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EVALUATION OF THE QUALITY OF DRINKING WATER ALONG THE WATER CHAIN IN HOUSEHOLDS IN A PERIPHERAL DISTRICT OF YAOUNDE CASE OF MINKAMA 4

A thesis submitted in partial fulfilment of the requirements to obtain a Master's Degree in Environmental Engineering (MEng)

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DEDICATION

TO MY FAMILY.

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ABSTRACT

Lack of access to improved drinking water is a global problem that affects approximately 663 million people worldwide and more than 18 million people die each year from water borne diseases in developing countries. Studies in Cameroon in 2008 showed less than 50% of the population were connected to the national water network, CAMWATER, and the alternative sources were characterized by high levels of microbial contamination. Understanding the risks and providing an appropriate treatment technology are therefore important because unsafe drinking water quality is directly related to health caused primarily by microbial contamination prevalent in developing countries. This work carried out in the Minkama 4 locality was aimed at evaluating the quality of household drinking water at the source, and during conservation and use, and propose solutions for the conservation of the drinking water quality. To attain this objective, a systematic methodology was adopted which comprised a documentary review, knowledge and practice survey through a questionnaire and laboratory analyses of three (03) water samples taken from the locality. All fifty (50) respondents to the survey reported groundwater as their primary source of drinking water though only 20% reported treating water before drinking. The results obtained from the water tests showed fecal coliform and streptococci content of up to 315 CFU/100 mL and 152 CFU/100 mL, and *E. coli* of 160 CFU/100 mL respectively and an average suspended solids concentration of 4.33 mg/L, values which exceed the maximum permissible limits set by the Cameroonian and WHO norms. This was due to the non-respect of source protection perimeters. Other physicochemical parameters were more or less within the norm limits. A few treatment methods were then proposed to ameliorate the water quality and hence preserve the health of the population.

KEY WORDS: drinking water, water quality, fecal contamination, Minkama 4

RESUME

Le manque d'accès à une eau potable améliorée est un problème mondial qui affecte environ 663 millions de personnes dans le monde et plus de 18 millions de personnes meurent chaque année de maladies d'origine hydrique dans les pays en développement. Des études menées au Cameroun en 2008 on montre que moins de 50% de la population était connecté au réseau national d'eau, CAMWATER, et que les sources d'alternance étaient caractérisées par des niveaux élevés de contamination microbienne. Il est donc important de comprendre les risques et de fournir une technologie de traitement appropriée, car la qualité dangereuse de l'eau potable est directement liée aux problèmes de sante causes principalement par la contamination microbienne répandue dans les pays en développement. Ces travaux menés dans la localité de Minkama 4 visaient à évaluer la qualité de l'eau potable des ménages à la source, et pendant la conservation et l'utilisation, et proposer des solutions pour la conservation de la qualité de l'eau potable. Pour atteindre cet objectif, une méthodologie systématique a été adoptée qui comprenait une revue documentaire, une enquête sur les connaissances et les pratiques à travers un questionnaire et des analyses en laboratoires de trois (03) échantillons d'eau prélevés dans la localité. Les cinquante (50) personnes interrogées ont indiqués que les eaux souterraines étaient leur principale source d'eau potable, mais seulement 20% ont déclarés traiter l'eau avant de boire. Les résultats obtenus à partir des tests de l'eau ont montrés une teneur en coliformes fécaux et streptocoques allant jusqu'au 315 UFC/100 mL et 152 UFC/100 mL, et E. coli de 160 UFC/100 mL respectivement et une concentration moyenne en Matières en suspension de 4,33 mg/L, valeurs qui dépassent les limites maximales admises par les normes Camerounaises et OMS. Cela était dû à la non-conformité des périmètres de protection des sources. D'autres paramètres physicochimiques étaient plus ou moins dans les limites de la norme. Quelques méthodes de traitement ont ensuite été proposées pour améliorer la qualité de l'eau et donc préserver la sante de la population.

MOTS CLES : eau potable, qualité de l'eau, contamination fécale, Minkama 4

SUMMARY

ABBREVIATIONS AND ACRONYMS

APHA : American Public Health Association

CFU : Colony Forming Units

CO_2 : Carbondioxide molecule

EC : Electrical conductivity

E coli* :Escherichia coli*

EDTA: Ethylenediaminetetraacetic acid

EGTA : Ethylene Glycol tetraacetic acid

EPA : Environmental Protection Agency

FC : Fecal Coliform

FS: Fecal Streptococci

GBHS : Government Bilingual High School

H_2O: Water molecule

H_3O^+ : Hydrozonium ion

HCO_3- : Hydrogen carbonate ion

INS : Institut National de Statistique

JMP: Joint Monitoring Program

MDG: Millennium Development Goal

MeS : Matieres en Suspension

MPFs : Mineral Pot Filters

$NaHCO_3$- : Sodium bicarbonate compound

pH : Hydrogen potential

RMM : Relative Molecular mass

SODIS : Solar Disinfection

SS : suspended solids

TDS : total dissolved solids

UNICEF : united nations children emergency fund

USEPA: United States Environmental Protection Agency

USGS: United States Geological Survey

µS/cm: micro Siemens per centimeter

WHO : World Health Organization

WQI: Water Quality Index

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GENERAL INTRODUCTION

Water is an invaluable resource. The benefits to mankind from proper management of this resource as well as the disastrous consequences of its mismanagement are very well known. The public awareness about water quality is at its zenith now but at the same time, the danger signals have not shown any abatement. Thus, the study of water quality has remained an important preoccupation with the environmentalist both from the practical and academic viewpoints.

For ages now, water assessment has always been a major concern and the concept of quality raises a number of questions (which are often controversial disparities in technological and individual perceptions). Technologically, water quality can be catalogued in terms of appropriate physical, chemical and bacteriological parameters, which must be accurate, unambiguous, quantitative and reproducible (Lamb, 1985). Today, however, the principal difficulty is not so much access to water but more precisely the access to water suitable for drinking. Many pathogens or disease causing organisms, usually voided into the external medium in human or animal faeces, are transported by water and can be at the origin of many water borne diseases.

From the statistics in 2008 in Cameroon, the rate of access to drinking water hardly reaches 32% (INS, 2008). In general, the only water supplier (CAMWATER) recognized by the state cannot satisfy the need of the increasing population who have resolved to using water of doubtful portability, usually groundwater. Groundwater is a valuable natural resource for various human activities (Prasad &Narayana, 2004) and its contamination by high faecal pollutant concentrations is of major concern, being a considerable health problem. Water borne diseases (conditions caused by pathogenic micro-organisms that are transmitted in water) can be spread while bathing, washing, drinking water, or by eating food exposed to contaminated water. While diarrhea and vomiting are the most commonly reported symptoms of waterborne illness, other symptoms can include skin, ear, respiratory, or eye problems (WHO, 2008). The World Health Organization (WHO) estimated about 3.1 million deaths due to diarrhea in 1996 of whom a large majority were children less than five years (WHO, 2008).

Lack of access to improved drinking water is a global problem that affects approximately 663 million people (figure 1) worldwide (WHO/UNICEF, 2015) and unfortunately, in developing countries, more than 18 million people die each year from water borne diseases (WHO, 2006). This is evident in Cameroon like in most countries in Sub Saharan Africa where less than 50% of the population are connected to the national pipe-borne water network (Kuitcha et al., 2008). Studies from various parts of Cameroon showed that many water sources used for drinking and domestic needs have alarming levels of microbiological contaminants (Ketchemen et al. 2017; Magha et al. 2015; Engsrom et al. 2015; Sorlini et al. 2013). Understanding the risks and providing an appropriate treatment technology are important because unsafe drinking water quality is directly related to health issues including premature fatalities caused primarily by microbial contamination prevalent in developing countries (WHO, 2011; Pruss-Ustun et al, 2014).

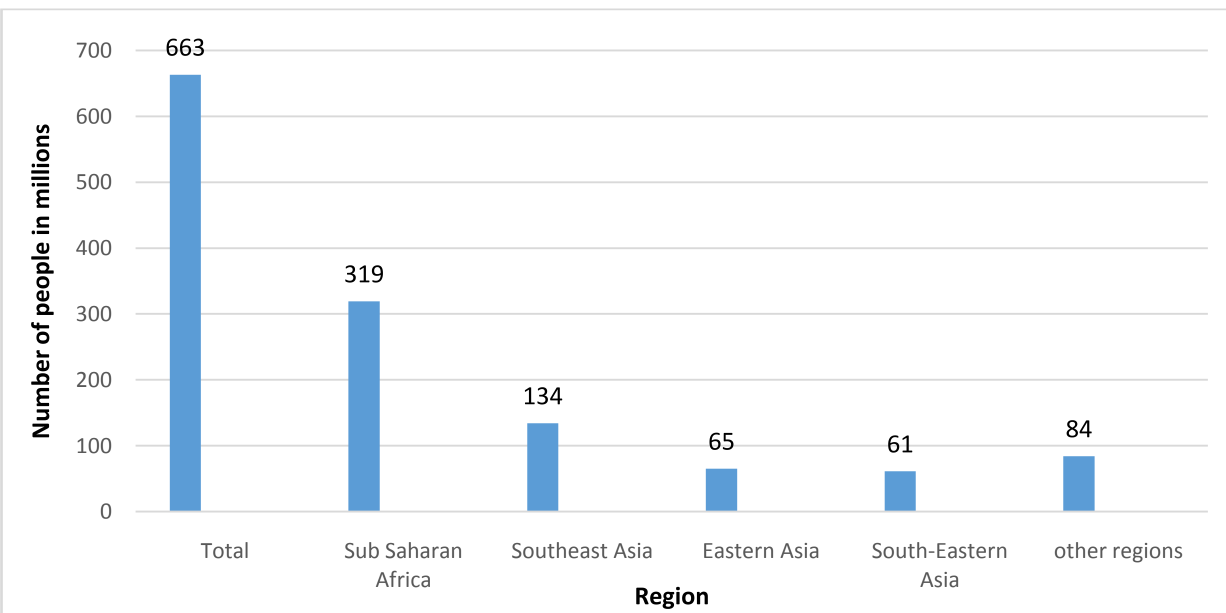

Figure 1: Global and Regional populations' lack of access to improved drinking water sources (from data provided in WHO/UNICEF, 2015)

As per the JMP (WHO/UNICEF, 2015), 15% of the Cameroonian rural population rely on surface water for drinking water while 31% collect water from unimproved sources. Others rely on improved sources for which collection time exceeds 30 minutes for a round trip, including queuing (figure 2).

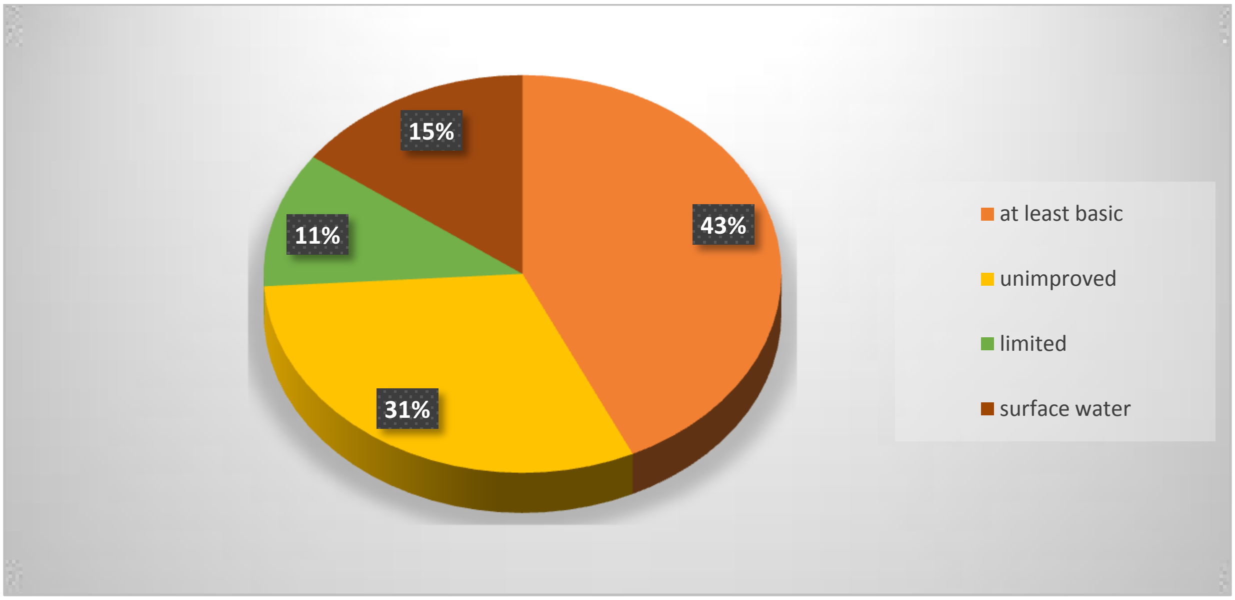

Figure 2: Cameroonian rural drinking water trends (from data provided in WHO/UNICEF, 2015)

This work carried out in the Minkama 4 locality is aimed at evaluating the quality of drinking water at the source and during conservation and use, and to propose solutions for the improvement of the water quality. Included in the first chapter are a brief presentation of the locality and some general concepts related to water, the second chapter describes the methodology and instruments used to carry out this work, the results obtained as well as the interpretations are presented in the third part and finally, some water treatment methods coupled with some perspectives on proper water conservation are outlined so as to ensure good water quality and thereby preserve the health of the population.

Chapter 1. STUDY ENVIRONMENT AND GENERALITIES ON WATER.

Focus Area

The Integrated management of water resources varies from community to community given their differences in environmental factors such as climate, perspectives, economy and socio-educational status. This work, carried out in the Minkama locality of the Centre Region of Cameroon, was aimed at assessing the quality of drinking water at the source and during conservation and use, and to evaluate the extent to which water sources are protected.

Cameroon is a country in Central Africa. It is bordered by Nigeria to the west and north, Chad to the north-east, the Central African Republic to the east; and Equatorial Guinea, Gabon and the Republic of Congo to the south (figure 3). Its coastline lies on part of the Gulf of Guinea and the Atlantic Ocean and the country is often referred to as "Africa in miniature" for its geological and cultural diversity (National Climatic Data Center, 2012; Linguistic Diversity in Africa, 2011).

The Lekie Division (named after the Lekie River) of the Centre Region of Cameroon (figure 4) covers an area of 2,989 km^2 and as of 2001 had a total population of 354,864 inhabitants. It is divided administratively into nine (09) municipalities and further into villages. The nine constituent municipalities are:

- Batchenga
- Ebebda
- Obala
- Monatélé
- Lobo
- Okola
- Sa’a
- Elig-Mfomo
- Evodoula

The Obala municipality covers a total of 475 sq. kilometers. It counts a total of 133014 inhabitants, with a population density of 263 inhabitants/ Km^2. It is bounded in the North by Sa'a and Monatélé, in the West by Elig-Mfomo, in the east by Batchenga, Edzendouan, Soa and Yaoundé 2, and in the south by Okola. There are a total of 83 villages in the municipality, one of which is Minkama. The ethnic groups here are the Eton, Bamiléké, Haoussa, Bamoun, Yambassa, Ndong,Elendé et les Bassa.

Minkama, otherwise known as Minkan or Minkana, is a rural zone of the Obala municipality located in the Lekie Division, Centre Region of Cameroon. Its geographical coordinates are 4^o

10' 60" North, 11° 34' 60" East in DMS (degrees, minutes, seconds) or 4.18333 and 11.5833 in decimal degrees. It is located at 567metres above sea level and the time zone for Minkan is UTC/GMT+1.

Minkama has a tropical climate with four seasons: two minor rainy and dry seasons and two major rainy and dry seasons. The rainfall here averages 1632 mm. The driest month is January, with 16 mm of rainfall while the greatest amount of precipitation occurs in October, with an average of 291 mm. The average temperature ranges between 20 and 35 °C. The warmest month of the year is March, with an average temperature of 25.7 °C. The lowest average temperatures in the year occur in July, when it is around 23.3 °C. The relief here mostly comprises hills and plateaux, and the soils are ferralitic or basic, sandy-loamy and hydromorphic (CVUC, 2014).

Figure 3: Map of Cameroon in the context of Africa

Figure 4: Map of the Centre region in the context of other regions in Cameroon (yellow zone) and situation of the Lekie division in the Centre Region (red zone)

LITERATURE REVIEW

Importance of Water

Water is the symbol of life and an essential unique universal solvent needed by living organisms. Without it, life would not be possible on this planet. It acts as a medium for chemical and biological metabolic reactions, and also acts as an internal and external medium for several organisms. It is the most common, vital, and the most precious resources on the earth. As a source of life for human beings, plants and other forms of life, it cannot be replaced by any other solvent. We can say that the search of life begins with the search of water. Water makes up about 60% of the body weight in men and 55% of weight in women (Miller, 2006). A baby is composed of about 70% to 80% water while the elderly are composed of around 45% (Jones & Bartlett, 2012). Good drinking water quality is of basic importance to human physiology and the existence of life depends very much on its availability (Lamikanra, 1999; FAO, 1997). According to the World health Organization, "access to safe drinking water is essential to health, a basic human right and a component of effective policy for health protection (WHO, 2017).

Water constitutes two-thirds of the human body weight and all cells and organs depend on it for their proper functioning. In fact, the origin and evolution of life on earth is ultimately linked with water (Hoko, 2005). Water is also the vehicle for the figurative elements of the blood as well as that of certain secretions such as tears and digestive juices. It is necessary for homeostasis and for the elimination of soluble waste through urine and sweat. A water loss of 10% - 15% in the body can lead to death. Therefore, its quantity must remain constant as well as the concentration of its constituent ions – essentially Na^+ and K^+. Water provides us with everything our body needs daily to improve hygiene and comfort with regards to its living conditions (hydration, cleaning, cooking). Water does not exist pure in its natural state. In its movement through the earth, it dissolves elements that are essential for health but also encounters substances which are potentially harmful or toxic to organisms.

Now we ask the question, "Where can we find water?"

Water Resources and the Water Cycle

a.) Sources of water

The chief sources of water are rainwater, sea water, ground water and surface water. In Cameroon, the climate is tropical, semi-arid in the north, and humid and rainy in the rest of the country. Almost everywhere, there is a dry season in winter and a rainy season in summer due to the African monsoon, which is shorter in the north and longer in the south, while along the coast, even in winter there can be some showers. The northernmost part of the country, on the shores of Lake Chad, is the driest area, where less than 600 millimeters (23.5 inches) of rain fall per year, while the wettest is the coast, where rainfall exceeds 3,000 mm (120 in) per year.

Of the 322 billion cubic meters of total available water resources, groundwater constitutes 21% (57 billion cubic meters) of this resource (Ako Ako et al. 2009; Sigha-Nkamdjou et al. 1998). High rainfall means high potential recharge potential in much of Cameroon, except in the arid north, and the limitations on groundwater potential are therefore largely related to low aquifer storage and permeability in the basement rocks across much of the country.

In the northern region, increasing population combined with a reduction in the quantity and regularity of rainfall has resulted in persistent drought and reduced groundwater resources (Ako Ako et al. 2009). Most groundwater in Cameroon is thought to be of good natural inorganic quality. The least mineralised groundwater overall is in basement aquifers. Some of the most mineralised groundwater is in volcanic aquifers, but the most mineralised are springs in the Mamfé basin that are related to evaporites.

Some groundwater in deeper aquifers contains low oxygen and corresponding high iron and even hydrogen sulphate gas (Mafany &Fantong 2006). However, much of the shallow groundwater is vulnerable to contamination. Shallow coastal aquifers are subject to seawater intrusion. There is no evidence for widespread inorganic contamination of groundwater, even in urban areas, but there is widespread bacteriological contamination of shallow groundwater in urban areas, such as Yaoundé and Douala, derived from domestic, industrial and hospital waste (Mafany &Fantong, 2006).

The rural population, Minkama inclusive, largely relies on groundwater for water supply, through springs, hand dug wells, and boreholes equipped with hand pumps (Ako Ako et al. 2009) and some urban centers also widely use groundwater.

b.) Sources Classification of Drinking Water

Water for drinking can be obtained from a number of different sources including but not limited to rainwater, groundwater, and surface water such as natural reservoirs. The Joint Monitoring Program- JMP (WHO/UNICEF, 2015) developed classifications for monitoring the use and safety of different water sources (Table 1). Later on in 2017, the Sustainable Development Goals included two new classifications of water sources to address the limitations of improved water sources, basic and safely managed (WHO/UNICEF, 2017). Although water may be obtained from an improved source, it still may not adhere to the quality standards set by the local government or pose health risks. That notwithstanding, a contaminated water source may still be treated to make it suitable or safe for drinking. Three of the most common stages of treatment are sedimentation, filtration, and disinfection (Mihelcic et al., 2009) and they all have varied efficiencies, advantages and disadvantages. Therefore, it is key to every community to find the appropriate treatment method suitable to its case so as to improve the health and wellbeing of its population.

Survey results carried out by the JMP (WHO/UNICEF, 2017) showed that microbial water quality often deteriorates between the point of collection and the point of use. When water supplies are located off premises there is an increased risk of contamination, which highlights the importance of safe handling, storage and treatment of water within the household.

Table 1: Classifications and definitions of different water sources from 2015 (WHO/UNICEF, 2015a) to 2017 (WHO, UNICEF, 2017)

Year			
2015		2017	
Classification	definition	classification	Definition
Improved	Piped water on premises (tap water in the dwelling, yard, or plot or public) and non-piped supplies (boreholes/tube wells, protected wells and springs, rainwater, packaged water, including bottled water and sachet water, delivered water, including tanker and trucks and small carts)	Safely managed	Improved water sources located on premises, available when needed and free from faecal and priority chemical contamination
		basic	Improved source provided collection time is not more than 30 minutes for a round trip, including queuing
		limited	Improved source for which collection time exceeds 30 minutes for a round trip, including queuing
Unimproved	Non-piped supplies (unprotected wells and springs) and surface water (river, dam, lake, pond, canal, irrigation channels)	Unimproved	Non piped supplies (unprotected wells and springs)
		Surface water	Directly from a river, dam, lake, pond, stream, canal, or irrigation channel)

c.) The Water Cycle

Water for all of us is undoubtedly and undeniably the pillar of life and one would think that it has therefore been studied in depth. However, this is not the case since, up till date, many of its particularities still elude us. Water's predominant characteristic is to be in movement both in our bodies and in the earth and this movement leads to the phenomenon known as the water cycle (figure 5). The water cycle or Hydrologic cycle is a scheme which describes how water evaporates from the surface of the earth (primordially from the ocean reserves) rises into the atmosphere as hot vapour, cools and condenses into rain or snow in clouds, and falls again to the surface as precipitation. The water falling on land collects in rivers and lakes, soil, and porous layers of rock, and much of it flows back into the oceans, where it will once more evaporate. It is only in the earth where water is present in these three states and the balance between them is in fact very fragile. The cycling of water in and out of the atmosphere is a significant aspect of the weather patterns on Earth. Due to the upheavals of climate, the water cycle is very disturbed. According to Orzagh (1998), climate change risks depriving groundwater of renewal due to the displacement of summer and winter.

Precipitation is a vital component of how water moves through Earth's water cycle, connecting the ocean, land, and **atmosphere.** Knowing where it rains, how much it rains and the character of the falling rain, snow or **hail**allows scientists to better understand precipitation's impact on streams, rivers, surface **runoff** and **groundwater.** Frequent and detailed measurements help scientists make models of and determine changes in Earth's water cycle (NASA, precipitation education).

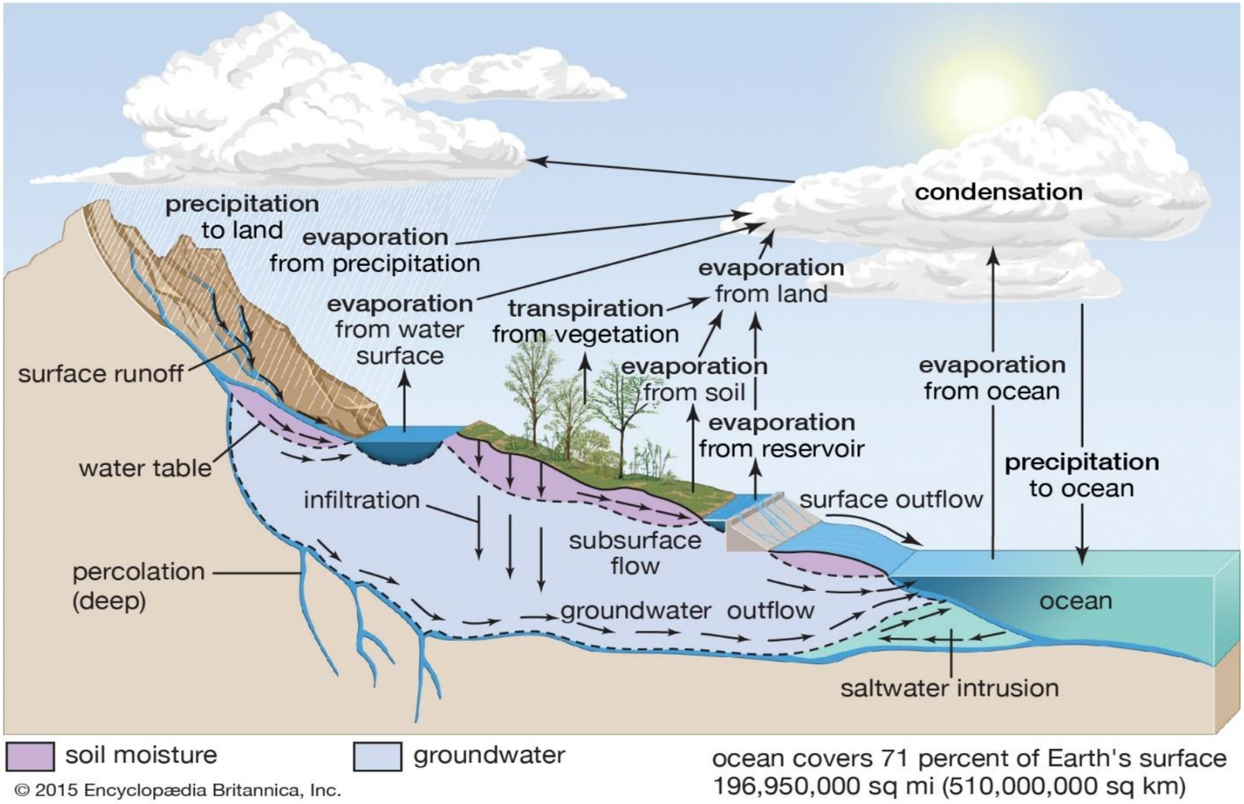

Figure 5: Processes of the water cycle

The Concept of Quality

a) Water quality

Water quality refers to the chemical, physical, biological and radiological characteristics of water (Diersing& Nancy, 2009). It is the measure of the condition of water relative to the requirements of one or more biotic species and/or to any human need or purpose (Johnson & al., 1997). The most common standards used to assess water quality relate to health of ecosystems, safety of human contact, and drinking water. The parameters for water quality are determined by the intended use. Work in this area tends to be focused on water that is treated for human consumption, industrial use, or in the environment but we are to going to be focused more on qualities for human consumption in this work.

Human Consumption.

Contaminants that may be in untreated water include; microorganisms such as viruses, protozoa and bacteria; inorganic contaminants such as salts and metals; organic chemical contaminants from industrial processes and petroleum use; pesticides and herbicides; and radioactive contaminants. Water quality depends on the local geology and ecosystem, as well as human uses such as sewage dispersion, industrial pollution, use of water bodies as heat sink, and overuse.

In the United States, the Safe Drinking Water Act authorizes the Environmental Protection Agency (EPA) to issue two types of standards:

- primary standards; these regulate substances that potentially affect human health (EPA, 2017 and
- Secondary standards; which prescribe aesthetic qualities, those that affect taste, odor, or appearance (EPA, 2017).

Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants however does not necessarily indicate that the water poses a health risk. Unsafe drinking water can pose a health risk to the consumer if its level of contamination is significant enough.

In urbanized areas around the world, water purification technology is used in municipal water systems to remove contaminants from the source water (surface or groundwater) before it is distributed to homes, schools, and other recipients. Water drawn directly from a stream, well, lake or aquifer and that has no treatment will be of uncertain quality and the consumption of such water may have very significant health impacts on the populations concerned.

b) Groundwater Quality

As seen previously, the rural population largely relies on groundwater for water supply especially through hand dug wells, springs and boreholes equipped with hand pumps. But this is usually done in ignorance of the quality of the water they are consuming.

Water quality expresses the suitability of water for various uses and processes and it comprises the physical, chemical and biological qualities which can be described in terms of concentration and state of some or all of the organic or inorganic material present in the water, together with certain physical characteristics of the water. Because water is **such an excellent solvent** it can contain lots of dissolved chemicals. And since groundwater moves through rocks and subsurface soil, it has a lot of opportunity to dissolve substances as it moves. For that reason, groundwater will often have more dissolved substances than surface water will.

Groundwater in its natural state is generally of good quality because rocks and their derivatives such as soils act as filters. However, the natural waters are not pure and contain some amounts of dissolved gases, solids, and suspended materials (Fetter, 1994). The quality of groundwater depends on the composition of the recharged water, the interactions between the water and the soil, dissolved gases, geological conditions, the residence time and reactions that take place within the aquifer. Therefore, considerable variations may be found, hence it is necessary to monitor all aspects related to provision of suitable quality of water for various purposes and a special attention needs to be made on identifying various physical, chemical, bacteriological and radiological parameters influencing water quality. For proper monitoring of parameters, it is required to set up appropriate mechanisms from top to bottom level in country.

The characteristics temperature, colour, odour, taste and electrical conductivity determine the physical quality. Most of the ground waters are colourless, odourless and without specific taste. The chemical composition is derived mainly from the dissolution of minerals in the soil and rocks with which it is or has been in contact. And the chemical characteristic depends on interaction with solid phases, residence time of groundwater, seepage of polluted runoff water, mixing of groundwater with pockets of saline water and anthropogenic impacts (Umar et al., 2006). The type and extent of chemical contamination of the groundwater is largely dependent on the geochemistry of the soil through which the water flows prior to reaching the Aquifers (Zuane, 1990).

As water flows through the ground the dissolution of minerals continues and the concentration of dissolved constituents tends to increase with the length of the flow path. At great depths, where the rate of flow is extremely slow, groundwater is saline, with concentrations ranging up to ten times the salinity of the sea. Groundwater can become non potable if it becomes polluted and is no longer safe to drink. In areas where the material above the aquifer is permeable, pollutants can seep into groundwater.

Groundwater is more mineralized in alluvial aquifers than in the weathered basement aquifers (Kundell, 2008). The importance of drinking water quality has been enhanced in the last few years by the increased awareness and attendant publicity afforded to the pollution of water courses. Globally, the UN declared an International Drinking water supply and Sanitation Decade between 1981 and 1991.

The physical and chemical qualities of water are important since the portability of the water and its fitness for domestic purposes largely depend on its chemical quality (Tiwari & Ali, 1988). In view of the wide variations in chemical quality of water available in different parts of the world, rigid limits cannot be laid down with regards to chemical constituents. Certain chemical substances, which may be present in natural waters, are toxic to human beings though it is expected that a great majority of water quality problems are related to bacteriological contamination. A significant number of very serious problems may also occur as a result of chemical contamination of water sources from agricultural practices and malpractices (Mawulikwame, 2011).

Chemical and physical constituents should not be permitted in drinking water in excess of the permissible concentration. Certain other parameters that render the water unpalatable and unfit for domestic use should have maximum permissible limits. The suitability of water for drinking purposes with regard to its chemical and physical quality has, therefore, to be determined on the basis of general characteristics of the water available in the locality, and its freedom from toxic substances.

Generalities on Drinking water

a.) Drinking Water

Drinking water, also known as potable water, is water that is safe to drink or to use for domestic and industrial processes without risk to health. According to Article 2 of Prime Ministerial decree no 2001/163 of 8th May 2001, potable water is defined as any surface, groundwater or spring water which, naturally or after appropriate physico-chemical or microbiological treatment, can be consumed harmless to health. It can be distributed as bottled water, tap water, in tanks for industries or even abstracted from a borehole or well. Though the soil, serving as a natural filter, ensures good water quality, further treatment of groundwater is necessary to completely eliminate impurities. The amount of drinking water required to maintain good health varies and depends on physical activity, age, health-related issues, and environmental conditions (Grandjean, 2004). According to the World Health Organization's 2017 report, safe drinking water is water that "does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages" (WHO, 2017). About 1 to 2 billion people lack access to safe drinking water (WHO, 2018), a problem that causes 30,000 deaths each week (Albertiri, 2018). The U.N Secretary General Ban Ki-Moon even noted that more people die from unsafe water than from war (UN News, 2010).

Drinking water is not a single compound but a very dilute solution in which a number of chemicals are dissolved. Some of these are necessary for maintaining an equilibrium in biochemical reactions taking place in the organisms. Unlike spring water which is usually drinkable when it is drawn, most of the water we drink contains mineral and organic substances, some of which can pose health risks to the consumers. These substances come not only from rocks and sedimentary layers but also from discharges caused by human activities or the decomposition of biomass.

For our system to function well requires water and water of good quality. To be considered potable, water must be free from all substances deemed harmful to health. On the other hand, substances naturally contained in water which are deemed necessary for health such as mineral salts (Ca^{2+}, Mg^{2+}) and trace elements (Fluorine, Zinc …) must be maintained in the water we drink.

b.) Parameters for drinking water

For it to be consumed safely, water must meet very strict drinking criteria or standards. These standards vary depending on the legislation of each region. To date, there are 63 criteria for drinking water and they are grouped into five (05) main parameters:

- **Physicochemical parameters.** They correspond to the characteristics of water such as pH, temperature, conductivity and hardness. They also determine the maximum permissible limits of certain components such as ions, chlorides, potassium and Sulphates.

- **Organoleptic parameters.** These are parameters linked directly to consumption comfort but have no direct health value. They relate to color, taste, smell, temperature, dissolved oxygen and saturation rate. Water should be pleasant to drink, clear and odorless.
- **Microbiological parameters.** Allow to check that the water is void of all pathogenic germ such as viruses, bacteria or parasites, which can cause disease or even epidemics.
- **Parameters related to undesirable substances.** Refer to substances such as Nitrates, Nitrites, Pesticides and herbicides.
- **Parameters linked to toxic substances.** They include micro-pollutants such as Arsenic, Cyanide, Chromium, Nickel, Selenium, and some Hydrocarbons. They are subject to very strict standards due to their high toxicity, having a tolerated content order of a millionth of a gram.

c.) Drinking Water and Public Health

All humans require an adequate supply of clean water in order to survive and a lack of this resource is known to significantly decrease the quality of life (WHO, 2011). The level of access to clean water varies over different populations. However, four (04) criteria can determine whether users have access to this resource or not;

i. a sufficient quantity,

ii. an acceptable quality,

iii. local availability,

iv. Affordable price. (Jain et al., 2011)

Although many people have access to a sufficient supply of water, many still do not. The WHO/UNICEF Joint Monitoring Program (JMP) for Water Supply and Sanitation which was tasked with monitoring the Millennium Development Goal relating to drinking water and sanitation (MDG 7, Target 7c) reports that approximately 663 million people do not use an improved drinking water source (WHO/UNICEF, 2015) and the health effects are more severe on the elderly, the young and those in unsanitary conditions (WHO, 2011) who sometimes lose their lives. Although global reports provide estimates on those now being serviced by improved water sources, the term improved can be deceptive or inaccurate.

An Improved Water Source is defined by the JMP as one that, by nature of its construction or through active intervention, is likely to be protected from outside contamination with fecal matter. It can also be defined as tap water in the dwelling yard or plot, public stand posts, boreholes/tube wells, protected wells and springs, rainwater, packaged water including bottled and sachet water, and delivered water (WHO/UNICEF, 2017). By nature of their design and construction, improved drinking water sources have the potential to deliver safe water and in order to meet the criteria for a safely managed drinking water service, the source should;

- Be accessible on premises,
- Be available when needed
- Be free from contamination.

If the improved source does not meet any one of these criteria, but a round trip to collect water takes 30 minutes or less, it will be classified as a Basic drinking water service. If water collection from an improved source exceeds 30 minutes, it will be categorized as a Limited service (JMP WHO/UNICEF, 2017)

Conversely, unimproved drinking water sources are vulnerable to permanent or temporary quality deterioration and often do not meet the WHO guideline values for safe drinking water. Unimproved sources include unprotected wells or springs, and surface water sources. Monitoring and evaluation have revealed that only 34% of reported improved water sources adhere to the originally developed standards in some instances (Howard et al., 2012). Consequently, the actual number of people being served by improved water sources most likely falls below what is formally reported.

There are different types and levels of contamination but the most contamination occurs due to anthropological activities (Jain, 2012). Typical water quality parameters important for public health include the presence of microbiological indicators and pathogens, turbidity and suspended solids, and inorganic and organic pollutants. Although each of these parameters can have associated health risks, many agree that microbial contamination poses the greatest health risk to humans in developing countries in regards to drinking water contamination (Howard, 2002; Jain et al., 2011; WHO, 2011; Jain, 2012; Pruss& al., 2014). Independently, turbidity in itself is not a health risk. However, it is associated with the concentration of suspended solids to which harmful microorganisms or other pollutants can be attached (Howard, 2002). In addition, turbid and odorous water can also be aesthetically unpleasant resulting in rejection by the user (WHO,2011).

d.) Water Quality Standards

The chemical composition of surface and groundwater depends on the chemical nature of earth's crust and the distribution of rock types and chemical nature of water is also influenced by the composition of rain and human activities such as disposal of industrial and municipal wastes. Due to this, various institutions, associations, organizations and health agencies have proposed the standards at international level for acceptable potable water such as American Public Health Association (APHA), Indian Council of Medical Research (ICMR), World Health Organization (WHO) (Table 2) and NormeCamerounaise NC 207.

One of the recent WHO guidelines for drinking water quality contains a comprehensive list of recommendations with health criteria and supporting information which are not intended to serve as standards by themselves; instead, they provide a basis on which individual countries can develop their own standards or regulations in the context of appropriate environmental, social, economic and cultural conditions. Therefore, national standards may be considerably different from the international guidelines

Table 2: WHO and ICMR Drinking Water Standard (ICMR, 1975; WHO, 2008)

Parameter		**WHO**	**ICMR**
pH	Desirable limit	7 – 8.5	7 – 8.5
	Maximum permissible limit	6.5 – 9.2	6.5 – 9.2
fluoride	Desirable limit	0.7	1
	Maximum permissible limit	1.5	1.5
TDS	Desirable limit	500	500
	Maximum permissible limit	1500	1500
Chloride	Desirable limit	200	200
	Maximum permissible limit	600	1000
Nitrate	Desirable limit	45	20
	Maximum permissible limit	-	50
turbidity	Desirable limit	5 NTU	5 NTU
	Maximum permissible limit	25 NTU	25 NTU
Sulphates	Desirable limit	200	200
	Maximum permissible limit	400	400
Sodium	Desirable limit	200	-
	Maximum permissible limit	250	-
Calcium	Desirable limit	75	75
	Maximum permissible limit	200	200
magnesium	Desirable limit	30	50

	Maximum permissible limit	150	150
Total hardness	Desirable limit	300	300
	Maximum permissible limit	500	600
potassium	Desirable limit	10	-
	Maximum permissible limit	-	-
bicarbonate	Desirable limit	500	500
	Maximum permissible limit	-	-
Arsenic	Desirable limit	0.01	0.05
	Maximum permissible limit	NR	NR
Iron	Desirable limit	0.3	0.1
	Maximum permissible limit	1.0	1.0

Some properties of water

A water molecule is comprised of one atom of oxygen and two atoms of hydrogen. It is peculiar in that it is a bipolar molecule (that is, it has a net negative charge around the oxygen atom and a net positive charge around the hydrogen atoms).

- **Chemical properties**

- Chemical formula: H_2O
- Relative molecular mass: 18 g/mol
- It has a pH of 7 at 25^0C
- It is amphoteric. (it has the ability to act as either an acid or a base in chemical reactions)

NH_3 (base) + H_2O (acid) ⇌ $NH^+_4 + OH^-$

HCl (acid) + H_2O (base) ⇌ $H3O^+ + Cl^-$

- **physical properties**

- Tasteless and odorless liquid at room temperature and pressure

- Liquid water has weak absorption bands at wavelengths of around 750 nm which cause it to appear to have a blue colour

- The liquid phase is the most common and is the form that is generally denoted by the word "water". The solid phase of water is known as ice and commonly takes the structure of hard, amalgamated crystals, such as ice cubes, or loosely accumulated granular crystals, like snow. The gaseous phase of water is known as water vapor (or steam). Visible steam and clouds are formed from minute droplets of water suspended in the air.

- The density of water is about 1 gram per cubic centimetre (1 g/cm^3). The density varies with temperature, but not linearly: as the temperature increases, the density rises to a peak at 3.98 °C (39.16 °F) and then decreases. (*Ramires et al., 1995).*

Water Quality Management

a.) Testing Water Quality

Water quality tests can determine the potential threat of using a certain water source. Moreover, test results are necessary for developing public health measures and interventions to minimize the risk and improve the health of the users (Gwenzi et al., 2015). Although measuring water quality informs methods for subsequent actions, barriers associated with testing water quality exist. For example, microbial contamination of water poses a possible health risk on communities; however, microbial quality oftentimes remains unknown due to the cost, difficulty, time requirement, and skilled expertise needed for conducting the tests (Gunda et al., 2016). As a result, rural settings with limited resources and non-piped water sources most in need of assessment due to the likelihood of contamination receive the least monitoring. This information underscores the need for more water quality testing at a greater convenience than currently commercially available for low-resource areas and decentralized water sources. In addition to determining the water risk level, water quality tests also serve other purposes. For example, water test results can help determine specific routes exposure by a direct comparison. So, water quality tests along with recording potential risk factors such as the seasonality or sanitary conditions can help identify trends in quality and the strongest associated risk factors or routes of contamination. Additionally, test results can also determine whether samples comply with national or international standards (Howard et al., 2012). Moreover, water quality tests can be used to show the effectiveness of a treatment technology by showing the level of reduction of contaminants by comparing the raw water to the treated water (CAWST, 2013). Conclusively, water quality tests can serve many purposes and provide valuable information towards improving public health.

b.) Pollution in water

Water is essential for the survival of any form of life. It is one of the most important commodities which is exploited much more than any other resource for the sustenance of life. Injudicious and uncontrolled explorations of water bring about a change in the physical, chemical, biological quality of the water and it thus becomes unfit for drinking and other domestic uses. Human activities can change the natural composition of ground water through the disposal of chemicals and microbial matter at the land surface and into soils, or through injection of wastes directly into ground water leading to pollution (figure 6). Groundwater pollution is defined as an undesirable change in natural groundwater quality resulting due to addition of solid, liquid or gaseous wastes and/or addition of physical, chemical or biological agents or sewage or industrial effluents. Hydrological connectivity between groundwater and the land surface provides the opportunity for the contamination of groundwater and a subsequent reduction in water quality (Stamatis et al., 2001). The signs of water pollution are bad taste of drinking water, offensive odors from water bodies, unchecked growth of aquatic weeds in water, decrease in number of fish in fresh water, oil and grease floating in water surfaces. These factors disturb the normal uses of water for public water supply, recreation and aesthetics, aquatic organisms and wild life, agriculture and industry. Water pollution is mainly caused by natural and anthropogenic processes.

Water pollution can be classified into three main categories. These are physical, chemical, and biological pollution of water.

i. Physical Pollution of Water

It brings about changes in water with regard to its color, odor, density, taste, turbidity and thermal properties etc.

- **Color** - Water used for drinking purposes should be free of color. Pure water is colorless but water in nature is often colored by foreign substance. Water having color partly due to suspended matter, is said to have apparent color. Color contributed by dissolved solids which remains after removal of suspended matters, is known as the true color. The presence of organic matter, Iron and Manganese may impart color in groundwater. Iron oxide causes reddish water and Manganese Oxide causes brown or blackish water. Color changes in water may affect the penetration of sunlight inhibiting plant and animal metabolism.
- **Turbidity** - Turbidity in water mainly arises from colloidal matter, fine suspended particles and soil erosion. Turbidity is the most important problem for the aesthetic value of water quality. Although it does not necessarily adversely affect human health, it can protect microorganisms from disinfection effects, can stimulate bacterial growth, and indicate problems with treatment processes (WHO, 2004). For effective disinfection, median turbidity should be below 0.1 NTU although turbidity of less than 5 NTU is usually acceptable to consumers (WHO, 2004).
- **Taste and Odour** - Unpleasant earthy or musty taste and odour problems usually arise due to total dissolved solids in water. They are produced also by industrial effluents containing Iron (Fe), Manganese (Mn), free chlorine, phenols and aquatic actinomycetes in industrial zones.

ii. Chemical Pollution of Water

The chemical pollution of water causes changes in acidity, alkalinity or pH, total dissolved solids, electrical conductivity and dissolved oxygen. It may be caused either by organic pollutants or inorganic pollutants or by both. The organic pollutants can be biodegradable or non-biodegradable.

- **pH** - An important operational water quality parameter is pH, although within typical ranges it has no direct impact on consumers. The pH of a solution is the negative logarithm of the hydrogen ion activity. Low pH levels can enhance corrosive characteristics resulting in contamination of drinking-water and adverse effects on its taste and appearance (WHO, 2004). Higher pH levels can lead to calcium carbonate deposition. Exposure to extreme pH values results in irritation to the eyes, skin and mucous membranes. Careful consideration of pH is necessary to ensure satisfactory water disinfection with chlorine, which requires pH to be less than 8 (WHO, 2004).
- **Total Dissolved Solids (TDS)/ Electrical Conductivity (EC)** - TDS is the primary indicator of the total mineral content in ground water. TDS term is used to describe the inorganic salts and small amounts of organic matter present in solution in water. EC is a measure of the ionic activity of a solution. As TDS and EC increase, the corrosive nature of the water increases.

iii. Biological Pollution of Water

Bacterial pollution in water is caused by the excretory products of man, animals and birds. The main pollutants belong to coliform group and certain subgroups, faecal streptococci and miscellaneous organisms. Biological pollution is also brought about by bacteria, viruses, algae, diatoms like protozoa, rotifers, crustaceans and plant toxins.

The diseases caused by water related microorganisms can be divided into four main categories:

- **Water-borne diseases** - caused by water that has been contaminated by human, animal or chemical wastes. Examples include cholera, typhoid, meningitis, dysentery, hepatitis and diarrhea. Diarrhea is caused by a host of bacterial, viral and parasitic organisms most of which can be spread by contaminated water (WHO, 2006). Poor nutrition resulting from frequent attacks of diarrhea is the primary cause for stunted growth for millions of children in the developing world (Gadgil, 1998).

- **Water-related vector diseases** - These are diseases transmitted by vectors, such as mosquitoes that breed or live near water. Examples include malaria, yellow fever, dengue fever and filariasis. Malaria causes over 1 million deaths a year alone (WHO, 2006). Stagnant and poorly managed waters provide the breeding grounds for malaria-carrying mosquitoes.
- **Water-based diseases** - These are caused by parasitic aquatic organisms referred to as Helminths and can be transmitted via skin penetration or contact. Examples include Guinea worm disease, filariasis, paragonimiasis, clonorchiasis and schistosomiasis.
- **Water-scarce diseases** - These diseases flourish in conditions where freshwater is scarce and sanitation is poor. Examples include trachoma and tuberculosis.

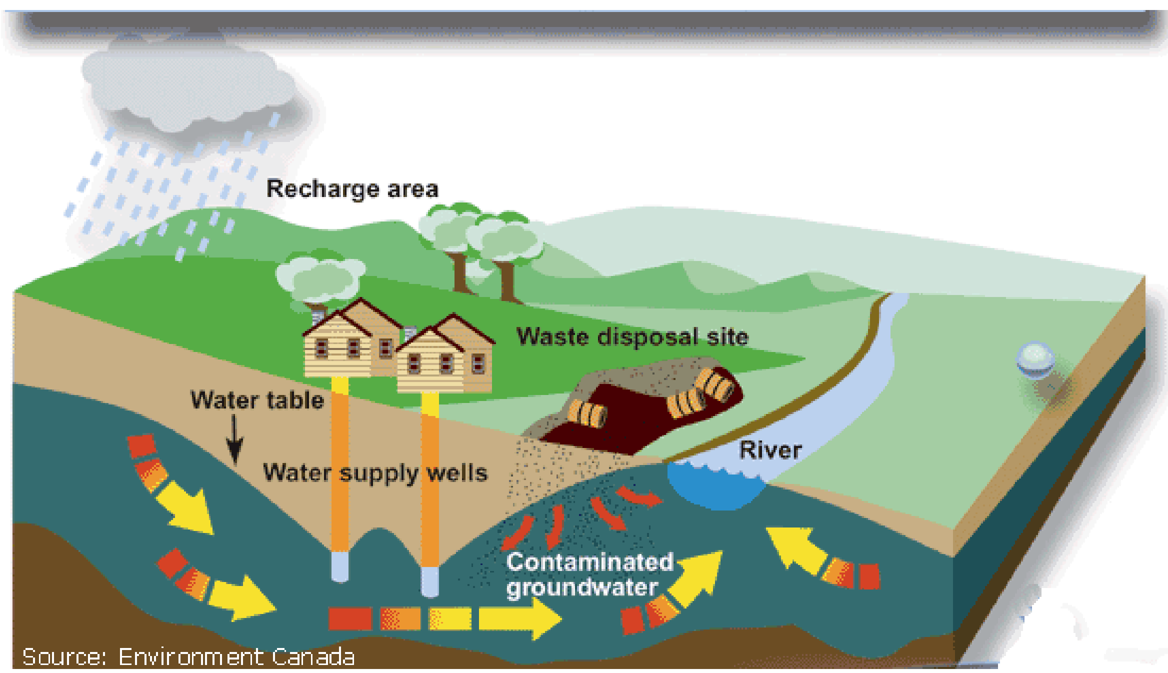

Figure 6: Groundwater contamination from a waste disposal site (USGS, groundwater quality)

c.) Managing Water Quality – Contamination Prevention and Treatment Technologies

Many different factors affect whether or not a community manages its water effectively and safely for consumption. The three pillars of sustainable development (social, economic, and environmental) should be considered when evaluating community management and suggesting interventions in order to increase the likelihood of success especially in developing communities, which may already have preconceived perceptions and established practices. Interventions must be culturally acceptable, inexpensive, simple, and easy to use (Kwaadsteniet& al., 2013). In addition, the communities should be involved as much as possible during all stages of the intervention to help ensure sustainability (Francis & al., 2015). For water management interventions specifically, many agree that there are three paramount points of intervention;

- Education,
- Treatment and
- Recontamination prevention (Schafer, 2010; Jain, 2012; Gwenzi& al., 2015).

Due to the management structure, educational setting, and general openness to innovation, schools are considered to be appropriate institutions for water management interventions (Meierhofer and Wegelin, 2002). Water treatment can effectively prevent exposure to harmful contaminants and reduce pathogen concentrations.

Many different treatment types and technologies exist, and the quality of the raw water should be one factor determining the selected method (Kioko&Obiri, 2012). In other words, different technologies have their advantages and disadvantages, and the specific factors including water quality and the environment can guide, which treatment method or combination of treatment methods is most appropriate. Three of the most general types of treatment include sedimentation, filtration, and disinfection (Mihelcic& al., 2009; CAWST, 2013). Each of these general types of treatment methods can be applied singly or in combination with other methods.

i. Sedimentation

It is a physical water treatment process using gravity to remove suspended solids from water. Sedimentation in potable water treatment generally follows a step of chemical coagulation and flocculation which allows grouping particles together into flocs of a bigger size. This increases the settling speed of suspended solids and allows settling colloids. The particles that settle out from the suspension become sediment, and in water treatment is known as sludge.

ii. Filtration

It is a treatment method which involves separating contaminants as the water passes through smaller pores. Many types of filters exist though sand filters are very commonly used. Slow sand filters are common in developing countries; they have a porous filter media, which is able to filter Helminths and some protozoa at a flow rate of 480,000 L/day (Peter-Varbanets, 2009; Kwaadsteniet et al., 2013). Alternatively, rapid sand filter have a filter media with larger pore sizes which can be an effective pretreatment method to reduce turbidity at a faster flow rate but is ineffective at reducing microbial contamination (Abraham et al., 2015). A study on a sand filter composed of fine gravel and fine sand from the Red River banks, highlighting the simplicity of obtaining this essential material for the filter, significantly reduced arsenic and iron concentrations (95% and 100% respectively); however, the authors suggested disinfection of the effluent water before consumption due to increased microbial contamination. Many different types of sand filters exist, and users are developing inexpensive and innovative design in developing countries. For example, some designs use local materials including cast iron, brick shards, sand, and charcoal that have been successful at reducing both arsenic and coliforms (Ray and Jain, 2011). Another design separated layers of the sand filter with spaces in between to diminish commons issues with sand filters such as clogging, odor, and excessive spatial requirements (Nitzsche et al., 2015). Another study found that two full-scale biosand filters reduced E. coli at a log10 removal of 1.7 (Lynn et al., 2013).

iii. Disinfection

It is another type of water treatment method, which involves inactivating microbial contaminants (Abtahi et al., 2015). Three common types of disinfection include chemical, heat, and UV disinfection as outlined in the Global Water Pathogen Project website at http://www.waterpathogens.org/.

Chlorination is the most commonly used type of chemical disinfection shown to be the most widely used treatment method in a Western Kenyan study (Kioko and Obiri, 2012). However, chlorination can fail to disinfect some protozoan pathogens such Cryptosporidium and some viruses (WHO, 2011).

Boiling is generally the most highly recommended treatment method (WHO, 2011), but this most oftentimes requires fuel for heating such as firewood, which could have negative environmental impacts including deforestation and high carbon footprint (Islam et al., 2006; Held et al., 2013). Pasteurization, heating at temperatures below boiling point, is also effective at removing pathogens; however, indicator bacteria such as E. coli can be reduced below detection limits while other pathogens such as Yersinia spp., Legionella spp. and Pseudomonas spp. can still survive at the same temperatures (Kioko and Obiri, 2012). Research has been conducted showing the inactivation of microorganisms in an aqueous solution depends on water temperature and heating time period. For example, it is reported that a time period of approximately 12 seconds is required kill 99.999% of E. coli, rotavirus, Salmonella typhi, Vibrio cholerae, and Shigella sp. at a pasteurization temperature of 70 ºC. The required temperature to inactivate the microorganisms decreases exponentially with time. For example, 90% of E. coli organisms are inactivated at a temperature of 65 ºC for 12 seconds; the same result is achieved at 60 ºC for one minute (Ray and Jain, 2011).

Another type of disinfection, called Solar Disinfection (SODIS), uses a synergetic effect from both increased temperatures that leads to pasteurization and UV light to reduce microbial contamination in water (Meierhofer and Wegelin, 2002). A major advantage of disinfection as a treatment method versus sedimentation and filtration is that disinfection inactivates small contaminants like viruses and bacteria, which are usually not reduced significantly by filtration and sedimentation.

d.) Associated Perceptions and Practices

Investigating knowledge, attitudes, and practices of individuals and communities can assist researchers understand the reasons behind consumption of unsafe drinking water and accordingly, develop successful interventions (AbRazak et al., 2016). As stated previously, the greatest concern related to unsafe drinking water is microbial contamination (Howard, 2002; Jain et al., 2011; WHO, 2011; Jain, 2012; Prüss- Ustün et al., 2014), yet many do not prioritize preventing this. A study in Iran found that turbidity and corrosiveness were the two causes for health and acceptability issues (Abtahi et al., 2015). Another study conducted in western Kenya showed that communities perceived water to be safe for consumption given favorable physical parameters including the lack of suspended solids that would cause odor and color (Kioko and Obiri, 2012). In regards to causes of illnesses, a study in rural southern India revealed that community members did not believe that consumption of contaminated drinking water caused diarrheal diseases (Francis et al., 2015). Concerning perceptions of safety, survey responses in Central Uganda indicated rainwater could be consumed safely if it did not remain stagnant (Prouty et al., 2016). Each example shows that these easily recognizable factors cause concern about their drinking water. However, the knowledge about the significant risk of microbial pathogenic contamination of water is limited. Although many cases demonstrate that faulty perceptions result in the consumption of unsafe water, communities sometimes continue risky practices even with appropriate knowledge. For example, the study in western Kenya revealed that survey respondents were both knowledgeable of good hygienic practices and treatment, collection, and storage methods, yet the communities did not practice them (Kioko and Obiri, 2012). In addition, the study mentioned previously from India (Francis et al., 2015) concluded that the simplicity of access from the sources, and the economic requirements along with the ability to recognize health benefits, directly related to the successful impact of interventions and sustained practices. Therefore, communities' existing perceptions, practices, and priorities help explain some reasoning behind consumption of unsafe drinking water and guide successful intervention plans.

Chapter 2. METHODOLOGY

This chapter discusses the methods used to carry out this research and achieve its objectives. It also includes the preparation, sample collection, instrumentation and tools, and procedures.

Preparation

To conduct this study, the thesis author paid regular visits to Minkama 4 for a period of 20days watching and observing the local water management practices. This experience helped further the understanding of the culture and the current management practices and knowledge of water quality in relation to health. During this time we observed the population's practices, and looked for trends in behaviors that could be improved.

Research population

The target population for this research is any person in the Minkama 4 locality who is not connected to the national water supply network (CAMWATER) and who does not use bottled water. The study considered people who rely on natural sources such as wells and springs for drinking water especially. Given that every human uses and manages water, understanding perceptions and practices in relation to public health risks is applicable to all individuals in the study location.

Tools and instrumentation

The following five tools and instruments were used to collect the thesis data:

- Documentary research
- A sanitary inspection
- Knowledge, attitudes, and practices survey,
- Water sampling
- Water quality tests.

Documentary Research

This phase lasted literally throughout the entire length of the research. It involved mostly internet research with softcopy publications. The material studied in this phase were obtained from;

- Books
- Articles
- Official websites
- Validated thesis works

This approach allowed the pursuit of five specific goals

a. Specify the degree of progress of research work on the subject

b. Identify and define concepts and variables based on the writings of other researchers

c. Be informed about research quotes, methods, instruments and analysis techniques

d. This phase provided us with information on the environment of study such as population, soil type.

e. Recognize the difficulties and ethical issues related to drinking water, especially in rural areas such as Minkama 4

Knowledge, Attitudes and practices Survey

A cross sectional and qualitative survey was developed to ask about participants' knowledge, attitudes towards health risks and water obtaining and management practices. This was done through the administration of a questionnaire. Greetings and a general introduction of the project were done on arrival at each participant's house after which the participant's consent was solicited to answer the questionnaire. For those who gave their accord, the questions (APPENDIX 3) were read to them directly from the survey in English language and their answers were written as the interview was conducted. If a study participant did not understand English, as was the case with a majority of the participants, a guide was invited to translate the questions into the local language or French.

Questions were included in this questionnaire about participants' primary sources of drinking water given that they are not connected to the national water supply network. Also, questions were asked about participants' current treatment methods or lack of treatment methods. We furthermore tried to understand how long it takes for a round trip collection and reasons why respondents had resorted to consuming untreated water. The complete questionnaire is included in the appendix section at the end of this work.

Sanitary Inspection

In addition to the survey, a sanitary inspection was carried out to determine the likely routes of contamination of water sources and assess the risks involved in consumption of water from these sources. This phase involved a descent to the locality and an observation of the populations' drinking water sources and peripheries in order to better understand the problems of water and if there is as much protection of source perimeters as stipulated by Prime Ministerial decree n° 2001 / 163 of 8th May 2001. It was verified, using a measuring tape, for the sources if the reference radius of 35 metres from latrines was respected. Photos were taken with the use of a mobile iphone camera. The results from the sanitary inspection were later compared to the results of the water quality tests in order to test the validity of the sanitary inspection tool.

Water sampling

In order to obtain information on the physical, chemical and microbial properties of water, three samples were taken from three different points;

- a well located in a resident's compound,
- an open source known as Makocgo and
- From a household.

The samples were collected with the help of three 500mL plastic polyethylene bottles (figure 7), an isothermal flask (figure 8) with a cool pack (figure 9) in it to keep the sample temperatures at about 4 ^{0}C, an inkjet pen and stickers for labelling the samples. The bottles were first properly washed and rinsed with distilled water. Keeping the sample at low temperatures was a measure taken in order to slow the rate of chemical reactions and phase changes, and microorganism activity which could result to changes in pH and solubility of chemicals of interest. The temperature was measured on-site with the use of a thermometer and the values recorded. Other parameters such as the aspect and odour were also noted on-site at the time of sampling.

The samples conserved in this fashion were then taken to the laboratory for analyses.

Figure 7: Plastic PET bottles for sample collection

Figure 8: Cool pack

Figure 9: Isothermal flask

Water quality Tests

The three collected samples, after proper conditioning for transportation, were then taken to a chemistry laboratory for tests to be conducted. These tests were aimed at determining some of the physical, chemical and bacteriological characteristics of the water (appendix 2). The different parameters tested for, as well as the apparati used and procedures followed are described below.

a. Determination of pH

Measures of pH were determined using a pH meter (figure 10) of the Hach (HQ11d) mark. After pre-calibrating the pH meter using buffer solutions with pH values 7.00 and 4.01, the green electrode was introduced in 100 ml of the sample waters and the values projected on the digital screen were recorded.

Figure 10: Hach (HQ11d) pH meter

b. Determination of conductivity

Measurements of the electrical conductivity (EC) of water, which is the conductance of a water column between two metal electrodes 1 cm^2 in area and separated from each other by 1 cm, were carried out using a Hach conductivity meter. This apparatus is equipped with a standard probe which is vertically immersed in the solution whose concentration is to be determined. The conductivity value is read on a digital display (figure 11).

Figure 11: Determination of conductivity using Hach (HQ14d) conductivity meter

c. Determination of Total Suspended Solids

Total suspended solids (TSS) are determined by the so-called "photometric" method. Twenty-five (25) ml of the water sample were introduced into a spectrophotometric cell tube and placed in the Hach DR/3900 spectrophotometer (figure 12). The TSS content by reference to a control, which is distilled water, were read directly on the digital display in mg/L, at wavelength 810 nm.

d. Determination of Nitrate.

Nitrate ions were determined by the cadmium reduction method with the aid of the Hach DR/3900 spectrophotometer. After the introduction of 10 mL of sample in a spectrophotometric cell, a sachet of Nitraver 5 was added therein. The mixture was then homogenized and allowed to settle for 5 minutes (reaction time). The coloration developed in the presence of NO_3^- was subsequently read on the spectrophotometer at a wavelength of 500 nm. The concentration of the parameter under study were read on the digital screen of the apparatus with reference to a control consisting of 25 mL of sample. The results are expressed in mg/l.

e. Measurement of Ammonium ions

Ammonium ion concentrations were determined using the Nessler method. Three (03) drops of mineral stabilizer and three (03) drops of 'Polyvinyl alcohol dispersing agent' and 1 mL of Nessler's reagent (alkaline Potassium Iodo-Mercurate) were added in turn to 25 ml of distillate and 25 ml of control (distilled water). These reagents respectively allow the formation of a hard complex and contribute to the formation of a yellow colour during the reaction of the Nessler reagent with Ammonium ions. The intensity of this colour is proportional to the concentration of Ammonium ions in the sample. The reading is taken with the DR/3900 spectrophotometer and the results are expressed in mg/L of NH_4^+.

f. Determination of Calcium, Magnesium and Sodium

The determination of calcium and magnesium was done by the colorimetric calmagite method (Anonymous, 2005). This method of measuring complete hardness is the volumetric method and was used in this study because it is more common and due to its ability to measure very low concentrations of Calcium and Magnesium. Also, the interference of some metals will be made negligible during dilution to bring the sample into the measuring range of the colorimetric analysis.

The indicator used was calmagite which forms a blue-violet coloration in strongly alkaline solution and turns red in the presence of free calcium or magnesium. The analysis of calcium and magnesium is carried out by complexing calcium with EGTA to destroy any red coloration due to calcium and by complexing calcium and magnesium with EDTA to destroy the red coloration due to these two elements (Ca + Mg). By measuring the red coloration in these different states, the concentrations of calcium and magnesium are obtained.

The method of analysis was as follows.

- 100 ml of the sample to be analysed was poured into a test tube and 1 mL of Calcium Magnesium Indicator Solution added using the 1 mL eye-dropper.
- The solution was then stirred to mix and 1 mL of alkaline solution of calcium and magnesium was added using the 1 mL dropper.
- 25 mL of this solution was poured into 3 colorimetric cells and one (01) drop of 1 M EDTA solution added to one of the cells (the blank) and the solution was shaken to mix.
- One drop of EGTA solution was then added to another vial (the prepared sample) and shaken to mix.
- The reading was taken with the DR/3900 spectrophotometer (figure 12) at a wavelength of 522 nm. The values are given in mg/L Calcium and Magnesium.

For the determination of Sodium, the analysis consisted of a direct measurement of the intensity of the yellow coloration of the alkaline Sodium Chromate solution. In acidic medium, the solution is orange and must be treated. A neutralizing reagent is added to raise the pH, giving the yellow colour necessary for the determination. The Sodium determination was carried out using the direct colorimetric method as follows:

- A colorimetric cell was filled with 25 ml of sample water and the contents of one capsule of neutralizing reagent added to the vial and shaken.
- Then another colorimetric cuvette (the control experiment) was filled with 25 ml of colourless water.
- Then the samples were read off with the at wavelength 670 nm. The result is given in mg/L Sodium Chromate (Na_2CrO_4).

Figure 12: DR 3900 spectrophotometer

g. Determination of Bacteriological parameters.

Faecal streptococci (FS) and faecal coliforms (FC) present in the samples were determined using the membrane filtration technique and counted in conformity with standard protocols as described by Rodier (2009). The culture medium used for FS is the BEA medium (Bile EsculineAzide agar) while that for FC is the TTC and Tergitol 7 medium. After decimal dilution of percolate samples using sterilized dilution water, the samples were filtered on membrane with the aid of a vacuum pump. Next, the filter membranes were placed in the respective culture media.

The Faecal streptococci medium was placed in an incubator (figure 13) at 35 ^{0}C and left to incubate for 24 hours. The faecal coliform medium was also placed in an incubator at 44.5 ^{0}C for a period of 24 hours (figures 14 & 15)

Figure 13: Oven incubator for FC and FS

After incubation, the colonies were counted and their total number estimated using the following formula:

$$\frac{CFU}{mL} = \frac{(number\ of\ colonies * dilution\ factor)}{volume\ of\ culture\ plate}$$

With CFU= Colony Forming Units for 100 ml.

Figure 14: Process for determining FC and FS

Figure 15: Portable incubator

Chapter 3. RESULTS AND INTERPRETATION

In this section will be presented the area of study with photos of some water points in the locality. Also, the results of the knowledge, attitude and practice survey will be presented as well as the results obtained from the laboratory sample analyses. A few measures on how to protect water sources from eminent pollution will be elaborated and some treatment methods or techniques will be suggested based on the type of contamination noticed from the laboratory tests in order to improve the quality of the drinking water and preserve the health of the population.

Area Description

Throughout the locality of our study, we were able to identify a total of twenty six (26) hand dug wells, four (04) boreholes and six (06) ponds.

- The wells in this study include cased (managed) and uncased (unmanaged) hand dug wells equipped with buckets for drawing water.
- Boreholes were cased and drilled systems equipped with hand pumps and an outlet for collecting water.
- Considered ponds were natural flowing springs which may have (managed) or may not have (unmanaged) modest improvements such as cemented discharge points and outlet pipes.

Of the four (04) boreholes in this locality, one (01) is not functional. This is the oldest of the boreholes, a Netherlander hand pumped VOLANTA whose construction dates back to the year 1990. It has long been abandoned (figure 16).

Of the three (03) functional boreholes, two (02) are privately owned. One located at a residents domicile close to the Government primary school and the other around the checkpoint along the road leading to Batchenga, at the border between Minkama 4 and Minkama 3. The lone public borehole is located at the entrance to the locality and was donated by the PROVILLAGE BOSAPPAL project in 2004 (figure 17).

Figure 16: Abandoned VOLANTA boreholes built in the year 1990

Figure 17: The PROVILLAGE BOSAPPAL borehole

Water collection at these boreholes is scheduled and does not entail any financial requirements. The public borehole is usually opened on Mondays, Wednesdays and Fridays from 4pm to 6:30pm. The locals even have less access to this borehole during the dry season. This is because the dry season is usually characterized by little or no rainfalls which lead to a consequent decrease in the level of groundwater hence slower refill of the water system. In view of this, and with a corresponding increase in demand of water, the source is opened less frequently as a precautionary measure so as to avoid over pumping and complete drying up of the source. This measure is not without consequences as it causes most locals to resort to consuming water from wells and ponds which are of doubtful quality.

Other water points

The installation of the water points in this locality is to the credit of Non-Governmental Organizations (NGOs) and the locals themselves. As at the moment, the Obala council is yet to implant a water point in the locality. As a matter of fact, we learned from the locals that some seven (07) years ago, the council did a survey of the area and pin pointed strategic areas where they said they were going to position taps for a water supply. But till date, nothing has been heard of them nor have any works in that light begun. Many locals even think all that was for political motives.

The most used water sources in this locality are the local hand dug wells. Due to the difficulties encountered in the obtaining water from the community borehole, most locals have resorted to consuming well water. However, water for drinking purposes is not collected from all the wells. Due to past trends, they consider only a few wells fit for drinking water collection while the others water for carrying out domestic activities such as laundry, cooking, cleaning and bathing. A few of the water sources are presented below.

- The borehole situated at the entrance to the locality donated by the PROVILLAGE BOSAPPAL project in 2004. Water collected here is usually for drinking and cooking purposes. The source is opened only on Mondays, Wednesdays and Fridays from 4pm to 6:30 pm. operated by the use of a hand pump and usually characterised by long queues (figure 18)

Figure 18: View of the PROVILLAGE BOSAPPAL borehole and queue

- The pond at Makocgo (figure 19). A natural source which was once managed by the locals who increased its depth and cemented around it with an outlet but it is now being neglected. Water obtained here is used for several house purposes including drinking water.

Figure 19: Water source known as Makocgo

- The Kede Angela water source (figure 20). Serves as a source of drinking water during the dry season when other convenient sources are dried up. Also, the locals use it for doing laundry. It was a once managed source which now suffers neglect also.

Figure 20: The Kede Angela source

- A natural pond situated about 40 metres from the Government Bilingual High school in a swampy area (figure 21)

Figure 21: Source at about 40metres from the GBHS

- A well located at the domicile of a resident (figure 22). Due to the inconveniences caused by scheduled openings of boreholes, queues and long distance, some locals use the water obtained here for drinking purposes.

Figure 22: Well located at a resident's.

- Well situated at the GBHS (figure 23). Students drink from it and some households located

Figure 23: Well situated at the GBHS

Collection and Transportation of water

Water is usually collected from ponds, streams, wells and boreholes even though this process is never an easy task for the locals. They either have to face long queues at the boreholes which also are at a considerable distance away from their homes and require manpower to pump water out or the strenuous act of drawing water from wells or walking long distances to the ponds to get water. The containers used in collecting water are mostly buckets, aluminum pots, empty soft drink bottles and 20 litre gallons. These are usually smaller than the storage containers in the homes so as to ease transportation. Given most of the locals are farmers or students who leave to the farms or schools respectively early, the water fetching activity is usually done in the evenings. At the source, the collection containers are rinsed and filled with water. For the wells, locals each possess a small plastic bucket to which a long chord has been attached and this used to draw water (figure 24). The filled containers are then transported to the houses in wheelbarrows for those who have or carried on the head. The locals face the problem of slippery roads and ascents and descents especially those who rely on the ponds. This makes the activity very strenuous. The problem of access paths poses a problem too. Most paths leading to the sources are very narrow and bushy (appendix 4) hence, collection times usually exceed 20 minutes.

Figure 24: Typical collection containers and chorded bucket for drawing water

Conservation of collected water

At the homes, the water collected from the sources in smaller containers is transferred to more voluminous prepared containers for storage. These are usually very large aluminum pots with lids or large plastic barrels for drinking water. The storage containers are strategically chosen to be larger so as to store enough water and avoid a daily routine of collection which is energy and time demanding. In cases where the water is not meant for drinking, there is less care whether the storage container has a lid or not. Usually, water for purposes other than drinking are stored in large plastic basins or bowls in the kitchens or sitting rooms, exposed to ambient air (figure 25).

Figure 25: Typical storage containers

In some households, when the stored water initially aimed for drinking is not consumed after some days, it is poured out into different containers and used for household activities such as laundry or cleaning and water for drinking fetched anew.

Knowledge, Attitudes and practices Survey

Fifty (50) surveys were administered in fifty (n=50) different homes. All the respondents reported that the populations at their sites did not have access to the CAMWATER supply network. All the respondents (n=50) reported groundwater (well, borehole) as their primary source of drinking water but of these, only ten (10) reported treating their water with bleaching agent at household level before consumption. These ten, however, did not know exactly what quantity of bleach to use in treating any given quantity of water. They reported that the quantity of bleach used was based on their instinct and how dirty or clean they perceived the water to be. The forty (40) respondents who reported not treating their water at household level before consumption, when asked to give reasons for their actions, gave several reasons. In all, eight (08) respondents raised the problem of cost, four (04) said it was too time consuming, four (04) doubted the efficiency of any treatment methods, eighteen (18) reported they perceive the water as already clean and six (06) gave reasons related to past trends inherited from their ancestors saying their ancestors drank from those same sources and nothing happened to them. The responses are distributed as shown in figure 26.

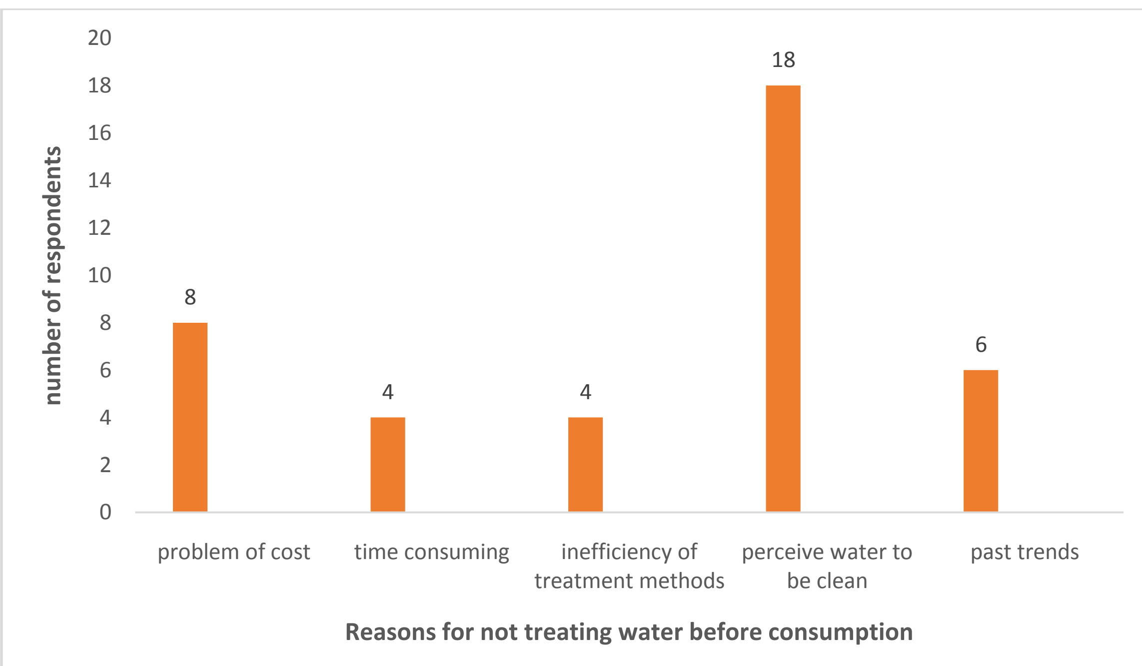

Figure 26: Distribution of responses to the reasons for not treating water before consumption.

As regards how long it took the respondents to fetch water and return, twenty respondents reported a round trip collection time between 1 – 10 minutes, twelve respondents reported a time range of 11 – 20 minutes, ten respondents a time range of 21 – 30 minutes and eight a collection time greater than 30 minutes. The results are summarized in Table 3

Table 3: Round trip collection time as reported by the respondents (n = 50)

Time range (minutes)	**1 - 10**	**11 - 20**	**21 - 30**	**More than 30**
Number of respondents	20	12	10	8

When asked how long they kept their drinking water, sixteen respondents reported two days maximum, fourteen others reported three days maximum, twelve reported seven days maximum and eight reported fourteen days maximum.

Participants were asked, “What are the possible causes of diarrhea?” to address whether or not the perceived contaminated drinking water could be a cause of diarrhea. Participants were able to choose all the responses that apply. Their responses are distributed as shown in figure 27.

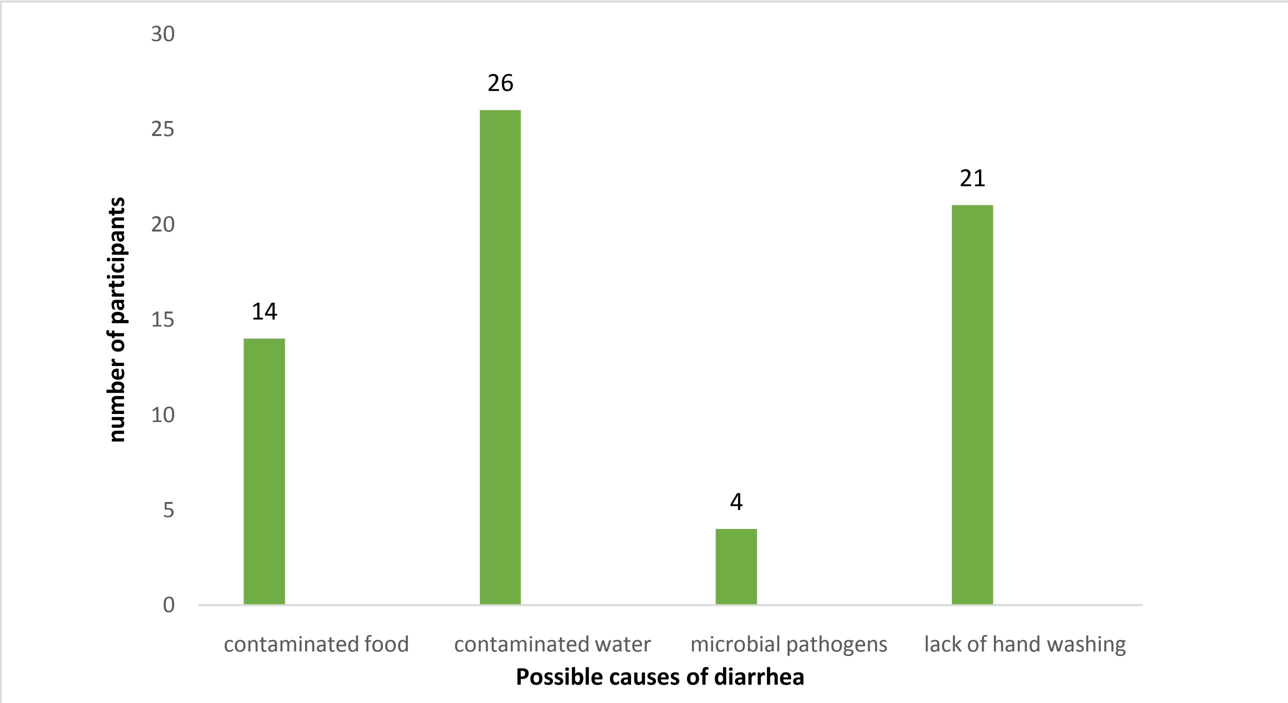

Figure 27: Distribution of responses to the question "What are the possible causes of diarrheal disease?"

As shown, twenty six of the respondents reported that contaminated water could be the cause of diarrheal disease. Also, twenty one of the respondents reported that the lack of hand washing could also be a cause of the diarrheal disease. A relatively lesser number of respondents (fourteen) thought eating contaminated food could lead to diarrhea. Of the fifty respondents, only four proposed microbial pathogens as a cause of diarrheal diseases. This may be because of the respondents' unfamiliarity with the specific term "microbial pathogens" or the lack of knowledge of these as microbial contaminants. These results show that the respondents are aware of the potential risk of diarrhea from contaminated water.

Sanitary Inspection

The sanitary inspection was carried out aimed at assessing whether the protective perimeters around sources are respected and determining the likely routes of contamination. The following observations were made about possible routes of contamination:

- Of all the wells counted in the locality, just one was well built and encased with a lid and a pulley system. The others were either encased with no lids or not encased and with no lids at all. The absence of lids favors the introduction of materials such as leaves from trees or wind transported particles or other materials into the wells, thereby leading to degradation of the water quality. Also, runoffs from rainfall, with all the foreign material it transports as it moves, easily run into the wells with no encasement. Animals too, especially small rodents such as rats, may fall into these open non encased wells and die.
- There is a common practice of doing laundry and bathing at the ponds. This is a potential source of introduction of unwanted chemicals into the water.
- Loose or uncontained rearing of domestic animals such as birds, goats and pigs. These defecate at random even around the water sources and this may be a potential source of fecal contamination.

As regards the precautionary distance of at least thirty five (35m) metres of latrines from water sources, twenty of the twenty six wells were in conformity while the other six were at distances less than 35m from latrines. All the ponds were located very far away from residents' homes but the perimeters were not protected. Three boreholes were well built and protected save one which was not functional and abandoned.

Results of the water quality tests

a. Results of the physicochemical and bacteriological tests of the well sample.

The well from which the sample was collected is located around households and is surrounded by trees, mostly cocoa trees (figure 28). It once had been built and covered with a lid but has over the years not been subject to any renovation works though visited for its water on a daily basis.

Figure 28: A view of the well located at a resident's

The results of the analyses for some parameters of the sample collected from the well are as shown (table 4)

Table 4: Physicochemical and bacteriological analyses of the well water

PARAMETER	UNIT	standard	RESULT	Cameroonian*/ WHO max permissible limit**
Physicochemical Parameters				
Odour	-	-	none	Absent
taste	-	-	-	Absent
aspect	-	-	clear	ND
Temperature	^{0}C	NM 03.7.008	27.4	≤ 25*
pH	-	NM ISO 10523	5.72	6.5 - 9*
Electrical	µS/cm	NM ISO 7888	106,1	1000*

conductivity				
Suspended solids	mg/L	T90-105	6	0**
Nitrates	mg/L	ISO 7890-3	9.4	≤ 50*
Ammonium	mg/L	ISO 10566	0.10	≤ 0.5*
Calcium	mg/L	ISO 6058	0	≤200
Magnesium	mg/L	ISO 6058	0.55	≤ 50*
Sodium	mg/L	NF T90-014	0.75	≤ 150*
Potassium	mg/L		1.37	≤ 12*
Bacteriological Parameters				
Fecal coliform	CFU/100mL		210	Absent*
Fecal streptococci	CFU/100mL	NM ISO 6222	116	Absent*
Escherichia coli	CFU/100mL		96	absent

b. Results of the physicochemical and bacteriological tests of the Makocgo source sample

- The Makocgo source is a non-managed source and its environment is characterised by cocoa trees, litter from used laundry detergents and decaying matter. This water point used to have modest improvements comprising a cemented discharge point and an outlet pipes (figure 29).

Figure 29: View of the Makocgo source

The results of the physicochemical and bacteriological analyses carried out are as shown (Table 5)

Table 5: Physicochemical and bacteriological analyses of the Makocgo source

PARAMETER	UNIT	standard	RESULT	Cameroonian*/ WHO norm**
Physicochemical Parameters				
Odour	-	-	yes	Absent
taste	-	-	yes	Absent
aspect	-	-	cloudy	ND
Temperature	^{0}C	NM 03.7.008	27.5	≤ 25*
pH	-	NM ISO 10523	6.03	6.5 - 9*
Electrical conductivity	µS/cm	NM ISO 7888	75.7	1000*
Suspended solids	mg/L	T90-105	2	0**

Nitrates	mg/L	ISO 7890-3	1.1	≤ 50*
Ammonium	mg/L	ISO 10566	0.23	≤ 0.5*
Calcium	mg/L	ISO 6058	0.08	-
Magnesium	mg/L	ISO 6058	0.43	≤ 50*
Sodium	mg/L	NF T90-014	0.82	≤ 150*
Potassium	mg/L		1.03	≤ 12*
Bacteriological Parameters				
Fecal coliform	CFU/100mL		315	Absent*
Fecal streptococci	CFU/100mL	NM ISO 6222	152	Absent*
Escherichia coli	CFU/100mL		160	absent

c. Results of the physicochemical and bacteriological tests of the household borehole water sample

In order to access the quality of water stored at residents' houses aimed for consumption, a sample was taken from a household and analysed for some physicochemical and bacteriological parameters. The results obtained are presented (Table 6).

Table 6: Physicochemical and bacteriological analyses of the borehole water stored in a household

PARAMETER	UNIT	standard	RESULT	Cameroonian*/ WHO norm**
Physicochemical Parameters				
Odour	-	-	none	Absent
Taste	-	-	yes	Absent

Aspect	-	-	clair	ND
Temperature	^{0}C	NM 03.7.008	27.7	≤ 25*
pH	-	NM ISO 10523	5.79	6.5 - 9*
Electrical conductivity	µS/cm	NM ISO 7888	91.2	1000*
Suspended solids	mg/L	T90-105	5	0**
Nitrates	mg/L	ISO 7890-3	0.5	≤ 50*
Ammonium	mg/L	ISO 10566	0.06	≤ 0.5*
Calcium	mg/L	ISO 6058	0	-
Magnesium	mg/L	ISO 6058	0.71	≤ 50*
Sodium	mg/L	NF T90-014	1.76	≤ 150*
Potassium	mg/L		0.98	≤ 12*
Bacteriological Parameters				
Fecal coliform	CFU/100mL		160	Absent*
Fecal streptococci	CFU/100mL	NM ISO 6222	76	Absent*
Escherichia coli	CFU/100mL		96	absent

Observations

- The water from the Makocgo source had a cloudy appearance.
- The well and Makocgo source waters had somewhat unpleasant tastes.
- The pH value for all the samples do not fall in the range recommended both by the Cameroonian and WHO norms. pH values tested were less than the lower bound set by the norm (Makocgo – 6.03, Well – 5.72, borehole – 5.79) hence sources are acidic and there is a chance that the water may be corrosive.
- The samples exhibit low electrical conductance most likely due to low mineralization.

- The samples were all tested to contain suspended solids. This is most likely due to exposure of the sources to ambient environment which allows dust or other aerosol particles to settle in the waters.
- There is a very low concentration of Calcium in all the three samples with zero concentration in the well and borehole samples. This also confirms the low electrical conductivity tested in the sample waters.
- The samples show low concentrations of Nitrates. Groundwater samples usually show high concentrations of nitrate mostly because of leaching from landfill and surrounding agricultural land and that is not the case in this locality.
- The Ammonium levels are below the maximum permissible limits for all three samples.
- All three samples analyzed presented very elevated microbial concentrations thereby attesting the presence of fecal contamination (fecal coliform, fecal streptococci and *E coli).* The Makocgo source presents the highest concentration of fecal contaminants because it is the most pollution exposed and unprotected source.

Interpretation of Results

The sample analyses showed that the sources are lowly mineralized, with acceptable concentrations of ammonium ions. The low concentrations of calcium and magnesium ions indicate low hardness of the water.

The fact that the public borehole sample presented evidence of bacteriological contamination demonstrates that there are no strategies put in place to monitor and conserve the water quality.

The taste and odour of the two samples is mainly due to the presence of foreign matter such as organic compounds, inorganic salts or dissolved gases in the groundwater. Odour estimation determines whether the water is of acceptable quality and also the presence of pollution. Gases and some organic compounds and minerals may also give unpleasant taste and odour to groundwater.

We can also say that the presence of suspended matter like clay sub organic matter, phytoplankton's and other microscopic organism above Norm value, implies a relatively high turbidity of the water in the sources. Turbidity or cloudiness is an optical property of water, which can be described by the observation that when a beam of light passes through muddy water, the intensity of the light is reduced. As earlier seen, turbidity does not necessarily adversely affect human health but can protect microorganisms from disinfection effects, stimulate bacterial growth and pose problems to treatment processes (WHO, 2004). Prior filtration is required before disinfecting turbid water or water containing suspended matter.

The pH values indicate that the source waters are acidic. . Though pH has no direct impact on consumers, it remains an important quality parameter (USEPA, 1983) which controls water solubility and the rate of metallic reaction. Exposure to extreme pH values results in irritation to the eyes, skin and mucous membranes. Eye irritation and exacerbation of skin disorders have been associated with pH value greater than 11. In addition, solution of pH 10-12.5 has been reported to cause hair fibers to swell (Burtton&Cornill, 1997). Exposure to low pH values can also result in similar effects like redness and irritation of the eyes and damage to the epithelium.

Calcium is one of the alkaline earth metals which is widely distributed on the earth's crust and a major constituent of various types of rock, and present nearly in all water. Calcium is a cause for hardness in water and incrustation in boilers. Calcium is an essential constituent of the human being. Its low content in drinking water may cause rickets and defective teeth. It is essential for nervous system, cardiac function and coagulation of blood (Ambiga&Durai, 2013). Calcium is not known to produce any hazardous effect on human health.

The most alarming concentrations are those of the germs which attest a high degree of fecal contamination in the source waters. The risk of contracting a water borne illness is increased when coliform bacteria are present in water. The bacteria in themselves are not harmful but they indicate a possible presence of harmful, disease causing pathogens which can be viruses, protozoa or bacteria which may cause gastrointestinal upsets and general flu-like symptoms such as fever, abdominal cramps, and diarrhea. Some rare strains of E coli, particularly the strain 0157:H7, can cause serious and life threatening illnesses to humans.

Conclusion

All the three water samples showed microbial concentrations and suspended solids content above the values set by the Cameroonian and WHO norms thereby indicating they are not good for direct consumption but require a pre-treatment so as to preserve the health of the population.

Chapter 4. PROPOSITION OF SOLUTIONS

Introduction

As seen previously, the drinking water samples that were analyzed presented microbiological concentrations of varying degrees of germs all above the respective guide values recommended by the Cameroonian and World Health Organization (WHO) norms, witnessing fecal contamination. They are therefore not suitable for direct human consumption but require a pre-treatment in order to conserve human health. It was as well noticed that some physicochemical parameters such as the pH and suspended solids concentration did not meet the values set by the norms. Furthermore, the water sources as presented were not protected enough to prevent as much contamination as possible.

In this light, therefore, a few measures for protecting the wells and natural sources are presented below as well as some appropriate methods for treatment and conservation of water that can be used in this locality.

Protecting wells and water sources

The installation of distribution systems of drinking water must be designed, constructed and maintained in such a way as to prevent the introduction or accumulation of substances constituting a potential danger, or to be at the origin of a deterioration in the quality of the water. The following are measures aimed at conserving water so as to reduce to a maximum, the risks of contamination.

- ✓ All water sources from which drinking water is obtained should be tested regularly for bacteriological pollution and appropriate measures taken to improve water quality.
- ✓ Wells should be plugged from bottom to top with betonite to prevent surface water from draining into the water supply.
- ✓ The plugged sources should be equipped with a capping to prevent unwanted material like ash, falling leaves from trees or other particles entering the water source.
- ✓ Domestic activities such as laundry and bathing should not be carried out very close to drinking water sources so as to prevent the introduction of contaminants from detergents into the water supply.

- ✓ All water sources from which drinking water is obtained should be located at least 35 meters from latrines.
- ✓ For areas with shallow wells, the over-application of materials such as fertilizers, manure and other chemicals for agriculture which can seep into groundwater should be avoided.
- ✓ Sources should be equipped with a common bucket for drawing water to avoid the use of individual multiple buckets of doubtful sanitary states.

Treatment of water

A few treatment methods are suggested here based on the characteristics of the sample waters.

a.) Disinfection with bleaching agent

Given the lack of means to access more advanced disinfection agents like chlorine and the current perceptions and practices of the locality, water at the sources in Minkama 4 can be disinfected using household bleaching agent commonly called “Eau de Javel”. It is recommended by the EPA to only use regular, unscented chlorine bleach products that are suitable for disinfection and sanitization as indicated on the label. Scented, color safe and bleaches with added cleaners are not advised for drinking water disinfection. For regular bleaches, the label may say that the active ingredient contains 4% to 8.25% Sodium Hypochlorite. The ratio of amount of bleach to volume of water to be treated is presented below (table 7).

Table 7: Amount of bleach to volume of water to be treated

Volume of water	Amount of 6% bleach to add	Amount of 8.25% bleach to add
1 litre	2 drops	2 drops
1 gallon	8 drops	6 drops
2 gallons	16 drops (1/4 teaspoon)	12 drops
4 gallons	1/3 teaspoon	¼ teaspoon
8 gallons	2/3 teaspoon	½ teaspoon

If the litres, drops, gallons, teaspoons and percentages are easy to lose track of, a simple memory phrase may be used when it comes to disinfecting water with bleach. The phrase is; **you must be 21 to drink!** A simple reminder that it requires 2 drops of bleach per 1 litre of water hence 10 drops per 5 litres and so on. A wait time of about 30 minutes is usually required before consuming the water. However, if the water is cloudy, both the bleach doze and waiting time should be doubled.

Advantages of using bleach

- Very effective against bacteria. Six times as effective as iodine against *E coli.*
- Relatively cheap and can economically disinfect small to large amounts of water.
- An added advantage in the case of Minkama 4 is that l'eau de Javel is basic (pH 11.5 – 12.5) and thus may help reducing the acidity of the sampled waters.

Disadvantages of using bleach

- Relatively low protection against protozoa.
- May be difficult to use due to its specifications.
- Lower disinfection effectiveness in turbid waters.
- Potential taste and odor objections.

b.) Disinfection by Boiling

As a method of disinfecting water, bringing it to its boiling point at 100 ^{0}C is the oldest and most effective way. The elimination of micro-organisms by boiling follows first-order kinetics – at high temperatures, it is achieved in less time and in lower temperatures, in more time. The heat sensitivity varies, at 70 ^{0}C, Guardia species can take ten minutes for complete inactivation while most intestine affecting microbes and *E coli* take less than a minute. *Vibrio cholerae* (cholera) takes ten seconds and hepatitis virus, one minute. Boiling, however, does not ensure complete sterilization of water; the bacterial spores Clostridium can survive at 100 ^{0}C but are not intestine affecting.

The traditional advice of boiling water for ten minutes is mainly for additional safety, since microbes start getting eliminated at temperatures greater than 60 ^{0}C and bringing it to its boiling point is also a useful indication that can be seen without the use of a thermometer, and by this time, the water is disinfected.

Advantages of boiling

- Does not affect the taste of water.
- Is effective despite contaminants or particles present in water.
- It is a simple one step process.
- Eliminates most microbes responsible for causing intestine related diseases.

Disadvantages of boiling

- It cannot remove chemical toxins or impurities.
- The dead micro-organisms and impurities settle at the bottom of the water requiring a pre or post filtration to eliminate them. It is therefore not self-sufficient.
- Requires fuel for heating such as firewood, which could, added to its cost, have negative environmental impacts including deforestation and high carbon footprint.
- It is not advisable if water is contaminated with toxic metals and chemicals (lead, mercury, pesticides, etc.) because it may concentrate these contaminants while pure water vaporizes off.

c.) Solar Water Disinfection - SODIS

Also known as SODIS, it is a method of disinfecting water using only sunlight and plastic PET bottles. Exposure to sunlight has been shown to deactivate diarrhea causing organisms in polluted drinking water. Three effects of solar radiation are believed to contribute to the inactivation of pathogenic organisms:

- UV-A interferes directly with the metabolism and destroys cell structures of bacteria.

- UV-A (wavelength 320-400nm) reacts with oxygen dissolved in water and produces highly reactive forms of oxygen (free radicals and hydrogen peroxides) that are believed to also damage pathogens.
- Cumulative solar energy heats the water. If the water temperature rises above 50 ^{0}C, the disinfection process is three times faster.

The process involves filling clean plastic PET bottles with contaminated and capping. Then exposing the bottles to direct sunlight for at least six hours or for two days under very cloudy conditions. To improve oxygen saturation, bottles can be filled three quarters, shaken for 20 seconds (with the cap on), then filled completely and recapped. Very cloudy water with a turbidity higher than 30 NTU must be filtered prior to exposure to the sunlight. Filled bottles are then exposed to the sun. Bottles will heat faster and to higher temperatures if they are placed on a sloped sun-facing corrugated metal roof as compared to thatched roofs. Suggested treatment schedules are as shown (table 8)

Table 8: Suggested treatment schedules

Weather Conditions	**Minimum Treatment Duration**
sunny (less than 50% cloud cover)	6 hours
cloudy (50-100% cloudy, little to no rain)	2 days
continuous rainfall	unsatisfactory performance, use rainwater harvesting

The treated water can be consumed directly from the bottle or poured into clean drinking cups. The risk of re-contamination is minimized if the water is stored in the bottles.

Advantages

- Can be effectively applied at household level.
- More economical and an environmentally friendly option.

Disadvantages

- It is ineffective for highly turbid water.
- Requires too much time and depends on sunlight which is very variable.
- Applying SODIS without proper assessment (or with false assessment) of existing hygienic practices & diarrhea incidence may not address other routes of infection.

d.) Filtration

Filtration is one effective way of eliminating suspended solids, a considerable number of microbes and insect larvae thereby purifying water. The filtration method utilizes chemical absorption process that effectively removes unwanted compounds from water through a medium within which most of the particles in the water are captured. It can be done at the local low income level using a piece of fine, clean cotton cloth over a collecting vessel (figure 30). This is referred to as straining. The thicker the fabric, the longer the time it would take to filter the water. The filtering cloths must be regularly cleaned to allow a regular flow of water and prevent over accumulation of dirt that may pose a risk of contamination. Straining alone is not a sufficient method of treatment. Nevertheless, straining water before treating by another means will significantly improve the quality of the water obtained.

Where the means are available, a more advanced filter may be used. These include filters that are designed such that they combine filtration and disinfection such as the mineral pot filters (MPFs). They are divided into two parts; the upper part (bucket) includes a porous ceramic filter with pores of diameter 1 micron for the elimination of suspended particles and the bottom bucket which has a tube containing activated carbon which is effective for the elimination of microbes (figure 31).

Figure 31: Straining water through a cloth (Red Cross, nd)

Figure 30: mineral pot water filter

Advantages

- Provides better smelling and better tasting water.
- Simple to use.
- Does not affect the mineral composition of the water.

Disadvantages

- It does not disinfect water but renders it void of solid impurities.
- It is costly to obtain the filters.

e.) Increasing the pH

Low pH of water is usually due to an excess concentration of Hydrozonium ($pH = -log_{10}\,[H_3O^+]$) ions and an increase in pH can be achieved using Sodium Bicarbonate which dissolves in water making it slightly more basic. The partial reactions when the compound is introduced in water are given below;

$$NaHCO_3 \rightarrow HCO_3^- + Na^+ \ldots\ldots \ (1)$$

The HCO_3^- release in solution neutralize the H_3O+ in the following equation;

$$\boldsymbol{HCO_3^- + H_3O^+ \rightarrow H_2O + CO_2} \ldots. \textbf{(2)}$$

From the equation, 1 mole of HCO_3^- is required to neutralize 1 mole H_3O+. We take the well source pH for example. We wish to raise the pH from 5.72 to 7.4.

At pH 5.72, $[\boldsymbol{H_3O^+}] = 10^{-5.72}$

= 0.000001905460718 mol/dm^3

At our desired pH of 7.4, $[\boldsymbol{H_3O^+}] = 10^{-7.4}$

= 0.000000039810717 mol/dm^3

This implies, amount of H3O+ to neutralize = 0.00000186565 mol/dm^3

Hence, 0.00000186565 mol/dm^3 of HCO_3^- required.

Recall the formula, concentration, C = number of moles, n/ volume, V where n = mass/ RMM

Here we assume a volume of 20 litres of water (20 dm^3)

RMM of HCO_3^- = 61 g/mol

Mass of HCO_3^- = C * RMM * V

= 0.00000186565 mol/dm^3 * 61 g/mol * 20 dm^3

= 0.0023g of HCO_3^-

61gHCO_3 are contained in 84g of $NaHCO_3^-$, therefore 0.0023g HCO_3 will be contained in 0.0032g of $NaHCO_3$.

3.2 mg of Sodium bicarbonate are therefore required to raise the pH of 20 litres of the well water to a value of 7.4.

The same procedure can be applied to raise the pH of any other volume of water to a desired value.

Propositions for the conservation and use of drinking water

Drinking water can also become contaminated during storage; how the water is drawn from storage container, where the drawing materials are kept and the duration of water storage in general have an effect on the bacteriological quality of stored water. The problem of conservation of water for domestic use is still a concern for many countries, especially in rural areas such as Minkama 4 where home running services are not installed yet. Water is usually stored at home since it is too restrictive to make frequent nonstop round trips to the nearest water point.

For more effective storage, clean containers with a narrow opening are by far more advisable, especially if they are fitted with a closure system (stopper, lid). Bottles are highly recommended in this case. However, large-opening containers such as buckets and pots can also be used, provided that they are covered by a clean lid so as to prevent the introduction of foreign material such as dust or dirt into the water.

Storage containers should be washed and kept clean in well tidied parts of the home at all times. Containers should be kept at elevated heights to avoid ground particles from entering during house cleanups. Basic principles of hygiene should also be respected when obtaining water from the storage containers, especially with the large-opening containers. Hand washing and the sanitation of the vessels used to obtain water from storage cans cannot be overemphasized.

Study limitations

This study had several limitations;

First, some data were collected using a survey. Although the survey was designed to minimize the number of flaws and biases, some still expectantly exist. For example, respondents may not have answered some questions truthfully because the answer would imply practices such as not treating water that the respondent already understands as a health risk. Some respondents may have reported treating water when they do not actually treat their water before consumption. Also, the microbial water quality tests could have been improved. The specific parameters were chosen due to performance and low cost. However, performing the test multiple times for each sample would have been advantageous for more accurate concentrations and detections.

Due to the problem of cost, certain parameters such as Zinc (Excess concentration of Zinc in drinking water may cause dehydration, electrolyte imbalance, abdominal pain, nausea and vomiting), Cadmium (Cadmium is poisonous at extremely low concentration and is known to accumulate in human kidney and liver. It causes hypertension, emphysema and renal damage), Lead (Even smaller concentration of lead in human beings is toxic), and Fluoride (Higher concentration of fluoride in groundwater causes fluorosis[1] which becomes a considerable health problem in several regions of the world (CPCB, 1995-2004))

The most accurate measurements of water quality are made on-site, because water exists in equilibrium with its surroundings. Measurements usually made on-site and in direct contact with the water source in question include temperature, pH, dissolved oxygen, conductivity, and turbidity and Secchi disk depth. However, in this work, because of restrictions from taking apparati out of the laboratory, only the temperatures were taken on-site.

[1]Fluorosis is a common dental disorder, characterized by hypo-mineralization of tooth enamel caused by ingestion of excessive fluoride during enamel formation. It appears as a range of visual changes in enamel causing degrees of intrinsic tooth discoloration, and, in some cases, physical damage to the teeth.

GENERAL CONCLUSION AND PERSPECTIVES

General conclusion

The national water supplier, CAMWATER, is yet to ensure the distribution of drinking water throughout the national territory. This implies certain localities, especially the rural populations such as those of Minkama 4 are obliged to rely on other sources for drinking water; most often, these are of doubtful quality.

From this work which was aimed at evaluating the quality of drinking water along the water chain in households in the Minkama 4 locality, it was observed that drinking water collected from the most frequented water sources in the locality was unhealthy and not fit for direct consumption by the population. This was evidenced by the presence of high levels of fecal coliform, fecal streptococci and *E. coli,* which are witnesses of bacteriological pollution. Regardless of this, only 20% of the interviewed population reported some form of household treatment of water with household bleaching agent before consumption though 96% were aware of risks of diarrhea. Surprisingly, none reported treatment by boiling and some even declared they perceived the water, from the public borehole in particular, to be already clean.

Perspectives

- The populations should be sensitized on affordable water treatment methods and hygienic ways of conserving water.
- All water sources should be well constructed and protection perimeters as stipulated in the Prime Ministerial Decree respected.
- Physicochemical and bacteriological tests of source waters should be carried out regularly and the necessary precautionary measures taken where need be so as to preserve the health of the population.

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ANNEXES

Annex1: Norme Camerounaise NC 207 : 2003 – 02.

Paramètres	Unité	Valeur
Coloration (après filtration simple)	mg/l échelle Pt/Co	≤ 15
Odeur, saveur		Absence
Turbidité	Unité Jackson	≤ 2
Paramètres	Unité	Valeur
pH	u pH	5.5 - 9
Température	°C	≤ 25
Conductivité	µS/cm	1000
Sulfates	mg/l SO4	≤ 250
Chlorures	mg/l Cl	≤ 200
Magnésium	mg/l Mg	≤ 50
Sodium	mg/l Na	≤ 150
Potassium	mg/l K	≤ 12
Aluminium total	mg/l Al	≤ 0.2
Résidus secs à 180 °C	mg/l	≤ 1500
Paramètres	Unité	Valeur
Nitrates	mg/l NO3	≤ 50
Nitrites	mg/l NO2	≤ 0.1
Fluorures	mg/l F	≤ 0.7 / 1
Argent	mg/l Ag	≤ 0.01
Fer	mg/l Fe	≤ 0.2
Manganèse	mg/l Mn	≤ 0.05
Cuivre	mg/l Cu	≤ 1
Zinc	mg/l Zn	≤ 5
Agents de surface	mg/l (lauryl-sulfate)	≤ 0.2
Phénols	mg/l	≤ 0.0005
Hydrocarbures dissous	mg/l	≤ 0.01
Oxydabilité au KMnO4	mg/l O2	≤ 5
Azote Kjeldahl	mg/l N	≤ 1
Phosphore	mg/l P2O5	≤ 5
Hydrogène sulfuré		Absence
Ammonium	mg/l NH4	≤ 0.5
Paramètres	Unité	Valeur
Demande Chimique en Oxygène (DCO)	mgl/l O2	≤ 30
Demande Biochimique en Oxygène (DBO)	mg/l O2	≤ 2
Substances Extractibles au Chloroforme (SEC)	mg/l	Absence
Coliformes totaux	u /100 ml	Absence
Coliformes fécaux	u /100 ml	Absence
Streptocoques fécaux	u /100 ml	Absence

Annex 2: Results of the laboratory tests delivered and signed by the Wastewater Research Unit

WASTEWATER RESEARCH UNIT

Etudes, Conseils, Analyses, Formations, Suivi et Evaluation des projets
BP: 8250 Yaoundé, Cameroun.
Tel: (237) 679 21 50 96 / 677 55 34 01/ 696 43 94 24
Email: wrucabinet@gmail.com

Yaoundé le 08/02/2020

Demandeur: M. ACHO ABONGWA
Titre: Analyse physico-chimique et bactériologique de trois (03) échantillons d'eaux souterraines.

Echantillonnage	Effectué par le demandeur
Conservation	Bouteilles en polyéthylène de 500 mL
Transport	Par route avec conservation
Identification de l'échantillon	Eaux souterraines
Réception au Laboratoire	01/02/2020

Paramètres \ Echantillons	Unités	Puits	Source	Forage	Normes OMS*/UE**
Température	°C	27,4	27,5	27,7	/
Potentiel d'Hydrogène (pH)	/	5,72	6,03	5,79	6,5-8,5
Conductivité (Cnd)	µS/Cm	106,1	75,7	91,2	400
Matières En Suspension (MES)	mg/l	6	2	5	0
Nitrates (NO_3^-)	mg/l	9,4	1,1	0,5	40
Ammonium (NH_4^+)	mg/l	0,10	0,23	0,06	0,5
Calcium (Ca^{2+})	mg/l	0	0,08	0	/
Magnesium (Mg^{2+})	mg/l	0,55	0,43	0,71	/
Sodium (Na^+)	mg/l	0,75	0,82	1,76	/
Potassium (K^+)	mg/l	1,37	1,03	0,98	/
Coliformes Fécaux (CF)	UFC/100 ml	210	315	160	0
Streptocoques Fécaux (SF)	UFC/100ml	116	152	76	0
Escherichia Coli	UFC/100ml	96	160	96	0

OMS : Organisation Mondiale de la Santee ; UE : Union Européenne

Conclusion : Les eaux de boisson analysées ont présenté sur le plan microbiologique des concentrations plus ou moins élevées en germes témoins de la contamination fécale (CF, SF et *E. coli*), tous au-dessus de leurs valeurs guides respectives recommandées par l'Organisation Mondiale de la Santé (OMS) et l'Union Européenne (UE). Elles sont de ce fait impropres à la consommation humaine directe.

P.o.

Le Directeur Technique

Dr Djamyon Wafo Guy V.
Water & Sanitation Specialist
Lab Assistant

WASTEWATER RESEARCH UNIT ★ WWRU BP. 8250 Yaoundé - Cameroun

Siège Social Yaoundé - Simbock sis (Jean Jaures) C/C: PO58512416981H RC/YAO/2015/A/5653
Compte Afriland First Bank Nro : 10005 00024 04757361001-12

Annex 3: Questionnaire addressed to the sample population

Evaluation of Drinking Water Quality in this locality. This questionnaire is intended to help me better my understanding of your common practices and perceptions to drinking water quality and health.

QUESTIONAIRE

1. Are you connected to the CamWater network?

- Yes
- No

2. If yes how often do you have water?

- Everyday
- After two days
- Weekly
- Monthly

3. If no, what is your primary drinking water source?

- bottled water
- rainwater
- groundwater (well, borehole)
- other (please specify) ____________________
- surface water
- spring

4. How long does it take you to fetch water from your water sources? (To and fro)

- 0 - 10 minutes
- 11 - 20 minutes
- 21 - 30 minutes
- More than 30 minutes

5. Do you treat your water before drinking?

- yes
- No

- chlorine
- distillation
- boiling
- filtering
- settling
- solar disinfection
- coagulation
- flocculation
- other (please specify) ____________________

7. If no, why don't you treat your water before drinking?

- too expensive
- time consuming
- ineffective
- water is already clean
- other (please specify) ____________________

8. How do you store your water?

____

____

____

9. For your long do you store your drinking water?

____________ Days.

10. Have you heard of diarrhea?

- Yes
- No

11. If yes, has any member of your family ever suffered from it?

- Yes
- no

12. What, in your opinion, are the possible causes of diarrhea?

- eating contaminated food
- drinking contaminated water
- lack of hand washing
- microbial pathogens
- others (please specify)

____

____

Annex 4: Path leading to the Makocgo source