UNIVERSITY OF NAIROBI

INVESTIGATION OF PORTABLE WATER QUALITY AND PROVISION IN THE CITY OF NAIROBI, KENYA

BY

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DECLARATION

"I declare that this thesis is my original work and has not been submitted elsewhere for examination, award of a degree or publication. Where other people's work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements".

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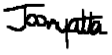
3.	Dr. John O. Onyatta Department of Chemistry University of Nairobi		__02/12/2022_____

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DEDICATION

This work is dedicated to my parents, wife Caroline, son Prince and daughter Princess for their support.

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ABSTRACT

Water quality is one of the indicators that can provide consumer confidence in drinking water distributed in the City of Nairobi. A safe water supply is crucial to public health hence the quality of portable water may have negative consequences on the general public health, the water's taste and odour. Kenya's capital city, Nairobi, faces several water challenges such as water shortages which could lead to the distribution of substandard water. The aim of this study was to investigate the portable water quality and provision specific to assessing point-of-use water treatment systems, determining selected quality parameters, evaluating the efficiency of water treatment techniques and assessing the portable water packaging for the various brands marketed in the City of Nairobi, Kenya. Water samples were randomly obtained from thirty two households, twenty eight shops and supermarkets and twenty eight water vending stations. The physical, bacteriological, and chemical properties of the water samples were analysed using spectrophotometry for the colour test, glass–electrode method for pH analysis, multiparameter-photometer for the Fluoride test, Microwave Plasma Atomic Emission Spectrometer for Iron (II), Manganese and Silicon ions, and Most Probable Number method for microbial tests. Analysis of residual Chlorine was done at the point of sampling as opposed to laboratory-based analysis of bacteria, pH, colour, conductivity and chemicals. The study indicated that 12.5 % of the household population living in Nairobi sterilized their water chemically or through boiling. Additionally, 87.5 % of the household population under study consumed untreated water. Water boiling was an effective method of water sterilization compared to the chemical method since it killed bacteria and viruses that are the major causes of waterborne diseases. The presence of *Escherichia coli* and faecal coliform contamination was detected in twenty of the sampled households. This represents 62.5 % of the household population consuming contaminated water. Bottled water from supermarkets and shops recorded nil of *Escherichia coli* and total coliforms. However, 50 % of water samples from vending stations recorded levels ranging from 1 to 35 MPN/ 100 ml of total coliforms while 18 % recorded 1 to 8 MPN/ 100 ml of *Escherichia coli*. Moreover, a total population of 6.82 % was found to be taking water with Fluoride above the recommended limits. The recommended Fluoride level in drinking water is 1.5 $mg.L^{-1}$ according to KS EAS 153:2018 – standard on purified water and KS EAS 12:2018 – potable water specifications. The Point-of-Use treatment techniques found include boiling and use of Sodium Hypochlorite at 6.25 % in households, bottled water at 100 % in shops, kiosks and supermarkets, and reverse osmosis at 100 % in water vending stations. The quality of selected parameters was 13.6 % within the set specifications. This means, 86.4 % of the total population in the City of Nairobi is drinking unsafe water. The efficiency of the various water treatment techniques used for bottled water from supermarkets, shops and water vending stations was 80 %. Furthermore, portable water packaging compliance was 42.9 %. Households should consider boiling water as a means of treatment over the use of Sodium Hypochlorite. Additionally, Water quality should be monitored on a regular basis among vendors and bottling industries as Kenya Bureau of Standards strictly enforce compliance with portable water packaging. The findings of this study have revealed that the population of Nairobi is vulnerable to substandard water quality in terms of pH, colour, conductivity, residual Chlorine, Fluoride ions, Iron (II) ions, Silicon ions, Manganese ions, total coliform and *Escherichia coli*.

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LIST OF ABBREVIATIONS AND ACRONYMS

AL	Action Level
AMCOW	Africans Ministers' Council On Water
AWWAR	American Water Works Association Research Foundation
BSF	Biosand Filter
DPD	N,N-diethyl-p-phenylenediamine
DWDS	Drinking water distribution systems
GWA	Gender and Water Alliance
HWT	Household Water Treatment
IBWA	International Bottled Water Association
IDA	International Disaster Assistance
KEBS	Kenya Bureau of Standards
KNBS	Kenya National Bureau of Statistics
LDPE	Low-density polyethylene
MPN	Most Probable Number
N.D	Not Detectable
NCCAP 2018-2022	National Climate Change Action Plan 2018 -2022
NCWSC	Nairobi City Water and Sewerage Company
NEMA	National Environment Management Authority
PET	Polyethylene Terephthalate
POU	Point of Use
R.C	Residual Chlorine
RO	Reverse Osmosis
SODIS	Solar Water Disinfection
T.C	Total Coliform
TDS	Total Dissolved Substances
TGWC	The Glasgow Whisky Company
UN	United Nations
UNDP	United Nations Development Programme
UNICEF	United Nations International Children's Fund
UV	Ultraviolet
WASREB	Water Service Regulatory Board

WBAK	Water Bottlers association of Kenya
WHO	World Health Organisation
WOP	Water Operators Partnerships
WRA	Water Resources Authority
WSP	Water and Sanitation Program
WUP	Water Utility Partnership

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Portable water is defined as drinking water treated at the point-of-use which can be moved physically from place to place that include bottled water in supermarkets, shops, kiosks, vending stations and households comprising of harvested water. The basic human right is to have access to water and every human needs it (UN water, 2015). A large number globally still lack quality drinking water. Approximately 6 million die every year globally resulting from disasters and water borne diseases (UN water, 2015). Contamination of water sources by faeces or direct contact with children has been associated with about 700,000 deaths amidst young ones below five years of age annually (UN water, 2015). Globally, three billion people are approximated to live under water stress by 2035 (Nganga *et al.*, 2012). Increase in urbanization stands to be the leading factor of water scarcity in Africa continent where an increase in population in urban areas is estimated.

Kenya's current water per capita is 647 m^3 which is an indication of limited water supply (WRA, 2019). Unfortunately, the water per capita is projected to further decline at a rate of 359 m^3 in a year with estimations indicating that Kenya's per capita water supply will be about 235 m^3 which will translate into two third short of the current per capita. The latter has been associated with the increase in population. Kenya's present per capita of water supply is significantly low compared to the global standards of 1000 m^3 annual per capita ((WRA, 2019). To enhance water accessibility and the availability of safe drinking water, there is a need for quick action and planning.

The aim of National Climate Change Action Plan 2018–2022 is to improve annual water availability per capita to 1000 m^3. To achieve this goal, the plan advocates for concrete actions to strengthen the water sector's resilience by ensuring adequate access and efficient use of water for wildlife, manufacturing, agriculture, and other purposes. The planned water-related climate change actions include women who help to reduce water waste at the household level and, to some extent, help water agencies reduce waste. The actions also help to advance the blue economy by encouraging low-carbon actions in the maritime sector, establishing coastal infrastructure that can withstand projected sea-level rises and storm surges, and assisting coastal fishing communities in surviving in a changing climate.

Currently, Kenya has population of people that lack access to quality water which has caused continuous use of poor quality water or travelling long distances and queuing for water access points (Uwazi, 2010). In addition, Uwazi (2010) observed that non-marginalised people have direct access to piped water that is directly supplied to their houses at reduced costs as opposed to marginalized populations that struggle to access quality and sufficient amounts of water. Due to economic pressures of unemployment across Africa and in Kenya, the region has experienced massive rural to urban migration in search for greener pastures. Many of the informal settlements in Kenya lack constant water supply. Approximately two thirds of the Africans in cities are currently living in these types of settlements (WSP, 2005). Sixty five percent of homes in 2009 were able to access improved sanitation services. Between 2015 and 2016, the rate of access went up to 65.2 % (Development initiatives, 2015). In Kenya, sustainable supply of quality and safe water was estimated to be 60 % and 40 % in urban and rural areas respectively (Development initiatives, 2015). Consequently, adequate supply of quality water in pH, colour, conductivity, residual Chlorine, Fluoride ions, Silicon ions, Iron (II) ions, Manganese ions, total coliform, *Escherichia coli* among others that is an essential aspect of sanitation has been on a decline.

1.2 Problem Statement

Kenya's capital city, Nairobi, has the largest population compared to other parts of the country indicating portable water demand. This has led to increased number of water vendors in the city (Nganga *et al*., 2012). Nairobi's insufficient water supply system is unable to accommodate the city's large population because it was not built to supply water to more than 4.3 million people (KNBS, 2019). As a result of the increase in population and decrease in water supply, poor quality portable water ends up in the market and more specifically at the point-of-use. The poor quality of portable water supplied is of health concern (Kaluli *et al*., 2011). A substantial number of residents in the country's capital city lack access to water and are compelled to rely on vendors to meet their domestic needs (Nganga *et al*., 2012). Similarly, majority of Kenyans have access to poor quality water a situation that has been linked to the outbreak of waterborne diseases such as cholera that has profoundly dented people's health and livelihoods (Nganga *et al*., 2012). Ruiru public health records indicated that about 30 % to 40 % of the total patients that sought medical attention in 2010 were cases of diarrheal who suffered from diseases like typhoid and amoebiasis (Kaluli *et al*., 2011). Determining the portable water's quality index is necessary for this reason. The treatment techniques utilized and the hygiene of the storage

facility are what determine the quality of the water distributed. Therefore, it is crucial to look at the effectiveness of the treatment methods. The quality of the water consumed at the point-of-use is also significantly influenced by the compliance of portable water packaging. As a result, it is imperative to investigate the packaging material's level of conformity with the KS EAS 153:2018 guidelines for the packaging of drinking water.

1.3 Objectives

1.3.1 General Objective

The general objective of this study was to investigate the portable water quality and provision in Nairobi City, Kenya.

1.3.2 Specific Objectives

The specific objectives of this study were:

1. To assess point- of- use water treatment systems in the city of Nairobi.
2. To determine selected quality parameters in portable water in Nairobi City.
3. To evaluate efficiency of portable water treatment techniques in the city of Nairobi.
4. To assess the portable water packaging in the city of Nairobi.

1.4 Justification of the Study

This study is significant because it provides data on the types of water treatment systems at the point-of-use, the potability of portable water, the effectiveness of the portable water treatment techniques, and the level of compliance of portable water packaging in the City of Nairobi.

1.5 Significance of the Study

The results of the study will aid in the implementation and improvement of water treatment systems at the point-of-use, the quality of portable water, the efficiency of the treatment methods, and portable water packaging by the relevant government institutions, authorities, industries, and households.

CHAPTER TWO

LITERATURE REVIEW

2.1 Global Water Availability and Water Sources

In order to fight poverty, hunger and diseases, developing countries need growth in accessing water and service delivery. All over the world, Africa has the least coverage of water supply. Large number of low-income earners depend on over one source to obtain the water needed to survive (Hassan *et al.,* 2018). A number of households acquire water from sources that include vendors, water kiosks, supermarkets, mini-supermarkets and harvested water by landlords.

Urban water usage is anticipated to grow by double digit by 2025 due to urbanization that exerts pressure on access to water in urban and peri urban areas that is as a result of speedy population growth, poor planning, competing needs on the water resource and poverty (GWP, 2012, Hassan *et al.*, 2018). Global urban population growth is anticipated as 2 billion from 2000 to 2025 and this may result to the whole population increase in decades to come being solely urban population and specifically in Asia and also Sub-Saharan Africa (Aquaya, 2009, Lundqvist *et al*., 2014).

Urban water distributors and authorities continue to face significance challenge to feed the growing need for sanitation and water in many countries as they try to achieve sustainable urban water system (Mahgoub *et al*., 2010). Lack of access to quality water and hence poor sanitation levels in urban areas is as a result of exponential population growth or lack of political will to intervene in resolving the water challenges in developing countries (UN, 2015). Some of the factors that determine the quality of the water that is provided to its consumers are the number of people sharing a common water source, accessibility, the distance between the water sources, the quality of the water, and the amount in litres per capita per day (Moriarty *et al.,* 2011).

The major challenge facing a big number of water utilities in urban areas is significance expansion of water access to cater for the demand of an increasing population (UN, 2015). Large number of water utilities in Africa get only 50 % revenue from water production which is the major weakness making it a challenge for them to meet the overall production and operating costs.

The percentage of water piping in the country ranges from 42 % to 59 % which proves that approximately 50.5 % of Kenyans are lacking water access (World Bank, 2009). In the City of Nairobi, Kenya, only 2 % of middle-class families have access to water kiosks; by contrast, 36

% of poor households have access to water kiosks, which is a third greater (Uwazi, 2010). This is an indication of lack of equity in water service provision.

In the early 1990s, Nairobi City Council made water connections to consumers in Kibera which formed principal outlets and 64 % of 1,014 connections accounted for water kiosks (Uwazi, 2010). Nevertheless, the water pipes are placed beside open sewers by the kiosk owners. The open sewers contain solid waste and polluted water. This clearly indicates that the quality of water distributed is contaminated. Among the factors that contribute to water contamination include poor storage and lack of hygiene in water handling. Outlandish water supply found affects negatively on social-economic activities according to a study done at Githurai (Ngima, 2015). In this regard, there is a need to investigate provision, evaluate the quality distributed, packaging integrity and evaluate the efficiency of water treatment methodologies of portable water in the city of Nairobi. Acquiring the latter understanding is essential in catering for the needs of Nairobi's growing population.

Water treatment methodologies involve some of the following steps; collecting, screening, straining, adding of chemicals, coagulating, flocculating, sedimentation, clarification, disinfecting, storing, and later distributing. Other processes include use of reverse osmosis, Ultraviolet, Hydrogen Peroxide and ultrafiltration among others. This research will evaluate efficiency of these treatment methodologies in the city of Nairobi.

Aberdare ranges, that is among the five water towers in Kenya, is the water source for Sasumua, Ruiru, and Ndakaini dams that feed Nairobi with water. Additionally, Nairobi City Water and Sewerage Company (NCWSC) is mandated with water collection and distribution within the metropolis. Unfortunately, the water quality in Nairobi is being affected by both natural reasons such as levels of Fluorine above 1.5 ppm in phreatic water and human reasons such as poor wastewater and solid management practices.

2.1.1 Water Quality

The quality of water supplied to consumers is one of the key determinants of the quality of service being offered. It is in consensus that the quality of water has an impact on the aesthetic value of water and the health of the public. Kenya is categorized as a water scarce country with 647 m^3 of renewable freshwater per capita well below that of the global standards of 1000 m^3. Worsening the situation are the multiple setbacks with the water distribution in Nairobi that leads to significant effects on the water quality.

Malathy *et al*. (2017) put forth that determining the quality of water that is being consumed is an important aspect. A train of thought advanced by Naidoo and others with their conclusion that drinking water that is quality and appreciable levels of sanitation are crucial components for the sustenance of life on earth (Naidoo *et al., 2013).* A study by Nyagwecha *et al.* (2017) linked the use and consumption of contaminated water to illness across the world and specifically to developing countries such as Kenya. Below is a photograph taken during water sampling at Rurii village, Mountain View ward in Westland sub-county showing residents fetching water from a spring.

Figure 2. 1: Resident fetching water from a spring in Westland sub-county

According to Nyagwencha (2017), there are 2.6 billion people in the world who are lacking access to clean water and as a result water-related diseases lead to 3.4 million deaths mostly in children every year (Malathy, 2017). According to United Nations Children's Fund (UNICEF) assessment, contaminated water leads to 4000 children mortalities daily in the entire world. By just raising the quality of the water people drink, Malathy *et al.,* (2017) estimated that the global illness burden could be reduced by around 4% annually.

Water is a basic need for life on earth and as espoused by Rashid *et al.,* (2018) accessibility to safe water for consumption is a human right grounded on its determination for a healthy life. Evidently, Sustainable Development Goal 6, highlights the importance of water accessibility for everyone within the context of achieving sustainable development. However, the burgeoning demand for water tied to global pollution, increased population, and creation of urban areas diminishes the availability of safe water for consumption. In specific, there are challenges along the water distribution networks and not at the sources of water that hamper the quality of water in supply. United Nations (2019) emphasizes on the need to enhance the water quality by mitigating global pollution, increasing water treatment levels, advocating for water recycling and reusing water if it is safe.

According to Vidija (2019), Nairobi residents have either consumed or are being exposed to water that is contaminated a factor that has contributed to incidences of increased cases of waterborne diseases such as cholera. A report by UNEP (2009), Nairobi's water quality is compromised by the presence of Fluoride levels above 1.5 ppm content mostly from the groundwater and resulting human activities such as the poor management of waste.

Methods in risk assessment that not only examine absence or presence of pathogens or chemical concentrations in water but also disease risk are the guidelines for quality water assessment (WHO/UNICEF, 2016). Domestic water uses accounts for 5 % of total water consumption globally and the percentage should be protected in terms of quality since water is a basic need. Public health and hygiene are influenced by water quality delivered and used by households which is a major feature of supplies in domestic water (WHO, 2013). The absence of sufficient supply of water and sanitation amenities is a cause to millions of avoidable deaths among the globe's poorest. Additionally, hundreds of millions more continue to suffer as a result of waterborne diseases that torment their lives for example worm infestations and typhoid (Forstinus *et al.,* 2015).

The dissimilarity in safe water availability where 60 % of deaths in children is as a result of diarrheal disease caused by water that is of low-quality, poor hygiene and degraded sanitation is definitive of world health inequalities. Children and women are mostly affected by water that is polluted since they are more into contact with it from collection and drinking (Cap-Net, GWA, 2006). According to IDA (2009), approximately 1 billion people in the world lack access to clean drinking water. Contamination of water may occur from the point of collection, transportation, storage and also increased collection time (Kayser, *et al*., 2013).

The average residents in Kibra get treatment in every three months for water borne diseases (Kaluli *et al*., 2011). This is a clear indication that an average of the population drink

contaminated water. About 30 to 40 % of patients going for treatment turn out to be diarrheal disease. The results from this study will be used to fill in the gaps in the quality of portable water, providing a path for future quality improvement.

2.1.2 Distribution Channels

Water coverage currently stands at 59 % in urban and urbanizing areas in Kenya. The trend in coverage has been growing albeit slowly, with a growth of only four percentage points in the last five years (WASREB,2020). Water access issue has been a worldwide concern. Millennium Development Goals that were abandoned in 2015, outlined water access as a concern, consequently, outlining the need to half the population of people lacking access to safe drinking water. Since 1990, about 2.6 million people globally were able to access sources of clean drinking water (Millennium Development Goals Report, 2015).However, 40 % of people globally are affected by the issue of water scarcity and the number is anticipated to increase (UN, 2015).

Despite of coverage growth from 56 to 66 % in 1990 and in 2010 respectively in drinking water, the population dependent on unimproved source of drinking water stood up from 279 to 344 million in 1990 and 2010 respectively (AMCOW, 2012). In 2010, there were 65 million people in Africa who lacked the access to clean water sources that presented a worse situation than in 1990 (AMCOW, 2012). An upgraded drinking water is a source that is likely to give drinking water that is safe in comparison of convectional drinking water sources as stipulated by Joint Monitoring program. This is by the nature of its construction in which water source is prevented from faecal contamination (WHO/UNICEF, 2006).

2.1.3 Physical Accessibility

Physical accessibility suggests that sufficient quantities, acceptable and safe water should be available within the nearest vicinity of each workplace, educational institution and household (UNDP, 2006). The time taken to access water must not exceed thirty minutes while the distance to the source of the water must be within or in 1000 metres of household (WHO, 2003). Both the marginalised and most vulnerable groups must be included in this. Children and women spend one hour on average per trip collecting water in low-income countries reducing attendance in school children leading to musculoskeletal injuries and related disabilities as a result of carrying water. In Asia and Africa, women walk for 6 kilometres on average to collect water (UNDP, 2006).

The city of Nairobi households on average takes fifty four minutes to the kiosk during normal times, and over twice (one hundred and twenty six minutes) amid water scarcity times and the situation worsens in other places (Uwazi, 2010). Some of the villages in Kibera, the water collection time is approximately 10 - 30 minutes whilst other villages experiencing frequent water shortage takes them approximately fourty minutes to get water (Hakijamii Trust, 2007)**.** In Southern Kenya, studies show the rate of water scarcity is rising in pastoralist areas where they have to walk for long distances looking for water to feed their cattle since boreholes, the major sources of water, are accessible 25 kilometers afar of and others tend not function (Langendijk *et al.*, 2014).

2.2 Point-of-Use Water Treatment Systems

Water borne diseases are prevalent in developing countries as a result of shortage in safe water. However, people that are not able to access clean and safe water for consumption have an alternative with point-of-use (POU) water treatment technology. Consequently, there are numerous point-of-use water treatment technologies in application with boiling having gained sustained and a wide-use. Sustained use of household water treatment technology (HWT) is termed as that which is able to provide quality water for a prolonged period which is hard to realize. Point of use house water treatment technology that receive wide advocacy based on their effectiveness undergo rigorous performance and sustainability checks (Hug *et al.*, 2020). Filters made from biosand and ceramic are viewed as very effective based on the existing evaluation criteria. As a result, they are perceived to have the highest potential for extensive use and are equally lauded for promoting water quality therefore mitigating the incidence of waterborne diseases and resulting fatalities (Camille *et al*., 2021).

Globally, one billion people depend on unsafe surface and groundwater due to lack of access of decent sources of water. It is also important to note that there are populations who have access to somewhat improved water sources such as piped household water, standpipes in public places, and boreholes may be exposed to water that does not meet the microbiological standards. As a result, improved water supplies may contain pathogens that are responsible for causing infectious diseases. Moreover, absence of safe water has been associated with direct infections and indirectly causing enteric health effects such as growth and development retardation, neurological syndromes, and reactive arthritis (Kosek *et al*., 2003).

Among those adversely affected by diarrheal diseases are children under the age of five years that experience an annual fatality of 1.6 million (Fewtrell *et al.*, 2005) . Diarrheal disease has

a higher frequency of occurrence in developing countries with cyclical occurrence (Kosek *et al*., 2003).There is empirical evidence suggesting that interventions aimed at enhancing water hygiene and sanitation therefore improving the quality of household drinking water have in the past been underestimated in reducing the outbreak of diarrheal disease. Improving the quality of household drinking water has a substantial decline in the frequency and occurrence of diarrheal with about 30-40 % reduction (Clasen *et al.,* 2007). Consequently, the purpose of applying point-of-use household water treatment and sound water storage practices is to improve the quality of house-hold water. Notably, there are several POU technologies that are the disposal of the legislators, practitioners, and end users that fit various circumstances and populations. This is based on the fact that all POU technologies have been tested and given out for sale but neither of them has similar efficiency nor sustained use. Among the challenges that confound the desire for an informed choice of POU technologies is the absence of reliable empirical evidence of beneficial health impacts, improved water quality over time and proof sustained use. (Clasen *et al.,* 2007).

The POU technologies are as follows.

2.2.1 Chlorination with Safe Storage.

The United States Center for Disease Control (CDC) advocated for the use of POU free chlorine (hypochlorite) treatment. However, it has been reported that water that are concentrated with of organic particles has the probability to limit the efficacy of chlorine disinfection (Thomas, 2018). The latter results to formation of compounds that have undesirable taste and odor which results to end-users and almost the same appearance of water (Clasen *et al.,* 2007).

2.2.2 Combined Coagulant-Chlorine Disinfection Systems.

In these types of Point of Use (POU) technology, dry coagulant-flocculant and chlorine that is usually in form of tablets or granular particles wrapped in sachets is combined with commercial technologies before being put in water. Examples of commercial technologies include Water Maker. By eliminating turbidity, bacteria, and organic matter through flocculation and settling, combined coagulant-chlorine disinfection systems can visually improve water quality while also increasing the Chlorine's effectiveness (Clasen *et al.,* 2007).

2.2.3 Solar Water Disinfection (SODIS)

In this technology, aerated water that is intended for treatment is filled in bottles made of transparent polyethylene terephthalate (PET) which are later exposed to Ultra-Violet energy from the sun for heating during the day. However, UV has limited penetration making SODIS ineffective in treating water with concentrated turbidity and bottles that are easily scuffed. One of the shortcomings of this technology is that users are not able to determine at what point is the water turbidity concentrated or when the color is inappropriate and the bottles too used to enable sufficient penetration of ultra-violet light (Clasen *et al.,* 2007).

2.2.4 Ceramic Filter

Another point-of-use technology that is used to filter out microbes depending on their size, remove turbidity, organic matter and microbes is the porous ceramic- fired clay (Sobsey *et al.*, 2007). One of the main distinctions between use is that ceramic candle filters are extensively used in developed countries which are produced to fit specific demands and candle or pot design are commonly found in developing countries where efficiency levels vary. Ceramic filters are simple to clean and therefore restoring efficacy and flow rate with increased accumulation of particulate matter (Clasen *et al.*, 2007, Haiyan *et al.*, 2020). A point-of-use ceramic filter is depicted in Figure 2.2 below.

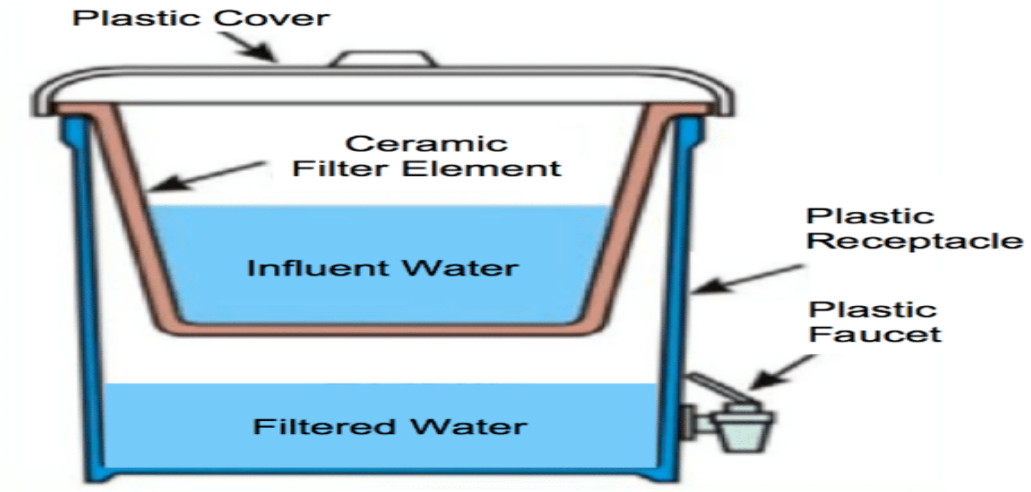

Figure 2. 2: Ceramic filter.

2.2.5 Biosand Filter

Biosand filter is a wide-scale slow operated sand filter that is modified to operate on large scale by batch wise dosing of household water. This technology has the ability to remove the water turbidity, organic matter, and microbes which adds to its other advantages of easy to clean and restore efficacy (Clasen *et al.,* 2007). The diagrammatic and photographic views of the Biosand filter are shown in Figure 2.3 below.

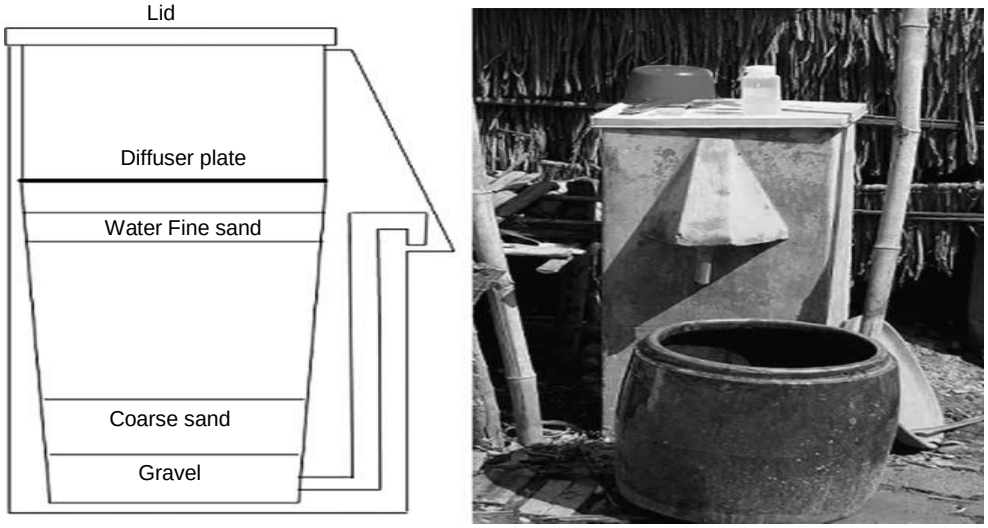

Figure 2. 3**:** Biosand filter.

2.3 Other Water Treatment Systems

The various water treatment systems are discussed in the following subsections.

2.3.1 Boiling

Bacteria, viruses, protozoa, helminths and other pathogens found in drinking water are effectively killed when water attains boiling temperatures. Nonetheless, water contamination as a result of chemicals such as arsenic is not resolved through boiling.

2.3.2 Reverse Osmosis

Membrane technology was first used to obtain drinking water from sea water through reverse osmosis (RO). Reverse Osmosis makes use of a semipermeable membrane to filter out dissolved solutes such as charged ions, sodium and chlorine ions. RO is construed as a form of diffusion that is controlled and where ions diffuse through membranes. However, in comparison to other filtrations systems, there are no physical holes. This technology is termed to be hydrophilic- water loving- allowing water to readily diffuse through the polymeric membrane structure and sieving out solutes with a size of 0.001 micrometers.

Plate and frame, tubular, spiral wound, and hollow fiber membranes are the four types of reverse osmosis membranes. The spiral-wound module is the most commonly used of the four types in the purification of drinking water. Reverse osmosis configuration either involves a single stage, two stages, or two-pass system. The desired quality of the purified water determines the choice of the RO configuration. The pass system produces the highest quality of water and is preferable in the preparation of make-up boiler water. It is also important to note that the single stage system has the simplest layout giving it popularity in terms of use among the various desalination applications. The two-stage system is more preferred for the filtration of brackish water where an overall recovery ratio is needed (Nicolaisen, 2002).

Reverse osmosis has gained wide popularity in industrial applications mostly for the purposes of separating solutes from solvents. Further, RO is being used for desalination in residential settings to obtain better taste in water and to get rid of contaminants. Brackish water is currently portable adding to water supplies by making use of reverse osmosis. Consequently, desalination is being used in water-scarce areas to obtain fresh water. As a result of technological advancements of the membrane materials and pre-treatment processes, reverse osmosis has increasingly become economically viable even in the desalination of seawater. More so, the scale of reverse osmosis applications has become vast with plants with excesses of 19,000 m^3/d being is use.

The factors that have been associated with the increased application of reverse osmosis is its economical operation and simplicity in use. Current developments in reverse osmosis technology have enabled its application in low pressure- the membrane is able to reject salt at 7 bar which is far much less than the initial cellulose acetate membrane at 28 bar. These types of membranes are able to reject more salt at lower pressures and yet pass more water. There is also a noted increase in separation efficiency in some special types of membrane from 97 to 99.5 % has been observed with newer membranes. RO has a simple layout compared to the large-scale thermal desalination processes further adding to its advantages. It also has a modular design which allows for extension and therefore increased production capacity. In addition, the specific power consumption of reverse osmosis is about 5 kWh/m^3 which makes its significantly low and similar to the pumping power of major thermal desalination processes (Khawaji, 2008).

A notable setback that is associated with Reverse Osmosis is that it can't operate on the surface of feed seawater. Further, compared to thermal desalination processes, RO membranes are more sensitive to scaling, fouling, chemical and biological attacks with the fouling being a major concern. As a result, RO is viewed more as an energy efficient alternative to thermal

desalination processes but faces competition from other technologies due to the pre-treatment requirements (Khawaji, 2008). A stepwise process of water treatment using reverse osmosis membranes is depicted in figure 2.4 below.

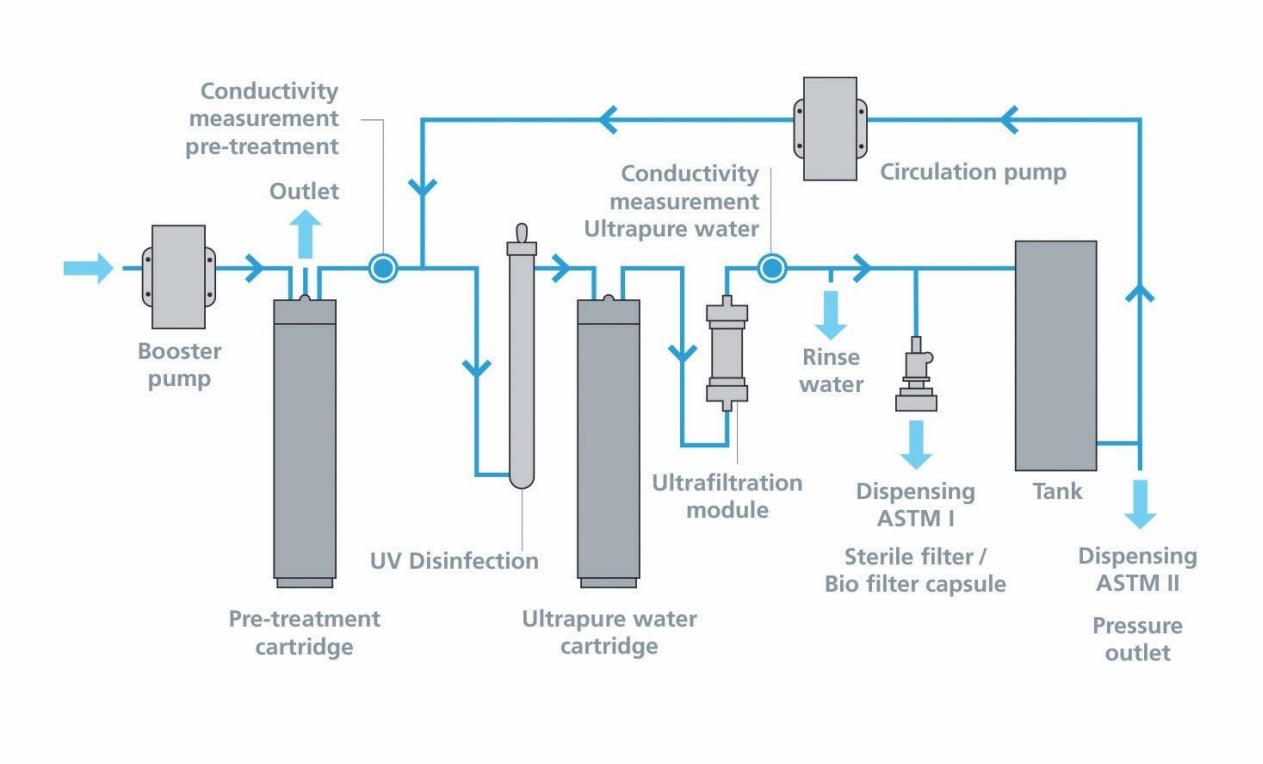

Figure 2. 4: Reverse Osmosis treatment method

2.4 Selected Quality Parameters in Drinking Water

2.4.1 Colour

The absorption of specific wavelengths of light by coloured compounds causes true colour. True colour is defined as the colour of water produced solely by dissolved substances; all suspended substances have been eliminated and are thus unable to "conceal" or alter the water's colour (APHA, 2005).One of the quality parameters used to define water is its' colour. Based on colour, water can either be defined as having an apparent or true color .

2.4.1.1 Apparent Colour

Water's apparent colour is that as observed by the human eye with distinct colours such as blue or green and is usually as a result of either dissolved substances or suspended materials. It is however important to note that there are other factors that dictate the colour of water, including that of the holding material (Roger, 2002).

Scientists from Europe, developed Forel-Ule colour scale for water management professionals to determine the colour of water. The Forel-Ule scale has twenty two water colours ranging from blue to brown. Apparent color of water is determined by visually matching the color of the water sample to that on the color spectrum of the Forel-Ule scale. However, the Forel-Ule scale is not widely used in the United States for being cumbersome and difficult to use (Roger, 2002).

2.4.1.2 True Colour

To determine the true colour of water, all suspended substances are removed. Once the water has been filtered, it is compared against a specific colour scale usually on a laboratory spectrophotometer. Platinum-cobalt units (PCU- or Pt-Co units) is the most used colour scale which compromises of 1,000 colour units (Roger, 2002).

2.4.2 Conductivity

The conductivity of water is a measure of its ability to conduct an electrical current. Inorganic dissolved particles such as chloride, nitrate, sulfate, and phosphate anions (ions with a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations affect water conductivity (ions that carry a positive charge). Oil, phenol, alcohol, and sugar are organic substances with low conductivity in water because they do not transmit electrical current well (APHA, 1992).

2.4.3 Residual Chlorine

The low-level amount of chlorine left in the water after a particular period or contact time after its first application is known as residual chlorine.

2.4.4 Fluoride Ions

Fluoride has both positive and negative effects on humans, depending on the total amount consumed. Fluoride is commonly found in drinking water, although it is not always the case, and Fluoride is sometimes added to public water supplies to assist prevent dental cavities. Fluoride is known to be unsafe in limits above 1.5 ppm and intake of Fluoride from water is absorbed and transmitted throughout the blood system (Ekstrand *et al., 2005*).

Fluoride is absorbed through the human skin just like hydrofluoric acid. It is also absorbed through passive diffusion from the stomach inversely proportional to the pH. However, after

the emptying of the small intestine Fluoride is rapidly absorbed (Ekstrand *et al., 2005).* About 99 % of the absorbed Fluoride is circulated within the body through the blood. It is deposited in the teeth and bones and rarely does it accumulate in the soft-tissue. Conversely, kidneys in the human body often reflect high Fluoride concentrations and even higher in the plasma. Therefore, kidneys are probable sites for Fluoride toxicity. Notably, Fluoride in the form of Hydrogen Fluoride can be found in the intracellular fluids and is determined by the concentration in the blood. Nonetheless, an intake of a diet with substantial amounts of Calcium or Calcium carbonate hinders the absorption of Fluoride (Jacks *et al*., 2005).

The human placenta is able to regulate the movement of Fluoride from the maternal blood to that of the fetus. Consequently, Fluoride is poorly diffused from the plasma to the milk with some measures indicating 5-10 micrograms per liter. The levels of Fluoride in plasma matches the levels in the saliva, normally, ingested Fluoride finds its way out of the body through the saliva. Elsewhere, Henschler et al. observed that the levels of Fluoride in sweat are comparatively low at about 20 % of the plasma levels. The Fluoride excreted through the renal ranges from about 35 to 70 % in grown-ups. As a result, Fluoride exposure levels can be determined through the analysis of the urine, plasma or saliva. It was also concluded that the levels of Fluoride in the fingernail clipping of children was proportional to that of the water they were drinking in Hungary and Brazil. Consequently, it was concluded possible to use fingernails clippings as a biomarker exposure though Fluoride in fingernails is observed three to six months after consumption. However, the latter is not clearly standardized against those of the bone and plasma concentration (Henschler *et al., 2005).*

Adults living in areas with Fluoride concentrations between 0.3 $mg.L^{-1}$ to 1.0 $mg.L^{-1}$ normally report a mean intake of between 0.004- 0.014 mg/kg/day and 0.02 to 0.048 mg/kg/day respectively. Among children, the daily intake of Fluoride is between 0.03-0.06 mg/kg/day in areas that has fluoridated water and between 0.01 to 0.04 mg/kg/day in those without. Bottle-fed infants with milk formula made from water containing Fluoride, reportedly ingest 0.12 to 0.18 mg/kg/day and those with weights between 8.1 kgs at the ages of 6 months have a total Fluoride intake of 1.0 to 1.5 mg/day. Despite (Liang *et al.,* 2013) suggesting that Fluoride intakes of 0.15 to 0.25 mg/kg/day have no observed adverse effects, there is a ranging scientific debate (Liang *et al.,* 2013).

According to a survey by (Nair *et al*., 2004) Fluoride levels in Kenya ranges from between 1 to 8 ppm. Within the population, Fluorosis incidence levels were reported to be between 11.7 to 56.5 % across the provinces which showed close relationship with the area's water Fluoride levels. Fluorosis levels in Kenya range between 44 to 77 %. However, there are areas where

the dental Fluorosis levels are considerably higher than what would be expected from the Fluoride present in the drinking water. People consuming borehole water with Fluoride at about 18ppm have been reported to suffer from skeletal Fluorosis (Nair *et al*., 2004).

2.4.5 Dental Effects of Fluoride

2.4.5.1 Dental Caries

Dental caries causes the demineralization of inorganic components of the teeth and the dissolution of organic substance of microbial aetiology. Dental carries are a multifactorial disease that is caused by bacterial- streptococcus mutans and lactobacilli- activity within unhygienic oral cavity (Kaimenyi, 2004). Through fermentation the latter leads to formation of lactic, propionic, and acetic acid which corrodes the enamel creating black spots on the teeth known as tooth cavity. It is possible for the bacterial activity to go through the dentin and get to the soft pulp tissue. Un-attended cases on caries result to pulpal necrosis, loss of the dental function, extraction of teeth, and other infections (Susheela *et al.*, 2003).

2.4.5.2 Dental Fluorosis

Dental Fluorosis is an infection in the tooth forming cells known as ameloblasts whose early signs of attack are visible. It is a form of hypocalcicification that extends to staining the enamel. Dental Fluorosis has been argued to be a result of a delay in the hydrolysis and subsequent removal of amelogenin matrix proteins that are necessary during enamel maturation and crystal growth (Neurath *et al.*, 2005). Ameloblasts secret amelogenins that prevent the formation of enamel crystallites. To facilitate crystallite growth during the early stages of tooth maturity, amelogeninases removes amelogenins. Fluoride levels above 1.5 ppm greatly affect the enamel maturation stage as the Calcium rich composition of the teeth- enamel and the dentin- easily reacts with Fluoride to form Calcium Fluoropatite crystals. Therefore, with the accumulation of Fluoride, the teeth loose Calcium making it weaker due to the loss of Calcium ions- making the teeth weaker. Fluoride causes the enamel to be porous, pitted, discolored and susceptible to wear and fracture due to the corrosion of the mineralized zone. Teeth fracture is usually as a result of structural alterations, reduction of the mineral content, morphological aberrations and the damage to the enamel mineralization (Parnell *et al.*, 2009).

Dental Fluorosis causes teeth discoloration from white, yellow, brown and finally to black which usually appear as spots or streaks with an asymmetrical orientation as layers continue to form through the tooth development. Consequently, Fluoride strains are seen as patterns

throughout the teeth development and not as single strands. Teeth discoloration as a result of Fluoride occurs on the surface of the enamel far from the gums, therefore becoming part of the tooth matrix which makes the enamel lose its shine appearance. Discoloration along the teeth periphery and the gums is mostly as a result of other causes such as tea stains, tobacco, smoking, or chewing coffee. Dental Fluorosis appears as horizontal lines and not as vertical brands because enamel strands are deposited as incremental layers at prenatal and postnatal periods (Parnell *et al.,* 2009).

2.4.3.2 Skeletal Fluorosis

Long exposure and resulting accumulation of Fluorosis leads to fragile bones and low tensile strength affecting both the joints and the bones. Skeletal Fluorosis is only detectable at advanced stages and in the early stages, its symptoms may appear similar to those of arthritis. Skeletal Fluorosis affects millions of people in India, China, and Africa with its severe form manifesting as disability. The latter is a major public health concern with significant socio-economic impacts (World Health Organization, 2002).

Absorption of Fluoride by the skeletal surface is determined by the age and type of the bone with younger bones and cancellous ones being more susceptible. For example, the amount of Fluoride found within the pelvis and the vertebrae is usually higher than that in the limb bones which further depends on the activity of the muscles that are attached to them. While the individual effects of Fluoride depend on the duration of exposure, aspects such as age and sex are important determinants (Wang *et al.,* 2004). A percentage of Fluoride (99 %) is found in the bones and a relatively few amounts in the teeth with the rest of the amount in the body being distributed in the vascularized soft tissues and blood. Healthy tissues and organs are less susceptible to Fluoride compared to cancellous and actively growing parts of the body. As the amount of Fluoride increase in the body, its uptake gradually decreases to assume a plateau like shape at about fifty years of age. However, correlational studies of Fluoride levels as a function of age and water Fluoride concentration (Reddy, 2000).

Fluoride in the body influences the chemical composition and the physical structure of the bones. Skeletal accumulation as a result of long-term exposure to Fluoride leads to bone fractures and skeletal Fluorosis which represents the most serious effects of Fluoride. Fluoride has been reported to influence the accretion and resorption of bone tissues that later on affect the homeostasis of the metabolism of bone mineral (Liang *et al.,* 2013). Bone lesions are characterized by a combination of osteosclerosis, osteomalacia, and osteoporosis all to varying

extents. Fluoride toxicity is characterized by the metabolic turnover of the bone, disfranchised synthesis of the bone collagen, and increased Calcium avidity. The latter is with the addition of changes to hormones responsible with the creation of bone mineral. Several other structural deformations occur, which include growth of cartilaginous lesions in malignant bones, increase in the osteon diameter and trabecular bone volume, cortical porosity, mottling of oteons, exostosis on the bone surfaces, and increased bone mass and density (Susheela *et al.*, 2003).

Empirical evidence suggests that Fluoride ions swap with hydroxyl ions with the likelihood of even replacing bicarbonate ions that have a relationship with hydroxyapatite. The latter is a mineral inter-stage which occurs during the bone formation process of hydroxyflouropatite and has substantial effects on the bone structure. Fluoride ions reside on the planes of Calcium ions forming an electrostatically stable and a structure that is structurally compact therefore changing the mineralization profile into a more dense and hard structure. The profile change is either as a result of hyper mineralization of earlier and denser fractions or an increase in density of hydroxyapatite crystals. Despite the mineralization process increasing the bone density making it both denser and harder, bones mechanical strength reduces as the collagen and mineral interface that determine the mechanical strength of the bone gets eroded with continued accumulation of Fluoride deposition. Long term exposure to Fluoride leads to the replacement of hydroxyl ions within the hydroxyl apatite structure of the bone irreversibly (Chachra *et al.*, 2010).

Patients with skeletal Fluorosis suffer from osteosclerosis which is the hardening and calcifying of the bones due to increased rate of bone material synthesis- hydroxyl apatite. Continued Fluoride exposure and accumulation makes the bones heavier and brittle. Denser bones are generally brittle and fragile than the normal bones making them comparatively inferior. Interestingly, Fluoride has been used in the treatment of osteoporosis due to its activation of bone formation by adding mass and inhibiting resorption. However, increasing the spinal's bone mass runs the risks of causing hip fractures despite the beneficial attributes. Fluoride is the most effective element used to increase the axial bone volume of the osteoporotic skeleton. Nonetheless, it has a very narrow therapeutic window (Freid *et al.*, 2003).

Despite the fact that severe forms skeletal Fluorosis is as a result of intake of Fluoride above 1.5 ppm it is also exacerbated by an interplay of other factors such as malnutrition, excessive manual work, impaired renal function. Severe form of Fluorosis is manifested as crippling skeletal Fluorosis. The latter is manifested by paraplegia which is the paralysis of the lower parts of the body including the lugs, quadriplegia that is the paralysis of the four limbs, scoliosis which is the lateral curvature of the vertebral column, flexon deformity that is the bending and

kyphosis that is the abnormal increment in convexity of the thoracic spine. Pressure as a result of bony outgrowth, narrowing of the intervertebral foramen, spinal canal, and the increased size of the body of the vertebrae leads to paralysis. Generally, men are reported to suffer more from the severe forms of Fluorosis assumedly due to intensive manual labor (Susheela *et al.*, 2003).

In India, two very important forms of skeletal Fluorosis have been reported; 'Genu vaum' or what is commonly known as bow legs as well as Genu valgum commonly referred to as knock knees. Concomitant osteoporosis and osteosclerosis of both the limbs and the spine have been observed in addition to Genu valgum in the cases of severe forms of Fluorosis. Both of the latter conditions have been linked to concentrations of serum parathyroid hormone levels which is an indicator of hyperparathyroidism. Persons suffering from Fluorosis have locomotion difficulties due to continued weakening of the hid limbs. In some instances, the feebleness may spread to the upper limbs resulting to difficulties related to neurological disabilities. Patients with such deficits account for about a tenth of all Fluorosis cases, and they are frequently immobile. Notably, skeletal Fluorosis progresses slowly but steadily, and the neurological impairments that accompany it can sometimes be triggered by trauma. Furthermore, because severe malformations at the knee, hips, and other joints sometimes coexist, determining whether the disabilities are caused by skeletal deformities or neurological diseases can be challenging. These examples have been discovered to reflect a wide range of neurological abnormalities that appear as upper motor neuron or lower motor neuron problems. Even more common, the neurological defects may manifest themselves in both the upper and lower motor neuron. The anatomical properties of the cervical spine are frequently compromised in later stages of skeletal Fluorosis. It is characterized by cachexia and may occur as a result of the neglect of trunk and limb muscles. According to the literature, perceptive deafness is common, while total deafness can also occur in rare circumstances. The nerve compression in the constricted and sclerosed auditory canal is thought to be the cause of deafness in Fluorosis. Crippling and skeletal Fluorosis frequently have severe social consequences, such as loss of livelihood and employment. Psychological trauma, social aloofness, significant medical expenses, and other symptoms are also present with the inclusion of fatality (Krishnamachari *et al.*, 2007).

2.4.6 Manganese Ions

Spectrophotometry, mass spectrometry, neutron activation analysis, and x-ray fluorimetry can all be used to investigate manganese ions. An atomic emission technique is microwave plasma atomic emission spectroscopy. It makes use of the fact that when an atom of a specific element is excited, it emits light in a distinct pattern of wavelengths - an emission spectrum - as it returns to its ground state. For a typical multi-element analysis, an MP-AES has higher sensitivity with detection limits as low as ppb and is faster than conventional flame Atomic Absorption (AA). According to the WHO (2002), Manganese is a naturally occurring mineral element that constitutes about one percent of the Earth's crust. Consequently, divalent manganese dissolves from the soils and the bedrock into ground water sources (Ljung *et al.,* 2007). Natural manganese concentrations are normally low, but can reach 1.5 $mg.L^{-1}$ or greater in extreme cases. Anthropogenic activities can also cause Manganese to enter surface and ground waterways. A study by Heal (2001) in Scotland reported that draining ditch building, land plowing, application of fertilizers, liming, and conifer afforestation increased the Mn^{2+} levels in surface waters. Further, NAWQA (2000) noted that water from mining sites and flood waters can significantly lead to an increase in Manganese concentration that contaminates the drinking sources.

Soluble Mn^{2+} that are usually present in drinking water can be converted to Mn^{3+} and Mn^{4+} that are insoluble through the use of oxidizing disinfectants and bacteria that oxidizes metals (Cerrato *et al.*, 2006; Kohl *et al.*, 2006; Manceau *et al.*, 1992; Negra *et al.*, 2005). The insoluble products occur as precipitation on the pipe interior surfaces or corrosion in drinking water distribution systems. Manganese oxides and oxyhydroxides easily react with ions such as chromium, copper, iron, lead, and strontium (Manceau *et al.*, 1992; Manceau *et al.*, 1992; Negra *et al.*, 2005; Colmenares *et al.*, 1999; Takahashi et al., 2007; Ghosh *et al.*, 2020; Villalobos *et al.*, 2005; Benjamin, 2013). Unfortunately, there is a potential health hazard of quantities of dissociated adsorbed metal ones, a situation that regulators have not taken note. Accepted Mn^{2+} concentrations in several countries remains at 0.5 mg L^{-1} a value aimed at protecting the populations from manganese toxicity as well as achieving water esthetic levels a value known as the action level (Al). The Al^{3+} coincides with the World Health Organization's guiding standards (WHO, 2004).

2.4.7 Iron (II) Ions

Iron is in abundance in the Earth crust and can be found as a solution as ferrous iron or as complex ferric iron. The former as bivalent iron in dissolved form Fe^{2+} or Fe $(OH)^{+}$) and the latter as trivalent iron: Fe (III)/ Fe $(OH)_3$). There is also industrial water that originates from mining activities, corrosion and from the iron and the steel industry. It is important to get rid of iron contaminants from water used for various industrial applications. The presence of iron in water results to reddish tint and stench (Ghosh *et al.,* 2008).

Removing iron from portable drinking water is one of the most tedious activities of attaining quality water with difficulties such as taste, visual impacts, and clogging. Due to factors such as residue of iron-based coagulants and pipe corrosion iron is usually found in groundwater. Also, filtering rain water using rocks, soil, and minerals results to iron contamination. Rainwater takes iron from various sources as it descends and deposits it in the groundwater. In normal situations, iron concentrations range from about 0 to 50 $mg.L^{-1}$ (Patrick *et al.,* 2011).

The amount of iron recovered is influenced by the acidity of the water and the amount of dissolved oxygen present. Corrosion is exacerbated by increased acidity and dissolved oxygen levels. The goal of groundwater treatment is to provide potable water that appears natural. The flavor and appearance of water are influenced by the presence of dissolved iron. People may detect a metallic taste and red colouring depending on the type and amount of iron present. Additionally, residual iron levels greater than 0.3 $mg.L^{-}1$ may discolor surfaces and clothing. Certain bacteria flourish in high-iron environments and may cling to pipe surfaces for a safe haven. These bacteria could build up to the point where they obstruct pipes (Patrick *et al.,* 2011).

Unfortunately, it is difficult to eliminate a colony after it has been formed. Furthermore, if the pipe is made of iron, it will corrode over time, resulting in punctures and leaking. If there is ferrous bicarbonate in the water, clogging will develop. Iron hydroxide is formed when ferrous bicarbonate is combined with water and oxygen, as seen in the chemical process below. Because this chemical compound is insoluble, it can collect in pipes and cause a blockage (Patrick *et al.,* 2011).

$4Fe(HCO_3)_2 + 2H_2O + O_2 \rightarrow 4Fe(OH)_3 + 8CO_2$ Equation 1

Fortunately, iron is a necessary vitamin that has beneficial impacts on human health when consumed in moderate amounts. People drink about 2 liters of water every day on average. The recommended iron consumption varies between 10 and 50 $mg.L^{-1}$ based on age, sex, and

physiological health. Iron levels in raw fresh water rarely surpass 50 mg.L-1. As a result, individuals would not be harmed by drinking untreated water (Patrick *et al.,* 2011).

In the purification of water, there are numerous methods for removing iron. Because of the strong adsorptive ability of iron oxyhydroxides, this is mainly caused by the precipitation of iron oxide/oxyhydroxides and frequently involves the co-removal of inorganic and organic contaminants. Commercially, such methods are important. Gelatinous, metastable iron precipitates are notoriously difficult to settle and filter. This can cause a bottleneck in the process (Loan *et al.,* 2006).

The World Health Organization (WHO) has established a drinking water iron recommendation of 0.3 $mg.L^{-1}$ (World Health Organization, 2008). Ion exchange and water softening (Vaaramaa *et al.,* 2003), activated carbon and other filtration materials (Langwaldt *et al.,* 2005), supercritical fluid extraction (Andersen *et al.,* 2003), bioremediation (Vasudevan *et al.,* 2009) and limestone treatment (Aziz *et al.,* 2004), oxidation by aeration, chlorination, and ozonation followed by filtration (Ellis *et al.,* 2000), by ash (Das *et al.,* 2007), by aerated granular filter (Cho, 2005), and by adsorption (Tahir *et al.,* 2004), are some of the methods for removing iron from drinking water. The most prevalent method for removing iron from groundwater in public water supply systems is aeration and separation, which is less popular at home. The natural airborne oxidation of iron to its oxides, which then separate off, results in a reduced iron level in surface water. Traditional knowledge or customs can occasionally provide crucial clues to resolving major issues.

2.4.8 Total Coliform and *Escherichia coli*

Faecal Coliforms are bacteria that naturally occur in the intestines of all warm-blooded animals, including humans and birds. The presence of Faecal Coliforms indicates faecal matter contamination (Mccaffrey, 2017). Coliforms in the feces suggest a danger to human health. They are not pathogenic (disease-causing), but they do signal the presence of harmful bacteria and viruses. Due to their ubiquity in the guts of warm-blooded animals as well as significant numbers discharged in the urine, E. coli is usually recognized as one of the first microorganisms of choice in water quality monitoring programs and acts as the major indication for water contaminated with faecal matter.

There are about one billion people in the world that don't have access to safe drinking water with an additional 2.5 billion lacking sanitation facilities. Further, there are about four billion cases of waterborne disease which about 3.4 million result to deaths. Water-borne diseases

remain among the major causes of death among children below five ages in the world. In developing countries set-up, waterborne diseases are more prevalent in the rural settings.

There are about 159 million people across the globe who depend on surface sources of water such as rivers and an additional 423 million others who source their water from unprotected springs that are susceptible to water-borne diseases (WHO, 2017). Drinking microbiologically hazardous water results to infections such as diarrhea. Kenya is among the countries with severe water shortages with the country's water per capita storage capacity at about 8 m^3. A huge percentage of the population that depends on unimproved community water sources results to Moringa, Oleifera seed extracts and Aluminium Sulfate to purify rainwater (Futi *et al.,* 2011).

There is a considerable population in Kenya that faces acute water shortage due to their geographical inhabitants of arid and semi-arid regions. Among the issues identified as major obstacles in achieving Kenya's development blue print dubbed as Vision 2030 and the United Nations Sustainable Development Goals 3 and 6 are water scarcity and sanitation drawbacks. Herrero et al. study concluded while 40 % of the population in urban set-up has access to piped water, only an equal percentage receives water on a consistent basis throughout the day. The rest of the population depends on water from vendors and illicit hookups whose quality is largely compromised predisposing consumers to waterborne diseases.

Total coliforms and *Escherichia coli* are among the microorganisms of concern in water that make it unfit for human consumption, according to a study by Gwimbi (Gwimbi, 2011). The bacteria can also be utilized as indications of fecal contamination, which causes diarrhoeal disease (Onyango *et al.,* 2010) . Water for human consumption should be free of disease-causing bacteria per 100 mL, according to a WHO assessment on drinking water.

2.5 Rationale of Analytical Techniques used

2.5.1 Colour

The visual approach and the instrumental method are two procedures that can be used to determine the colour of water. The visual method is the most straightforward, as it involves comparing a water sample to a sequence of coloured slides or tubes (Roger, 2002). This approach can be utilized in most situations, although it is not recommended for contaminated water. If the colour of the water cannot be accurately depicted using the visual method, various instrumental methods can be utilized to provide a more accurate picture. Colorimetry and spectrophotometry are the two most common forms of instrumental technology methods for

measuring and classifying colour. Colorimetry is a scientific technique that uses the Beer–Lambert equation, which states that the concentration of a solute is proportionate to its absorbance, to determine the concentration of coloured compounds in solutions. Spectrophotometry is a technique for determining how much light a chemical substance absorbs by measuring the intensity of light passing through a sample solution. Colorimetry used to be dependent on human colour vision, which was heavily influenced by personal perception as well as external factors like ambient light and brightness. Subjective visual judgment was replaced with an objective and reliable measurement only with the use of photometers and defined uniform colour systems. Spectrophotometric methods allow for the determination of a single colour value that represents consistent chromaticity differences even when the sample colour differs greatly from platinum cobalt standards. The determination was made using the Spectrophotometry method using a multiparameter Photometer (Model HI 83099 COD and Multiparameter Photometer).

2.5.2 pH

pH is a scale that specifies the acidity or basicity of an aqueous solution. It also denotes potential of hydrogen or power of hydrogen. The following methods are used to determine pH.

2.5.2.1 Measuring pH using an indicator

This approach is separated into two parts: One method involves comparing the color of a standard indication immersed in the test liquid with the color of a standard color corresponding to a specified pH. The other method entails first soaking pH test paper in the indicator, then immersing it in the test liquid and comparing the color to the standard hue. This method is straightforward, although it is prone to errors. It is impossible to reach a better level of precision.

The indicator method cannot be used to test the pH of high-purity water because the indicator's influence is too great.

2.5.2.2 Hydrogen – Electrode method

To make a hydrogen electrode, platinum black is mixed with platinum wire or a platinum plate.

It is immersed in the test solution, which is then electrically charged and saturated with hydrogen gas. The electrode potential is measured between the platinum black electrode and the silver chloride electrode. The pH of the solution has an inverse relationship with this potential. Because of the time and money required, as well as the inconvenience of handling hydrogen gas and the significant influence of highly oxidizing or reducing compounds in the test solution, this method is not suitable for everyday use.

2.5.2.3 Quinhydrone – Electrode method

Quinhydrone splits into hydroquinone and quinone when added to a solution. The voltage between a platinum and a reference electrode can be used to calculate pH since quinone solubility fluctuates based on the pH value of the solution. Despite its simplicity, this approach is rarely used nowadays since it does not function when oxidizing or reducing compounds are present, or when the test solution has a pH greater than 8 or 9.

2.5.2.4 Antimony – Electrode method

This method entails submerging the tip of a polished antimony rod in a test solution, along with a reference electrode, and measuring pH based on the potential difference between them. Because the device is strong and easy to use, this method was previously commonly utilized. However, because the results vary based on the degree of electrode polish and reproducibility is low, its use is presently restricted.

2.5.2.5 Glass – Electrode method (pH meter)

The glass electrode method measures the voltage (potential) between two electrodes, a glass electrode and a reference electrode, to estimate the pH of a solution. This method is the most often used for pH measurement because the potential quickly finds equilibrium and has good consistency, and because it can be used on a variety of solutions with little effect from oxidizing or reducing chemicals. Using a pH meter from the Ohaus Starter 2100 series, this procedure was utilized to analyze all water samples. pH meters use a computer or digital user interface providing with an instant pH reading on a readable display, therefore, considered extremely accurate method of pH analysis.

2.5.3 Conductivity

The capacity of a solution to pass an electric current is known as conductivity. Cations and anions carry current in solutions, whereas electrons carry current in metals. The concentration of ions, mobility of ions, valence of ions, and temperature all influence how effectively a solution conducts electricity. Conductivity exists in all substances to some extent. The level of ionic strength in aqueous solutions ranges from ultrapure water's low conductivity to concentrated chemical samples' high conductivity. A conductivity meter was used to analyze all of the water samples (Model 86503 series).

2.5.4 Residual Chlorine

There are three major ways for determining the amount of free chlorine in drinking water. Pool test kits, color-wheel test kits, and digital colorimeters are among them. In the presence of total chlorine, the liquid chemical OTO (orthotolidine) causes the color of pool test kits to change to yellow. Color wheel test kits use the powder or tablet chemical DPD (N,N diethyl-p-phenylene diamine) in the presence of chlorine to produce a pink color change. DPD tablets or powder are introduced into a vial of sample water in digital colorimeters, causing a pink color change. They also use a meter to determine and display the color intensity (free and/or total chlorine residual) by emitting a wavelength of light and digitally determining and displaying the color intensity (free and/or total chlorine residual). The meter's range is 0–4 mg/L, which is comparable to 0 to 4 ppm (parts per million). The LOVIBOND Chlorine (DPD) Checkit was used to determine residual chlorine using a digital colorimeter. The specifications of LOVIBOND Chlorine (DPD) Checkit were 0.2 to 8.0 $mg.L^{-1}$ in range.

2.5.5 Fluoride Ions

The use of a multiparameter photometer to test Fluoride in water is a more advanced method. For exceptionally fast and reproducible measurements, this meter features a superior optical system that includes a reference detector and narrow band interference filters. Fluoride ions were measured in all of the water samples using a multiparameter photometer (Model HI 83099 COD and Multiparameter Photometer). The photometer had a range of 0.00 to 2.00 $mg.L^{-1}$ with

a resolution of 0.01 $mg.L^{-1}$ at a temperature of 25 °C. Tungsten lamp with narrow band interference filter @ 575 nm was used as the light source.

2.5.6 Ions of Manganese, Iron (II) and Silicon

Spectrophotometry, mass spectrometry, neutron activation analysis, and x-ray fluorimetry can all be used to examine ions. An atomic emission technique is microwave plasma atomic emission spectroscopy. It makes use of the fact that when an atom of a certain element is excited, it emits light in a defined pattern of wavelengths known as an emission spectrum as it returns to its ground state. For a typical multi-element analysis, an MP-AES has great sensitivity with detection limits down to sub parts per billion (ppb) levels and is faster than standard flame Atomic Absorption (AA). Microwave Plasma Atomic Emission Spectrometer model 4210 was used to examine the ions.

2.5.7 Total Coliforms and *Escherichia coli*

The Most Probable Number (MPN) test method was used to determine Total Coliforms and Escherichia coli. The ISO 9308-certified Most Probable Number (MPN) test method is used to determine Total Coliforms and Escherichia coli (Guruvayurappan et al., 2017).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 Sample Collection

Samples were taken in eleven sub-counties, as is detailed in the section below on sampling sites. A questionnaire was given out prior to sample collection in order to gather more sample information. One litre samples totaling to eighty eight were collected. Analysis of residual Chlorine was done at the point of sampling as opposed to laboratory-based analysis of bacteria, pH, colour, conductivity and chemicals.

3.1.1.1 Sampling Sites

The research was carried out in Nairobi, Kenya's capital City. The study area was chosen to investigate portable water quality and provision in the city. The research location lies on the outskirts of South-Eastern Kenya. The city is located between the longitudes and latitudes of 1° 9'S, 1° 28'S, and 36° 4'E, 37° 10'E, and has an area of approximately 696 km^2 (CBS, 2011). The changes in latitude range from 1,600 to 1,850 meters above sea level (Mitullah, 2013). Parts of the city on the western side are on high elevation, around 1700-1800 meters above sea level, with a mountainous scenery, while the eastern side is low, around 1600 meters above sea level, and flat (Saggerson, 1991). The sub-counties of Starehe, Westlands, and Njiru, and more especially Central Business District, Kangemi and Dandora respectively were among the regions of interest. The map of the study area is provided in figure 3.1 below which shows the sub-counties of: Embakasi, Kasarani, Njiru, Dagoretti, Westlands, Kamukunji, Starehe, Mathare, Lang'ata, Makadara, and Kibra. The study concentrated primarily on Nairobi's 11 sub-counties. The population density of the sub-counties is shown in table 3.1 below.

Table 3. 1:Population distribution in Nairobi City Sub-counties.

S/No	Sub-County	Population Size	Land Area (Sq.Km)	Population Density (No. Per Sq. Km)
1.	Embakasi	988,808	86.3	11,460
2.	Kasarani	780,656	86.2	9,058
3.	Njiru	628,482	129.9	4,821
4.	Dagoretti	434,208	29.1	14,908

5.	Westlands	308,854	97.5	3,167
6.	Kamukunji	268,276	10.5	25,455
7.	Starehe	210,423	20.6	10,205
8.	Mathare	206,564	3.0	68,941
9.	Lang'ata	197,489	216.8	911
10.	Makadara	189,536	11.7	16,150
11.	Kibra	185,777	12.1	15,311

The total population is 4,397,073 (KNBS census, 2019).

The water samples were collected from the sites depicted in figure 3.1 below, which represent all 20 sampling sites in the City of Nairobi.

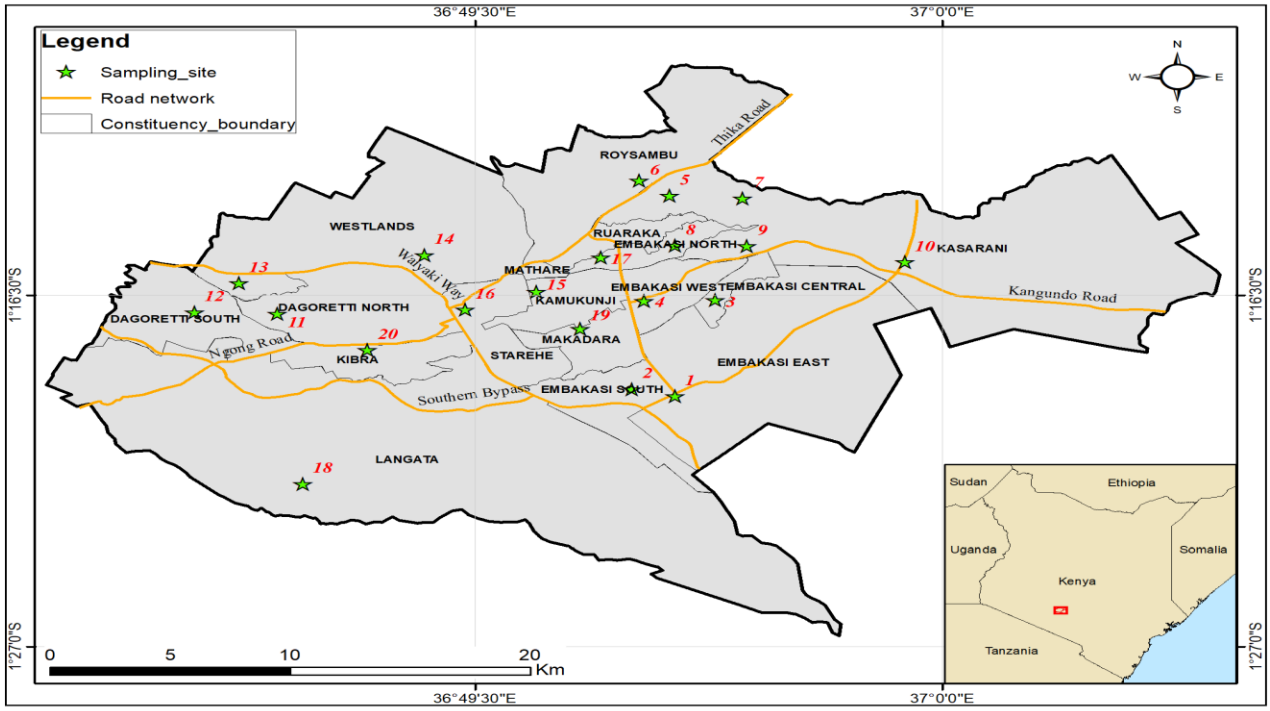

Figure 3. 1: Study area map (The City of Nairobi)

An elaborate explanation of the number of samples shown in figure 3.1 above that were collected in every sampling site is shown on table 3.2 below.

Table 3. 2: Sampling sites as per the study area map

KEY					
		No. of samples			No. of samples
1	Embakasi	8	11	Kawangware	4
2	Mukuru Kwa Njenga	4	12	Waithaka	4

3	Kayole	4	13	Kangemi – Mt View (Rurii)	4
4	Umoja Phase 1	4	14	Highridge (Third parklands Avenue)	4
5	Kasarani	4	15	Eastleigh North (Garage area)	4
6	Roysambu	4	16	CBD	8
7	Mwiki	4	17	Huruma	4
8	Dandora	4	18	Mugumoini	4
9	Njiru	4	19	Maringo	4
10	Ruai	4	20	Woodley	4

3.1.1.1.1 Embakasi sub-county

With a total population of 988,808, Embakasi is the ranked top populated sub-county in the City of Nairobi (KNBS, 2019). The subdivisions of the sub-county are Embakasi North, Embakasi South, Embakasi Central, Embakasi East, and Embakasi West. A 2019 census report placed it as the sixth least densely populated sub-county in the City of Nairobi with a population density of 11,460 persons per Km^2 . Twenty samples in total were collected from the households. No apparent storage problem that would have compromised the water quality was observed.

3.1.1.1.2 Kasarani sub-county

With 780,656 residents, Kasarani is ranked second in population size in the City of Nairobi (KNBS, 2019). With 9,058 persons per Km^2 due to the wide land area, it is the fourth least densely populated sub-county in the City of Nairobi. Samples were taken from twelve randomly selected water vending stations. Every vending station did not have any observable unhygienic conditions that could not jeopardize the water quality.

3.1.1.1.3 Njiru sub-county

Njiru is ranked third populous sub-county, but it is also the third least densely populated due to its large land area of 129.9 km^2 in the City of Nairobi (KNBS, 2019). Twelve water kiosk samples were collected in total. The photograph in figure 3.2 below was taken during sampling at Dandora Phase 2 in Njiru sub-county.

Figure 3. 2: Sampling at Dandora Phase 2 in Njiru sub-county.

3.1.1.1.4 Dagoretti sub-county

Dagoretti is ranked fourth populous sub-county in Nairobi, with a land area of 29.1 km^2 (KNBS, 2019). The sub-county is divided into Kawangware and Waithaka. Eight samples were collected in households. No observable unhygienic conditions that could compromise water quality.

3.1.1.1.5 Westlands sub-county

Westlands is the second sparsely populated sub-county in the City of Nairobi with a population density of 3,167 per Km^2 (KNBS, 2019). The sub-county is divided into three sections: Highridge, Kangemi, and Kilimani. Eight samples were collected in various households. All storage facilities were found to be clean during sampling.

3.1.1.1.6 Kamukunji sub-county

Eastleigh and Pumwani forms part of Kamukunji sub-county. The sub-county is ranked second smallest in land area size with 10.5 Km^2 (KNBS, 2019) and the second populous with 25,455 number of people per Km^2 in the City of Nairobi (KNBS, 2019). Four samples were collected from two randomly selected supermarkets. The samples were tightly and thoroughly sealed, with no signs of tampering.

3.1.1.1.7 Starehe sub-county

The population of Starehe sub-county is 210,423 (KNBS,2019), divided into three areas: the Central Business District area, the Central area (Kariokor and Racecourse), and the South B area (Landmawe and Mukuru Nyayo). Eight samples from randomly picked supermarkets in

Central Business District were collected. The samples were tightly and thoroughly sealed, with no signs of tampering.

3.1.1.1.8 Mathare sub-county

Mathare is the smallest sub-county in terms of land area but the most populous, with 68,941 people per km^2 in the City of Nairobi (KNBS, 2019). It is divided into two sections: Mathare (Mabatini and Mlango Kubwa) and Huruma (Huruma and Kiamaiko). Four samples were obtained from two separate supermarkets (Hope Supermarket and Royalmart Supermarket). The tightly and thoroughly sealed samples showed no signs of tampering.

3.1.1.1.9 Langata sub-county

Lang'ata is the most sparsely populated sub-county, with 911 people per Km^2 and has the largest land area at 216.8 Km^2 in the City of Nairobi (KNBS, 2019). The sub-county is divided into Karen, Nairobi West, and Mugumoini. Four samples were collected at random from various shops. There were no signs of tampering with the samples, which were tightly and thoroughly sealed.

3.1.1.1.10 Makadara sub-county

Makadara is the second least populous sub-county and due to the tiny land area size, it is ranked third in dense population, with 16,150 persons per Km^2 in the City of Nairobi (KNBS, 2019). Makadara is divided into Bahati, Makadara area (Maringo) and Viwandani. Four samples were collected from randomly selected kiosks. The samples, which were tightly and thoroughly sealed, showed no signs of tampering.

3.1.1.1.11 Kibra sub-county

Kibra is the least populous sub-county in the City of Nairobi, with a population of 185,777 people (KNBS, 2019). Kibra is divided into three sections: Kibera, Woodley, and Laini Saba. Four samples were taken from shops and kiosks chosen at random. The samples were kept in a tightly sealed polybottle with no evidence of contamination.

3.1.1.2 Sampling Period

Sample collection was done in a period of twenty nine days starting from 1st May 2021 to 29th May 2021. A summary of sampling period with respect to the various sub-counties is shown in table 3.3 below.

Table 3. 3: Summary of sampling period with respect to the various sub-counties.

S/No	Sub-County	Sampling Sites	Sampling period
1.	Westlands	Kangemi (Rurii) and Highridge (Third Parklands Avenue)	1st May 2021 from 9am to 4pm
2.	Dagoretti	Kawangware and Waithaka	8th May 2021 from 10am to 12.30pm
3.	Kibra	Woodley	14th May 2021 from 8.30am to 10.30am
4.	Lang'ata	Mugumoini	14th May 2021 from 10.45 am to 12.30 pm
5.	Makadara	Maringo	14th May 2021 from 2pm to 3.30 pm
6.	Mathare	Huruma	15th May 2021 from 9am to 10am
7.	Kamukunji	Eastleigh North (Garage Area)	15th May 2021 from 11am to 1pm
8.	Starehe	Central Business District (CBD)	15th May 2021 from 2pm to 4pm
9.	Njiru	Dandora, Njiru and Ruai	21st May 2021 from 9am to 5pm
10.	Kasarani	Kasarani, Roysambu and Mwiki	22nd May 2021 from 9am to 5pm
11.	Embakasi	Embakasi, Mukuru Kwa Njenga and Kayole	28th May 2021 from 9am to 6 pm
		Umoja	29th May 2021 from 10am to 1 pm

3.1.2 Reagents and Chemicals

The table below depicts a list of reagents and chemicals that were used during the laboratory work.

Table 3. 4: List of reagents and chemicals used

Item No.	Chemical	Concentration	Manufacturer
1.	pH standard buffer solutions pH 4.01	pH 4.01	Hanna Instruments,Inc.,USA
2.	pH standard buffer solutions pH 7.01	pH 7.01	Hanna Instruments,Inc.,USA
3.	pH standard buffer solutions pH 10.01	pH 7.01	Hanna Instruments,Inc.,USA
4.	Conductivity Meter buffer solution	1413µS/cm	Hanna Instruments,Inc.,USA
5.	HI 93729-0 Fluoride LR Reagent	1 ml	Hanna Instruments,Inc.,USA
6.	DPD no.1 tablets	1 tablet	Tintometer GMBH Ltd
7.	Brilliant Green lactose (bile) broth	2 %	HiMedia Laboratories Pvt.Ltd, India
8.	Kovacs reagent for indole	Neat	HiMedia Laboratories Pvt.Ltd, India
9.	Sterile MacConkey Broth purple	Single and double strength	E&O Laboratories Limited, United Kingdom.
10.	Tryptone water	15 g/l	Oxoid Ltd, United Kingdom
11.	EC broth medium	37 g/l	HiMedia Laboratories Pvt.Ltd, India
12.	Concentrated HCl	Neat – 3 drops	Finar Limited, India
13.	Standard solution of Manganese, Iron and Silicon	1000ppm	Merck KGaA, Germany

3.1.3 Instruments

A summary of the model and manufacturer of the instruments used during analytical work is shown in table 3.5 below.

Table 3. 5: List of equipment

Item No.	Instrument	Model	Manufacturer
1.	pH meter	Ohaus Starter 2100 series	Ohaus Corporation, USA
2.	Conductivity meter	Model 86503 series	AZ Instrument Corporation
3.	COD and Multiparameter Photometer	HI83099	JJS Technical Services, USA
4.	LOVIBOND Chlorine (DPD) Checkit	AF530	Test All Water Limited, United Kingdom.
5.	Autoclave	LS-B75L	Jiangsu Baitai Medical Equipment Co.,Ltd. China
6.	Vortex mixer	VM-2000	Digisystem Laboratory Instruments Inc. Taiwan

7.	Incubator	Memmert	Memmert GmbH + Co. KG, Germany
8.	Water bath	Memmert	Memmert GmbH + Co. KG, Germany
9.	Microwave Plasma Atomic Emission Spectrometer (MP-AES)	model 4210	Agilent Technologies, USA
10.	Weight balance	Scout-Pro	Ohaus Corporation, USA

3.1 Methods

Random sampling on five water outlets that included supermarkets, shops, kiosks, water vending stations and households was applied. The sampling areas had almost equal population size as guided by 2019 Kenya census. Water samples from supermarkets, shops, kiosks and water vending stations were collected in their original packaged polybottles while water sampled in households were collected using sterilized polybottles. Sterilization of polybottles was done at 121^{o}C in 15 minutes. The use of dark brown bottles was unnecessary because all of the parameters tested in the laboratory were not light sensitive. All the samples were transported using cooler boxes to Analabs Ltd laboratory which is an ISO/IEC 17025:2017 accredited laboratory. The samples were immediately analysed for microbial parameters. The samples were kept in cooler boxes awaiting chemical analysis a day after sampling. Residual chlorine parameter was done onsite for all household water samples. The figure 3.3 below depicts (a) a photograph taken during the transportation of samples from Rurii village Mountain View ward to the laboratory using a cooler box. (b) Sample microbial analysis in the laboratory.

Figure 3. 3: Sample collection using cooler box and laboratory microbial analysis.

3.1.1 pH

Water pH was analysed using pH meter. The digital pH meter was turned on and let to stand for a few minutes before being calibrated using the manufacturer's pH standard buffer solutions (pH 4.01, pH 7.01, and pH 10.01). The pH probe was completely washed with distilled water and the pH mode was switched on after 20 ml of the sample was poured into a 25 ml clean universal bottle. After that, the pH probe was submerged in the water sample. To ensure homogeneity between the probe and the sample, the sample was stirred with a stirring bar to achieve equilibrium. The pH was measured and recorded. The figure below shows recording taken during pH analysis in the laboratory.

Figure 3. 4: pH determination of water samples using a pH meter

3.1.2 Conductivity

Water conductivity was determined by using conductivity meter. 20 ml of the sample was dispensed from sampling bottles to a clean universal bottle. The conductivity probe was thoroughly rinsed with deionised water and dried with soft dry clean tissue. The conductivity meter was allowed to stabilize and the readings were noted. The probe was properly cleaned with distilled water and kept in fresh deionized water after taking the sample reading. A photograph taken during a water conductivity analysis is shown in Figure 3.5.

Figure 3. 5: Conductivity determination of water samples using a conductivity meter

3.1.3 Colour

Water colour was analysed using Multiparameter Photometer. The color was chosen in accordance with industry standards for water and wastewater testing (Colorimetric Platinum Cobalt Method, n.d.).

The photometer range was 0 to 500 PCU (Platinum Cobalt Units), as well as a silicon photocell light detector. Tungsten lamp with narrow band interference filter @ 420 nm was used as the light source. The machine was turned on followed by selecting colour of water method. Blank sample was prepared by filling one cuvette with 10 ml deionized water. The machine was zeroed by running blank sample inside the sample container. The sample holder was filled with 10 ml of water sample cuvette and the lid was closed. READ key was pressed and the reading recorded in the laboratory workbook. The readings were in PCU (Platinum Cobalt Units). A photograph below shows recordings of zeroed and water test record respectively during colour determination.

Figure 3. 6: Colour analysis of the water samples using Multiparameter Photometer.

3.1.4 Fluoride ions

The Fluoride ions were determined using a Multiparameter Photometer. Multiparameter Photometer was turned ON via the ON/OFF power switch where Fluoride method was selected using METHOD key. 1 mL HI 93729-0 Fluoride LR Reagent was added to two separate cuvettes where one cuvette was filled to the mark (10ml) using deionised water and the other cuvette with the water sample. The cuvettes were capped and inverted several times to obtain a homogenous solution. The cuvette with deionised water was first placed in the sample holder and lid closed. The Timer was pressed and countdown done for two minutes and the display showed "-0.0-". By this, the meter was zeroed and ready for measurement. The same procedure was repeated for water sample analysis. The results of the multiparameter photometer were

displayed in milligrams per litre of Fluoride. Below is a figure showing recordings of zeroed and water test record respectively during colour determination.

Figure 3. 7: Fluoride analysis of the water samples using Multiparameter Photometer.

3.1.5 Residual Chlorine

Residual chlorine was determined using LOVIBOND Chlorine (DPD) Checkit. DPD no.1 tablets were used for the test. Three compartments of the CHECKIT were rinsed with water sample. The left compartment was used to check the levels of residual Chlorine where the water sample was filled to the mark (10 ml). One DPD no. 1 tablets was placed in the compartment and crushed using clean stirring rod and the stopper was replaced. The stopper was held firmly and repeated inversion was done until the tablet was fully dissolved. The colour formed in the water sample was compared against the standard using daylight. The nearest colour match was selected and recorded the concentration in mg.L^{-}. Below is figure 3.8 of a photograph taken during water sampling analysing residual Chlorine using LOVIBOND Chlorine (DPD) Checkit

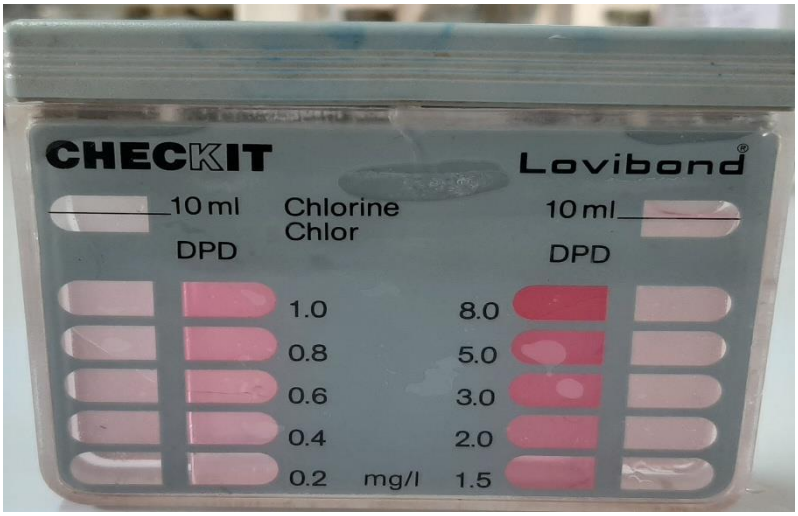

Figure 3. 8: Residual Chlorine analysis using LOVIBOND Chlorine (DPD) Checkit.

3.1.6 Total Coliform and *Escherichia coli.*

Weighing balance, spatula, autoclave, autoclave tape, bunsen burner, vortex mixer, incubator @ 37^{o}C ± 0.5^{o}C, water bath @ 44 ^{o}C ±0.5^{o}C, conical flask, 1000 l automated pipette, sterile 1

ml pipette tips, sterile 125 ml bottles, sterile 20 ml, conical flask, 1000 l automatic pipette, universal bottles (five), 200 mL water samples, 2 percent brilliant Green lactose (bile) broth, Kovacs reagent for indole, sterile MacConkey Broth purple, Durham tubes, sterile tubes, pH meter, Tryptone water, and EC Medium were used during microbial analysis.
The various mediums were prepared using the following procedures.

3.1.6.1 Preparation of Sterile MacConkey Broth (Purple)

3.1.6.1.1 Single Strength

A litre of distilled water was mixed with forty grams of MacConkey Broth (Purple) base. Thereafter, 5 mL of each solution were placed in test tubes fitted with inverted Durham tubes. Before inoculating the sample, the tube was sterilized and no gas was trapped inside. The autoclave was used to sterilize the items for 15 minutes at 121 ºC. The 15 mL of the media was transferred to a universal bottle that had been cooled to 25 ºC.

3.1.6.1.2 Double Strength

Twice the amount of MacConkey Broth (Purple) base used for single strength was dissolved in the same volume of distilled water and distributed as; 50 ml into 150 ml bottles fitted with Durham tubes,10 ml into universal bottles fitted with Durham tubes. The Durham tubes were fitted inverted. Sterilization was done and made sure that no gas was trapped in the tube before inoculating the samples.

3.1.6.2 Preparation of 2 % Sterile Brilliant Green Bile Broth

A litre of distilled water was mixed with 40 g of Brilliant Green Bile (2 %) Broth. Mixing was done using vortex mixer and distributed into test tubes fitted with Durham tubes. Autoclaving was done at 121 ºC for 15 minutes. Finally, 15 ml of the 2 % Sterile Brilliant Green Bile Broth media was cooled down to 25 ºC.

3.1.6.3 Preparation of Tryptone Water

To ensure complete dissolution, 15 g of tryptone water powder was weighed and added to one litre of distilled water while stirring with a vortex mixer. Bijou bottles were filled with 2.5 mL of Tryptone Water. Sterilisation was done by autoclaving at 121 ºC for 15 minutes. Finally, 15 ml of the media was cooled down to 25ºC.

3.1.6.4 **Procedure for testing Total Coliform and *Escherichia coli***

The water samples were injected into bottles and tubes where mixing thoroughly by inverting the bottle at least 10 times. Purple-inoculated the sterile MacConkey Broth bottles by introducing 50 mL of water sample to a bottle containing 50 mL of MacConkey broth (double strength). Each of the five Universal bottles carrying 10ml (double strength) broth received 10 ml of water sample. Each of the five tubes carrying 5 ml of (single strength) soup received 1 ml of water sample. An inverted Durham tube was included in each bottle to collect gas. The tubes were made from of small Durham tubes, whereas the medical flat bottles were made out of medium Durham tubes. Stoppers and loose caps were used to incubate the inoculated broths in a water bath at 35 ^{o}C for 48 hours. After 24 hours, the bottles were examined and regarded as positive reactions for those which had turbidity due to bacterial growth and gas formation in the Durham tubes, together with acid production (indicated by change of broth colour from purple to yellow). The remaining bottles that did not display any or all of these changes were re-incubated and tested for positive reactions after 48 hours. By incubating one of the brilliant green lactose (bile) broths at 35 ^{o}C for 48 hours and looking for gas production, the presence of coliform organisms was confirmed. Presumptive E.coli was proven by incubating a tube of tryptone water for 24 hours at 44 °C and testing for indole production, then adding 0.3 ml of Kovacs' reagent to the tryptone water tube. The presence of indole was established by the formation of a pinkish ring after moderate addition of the Kovacs reagent.

3.1.6.5 Determination of *Escherichia coli*

Determination of E.Coli was carried using the above described procedure. The most likely quantities of coliform organisms and presumptive E.coli in 100 ml of the sample were calculated using the statistical tables 3.6 below, based on the number of tubes of isolation medium and confirmatory tests yielding positive results. For instance, if a sample yielded 50ml bottle positive (i.e., gas and fermentation), 3 bottles of 10 ml positive, and 3 bottles of 5 ml positive, the profile would be 1 3 3. When one 50 ml, five 10 ml, and five 1 ml pieces were used, this was interpreted as 18 coliforms/100 ml water using the table 3.6 below.

Table 3. 6: MPN values per 100 ml of sample and 95 % confidence limits.

Number of tubes giving positive reaction			**MPN** (per 100 ml)	**95 % confidence limits**	
1 of 50 ml	5 of 10 ml	5 of 1 ml		**Lower**	**Upper**

0	0	0	<1		
0	0	1	1	<1	4
0	0	2	2	<1	6
0	1	0	1	<1	4
0	1	1	2	<1	6
0	1	2	3	<1	8
0	2	0	2	<1	6
0	2	1	3	<1	8
0	2	2	4	<1	11
0	3	0	3	<1	8
0	3	1	5	<1	13
0	4	0	5	<1	13
1	0	0	1	<1	4
1	0	1	3	<1	8
1	0	2	4	<1	11
1	0	3	6	<1	15
1	1	0	3	<1	8
1	1	1	5	<1	13
1	1	2	7	1	17
1	1	3	9	2	21
1	2	0	5	<1	13
1	2	1	7	1	17
1	2	2	10	3	23
1	2	3	12	3	28
1	3	0	8	2	19
1	3	1	11	3	26
1	3	2	14	4	34
1	3	3	18	5	53
1	3	4	20	6	66
1	4	0	13	4	31
1	4	1	17	5	47
1	4	2	20	7	69
1	4	3	30	9	85
1	4	4	35	12	101
1	4	5	40	15	117
1	5	0	25	8	75
1	5	1	35	12	101
1	5	2	50	18	138
1	5	3	90	27	217
1	5	4	161	3	450
1	5	5	>180	-	-

3.1.7 Determinations of Manganese, Iron (II) and Silicon ions

The levels of Mn^{2+}, Fe^{2+} and Si^{4+} in water samples were analysed using Microwave Plasma Atomic Emission Spectrometer. 20 ml of water samples was prepared by adding 3 drops of concentrated HCl to increase the rate of oxidation. A ready to use 1000 ppm standard solution of Manganese, Iron and Silicon was used. The water samples were nebulized into radio-

frequency microwave plasma. Spectra of elements were dispersed by grating spectrometer and intensities measured by photomultiplier tubes. The concentrations of the water samples were deduced from calibration graph obtained from the standard solutions.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Point-of-use Water Treatment Systems

Only four households sterilized their drinking water before drinking it using a chemical method (use of Sodium Hypochlorite) and a boiling water treatment method, accounting for 6.25% of water treatment systems in each category. Samples 001 and 003 from Waithaka ward Dagoretti sub-county and Rurii ward Westlands sub-county were treated with Sodium Hypochlorite before drinking. Sodium Hypochlorite is a broad-spectrum sterilizer that is effective for the sterilization of viruses, bacteria, fungi and mycobacterium.

The full analysis of the two samples are tabulated below in table 4.1

Table 4. 1: Point of Use treatment household results

Test	**R.C**	**T.C**	**E.coli**	**Mn^{2+}**	**Fe^{3+}**	**F^{-}**	**Si^{4+}**	**pH**	***Conductivity***	***Colour***
Sample 003	0	<1	<1	0.04	0.21	0.45	1.29	7.25	83.3	25
Sample 001	0	90	<1	0.06	0.16	0.21	2.43	6.58	81.7	16

Sample 003 water sample collected in Westland sub-county passed in all the tests while Sample 001 Total Coliforms test was out of specifications. Total Coliforms and *Escherichia coli* should be absent. The point of use chemical treatment of sample 003 shows effectiveness especially in killing of bacteria while Sample 001 method was ineffective. This could be attributed to the use of Sodium Hypochlorite below the recommended concentration level or the unhygienic storage conditions leading to water contamination.

Sample 004 and 001 were collected in Westlands Sub-county in Rurii ward and Embakasi sub-county Kayole respectively were treated using boiling - point of use water treatment method. The full analysis of the two samples are tabulated below in table 4.2

Table 4. 2: Household samples treated through boiling

Test	**R.C**	**T.C**	**E.coli**	**Mn^{2+}**	**Fe^{3+}**	**F^{-}**	**Si^{4+}**	**pH**	***Conductivity***	***Colour***
Sample 004	0	<1	<1	0.10	0.09	0.51	2.99	7.46	101.5	60

Sample 001	0	<1	<1	0.11	0.49	0.85	4.88	7.8	85.7	22

Bacteria and viruses that cause cholera, typhoid, dysentery, and other watery diseases were killed by boiling. The treatment was effective because neither total coliforms nor E.Coli were found, even though some physico-chemical were above the limits.

4.2 Determination of Selected Quality Parameters in Portable Water Distributed in the City of Nairobi, Kenya.

4.2.1 Physico-Chemical Parameters

The physico-chemical parameter of water is any physical parameter that is measurable. The physico-chemical parameter pH, electrical conductivity, Colour, temperature, turbidity, TSS, TDS, DO, COD and specific gravity.

4.2.2 pH

The pH values averages for the water samples collected from the selected points in the city are shown in figure 4.1 below.

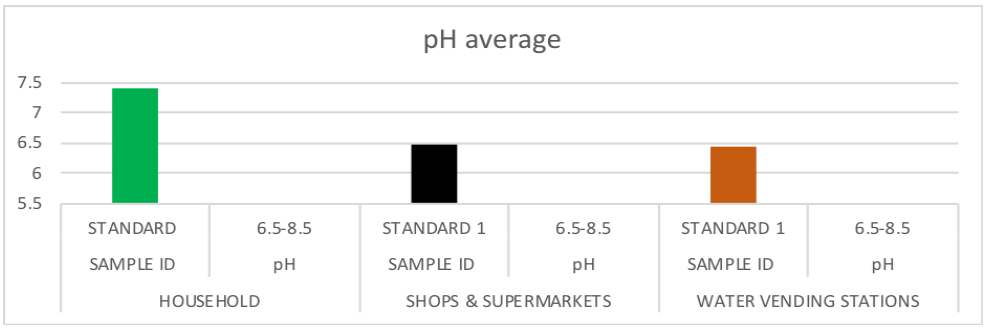

Figure 4. 1: Average pH comparisons

The sample pH averages include 7.48, 6.48 and 6.44 for households, shops & supermarkets and water vending stations respectively. The standard deviation for the three group categories was ±0.54. The study showed that out of eighty eight samples collected in the City of Nairobi, twenty six samples had pH values which were not within the KS EAS standards, representing 29.6 % of the total samples. The highest pH recorded was 8.95 for sample HHEMWK001 collected from Embakasi sub-county for the household water samples while the lowest pH was 5.5, for the SPDSWOD001 bottled water from Woodley in Kibra sub-county as shown in figure 4.1 above. The pH recorded for the household water samples included the HHUNMTV001

sample from Westlands and HHHWWA003 from Dagoretti sub-counties. HHUNMTV001 was a spring water from Rurii ward, Westlands sub-county. According to the survey carried out using a questionnaire that was randomly administered during sampling, the first respondent explained how the nearby residents fetch water from the water spring for household purposes. The pH, below the accepted KS EAS standards, could be attributed to the water sample obtained from the springs by the residents. Spring water is a type of underground water whose Physico-chemical properties may be affected by the geological properties of the underground rocks. Sample HHHWWA003 was a household sample collected from Waithaka ward in the Dagoretti sub-county. It was from harvested water. All the other samples collected from the same area were within the KS EAS standards. The samples which were not within the accepted range could be due to contamination during harvesting and water storage facility. The study further showed that water samples that recorded pH values below 6.5 were collected from shops, supermarkets and water vending stations. The average pH values for the water samples collected from Households, Shops, Supermarkets and vendors are compared in Figure 4.1 above. Household samples had the highest average pH recording 7.40 while water vending stations had the lowest pH average of 6.44 which is 0.04 less compared to shops and supermarket samples. The coded water samples from various sources in the city that were analyzed are presented in table 4.3 below.

Table 4. 3: Bottled water samples from selected sources in Nairobi

Bottled water	**Brand codes**	**pH Values**	**Source**	**Subcounty**	**KS- EAS standards**
Brand 1	SPDSWOD001 SPDSWOD002 SPDSWOD003 SPDSWOD004	5.5 5.79 5.87 6.32	Woodley ward	Kibra sub-county	6.5 – 8.5
Brand 2	SMQUHUR002 SMQUHUR003 SMQUHUR003	6.46 6.43 6.4	Huruma	Mathare sub-county	
Brand 3	SMACGAR001 SMACGAR002 SMACGAR003 SMACGAR004	6.41 6.33 6.27 6.03	Garage	Kamukunji sub-county	

Brand 4	SMKECBD001 SMKECBD002 SMKECBD004	6.44 6.45 6.42	Central Business district (CBD)	Starehe sub-county	
Brand 5	SMNVCBD001 SMNVCBD003 SMNVCBD004	6.45 6.46 6.43			
Vending Station	WKNJIR001 WKNJIR002 WKNJIR003 WKNJIR004	6.12 6.11 6.18 6.04	Njiru	Njiru sub-county	
	WKRUA004	6.46	Ruai		
Household	HHEMWK001 HHEMWK002	8.95 8.67	Juakali	Embakasi sub-county	

Brands 1, 2, 3, 4 and 5 of bottled water as shown in table 4.3 above were all out of KS-EAS standards. Out of eight samples collected in the Central Business District of Nairobi City, six samples recorded a pH value of less than 6.5. This reflected 75 % out of specification for the pH parameter. This could have been attributed to inefficient treatment methodology where acidic cations were not efficiently osmotically eliminated. The vending station water samples as shown in table 4.3 above had pH values ranging from 6.04 to 6.46 indicating a 100 % out of specification for the pH parameter. Again, the pH values below the limit recorded were attributed to inefficient treatment methodology where acidic cations were not efficiently osmotically eliminated. It was observed that only two household water samples as shown in table 4.3 above had a pH above 8.5 KS standard recording pH values of 8.95 and 8.67. The pH values above the limit recorded could have been attributed to alkaline-contaminated storage conditions or inefficient water treatment methodology. The raw data is shown on appendix 1

4.2.3 Conductivity

The average Conductivity of the water samples from various sources (Households, shops and supermarkets and vendors) in different sub-counties are presented in figure 4.2.2 below.

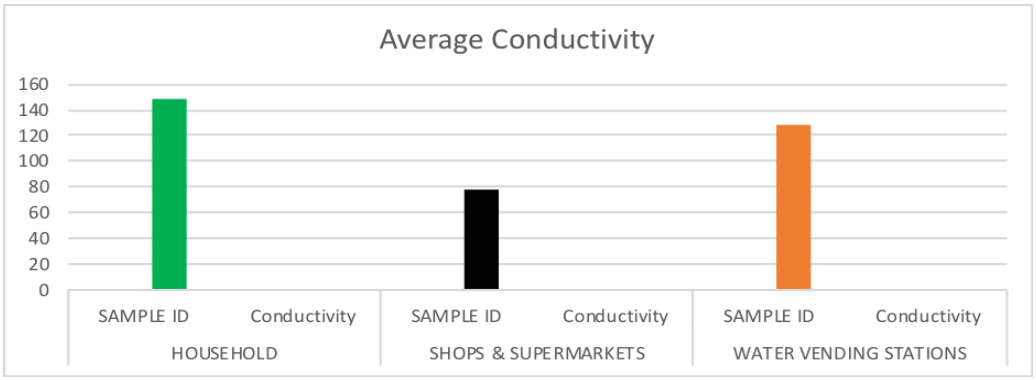

Figure 4. 2: Average Conductivity of the water samples from various sources

The conductivity values were found to vary depending on the source. The household water samples recorded 147.76 µs, vending stations recording 128.11 µs while the water samples from shops and supermarkets recorded 78.47 µs. In addition, the standard deviation for the three categories was ±35.71. The conductivity values in household water samples could have been attributed to contaminated storage facilities. All of the water samples, however, were within the acceptable ranges of a maximum conductivity of 2500 µs. However, one water sample, HHHWWA003, collected from Waithaka ward, Dagoretti sub-county, recorded 1159 s but remained within the accepted conductivity specification as guided by KS EAS 153:2018 - standard on purified water and KS EAS 12:2018 for potable water. The conductivity value could be attributed to an unclean storage facility.

Column representation of conductivity results are presented in figures 4.2.3 and 4.2.4 below. The representation depicted that all of the samples had an even column representation, with the exception of sample HHHWWA003, whose conductivity value was an outlier. The raw data is shown on appendix 2.

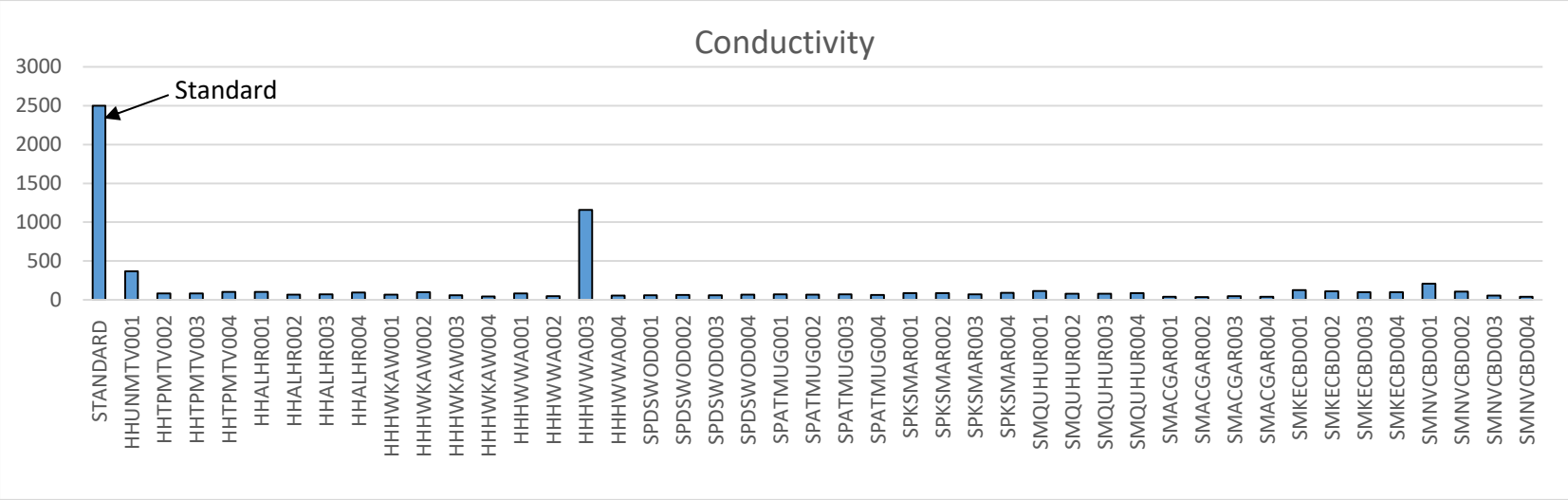

Figure 4. 3: Conductivity (µs) of water samples compared to the standard value

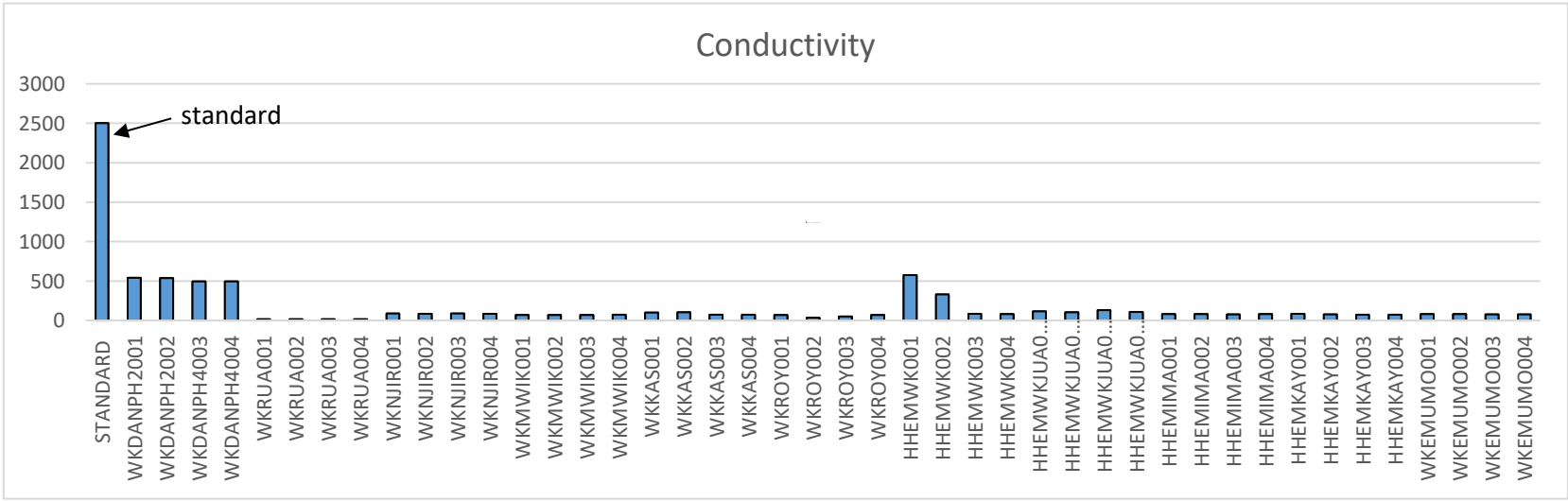

Figure 4. 4: Conductivity (µs) of water samples to the standard value

4.2.4 Colour

According to KS EAS 12:2018 – potable water specifications, colour specification is divided into two; natural portable water with a maximum of 50 PCU/TCU and treated potable water of up to 15 PCU/TCU. The household water samples were categorized as natural potable water while shops and supermarkets and water vending stations samples classified as treated potable water.

From a total sample size of thirty two, five household water samples were above the limit of 50 PCU reflecting 15.61 % out of limit. However, the average colour values for the household samples were within the limit recording 33.53 PCU. The results showed that 15.61 % of population living in the city of Nairobi are drinking household water that is not colour compliant. 84.39 % of the water samples were safe for drinking. The percentage of compliance in household water samples could be attributed to the source of the water some harvesting while others boiled the water before drinking. Shops and supermarkets samples recorded an average of 52.93 PCU. In addition, two samples from a sample size of twenty eight were within 15 PCU specifications indicating that 7.14 % of people drinking bottled water from supermarkets and shops in the city of Nairobi are drinking water that is safe. The data shows inefficiency of treatment methodology and more specifically filtration process. This could be the possible reason why only 7.14 % of sample were within KS EAS 12:2018 – potable water specifications. Only 25 % of water vending station samples were found to be within 15 PCU specifications, while only seven samples from a sample size of twenty eight ranged from 5 PCU to 14 PCU. The average colour test was 24.25 PCU. Although the average is out of limit, the value is far below the shops and supermarkets average colour test results showing how efficient filtration process in water vending stations is as compared to bottled water in shops and supermarkets.

The average colours for the water samples collected from the households, shops and supermarkets and from the vendors are compared in figure 4.2.5 below. According to the study, water samples from shops and supermarkets had a colour value of 52.53 PCU, households at 33.53 PCU, and finally samples from vendor stations at 24.25 PCU with the three categories having a standard deviation of ±14.64. The raw data is shown on appendix 3.

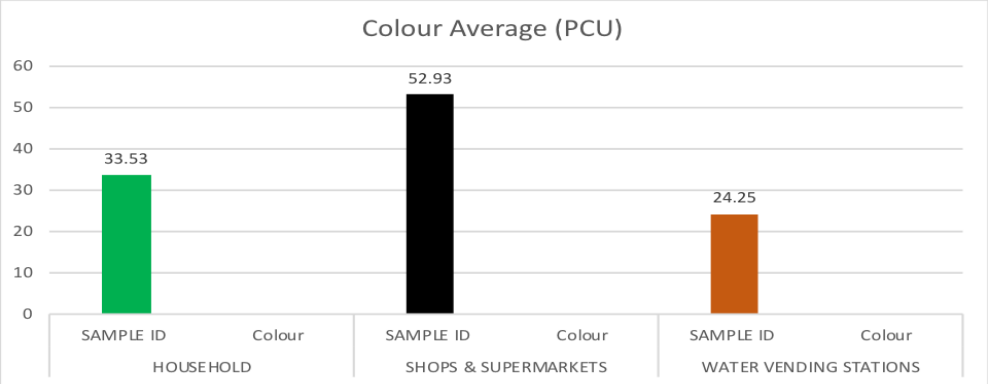

Figure 4. 5: Colour average comparisons.

4.2.5 Fluoride Ions

Out of eighty eight samples that were collected in the city of Nairobi, six sample results were above 1.5 ppm as per KS EAS 153:2018 – standard on purified water and KS EAS 12:2018 – potable water specifications reflecting 6.82 %. This means that 6.82 % population in the City of Nairobi is drinking unsafe water with Fluoride levels above 1.5 ppm, exposing approximately 300,000 people to Fluoride contamination risks. All the water samples collected in Dandora, Njiru sub-county WKDANPH2001, WKDANPH2002, WKDANPH4003, WKDANPH4004 were above 1.5 ppm recording 1.82 ppm,1.78 ppm,1.90 ppm and 1.83 ppm respectively. The level of Fluoride is possibly due to lack of treatment before freely distributing to the entire population in Dandora and the geological structure of the sampling area. One bottled water sample collected in CBD, Starehe sub-county recorded 1.76 ppm while another household water sample collected in Juakali, Embakasi sub-county recorded 1.93 ppm. The variation in the other samples was noted to be negligible. All the averages were within 1.5 ppm specification. Fluoride comparison between household, shops and supermarkets and water vending stations are shown in figure 4.6 below.

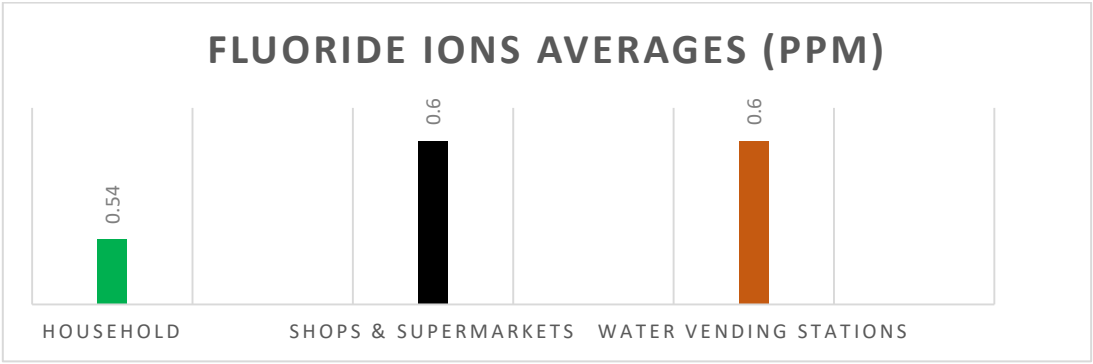

Figure 4. 6: Average Fluoride ions results comparisons from various water sources.

Both shops and supermarkets and water vending stations recorded an average of 0.6ppm while household samples recorded an average of 0.54. The three category had a standard deviation of ±0.04. All the averages were within 1.5 ppm as per KS EAS 153:2018 – standard on purified water and KS EAS 12:2018 – potable water specifications. The raw data is shown on appendix 4.

4.2.6 Residual Chlorine

According to KS EAS 153:2018 – standard on purified water and KS EAS 12:2018 – potable water specifications, no residual Chlorine should be detected. There was no residual Chlorine detected for all the samples analysed in the laboratory. From a total sample size of 88, residual Chlorine was detected in 8 water samples, reflecting 9.1 %. These samples were collected from water vending stations in Dandora and Kasarani town Njiru and Kasarani sub-counties respectively where analysis was done in the field. The inefficient filtration treatment process could have contributed to the presence of residual Chlorine in the water samples. According to KS EAS 153:2018 standard on purified water and KS EAS 12:2018 standard for potable water, no residual Chlorine should be detected. The raw data is shown on appendix 5.

4.2.7 Manganese Ions

The study showed that eighteen water samples were above 0.1 ppm which is the maximum concentration in any potable water. These represent 20.46 % of the samples that were out of limit. This means that 20.46 % of Nairobi's total population is drinking water contaminated with Manganese ions. The distribution of the out of limit samples was six household water samples that recorded an average 0.28 ppm, ten bottled water samples from supermarkets and kiosks with an average of 0.14 ppm and two water vending samples with an average of 0.13 ppm. Manganese concentration was ranging between <0.001 ppm to 0.68 ppm.

The out of limit household samples was attributed to lack of treatment methodology. For example, HHHWWA003 collected in Dagoretti sub-county recorded the highest Manganese concentration of 0.68 ppm. The water sample had been harvested and there was no treatment done prior to drinking. The ten bottled water samples that were out of limit was attributed to inefficient treatment methodologies where the ions were not efficiently removed. Although only two samples from water vending stations were out of limits with an average of 0.13 ppm, this clearly shows the treatment methodologies are more efficient as compared to bottling

industries. Manganese ion comparison between household, shops and supermarkets and water vending stations is shown in figure 4.7 below.

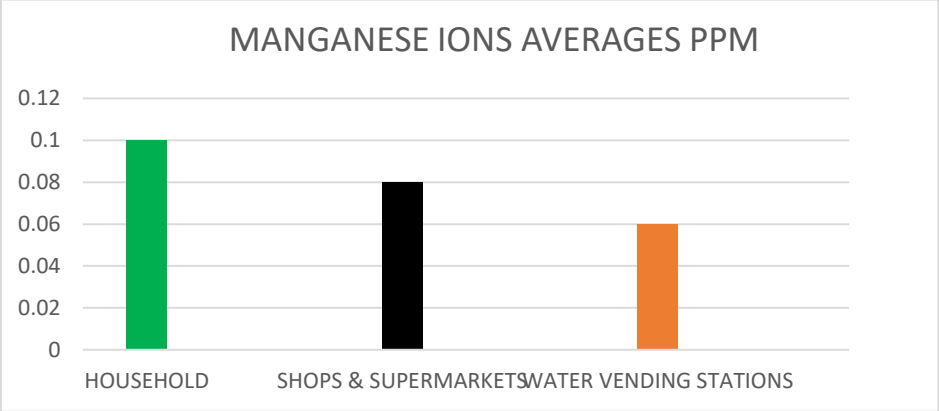

Figure 4. 7: Manganese ions averages Comparisons.

Comparatively, household water average was 0.1 ppm, 0.08 ppm for shops & supermarkets and 0.06 ppm for vending stations. In addition, the standard deviation for the three categories was ±0.02. The raw data is shown on appendix 7.

4.2.8 Iron (II) Ions

A total of sixteen out of eighty eight samples recorded Fe^{2+} concentration above the recommended 0.3 ppm representing 18.2 % of sample size. 18.2 % of total population in the City of Nairobi are drinking water with levels of Iron above 0.1 ppm putting their health at risk. Household and water vending station recorded five samples that were out of limit with an average of 0.18 ppm and 0.17 ppm respectively while bottled water samples from shops and supermarkets recorded 6 samples with an average of 0.23 ppm. The concentration ranged from <0.001 ppm to 0.53 ppm. The out of limit samples of above 0.3 ppm were attributed to lack of water treatment methodologies in households where the respondent clearly indicated they did not treat drinking water. Additionally, water vending stations and supermarket/shops out of limit samples were attributed to inefficient treatment methodology. However, the results showed that bottling companies have better Iron treatment methodologies as compared to water vending stations which is not the case in Manganese ions treatment methodology. Iron (II) ion comparison between household, shops and supermarkets and water vending stations is shown in figure 4.8 below.

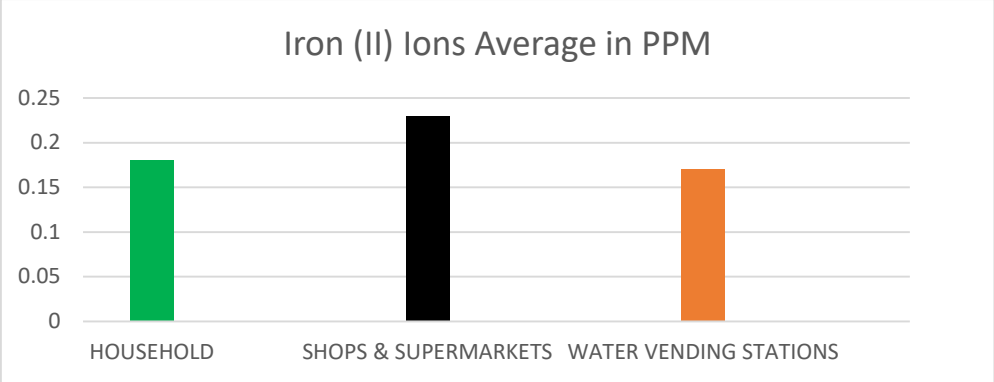

Figure 4. 8: Iron (II) ions averages Comparisons from various water sources.

Shops and Supermarkets recorded 0.23 ppm of Iron (II) ions average results while water vending stations recorded 0.17 ppm as households recorded 0.18 ppm. The standard deviation for the three categories was ±0.03. All the averages were within the standard on purified water and KS EAS 12:2018 – potable water specifications. The raw data is shown on appendix 8.

4.2.9 Silicon Ions

All the samples analysed for Silicon ions were within the KS EAS 153:2018 standard on purified water and KS EAS 12:2018 standard on potable water, with specifications of 50 ppm maximum.

Bottled water samples collected in supermarkets and shops were ranked last in Silicon ion test having an average concentration of 2.99 ppm while water samples collected in water vending stations recorded an average concentration of 3.44 ppm which was still within the 50ppm allowable limits.

Water samples coded HHALHR003 collected from households recorded a concentration of 10.23 ppm while HHALHR002 recorded concentration of 0.56 ppm. Silicon ion comparison between household, shops and supermarkets and water vending stations recording 3.25 ppm, 2.99 ppm and 3.44 ppm respectively as shown in figure 4.9 below.

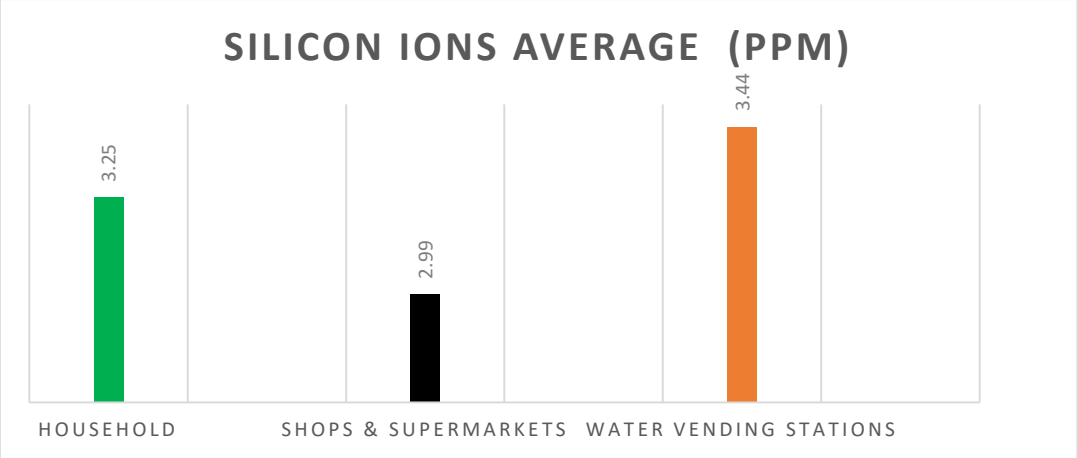

Figure 4. 9: Silicon ions averages Comparisons.

The standard deviation for the three categories was ±0.23. Water samples from water vending stations recorded the highest Silicon ions average concentrations of 3.44 ppm while shops and supermarkets reported the least at 2.99 ppm. However, all the averages were within the 2018 standard on purified water and KS EAS 12:2018 standard on potable water as shown in figure 4.9 above. The raw data is shown on appendix 9.

4.2.10 Total Coliform and *Escherichia coli*

All the bottled water samples collected in shops and supermarket recorded <1 MPN/Index 100mL for both Total Coliform and *Escherichia coli* test . This showed that the bottled water that is distributed in the city of Nairobi is thoroughly treated for microbial parameters and that the microbial treatment methods in use were efficient.

However, out of twenty eight water vending samples in different sub-counties, thirteen samples recorded <1 MPN/Index 100 mL in both Total Coliform and *Escherichia coli* test. This depicted that 53.57 % of water vending stations in the City of Nairobi are distributing drinking water that is non-compliant to microbial properties, which indicated that the population is exposed to unsafe water in water vending stations. The out of compliance in microbial of water vending stations sample could be attributed to ineffective microbial treatment methods where the owners opt not to use the correct amounts of Chlorine to kill micro-organisms for cost reduction reasons.

Out of thirty two water samples in the eleven sub-counties of the City of Nairobi, only eleven samples that were found to be within KS EAS 153:2018 – standard on purified water and KS EAS 12:2018 – potable water specifications for Total Coliform and *Escherichia coli* test. The compliance level for the household category was 35 %. This demonstrates that 65% of Nairobi's

household population is drinking water that is unsafe in terms of microbial properties. The non-compliance in household could be associated with non-hygienic storage facilities, lack of water treatment and storage for longer durations. Four samples recorded >180 MPN/100 ml in Total Coliform showing microbial contamination. The raw data is shown on appendix 6.

4.2.11 Chart Illustration of Test Results in Various Sub-counties.

The following is a summary of test results from various sub-counties as shown in table 4.4.

Table 4. 4: Summary of test results

Sub-county		Samples collected	Compliant with KEBS Specification
1.	Embakasi	20	6
2.	Kasarani	12	2
3.	Njiru	12	1
4.	Dagoretti	8	0
5.	Westlands	8	1
6.	Kamukunji	4	0
7.	Starehe	8	0
8.	Mathare	4	2
9.	Lang'ata	4	0
10.	Makadara	4	0
11.	Kibra	4	0

The chart illustration of the total samples tested is shown below in figure 4.10 below

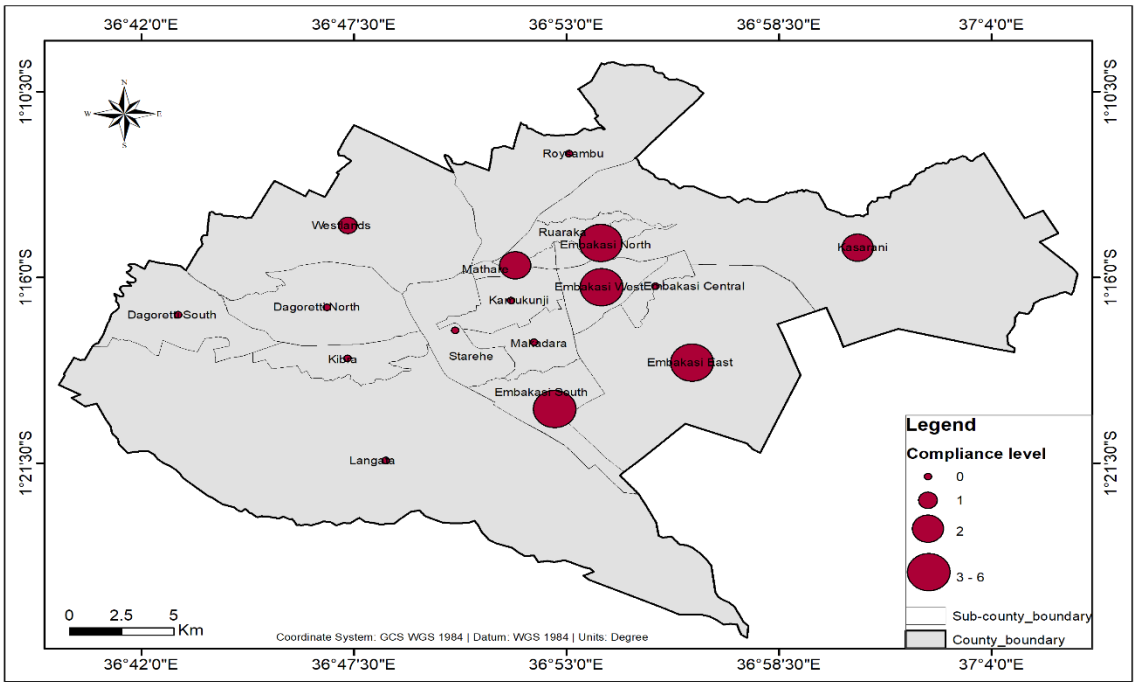

Figure 4. 10: Chart illustration of sample compliance from various sub-counties

4.3 Evaluation of Efficiency of Water Treatment Techniques in the City of Nairobi, Kenya.

Efficiency of water treatment techniques was evaluated using the total number of tests that were within the limits in comparison with total number of tests done for all the samples collected in supermarkets, shops and water vending stations. The efficiency was evaluated using the following expression.

η = Number of tests within the limits / Total number of tests done. Equation 2

Where η is efficiency.
For a total of 560 tests that were performed on the water samples collected in supermarkets, shops and water vending stations, 438 tests that were within the limits. hence the efficiency of the technique was.

$$\eta = 438/560$$

$$\eta = 0.78 \approx 0.8$$

The study showed that the efficiency of the water treatment technique for all the water samples collected in supermarkets, shops and water vending stations was 0.8. This meant that the treatment techniques were 80 % efficient.

4.4 Assessment of Bottled Water Packaging in the City of Nairobi, Kenya.

One brand out of four bottled water samples were packaged in 1 litre clear Polyethylene Terephthalate (PET) bottles sealed with blue caps with two threads in Kibra sub-county Woodley (Toi) ward. The caps were 120 mm tall. The figure below depicts the primary packaging used.

Figure 4. 11: 1L clear PET packaging with two threaded cap water sample.

The packaging of the water samples was well sealed suitable for preventing possible adulteration or contamination as guided by KS EAS 153:2018 on packaged drinking water specification. The packaging material was strong enough to withstand normal handling and transportation.

The brand name of the bottled water was visible and the label describing the amount of mineral content in $mg.L^{-1}$. However, the KS EAS standard required the bottling company to declare TDS in $mg.L^{-1}$ and pH value in pH units which was not declared in the label. Additionally, the postal and physical addresses were indicated and contact numbers available as required by the guideline.

In Langata sub-county Mugumoini ward, another brand of 4 bottled water samples packaged in 1.5 litre PET bottles and light blue caps with one thread were sampled. The caps were 80 mm in height wrapped with Low-density polyethylene (LDPE) paper . The packaging was well sealed and material strong enough to withstand normal handling and transportation. The photograph below shows clear PET packaging with one threaded cap water sample.

Figure 4. 12: 1.5L clear PET packaging with one threaded cap water sample.

The labels had clearly indicated mineral content in $mg.L^{-1}$ including TDS and pH values. This type of brand complied with labelling requirement as compared to the other bottled brand sampled in Kibra. It is also clear that, bottling industry have different types of packaging as guided by cost. For example, the brand of water sampled in Kibra sub-county had a two threaded cap with 120 mm in height while the one sampled in Langata had one threaded cap with 80 mm in height.

Bottled water sampled in Makadara sub-county were also packaged in 1.5 litre clear PET bottle with threaded blue caps with a height of 140 mm. The caps were wrapped with light blue LDPE paper. The primary packaging used is shown in figure 4.13 below.

Figure 4. 13: 1.5L clear PET packaging with two threaded cap water sample.

The label visibly indicates mineral contents including pH and TDS. However, the label indicated postal and physical addresses and contact numbers available as required by the KS EAS 153:2018. Samples collected in Mathare sub-county in Huruma ward from a different bottling company were packaged in 1 litre clear PET bottles with threaded blue caps sealed with LDPE paper. The caps were 110mm while the PET bottle was 268 mm in height. Mineral content was declared as guided by KS EAS 153:2018 guidelines. Although the label had the bottler postal and physical addresses, the contacts were missing. The photograph below taken during laboratory analysis show the type of packaging used.

Figure 4. 14: 1L clear PET packaging with two threaded cap water sample.

Kamukunji sub-county Garage area bottled samples were packaged in 1 litre clear PET bottles with two threaded white caps sealed with a branded LPDE paper. The caps were 100 mm while PET bottles were 265 mm in height. The declared mineral content was as per KS EAS 153:2018 guidelines. The label also indicated the bottler postal and physical addresses including customer service contacts. The type of packaging used is shown in figure 4.15 below.

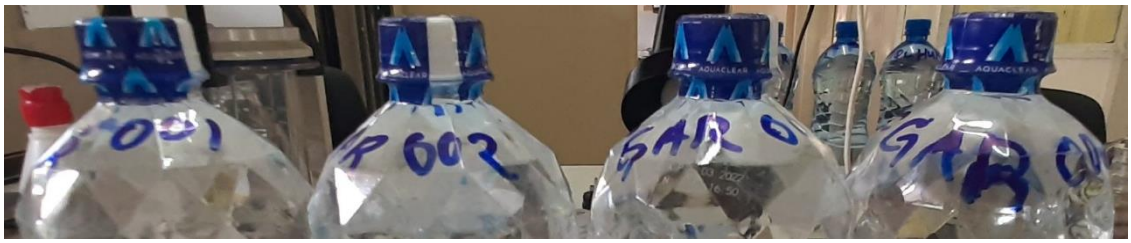

Figure 4. 15: 1L clear PET packaging with two threaded cap water sample.

Eight bottled samples were collected in two randomly sampled supermarkets from two different brands. The samples were bottled in 1 litre clear PET bottles, one brands having one threaded green caps while the other two threaded caps both with branded LPDE paper. 242 mm and 270 mm were the heights of the PET bottles for the two brands. In one of the brand the caps were not of the same size putting the quality of the packaging used in question.

The label information for one of the brand was fully compliant with KS EAS 153:2018 on packaged drinking water specification while the other brand failed to declare pH values as

required by the standards. The type of primary packaging used is shown in figure 4.16 and 4.17 below

Figure 4. 16: Aerial view of CBD bottled water sample brand 1 Packaging

Figure 4. 17: CBD bottled water sample brand 2 packaging

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

a. The Point-of-Use treatment systems in the City of Nairobi were boiling and the use of Sodium Hypochlorite at 6.25% each in households, bottled water in shops, kiosks, and supermarkets at 100%, and reverse osmosis in vending stations at 100%. Out of 32 household water sampling points, only 4 households treated water before drinking. This represented 12.5 % of total population drinking water from other sources other than municipal and bottled water. Residual chlorine, Silicon ions and conductivity tests were within KS EAS 12:2018 standards for the natural potable water specifications. In addition, forty three tests out of three hundred and twenty tests from Total Coliform, *E. Coli*, Fluoride ions, Manganese ions, Iron ions, pH and colour were above KS EAS 12:2018 standard for the natural potable water specifications representing 13.4 %. Therefore, 13.4 % of household population in the City of Nairobi were drinking water from other sources other than municipal and bottled which could be considered unsafe.
b. The quality of selected parameters was 13.6% within the set specifications. Out of eighty-eight samples, twelve water samples complied reflecting 13.6%.
c. The efficiency of the techniques used to purify water was 80% for all the samples collected in supermarkets, shops and water vending stations. A total of five hundred and sixty tests performed on the samples collected from supermarkets, shops and water vending stations, four hundred and thirty eight samples were within the respective parameter limits as shown in appendix 1 to 7 . Boiling drinking water, one of the point-of-use water treatment methods, was more effective in sterilization with 100 % compliance than the use of Sodium Hypochlorite with 50 % compliance.
d. Portable water packaging compliance was 42.9%. Twelve bottled water samples out of twenty-eight complied with label information. The assessment done on the packaging of bottled water in the City of Nairobi, showed that different brands used different sizes and colours of caps and PET bottles, however all the samples were packaged with the same material that was strong enough to withstand normal handling and transportation as guided by KS EAS 153:2018 standards on packaging of drinking water.

5.2 Recommendations

From this study it is recommended that:

a. There is a need to sensitize the population in the City of Nairobi on the importance of water treatment before drinking and especially in the households that drink harvested rainwater and from other natural sources. In addition, households should consider boiling water as a means of treatment over use of Sodium Hypochlorite. Boiling is affordable and more effective.
b. Establish the dosage of Sodium Hypochlorite used in households due to the fact that the samples were treated using Sodium Hypochlorite but had significant difference in efficiencies.
c. Water quality to be frequently monitored among the vendors and bottling industries.
d. Kenya Bureau of Standards to strictly enforce compliance with portable water both in bottling industries and water vending stations. This is through creating awareness among the players and the public. Additionally, compliance should be enforced for all water brands on packaging standards.

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APPENDICES

Appendix 1: pH test

S/no	Sample Id	pH *6.5-8.5 (Std)*	S/no	Sample Id	pH *6.5-8.5 (Std)*	S/no	Sample Id	pH *6.5-8.5 (Std)*
1.	HHUNMTV001	5.85	31.	SMQUHUR003	6.43	61.	WKKAS001	7.30
2.	HHTPMTV002	7.26	32.	SMQUHUR004	6.40	62.	WKKAS002	7.37
3.	HHTPMTV003	7.25	33.	SMACGAR001	6.41	63.	WKKAS003	6.88
4.	HHTPMTV004	7.46	34.	SMACGAR002	6.33	64.	WKKAS004	6.84
5.	HHALHR001	7.60	35.	SMACGAR003	6.27	65.	WKROY001	6.68
6.	HHALHR002	7.67	36.	SMACGAR004	6.03	66.	WKROY002	6.57
7.	HHALHR003	7.70	37.	SMKECBD001	6.44	67.	WKROY003	6.50
8.	HHALHR004	7.51	38.	SMKECBD002	6.45	68.	WKROY004	6.80
9.	HHHWKAW001	6.75	39.	SMKECBD003	6.52	69.	HHEMWK001	8.95
10.	HHHWKAW002	7.02	40.	SMKECBD004	6.42	70.	HHEMWK002	8.67
11.	HHHWKAW003	6.95	41.	SMNVCBD001	6.45	71.	HHEMWK003	7.30
12.	HHHWKAW004	6.92	42.	SMNVCBD002	6.80	72.	HHEMWK004	7.30
13.	HHHWWA001	6.58	43.	SMNVCBD003	6.46	73.	HHEMWKJUA001	7.86
14.	HHHWWA002	6.76	44.	SMNVCBD004	6.43	74.	HHEMWKJUA002	7.72
15.	HHHWWA003	6.41	45.	WKDANPH2001	8.10	75.	HHEMWKJUA003	8.06
16.	HHHWWA004	6.85	46.	WKDANPH2002	8.16	76.	HHEMWKJUA004	7.48
17.	SPDSWOD001	5.50	47.	WKDANPH4003	8.15	77.	HHEMIMA001	7.57
18.	SPDSWOD002	5.79	48.	WKDANPH4004	8.25	78.	HHEMIMA002	7.60
19. .	SPDSWOD003	5.87	49.	WKRUA001	6.80	79.	HHEMIMA003	7.61
20.	SPDSWOD004	6.32	50.	WKRUA002	6.74	80.	HHEMIMA004	7.59
21.	SPATMUG001	7.03	51.	WKRUA003	6.57	81.	HHEMKAY001	7.80
22.	SPATMUG002	6.98	52.	WKRUA004	6.46	82.	HHEMKAY002	7.55
23.	SPATMUG003	6.97	53.	WKNJIR001	6.12	83.	HHEMKAY003	7.58
24.	SPATMUG004	6.97	54.	WKNJIR002	6.11	84.	HHEMKAY004	7.60
25.	SPKSMAR001	6.66	55.	WKNJIR003	6.18	85.	WKEMUMO001	7.48
26.	SPKSMAR002	6.80	56.	WKNJIR004	6.04	86.	WKEMUMO002	7.48
27.	SPKSMAR003	6.97	57.	WKMWIK001	6.68	87.	WKEMUMO003	7.58
28.	SPKSMAR004	6.81	58.	WKMWIK002	6.76	88.	WKEMUMO004	7.60
29.	SMQUHUR001	6.55	59.	WKMWIK003	6.84	89.		
30.	SMQUHUR002	6.46	60.	WKMWIK004	6.91	90.		

Appendix 2: Conductivity test

S/no	**Sample Id**	µs ***Std-2500*** µs	**S/no**	**Sample Id**	µs ***Std-2500*** µs	**S/no**	**Sample Id**	µs ***Std- 2500*** µs
1.	HHUNMTV001	367	31.	SMQUHUR003	78.1	61.	WKKAS001	101.4
2.	HHTPMTV002	80.4	32.	SMQUHUR004	86.1	62.	WKKAS002	102.6
3.	HHTPMTV003	83.3	33.	SMACGAR001	40.7	63.	WKKAS003	73.4
4.	HHTPMTV004	101.5	34.	SMACGAR002	36.3	64.	WKKAS004	72.0
5.	HHALHR001	101.0	35.	SMACGAR003	46.3	65.	WKROY001	71.3
6.	HHALHR002	66.7	36.	SMACGAR004	37.7	66.	WKROY002	35.6
7.	HHALHR003	68.4	37.	SMKECBD001	125.8	67.	WKROY003	49.5
8.	HHALHR004	93.3	38.	SMKECBD002	111.1	68.	WKROY004	70.8
9.	HHHWKAW001	65.6	39.	SMKECBD003	98.6	69.	HHEMWK001	577
10.	HHHWKAW002	98.1	40.	SMKECBD004	98.4	70.	HHEMWK002	329
11.	HHHWKAW003	59.3	41.	SMNVCBD001	206	71.	HHEMWK003	85.1
12.	HHHWKAW004	42.4	42.	SMNVCBD002	105.9	72.	HHEMWK004	81.6
13.	HHHWWA001	81.7	43.	SMNVCBD003	54.7	73.	HHEMWKJUA001	114.5
14.	HHHWWA002	48.1	44.	SMNVCBD004	40.0	74.	HHEMWKJUA002	102.6
15.	HHHWWA003	1159	45.	WKDANPH2001	541	75.	HHEMWKJUA003	131.1
16.	HHHWWA004	52.8	46.	WKDANPH2002	539	76.	HHEMWKJUA004	108.5
17.	SPDSWOD001	59.1	47.	WKDANPH4003	497	77.	HHEMIMA001	81.8
18.	SPDSWOD002	61.2	48.	WKDANPH4004	497	78.	HHEMIMA002	79.6
19. .	SPDSWOD003	57.5	49.	WKRUA001	16.48	79.	HHEMIMA003	77.1
20.	SPDSWOD004	65.1	50.	WKRUA002	16.20	80.	HHEMIMA004	82.7
21.	SPATMUG001	71.1	51.	WKRUA003	15.22	81.	HHEMKAY001	85.7
22.	SPATMUG002	65.6	52.	WKRUA004	15.48	82.	HHEMKAY002	78.1
23.	SPATMUG003	69.3	53.	WKNJIR001	87.3	83.	HHEMKAY003	72.4
24.	SPATMUG004	62.8	54.	WKNJIR002	86.8	84.	HHEMKAY004	73.0
25.	SPKSMAR001	86.0	55.	WKNJIR003	89.8	85.	WKEMUMO001	81.5
26.	SPKSMAR002	86.0	56.	WKNJIR004	87.2	86.	WKEMUMO002	79.8
27.	SPKSMAR003	69.7	57.	WKMWIK001	71.2	87.	WKEMUMO003	76.4
28.	SPKSMAR004	88.3	58.	WKMWIK002	70.9	88.	WKEMUMO004	77.0
29.	SMQUHUR001	113.3	59.	WKMWIK003	70.2	89.		
30.	SMQUHUR002	76.5	61.	WKMWIK004	71.9	90.		

Appendix 3: Colour test

S/no	Sample Id	Colour (PCU) *Std- 50 PCU (NPW) & 15 (TPW)*	S/no	Sample Id	Colour (PCU) *Std- 50 PCU (NPW) & 15 (TPW)*	S/no	Sample Id	Colour (PCU) *Std- 50 PCU (NPW) & 15 (TPW)*
1.	HHUNMTV001	55	31.	SMQUHUR003	67	61.	WKKAS001	16
2.	HHTPMTV002	33	32.	SMQUHUR004	55	62.	WKKAS002	30
3.	HHTPMTV003	25	33.	SMACGAR001	60	63.	WKKAS003	32
4.	HHTPMTV004	60	34.	SMACGAR002	63	64.	WKKAS004	86
5.	HHALHR001	36	35.	SMACGAR003	98	65.	WKROY001	31
6.	HHALHR002	52	36.	SMACGAR004	41	66.	WKROY002	25
7.	HHALHR003	38	37.	SMKECBD001	47	67.	WKROY003	85
8.	HHALHR004	39	38.	SMKECBD002	36	68.	WKROY004	31
9.	HHHWKAW001	34	39.	SMKECBD003	80	69.	HHEMWK001	33
10.	HHHWKAW002	48	40.	SMKECBD004	90	70.	HHEMWK002	31
11.	HHHWKAW003	11	41.	SMNVCBD001	49	71.	HHEMWK003	52
12.	HHHWKAW004	3	42.	SMNVCBD002	52	72.	HHEMWK004	27
13.	HHHWWA001	16	43.	SMNVCBD003	49	73.	HHEMWKJUA001	48
14.	HHHWWA002	16	44.	SMNVCBD004	58	74.	HHEMWKJUA002	43
15.	HHHWWA003	18	45.	WKDANPH2001	31	75.	HHEMWKJUA003	54
16.	HHHWWA004	21	46.	WKDANPH2002	31	76.	HHEMWKJUA004	30
17.	SPDSWOD001	47	47.	WKDANPH4003	16	77.	HHEMIMA001	36
18.	SPDSWOD002	28	48.	WKDANPH4004	16	78.	HHEMIMA002	55
19. .	SPDSWOD003	74	49.	WKRUA001	16	79.	HHEMIMA003	49
20.	SPDSWOD004	55	50.	WKRUA002	16	80.	HHEMIMA004	22
21.	SPATMUG001	19	51.	WKRUA003	11	81.	HHEMKAY001	22
22.	SPATMUG002	47	52.	WKRUA004	16	82.	HHEMKAY002	16
23.	SPATMUG003	2	53.	WKNJIR001	14	83.	HHEMKAY003	35
24.	SPATMUG004	76	54.	WKNJIR002	9	84.	HHEMKAY004	15
25.	SPKSMAR001	55	55.	WKNJIR003	5	85.	WKEMUMO001	33
26.	SPKSMAR002	57	56.	WKNJIR004	13	86.	WKEMUMO002	30
27.	SPKSMAR003	47	57.	WKMWIK001	14	87.	WKEMUMO003	25
28.	SPKSMAR004	7	58.	WKMWIK002	16	88.	WKEMUMO004	48
29.	SMQUHUR001	64	59.	WKMWIK003	14	89.		
30.	SMQUHUR002	59	62.	WKMWIK004	17	90.		

Appendix 4: Fluoride test

S/no	Sample Id	Fluoride (ppm)	S/no	Sample Id	Fluoride (ppm)	S/no	Sample Id	Fluoride (ppm)
		Std-1.5ppm Max			***Std-1.5ppm Max***			***Std-1.5ppm Max***
1.	HHUNMTV001	0.44	31.	SMQUHUR003	0.5	61.	WKKAS001	1.17
2.	HHTPMTV002	0.24	32.	SMQUHUR004	0.47	62.	WKKAS002	1.25
3.	HHTPMTV003	0.45	33.	SMACGAR001	0.33	63.	WKKAS003	0.44
4.	HHTPMTV004	0.51	34.	SMACGAR002	0.29	64.	WKKAS004	0.03
5.	HHALHR001	0.59	35.	SMACGAR003	0.31	65.	WKROY001	0.53
6.	HHALHR002	0.47	36.	SMACGAR004	0.52	66.	WKROY002	0.69
7.	HHALHR003	0.41	37.	SMKECBD001	0.98	67.	WKROY003	0.5
8.	HHALHR004	0.43	38.	SMKECBD002	1.33	68.	WKROY004	0.42
9.	HHHWKAW001	0.27	39.	SMKECBD003	1.4	69.	HHEMWK001	1.2
10.	HHHWKAW002	0.22	40.	SMKECBD004	1.47	70.	HHEMWK002	1.6
11.	HHHWKAW003	0.17	41.	SMNVCBD001	1.76	71.	HHEMWK003	0.41
12.	HHHWKAW004	0.06	42.	SMNVCBD002	1.28	72.	HHEMWK004	0.32
13.	HHHWWA001	0.21	43.	SMNVCBD003	0.31	73.	HHEMWKJUA001	1.16
14.	HHHWWA002	0.62	44.	SMNVCBD004	0.34	74.	HHEMWKJUA002	0.7
15.	HHHWWA003	0.53	45.	WKDANPH2001	1.82	75.	HHEMWKJUA003	1.93
16.	HHHWWA004	0.62	46.	WKDANPH2002	1.78	76.	HHEMWKJUA004	0.72
17.	SPDSWOD001	0.21	47.	WKDANPH4003	1.9	77.	HHEMIMA001	0.34
18.	SPDSWOD002	0.12	48.	WKDANPH4004	1.83	78.	HHEMIMA002	0.28
19. .	SPDSWOD003	0.5	49.	WKRUA001	0.07	79.	HHEMIMA003	0.3
20.	SPDSWOD004	0.21	50.	WKRUA002	0.19	80.	HHEMIMA004	0.31
21.	SPATMUG001	0.51	51.	WKRUA003	0.11	81.	HHEMKAY001	0.85
22.	SPATMUG002	0.48	52.	WKRUA004	0.13	82.	HHEMKAY002	0.48
23.	SPATMUG003	0.48	53.	WKNJIR001	0.32	83.	HHEMKAY003	0.42
24.	SPATMUG004	0.47	54.	WKNJIR002	0.39	84.	HHEMKAY004	0.05
25.	SPKSMAR001	0.33	55.	WKNJIR003	0.31	85.	WKEMUMO001	0.41
26.	SPKSMAR002	0.52	56.	WKNJIR004	0.34	86.	WKEMUMO002	0.22
27.	SPKSMAR003	0.26	57.	WKMWIK001	0.47	87.	WKEMUMO003	0.28
28.	SPKSMAR004	0.48	58.	WKMWIK002	0.51	88.	WKEMUMO004	0.28
29.	SMQUHUR001	0.42	59.	WKMWIK003	0.31	89.		
30.	SMQUHUR002	0.6	63.	WKMWIK004	0.45	90.		

Appendix 5: Residual Chlorine test

S/no	Sample Id	R.C $Mg.L^{-1}$ *Std- N.D*	S/no	Sample Id	R.C $Mg.L^{-1}$ *Std- N.D*	S/no	Sample Id	R.C $Mg.L^{-1}$ *Std- N.D*
1.	HHUNMTV001	N.D	31.	SMQUHUR003	N.D	61.	WKKAS001	0.2
2.	HHTPMTV002	N.D	32.	SMQUHUR004	N.D	62.	WKKAS002	0.2
3.	HHTPMTV003	N.D	33.	SMACGAR001	N.D	63.	WKKAS003	0.2
4.	HHTPMTV004	N.D	34.	SMACGAR002	N.D	64.	WKKAS004	0.2
5.	HHALHR001	N.D	35.	SMACGAR003	N.D	65.	WKROY001	N.D
6.	HHALHR002	N.D	36.	SMACGAR004	N.D	66.	WKROY002	N.D
7.	HHALHR003	N.D	37.	SMKECBD001	N.D	67.	WKROY003	N.D
8.	HHALHR004	N.D	38.	SMKECBD002	N.D	68.	WKROY004	N.D
9.	HHHWKAW001	N.D	39.	SMKECBD003	N.D	69.	HHEMWK001	N.D
10.	HHHWKAW002	N.D	40.	SMKECBD004	N.D	70.	HHEMWK002	N.D
11.	HHHWKAW003	N.D	41.	SMNVCBD001	N.D	71.	HHEMWK003	N.D
12.	HHHWKAW004	N.D	42.	SMNVCBD002	N.D	72.	HHEMWK004	N.D
13.	HHHWWA001	N.D	43.	SMNVCBD003	N.D	73.	HHEMWKJUA001	N.D
14.	HHHWWA002	N.D	44.	SMNVCBD004	N.D	74.	HHEMWKJUA002	N.D
15.	HHHWWA003	N.D	45.	WKDANPH2001	N.D	75.	HHEMWKJUA003	N.D
16.	HHHWWA004	N.D	46.	WKDANPH2002	N.D	76.	HHEMWKJUA004	N.D
17.	SPDSWOD001	N.D	47.	WKDANPH4003	N.D	77.	HHEMIMA001	N.D
18.	SPDSWOD002	N.D	48.	WKDANPH4004	N.D	78.	HHEMIMA002	N.D
19. .	SPDSWOD003	N.D	49.	WKRUA001	N.D	79.	HHEMIMA003	N.D
20.	SPDSWOD004	N.D	50.	WKRUA002	N.D	80.	HHEMIMA004	N.D
21.	SPATMUG001	N.D	51.	WKRUA003	N.D	81.	HHEMKAY001	N.D
22.	SPATMUG002	N.D	52.	WKRUA004	N.D	82.	HHEMKAY002	N.D
23.	SPATMUG003	N.D	53.	WKNJIR001	N.D	83.	HHEMKAY003	N.D
24.	SPATMUG004	N.D	54.	WKNJIR002	N.D	84.	HHEMKAY004	N.D
25.	SPKSMAR001	N.D	55.	WKNJIR003	N.D	85.	WKEMUMO001	N.D
26.	SPKSMAR002	N.D	56.	WKNJIR004	N.D	86.	WKEMUMO002	N.D
27.	SPKSMAR003	N.D	57.	WKMWIK001	N.D	87.	WKEMUMO003	N.D
28.	SPKSMAR004	N.D	58.	WKMWIK002	N.D	88.	WKEMUMO004	N.D
29.	SMQUHUR001	N.D	59.	WKMWIK003	N.D			
30.	SMQUHUR002	N.D	64.	WKMWIK004	N.D			

Appendix 6: Total Coliform and *E.Coli*

S/no	Sample Id	T.C	*E.Coli*	S/no	Sample Id	T.C	*E.Coli*	S/no	Sample Id	T.C	*E.Coli*
1.	HHUNMTV001	>180	160	31.	SMQUHUR003	<1	<1	61.	WKKAS001	<1	<1
2.	HHTPMTV002	5	<1	32.	SMQUHUR004	<1	<1	62.	WKKAS002	2	<1
3.	HHTPMTV003	<1	<1	33.	SMACGAR001	<1	<1	63.	WKKAS003	5	<1
4.	HHTPMTV004	<1	<1	34.	SMACGAR002	<1	<1	64.	WKKAS004	1	<1
5.	HHALHR001	<1	<1	35.	SMACGAR003	<1	<1	65.	WKROY001	20	<1
6.	HHALHR002	3	<1	36.	SMACGAR004	<1	<1	66.	WKROY002	<1	<1
7.	HHALHR003	<1	<1	37.	SMKECBD001	<1	<1	67.	WKROY003	5	<1
8.	HHALHR004	50	<1	38.	SMKECBD002	<1	<1	68.	WKROY004	<1	<1
9.	HHHWKAW001	>180	<1	39.	SMKECBD003	<1	<1	69.	HHEMWK001	8	1
10.	HHHWKAW002	>180	<1	40.	SMKECBD004	<1	<1	70.	HHEMWK002	25	<1
11.	HHHWKAW003	160	1	41.	SMNVCBD001	<1	<1	71.	HHEMWK003	35	1
12.	HHHWKAW004	>180	2	42.	SMNVCBD002	<1	<1	72.	HHEMWK004	5	1
13.	HHHWWA001	90	<1	43.	SMNVCBD003	<1	<1	73.	HHEMWKJUA001	<1	<1
14.	HHHWWA002	1	<1	44.	SMNVCBD004	<1	<1	74.	HHEMWKJUA002	<1	<1
15.	HHHWWA003	50	<1	45.	WKDANPH2001	13	3	75.	HHEMWKJUA003	50	1
16.	HHHWWA004	25	<1	46.	WKDANPH2002	35	8	76.	HHEMWKJUA004	160	3
17.	SPDSWOD001	<1	<1	47.	WKDANPH4003	11	1	77.	HHEMIMA001	<1	<1
18.	SPDSWOD002	<1	<1	48.	WKDANPH4004	35	5	78.	HHEMIMA002	<1	<1
19. .	SPDSWOD003	<1	<1	49.	WKRUA001	<1	<1	79.	HHEMIMA003	<1	<1
20.	SPDSWOD004	<1	<1	50.	WKRUA002	1	<1	80.	HHEMIMA004	<1	<1
21.	SPATMUG001	<1	<1	51.	WKRUA003	5	<1	81.	HHEMKAY001	<1	<1
22.	SPATMUG002	<1	<1	52.	WKRUA004	<1	<1	82.	HHEMKAY002	14	<1

23.	SPATMUG003	<1	<1	53.	WKNJIR001	8	<1	83.	HHEMKAY003	30	2
24.	SPATMUG004	<1	<1	54.	WKNJIR002	20	2	84.	HHEMKAY004	<1	<1
25.	SPKSMAR001	<1	<1	55.	WKNJIR003	13	<1	85.	WKEMUMO001	<1	<1
26.	SPKSMAR002	<1	<1	56.	WKNJIR004	<1	<1	86.	WKEMUMO002	<1	<1
27.	SPKSMAR003	<1	<1	57.	WKMWIK001	<1	<1	87.	WKEMUMO003	<1	<1
28.	SPKSMAR004	<1	<1	58.	WKMWIK002	<1	<1	88.	WKEMUMO004	<1	<1
29.	SMQUHUR001	<1	<1	59.	WKMWIK003	<1	<1				
30.	SMQUHUR002	<1	<1	65.	WKMWIK004	<1	<1				

Appendix 7: Manganese Ions test

S/no	Sample Id	Mn^{2+} (ppm) ***Std-0.1ppm Max***	S/no	Sample Id	Mn2+ (ppm) ***Std-0.1ppm Max***	S/no	Sample Id	Mn2+ (ppm) ***Std-0.1ppm Max***
1.	HHUNMTV001	0.08	31.	SMQUHUR003	0.05	61.	WKKAS001	0.05
2.	HHTPMTV002	0.07	32.	SMQUHUR004	0.03	62.	WKKAS002	0.04
3.	HHTPMTV003	0.04	33.	SMACGAR001	0.15	63.	WKKAS003	0.06
4.	HHTPMTV004	0.1	34.	SMACGAR002	0.05	64.	WKKAS004	0.08
5.	HHALHR001	<0.001	35.	SMACGAR003	0.01	65.	WKROY001	<0.001
6.	HHALHR002	0.09	36.	SMACGAR004	0.12	66.	WKROY002	0.07
7.	HHALHR003	0.07	37.	SMKECBD001	0.09	67.	WKROY003	0.08
8.	HHALHR004	0.03	38.	SMKECBD002	0.14	68.	WKROY004	0.04
9.	HHHWKAW001	0.12	39.	SMKECBD003	0.03	69.	HHEMWK001	0.05
10.	HHHWKAW002	0.09	40.	SMKECBD004	0.11	70.	HHEMWK002	0.08
11.	HHHWKAW003	0.08	41.	SMNVCBD001	0.13	71.	HHEMWK003	0.08
12.	HHHWKAW004	0.06	42.	SMNVCBD002	0.09	72.	HHEMWK004	0.08
13.	HHHWWA001	0.06	43.	SMNVCBD003	0.16	73.	HHEMWKJUA001	0.12
14.	HHHWWA002	0.04	44.	SMNVCBD004	0.04	74.	HHEMWKJUA002	0.08
15.	HHHWWA003	0.68	45.	WKDANPH2001	0.05	75.	HHEMWKJUA003	0.05
16.	HHHWWA004	0.51	46.	WKDANPH2002	0.08	76.	HHEMWKJUA004	0.12
17.	SPDSWOD001	0.06	47.	WKDANPH4003	0.07	77.	HHEMIMA001	0.02
18.	SPDSWOD002	0.03	48.	WKDANPH4004	0.17	78.	HHEMIMA002	0.04
19. .	SPDSWOD003	0.14	49.	WKRUA001	0.01	79.	HHEMIMA003	0.1
20.	SPDSWOD004	0.02	50.	WKRUA002	0.1	80.	HHEMIMA004	0.02
21.	SPATMUG001	0.04	51.	WKRUA003	0.05	81.	HHEMKAY001	0.11
22.	SPATMUG002	0.15	52.	WKRUA004	0.08	82.	HHEMKAY002	0.09
23.	SPATMUG003	0.1	53.	WKNJIR001	0.06	83.	HHEMKAY003	0.1
24.	SPATMUG004	0.07	54.	WKNJIR002	0.02	84.	HHEMKAY004	0.07
25.	SPKSMAR001	0.08	55.	WKNJIR003	0.03	85.	WKEMUMO001	0.1
26.	SPKSMAR002	0.05	56.	WKNJIR004	0.11	86.	WKEMUMO002	0.02
27.	SPKSMAR003	0.15	57.	WKMWIK001	0.1	87.	WKEMUMO003	0.1
28.	SPKSMAR004	0.12	58.	WKMWIK002	0.09	88.	WKEMUMO004	0.002
29.	SMQUHUR001	0.06	59.	WKMWIK003	0.08			
30.	SMQUHUR002	0.05	66.	WKMWIK004	<0.001			

Appendix 8: Iron test

S/no	Sample Id	Fe^{2+} (ppm) ***Std-0.3ppm Max***	S/no	Sample Id	Fe^{2+} (ppm) ***Std-0.3ppm Max***	S/no	Sample Id	Fe^{2+} (ppm) ***Std-0.3ppm Max***
1.	HHUNMTV001	0.07	31.	SMQUHUR003	0.23	61.	WKKAS001	0.04
2.	HHTPMTV002	0.12	32.	SMQUHUR004	0.1	62.	WKKAS002	0.19
3.	HHTPMTV003	0.21	33.	SMACGAR001	0.28	63.	WKKAS003	0.15
4.	HHTPMTV004	0.09	34.	SMACGAR002	0.25	64.	WKKAS004	0.22
5.	HHALHR001	0.11	35.	SMACGAR003	0.14	65.	WKROY001	<0.001
6.	HHALHR002	0.22	36.	SMACGAR004	0.3	66.	WKROY002	0.15
7.	HHALHR003	0.18	37.	SMKECBD001	0.38	67.	WKROY003	0.44
8.	HHALHR004	0.15	38.	SMKECBD002	0.15	68.	WKROY004	0.33
9.	HHHWKAW001	0.08	39.	SMKECBD003	0.31	69.	HHEMWK001	0.37
10.	HHHWKAW002	0.13	40.	SMKECBD004	0.35	70.	HHEMWK002	0.35
11.	HHHWKAW003	0.1	41.	SMNVCBD001	0.48	71.	HHEMWK003	0.07
12.	HHHWKAW004	0.16	42.	SMNVCBD002	0.08	72.	HHEMWK004	0.14
13.	HHHWWA001	0.16	43.	SMNVCBD003	0.3	73.	HHEMWKJUA001	<0.001
14.	HHHWWA002	0.39	44.	SMNVCBD004	0.25	74.	HHEMWKJUA002	0.11
15.	HHHWWA003	0.16	45.	WKDANPH2001	0.2	75.	HHEMWKJUA003	0.12
16.	HHHWWA004	0.25	46.	WKDANPH2002	0.12	76.	HHEMWKJUA004	0.19
17.	SPDSWOD001	0.14	47.	WKDANPH4003	<0.001	77.	HHEMIMA001	0.12
18.	SPDSWOD002	0.13	48.	WKDANPH4004	0.52	78.	HHEMIMA002	0.21
19. .	SPDSWOD003	0.1	49.	WKRUA001	0.13	79.	HHEMIMA003	0.28
20.	SPDSWOD004	0.17	50.	WKRUA002	0.09	80.	HHEMIMA004	0.42
21.	SPATMUG001	0.37	51.	WKRUA003	0.19	81.	HHEMKAY001	0.49
22.	SPATMUG002	0.15	52.	WKRUA004	0.09	82.	HHEMKAY002	0.08
23.	SPATMUG003	0.22	53.	WKNJIR001	0.1	83.	HHEMKAY003	0.2
24.	SPATMUG004	0.1	54.	WKNJIR002	0.32	84.	HHEMKAY004	0.06
25.	SPKSMAR001	0.35	55.	WKNJIR003	0.06	85.	WKEMUMO001	0.15
26.	SPKSMAR002	0.14	56.	WKNJIR004	0.07	86.	WKEMUMO002	0.08
27.	SPKSMAR003	0.26	57.	WKMWIK001	0.12	87.	WKEMUMO003	0.16
28.	SPKSMAR004	0.15	58.	WKMWIK002	0.49	88.	WKEMUMO004	0.4
29.	SMQUHUR001	0.24	59.	WKMWIK003	0.23			
30.	SMQUHUR002	0.23	67.	WKMWIK004	0.22			

Appendix 9: Silicon Ions test

S/no	Sample Id	Si^{4+}	S/no	Sample Id	Si^{4+}	S/no	Sample Id	Si^{4+}
		Std-50ppm Max			***Std-50ppm Max***			***Std-50ppm Max***
1.	HHUNMTV001	1.85	31.	SMQUHUR003	5.46	61.	WKKAS001	8.15
2.	HHTPMTV002	1.01	32.	SMQUHUR004	3.52	62.	WKKAS002	1.66
3.	HHTPMTV003	1.29	33.	SMACGAR001	2.87	63.	WKKAS003	3.19
4.	HHTPMTV004	2.99	34.	SMACGAR002	2.94	64.	WKKAS004	4.17
5.	HHALHR001	1.65	35.	SMACGAR003	3.45	65.	WKROY001	3.49
6.	HHALHR002	0.56	36.	SMACGAR004	3.36	66.	WKROY002	1.81
7.	HHALHR003	10.23	37.	SMKECBD001	2.45	67.	WKROY003	4.59
8.	HHALHR004	2.1	38.	SMKECBD002	3.54	68.	WKROY004	3.02
9.	HHHWKAW001	1.73	39.	SMKECBD003	2.25	69.	HHEMWK001	2.62
10.	HHHWKAW002	2.43	40.	SMKECBD004	2.64	70.	HHEMWK002	3.69
11.	HHHWKAW003	4.32	41.	SMNVCBD001	2.54	71.	HHEMWK003	1.11
12.	HHHWKAW004	2.51	42.	SMNVCBD002	1.22	72.	HHEMWK004	4.67
13.	HHHWWA001	2.43	43.	SMNVCBD003	2.64	73.	HHEMWKJUA001	4.52
14.	HHHWWA002	7.54	44.	SMNVCBD004	2.77	74.	HHEMWKJUA002	7.39
15.	HHHWWA003	1.18	45.	WKDANPH2001	4.32	75.	HHEMWKJUA003	3.82
16.	HHHWWA004	3.47	46.	WKDANPH2002	1.42	76.	HHEMWKJUA004	2.09
17.	SPDSWOD001	1.14	47.	WKDANPH4003	1.43	77.	HHEMIMA001	3.36
18.	SPDSWOD002	3.43	48.	WKDANPH4004	3.39	78.	HHEMIMA002	3.02
19. .	SPDSWOD003	1.41	49.	WKRUA001	3.357	79.	HHEMIMA003	1.52
20.	SPDSWOD004	2.25	50.	WKRUA002	1.88	80.	HHEMIMA004	3.05
21.	SPATMUG001	3.1	51.	WKRUA003	3.42	81.	HHEMKAY001	4.88
22.	SPATMUG002	1.12	52.	WKRUA004	4.15	82.	HHEMKAY002	1.64
23.	SPATMUG003	2.24	53.	WKNJIR001	1	83.	HHEMKAY003	7.3
24.	SPATMUG004	8.35	54.	WKNJIR002	4.99	84.	HHEMKAY004	2.1
25.	SPKSMAR001	5.96	55.	WKNJIR003	3.83	85.	WKEMUMO001	2.18
26.	SPKSMAR002	4.45	56.	WKNJIR004	4.46	86.	WKEMUMO002	2.84
27.	SPKSMAR003	1.61	57.	WKMWIK001	5.42	87.	WKEMUMO003	4.89
28.	SPKSMAR004	2.32	58.	WKMWIK002	5.59	88.	WKEMUMO004	2.08
29.	SMQUHUR001	2.32	59.	WKMWIK003	3.69			
30.	SMQUHUR002	2.41	68.	WKMWIK004	1.76			