg/L	8	20,000.0	160,000.0
15	Fluoride, as F^-	mg/L	8	15,000.0	120,000.0
	Total Cost (without VAT)			**200,000.0**	**1,600,000.0**
	VAT (18%)			**36,000.0**	**288,000.0**
	Total Cost (VAT including)			**236,000.0**	**1,888,000.0**

Rwf One Million Eight Hundred Eighty Eight Thousand Only (Rwf 1,888,000.0)

PART B: QUOTATION ON THE STAFF MOBILISATION

S.N°	DESCRIPTION	UNIT	N° OF DAYS	AMOUNT (Rwf)	TOTAL AMOUNT (Rwf)
1.	Staff Mobilization for sampling; including per-diem.	day	1	50,000.00	**50,000.0**

RwfFiftyThousand only per day (Rwf 50,000.0 per day)

Note:

1) Paymentof **Part A (Rwf 1,888,000.0)** shall be deposited to UR-CONSULTANCY SERVICES account at National Bank of Rwanda; account no: **1000041102 (FRW)**
2) Payment of **Part B (Rwf 50,000.0)** shall be paid **cash** directly to staff personnel (Lab Technician) or by deposit to his **BK account: 00040-00336844-93 (RWF)** before the commencement of work.
3) Results of water tests are issued upon the completion of lab tests.
4) The Client is responsible for transport of both staff and equipment.

APPROVAL

Prepared by:	**Eng.Theogene HABUMUREMYI,** Lab Technician, Water Resources Engineering &Environmental Engineering Laboratories Dept. of CEGE, UR-CST	
Checked by:	**Dr. KABERA Telesphore,** Senior Lecturer in charge of Environmental Engineering Laboratories Dept. of CEGE, UR-CST	30.05.2019
Approved by:	**Assoc. Prof. Dr. G. Senthil KUMARAN** HOD-CEGE, UR-CST	UNIVERSITY OF RWANDA School of Engineering COLLEGE OF SCIENCE AND TECHNOLOGY

Copy to:
The Director, UR Consultancy Services
File

Testing carried out by College of Science & Technology (CST), University of Rwanda, under organized working procedures correlating to International Standards. Information contained herein is believed to be true and accurate, however all statements are made without warranty, expressed or implied, regarding accuracy of the information. In general, the concluded results confirming that for all materials and field tests conform to all references given in this report and to the General Technical Requirement

Bank Details: National Bank of Rwanda, Account Name: UR CONSULTANCY SERVICES, Account No: 1000041102 (FRW)

Appendix 6: Comparison Data Table

Parameters	Brands' laboratory Results								Standards		Content on brand's Bottle Label							
	A	B	C	D	E	F	G	H	WHO	RSB	A	B	C	D	E	F	G	H
pH (-)	6.13	6.47	6.9	6.50	6.07	6.33	6.80	7.13	6.5-8.5	6.5-8.5	6.5	6.7	6.8	_	7	7.50	7.00	7.20
Turbidity (NTU)	0.99	1.01	1.2	1.08	0.22	1.26	0.46	0.28	5	1	_	_	_	_	1.88	_	_	_
TDS (mg/l)	100	60	50	50.0	30.0	70.0	30.0	9.4	_	1000	176.6	44.7	_	_	43	_	9.0	_
EC (µs/cm)	220	140	120	110.0	70.0	150	30.0	14.33	_	1500	_	_	_	_	86	_	_	_
Nitrate (mg/l)	0.01	0.05	0.07	0.34	4.08	0.25	0.44	0.31	50	45	12.6	_	_	_	0.8	_	_	_
K (mg/l)	0.1	0.1	0.1	0.10	0.10	0.10	0.10	0.10	_	50	2.4	_	1.1	6	_	1	_	1
Ca (mg/l)	0.067	0.1	0.07	0.10	0.10	0.10	0.10	0.10	_	150	12.7	0.7	7.4	16	15.2	0.005	0.000	0.01
Mg (mg/l)	0.099	0.1	0.1	0.10	0.10	0.10	0.10	0.10	_	100	0.005	4.7	1.53	5	0.04	3.4	_	1
Fe (mg/l)	0.1	0.04	0.1	0.04	0.10	0.00	0.00	0.04	0.3	0.3	0.001	_	0.05	_	0.25	0.05	0.000	0.05
Al (mg/l)	0.097	0.1	0.1	0.10	0.10	0.10	0.10	0.10	0.2	0.2	_	_	_	_	0.18	_	_	_
F (mg/l)	0.066	0.1	0.01	0.07	0.10	0.10	0.10	0.40	1.5	1.5	_	0.02	_	_	0.02	_	_	_
Cl (mg/l)	0.098	0.1	0.9	0.10	0.10	0.092	0.090	0.373	250	250	47.46	6.4	6.24	45	0.23	33.7	_	4.5
SO4 (mg/l)	0.097	0.1	8	5.00	1.70	0.00	4.33	3.67	400	400	11.15	_	0.4	_	21	20	_	20
TA (mg/l)	20.67	12	12	16.00	22.1	26.67	25.30	10.00	_	_	_	_	_	_	_	_	_	_
Na (mg/l)	0.94	0.94	1.15	1.36	0.74	0.92	1.18	1.21	200	200	9.5	17.6	_	_	_	11.4	_	2

Appendix 7: Summary Statistix of Physicochemical Quality parameters of Bottled Drinking Water Sold in African Cities: Case of Kigali, Rwanda

Table 7.4.1. Mineral Composition of Selected Bottled Water (by brand) Produced in Kigali in June 2019

Treatment		pH	EC	NO3	K	Ca	Mg	Fe	Na
Water Brands (WB)		**------------------ Mean-values ---------------------------**							
A		6.133e	220a	0.01a	0.096b	0.0673b	0.0990a	0.100a	0.943c
B		6.466c	140c	0.04a	0.09ab	0.099ab	0.0977b	0.039b	0.936c
C		6.900b	120d	0.07a	0.09ab	0.0673b	0.098ab	0.097a	1.100b
D		6.500c	110e	0.33a	0.10ab	0.100ab	0.098ab	0.040b	1.360a
E		6.066e	70.0f	4.07a	0.09ab	0.3950a	0.098ab	0.099a	0.740d
F		6.333d	150b	0.24a	0.100a	0.098ab	0.0993a	0.001b	0.913c
G		6.800b	30.0g	0.44a	0.09ab	0.099ab	0.098ab	0.001b	1.180b
H		7.133a	14.3h	0.30a	0.10ab	0.099ab	0.0990a	0.004b	1.23ab
Analysis of variance									
Sources of variation	df	pH	EC	NO3	K	Ca	Mg	Fe	Na
Rep	3	**------------------ p-values ---------------------------**							
WB	7	**0.0000**	**0.000**	0.489	0.436	0.4414	0.098	**0.0001**	**0.0000**
Error (MS)	16								
Total	23								

Means followed by different alphabet in the same treatment are statistically significant at the 0.05 probability level.
p-values ≤ 0.05 are statistically significant.
pH: power of Hydrogen; EC: Electrical Conductivity; WB: Water Brands: Rep: Replication

Table 7.4.2. Mineral Composition of Selected Bottled Water (by brand) Produced in Kigali in June 2019 (continued)

Treatment		Turb	TDS	Al	F	Cl	SO4	TA
Water Brands (WB)		**------------------ Mean-values ---------------------------**						
A		0.99abc	100a	0.097ab	0.065b	0.098b	0.0967d	20.66ab
B		1.01abc	60.0c	0.096bc	0.09ab	0.097b	0.0977d	12.000c
C		1.2033a	50.0d	0.0983a	0.005b	0.900a	8.0000a	12.000c
D		1.073ab	50.0d	0.097ab	0.068b	0.098b	5.0000b	16.00bc
E		0.2167c	30.0e	0.0950c	0.10ab	0.096b	1.700cd	22.13ab
F		1.2633a	70.0b	0.095bc	0.10ab	0.092b	0.0000d	26.667a
G		0.46abc	30.0e	0.096bc	0.10ab	0.092b	4.333bc	25.333a
H		0.280bc	9.36f	0.0967b	0.395a	0.372b	3.666bc	10.000c
Analysis of variance								
Sources of variation	df	Turb	TDS	Al	F	Cl	SO4	TA
Rep	3	**------------------ p-values ---------------------------**						
WB	7	0.0640	**0.000**	**0.016**	0.3489	**0.0005**	**0.0001**	**0.0015**
Error (MS)	16							
Total	23							

Means followed by different alphabet in the same treatment are statistically significant at the 0.05 probability level.
p-values ≤ 0.05 are statistically significant.
TDS: Total Dissolved Solid; Turb: Turbidity; Rep: Replication

Appendix 8: Visit at Kimisagara Water Treatment Plant

Sedimentation bassins

Filtration bassins

Preparation of Chlorine disinfectant by electrolysis of sodium chloride