THE MICROBIAL AND PHYSICOCHEMICAL QUALITY OF

BOTTLED AND DOMESTIC WATER IN GABORONE, BOTSWANA

by

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Master of Environmental Health

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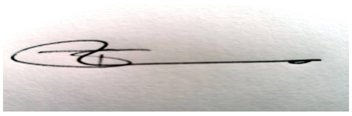
DECLARATION

I, **Thato Sengwaketse,** declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.



Signed: Date: 03 November 2021

ABSTRACT

Water is an essential resource of imperative use the world over and affects the well-being of each individual on a daily basis. Governments have put measures in place to provide acceptable, clean and safe drinking water. Several developed countries continue to provide tap water meeting basic drinking standards. Unfortunately, there are challenges with the safety of water and diarrhoea as an example remains one of the problematic outbreaks worldwide especially in countries where water quality and sanitation are compromised for one reason or another. Botswana like the rest of the world seasonally experiences diarrhoea outbreaks which is usually recognised in the under 5-year-olds because it is a notifiable disease. Water quality has been identified by WHO as a possible determinant for gastro enteritis. This study was conducted in Gaborone, Botswana which is also the capital city and attests to a lot of affluence and therefore the community appreciates the convenience of consuming bottled water. The increased utilisation of bottled water over domestic (municipal) water supplies seem to stem from the assumption that domestic (municipal) water is not as safe.

It was therefore vital to assess the drinking water options of Gaborone community and further examine the factors that determine their choices. Moreover, this study assessed the quality and safety of both bottled and domestic water. Concomitant to the above, this study was extended to understand the environmental health risks of water bottling facilities. The data collection tools used were questionnaires for the public, environmental health risk assessment (observation schedule) for water bottling facilities and microbial and physicochemical analysis of domestic and bottled water using approved standards. Data was coded through Microsoft Excel package and further analysed using SPSS.

The study indicates that 56.4% of participants preferred bottled water over other types of water and their preferences` were influenced by the perception that their choice of water was safe. Understanding of the health risks associated with water through water hygiene was assessed, and a majority of the participants indicated diarrhoea and other gastrointestinal diseases as major health risks. Of the schools that participated in the study for domestic water analysis, 2.9% had its water not compliant to the microbial water standards and 0.99% of domestic water supplies samples were found to be positive for total coliforms and *Escherichia coli;* the presence of these organisms in drinking water indicates recent faecal contamination. It also indicated that 14.3% of bottling facilities water samples were not compliant and 12.85% of the samples tested positive for *Pseudomonas aeruginosa;* an opportunistic human pathogen

capable of causing widespread infections in burn and immune-compromised patients. From the overall compliance level of environmental risk assessment of facilities the process flow and/or procedure for maintenance, cleaning of equipment and personal hygiene scored 59%, 51% and 65% respectively; which are factors that highly likely to contribute to the contamination of the bottled water products thus potentially affecting the product quality as per the BOS 306 - Bottled water code of hygienic practice.

The recommendation is made to the effect that health promotion and education policies should be strengthened to ensure that the general populace is knowledgeable on the health risks associated with water for ease of their control. Consumer education on water safety should also be upscaled for them to make informed choices with the types of water preferences. An in-depth analysis of recorded outbreaks to determine their root causes as its quite vivid that water may be a contributing factor to many. Stricter monitoring protocols for water bottling and filling facilities should be developed to reduce gaps in compliance with National Regulatory Standards of Botswana.

STYLE USED FOR THE CHAPTER LAYOUT OF THIS MANUSCRIPT

This study is structured more like article format to separate the segregated focus issues of the project. However this does not constitute a normal article format but merely separate sections for ease of reading.

Chapter 1: This chapter will focus mainly on the foundation of the study and reflect on the proposal that was approved. This reflects on the overall aim and its objectives inclusive of problem statement and other related issues pertinent to introduce the entire project.

Chapter 2: this chaoter will focus briefly on the literature review covering main topics related to the study i lin with the Botswana backgrond as well as both internatiomal and regional studies.

Chapter 3: This section will provide publics views as well as their choice of type of water source.

Chapter 4: This chapter will provide the results and analysis towards water quality based on Botswana standards which are in line with international proesses.

Chapter 5: this section provides and overview of the health risks associated with bottled water and the bottling water plants registered in Gaborone, Botswana.

Chapter 6: this secton provides overall conlcusions and reccomendations made from the study as well as future projects that were identified during the study.

Appendix: Relevant supoting documnt are attahced in ths sectyion for ease of reference.

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I wish to pass my sincere gratitude to the following for making the study possible;

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Finally, I would like to thank Professor Karabo Shale and Mr Thandazile Marazula - my supervisor and co-supervisor (respectively) who diligently guided me in making the study a success.

Last but not least the Government of Botswana for funding the study.

DEDICATION

This study is dedicated to my mother - Rachel Pelonomi Sengwaketse.

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GLOSSARY

AMCOW - African Ministers Council on Water.

AUC - African Union Commission.

BOBS - Botswana Bureau of Standards.

BOS 32:00 - Botswana Bureau of Standard Drinking Water Specification.

BOS 143:00 - Botswana Bureau of Standard Bottled Water other than natural water specification.

Bottled water - water that is sold in bottles and that has been treated to make it clean.

Drinking water - also known as potable water, is water that is safe to drink or use for food preparation.

E. *coli* - *Eschericia coli* a straight rod-shaped gram-negative bacterium (*Escherichia coli* of the family *Enterobacteriaceae*) that is used in public health as an indicator of feacal pollution (as of water or food).

Microbial/ microbes. Any of the microorganisms, especially those causing diseases or infections. They can be divided into six major types: bacteria, archaea, fungi, protozoa, algae, and viruses.

MITI - Botswana Ministry of investment, Trade and Industry.

MOHW - Botswana Ministry of Health and Wellness.

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CHAPTER 1
INTRODUCTION

1.1 Background to Research

About 40% of Africans lack improved water supply and the lack of safe water creates a remarkable burden of diarrhoeal disease and other debilitating, life-threatening illnesses for people in the developing world (Sila, 2019). Pathogenic microbes from human and animal wastes in the water that have been obtained from different studies includes: bacteria namely, *Campylobacter jejuni*, *Campylobacter coli*, Enteropathogenic *Escherichia coli*, *Salmonella typhi*, *Salmonella paratyphi*, other *Salmonella*, *Shigella* spp., *Vibrio cholerae*, *Yersinia enterocolitica*, *Pseudomonas aeruginosa*, *Aeromonas* spp., *Legionella pneumophila. Moreover, Leptospira* spp., various mycobacterium; viruses such as Adenoviruses, Enteroviruses, Polio viruses, Coxsackie viruses A, Hepatitis A, Enterically transmitted non-A, non-B hepatitis virus, hepatitis E, Echo viruses, Norwalk virus, Rotaviruses, small round viruses are some of the recorded and identified microbes lonked with water quality. In addition, protozoa such as *Entamoeba histolytica*, *Naegleria fowleri*, *Acanthamoeba castellani*, *Balantidium coli*, *Giardia intestinalis*, *Giardia lamblia*, *Cryptosporidium homonis*, *Cryptosporidium parvum*; and Helminths such as *Dracunculus medinensi* and *Ascaris lumbricoides have* been identified in water related studies (Sila, 2019).

In addition to the above, Hunter *et al*. (2010), indicated that the scientific observation from literature about pathogens is not surprising given that diarrhoea disease is the second most common contributor to the disease burden in developing countries (as measured by disability-adjusted life years [DALYs]). Poor-quality drinking water is an important risk factor for diarrhoea. Unfortunately, most of the excess disease burden in developing countries falls on young children as 17% of all deaths in children under 5 years are attributed to diarrhoea (WHO, 2017). These challenges are increased as some of the studies have shown that increase in development as a result of urbanisation has resulted in elevated scarcity of water resources and access to safe water and sanitation remains a serious challenge (Bisi-Johnson *et al*., 2017)

The Ministry of Health and Wellness (2018) highlights that Botswana is no different from what other countries are facing, as the country recently experienced a diarrhoea outbreak; where 5606 cases of diarrhoea with dehydration were recorded. Of the stool samples collected from these cases; positive cases were due to Rotavirus (67%), *Cryptosporidium* (6%), *Salmonella* (4%), *E. coli* (4%), *Shigella,* Taeniasis and Adenovirus were at (1%) each respectively. The remaining 27% were negative results and/or no microorganisms were isolated from the samples analysed.

During the same year of 2018, the Botswana Ministry of Health and Wellness Report on Water Quality Surveillance for the diarrhoea outbreak reflected that 221 samples from domestic water supplies were submitted for analysis. The results revealed that 10% of the samples were non-compliant to the drinking water quality standard, specifically the BOS 32:2015 indicating the presence of *Escherichia coli* and total coliforms. Conclusions could not be reached to ascertain whether the water samples contributed to the diarrhoea outbreak as there was no correlation between the non-compliance of water samples and diarrhoea incidences.

The Botswana Statutory Instrument No.44 of 2018 was introduced to ban the importation of bottled water contained in volumes less than ten (10) litres. This was a measure aimed at promoting the competitiveness and sustainability of the domestic water bottling sector. Furthermore, the statutory framework intended to stimulate investment in the sector which would in turn result in job creation and poverty alleviation. Implementation and enforcement of the Statutory Instrument No.44 have presumably put pressure on the local production companies to meet the demand. However, it can be argued that the local production companies might be inadequately resourced to provide the quality of water as per the Botswana Bureau of Standards - Bottled Water and Natural Water Specification - BOS 143:00.

Therefore, with this backdrop, it was deemed necessary that this study be undertaken, to assess the compliance levels of supplied drinking water from various sources; encourage for in-depth analysis of recorded outbreaks to determine the root causes and to also guide the country on effective implementation of National Regulatory Standards, guidelines and policies governing water safety.

1.2 Statement of the Problem

Water is known as an essential resource that is of imperative use and needed daily to sustain the survival of living species in the entire environment. However, the majority of population in developing countries has no access to clean water and/or any form of sanitation services. Consequently, millions of people are suffering from diseases related to water, sanitation, and hygiene, such as diarrhoea, skin diseases, and trachoma (Duressa *et al*., 2019). Moreover, research has shown that many countries are facing serious problems of natural sources scarcity. In view of economic development and population growth, water is in high demand (Gorde and Yadhov, 2013; Mathipa, 2016). Regulations have been developed at national and international levels to safeguard the drinking water quality and to ensure that the public is provided with water that meets basic drinking standards. However, there has been a rising trend globally towards the consumption of bottled water over tap water. The increased utilisation of bottled water over domestic (municipal) water supplies seem to stem from an assumption that domestic (municipal) water is not as safe.

The reviewed literature has shown that there are assumed health benefits associated with drinking bottled water relative to tap water and that bottled water generally contains higher concentrations of essential minerals compared to domestic water (Ward *et al.,* 2009 and Edokpayi *et al*., 2018b). However, Doria (2006) also accentuates that convincing the public to adopt sustainable behaviours, such as drinking tap water instead of bottled water, is a challenging task despite the significant environmental and social benefits. It is therefore vital to assess the drinking water options of Gaborone, Botswana community and further examine the factors that determine their choices, and assess the quality and safety of both bottled and domestic water.

1.3 Hypothesis and Research Questions

1. 3. 1 Hypothesis

Bottled water poses higher health risks than domestic water.

1. 3. 2 Research Questions

1. What possible public health risks may result from domestic and/or bottled water?
2. How does processing bottled water affect its quality?
3. Why does the public prefer bottled water over domestic /municipal water supplies?

1.4 Aims and Objectives of the Research

The overall aim of this project was to establish the water quality of bottled and tap water as well as. public's perceptions of and their choice of water source in Gaborone, Botswana

The aim will be achieved through the following objectives;

- To assess people's knowledge and perceptions on the choice of bottled water vis a vis domestic water.
- To conduct microbial and physicochemical assessments of bottled water and domestic water supplies.
- To conduct risk assessments in water bottling plants.
- To develop appropriate policy interventions for the possible health risks with water.

1.5 Delineation and Limitations of the Research

The study was only limited to assess the quality of domestic water and still bottled water in Gaborone, Botswana. The study was not intended to assess the effect of packaging material i.e. glass or plastic of bottled water due to lack of capacity. However, any observations noticed will be recorded where necessary although they won't form part of the concluding remarks. The study will be limited to only water-borne diseases, as Botswana is challenged with two diarrhoea outbreak seasons per annum and water may be one of the possible determinants. Therefore, the study interpretation will delve more in the microbial analysis than physicochemical. Furthermore, the study discussion path will only be from an environmental health perspective as this is linked with the focus area of the Ministry of Health and Wellness.

It is crucial to indicate that this study was conducted during the COVID-19 pandemic which affected SADC and the world at large. As a result, there were challenges in between due to closure of some water bottling companies. Moreover, there were challenges with accessing people for interviews due to required protocols adherence to minimise the spread of the virus. Some parts of the project were done online and this may have affected some responses and/or follow ups which one could be able to deal with when it was a face to face through observance of body language and or site visits during interviews.

1.6 Location of Study Area

The study was based in Gaborone, Botswana, an area with a population of 231 592 (Statistics Botswana, 2011) and it is the capital city and economic hub of the country. Gaborone is located in the South East Region of Botswana; geographically lies between latitudes 20º31` and 24º45` south of the Equator, and between of longitudes of 25:50` and 26:12` east of the Greenwich Meridian as per Figure 1.

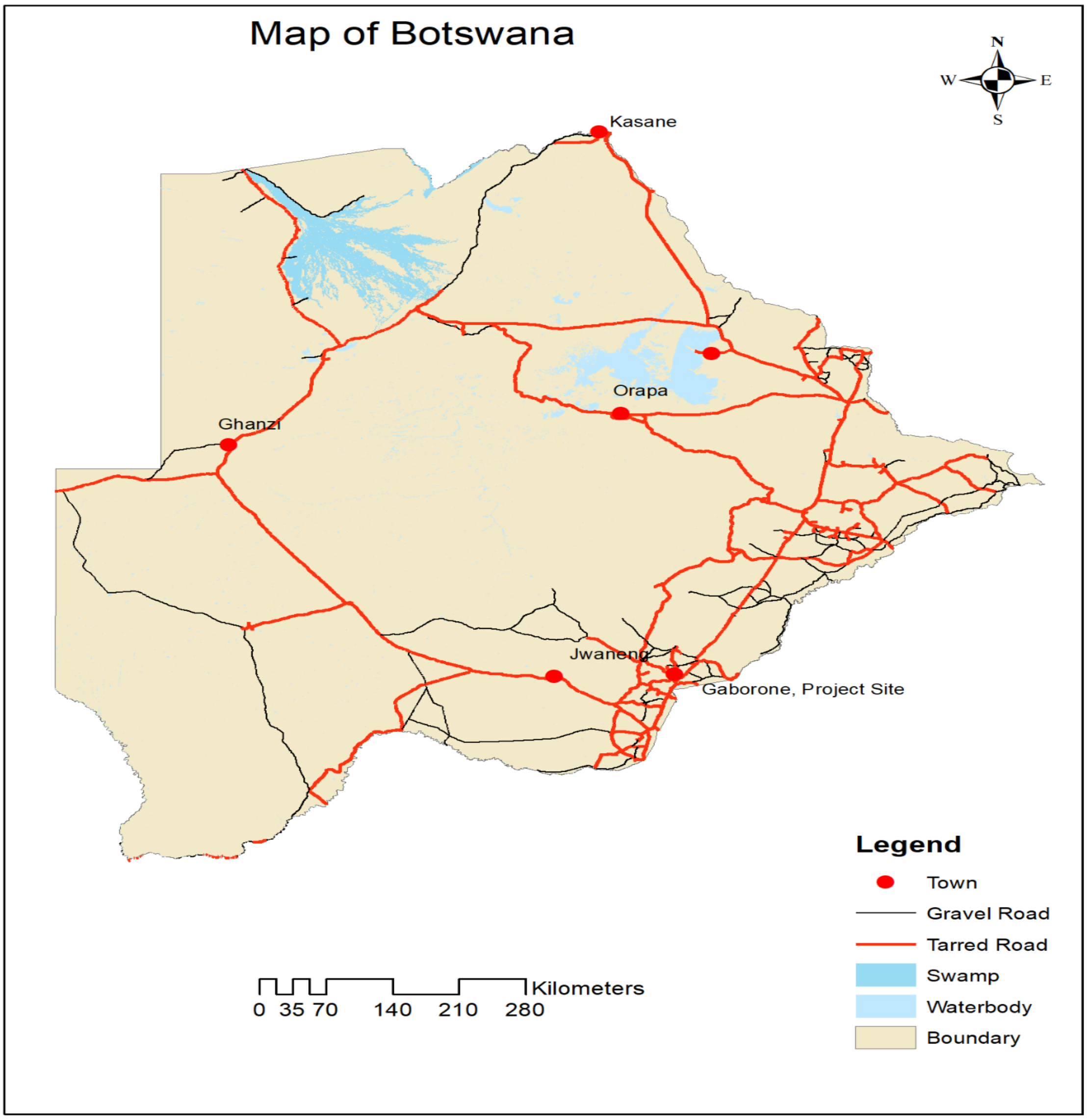

Figure 1.1: Map of Botswana indicating the project site (Source - Author).

1.7 Validity and reliability

To ensure that errors are reduced, and the data collected is reliable, valid, and of high quality, special attention was dedicated to the following:

- Various relevant literature resources were used for the study.
- Both the questionnaire and checklist were tested in a different area that was excluded from the final study.
- There were briefing and training for all supporting staff. This was conducted by the study leader before the use of any instruments to ensure that they are well versed.

- There were also tests conducted in accredited labs using accredited protocols.
- The researcher also analysed data but made use of a statistics expert for accuracy.

1.8 Ethical considerations

It is crucial to give attention to ethic consideration when conducting research. The protection of research participants' identities is one of the important aspects (Maree, 2016).

- Ethical approval was obtained from the Applied Sciences Faculty of Ethics Committee of CPUT.
- A research permit was issued by the Botswana Ministry of Health and Wellness.
- Consent forms and confidentiality forms from CPUT were used for the survey. These forms were available in English.
- Questionnaires and observation schedules were used to obtain information from the study area.
- Research participants were 18 years and older but where candidates were below the age at least the presence of an adult was required.

CHAPTER 2
LITERATURE REVIEW

2.0 Introduction

Clean and safe drinking water is vital for human health and can reduce the burden of common illnesses, such as diarrhoea disease, especially in young children. In most developing countries of the world, inadequate supplies of drinking water can contribute to the death of children and those with immune compromised systems in the region (Edokpayi *et al.,* 2018a). Concomitant to the above, thus the whole philosophy behind the use of the coliforms as indicators is to give a very high margin of safety to drinking water EPA (2001) hence reducing the possibility of waterborne diseases.

Water quality monitoring is vital because water as a colourless, tasteless, odourless liquid; is therefore easily contaminated and pure water is not met in nature or as tap water. Uncontaminated water has a neutral pH of 7 and water has many physical features that make it unique. It is naturally found as a liquid, a solid and a gas and is practically incompressible; the density of water is taken as the standard comparison for all liquids and solids (Basset, 2004). However, strictly speaking, chemically pure water does not exist for any appreciable length of time in nature (Gorde and Jadhav, 2013).

Cairncross and Feachem (1996) and Mathipa (2016) also emphasised that water is essential for life and all human communities must have some kind of water source. It may be dirty, it may be inadequate in volume and maybe several hours away but some water must be available. Water is a finite resource that plays a fundamental role in food security, economic growth, energy production and public health among others. Clean water improves human life, predominantly in the deterrence of the spread of disease-causing organisms with Covid-19 as a recent example. Provision of clean and safe water is undeniably paramount to human life, hence given priority concern by the United Nations (UN) Sustainable Development Goal (SDG) 6. The goal targets are set to achieve universal and equitable access to safe and affordable drinking water for all by 2030 (Chidya *et al*., 2019).

In addition to the above, the World Health Organisation (WHO, 2017) re-emphasised that access to safe drinking water is important as a health and development issue at national, regional, and global levels. In some regions, it has been shown that investments in water supply and sanitation can yield a net economic benefit because the reductions in adverse health effects and healthcare costs outweigh the costs of undertaking the interventions. Literature also indicates that interventions in improving access to safe water favour the poor in particular, whether in rural or urban areas and can be an effective part of poverty alleviation strategies (WHO, 2017).

2.1 Governance and Policy Frameworks

The access to safe drinking water is essential to health, a basic human right and a component of effective policy for health protection that can never be over accentuated. The importance of water, sanitation and hygiene for health and development has been reflected in the outcomes of a series of international policy forums. This includes, most recently, the adoption of the Sustainable Development Goals by countries, in 2015, which include a target and indicator on safe drinking water. Furthermore, the United Nations (UN) General Assembly declared in 2010 that safe and clean drinking water and sanitation is a human right, essential to the full enjoyment of life and all other human rights. These commitments build on a long history of support including the UN General Assembly adopting the Millennium Development Goals in 2000 and declaring the period 2005–2015 as the International Decade for Action, “Water for Life” (WHO, 2018).

In Africa, some 285 million people (28 percent of the population) still have no access to clean water and without access, only very limited progress is possible in areas of economics, health, gender and environment. In recognition of the challenges; the African Union Commission (AUC) in collaboration with United Nations Economic Commission for Africa (UN-ECA) and the African Development Bank (AfDB) developed the Africa Water Vision for 2025: Equitable and Sustainable Use of Water for Socio-Economic Development of 2000. This Vision highlighted that depletion of water resources through pollution and environmental degradation are human threats which may pose challenges to the management of water resources on the continent and the satisfaction of competing demands for basic water supply. The vision also emphasises sustainable access to safe adequate water supply (AUC, 2009).

In 2008 at the 11th Ordinary Session Of the African Union Assembly, the Assembly agreed on the Commitments of the Sharm El Sheik to accelerate the achievement of water and sanitation goals in Africa and mandated African Ministers Council on Water (AMCOW); a specialised committee for water and sanitation at the African Union, to develop and follow up an implementation strategy for the commitments (AUC, 2008).

Moreover, African Union Commission through its mandate to African Ministers Council on Water, has a marked a step-change in the implementation and achievement of Africa Water Vision 2025 and the Sustainable Development Goals of 2030 specifically Sustainable Development Goal 6 which focuses on clean water and sanitation. The AUC also recognises that the “whole is equal to the sum of its parts,” and therefore it will endeavour to see that no Member State is left behind in the evolution of Water Resources Management, water security and safely managed sanitation in Africa (AMCOW, 2018).

In cascading the AUC policy to sub-regional level; the Southern African Development Community (SADC) member states developed a policy acknowledging the vitality of the water resource in the region. Apart from sustaining a rich diversity of natural ecosystems, the region‘s water resources are critical for meeting the basic needs related to water supplies for domestic and industrial requirements, and sanitation and waste management for about 200 million people.

Since the mid-1990s the SADC Member States have engaged in wide-ranging and intense consultations on the development of the water sector in the region. This has brought about a heightened awareness of the importance of water for socio-economic development, regional integration and poverty reduction. However, there are several institutional, technical, economic, social and environmental factors which, to one degree or another, still constrain effective management of the region‘s water resources. These factors are being addressed through programmes and projects that form part of the Regional Strategic Action Plan for Integrated Water Resources Development and Management. However, water resources development in the region still face challenges which include the following;

- low access to safe drinking water and adequate sanitation, primarily as a result of
- inadequate infrastructure, and
- poor operation and maintenance of facilities (Southern African Development Community, 2005).

With the above regional plans, the Botswana National Water Master Plan Review in 2006 recommended that a series of institutional reforms be developed within the water sector. These are needed to meet the increasingly complex challenges facing Botswana in;

- the development of water resources,
- the supply of water and overall management of the sector,
- recognising that water represents one of the key constraints to future sustained growth for development.

Therefore, water will be central to realising these objectives and positioning the country to deal with future development challenges. The National Water Policy represents the first step in a continual process to ensure that water is properly positioned to meet the needs of the country and its people. The overall objective of the policy is, therefore, to provide a national framework that will facilitate access to water of suitable quality and standards for the citizenry and provide the foundations for sustainable development of water resources (Botswana, 2012).

2.2 Global Water Quality Standards

The main imposition of water standards (which may necessitate extensive treatment before use) is the protection of the end uses, be these by humans, animals, agriculture or industry. In the present context, however, the main considerations are regarding safeguarding public health and the protection of the whole aquatic environment (EPA, 2001 and 2018; WHO, 2008 and 2017). This is imperative to focus on some of the aspects covered in the 2018 Edition of drinking water standards and health advisories (EPA, 2018) and WHO guidelines of 2008 and 2017 which informed Botswana standards.

Cairncross and Feachem (1996), demonstrate that more stringent control of water contaminants and higher quality standards, apply to water intended for human consumption than for other uses. Although drinking water quality is and monitored in many countries, increasing knowledge leads to the need for reviewing standards and guidelines on a nearly permanent basis, both for regulated and newly identified contaminants (Levallois and Villaneuva, 2019).

Moreover, following the WHO Guidelines for Drinking water Quality (2017), health-based targets is an essential component of the drinking-water safety framework. The targets should be established by a high-level authority responsible for health in consultation with other stakeholders, including water suppliers and affected communities. The health-based targets should take account of the overall public health situation and contribution of drinking water quality to disease due to waterborne microbes and chemicals, as a part of overall water and health policy. They must also take account of the importance of ensuring access to water for all consumers.

2. 2. 1 Regional Water Quality Standards

The AMCOW Regional Strategy 2018-2030 recognises the interdependencies of SDG 6 which advocates for Clean Water and Sanitation with other goals including SDG 3 whose focus is ensuring healthy lives and promote wellbeing for all at all ages. Therefore, AMCOW takes on a role to support the continent to help it realise SDG 6 and to act as Africa's key interlocutor for the constellation of initiatives and actors working in the other SDGs that depend on the achievement of SDG 6.

One of the strategic priorities in the AMCOW Strategy is to "Ensure water security", and it is defined by the United Nations (UN) as "The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability". The strategy document further elaborates the key actions under the above pillar as "promotion and facilitation of the development of infrastructure for increased water storage, improved water quality, reduced water disasters, and sustainable water supply for multiple uses" in collaboration with regional and international partners and stakeholders and several mechanisms and organisations (AMCOW, 2018).

The Southern African Development Community Regional Water Strategy of 2008 chapter on water Development and Poverty Reduction describes the following:

i) role of water in socio-economic development
ii) the provision of basic services and the improved water supply, sanitation and hygiene,
iii) the role of water in food security, and
iv) water for energy development and water for sports recreation.

The strategy also recognises that less than 40% of the people in Southern Africa have access to safe water to meet their basic human needs and proper sanitation. The health and socio-economic implications are enormous, with high morbidity and mortality from water-borne diseases, such as cholera, resulting in the loss of life, children kept out of school, and women deprived of time for productive pursuits due to daily drudgery of fetching water and caring for sick family members (SADC, 2002).

2. 2. 2 National (Botswana) Water Quality Standards

Botswana's Food Control Act Chapter 65:05, provides for the regulation of water meant for public or which the public does use for drinking or domestic purposes, and to take all necessary measures against any person so polluting any such supply, or polluting any stream to be a nuisance or a danger to health. The Drinking Water Standard - BOS 32:00 gives specifications on the quality of drinking water defined in terms of microbiological, physical, organoleptic and chemical determinants (Botswana Bureau of Standards, 2015).

According to the Standard, water that complies is deemed to present an acceptable health risk for lifetime consumption. There are available water standards in Botswana namely; Bottled water other than natural water BOS 143:00 and Bottled Natural water - BOS 262:00. The Standards specify the chemical, physical and microbiological requirements for bottled water, and water bottled at source meant for human consumption, they also specify permissible treatments and requirements for bottling and labelling. However, it's worth noting that the Standards are applicable to still and carbonated water and excludes water that contains sugar sweeteners, flavourants or other additives (Botswana Bureau of Standards, 2011).

2. 2. 3 Microbiological Characteristics for Water Quality

For Water Quality The World Health Organisation (2017) indicated that microbial water quality may vary rapidly and widely and; short term peaks in pathogen concentrations may increase disease risks considerably and also trigger outbreaks of waterborne disease. Microorganisms can accumulate in sediments and are mobilised when water flow increases. Cairncross and Feachem (1996) further illustrate that microbiological quality of drinking water is typically expressed in terms of the concentration and frequency of occurrence of particular species of bacteria, and by convention, the most commonly used indicator bacteria are the coliforms.

However, Matin *et al.* (1999), indicate that the original logic behind indicator (now index) still holds, in that a range of pathogens may be shed into the water from faecal matter of infected people and animals. As such it is neither practicable nor recommended to examine water for every known pathogen to be present.

Therefore, the microbial water quality indicator parameters and those that are suited to a range of purposes, with the main thrust towards minimising waterborne diseases as per the Botswana BOS 32:00 - Drinking Water and BOS 143:00 - Bottled Water other than natural water specifications are; total coliforms, *Escherichia coli, faecal* coliforms, *Cryptosporodium, Giardia, Pseudomonas aeruginosa, Enterococcus* and *Clostridium* spores respectively. Some of these microbes are briefly reflected below.

a) Total Coliforms

Total coliforms are an indicator for cleanliness and integrity of the distribution system. Their presence even in very low concentrations is indicative of a failure in the treatment plant or subsequent pollution of treated water. Therefore the WHO (1984) suggests the following guideline for treated drinking water;

i) water entering the distribution system should contain no coliform

ii) water at the tap should contain no coliforms in 95% of samples taken in one year and it should never contain more than three (03) coliforms/100ml.

However the BOS 32:00 assets that the presence of total coliforms in drinking water indicates the general microbiological contamination and therefore the drinking water standards require non detection of the parameter in any sample.

b) Faecal coliforms

Faecal coliforms presence in drinking water samples indicate possible faecal contamination and therefore may pose acute and immediate health risks. The indicator also provides information on treatment efficiency after-growth in the distribution networks. Hence the standard requires not detection of the parameter during analysis of water meant for human consumption (BOS 32:00).

c) *Escherichia coli (E. coli)*

*Escherichia coli i*s the preferred indicator of faecal pollution as its normal habitat is the large intestine of man and warm blooded animals, it is usually unable to multiply in aquatic environments. The presence of *E. coli* in water does, therefore, indicate recent faecal contamination; therefore should not be detected in any sample (BOS 32:00).

d) *Cryptosporidium*

Cryptosporidium is present in faecal matter and may cause acute diseases in the young and the immunocompromised. This micro-organism may survive the disinfection process by chlorine and other disinfectants unless specific additional treatment is applied. Therefore, there are no allowable levels in drinking water (EPA, 2001).

e) *Clostridium* spores

Clostridium spores are indicator of effectiveness of disinfection and physical removal processes for viruses and protozoa in drinking water especially in bottled. The spores can survive in water much longer than the coliform group and are more resistant to disinfection and therefore indicative of intermittent or remote contamination (EPA, 2001).

f) *Giardia*

According to BOS 32:00 *Giardia* is a genus of protozoa that infect the gastrointestinal tract of some animals and human beings. The cysts are not amenable to destruction by chlorine. Ingestion by humans may cause poor health outcomes which may necessarily not be fatal. Suspect water may be subjected to boiling which has capability of destroying the microorganism (EPA, 2001).

g) Enterococci

Enterococci are organisms that originate from faecal matter. Despite having pathogenic properties, their main use as an indicator of faecal contamination is they can be reliably and easily determined. Their estimation is useful in clarifying the position of waters which show no *E. coli* but large number of coliform bacteria as a group (EPA, 2001).

h) ***Pseudomonas aeruginosa***

Pseudomonas aeruginosa is ubiquitous in the environment and can metabolise most types of organic matter in a variety of conditions. This microbe is the only one of the group which is pathogenic to man that is abundant in sewage (EPA, 2001). Their presence is not acceptable in any drinking water sample (BOS 143:00).

In summary from the above mentioned microbes most being indicator microbes; infectious diseases caused by pathogenic bacteria, viruses and parasites remain the most common wide spread health risk associated with drinking water. The public health burden is determined by the severity and incidence of the illnesses associated with pathogens, their infectivity and the population exposed; however, in vulnerable populations disease outcome maybe more severe (EPA, 2001).

2. 2. 4 Physicochemical Characteristics for Water Quality

Physical and chemical water quality standards are commonly laid for treated waters. These embrace both pollutants which are health hazards and qualities of water which may lead to its unpleasant taste, colour, appearance or other property likely to discourage use (Cairncross and Feachem, 1996). Water that is aesthetically unacceptable will undermine the confidence of the consumer, will lead to complaints and, more importantly, could lead to the use of water sources that are less safe (WHO, 2017). The WHO (2017) continues to emphasise that most chemicals arising in drinking water are of health concern only after extended exposure of years, rather than months. The principal exception is nitrate. Typically, changes in water quality occur progressively except for those substances that are discharged or leached intermittently to flowing surface water or ground water supplies.

According to the Environmental Protection Agency, (2001) in order for a particular chemical constituent to be evaluated to determine whether a guideline or a value should be derived; there is need for credible evidence of occurrence of the chemical in drinking water, combined with evidence of actual or potential toxicity and also of significant international concern.

The primary physicochemical indicator parameters for water analysis are covered below in line with Botswana National standards;

a) pH

pH is a chemical parameter which its extreme values will show either excessive alkalinity or acidity with organoleptic consequences. Extremes of pH can affect the palatability of water but the corrosive effect on distribution systems is a more urgent problem. pH also governs the behaviour of several other parameters of water quality; ammonia toxicity, chlorine disinfection efficiency and metal solubility are some of the examples (EPA, 2001).

b) Conductivity

Conductivity reflects the mineral salt content of water and has no direct health significance. In itself conductivity has little interest to the analyst but is an invaluable indicator of the range into which hardness and alkalinity values are likely to fall; and also of the order of the dissolved solids content of water (EPA, 2001).

d) Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) are natural or added solutes present in water and they principally give organoleptic implications. It is often convenient and acceptable to use the very rapid determination of conductivity to give an estimation of the total dissolved solids. TDS includes both ionised and non-ionised matter. Where TDS are high, the water may be saline (EPA, 2001).

e) Turbidity

Turbidity may usually originate from clay particles, silt, sand washings, organic and biological sludges which are not filtrable by routine methods. The existence of turbidity in water will affect its acceptability to consumers and markedly its utility in certain industries. The particles forming the turbidity may also interfere with the relatability of waters and in the case of the disinfection process the consequences could be grave. As turbidity may be caused by sewage matter in water there is a risk that pathogenic organisms could be shielded by the turbidity particles and hence escape the action of the disinfectant (EPA, 2001).

f) Residual Chlorine

Residual chlorine is a water supplies treatment process of disinfection to destroy micro organisms which may result in diseases like cholera or typhoid. Disinfection may be achieved in various ways but the vast majority of supplies are treated with chlorine which is a powerful oxidising agent and an extremely efficient disinfectant. As in many cases, the treatment works for public water supply may be a considerable distance from the consumers, it is essential that continuing protection be afforded along the distribution system, particularly if it is old and prone to leaks and/or infiltration of extraneous matter.The philosophy underlying chlorination is to ensure there is residual chlorine which will protect against recontamination. Dosage, contact time and other factors in chlorination process will be adjusted so that a concentration of 0.1 - 0.3mg/l remains after thirty minutes of contact time (EPA, 2001).

g) Ammonium (NH_3)

Ammonium is generally present in natural water, though in very small amounts, as a result of microbiological activity which causes the reduction of nitrogen containing compounds. The health perspective presence of ammonium in water, signifies the possibility of sewage pollution and the consequent possible presence of pathogenic micro-organisms (EPA, 2001).

h) Bromide (Br)

Bromide is a carcinogenic and mutagenic indicator from the health perspective; and this occurs when its ions are oxidised by ozone or any other oxidising including chlorine (EPA, 2001).

i) Calcium (Ca)

High levels of calcium is beneficial to health and waters which are rich in it (and hence very hard) are very palatable. This element is the most important and abundant in the human body and an adequate intake is essential for normal growth and health. There is some evidence to show that the incidence of heart disease is reduced areas served by a public water supply with a high degree of hardness, which the primary constituent is calcium (EPA, 2001).

j) Chloride (Cl)

Chloride exists naturally in water, the concentrations vary widely and maximum levels found in sea water. In fresh waters, the sources include soil, rock formations, sea spray and waste discharges. Sewage contains large amounts of chloride, as do some industrial effluents.Chloride does not pose a health hazard to humans and the primary consideration is in relation to palatability. At levels of above 250mg/L Cl water will begin to taste salty and will become increasingly objectionable as the concentration rises further. Sewage is a rich source of chloride, a high result may indicate pollution by sewage. Natural levels in rivers and other fresh water sources are usually in the range of 15 - 35mg/L Cl. However increase of 5mg/L at one station may give rise to suspicion of sewage especially if free ammonia levels are also elevated. Normal raw water treatment processes do not remove chloride (EPA, 2001).

h) Fluoride (Fl)

Fluoride occurs naturally in water and in quite rare instances, it arises almost exclusively from fluoridation of public water supplies and from industrial discharges. Health studies have shown that the addition of fluoride to water supplies in levels above 0.6mg/L F leads to reduction in tooth decay in children and that the optimum beneficial effect occurs around 1.0mg/L. At levels markedly over 1.5mg/L an inverse effect occurs and mottling of teeth (or severe damage at gross levels) will arise (EPA, 2001).

i) Magnesium (Mg)

Magnesium like calcium is abundant and a major dietary requirement for humans. It is the second major constituent of hardness and it generally comprises 15 - 20 percent of the total hardness of water expressed as calcium carbonate ($CaCO_3$). Its concentration is very significant when considered in conjunction with that of sulphate, as magnesium sulphate medicinally is regarded as a laxative (EPA, 2001).

j) Nitrate (NO_3)

Relatively, little amounts of the nitrate is found in water is of mineral origin, it mostly comes from organic and inorganic sources, the former being waste discharges and the latter comprising mainly artificial fertilisers. High nitrate levels in waters used for human consumption, will render them hazardous to infants as they induce the `blue baby syndrome` (methemoglobinaemia). It has hazardous effects in infants in concentrations of above 11mg/l N (EPA, 2001).

k) Nitrite (NO_2)

The significance of nitrite is mainly as an indicator of possible sewage pollution of water rather than as a hazard itself. There is stricter limit of nitrite in drinking water. In addition nitrites can give rise to the presence of nitrosamines by reaction with organic compounds and may have carcinogenic effects (EPA, 2001).

l) Phosphorous (P)

Phosphorous occurrence in water may be natural or added by organic matter through wastes discharge. This parameter indirectly indicates the overall water quality (EPA, 2001).

m) Potassium (K)

Potassium has no health implications in water quality unless in gross levels. The parameter is usually measured on samples solely to permit the calculation of an ion balance for the verification of the analysis (EPA, 2001).

n) Sodium (Na)

Sodium is an abundant constituent of rocks and soils and may cause hypertension if taken in access. Sodium is always present in natural waters. It is an essential dietary requirement and the normal intake is as common salt (sodium chloride) in food (EPA, 2001).

o) Sulphate (SO_4)

Sulphate occurrence in water is from rock formations and concentrations vary according to the nature of the terrain through which they flow. In polluted waters in which dissolved oxygen, sulphate is readily reduced to sulphide causing noxious odours (EPA, 2001).

2.3 Health Effects of Poor Water Quality

The WHO Drinking Water Guidelines of 2017 indicate that safe water, should not present any significant risk to health over a lifetime of consumption, including the different sensitivities that may occur between life stages. Rather, those at greatest risk of waterborne diseases are those with compromised immune system, infants and young children, people who are debilitated and the elderly, especially when living under unsanitary conditions.

Drinking water compliant to the required quality standards promotes the health of communities; and World Health Organisation continues to emphasise that where there are lapses in standards the public becomes more prone to diseases and impairments, therefore, the consideration by WHO to categorise water as a vital determinant of health (WHO, 2018).

While literature elaborates that Public Health objectives for the analysis of water samples are mainly to; determine its safety and suitability, particularly for domestic purposes; and ensure concentrations of contaminants are below the maximums laid down as per existing policies and standards (Basset, 2004).

Infectious diseases caused by pathogenic bacteria, viruses and parasites (e.g protozoa and helminths) are the most common wide spread health risk associated with drinking water of poor quality. The public health burden is determined by the severity and incidence of the illnesses associated with pathogens, their infectivity and the population exposed (WHO, 2017). Basset (2004), further highlights that infectious diseases may be classified according to the transmission route i.e. waterborne, water washed (scarce), water based or water related.

Chemical composition affects the sight, taste, smell, and even the feel of water. Absence of necessary constituents or an excess of harmful compounds in water chemistry may lead to diseases. The disease conditions resultant water chemistry are non-infectious and therefore may be managed by the removal of the excess chemical or addition of the chemicals which are deficient (Cairncross and Faechem, 1996).

WHO (2017), further elaborates that the concentration at which physical constituents are objectionable to consumers varies and dependent on individual and local factors, including the quality of water the community is accustomed to and a variety of social, environmental and cultural considerations.

2.4 Public Perceptions of Bottled Water versus Tap Water

Bottled water use continues to expand worldwide in the last two decades, a significant number of consumers have shifted from tap water due to *Cryptosporidium* outbreaks (Juba and Tanyanyiwa, 2018). The statement is affirmed by Ward *et al*. (2009), of the increase in the last decade, making bottled water the fastest-growing segment of the non - alcoholic beverage market worldwide; and for some of these consumers, bottled water has become a complete substitute for tap water. Ward *et al*. (2009), also elaborates that the majority of the participants of the study believed that bottled water had some health benefits, however, did not confer significant if any over tap water. Hence Juba and Tanyanyiwa (2018) and Joseph *et al.* (2018), highlights that consumers used bottled water as their primary drinking source when they perceived that tap water was not safe and perceptions of purity of the water, bottled water convenience and tap water unavailability seemed to determine consumption patterns among users.

However, Theodorou, (2019) highlighted that bottled water is easily available in the market, it has low cost and can easily be transferred from one place to the other due to its plastic packaging and; consumers living in urban areas prefer to drink bottled water as tap water is transferred through old pipes which may lead to contamination of the water with lead. While Doria (2006) emphasised that trust in tap water companies influenced public behaviour in their preferences. Indeed, for some consumers bottled water has become a complete substitute for tap water. However, the increases in the United Kingdom at least, fly in the face of improving tap water quality over the last ten years and are even more surprising given that bottled water can cost an average of 500-1000 times more per litre than tap water (Ward *et* al., 2009).

Chidya *et al*. (2019), highlights that the dramatic rise in the consumption of bottled water globally is also attributed to consumer connotations of higher social status and the prevalent conception that it contains fewer contaminants. Furthermore, there is a common belief and perception that mineral waters valuable medicinal and health effects. Additionally, some believe that drinking bottled water provides an essential mineral supplement for proper growth has also found widespread usage in infant formula preparation, re-forming other foods, filling humidifiers and skincare. The bottled water is also perceived to taste better compared to tap water and is served at many organised gatherings. In contrast to public belief, bottled waters are not always completely safe and free of contaminations. Some kind of microbial contamination such as bacteria may be indigenous in water resources or enter the water during the bottling process. The bacteria could proliferate during transport and storage of filled bottles, and attain infective doses (Matin *et al.,* 2015*).*

2.5 Conclusion

Therefore any water meant for human consumption must meet the set quality standards for microbiological, chemical and the physical appearance as stipulated in local policies and standards. Where countries do not have existing policies the WHO water quality standards may be used. Continuous monitoring of water as a crucial control measure should be implemented to minimise the possible public health risks which may lead to waterborne diseases. The WHO (2017) recommends for utilisation of Water Safety Plans (WSPs) by authorities responsible for water quality monitoring.

CHAPTER 3:
PUBLIC KNOWLEDGE AND PERCEPTIONS ON THE SAFETY OF TAP AND BOTTLED WATER IN GABORONE, BOTSWANA

3.0 Introduction

Water is known as an essential resource that is of imperative use and required daily to sustain the survival of plants and animals in the entire environment. Regulations have been developed at national and international levels to safeguard the drinking water quality and to ensure that the public is provided with water that meets basic drinking standards. However, there has been a rising trend globally towards the consumption of bottled water over tap water. The increased utilisation of bottled water over domestic (municipal) water supplies seem to stem from an assumption that domestic (municipal) water is not as safe.

During the year 2018, the Botswana Ministry of Health and Wellness Report on Water Quality Surveillance (2018) for the diarrhoea outbreak reflected that 221 samples from domestic water supplies were submitted for analysis as a result of some concerns about water quality. The results revealed that 10% of the samples were non-compliant to the drinking water quality standard, specifically the BOS 32:00 indicating the presence of *Escherichia coli* and total coliforms. Conclusions could not be reached to ascertain whether water had contributed to the diarrhoea outbreak as there was no correlation between the non-compliance of water samples and diarrhoea incidences.

Outbreaks such as this may have an influence on consumers on the preference of bottled water over domestic or tap water. Bottled water use continues to expand worldwide in the last two decades, a significant number of consumers have shifted from tap water due to *Cryptosporidium* outbreaks (Juba and Tanyanyiwa, 2018). The statement is affirmed by Ward *et al.,* (2009), of the increase in the last decade, making bottled water the fastest-growing segment of the non - alcoholic beverage market worldwide; and for some of these consumers, bottled water has become a complete substitute for tap water. This is no different in Botswana hence it is crucial to understand the perceptions of the members of the public on the matter.

Access to safe drinking-water is important as a health and development issue at national, regional and local levels. In several countries, some scholars identified and evaluated the public awareness of drinking water, for example, evaluation of drinking water issues and concerns of the urban public in some United States of America communities found that the urban public is satisfied that their home drinking water is safe (Li Wang *et al*., 2018). Therefore with urbanisation and growth in knowledge of general populace and the ever emerging water quality risks, Botswana will also benefit from such an evaluation in-order to improve its policies in guidelines.

A questionnaire was utilised to assess the perceptions and preferences of the community of Gaborone, Botswana about the choice, safety and water hygiene of bottled and domestic (tap) water supplies. Through this tool, the possible public health risks which might emanate from drinking unsafe water were also assessed.

The researcher coded the questionnaire using excel template. The questionnaire variables were input into the Statistical Package for the Social Sciences (SPSS) software package (IBM, version 26, 2019). The variables were coded as indicated below:

i) The number **1** was used to represent the first question and response, and the subsequent ones were represented by sequential numbering

ii) In case of optional responses, for example; **1 = yes**, **2 = no**

iii) For open or string questions responses inductive coding was used once data was collected.

3.1 Sampling Procedure

To determine the sample size of the target population for the questionnaire; Slovin`s formula was used, the margin of error was identified as 5%; and taking into consideration that the population of Gaborone is 231 592 (Statistics, Botswana, 2011).

Slovin`s formula i.e. $n = N / (1 + Ne^2)$

N represents the target population

e represents a margin of error

N = 231 592

e = 5%

Therefore n = 399.998

≈ 400

The participants were selected from the twenty - two (22) shopping centres around Gaborone as provided by the Physical Planning Department using convenience sampling. To establish the number of people to be interviewed at each shopping centre and ensure a balance of demographics, the sample size of Gaborone which was 400 was divided equally amongst the shopping centres. Therefore, convenience random sampling of eighteen (18) participants was conducted for those interviewed per shopping centre. All participants had to provide a recognised form of identification to minimise any possible duplication and also account for the age and gender.

The map in figure 3.1 below outlines the various land uses and zoning indicating the commercial/shopping centres where sampling of respondents was undertaken to garner their perceptions.

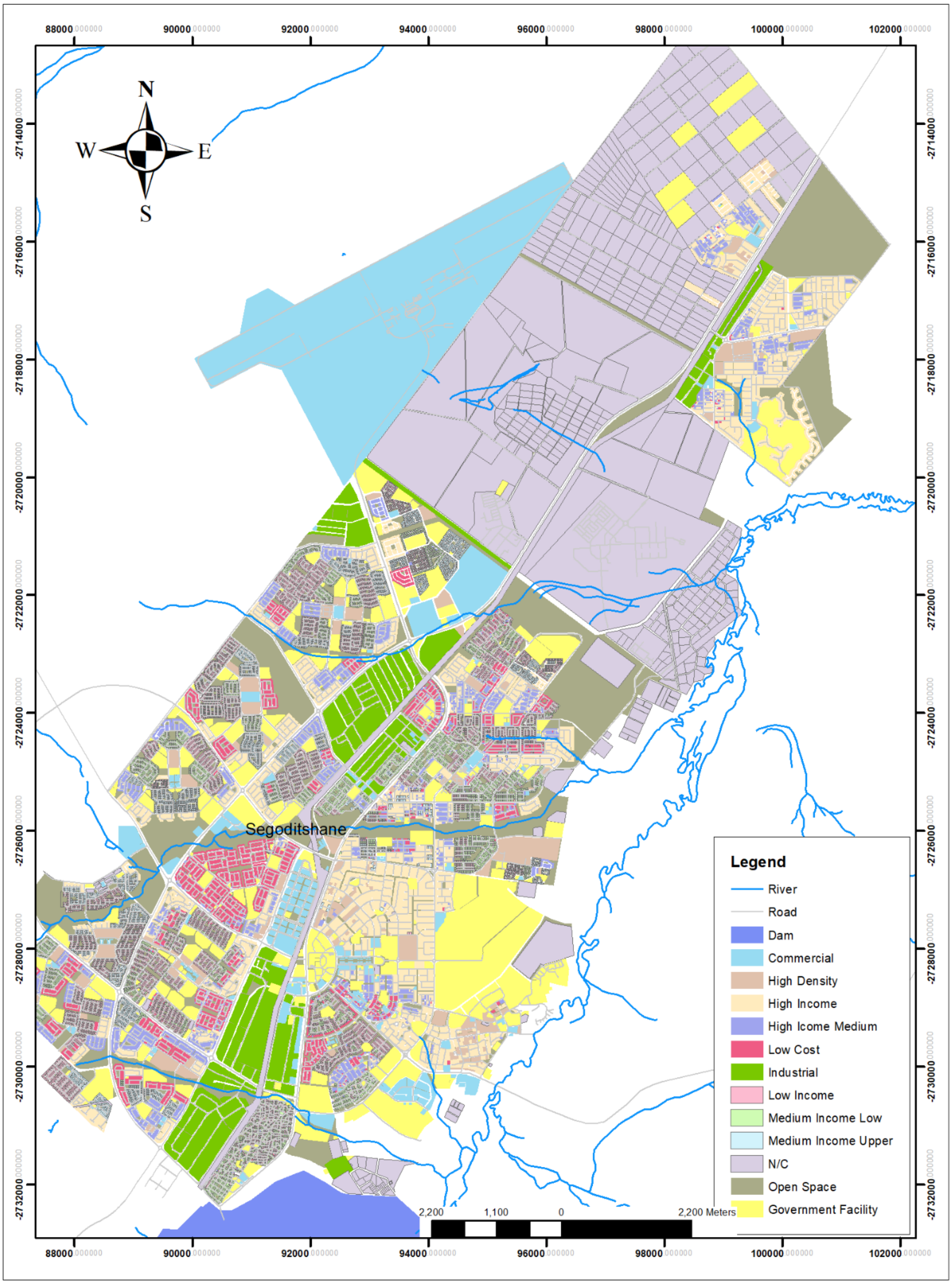

Figure 3.1: Gaborone land use zones indicating the commercial or shopping centre areas (Source: Author).

3.2 Limitations of the Questionnaire

i) The researcher observed that respondents in low-density areas (high-income areas) were not keen to participate in the study.

ii) The COVID-19 pandemic lockdown impacted on the interviews and therefore the researcher failed to interview the required 400 as per the sampling plan and ended up interviewing only 383 participants.

3.3 Ethical Considerations

Consent letters were issued to all those who participated in the interviews. Confidentiality was assured in the publication of the report and was also advised that the study was voluntary and therefore they were free to withdraw whenever they felt otherwise.

3.4 Method of Analysis

Descriptive statistics were used in the organisation and presentation of data. These were in the form of tables and numerical values.

3.5 Results

The results of the questionnaire were analysed according to the categories in Table 3.1 below;

Table 3.1 Questionnaire categories of analysis

Section	Category
A	Demographic characteristics
B	Understanding water hygiene
C	Consumer preference

3. 5.1 Section A: Demographic Characteristics of Respondents

3.5.1.1. Age of Respondents

Table 3.2 indicates that 13 (3.4%) of the respondents were below 18 years of age, 191 (49.9%) were between 18 and 29 years, 99 (25.8%) were between 30 and 39 years, 48 (12.5%) were between 40 and 49 years, 27 (7%) were between 50 and 64 years and 5 (1.3%) were above 64 years old.

Table 3.2 Age distribution of respondents

Age	Frequency	Percent
<18	13	3.4
18-29	191	49.9
30-39	99	25.8
40-49	48	12.5
50-64	27	7.0
>64	5	1.3
Total	**383**	**100.0**

3. 5. 1. 2 Gender of Respondents

Table 3.3 indicates that 215 (56.1%) of the respondents were female whilst 166 (43.3%) were male. However 2 (0.5%) did not align with either female or male data variable.

Table 3.3 Gender distribution of respondents

Gender	Frequency	Percent
Female	215	56.1
Male	166	43.3
Missing	2	0.5
Total	**383**	**100**

3. 5. 1.3 Income Level - Botswana Pula (BWP)

Table 3.4 shows that 283 (76.5%) earned below BWP 5000.00, 56 (14.6%) earned between BWP 50001 and 10000 whilst 2 (0.5%) were unemployed.

Table 3.4 Respondents Income distribution

Income (BWP)	Frequency	Percent
0 - 5000	293	76.5
5001 - 10000	56	14.6
10001 - 15000	32	8.4
Missing	2	0.5
Total	**383**	**100.0**

3. 5. 2 Section B: Understanding Water Hygiene

3. 5. 2.1 Benefits of Drinking Water

Table 3.5 indicates that 365 (95.3%) of the respondents said they knew the benefits of drinking water whilst 16 (4.2%) did not and 2(0.5%) did not respond.

Table 3.5 Response to knowledge the benefits of drinking water

Variable	Response	Frequency	Percentage
Do you know the benefits of drinking water	Yes	365	95.3
	No	16	4.2
	Non responsive	2	0.5
	TOTAL	383	100

3. 5. 2. 2 Understanding of the Benefits of Drinking Water

Table 3.6 indicates that of the 383 respondents who were interviewed on their knowledge on the benefits of drinking water 286 (74.7%) said it was essential for living, 54 (14.1%) said it refreshed and relaxed the body, 26 (6.8%) highlighted that it was good for the skin, 14 (3.7%) said it helped with excretion of toxins from the body whilst 1 (0.3%) believed it helped with bad breath and 2 (0.5%) did not respond to the question.

Table 3.6 Understanding of Drinking Water Benefits

Variable	Response	Frequency	Percentage
Explain the benefits of drinking water	Good for the skin	26	6.8
	Good for bad breath	1	0.3
	Refreshes and relaxes the body and induces metabolism	54	14.1
	Helps with excretion of toxins for the body	14	3.7
	Essential for living	286	74.7
	Non responsive	2	0.5

Variable	Response	Frequency	Percentage
	TOTAL	383	100

3. 5. 2. 3 Knowledge of Water Hygiene

Table 3.7 infers that 262 (68.4%) stated that water hygiene was clean water, 78 (20.3%) did not know what it was, 24 (6%) said it was the promotion, preservation and appropriate handling of water, 14 (3.6%) said it was the condition of water, 3 (0.8%) did not respond to the question, whilst 1 (0.3%) each said it was the importance of water and removal of toxins from the body respectively.

Table 3.7 Distribution of responses on knowledge of water hygiene

Variable	Response	Frequency	Percentage
What water hygiene is?	Clean water	262	68.4
	Condition of water	14	3.6
	Importance of water	1	0.3
	Promotion/ preservation and handling of water	24	6.3
	Removal of toxins from the body	1	0.3
	No	78	20.3
	Non responsive	3	0.8
	TOTAL	383	100

3. 5. 2. 4 Health risks associated with water

Table 3.8 shows that 273 (71.3%) agreed that water could pose health risks, at the same time 107 (27.9%) did not agree and 3 (0.8%) did not respond.

Table 3.8 Knowledge of water health risks

Variable	Response	Frequency	Percentage
Can water pose health risks?	Yes	273	71.3
	No	107	27.9

	Non responsive	3	0.8
	TOTAL	383	100

3.5.2.5. Understanding the water health risks

Table 3.9 shows that 285 (74.4%) believed that diarrhoea diseases and other infections were health risks associated with water, 90 (23.5%) did not respond to the question, 6 (1.6%) said the risks were body malfunctions and 2 (0.5%) said the risks were non-infectious diseases like the browning of teeth.

Table 3.9 Respondents knowledge of water health risks

Variable	Response	Frequency	Percentage
Name the health risks associated with water	Diarrhoea, diseases and other infections	285	74.4
	Causes body malfunctions	6	1.6
	Non-infectious conditions	2	0.5
	Non-responsive	90	23.5
	TOTAL	383	100

3. 5. 2. 6 Control of Water Health Risks

Table 3.10 highlights that 193 (50.4%) said water should be purified or boiled to control the risks, 109 (28.5%) sad health promotion should be undertaken, 59 (15.4%) did not respond to the question, 11(2.9%) said people shoaled check out expiry and best before dates before purchasing water, 5 (1.3%) each believed people should not drink stagnant water and the environment should be kept clean off pollution respectively whilst 1 (0.3%) said the government should provide safe water for drinking.

Table 3.10 Knowledge of the control of water associated health risks

Variable	Response	Frequency	Percentage
What can be done to control water health risks?	Health promotion	109	28.5
	Not to use stagnant water	5	1.3
	Check out best before dates purchase in stores	11	2.9
	Purify/ boil water before drinking	193	50.4
	Government to provide safe water	1	0.3
	Maintain clean environments to avoid pollution of water sources	5	1.3
	Non-responsive	59	15.4
	TOTAL	**383**	**100**

3. 5. 2. 7 Water Types Posing Health Risks

Table 3.11 indicates that 263 (68.7%) believed tap water posed more health risks, 115 (30%) believed bottled water could pose more risk and 4 (1%) did not respond.

Table 3.11 Consumer beliefs of the type of water posing risks

Variable	Response	Frequency	Percentage
Which type of water poses more risks between tap and bottled?	Tap	263	68.7
	Bottled	115	30
	Non-responsive	5	1.3
	TOTAL	**383**	**100**

3. 5. 3 Section C: Consumer Preferences

3. 5. 3.1 Consumer Water Preferences

Table 3.12 indicates that 158 (41.3%) of people interviewed preferred tap water, 216 (56.4%) bottled water, 4 (1%) boiled water and whilst only 1(0.3%) preferred rain water.

Table 3.12 Types of water preference

Variable	Response	Frequency	Percenta
What is your water preference?	Tap	158	41.3
	Bottled	216	56.4
	Boiled	4	1
	Rain	1	0.3
	TOTAL	**383**	**100**

3. 5. 3.2 Influence of Consumer Water Preferences

Table 3.13 reflects that 306 (79.9%) of the respondents have their preferred choice of water as per Table 5 (i) because they believed their particular choice was safe, 41 (10.7%) affordable, 29 (7.6%) easily accessible, 7 (1.6%) assured quality whilst 1 (0.3%) thought it tasted better.

Table 3.13 Influences of water choices

Variable	Response	Frequency	Percentage
Why do you prefer your choice?	Affordable	41	10.7
	Safe	306	79.9
	Easily accessible	29	7.6
	Assured quality	7	1.6
	Tastes better	1	0.3
	TOTAL	**383**	**100**

3. 5. 3. 3 Illnesses Associated with Water

Table 3.14 shows that 255 (66.6%) of the respondents said they had never fallen ill from drinking any type of water whilst 128 (33.4%) had fallen ill.

Table 3.14 Respondents` illnesses from drinking water

Variable	Response	Frequency	Percentage
Have you ever fallen ill from drinking water?	Yes	128	33.4
	No	255	66.6
	TOTAL	**383**	**100**

3. 5. 3. 4 Types of Water Causing Illnesses

Table 3.15 infers that 255 (66.6%) respondents did not indicate the kind of water that had made them ill as they had never fallen ill from drinking water, 108 (28.2%) had fallen ill from tap water, 4 (1%) bottled water, 2 (0.5%) saline water and 1 (0.3%) each for dirty and container/tank water respectively.

Table 3.15 Type of water that caused illnesses amongst respondents

Variable	Response	Frequency	Percentage
Which type of water made you ill?	Tap	108	28.2
	Bottled	4	1
	Reservoir/ Tank	1	0.3
	Dirty water	1	0.3
	Saline water	2	0.5
	N/A	255	66.6

3. 5. 3. 5 Influence of Water Preference

Table 3.16 indicates that 233 (60.8%) of the participants did not respond to this question as they believed did not affect their water preference whilst 127 (33.2%) said their falling ill from drinking influenced their water preference and only 23 (6%) said it did not.

Table 3.16 Influence on water preference

Variable	Response	Frequency	Percentage
Have you ever fallen ill from drinking water?	Yes	128	33.4
	No	255	66.6
	TOTAL	**383**	**100**

3.6 Analysis

3. 6. 1 Perception of the participants on bottled water against tap water

The study indicates that 216 (56.4%) participants preferred bottled water over other types of water. The preference of choice of 306 (79.9%) participants was influenced by the perception that their choice of water was safe.

Of the 108 respondents who were legible to respond to the question (this translates to 93.9% of the respondents for the specific question) said they had fallen ill from tap water. Those who had fallen ill from any water which were 127 of the respondents (this translates to 97.6% of the respondents for the specific question) said it had influenced their preferences on their preferred choices of water.

Majority of the respondents 263 (68.7%) perceived tap water to have more health risks than bottled water.

3. 6. 2 Public Health Risks Associated with Water

To identify the public's understanding of the health risks and water, 273 (71.3%) of the participants indicated that water posed health risks. 285 (74.4%) of the participants in the study said diarrhoea and gastrointestinal diseases were major health risks associated with water. The participants also pointed out non-infectious diseases like teeth browning and body malfunctions to underscore their understanding of the health risks.

For the control of health risks, 193 (50.4%) of the participants which were the majority; said water purification or boiling was key whilst 109 (28.5%) vouched for health promotion and education.

3.7 Discussion and Conclusion

The study indicates that the majority of participants preferred bottled water to other types of water including domestic water supplies or tap. This is so because the public sees this water as safe for their health (WHO, 2011). Other studies have shown that when consumers are dissatisfied with the tap water provided by municipalities they often turn to bottled or barrelled water (Van Der Linden, 2015; Huyn and Tae, 2015).

The preferred water choice was influenced by the perception that it was safer and this relates to what Juba and Tanyanyiwa (2018) concluded by highlighting that consumers used bottled water as their primary drinking source when they perceived that tap water was not safe. However, Doria (2006) argues that even if perceived risks are in many cases inversely related to perceived benefits, customers may prefer bottled water for the potential health benefits but not because of eventual tap water risks.

Moreover, a study by Qian (2018) further reported that students in Singapore preferred bottled water due to various perceptions such as safety and hygiene, taste, costs, family habits and convenience as well as availability. For examples, recent decades have witnessed a rising global consumption of bottled water, especially in developed countries where water directly from the tap is drinkable. In the United States as an example, bottled water consumption has been doubled to an average annual per capita volume of 138.17 L in 2015. On the other hand, in the European Union this is roughly

104.1 L. However, Hong Kong had as high as 123.78 L in 2014. Lastly, Singapore, reported the sales volume of bottled water to be around $134 million in 2015, up 24% from five years ago (Qian 2009).

The participants in the study also indicated affordability, accessibility and `better tasting` as what influenced their preferred choice of water, which was also attested by Juba and Tanyinyiwa (2018) who indicated that participants believed bottled water tasted much better than tap water. Theodorou (2019) has also emphasised that consumers living in urban areas preferred to drink bottled water.

The study also shows that the majority of participants perceived tap water to have more health risks in comparison to bottled water even though others had also had fallen ill from drinking different types of water. According to the study, tap water had actually caused ailments to the majority of participants. Hence the ailments had influence on the majority's perception and their water preferences. This phenomenon has been attested by Tanyanyiwa and Juba (2018) where they indicate that bottled water use has continued to expand worldwide in the last two decades as a significant number of consumers have shifted from tap water due to *Cryptosporidium* outbreaks. Whilst Doria (2006) highlights that trust in tap water companies influences public behaviour in their preferences.

Majority of the respondents in the study emphasised the knowledge that water was essential to life and well being and this is underscored by the World Health Organisation (WHO) (2018) that drinking water compliant to the required quality standards promotes health in communities. The participants in the study further indicated that gastrointestinal and other related infections were the most likely diseases to be caused by water and WHO (2017) affirms that infectious diseases caused by pathogenic bacteria, viruses and parasites for example protozoa and helminths are the most common widespread health risks associated with drinking water of poor quality. This indicates similar responses with other studies where it has been shown that the publics perceptions and the understanding of the factors that influence public awareness of drinking water can contribute to improvements in water management and consumer services which in general will contribute towards safe societies towards using water (Frohler and Elmadfa, 2010).

WHO (2018) further indicates that lapses in standards make the public more prone to diseases and impairments therefore the consideration by the organisation to categorise water as a vital determinant of health. It is also reported that water quality has a close relationship with people's livelihood, and access to safe drinking water is essential to health of the people (WHO, 2011).

The researcher, therefore, recommends strengthening of programs, strategies and policies on health promotion to ensure that the general populace is more knowledgeable of the health risks associated with water so that they may be reduced. This would also improve the process of water handling, storage and transportation were necessary to control possible contamination. Consumer education on water safety should also be upscaled in general, for them to make informed choices with their type of water preferences**.**

CHAPTER 4:

MICROBIAL AND PHYSICOCHEMICAL QUALITY OF BOTTLED AND TAP WATER IN GABORONE, BOTSWANA

4.0 Introduction

The WHO Drinking Water Guidelines of 2017 indicate that safe water, should not present any significant risk to health over a lifetime of consumption, including the different sensitivities that may occur between life stages. People at greatest risk of waterborne diseases are those with a compromised immune system, infants and young children, those who are debilitated and the elderly, especially when living under unsanitary conditions.

For good quality water to reach the consumer depends on its original quality, the treatment processes it is subjected to; and how it is protected at source, in storage and distribution (Basset, 2004). Drinking water compliant to the required quality standards promote the health of communities; and the World Health Organisation emphasises that where there are lapses in standards the public becomes more prone to diseases and impairments, therefore, the consideration by WHO to categorise water as a vital determinant of health (WHO, 2018).

The World Bank (2017) indicates that changes in the quality and natural cycles of water and water systems have reaching impacts on all aspects of human life. As the population continues to grow and the global clean water supply is reduced by consumption, contamination and climate change, water issues will only increase in complexity and importance.

In relation to the population growth, drinking water quality varies from place to place, depending on the condition of the source water from which it is drawn. Based on the treatment it receives the presence of certain contaminants in our water can lead to health issues, including gastrointestinal illness, reproductive problems, and neurological disorders. Infants, young children, pregnant women, the elderly, and people with weakened immune systems may be especially at risk for illness (US EPA, 2020).

With this backdrop in mind, it therefore became vital to analyse the quality of bottled and domestic water as part of the study. As such water samples were collected from 35 schools, 14 public health facilities; and 14 water bottling plants as representation for both domestic water supplies and bottled water sampling points respectively.

Botswana has over the years invested in routine water quality monitoring to ensure that there is control of waterborne diseases through implementation of the Public Health Act, Food Control Act and the Botswana Bureau of Standards Water Quality Standards. It was no different in 2018 when the country was faced with the diarrhoea outbreak and water quality monitoring was one of the critical mitigation measures implemented.

4. 1 Sample Collection Procedure

The sample collection process was undertaken as per the BOS ISO 5667 - 5 - Water Quality Sampling - Guidance on Sampling of drinking water and water used for food and beverage processing. Metzger (2014) emphasises that in order to get the most accurate results, samples need to be collected properly. While every lab may have their own set of sampling standard operating procedures (SOP), there are some common best practices for collecting samples. Starting from the sampling up to the time of analysis, the content of water sample can be altered due to the chemical, physical, and biological reactions it undergoes (Sliwka-Kaszyska *et al.*, 2003).

The domestic water samples were collected from standpipes in thirty - five (35) schools and fourteen (14) public health facilities around the city identified as sampling points by Gaborone City Council under the water safety planning program. For microbial sample collection, the water was allowed to run for at least 30 seconds from the faucet, the faucet was then sterilised with an open flame and the sample collected in a sterile glass bottle supplied by the analysing Laboratory. Domestic water samples for chemical analysis were collected in plastic bottles supplied by the laboratory as well, however no flaming of the faucet was done.

Bottled water samples were collected in the containers that the products were packaged in for sale from the fourteen (14) bottling facilities that had consented to participate in the study.

The samples were transported in a cooler box with ice packs and delivered at the laboratory within 12 hours of collection. The sample handling and preservation were as per the BOS ISO 5667 - 5 - Water Quality Sampling - Guidance on Sampling of drinking water and water used for food and beverage processing. The most common type of preservation is temperature; most analysis requires samples to be kept cool, arriving at the lab between four and six degrees Celsius. The cooler temperature helps contaminants from breaking down during transit. Holding time is another important consideration — this refers to the amount of time from collection to when the analysis beings. Regulatory samples need to meet these holding times and recognised holding times may vary (Metzger, 2014).

4. 2 Test Methods

The laboratory analysis to assess the quality of both bottled water and samples from the domestic water supplies was following the BOS 143 - Bottled water other than natural water and BOS 32 - Drinking water Specifications respectively and the test methods recommended therein.

The below listed microbial, physical organoleptic and chemical parameters in Table 1 was used to assess the quality of bottled water and domestic / tap water including the test methods used.

Table 4.1: Parameters and test methods

Parameter	Type	Bottled Water	Domestic / Tap	Test Method
E. coli	Microbial	X	X	BOS ISO 9308-1/2
pH	Chemical	X	X	BOS ISO10523
Total coliforms	Microbial	X	X	BOS ISO 9308-1/2
Faecal coliforms	Micobial	X	X	BOS ISO 9308-1/2
Intestinal enterococci	Microbial	X		BOS ISO 7899-2
Pseudomonas aeruginosa	Microbial	X		ISO 16266
Turbidity	Physical	X	X	BOS ISO8288a)
Total dissolved solids (TDS)	Physical	X	X	BOS ISO 11923
Conductivity	Physical	X	X	BOS ISO 7888
Calcium	Chemical	X	X	BOS ISO 7980
Chloride	Chemical	X	X	BOS ISO 10304-1
Flouride	Chemical	X	X	BOS ISO 10304-1
Magnesium	Chemical	X	X	BOS ISO 7980
Potassium	Chemical	X	X	BOS ISO9964-3
Sodium	Chemical	X	X	BOS ISO 9964-3
Sulphate	Chemical	X	X	BOS ISO10304-1 SM 2160a)

Lithium	Chemical	X	X	BOS ISO9964-3
Ammonium	Chemical	X	X	BOS ISO9964-3
Nitrate	Chemical	X	X	BOS ISO 10304-1
Nitrite	Chemical	X	X	BOS ISO 10304-1
Phospahate	Chemical	X	X	BOS ISO 10304-1
Bromide	Chemical	X	X	BOS ISO 10304-1

4. 2. 1 Microbial test methods

4. 2. 1. 1 *Escherichia coli* and Coliforms

The method used for microbial analysis is the single membrane filtration technique which assesses the enumeration of *Escherichia coli (E. coli)* and coliforms in drinking water. It is based on the membrane filtration, subsequent culture on chromogenic coliform agar medium and/or membrane lactose glucuronide agar - (MLGA) and then calculated on the number of target organisms on the sample.

The test method is used for drinking waters with low bacterial numbers that will cause less than 100 total colonies on chromogenic coliform agar and/or membrane lactose glucorinide agar (MLGA). The test is done in line with the Botswana Bureau of Standards BOS ISO 9308-1/2 and the ISO 9308 - 1: 2014 Water quality - Enumeration of *Escherichia coli* and coliform bacteria - Part 1 Membrane filtration method for waters with low bacterial background flora.

4. 2. 1. 2 Intestinal Enterococci

The test method is suitable for microbiological analysis of bottled water samples which have undergone either ozonation, ultraviolet treatment, filtration, pasteurisation as per BOS 143: 2011 in performing of membrane filtration. The detection and enumeration of intestinal enterococci as guided by BOS ISO 7899-2 Water quality — Detection and enumeration of intestinal enterococci — Part 2: Membrane filtration method**.**

The election and enumeration of intestinal enterococci are based on filtration of a specific volume of the water sample through a membrane filter with 0.45µm which retains the bacteria. The membrane filter is paled on Slanetz and Bartley agar containing sodium azide to suppress the growth of Gram-negative bacteria and 2, 3,5-triphenyl tetrazolium chloride, a colourless dye, that is reduced red formazan by the intestinal enterococci.

Presumptive colonies are raised with either red, pink or maroon in the centre or throughout. Confirmation step is done by transferring membrane filter with the colonies onto bile -aesculin-azide agar, preheated at 44. Intestinal enterococci are known to hydrolyse aesculin in 2 hours on this medium, giving tan to black coloured compounds which diffuse into the medium.

4. 2. 1. 3 *Pseudomonas aeruginosa*

The test method used for detection of *Pseudomona aeruginosa* for water quality is ISO 16266 - Method by filtration.

Pseudomonas aeruginosa grows on selective media containing cetrimide and produce pyocyanin, or microorganisms that grow on selective media cetrimide, are oxidase-positive, fluoresce under UV radiation (360 ±20) nm can produce ammonia from acetamide.

A sample of water is filtered through a membrane filter of 0.45µm. The membrane filter is placed on the selective medium and incubated at 42. The numbers of presumptive *Pseudomonas aeruginosa* are obtained by counting the number of characteristic colonies on the membrane filter after incubation. Pyocyanin - producing colonies are considered as confirmed *Pseudomonas aeruginosa* but other fluorescing or reddish-brown colonies require confirmation.

Subcultures of colonies requiring confirmation are made from the membrane filter onto the plates of nutrient agar. After incubation, cultures that were not initially fluorescent are tested for the oxidase reaction, and oxidase-positive cultures are tested for the production of fluorescein and the ability to produce ammonia from acetamide. Cultures that were fluorescent initially are tested for the ability to produce ammonia from acetamide.

4. 2. 2 Physicochemical test methods

4. 2. 2.1 Turbidity

The procedure describes the process of determination of turbidity in drinking water including bottled water using a turbidimeter. Clarity of water is important introducing products meant for human consumption in many manufacturing operations and therefore the procedure is guided by BOS 39.

This method is based on comparison of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. The higher the intensity of scattered light, the higher the turbidity. Formazin polymer is used as a primary reference suspension.

4. 2. 2. 2 pH

The pH of water is determined through the use of a pH meter in line with BOS ISO 10523. Before the measurements are taken the pH meter is a calibrated through a two-point or three-point (standards at pH 4 and pH 7, pH 9 or 10) as per manufacturers instructions and with proper electrode storage. The calibration is then recorded in the logbook.

The electrode is rinsed with de-ionized water and blow-dried with a soft, clean paper towel and then transferred into the test solution. Reading is recorded after 5 - 20 seconds after insertion of the electrode in the solution. The electrode is then removed from the solution and rinsed with de-ionized water and stored according to manufacturers` instruction.

4. 2. 2. 3 Determination of Anions and Cations Using Ion Chromatography

The test method describes the determination of inorganic anions and cations in water using Ion Chromatography as per BOS ISO 10304-1. A sample was injected into a stream of KOH (potassium hydroxide) eluent and passed through an ion-exchange column. The anions and cations were separated according to their affinity to the anion or cation exchange resin in the column. After being passed through the column, the solution is passed through anion or cation self-generating suppressor (ASRS) to neutralise the eluent by exchanging the K^+ ion with the H^+ ion. After neutralization, the solution was passed through a conductivity detector. The number of anions or cations in the sample was determined by using external standards.

A Dionex ICS 2000 chromatography system equipped with a conductivity detector, AS50 Auto sampler with a sample dilution system, EG40 Eluent Generator and an ultra-pure water reservoir was used for analysis. The standards reagents used were specific to anion and cation determination.

4. 2. 2. 4 Conductivity

The conductivity was measured using an electronic conductivity meter, which generates a voltage difference between two electrodes submerged in the water. The drop in voltage due to the water resistance was then used to calculate the conductivity per centimetre.
The conductivity cell was introduced into the water sample, waiting a few seconds until the reading could be established. A digital conductivity meter was used, the sample's conductivity measurement appeared directly on the screen.

4.3 Sampling Procedure

The researcher will discuss the methods and processes to identify sampling points for samples collection.

4. 3. 1 Domestic Water Supplies

The Environmental Health Department had registered 48 public and private schools in Gaborone, Botswana as part of the school health program. The researcher then calculated the sample size using the margin of error and confidence level of 5 and 90% respectively;

Slovin`s formula i.e. $n = N / (1 + Ne^2)$

$N = 48$

$e = 5\%$

Therefore $n = 42.85$

≈ 43

The sample size was then determined as forty-three (43). Random sampling was then used to identify the 43 schools to participate in the study.

Hence, as per the council's / municipality water safety planning protocol for schools;

- 2 samples were collected per school for microbiological analysis which would equal to 86 samples
- 1 sample will be collected for chemical parameters analysis, which would equal 43 samples.

Gaborone has 15 public health facilities which receive a large number of the city's population daily which are either vulnerable or compromised to various diseases and public health conditions.

The sample size was then established as 15, using the margin of error and confidence level of 5 and 90% respectively;

Slovin`s formula i.e. $n = N / (1 + Ne^2)$

$N = 15$

$e = 5\%$

Therefore $n = 14.96$

≈ 15

Taking into consideration the council's /municipality's water safety planning for public health facilities; 1 sample was collected per facility for analysis of microbial and physical and chemical parameters which were 15 for each respectively.

Figure 4.1 below highlights the location of schools (public and private) and public health facilities which are the focus for domestic / municipal water samples for the study.

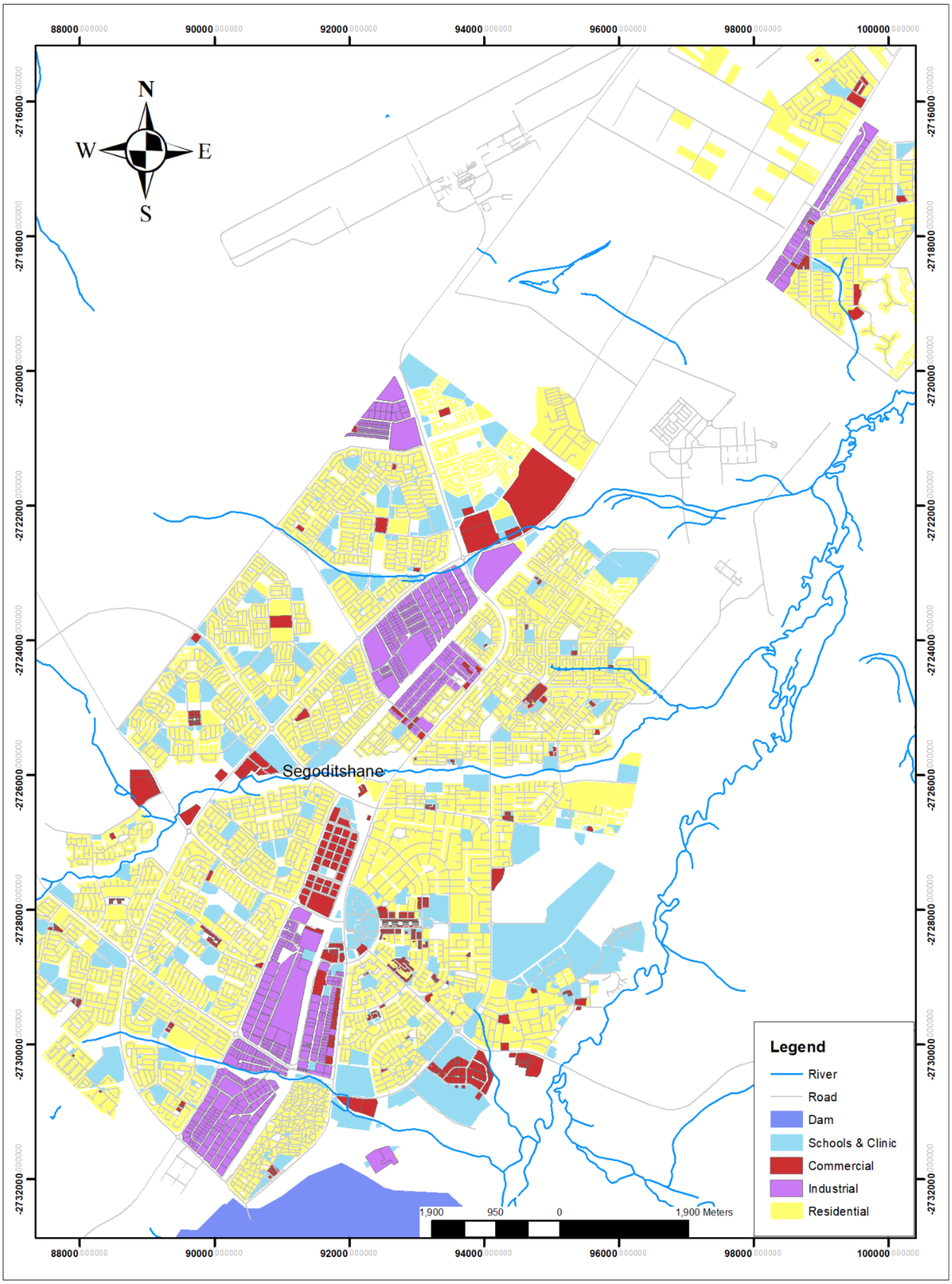

Figure 4.1: Map of Gaborone indicating the schools and clinics (Source: Author)

4.3.2. Bottled Water

The researcher liaised with Gaborone City Council to identify the licensed water bottling plants.The licensed facilities were forty-five (45) in Gaborone and the confidence level and margin of error were identified as 90% and 5% respectively were sample size was calculated as;

Slovin`s formula i.e. $n = N / (1 + Ne^2)$

$N = 45$

$e = 5\%$

Therefore $n = 40.45$

≈ 40

The sample size was calculated as forty (40) facilities, Random sampling was then used to identify the 40 facilities to participate in the study.

As per the Gaborone City Council water sampling protocol; approved by the Regulatory Authority samples were collected as follows:

I. For microbiological analysis the protocol specifies 5 containers per facility; thus two hundred (200) samples containers were to be collected

II. For physical and chemical analysis the protocol specifies 1 container per facility thus forty (40) containers were to be collected.

4.4 Limitations

1. Of the 40 water bottling plants sampled to participate in the study and were registered before the COVID - 19 pandemic only 25 were found to be in operational during data collection.
2. Only 14 bottling plants consented to participate in the study.
3. Some bottling facilities were sceptical to participate in the study for fear of exposure of business practises to competitors.
4. The COVID-19 pandemic lockdowns hampered the water sample collections and therefore the researcher could not collect the required number of water samples as initially planned for schools and public health facilities.
5. The lockdown also hampered the analysis of chemical parameters as the chromatography equipment had broken because the contracted supplier is based in South Africa.

4.5 Ethical Considerations

The research permit issued by the Ministry of Health and Wellness and the letter of authority to conduct research within the Jurisdiction of Gaborone City Council jurisdiction were shared with all schools, public health facilities. However for bottling plants consent letters were issued. Confidentiality was assured in the publication of the report and was also advised that the study was voluntary and therefore they were free to withdraw.

4.6 Results

Descriptive statistics were used in the organisation and presentation of data. These were in the form of charts and numerical values.

The results were presented in two parts;

A. Microbial

B. Physicochemical

4.6. 1 Microbial Analysis

4. 6. 1. 2 Number of Facilities where sampling was done

Figure 4.2 indicates of the researcher was able to access 35 out of 43 (81.4%) schools as planned, in public health facilities 14 out of 15 (93.3%) and 14 out of 40 (35%) for water bottling facilities.

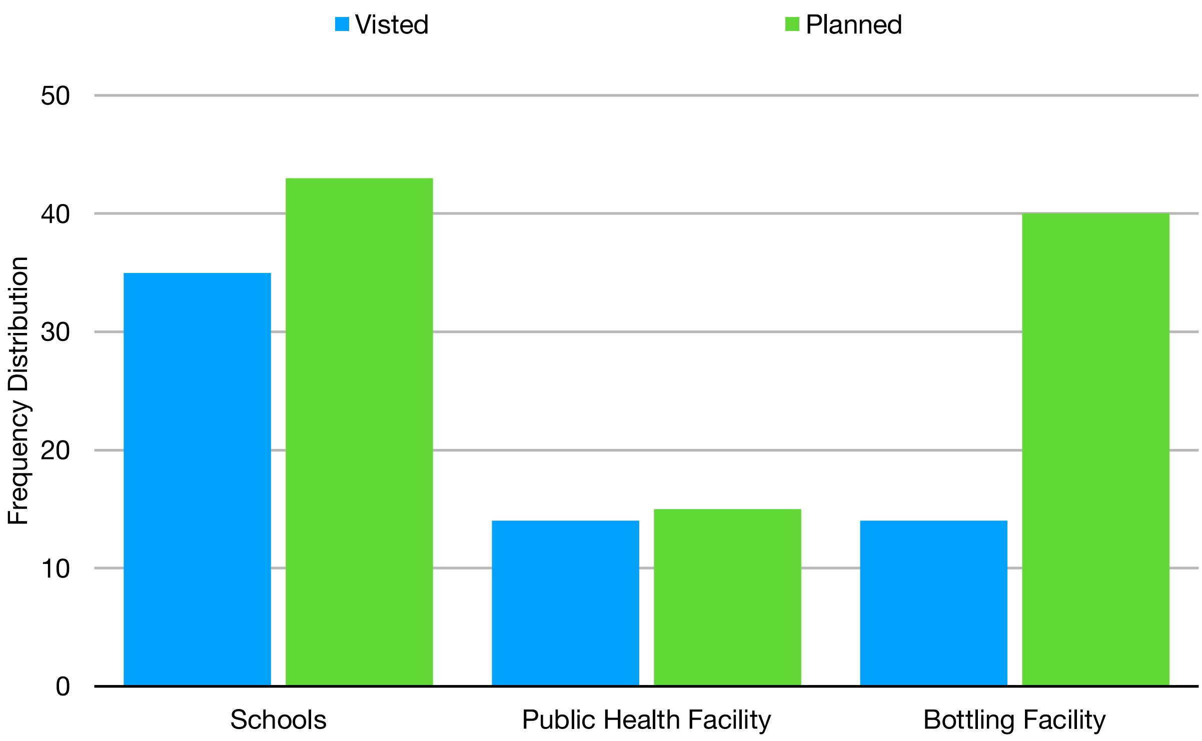

Figure 4.2. Number of sampling points visited

4. 6. 1. 3 RESULTS FOR MICROBIAL ANALYSIS

Figure 4.3 below indicates that 1 out of 35 (2.9%) schools microbial results were non-compliant to set standards, 15 out of 15 (100%) of public health facilities were compliant whilst 2 out 14 (14.3%) of bottling plant were no compliant.

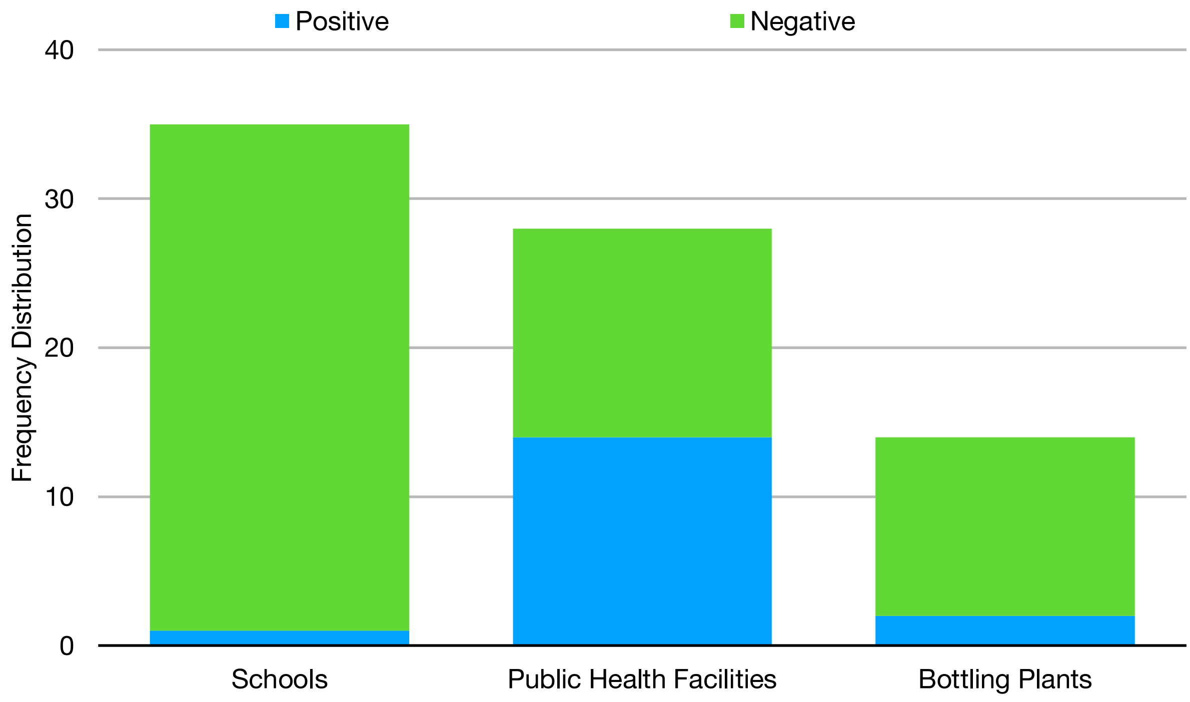

Figure 4.3: Overall compliance results samples

4. 6. 1. 4 Microbials Isolated

Figure 4.4 below indicates that 0.99% (01) of samples collected from schools for microbial analysis tested positive for total coliforms and *Escherichia coli* whilst 12.85% (09) of samples collected from bottling facilities were positive for *Pseudomonas aeruginosa*

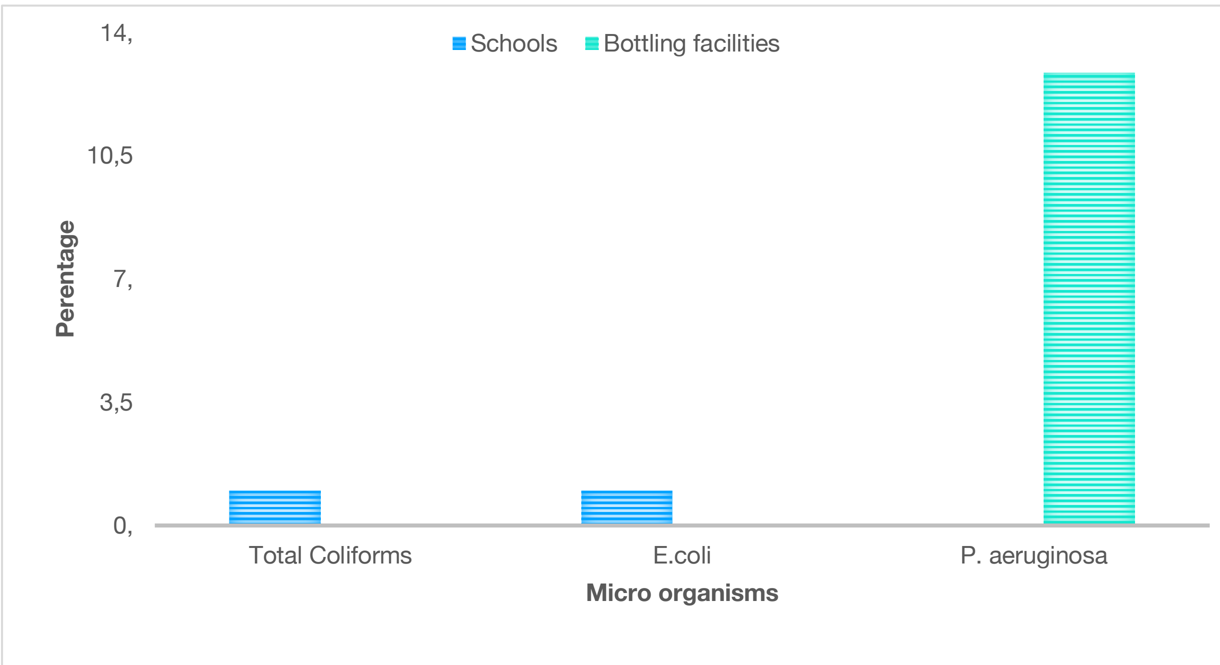

Figure 4.4: Micro organisms isolated in the analysis of all samples

4. 6. 1. 5 Microbial concentrations

Figure 4.5 below shows the colony counts of the microorganisms isolated during the laboratory analysis. The schools sample number 17 showed one (01) cfu/100ml of total coliforms and *E. coli* respectively: Bottling facility samples 4 A and 4C had two (02) each, 4 D had four (04), and 4 E had eight (08) cfus/100ml respectively of *Pseudomonas aeruginosa.* For bottling facility 12 A seventy (70), 12 B sixty-five (65), 12 C more than one hundred (>100) , 12 D two (02), 12 E seven (07) cfus/100ml of *P. aeruginosa* were isolated.

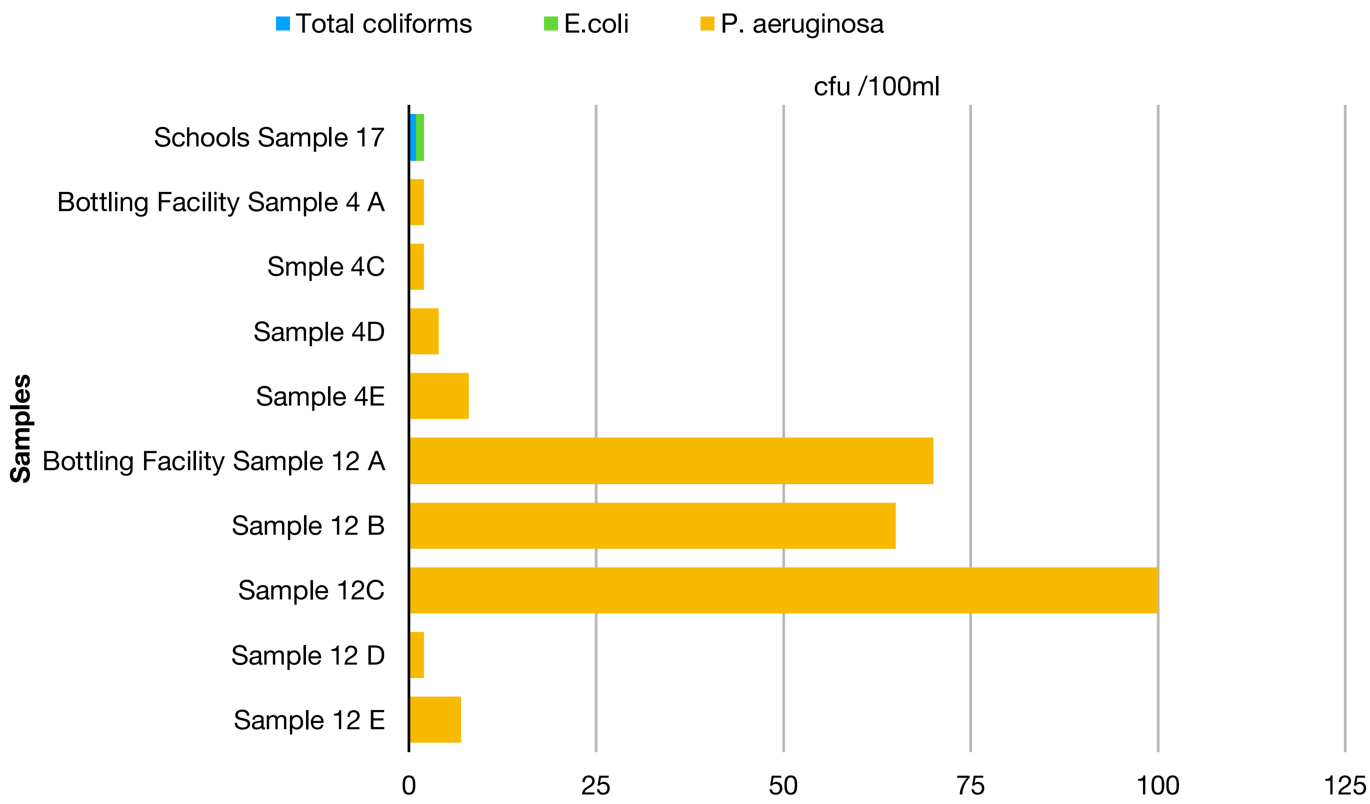

Figure 4.5: Microbes Colony counts per 100ml

4. 6. 2 Physicochemical Analysis

All samples submitted for laboratory analysis complied with the physicochemical specifications tested for. However the results for physical parameters of water bottling plantswhich were sample 4 and 12 as per figure 4.6 below; that its samples had tested positive for *P. aeruginosa* had higher values for pH, turbidity, conductivity and total dissolved solids (TDS) as per figure 4.6 below. Moreover, an overview of both bottled and tap water are reflected with their respective statistical analysis in figures 4.7, table 4.2, figure 4.8 and table 4.3.

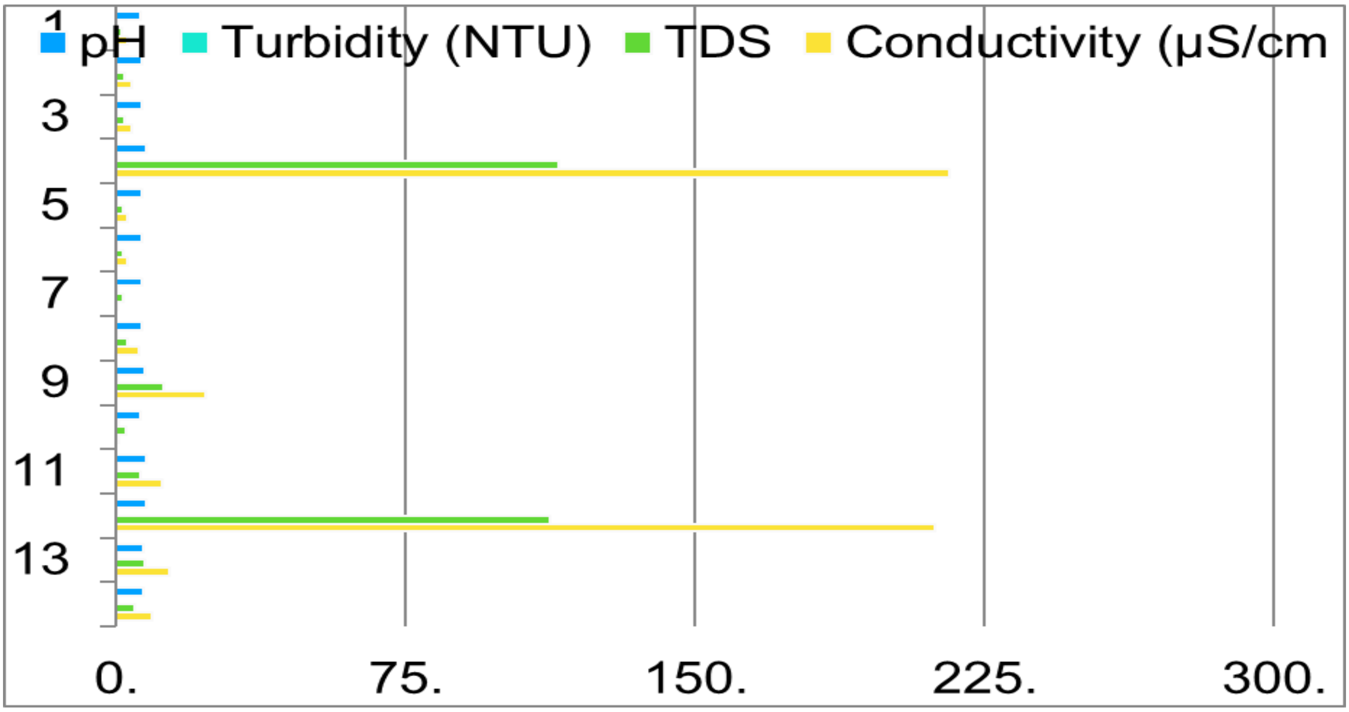

Figure 4.6 Comparative analysis for physical parametersfor samples that had tested psitive for *P. aeruginosa*

Table 4.2: Descriptive statistics for bottled water.

pH	***PH***	***Conductivity µS/cm***	***Total Dissolved Solids***	***Turbidity NTU***
Mean	6.792857	36.01429	19.01429	0.135714
Standard Error	0.055814	8.769018	4.652887	0.01255
Median	6.7	4.5	2.15	0.1
Mode	6.5	3	1.9	0.1
Standard Deviation	0.466973	73.36687	38.92884	0.104999
Sample Variance	0.218064	5382.697	1515.455	0.011025
Kurtosis	-0.13682	2.374415	2.373354	8.341763
Skewness	0.789308	2.06658	2.06618	3.097035
Range	1.7	213	113.2	0.4
Minimum	6.1	3	1.3	0.1

Maximum	7.8	216	114.5	0.5
Sum	475.5	2521	1331	9.5
Count	70	70	70	70
Largest(1)	7.8	216	114.5	0.5
Smallest(1)	6.1	3	1.3	0.1
Confidence Level(95.0%)	0.111346	17.49371	9.282255	0.025036

Table 4.3: Descriptive statistics for tap water.

pH	***PH***	***Conductivity µS/cm***	***Total Dissolved Solids***	***Turbidity NTU***
Mean	6.792857	36.01429	19.01429	0.135714
Standard Error	0.055814	8.769018	4.652887	0.01255
Median	6.7	4.5	2.15	0.1
Mode	6.5	3	1.9	0.1
Standard Deviation	0.466973	73.36687	38.92884	0.104999
Sample Variance	0.218064	5382.697	1515.455	0.011025
Kurtosis	-0.13682	2.374415	2.373354	8.341763
Skewness	0.789308	2.06658	2.06618	3.097035
Range	1.7	213	113.2	0.4
Minimum	6.1	3	1.3	0.1
Maximum	7.8	216	114.5	0.5
Sum	475.5	2521	1331	9.5
Count	70	70	70	70
Largest(1)	7.8	216	114.5	0.5
Smallest(1)	6.1	3	1.3	0.1
Confidence Level(95.0%)	0.111346	17.49371	9.282255	0.025036

4. 7 Analysis

The study indicates that 2.9% of the schools that participated in the study for domestic water analysis, had its water not complaint to the microbial water standards as set by the BOS 32:00; and 0.99% of domestic water supplies samples were positive for total coliforms and *Escherichia coli.* 100% of domestic water samples collected from the public health facilities were a complaint to the BOS 32:00.

It was also reflected in the study that 14.3% of bottling facilities water samples were not compliant to the BOS 143:00 standard as 12.85% of the samples tested positive for *Pseudomonas aeruginosa.*

It was revealed in the study that samples collected from bottling facility **`12`** had more *P. aeruginosa* colony counts than facility **`4`.** The facilities also used hydrogen peroxide as the sanitisation chemical of choice and only used filtration system while other facilities used filtration accompanied by either ozonation or ultraviolet light. Figure 4.6 below shows a correlation between total dissolved solids (TDS) and conductivity in bottled water samples, which according to Rusydi (2018) are water quality parameters, which are used to describe salinity level. However, even though two parameters were within the allowable limits the researcher assumes that the type of treatment system used by bottling facility influenced their levels because for samples collected where facilities had no ozonation or ultraviolet light treatments, their values were high as depicted in the graph below.

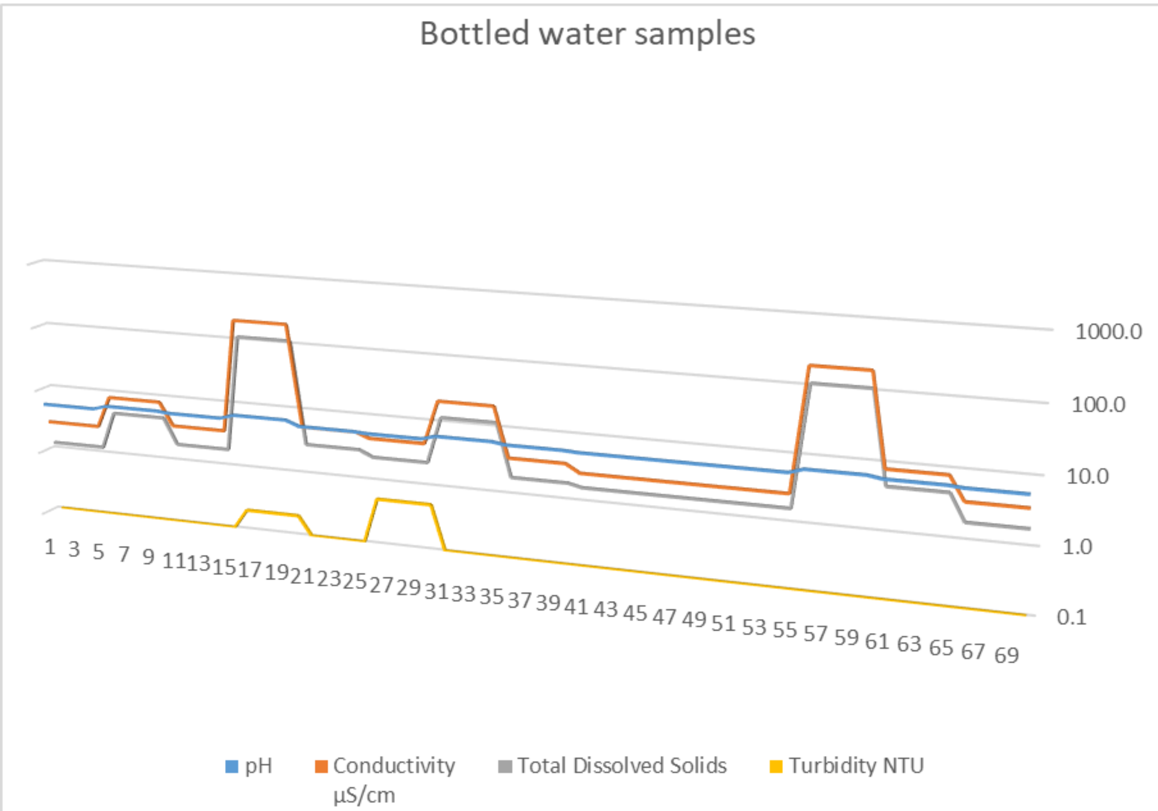

Figure 4.7: Overview of physiochemical data from 49 samples

4.8 Discussion and Conclusion

The researcher, therefore, will discuss the parameters isolated as they are crucial for public health purposes and this is supported by Sinton *et al.* (1999,) as the author noted that the original logic behind indicator (now index) still holds, in that a range of pathogens may be shed into water from faecal matter of infected people and animals. As such it is neither practicable nor recommended to examine water for every known pathogen to be present.

It is worth noting that, recorded levels of this study are lower than those recorded by Feeser (2016) in the study of microbial quality of packaged water samples inLatin America. Moreover, the study by Hunter (1992) had results for *P. aeruginosa* around 45 CFU in one of the study areas and thus higher than the current study.

4. 8. 1 Total Coliforms and *E. coli*

For domestic water samples, one school tested positive for *E. coli* and total coliforms which represents 0.99% of samples submitted for analysis; and this is indicative of faecal contamination and their presence regardless of how low the concentration; it is not ideal in drinking water. The current study is contrary to that of Ajobiewe *et al*., (2019) where they reported the presence of coliforms in all their samples and further exceeding WHO standards of zero coliforms per 100 ml. However, one of the studies by Shahaby *et al*., (2016) reported some levels of coliforms and *E. coli* although also different from the current study in tap water and bottled water.

The BOS 32:00 reflects that *E. coli* and total coliforms are indicators of faecal pollution as their normal habitat is the large intestine of man and warm blooded animals; and their presence in drinking water does indicate recent faecal contamination. Additionally, Metzger (2015) accentuates that Coliform and E. coli bacteria are the most commonly monitored since they are indicator bacteria and their presence could mean pathogens are present. The whole philosophy behind the use of the coliforms as indicators is to give a very high margin of safety to drinking water EPA (2001) thus reducing the possibility of waterborne diseases.

Cairncross and Feachem (1996), highlight that if one is examining a chlorinated water supply one knows that, if chlorination process is working correctly all coliform organisms including *E. coli* would have been killed. If the chlorinated water is tested at a tap, some distance from the treatment works; like in this particular instance it may also indicate the introduction of contamination at some pointing the distribution system.

4. 8. 2 *Pseudomonas aeruginosa*

12.85% of bottled water samples submitted for analysis tested positive for *P. aeruginosa*; a critical microbiological determinant which is not to be present in at least 100 ml of water as per the BOS 143:00 specification. Another study by Shahaby *et al*. (2016), reported that 14.3% of their samples tested positive for *P. aeroginosa* which is higher than the current study.

Both EPA (2001) and Mohammadi *et al.* (2015), indicated that *Pseudomonas aeruginosa* is an opportunistic human pathogen capable of causing widespread infections in burn and immune-compromised patients.

The laboratory analysis has indicated that more (12.85%) bottled water samples were contaminated in comparison to the (0.99%) of domestic water supplies. Thus Mohammadi *et al*.(2015), elaborating that in contrast to public belief, bottled waters are not free of microorganisms, and it is suggested that authorities should provide stricter monitoring and control plan for water resources and plants.

4. 8. 3 Total Dissolved Solids (TDS)

Comparing the TDS and conductivity of bottled water samples and those of domestic water through fig 4.6 and 4.7 below it clearly indicates that tap water is highly mineralised and Meride and Ayenew (2016) assert that high values of TDS in ground water are generally not harmful to human beings, but high concentration of these may affect persons who are suffering from kidney and heart diseases. Water containing high solid may cause laxative or constipation effects. Therefore through the study the researcher may assume that is why people prefer bottled water over domestic water.

The study has proven that the domestic water authority in Gaborone, Botswana strives to ensure that the water supply is safe. This revelation was astonishing since water bottling companies drew their supply water from the domestic water supply distribution network. This aligns to the submission by Cairncross and Feachem (1996), that stringent control of water contaminants and higher quality standards, should apply to water intended for human consumption than for other uses. Moreover, Shukla et al. (2013), reported that the samples of water is affected by various contaminants which may lead to health problems and this can be either microbial and/or physicochemical.

CHAPTER 5:

ENVIRONMENTAL HEALTH RISK ASSESSMENT AND COMPLIANCE LEVELS OF WATER BOTTLING PLANTS

5.0 Introduction

Environmental health is primarily concerned with the risks that arise from the adverse effects of environmental stressors; and typically a government will spend about 10% of its budget on the health sector but it is the other 90% of its expenditure that arguably has the most impact on human health (Basset, 2004). Assessing the impact of these external factors is vital that is why the study extended its coverage to the bottled water facilities.

To protect public health the Botswana Public Health Act of 2013 identifies nuisance as may be; any factory or trade premises not kept in a clean state and free from offensive smell, or not ventilated to destroy or render harmless and inoffensive, as far as practicable, dust or other impurities generated as to be injurious or dangerous to health. The WHO Drinking Water Guidelines of 2017 indicate that safe water, should not present any significant risk to health over a lifetime of consumption, including the different sensitivities that may occur between life stages.Those at greatest risk of waterborne diseases are those with a compromised immune system, infants and young children, people who are debilitated and the elderly, especially when living under unsanitary conditions.

Therefore, the local water bottling sector has a responsibility of ensuring compliance to the set statutory frameworks to protect public health; however, in adding to the challenge the Botswana government through Statutory Instrument No.44 of 2018 banned the importation of bottled water in less than ten (10) litre containers to promote the competitiveness and sustainability of the domestic water bottling sector which is a reserved business activity for citizens. The action presumably put pressure on the local bottled water production companies to meet the demand, even though they maybe inadequately resourced in terms of infrastructure and processes required to provide the quality of water as per the Botswana Bureau of Standards - Bottled Water and other Natural Water Specification - BOS143:00.

An informed and independent assessment is an essential part of total quality management (TQM) philosophy; which in the case of this study is guided by the BOS 306:2008 - Code of Hygienic Practice. In undertaking the risk assessments, the basic approach is to determine whether the processes and products are inherently safe. Therefore, the assessment of water bottling facilities was done to determine the extent to which the environment and product handling affected the quality of bottled water possibly resulting in waterborne diseases.

5.1 Sampling Procedure

An observation schedule in the form checklist was used to undertake environmental health risk assessments of water bottling plants; to determine their compliance to the Botswana Bureau of Standards BOS 306:2008 - Code of Hygienic Practice, Public Health Act of 2014 and the Food Control Act Cap 65:05. The observation schedule focussed on the following priority areas;

a) Processes / Procedures for maintenance
b) Equipment cleaning
c) Personal hygiene practises
d) Physical Infrastructure Hygiene
e) Records

The researcher coded the questionnaire variables on a Microsoft Excel template and were input into the Statistical Package for the Social Sciences (SPSS) software package. The variables were coded as below;

b) The number **1** was used to represent the first question and response; and the subsequent ones were represented by sequential numbering
c) In case of optional responses, for example; **1 = yes**, **2 = no**
d) **F**or open or string questions responses inductive coding was used once data was collected.

The researcher liaised with Gaborone City Council to identify the licensed water bottling plants just like for water sampling exercise in chapter three (03).The licensed facilities in Gaborone were forty-five (45). The margin of error was identified as 5%. The sample size was calculated using Slovin`s formula;

i.e. $n = N / (1 + Ne^{2})$

N= population

e = margin of error

N = 45

e = 5%

Therefore n = 40.45

≈ 40

With the sample size calculated as forty (40) facilities, random sampling was then used to identify the 40 facilities to participate in the study. These were the same facilities that bottled water samples were collected from. The observation schedules for water bottling facilities were indexed from one (01) to forty (40) after random sampling was undertaken.

5.2 Limitations

The limitations posed were similar to those of water sampling in these facilities and they were as follows;

1. Of the 40 water bottling plants sampled to participate in the study and were registered with Gaborone City Council before the COVID - 19 pandemic only 25 were found to be operational during data collection.
2. Only 14 bottling plants consented to participate in the study.
3. Some bottling facilities were sceptical to participate in the study for fear of exposure of business practises to competitors.

5.3 Ethical Considerations

Consent letters were issued to all the companies that consented to participate in the study. Confidentiality was assured in the publication of the report and were also advised that the study was voluntary and therefore, were free to withdraw at any point of data collection.

5.4 Method of Analysis

Descriptive statistics were used in the organisation and presentation of data. These were in the form of tables, charts and numerical values.

5.5 Results

The results of the observation schedule have been divided into five (05) sections in Table 5.2;

Table 5.1 Observational checklist sections.

Section	**Category**
A	Process flow/ Procedure for maintenance
B	Cleaning of Equipment
C	Personal Hygiene
D	Physical infrastructure hygiene
E	Records

5. 5. 1 Section A: Process Flow / Procedure for Maintenance

Table 5.2 indicates that 8 (57.1%) of the bottling plants had the area under the filter clear of excessive debris build up or glass contamination, 10 (71.4%) each had, (i) the canopies over empty and open filled bottles, (ii) bottling area free of repairs and (iii) cleaning of their filters done as required with proof records available.

Table 5.2 Process Flow

Variable	Response	Frequency	Percentage
Is the area under the filter clear of excessive debris build up or glass contamination	Yes	8	57.1
	No	6	42.9
	TOTAL	14	100
Are the canopies over empty and open filled bottles clean?	Yes	10	71.4
	No	4	28.6
	TOTAL	14	100
Is the bottling area free of repairs?	Yes	10	71.4
	No	4	28.6
	TOTAL	14	100
Cleaning of filter done as per required (proof from records)?	Yes	10	71.4
	No	4	28.6
	TOTAL	14	100

5. 5.1. 2 Water Quality Monitoring

Figure 5.1 infers that 9 (64.3%) bottling facilities undertook monthly water quality monitoring, 3 (21.4%) did it for each batch and 1(7%) each conducted it (i) weekly and (ii) never did water quality monitoring respectively.

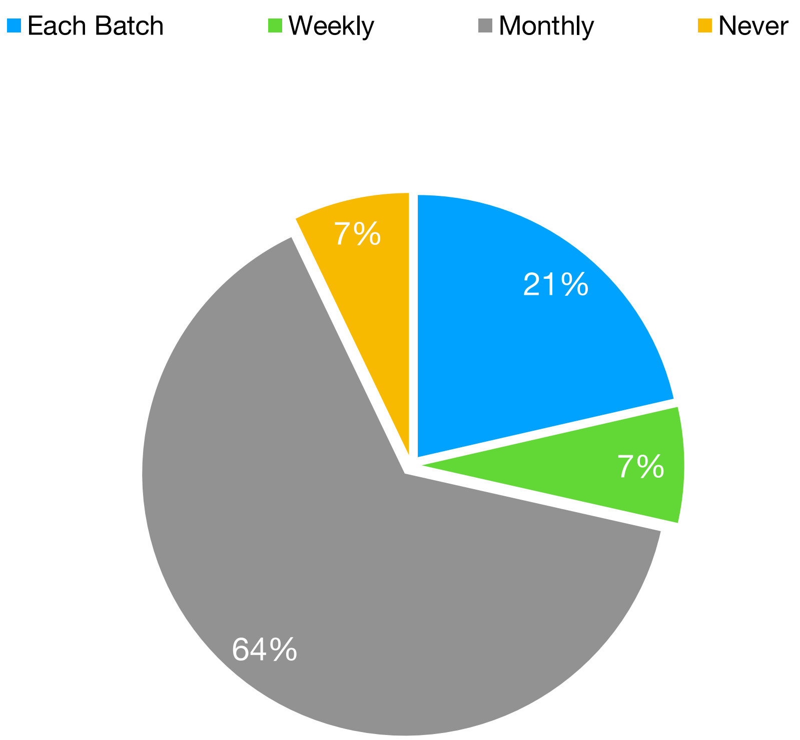

Figure 5.1: Water Quality Monitoring in Gaborone

5. 5. 2 Section B: Cleaning of Equipment

The researcher under this section will present results associated with cleaning of equipment within the bottling facilities as per the observation schedule.

5. 5. 2.1 Cleaning of Bottling line and Availability of Sanitisation Schedule

Table 5.3 indicates 10 (71.4%) of the water bottling facilities cleaned the bottling line after bottling or refilling whilst 8 (57.1%) facilities had available cleaning or sanitisation schedule for equipment and premises.

Table 5.3 Bottling line cleaning and Sanitisation schedule of water bottling facilities

Variable	Response	Frequency	Percentage
Cleaning of bottling line after bottling/ refilling	Yes	10	71.4
	No	4	28.6
	TOTAL	14	100
Availability of cleaning/ sanitisation schedule	Yes	6	42.9
	No	8	57.1
	TOTAL	14	100

5. 5. 2. 2 Chemicals used for cleaning

Figure 5.2 infers that 7 (50%) of the bottling facilities use alcohol sanitisers for cleaning, 4 (28.6%) use household detergent, 2 (14.2%) use hydrogen peroxide and 1 (7.1%) use ammonia .

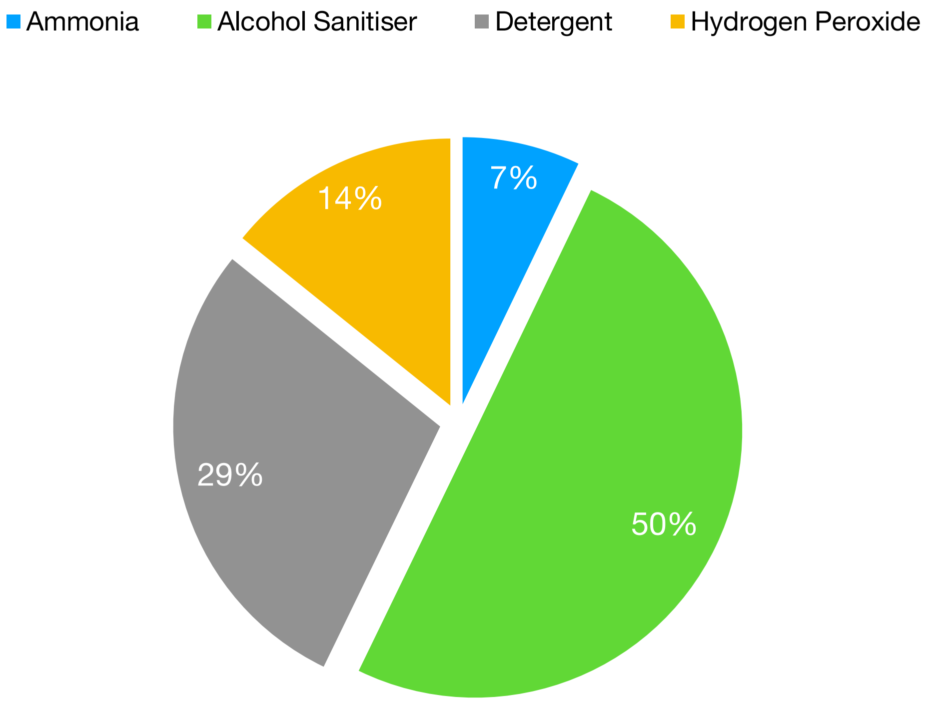

Figure 5.2 Types of cleaning chemicals used water bottling facilities

5. 5. 2.3 Cleaning of screw scoop

Figure 5.3 indicates that 8 (57.1%) of bottling plants cleaned the screw cap scoop `before only`, 3 (21.4%) (i) `before and after` and; (ii) at the `end of the shift` respectively.

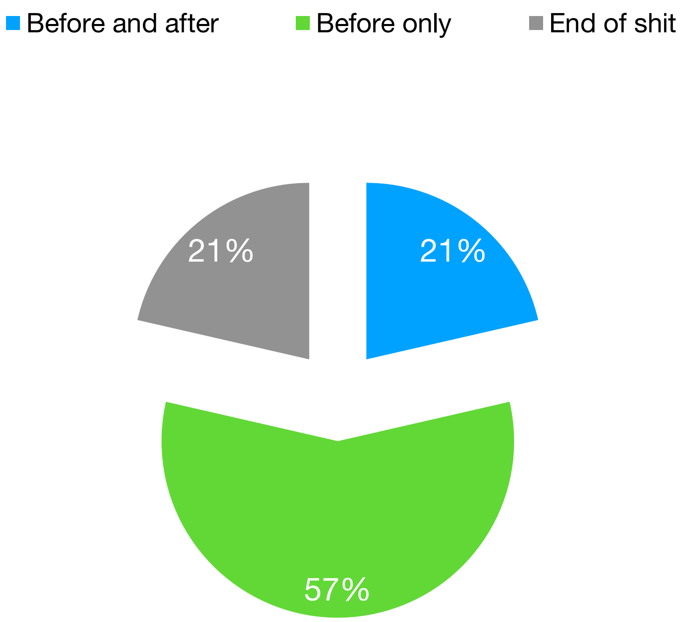

Figure 5.3 Frequency of cleaning of screw scoop in water bottling facilities

5. 5. 2. 4 Frequency of Cleaning Storage Tank

Figure 5.4 shows that 9 (64.3%) of 14 water bottling plants had `never` cleaned their water storage tanks, 3 (21.4) cleaned it once a month whilst 2 (14.3%) cleaned them weekly.

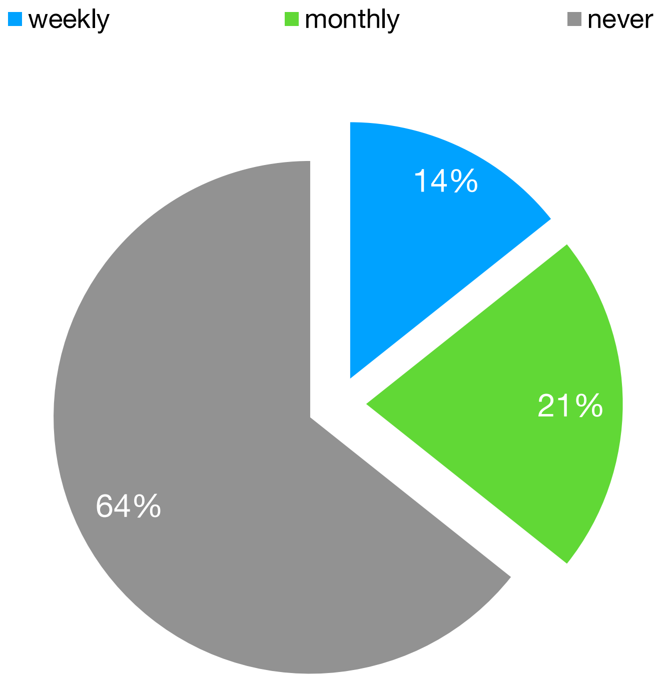

Figure 5.4 Frequency of cleaning water storage tanks in water bottling facilities

5. 5. 3 Section C: Personal Hygiene

Table 5.4 shows that 12 (85.7%) of the 14 water bottling plants followed hand washing procedures, 8 (57.1%) had the bottling line free of personal possessions, 11 (78.6%) had their operators free from jewellery and had their bottling line free of any evidence of eating and drinking, 5 (35.7%) had protective clothing worn properly and 8 (57.1%) of the employees had undertaken medical examination.

Table 5.4 Personal Hygiene Variables

Variable	Response	Frequency	Percentage
Are hand washing procedures followed?	Yes	12	85.7
	No	2	14.3
	TOTAL	14	100

Variable	Response	Frequency	Percentage
Is the line absent of personal possessions?	Yes	8	57.1
	No	6	42.5
	TOTAL	14	
Are operators on line free of any jewellery?	Yes	11	78.6
	No	3	21.4
	TOTAL	14	100
Is the line free of any evidence of eating and drinking?	Yes	11	78.6
	No	3	21.4
	TOTAL	14	100
Are protective clothing and safety shoes worn correctly?	Yes	5	35.7
	No	9	64.3
	TOTAL	14	100
Have employees undertaken medical exam?	Yes	8	57.1
	No	6	42.9
	TOTAL	14	100

5. 5. 4 Section D: Physical Infrastructure Hygiene

Table 5.5 indicates 9 (64.3%) of 14 water bottling facilities had floors clean and free from damage, 11 (78.6%) had clean walls free from damage, 12 (84.6%) had ceilings clean and free from damage; and 13 (92.9%).

Table 5.5 Physical Infrastructure

Variables	Response	Frequency	Percentage
Floors clean and free from damage	Yes	9	64.3
	No	5	35.7
	TOTAL	14	100

Variables	Response	Frequency	Percentage
Walls clean and free for damage	Yes	11	78.6
	No	3	21.4
	TOTAL	14	100
Ceiling clean and free from damage	Yes	12	84.6
	No	2	15.4
	TOTAL	14	100
Are the drains clean	Yes	13	92.9
	No	1	7.1
	TOTAL	14	100

5. 5. 5 Section E: Records

Figure 5.5 shows that 11 of the 14 (84.6%) of water bottling facilities had records which were legible and free from scribbling whilst only 9 (64.3%) have available records for water quality monitoring.

5.6 Overall Compliance of the Water Bottling Facilities

The figure 5.6 below indicates overall compliance levels for the water bottling plants as per the

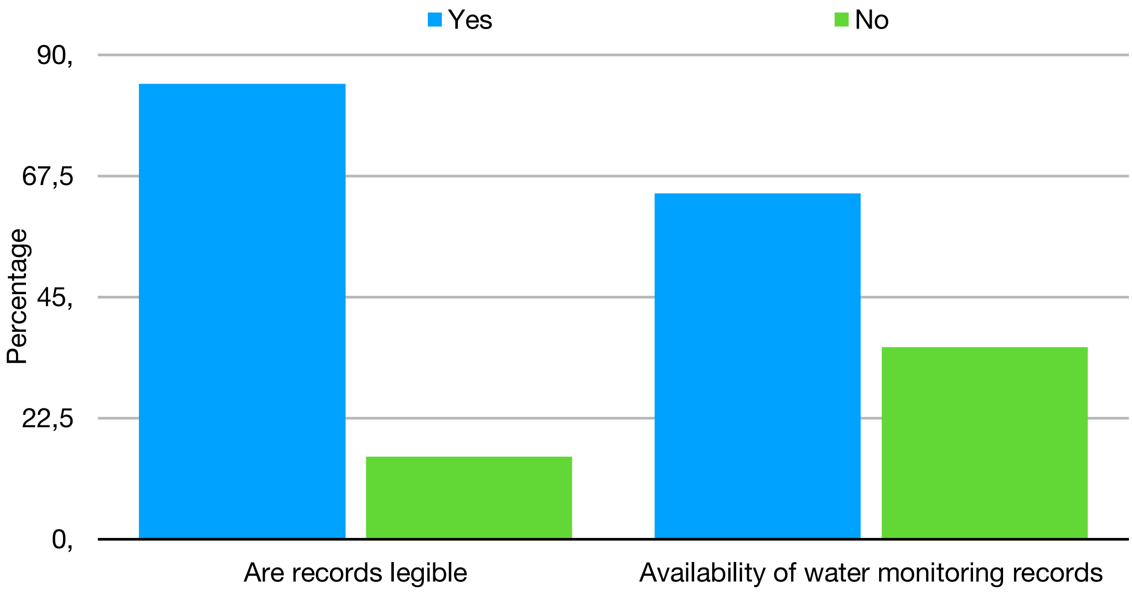

Figure 5.5 Records of water quality monitoring

thematic areas under which they were assessed are as follows; A - Process flow / procedure for maintenance as 59%, B - Cleaning of equipment 51%, C - Personal Hygiene 65%, D - Physical infrastructure hygiene 80% and E - Records being 74%.

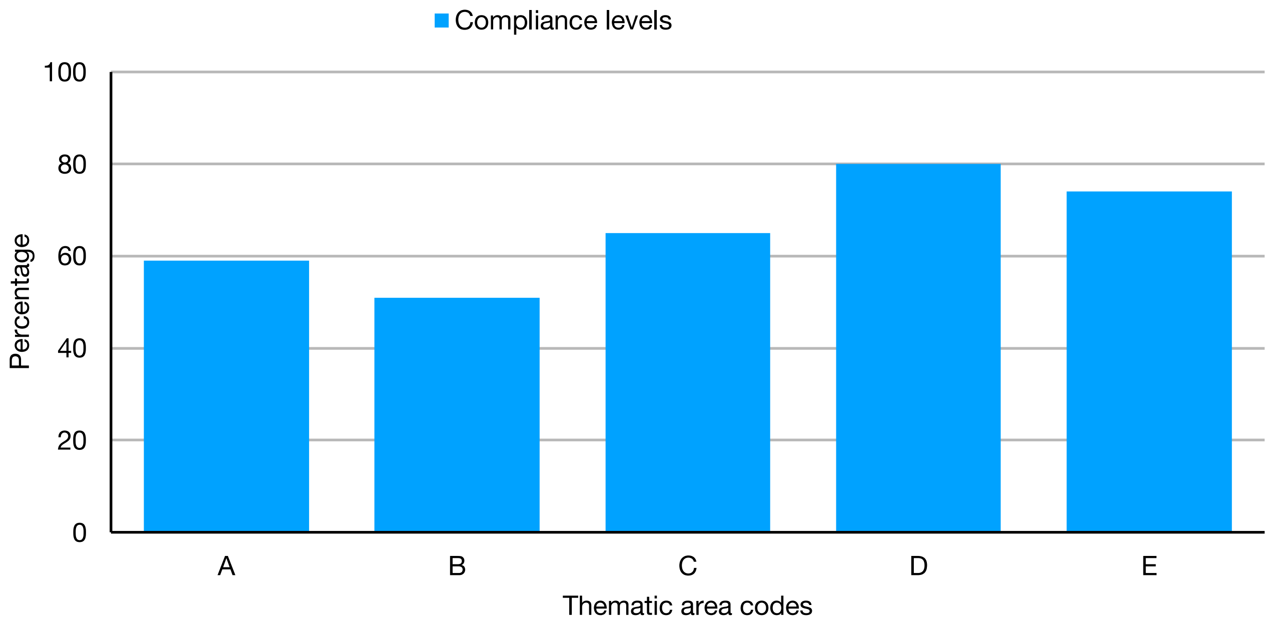

Figure 5.6 Overall compliance of water bottling facilities

5.7 Analysis

The study revealed that 71.4% of the bottling facilities had the canopies clean, free from debris and repairs and; filters where replaced as required thus reducing the risk of foreign matter being introduced into the products. Only 21.4% of the facilities that participated in the study actually undertook water quality monitoring for each batch as required by the Botswana Bureau of Standards for bottled water.

42.9% of the facilities had existing cleaning or sanitisation schedules pasted in their establishments, however 71.4% cleaned the production line immediately after refilling or bottling containers.

The study has also established that from the overall compliance level of facilities, process flow and / or procedure for maintenance, cleaning of equipment and personal hygiene were at 59%, 51% and 65% respectively; which are factors that are highly, likely to contribute to the contamination of the bottled water products thus potentially affecting the product quality as per the BOS 306 - Bottled water code of hygienic practice.

5.8 Discussion and Conclusion

Only 21.4% of the facilities that participated in the study actually undertook water quality monitoring for each batch as required by the Botswana Bureau of Standards for bottled water. Peletz, *et al.,* (2018) and Park, *et al.,* (2020) infer that water quality testing is critical for guiding water safety management and ensuring public health and in many instances, water suppliers and surveillance agencies do not meet regulatory requirements for testing frequencies.

The overall (65.8%) compliance level of the water bottling facilities as per existing regulatory frameworks is an indication that indeed handling and processing of bottled water may affect its quality; because 14.3% of bottled water failed the microbial analysis whilst 2.9% of domestic water supply failed, and yet water bottling facilities drew water from the municipal distribution network.

Schmidt (2009) highlights that the objective of cleaning and sanitising contact surfaces is to remove nutrients that bacteria need to grow, and to kill those bacteria that are present. It is important that the clean, sanitised equipment and surfaces drain dry and are stored dry so as to prevent bacteria growth. Having only 42.9% of the water bottling facilities complying to availability of sanitation and cleaning schedules can lead to lapses of maintaining cleanliness resulting in bacterial growth and ultimately waterborne illnesses.

However, Marriott, *et al.* (2018) indicates that unsanitary operations frequently result from a lack of understanding of the principles of sanitation and the benefits that effective sanitation will provide, which are and not limited to; reduced public health risks, product quality, maintenance costs, improved product acceptability.

The compliance level for water bottling facilities to the requirements set out in BOS 306 : Bottled water - Code of Hygienic Practice also took into cognisance the Public Health and Food Control Acts Regulations. The regulatory frameworks primary existence is to ensure that the quality of water as prescribed in the BOS 143 - Bottled water other than natural water are achieved in-order to protect public health. Emphasis on the matter is reiterated by Cairncross and Feachem (1996), that more stringent control of water contaminants and higher quality standards, should apply to water intended for human consumption than for other uses.

In support of the findings of the study, according to WHO Guidelines for Drinking Water Quality of 2017 emphasise that health-based targets are an essential component of drinking-water safety framework. The health based targets should take account of the overall public health situation and contribution of drinking water quality to disease due to waterborne microbes and chemicals, as a part of overall water and health policy.

The above statement infers that drinking water compliant to the required quality standards promotes the health of communities; and the World Health Organisation further emphasises that where there are lapses in standards the public becomes more prone to diseases and impairments, therefore, the consideration by WHO to categorise water as a vital determinant of health (WHO, 2018).

CHAPTER 6:
CONCLUSIONS AND RECOMMENDATIONS

6.0 Introduction

The chapter will focus on the conclusions and recommendations of the study as per the laid study aims and objectives and also determine if the hypothesis was tested and research questions answered.

The study was aimed at establishing the public's perceptions on water quality and assess the quality of bottled and domestic water in Gaborone, Botswana.

The following objectives were used to address the overall aim;

· To assess people's knowledge and perceptions on the choice of bottled water vis a vis domestic water.

· To conduct risk assessments in water bottling plants.

· To conduct microbial and physicochemical assessments of bottled water and domestic water supplies.

· To develop appropriate policy interventions for the possible health risks with water.

6.1 Objectives analysis

6. 1. 1 Knowledge and perceptions of the participants on bottled water against tap water

The study indicates that 56.4% participants (which is the majority) preferred bottled water over other types of water. The preference of choice of water for 84.6% of eligible participants was influenced by the perception that their choice of water was safe whilst 84.4% participants` choice was as result of them actually having fallen ill from drinking tap water.

Thus the study conclusion of preference of bottled water over tap or domestic water supplies by the participants over the assumption that was safe relates to Juba and Tanyanyiwa (2018) in concurrence that consumers used bottled water as their primary drinking source when they perceived that tap water was not safe. However, Doria (2006) argues that even if perceived risks are in many cases inversely related to perceived benefits, customers may prefer bottled water for the potential health benefits but not because of eventual tap water risks.

The study has also indicated that the majority of participants had said they had fallen ill from drinking different types of water and; tap water had actually affected most of the participants. Hence the ailments had influence on the majority's perception and their water preferences. This phenomenon has been attested by Tanyanyiwa and Juba (2018) where they indicate that bottled water use has continued to expand worldwide in the last two decades as a significant number of consumers have shifted from tap water due to *Cryptosporidium* outbreaks. Whilst Doria (2006) highlights that trust in tap water companies influences public behaviour in their preferences.

The fact that respondents were able to attest their falling ill to consumption of either water clearly indicates their understanding of water hygiene being clean and uncontaminated water to it influencing their choices and preferences mostly based on safety.

6. 1 .2 Health Risks Associated with Water

In assessing the understanding of health risks and water 74.7% of the participants indicated that water was essential and /or vital for living as a core benefit. 74.4% of the participants in the study said diarrhoea and gastro intestinal diseases were major health risks associated with water. The participants also pointed out non infectious diseases like teeth browning and body malfunctions to underscore their understanding of the health risks.

For the control of health risks the majority; 50.4% of the participants said water purification was key whilst 28.5% vouched for health promotion and education.

Having majority of the respondents in the study identifying water as essential to life and well being; is underscored by the World Health Organisation (WHO) (2018) that drinking water compliant to the required quality standards promotes health in communities. The participants in the study further indicated that gastrointestinal and other related infections were the most likely diseases to be caused by water and WHO (2017) actually affirms that infectious diseases caused by pathogenic bacteria, viruses and parasites are the most common wide spread health risk associated with drinking water of poor quality.

Moreover, Shukla et al. (2013), concludes that samples of water are affected by various contaminants which may lead to health problems and this may be either microbial and/or physicochemical.

6. 1.3 Risk assessments of water bottling facilities

The overall 65.8% compliance level of the water bottling facilities as per existing regulatory frameworks is an indication that indeed handling and processing of bottled water may affect its quality; because 14.3% of bottled water failed the microbial analysis whilst 2.9% of domestic water supply failed, when the water bottling facilities draw water for bottling from the municipal distribution network.

The compliance level for water bottling facilities to the requirements set out in BOS 306: Bottled water - Code of Hygienic Practice also took into cognisance the Public Health and Food Control Acts Regulations. The regulatory frameworks primary existence is to ensure that the quality of water as prescribed in the BOS 143 - Bottled water other than natural water are achieved in - order to protect public health.Emphasis on the matter is reiterated by Cairncross and Feachem, (1996) that more stringent control of water contaminants and higher quality standards, should apply to water intended for human consumption than for other uses.

In supporting the findings of the study, according to WHO Guidelines for Drinking Water Quality of 2017 emphasise that health-based targets are an essential component of drinking-water safety framework. The health based targets should take account of the overall public health situation and contribution of drinking water quality to disease due to waterborne microbes and chemicals, as a part of overall water and health policy.

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6. 1. 4 Microbial and Physicochemical assessments

The study revealed that all physicochemical analysis undertaken for all samples complied with the BOS 143:00 bottling water specification whilst some samples failed the microbial analysis.

The study will therefore only discuss the parameters isolated as they are crucial for public health purposes and this is supported by Sinton, *et al.,* (1999) as it noted that the original logic behind indicator (now index) still holds true, in that a range of pathogens may be shed into water from faecal matter of infected people and animals. As such it is neither practicable nor recommended to examine water for every known pathogen to be present.

6. 1. 4. 1 Total Coliforms and *E. coli*

One of the schools` domestic water sample tested positive for *E. coli* and total coliforms which was 0.99% of samples submitted for analysis; and this was indicative of faecal contamination and their presence regardless of how low the concentration; it is not ideal in drinking water.

The BOS 32:00 reflects that *E. coli* and total coliforms are indicators of faecal pollution as their normal habitat is the large intestine of man and warm blooded animals; and their presence in drinking water does indicate recent faecal contamination.

Cairncross and Feachem (1996) highlight that if one is examining a chlorinated water supply one knows that, if chlorination process is working correctly all coliform organisms including *E. coli* would have been killed. If the chlorinated water is tested at a tap, some distance from the treatment works; like in this particular instance it may also indicate the introduction of contamination at some pointing the distribution system.

The whole philosophy behind the use of the coliforms as indicators is to give a very high margin of safety to drinking water EPA (2001) thus reducing the possibility of waterborne diseases.

6. 1.4. 2 *Pseudomonas aeruginosa*

Bottled water samples submitted for analysis; 12.85% of them tested positive for *P. aeruginosa*; a critical microbiological determinant which is not to be present in at least 100ml of water as per the BOS 143:00 specification.

Both EPA (2001) and Mohammadi *et al.* (2015), indicated that *Pseudomonas aeruginosa* is an opportunistic human pathogen capable of causing widespread infections in burn and immune-compromised patients.

The laboratory analysis has clearly indicated that more 12.85% bottled water samples were contaminated in comparison to the 0.99% of domestic water supplies. Thus Mohammadi *et al*. (2015), elaborating that in contrast to public believe, bottled waters are not free of microorganisms, and it is suggested that authorities should provide stricter monitoring and control plan for water resources and plants.

6.2 Conclusion

The findings of the study in overall actually supports the hypothesis and positively respond to the research questions that indeed bottled water does pose higher health risks than domestic or tap water because of the handling and the production processes. This also indicates that the domestic water supply authority in Gaborone, Botswana strives to ensure that the water supply is safe and of grave concern is that water bottling companies draw water from the water authority distribution network and further process through filtration, ozonation and ultra violet light and yet bottled water quality is still compromised.

The observation and analogy of the study is attested by Diduch, *et al*., (2013) that with the ever-increasing popularity of bottled water means that it is important to analyse not only its mineral content but also, above all, its content of possible contaminants, especially the organic ones. In this respect, bottled waters are a special case, because apart from organic chemical contaminants derived from the well from which they were acquired, secondary contamination is always possible, during treatment or storage or transport in unsuitable conditions (sunlight and elevated temperature).

Having assessed the possible risks that may arise from bottled water production and the fact that this study has shown that the majority of respondents prefer bottled water over domestic water supplies clearly there is need for intensified public education as Doria (2006) has stated that from strictly objective perspective bottled water is not “better” or “worse” than tap water - it depends on the specificity of the particular cases. Several studies which compared bottled and tap water concluded that while some bottled water had better quality that tap water, this not always the case. Some pointed out that tap water is controlled by more rigorous standards and is more frequently analysed than bottled water.

Moreover, despite the number of publications that have reported various aspects of the microbes identified in bottled water, people continue to use bottled water and some do not even wonder about its public health significance, and as such many questions remain to be answered. Literature has shown that it is still not possible to adequately describe this complex ecosystem. Research has shown that at any given time some sampled bottled water may have a diversity and heterogeneity of the microbes.

6.3 Recommendations

1. The researcher encourages for in-depth analysis of recorded outbreaks to determine the root causes as its quite vivid that water may be a contributing factor to many.

2. There is need to guide the implementing authorities on effective implementation and consistency in application of National Regulatory Standards, guidelines and policies governing water safety through development of standard operating procedures.

3. Health promotion education is pivotal in making informed choices and for a healthy populace; therefore, it should adequately be resourced for water safety purposes.

4. Stricter monitoring protocols for water bottling and filling facilities should be developed to reduce gaps in compliance to National Regulatory Standards.

5. Assessment of water quality from various sources inclusive of rovers is required. This is in line with a study by Duvica (2018).

6. Analysis of other water quality parameters such as heavy metals and their sources is crucial for the country.

6. 3 Future Research

Future research may be undertaken to establish why bottled water does not comply with BOS 143:00 Standard when bottling water facilities draw their water from water authority distribution networks in Gaborone, Botswana. Moreover, Bowyer *et al*., 2017, indicated that there is a need for environmental assessment of bottled water on the environment ad this is important for the country as well. As bottled water use continues to expand around the world, there is growing interest in the environmental, economical, and social implications of that use, including concerns about waste generation, proper use of groundwater, hydrologic effects on local surface and groundwater, economic costs, and more. A key concern is how much energy is required to produce and use bottled water (Gleick and Cooley, 2009). These aspects are also important to understand going forward with the water quality of Botswana.

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Appendices

Appendix 1

Chapter 3 - Questionnaire Data Coding Matrix

The data coding matrix for analysis was as the below table;

Table 1 - Data Matrix

Category	**Theme/ Value**	**Code**
Age	a) > 18	a) 1
	b) 18-29	b) 2
	c) 30-39	c) 3
	d) 40-49	d) 4
	e) 50-64	e) 5
	f) <64	f) 6
Gender	a) Female	a) 1
	b) Male	b) 2
Income Bracket (BWP)	a) 0-5000	a) 1
	b) 5001	b) 2
	c) <15001	c) 3
Do you know the benefits of drinking water?	a) Yes	a) 1
	b) No	b) 2

Explain the response given above	a) Good for the skin b) Refreshes and relaxes the body and induces metabolism c) Good for bad breath d) Essential for living e) Helps with excretion of toxins for the body f) Non responsive	a) 1 b) 2 c) 3 d) 4 e) 5 f) 6
Can water pose health risks?	a) Yes b) No c) Non responsive	a) 1 b) 2 c) 3
Name the health risks associated with water	a) Diarrhoea, diseases and other infections b) Causes body malfunctions c) Non infectious conditions d) Non responsive	a) 1 b) 2 c) 3 d) 4

What can be done to control the risks	a) Health promotion b) Not to use stagnant water c) Check out best before dates purchase in stores d) Purify/ boil water before drinking e) Government to provide safe water f) Maintain clean environments to avoid pollution of water sources g) Non responsive	a) 1 b) 2 c) 3 d) 4 e) 5 f) 7 g) 8
Which type of water poses more health risks between tap and bottled water	a) Tap b) Bottled c) Non responsive	a) 1 b) 2 c) 3
What is your water preference?	a) Tap water b) Bottled c) Boiled d) Rain	a) 1 b) 2 c) 3 d) 4
Why do you prefer the choice indicated above?	a) Affordable b) Safe c) Easily accessible d) Assured quality e) Tastes better	a) 1 b) 2 c) 3 d) 4 e) 5
Have you fallen ill from drinking water?	a) Yes b) No	a) 1 b) 2

Which type of water?	a) Tap b) Bottled c) N/A d) Borehole e) Saline water f) Reservoir/ Tank g) Dirty-water	a) 1 b) 2 c) 3 d) 4 e) 5 f) 6 g) 7
Did the answer above influence your water preference?	a) Yes b) No	a) 1 b) 2

Appendix 2

PRIVATE BAG 0038
GABORONE
BOTSWANA
REFERENCE:

TEL: (+267) 363 2500
FAX: (+267) 391 0647
TELEGRAMS: RABONGAKA
TELEX: 2818 CARE BD

REPUBLIC OF BOTSWANA
MINISTRY OF HEALTH AND WELLNESS

REFERENCE NO: HPDME 13/18/1 **16 March 2020**

Health Research and Development Division

Notification of IRB Review: **New application**

Thato Sengwaketse
P.O. Box AE 567
Gaborone

Dear Sengwaketse

Protocol Title: **THE INVESTIGATION OF THE MICROBIAL AND PHYSICOCHEMICAL QUALITY OF BOTTLED WATER AND DOMESTIC WATER IN GABORONE, BOTSWANA.**

HRDD Approval Date:	16 March 2020
HRDD Expiration Date:	15 March 2021
HRDD Review Type:	Expedited Review
HRDD Review Determination:	Approved
Risk Determination:	Minimal risk

Thank you for submitting new application for the above referenced protocol. The permission is granted to conduct the study.

This permit does not however give you authority to collect data from the selected sites without prior approval from the management. Consent from the identified individuals should be obtained at all times.

The research should be conducted as outlined in the approved proposal. Any changes to the approved proposal must be submitted to the Health Research and Development Division in the Ministry of Health for consideration and approval.

Furthermore, you are requested to submit at least one hardcopy and an electronic copy of the report to the Health Research, Ministry of Health and Wellness within 3 months of completion of the study. Approval is for academic fulfillment only. Copies should also be submitted to all other relevant authorities.

Continuing Review

In order to continue work on this study (including data analysis) beyond the expiry date, submit a Continuing Review Form for Approval at least three (3) months prior to the

Appendix 3

Data Coding Matrix for Observation Schedule

Category	Theme	Code
Is the area under the filler clear of excessive debris build-up or glass contamination?	a) Yes b) No	a) 1 b) 2
Are the canopies over empty and open filled bottles clean?	a) Yes b) No	a) 1 b) 2
Is the bottling area free of repairs?	a) Yes b) No	a) 1 b) 2
Cleaning of filter done as per required (proof from records)?	a) Yes b) No	a) 1 b) 2
Frequency of water quality monitoring	a) each batch b) Weekly c) Never d) Monthly	a) 1 b) 2 c) 3 d) 4
Cleaning of bottling line after bottling/ refilling?	a) Yes b) No	a) 1 b) 2
Name of type of chemicals used for cleaning?	a) Ammonia b) Alcohol sanitiser c) chlorine d) Household detergent e) Hydro peroxide	a) 1 b) 2 c) 3 d) 4 e) 5
Cleaning / sanitisation schedule of equipment available?	a) Yes b) No	a) 1 b) 2
Frequency of cleaning screw cap scoop	a) before and after b) Before only c) After only d) At the end of the shift	a) 1 b) 2 c) 3 d) 4
Frequency of cleaning water storage tank?	a) Weekly b) Monthly c) Never	a) 1 b) 2 c) 3
Are hand washing procedures followed?	a) Yes b) No	a) 1 b) 2

Category	Theme	Code
Is the line absent of personal possessions? No cell phones? No personal medicine?	a) Yes b) No	a) 1 b) 2
Are Operators on line free of any jewellery?	a) Yes b) No	a) 1 b) 2
Is the line free of any evidence of eating and drinking?	a) Yes b) No	a) 1 b) 2
Are protective clothing and safety shoes worn correctly?	a) Yes b) No	a) 1 b) 2
Have the employees undertaken medical examination?	a) Yes b) No	a) 1 b) 2
Floors clean and free from damage?	a) Yes b) No	a) 1 b) 2
Walls clean and free from damage?	a) Yes b) No	a) 1 b) 2
Ceilings clean and free from damage?	a) Yes b) No	a) 1 b) 2
Are the drains clean?	a) Yes b) No	a) 1 b) 2
Are records legible and free from scribbling out	a) Yes b) No	a) 1 b) 2
Are records for monitoring of water quality available?	a) Yes b) No	a) 1 b) 2

Appendix 4

Cape Peninsula
University of Technology

Faculty of Applied Science

Department of Environmental and Occupational Studies

(Cape Town Campus)

2020 March 03

THE PARTICANT

Gaborone

Dear Sir/ Madam

REQUEST FOR CONSENT TO CONDUCT RESEARCH

I am Thato Sengwaketse, a Master of Environmental Health Student at the Cape Peninsula University of Technology, engaged in a study entitled he Investigation of Microbial and physicochemical analysis of bottled and domestic water in Gaborone, Botswana" under the supervision of Professor Karabo Shale in the Faculty of Applied Sciences.

The overall aim of this project is to establish public's perceptions on water quality and assess the quality of bottled and domestic water in Gaborone, Botswana.

To achieve the above aim the following objectives will be used:
1. To assess peoples perceptions on the use of bottled water against domestic water
2. To conduct risk assessments in plants for bottled water
3. To conduct microbial and physicochemical assessments of bottled water and domestic water supplies, and
4. To develop appropriate interventions for the possible health risks.

You were selected for possible participation in this study as a part of the population of Gaborone. Benefits regarding participation in this study is that you will have an opportunity to verbalise your experience with water consumption and the possible health risks. You will not be paid for participation. You will be asked open ended questions to determine your perceptions, preferences and knowledge on possible health risks on water.

If you sign this document, you will be giving consent to complete the questionnaire and to be interviewed by the researcher. Participation in the study is voluntary and even after the interview begins you may terminate at any given point. We undertake to ensure your anonymity by omitting the use of names. Confidentiality will be ensured in the undertaking of the study.

Thank you.

Yours faithfully

Appendix 5

All correspondence should be addressed to the

TOWN CLERK
Private Bag 0089
GABORONE
BOTSWANA
Telephones: 3657400
Fax: 3900141

REF:GCC/11/12/7

19 September 2019

The Dean
Faculty of Applied Sciences
Cape Peninsula University of Technology
Programme of Environmental Health
P O Box 652
Cape Town
8001

Dear Sir/ Madam

<u>AUTHORITY FOR MS THATO SENGWAKETSE - 219400075 TO UNDERTAKE STUDY WITH IN GABORONE CITY COUNCIL , BOTSWANA JURISDICTION</u>

Authority is hereby granted for Ms Thato Sengwaketse - 219400075, a Master of Environmental Health student with Cape Peninsula University of Technology to undertake a study titled: **MICROBIAL AND PHYSICOCHEMICAL QUALITY OF BOTTLED AND DOMESTIC WATER IN GABORONE, BOTSWANA.**

The sampling shall be done in collaboration with the Department of Environmental of Gaborone City Council and we look forward to the outcomes and analysis.

Yours Faithfully

....

Banabotlhe Mooketsi
for/ Town Clerk

Appendix 6

Cape Peninsula
University of Technology

Faculty of Applied Science

Department of Environmental and Occupational Studies

(Cape Town Campus)

2020 March 03

The Manager

Gaborone

Dear Sir/ Madam

REQUEST FOR CONSENT TO CONDUCT RESEARCH

I am Thato Sengwaketse, a Master of Environmental Health Student at the Cape Peninsula University of Technology, engaged in a study entitled he Investigation of Microbial and physicochemical analysis of bottled and domestic water in Gaborone, Botswana" under the supervision of Professor Karabo Shale in the Faculty of Applied Sciences.

The overall aim of this project is to establish public's perceptions on water quality and assess the quality of bottled and domestic water in Gaborone, Botswana.

To achieve the above aim the following objectives will be used:

1. To assess peoples perceptions on the use of bottled water against domestic water
2. To conduct risk assessments in plants for bottled water
3. To conduct microbial and physicochemical assessments of bottled water and domestic water supplies, and
4. To develop appropriate interventions for the possible health risks.

You company was selected for possible participation in this study as one of the licensed water bottling plants in Gaborone. Benefits regarding participation in this study is that you will have your water samples analysed for free and an inspection conducted where results will be shared with your company. You will not be paid for participation. Water samples will be collected for analysis at the regulatory laboratory and an inspection will be conducted to ensure compliance to BOS 143 Standard and the Public Health Act.

If you sign this document, you will be giving consent to complete the questionnaire and to be interviewed by the researcher. Participation in the study is voluntary and even after the interview begins you may terminate at any given point. We undertake to ensure your anonymity by omitting the use of names. Confidentiality will be ensured in the undertaking of the study.

Thank you.