INVESTIGATION OF THE PHYSICOCHEMICAL, MICROBIAL AND TRACE METALS PROPERTIES OF SELECTED PACKAGED DRINKING WATER SOLD IN KANSANGA, KAMPALA, UGANDA.

BY

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A DISSERTATION SUBMITTED TO THE DEPARTMENT OF PHYSICAL SCIENCES, SCHOOL OF ENGINEERING AND APPLIED SCIENCES, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE IN CHEMISTRY OF KAMPALA INTERNATIONAL UNIVERSITY

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DECLARATION

I, Suleiman Muntaka Mohammed hereby declare that this dissertation entitled **Investigation of the Physicochemical and Microbial Quality of Packaged Drinking Water Sold in Kansanga, Kampala, Uganda,** has been carried out by me in the Department of Physical Sciences, under the supervision of Dr. Emeka Thompson Nwankwere and Mr. Awuchi Godswill Chinaza. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at any university.

Signed………………………………...   Date………………………………

APPROVAL

We affirm that the work presented in this dissertation entitled "**Investigation of the Physicochemical and Microbial Quality of Packaged Drinking Water Sold in Kansanga, Kampala, Uganda"** was carried out by the candidate under our supervision.

Dr. Emeka Thompson Nwankwere.

Signature …………………………………...   Date………………………………

Mr. Awuchi Godswill Chinaza.

Signature…………………………………….   Date………………………………

DEDICATION

This research work is dedicated to my beloved Parents (May their gentle souls rest in perfect peace), and to the entire Suleiman family.

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LIST OF ACRONYMS/ ABBREVIATION

FAAS	Flame Atomic Absorption Spectrometer
AOAC	Association of Analytical Chemists
APHA	America Public Health Association
ANOVA	Analysis of Variance
AWWA	American Waste Water Association
BW	Bottle water
CFU	Coliform forming unit
TCU	True Color Unit
DW	Drinking Water
EC	Electrical Conductivity
Mg/L	Milligram per Litre
NTU	Nephelometric Turbidity Unit
PDW	Packaged drinking water
SAMA	Scientific Apparatus Makers Association
µS/cm	Micro Siemens per Centimetre
TH	Total Hardness
UNBS	Uganda Bureau of Standard
UNICEF	United Nations International Children's Emergency funds
US	Uganda Standard
WHO	World Health Organization

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ABSTRACT

This study aimed at investigating the physicochemical and microbial properties of Packaged Drinking Water, sold in Kansanga, Kampala. Seventy-two samples were selected by systematic random sampling from local stores in the study area. Three types of Packaged Drinking Water samples (bottled, sachet and handtied) were selected. Spring water samples were used as control samples. Titrimetric techniques were used to determine the Chlorides, Alkalinity and the Total Hardness, while Nitrogen and Phosphorus were determined by Colorimetric methods. The Spread plate technique was used to determine the microbiological purity. Flame atomic absorption spectrophotometry was employed in the determination of Trace Metals. The results showed that the mean values pH, electrical conductivity, colour, turbidity, alkalinity, nitrates, phosphates, chloride and total hardness in all the samples were within the recommended limits of the Ugandan National Bureau of Standards, UNBS (2011). The results of the microbial analysis for total plate count showed that there were microbiological contaminations in the water samples. Except for one bottled water sample (sample BJ), there were no contaminations from total coliform or *E. coli* found in all bottle water samples. Sachet Water samples having the highest mean concentration of 0.013 ± 0.009 mg/L. ANOVA (F:4, $\alpha = 0.05$) indicated that there were no significant differences in the microbial properties ($p < 0.05$) for all the PDW samples. Differences, were indicated in the level of metal contaminations. Multiple comparison with Least Significant Differences, LSD, showed that the differences were from both hand-tied and untreated spring water samples. While water samples seemed to be of safe physicochemical properties, contamination by microbes, above the CFU/ml limit recommended by UNBS for drinking water, were visible in all the types of PDW samples. Bottle water is the safest PDW type sold in Kansanga. Two hand-tied samples HC (9.00 ±26.46) and HE (553±4.16) were contaminated with total coliform and sample HI (1.60 ±2.89) was contaminated with *E. coli*. Except for Hand-tied and Sachet water samples, that were found to be contaminated with Pb, the PDW were found to have safe levels of Mn, Cu, Pb, Fe and Zn. However, it is recommended that one should know the hygiene status of person that prepare the Handtied before buying and even consuming. It is also recommended that care should be taken from manufacture to consumption to avoid water related diseases.

CHAPTER ONE

1.0 Introduction

1.1 Background

Freshwater is one of the most important resources crucial for the survival of all the living beings. It is even more critical for human beings as they depend upon it for food production, industrial and waste disposal, as well as a cultural requirement (Akpoveta *et al.*, 2011). People on globe are under tremendous threat due to undesired changes in the physical, chemical and biological characteristics of air, water and soil. Due to increased human population, industrialization, use of fertilizers and man-made activity water is highly polluted with different harmful contaminants. Natural water contaminates due to weathering of rocks and leaching of soils, mining processing etc. It is necessary that the quality of drinking water should be checked at regular time interval, because due to use of contaminated drinking water, human population suffers from varied of water borne diseases. The availability of good quality water is an indispensable feature for preventing diseases and improving quality of life. (Patil *et al.*, 2012). Access to safe drinking water is key to sustainable development and essential to food production, quality health and poverty reduction (Adekunle *et al.*, 2004; Chaurasia *et al.*, 2011;Kalwale and Savale, 2012). Safe drinking water is essential to life and a satisfactory safe supply must be made available to consumers (Yadav and Rajesh, 2011). Unsafe drinking water is a health threat, placing persons at risk of diarrhea and a host of other diseases as well as chemical intoxication (Hughes and Koplan, 2005). In sub-Saharan Africa, 319 million people live without access to an improved water source and 102 million people still use surface water (WHO/UNICEF, 2015).

High population growth nearly triples the global average and stresses the sanitation services that exist. An estimate of 61% of Ugandans, for example, lack access to safe water and 75%

do not have access to improved sanitation facilities (Jimenez-Redal *et al.*, 2018). However, due to population growth, industrialization, use of chemical fertilizers in the agriculture and man-made activity water became polluted with different harmful contaminants. More than 340,000 children under the age of 5, or almost 1000 per day, die each year from diarrheal diseases due to poor sanitation, poor hygiene, or unsafe water (WHO/UNICEF, 2015).The production of adequate and safe drinking water is a high priority issue for safeguarding the health and well-being of humans all over the world (Van Leeuwen, 2000). It is necessary that the quality of drinking water be checked at regular interval since using contaminated drinking water brings about various waterborne diseases (Patil *et al*., 2012).

Packaged Drinking Water (PDW), is any potable water that is processed for sale which is sealed in food-grade packaged intended for human consumption (Warburton, 2000; Venkatesan, 2014). Sale of PDW has exploded all over the world in recent years, largely as a result of public opinion that it is safe, tastes better, and has a better quality compared to raw tap-water. PDW has ever been implicated as a source of outbreaks of cholera and typhoid fever as well as traveler's disease in countries such as Portugal and Spain (Son *et al.,* 2015; fisher, 2015; Varga, 2011 and, Poudel and Hong, (2013). The global increase in the drinking of the commodity, could be associated with: increase in per capita as well as population growth (Dhaini and Nassif, 2014, and Umeh, *et al.,* 2005). Even in countries where tap-water properties are termed excellent, the demand is so high, making PDW the rapid growing product of the nonalcoholic beverage market worldwide (Doria, 2006 and Prüss Ustün, *et al.,* 2014).

1.2 Problem Statement

Unsafe water is a global public health threat, placing persons at risk for a host of diarrheal diseases as well as chemical intoxication, which results to cancer (Hughes and Koplan, 2005). There has also been a growing concern about the microbial quality of PDW products in developing countries. Although disease outbreaks due to contaminated packaged water are not common, any possible contamination may lead to widespread epidemic because of the high demand and coverage (Addo et al., 2009). In Kampala, consumption of PDW is at high rate and the market is inundated with a large number of brands of PDW. Demand for PDW has attracted many people to venture into the business as the industry becomes more profitable (Bwire, 2013).The increase in the demand of PDW is largely due to increasing population, increase in Per capita income, changed in passion toward consumption of designer water, perception of the consumer of its purity and portability for the travelers.

In Uganda, there are more than 70 producers of bottled drinking water on the local market, yet only 30 firms have been certified by Ugandan National Bureau for Standards, UNBS (Mugalu, 2014). There have been several reports on the sales of fake PDW in Kampala (Bwire, 2013; Business Focus, 2017). In July, 2018 Ministry of Health Uganda confirmed a total of seven cholera cases which were undergoing treatment at the China-Uganda friendship hospital, (CUFH) Naguru. In August, September, 2018 and 25th of January, 2019 water borne diseases were also reported in Kampala (WHO, 2019). The reports carefully elaborated factors responsible for the outbreak of these diseases, which includes contaminated drinking water. According to Halage *et al*., (2015) continuous surveillance of PDW quality at retail premises is not being carried out.

The UNBS in 2018 complained that resources do not permit for comprehensive operations in a given district since officers have to cover the district according to available funds; there is also need to beef up security officers while in transit in order to enhance safe operation (UNBS, 2018; Omara *et al*, 2019). This may lead to the sales and consumption of poor-quality packaged drinking water in Kansanga. This study, therefore, investigated the physicochemical and microbial quality of selected PDW sold in Kansanga, Kampala, Uganda.

1.3 General Objective of the Study

The aim of this research is to investigate the properties and characteristics of PDW sold for public consumption in Kansanga.

1.3.1 Specific Objectives

1. **T**o determine the physicochemical properties of PDW samples.
2. To determine the levels of fecal contamination in the PDW samples.
3. To determine the levels of selected trace metals in the PDW samples.
4. To compare the levels of contaminations in the water samples

1.4 Research Hypothesis:

1. H_{o1} = There is no significant differences in the level of physicochemical quality in the PDW samples.
2. H_{o2}= There is no significant difference in the levels of microbial properties in the PDW samples.
3. H_{o3}= There is no significant difference in the level of potentially toxic metals in the PDW samples.
4. H_{o4}= There is no significant correlation in the physicochemical, microbial, and trace metals in the PDW samples.

1.5 Research Questions

1. What is the average level of physicochemical pollution in PDW samples?
2. What is the average level of Microbial contamination in PDW samples?

3. What are the average levels of metals pollution in PDW samples?
4. What properties/characteristics of the PDW is most responsible for the extent of pollution found in the PDW samples?

1.7 Scope of the Study

1.7.1 Geographical scope

The study was conducted at Kansanga suburbs which is a representative of Makindye district in Kampala. All samples were sourced from local shops, as this division envelopes variety of people from diverse nationalities. The particularity of Kansanga lies within the convergence of different nationalities whose character, nature and socioeconomic status leave many of them with the alternative to buy and consume bottled, sachet, handtied or the very available spring water. This gives credence for the choice of Kansanga as the area of study.

1.7.2 Content scope

The study investigated selected Physicochemical, Microbial and trace metals (Pb, Zn, Cu, Fe, and Mn) properties of the PDW samples. Five trace metals were selected because they are among the water quality indicators. A total of 72 samples were collected and analyzed. Spring water was used as a natural control because many companies package ground water as PDW.

1.7.3 Time scope

The study was conducted within the month of May, 2018 – April, 2019.

1.6 Significance of the Study

The information obtained from the research will be beneficial to the general public by enlightening them on the dangers they could be exposed to after drinking packaged drinking water. It is a contribution to existing knowledge on drinking water quality and a foundation for more and improved research. And to the regulatory bodies, as this may buttress the need to tighten the standards.

CHAPTER TWO

2.0 Literature Review

2.1 Background

Approximately 2.6% of the global water supply is freshwater and available as drinking water. According to historical perspectives, groundwater supplies were believed to be free of microbial pathogens due to the natural filtering ability of the subsurface environment (Nazarovs *et al*., 2012). Another scholar, Basavaraja *et al*. (2011), further expounded that all living organisms on the earth need water for their survival and growth. The availability of good quality water is an indispensable feature for preventing diseases and improving quality of life.

2.2 Water Pollution

Water is a transparent, tasteless, odorless, and nearly colorless chemical substance. Water in two states: liquid (including the clouds, which are examples of aerosols), and solid (ice). Water is the main constituent of Earth's streams, lakes, and oceans, and the fluids of most living organisms. Its chemical formula is H_2O, meaning that each of its molecules contains one oxygen and two hydrogen atoms that are connected by covalent bonds (Onda *et al.*, 2014). Water is the most essential resource for human consumption. It forms 50 to 60% of body weight and play an active role in all the vital processes of our body (Kawther and Alwakeel, 2007) .Medema *et al*., (2003) reported that a lot of impurities adulterate the natural water with fecal material, domestic, industrial sewage slots, agricultural and postural run off from point sources and nonpoint sources increased risk of disease transmission to humans. Research conducted by Nollet, (2000), indicated that Pollution of surface and ground water is great problem due to rapid urbanization and industrialization. Looking at our market, can be seen that it is inundated with a large number of brands of bottled water. Water quality and suitability for use are determined by its taste, odor, colour, and concentration of organic and inorganic matters (Nollet, 2000).

2.3 Drinking Water Pollution

A clean and constant supply of Drinking Water is therefore essential to every community. People in large cities frequently drink water that comes in packages (in bottles, poly ethylene bags or large dispensers). Sometimes these sources could be polluted especially in developing countries where proper environmental sanitation is a challenge (Gyau-Boakye, and Dapaah 2000). It is necessary that the quality of drinking water should be checked at regular time interval, because human population suffers from variety of water borne diseases. It is difficult to understand the biological phenomenon fully because the chemistry of water reveals much about the metabolism of the ecosystem and explain the general hydro-biological relationship (Basavaraja *et al*., 2011). The increased use of metal-based fertilizer in agricultural revolution of the government could result in continued rise in concentration of metal pollutions in fresh water reservoir due to the water run-off. Also, fecal pollution of drinking water causes water borne disease which has led to the death of millions of people (Adefemi and Awokunmi, 2010).

Ikem et al., (2002), also reported that, the chemical quality of drinking water during recent years has deteriorated considerably due to the presence of toxic metals, which even in trace amounts can cause serious health hazards. Good quality of drinking water is very necessary for improving the life of people and to prevent diseases (Khan *et al*., 2013). The demand for good quality water for drinking and other purposes is no doubt exceeding supply especially in some regions of developing countries where drought has claimed thousands of lives and lifted economic and social damage (Frederiksen, 1996). The provision of an adequate supply of a safe drinking water was one of the eight components of primary health care identified by the international conference on primary health care in 1978 (Dufour *et al.*, 2002).

Contaminants in drinking water can affect the water quality and consequently the human health. The potential sources of water contamination are geological conditions, sewage slots, industrial, agricultural activities, and water treatment plants. These contaminants are further categorized as microorganisms, in organics, organics, radionuclides, and disinfectants (Azrina *et al*., 2011). The inorganic chemicals hold a greater portion as contaminants in drinking water in comparison to organic chemicals (Azrina, 2011).

2.4 Drinking Water Quality Indicators

A number of scientific procedures and tools have been developed to assess drinking water quality. These procedures include the analysis of the physicochemical parameters which form part of the drinking water quality indicators. These parameters include: pH, chloride, phosphorus, and colour, turbidity, alkalinity, electrical, conductivity, nitrate, manganese total hardness and heavy metals. These parameters can affect the drinking water quality, if their values are in higher concentrations than the safe limits set by the World Health Organization (WHO) and other regulatory bodies (WHO, 2011). Therefore, the investigation of the drinking water quality by researchers and governmental departments has been performed regularly throughout the world (Meng *et al*., 2010 and Pillay, 2001).Various countries have enforced drinking water standards for the maximum permissible levels of different contaminants (Krachler and Shotyk, 2009). In Uganda, the quality and safety of packaged drinking water and mineral water are monitored by UNBS. However, geographical locations may affect the quality of portable water, which its mineral contents are very dependent on the mineral compositions of the soil and pollutants such as heavy metal. In order to minimize mineral toxicity and maintain the whole someness of water consumption, the bottled water, sachet water and the handtied drinking water that are intended for human consumption should comply with the mandated standard limits (Azlan *et al.*, 2012). A list of the most important water quality indicators and their recommended limits have been presented in Table 2.1. Table 2.1 gives the WHO (2005) and the Ugandan National Bureau of Standards, UNBS (2011) guidelines to the limits of the given parameters in drinking water.

Table 2.1. Water quality indicators

Chemical property (mg/l	**WHO, 2016**	**UNBS,2011**
pH	6.5-9.5	5.5 - 8.5
Electrical conductivity (µS/cm)	---	1500
Colour (TCU)	….	15
Turbidity (NTU)	….	5
Alkalinity (mg/L)	---	_
Chloride (mg/L)	200	250
Phosphorus (mg/L)	…..	_
Nitrogen (mg/L)	45	50
Total hardness (mg/L)	200	_
Total plate count (CFU/ml)	100	100
Total coliform (CFU/ml)	00	00
Escherichia coli (CFU/ml)	00	00
Pb (mg/L)	10	0.01
Cu (mg/L)	2000	2.00
Fe (mg/L)	1.0	0.20
Zn (mg/L)	15	_
Mn (mg/L)	500	1.00

Source: International journal of applied research, (2016); UNBS – Ugandan National Bureau of Standards (2011).

2.5 The Burden of Diseases from Drinking Water

Countries throughout the world are concerned with the effects of unclean drinking water because water-borne diseases are a major cause of morbidity and mortality (Clasen *et al.*, 2007; WHO, 2016). Clean water is important for overall health and plays a substantial role in infant and child health and survival (Anderson *et al.*, 2002; Feutrell *et al.*, 2005; Ross *et al.*, 1988, and Vidyasagar, 2007). Griffith *et al.*, (2006), estimated that globally about 1.8 million people die from diarrheal diseases annually, many have been linked to diseases acquired from the consumption of contaminated waters and seafood. Persons with compromised immune systems, such as those with AIDS, are especially vulnerable to water- borne infections, including those infections that are self-limiting and typically not threatening to healthy individuals (Sylva, 2018).

Throughout the less developed part of the world, the proportion of households that use unclean drinking water source has declined, but it is extremely unlikely that all households will have a clean DW source in the foreseeable future (Mintz, 2001). WHO/UNICEF, (2014) reports that 884 million people in the world use unimproved drinking water source, and estimates that in 2015, 672 million people will still use an unimproved drinking water source. In another report, Jiménez, (2014) put the worldwide estimate for people without access to safe water at nearly 900 million. According to WHO/UNICEF, (2000), about 2.6 billion, almost half the population of the developing world, do not have access to adequate sanitation. Over 80 per cent of people with unimproved drinking water and 70 per cent of people without improved sanitation live in rural areas (Li *et al.*, 2009).

In Uganda, a vast majority of people living along the course of water bodies still source and drink from rivers, streams, open well and open spring water bodies irrespective of the state of these water bodies without any form of treatment. These natural waters contain a myriad of microbial species, many of which have not been cultured, much less identified. The number of organisms present varies considerably between different water types, and it is generally accepted that sewage-polluted surface waters contain greater number of bacteria than unpolluted waters (Curtis and Cairncross, 2003). Polluted surface waters can contain a large variety of pathogenic microorganisms including viruses, bacteria and protozoa (Servais *et al.,* 2007). These pathogens, often of fecal source, might be from point sources such as municipal wastewater treatment plants (Chigor *et al*., 2010; Lata *et al*., 2009; Amine *et al*., no date; Odjadjare *et al*., 2010, and Okoh *et al*., 2007) and drainage from areas where livestock are handled (Förstner and Wittmann, 2012), or from non-point sources such as domestic and wild animal defecation, malfunctioning sewage and septic systems, storm water drainage and urban runo (Kistemann *et al*., 2002 and Chigor *et al*., 2012). Fecal contamination of water is globally recognized as one of the leading causes of waterborne diseases (Nwabor *et al.,* 2016).

2.6 Water Borne Diseases

Waterborne diseases are those diseases that are communicated through the direct drinking of water polluted with pathogenic microorganisms. Most waterborne diseases are characterized by Cholera, which involves excessive stooling and vomiting, often resulting to dehydration and possibly death. Cholera was first reported in Uganda in 1971, when 757 cases were reported to the World Health Organization (WHO). During the subsequent years up to 1993, Uganda reported cholera cases every 2–4 years to the WHO. From 1994 to 1998, cholera was reported annually in Uganda (Hrudey and Hrudey, 2004). In 1998, Uganda reported almost 50,000 cases with incidence throughout the country (Blasi *et al*., 2008). The reported incidence has fluctuated between 250 and 5,000 cases every year since 2000. The reported case fatality ratio has decreased from 4–7% in the late 1990s to about 2–3% during 2004–2010.

The African Great Lakes, including Lake Albert and Lake Victoria on the border of Uganda, may provide a reservoir for cholera bacteria. Further, increases in incidence among the nations bordering these lakes have been shown to be correlated with El Niño warm weather events (Nkoko *et al*., 2011). WHO/UNICEF (2010), has recently revised its guidelines and states in a position paper that cholera vaccines should be used in combination with other prevention and control strategies in areas where the disease is endemic. “Endemic” is defined as areas with occurrence of culture-confirmed cholera in at least three of the previous five years. These data were used to compile national statistics and for reporting to the World Health Organization's (WHO, 2010),

Weekly Epidemiological Record regards to cholera case definition based on WHO criteria that depends on whether or not cholera is endemic in the area. In non-endemic areas: “a patient aged 5 years or more develops severe dehydration or dies from acute watery diarrhea.” In endemic areas: “a patient aged 2 years or more develops severe dehydration or dies from acute watery diarrhea.” (DuPont *et al.*, 2009).

2.7 Classification of Waterborne Diseases

Waterborne or water related diseases encompass illnesses resulting from both direct and indirect exposure to water, whether by consumption or by skin exposure during bathing or recreational water use. It includes disease due to water-associated pathogens and toxic substances. A broader definition includes illness related to water shortage or water contamination during adverse climate events, such as floods and droughts, and diseases related to vectors with part of their life cycle in water habitats (Satnwell, 2010). An outbreak of waterborne disease is generally defined as a situation in which at least two people experience a similar illness after exposure to water and the evidence suggests a probable water source. Basically, waterborne diseases can be transmitted through four main routes: Water- borne route, Water-washed route, Water-based route and Insect vector route or water related route. (Won, 2012)

As a result of unsafe drinking water, diarrheal disease accounts for an estimated 4.1% of the total daily global burden of disease, and it is responsible for the deaths of 1.8 million people every year and this estimates about 88% of that burden is also connected to poor sanitation and hygiene and is mostly among children in developing countries (WHO/UNICEF, 2000; WHO, 2005, and Pruss *et al.*, 2008). Most waterborne diseases are often transmitted via the fecal-oral route, and this occurs when human fecal material is ingested through drinking contaminated water or eating contaminated food which mainly arises from poor sewage management and improper sanitation. Fecal pollution of drinking water may be sporadic and the degree of fecal contamination maybe low or fluctuate widely (Pruss *et al*., 2008).

2.8 Water Borne Disease in Kampala

Cholera in Uganda appears to be largely an epidemic disease. However, endemic cholera occurs in high-risk areas along the southwestern border with DRC and in Kampala city slums. Endemic cholera is commonly noted before and during the rainy season, from December through March. Epidemic cholera can occur any time, but is often associated with extreme rain events or water supply disruptions (Craun *et al*., 2006).

The highest risk areas include the border areas with the Democratic Republic of Congo (DRC), Sudan, and Kenya as well as urban slums in Kampala. Displaced populations and their neighboring communities are at elevated risk. The ongoing migration of people into and within Uganda can lead to rapid spread of the disease. The African Great Lakes, including Lake Albert and Lake Victoria on the border of Uganda, may provide a reservoir for cholera bacteria. Further, increases in incidence among the nations bordering these lakes have been shown to be correlated with El Niño warm weather events.

The WHO/UNICEF, (2000), WHO, (2005) and Pruss *et al*., (2008), unveiled that, there is a dearth of information about the burden of cholera in low-income countries such as Uganda, and a more accurate picture of this burden is particularly important because it can be used to inform cholera prevention and control intervention questions. Equally, it can whether be used or not to introduce vaccination as a complement to other cholera prevention and control interventions. However, where and when it could be most necessary to do so, and a kind of demographic population to be targeted, should be considered (WHO, 2005).

2.9 Packaged Drinking Water

According to Warburton, (2000) Packaged Drinking Water is any portable water that is manufactured /processed for sale which is sealed in a food grade sachet, can, bottle, or any other container intended for human consumption. Emergence of packaged water began in the United Kingdom with the first water bottling at the Holy Well in 1621. High demand for packaged water for various occasions has led to springing up of small scale entrepreneurs who engage in production of packaged water without due regard to hygienic practices in the production processes. The implication of this is lack of guarantee that the product will meet set standards for drinking water. The demand for bottled water was fueled in large part by the resurgence in spa-going and water therapy among Europeans and American 17th and 18th centuries. The first commercially distributed water in America was bottled and sold by Jackson’s Spa in Boston in the year 1767 (Council, 2012). It was observed that early drinkers of bottled Spa waters believe that the water at these mineral springs had therapeutic properties and that bathing in or drinking the water could help treat many common ailments.

2.10 Types of Packaged drinking Water

2.10.1 Bottle water

Bottled water is drinking water packaged in PET bottle or glass water bottles. Bottled water may be carbonated or not. Size range from small single serving bottles to large carboys for water cooler. Although vessels to bottle and transport water were part of the human civilizations (Liu *et al*., 2013). The popularity of bottled mineral waters quickly led to a market for imitation products. As technological innovation in the nineteenth century lowered the cost of making glass and improved production speed for bottling, Bottled water was able to be produced on a larger scale and the beverage grew in popularity. Bottled water was seen by many as a safer alternative to 19th century municipal water supplies that could be contaminated with pathogens causing diseases like cholera and typhoid (Brei and Tadajewski, 2015).In Africa, including Uganda, the demand for bottled water has increased over years due to the fact that non-availability of reliable safe municipal water has left the impression that most bottled water offers a healthy, safer and water with better quality (Gardner, 2004).

2.10.2 Sachet water

Sachet water popularly called “pure water” which is manufactured by small scale industries (either in a shed or garage) with a registered name and supposed to have been prepared under Government stipulated hygienic quality regulations. According to the specifications, the water is passed through a series of activated charcoal or suitable filtering media and Millipore or equivalent filters of a specific pore size, and disinfected under ultraviolet radiation for a specific period. In some cases, the water is municipally-treated water (or occasionally from a storage tank or borehole), and sends it through some form of filtration media, and then into the sachet machine which fills a fixed volume (typically 500 mL) of a plastic roll, then heat-seals and slices the edge to create the individual sachet. Sachets typically drop into a basket on the floor and are quickly hand-packed into bags of thirty (i.e. 15 L by volume).

These bags – the unit size for virtually all sales and accounting metrics – may be stored on pallets before being loaded onto trucks and delivered either to wholesalers or directly to market. Sometimes the sealing is poor and quality control is rather questionable. The source in many cases is not well protected and human errors in the manufacturing process are possible. They are popular at social gatherings and public places, which has been widely observed that the advent of pure water has significantly increased the cases of Salmonellosis and typhoid fever in recent years (Adelegan, 2004). In addition to natural contamination, the product can also deteriorate before it reaches the consumer (Da Silva, 2007)

2.10.3 Handtied water

Handtied water is prepared by individuals who pour any available water into the nylon/plastic film sachets, tie manually, keep under ice and sold. The premises are not registered, unsanitary and the common sources of water are shallow wells, unprotected springs, boreholes, streams and ponds with no treatment. A young girl or a boy packs the water into the sachets by pouring through a funnel topped with a piece of cloth, nylon wrap or rags to strain off any particles. However, drinking water can be carefully evaluated for microbial contamination to ensure informative updates on the quality of water and provide authorities with on-time records for national control programs before any microbe could pose any health and economic problems (Obiri Danso *et al.*, 2003).

2.11 Perception of Packaged Drinking Water

Work on the people perception form a significant part of the research on drinking water has a strong emphasis on water-related behaviour, particularly on bottled water consumption (Doria, 2006). In addition, it should be noted that research has been conducted in developed countries with stringent water quality standards and reliable supplies. Current knowledge may be geographically biased and extrapolations to developing countries may be inadequate. However, looking at the main factors that modulate perceptions and concludes by looking at the way such factors are combined to shape the perception of drinking water quality. The importance given by the public to drinking water organoleptic (i.e. sensorial information from taste, odour, colour and turbidity) is currently paramount for quality perception, service satisfaction, willingness to pay and the selection of water sources (Feutrell, 2004; Proulx*et al*., 2012).

Under this context, some projections have estimated that taste will be the key issue for public waterworks managers by 2045, consumers attached more importance to taste (see Gordon, 2000). In many surveys, satisfaction with organoleptic is usually high in absolute terms (.70% of satisfied consumers), but it is often low when compared with other aspects of the water supply service (Parmelee, n.d; Turgeon *et al*., 2004; De-Franca *et al.*, 2009). It is not entirely understood why so much importance is given to something purely aesthetical, but it was suggested that the public may relate organoleptic to health risks (Proulx *et al*., 2012; Doria et al., 2005).

Another hypothesis is that drinking water is increasingly regarded as a product that should be enjoyed, rather than a basic necessity. Sensory information is often interrelated. Taste and odour rely on close physiological processes and the originating stimuli can derive from the same substance. In many circumstances, the interaction between taste, odour and colour can also be due to psychological factors, as people expect sensorial information to be consistent (Noble, 1996). Young *et al*., (1996), interrelated, the relative importance attributed to each of the senses varies according to time and culture. In western countries, water taste is usually identified as more important than odour or appearance (Feutrell, 2004; De-Franca *et al.*, 2009), perhaps because taste can detect water chemicals at lower concentrations than other senses. Survey research generally indicates that most people in countries with reliable supplies perceive tap water risks as small (Turgeon *et al*., 2004). Even in places with persistent water-treatment deficiencies and microbiological contamination, when consumer notifications are released, the magnitude of perceived risks of tap water is close to the average point of the questionnaire measurement scale (Anadu & Harding, 2000). Perceptions of drinking water safety and risk seem to be consistent and tap water is generally regarded as safe (e.g. Parmelee, n.d.; De-Franca *et al.*, 2009).

2.12 Packaged Drinking Water Quality in Africa

Packaged drinking water studies in the sub-Saharan Africa, where detectable total coliforms were found in packaged water (Fisher *et al*., 2015 & Halage *et al*., 2015). Correspondingly, majority of sachet water contaminated with total coliform higher than that in a study conducted in Accra, Ghana, where few of the samples exceeded recommended level (Stoler *et al.*, 2014).Unlike these studies, in Nigeria, all sachet water samples had total coliforms (Oyedeji *et al.*, 2010 and Nwachuku *et al*., 2015). The rate of contamination varied according to the type of packaged water. The rate of total coliform contamination in sachet water are higher than that in bottled water.

The presence of total coliform in packaged water can be linked to a number of factors such as the raw water source used, hygienic practices observed during production, improper storage in unhygienic and high temperature conditions, and lack of protective measures due to the common treatment methods used (ozonation and ultraviolet light) against bacterial regrowth (Halage *et al.*, 2015).

The poor sanitary conditions could be a probable contributor to the above observations as well as failure of some production facilities to adhere to good sanitation practices. However, it is very important to further investigate the source of these contaminations (Kassenga, 2007; Obiri-Danso *et al.,* 2003; Igbeneghu and Lamikanra, 2014).The possibility of regrowth of micro-organisms is greatly increased considering that the temperature in many African countries are as high as 28°C. Studies conducted in the United Arab Emirates and United States of America demonstrated that organisms multiply more easily between 25°C and 37°C (Raj, 2013).

Another study Fisher *et al*., (2015) carried out in Freetown, Sierra Leone, showed that increase in concentration of total coliforms may be due to growth of microorganisms already present within the packaged water. The authors suggested need for the government and other stakeholders to intensify surveillance activities and enforce strict hygienic measures in this rapidly expanding industry to improve water quality. The source and treatment process of sachet water should be monitored (Stoler *et al*., 2015; Bordalo; Machado, 2014; Ngwai, 2010, and Ugochukwu *et al*., 2015). However, studies in sub-Saharan Africa, where detectable total coliforms were found in packaged water (Fisher *et al*., 2015).

The trend observed in the contamination across the regions suggests more of a generalized rather than a centralized contamination. These microbial contaminants could have been either introduced during the manufacturing or post-manufacturing processes. It is probable that these contaminants be as a result of gaps in the manufacturing processes.

2.13 Study Gap

A lot of the studies (Brei and Tadajewski, 2015; Varga, 2011; Craun et al., 2006; Warburton, 2006; Vinieri et al., 2006; Wetzel et al., 1983) on the physicochemical and microbial analysis of PDW has been done in several countries. A study on perception of DW, titled "Bottled water versus tap water, understanding consumer preference" by Doria et al., (2006) in the United Kingdom in which the researcher did a comparative study between bottled and tap water without consideration of the physicochemical, microbial, and trace metals properties. It was concluded that a gap existed theoretically and conceptually on a complete investigation in the properties of these DW in the United Kingdom.

Research from Nigeria (Igbeneghu and Lamikanra, 2014; Oyedeji *et al*., 2010; Oyelude *et al* 2012; Omalu *et al.,* 2010) and Ghana (Obiri-Danso *et al*., 2003; Abdul *et al.,* 2014; Stoler, 2014) has shown that PDWs in these developing countries require care from production to consumption. A growing concern about the microbial quality of PDW products in developing countries is highlighted in these researches. Health related studies that include the microbial quality of bottled and sachet drinking water has also been carried out in Dar es Salam, Tanzania (Kassenga *et al*., 2007), South-Western Nigeria (Oyedeji, 2010); Sierra Leone (Fisher *et al.,* 2015) and in Zaria, Nigeria (Ngwai, (2010).In 2015, Halage *et al.,* (2015) studied the physical and bacteriological properties of PDW samples in Kampala. They highlighted the need for continuous survey of PDW samples. Extensive research on the PDW sold in Kampala suburbs is a gap to be filled.

Studies on the physicochemical and mineral properties of PDWs were conducted by Addo *et al*., (2009) & Azlan *et al*., (2012).Then, metals and nutrients like Cu, Fe, Pb, P, Zn, NO_3^-, and Cl^-in drinking water is an important parameter to investigate as it indicates the level of toxicity present in the water. A detailed comparison of the physicochemical and microbial contents of PDW samples should be investigated with a view of determining the most relevant quality indicators and the relationships between the tested parameters. This exists as a research gap in PDW studies in Africa. Another gap will be the investigation in the source of PDW to gain insight into to source of pollution. This research studied the physicochemical and microbial properties of bottled water, handtied water, sachet, and spring water samples. A detailed comparison was also carried out to investigate statistical associations in the tested parameters.

CHAPTER THREE

3.0 Materials and Methods

3.1 Sampling area / Sample Collection

The location of the sampling area (Kansanga); Coordinate: $00^{o}1714^{o}N$ $32^{o}36'28^{o}E/0.28722^{o}N$ $32.60778^{o}E$. Systematic random sampling technique was used in this study, where samples were obtained after every two stores. Except for the Handtied and spring water samples, all the production dates were within the past one month prior to analysis. All bottled water samples used were those without the ISO 9000 certification mark.

3.2 Sample Preparation

10ml of each of the water samples were transferred into the cuvet where 2drops of Conc. HNO_3 were added to each sample prior to the FAAS analysis.

A total of 72 packaged drinking water samples were randomly selected from local store in the study area (Kansanga).A set of 24 PDW samples (each in triplicates) were collected. Three samples each of both sachets and spring water samples were obtained from the study area. The spring water included served as control because it is source for PDW.

3.3 Sample Analysis

All experiments were carried out at the Kampala International University, Science Laboratory. Instrumental analysis was carried out at the College of Natural Sciences Chemistry Laboratory, Makerere University, Kampala, Uganda and Bio core enterprises.

3.3.1 pH

pH of the sachet water samples was determined using a digital pH meter (Model Lab Tech. 3320) after the meter had been duly calibrated with standard buffers each time.

3.3.2 Electrical Conductivity

The conductivity of the samples was determine using a digital conductivity meter (model Jenway, 4010).Electrical conductivity was measured directly by immersing a conductivity meter electrode into a beaker containing sample. The electrode was allowed to stabilize before the reading was taken.

3.3.3 Turbidity

2ml of the samples were transferred into the cuvet and inserted into the turbidity meter. Turbidity were measured and readings were reported in NTU.

3.3.4 Color

Colour was determined by the calorimetric method. A 10 ml of the sample were measured and transferred into the cuvet, of the colorimeter (model DR 1900) inserted and U.V were taken and reported in TCU.

3.3.5 Alkalinity

Dilute HCl was titrated against the water sample, 3 drops of phenolphthalein indicator were added. The result was reported as milligrams per liter (mg/L) of calcium carbonate.

3.3.6 Total Hardness

EDTA titration method was used to determine the total hardness. The sample, 50ml was pipetted into a conical flask, 1 drop of ammonium buffer and 3 drops of Eriochrome Black-T indicator was added. The mixture was titrated against standard 0.01M EDTA until wine red colour of the solution turned pale blue at the endpoint. Total hardness was calculated using the formula below.

$$\text{Total hardness} = (T)\,(1000)/V\ (\text{mg/L})$$

Where, T= volume of titrant and V = volume of sample (mg/L).

3.3.7 Chlorides

A 100 ml volume of each sample were transferred into a conical flask and 3 drops of 10% potassium chromate indicator was added and titrated against 0.014N silver nitrate till a reddish tinge end point. Distilled water served as the blank. Concentration of chloride was calculated using the expression:

Chlorides (Cl^-) = (A-B) (N) (35.45) / sample taken in ml.

Where A = Titre value of sample B = Titre value of distilled water N = Normality of Silver nitrate (NO_3^-).

3.3.8 Phosphate (PO_4^{3-})

From the standard solution of anhydrous potassium hydrogen phosphate (KH_2PO_4), 10 ml of the standards were measured into a test tube. 2ml of combined reagent (ascorbic acid and Molybdate antimonyl reagent) were added to the standards, which were transferred into the test tubes containing the samples, and another test tube containing distilled water which serves as the control. 0.05ml of phenolphthalein indicator were added to the solutions. Ten minutes was allowed to elapse for a colour development, after which absorbance of each solution were measured at 880nm on a UV-VIS spectrophotometer (model: DR 1900) as reported in Menzel and Corwin, (1965).

3.3.9 Nitrogen

Standard solutions of 0.02, 0.04, 0.06, 0.08 and 1.0M were prepared from a stock KNO_3 solution (100ppm). 5ml of sample was pipetted into a test tube. 1ml of 30% NaCl, 5ml of Conc. H_2SO_4 and 0.25ml of brucine reagent was added to the samples and to the standards, and mixed thoroughly. Absorbance for both the mixture and standards were taken from the UV-VIS spectrophotometer at a wavelength of 410nm (DR 900 colorimeter) as described in Azrina *et al*., (2011).

3.4 Microbial Analysis

Microbial analysis was carried out at the Microbiology Laboratory in the College of Veterinary Medicine, Makerere University, Uganda. The method for Microbiological analysis used was the Spread Plate Technique. Spread plate technique is the method of isolation and enumeration of microorganisms in a mixed culture and distributing it evenly. This is an easier technique for quantifying bacteria in a solution. All the media were prepared according to manufacturer's specifications. A 10-fold dilution was used, and 100µl was drawn from the appropriate desired dilution series onto the center of the surface of an agar plate. Sterilized L-shaped glass spreader was used to spread the sample evenly over the surface of the media (Chromo cult agar) carefully rotating the Petri dish underneath at the same time while spreading. The plate was incubated at 37°C for 24 hours. The CFU value of the sample was calculated from the colony count obtained, and was multiplied by the appropriate dilution factor which gives the CFU/ml in the original sample as described in Pant *et al.*, (2016).

3.5 Metal Analysis

FAAS analysis was carried out at the College of Natural Sciences Makerere University Uganda. Flame Atomic Absorption Spectroscopy FAAS (Agilent technology, model: 200 series AA) was used for the determination of trace metals. 10 ml of the samples were measured and a drop of conc. HNO_3 was added and the absorbance were taken and the standard were made to calibrate the FAAS machine prior to the analysis.

3.6 Statistical Methods

After all the laboratory analysis the experimental results were statistically analyzed using SPSS version 17 and Microsoft Excel. Descriptive data analysis was used to describe the data obtained using the mean and standard deviation. The data were represented in tables and histograms. Pearson's correlation was used to determine the level of association between the parameters tested and a Dendrogram was used to express the distances between the parameters by centroid linkage. Analysis of variance (ANOVA) was used to test if there were significant associations in the DW samples and if there were significant interactions in the parameters of the PDW samples.

3.7 Quality Control

To ensure quality, water samples were transported to the microbiological Laboratory and analyzed immediately for microbial properties. Samples were analyzed in triplicates using standard analytical methods. All Equipment were calibrated before use. A blank sample and a standard sample (de-ionized water) was included in the analysis (Halage *et al*., 2015).

CHAPTER FOUR

4.0 Results and Discussions

4.1 Physicochemical Properties of Packaged Drinking Water

4.1.1 Physicochemical properties in bottled water

The results of the physicochemical properties of the bottle water samples are presented in Table 4.1, The mean ± standard deviation of the pH, Electrical conductivity (EC), colour, Turbidity, Alkalinity, Nitrogen, Phosphorus, Total hardness and Chloride for the 11 bottled water samples were presented.

Results presented in Table 4.1 reveal that the pH in bottled water samples were within the UNBS/US, (2011) recommended limits. pH refers to the measure of acidity or basicity of a solution. The pH ranged from 4.60 ± 0.17 to 8.43 ± 0.15 with a mean pH of 7.15 ± 1.12. Except sample BJ which had 4.60 ± 0.17, which is slightly acidic (at this pH level the taste of the water can be felt as blighted). All other samples fall within the permissible range of UNBS/US, (2011).pH value below 6.5, affects disinfection efficiency and may have an indirect effect on human health (Uduma and Uduma, 2014). This result is in line with the findings of Halage et al. (2015), who found average pH ranged of 6.8-7.8 in PDWs in Kampala and also in line with another research conducted in Wondo genet campus, Ethiopia by Sasikaran et al. (2012)who recorded 6.52 – 6.83 in bottled water samples. It is also consistent with study conducted by Molefe *et al.*, (2018) in Maseru, Lesotho, and got 7.42-7.7.

Electrical conductivity can be defined as how much voltage is required to get an amount of electric current to flow in drinking water. The results for Electrical conductivity ranged from 85.67 ± 7.77 µS/cm to 320.33 ± 18.18 µS/cm with a mean value of 136.64 ± 66.35 µS/cm. This result is in line with the work of Molefe *et al.*, (2018) who had results ranging from 0.39 ± 0.01

to 155.83± 1.17 µS/cm. It also concurs with the finding of Oluyege *et al*., (2014) who conducted studies on PDW in south western Nigeria, had a range of 0.01 to 0.15 µS/cm with mean value for electrical conductivity of 0.07 µS/cm. Colour ranged from 0.00 TCU to 2.33 ± 0.58 TCU with mean level of 0.52 ± 0.94 TCU. The results fall within the UNBS permissible limits.

For colour, the findings are in line with the findings of Halage *et al.*, (2015) who also studied bottled water in Kampala and obtained0.00 TCU. Turbidity can be defined as the percentage of light that is deflected more than 2.5^0 from the incoming light direction. Turbidity result ranged from 0.53 ± 0.06 to 3.43 ± 0.06 NTU with the mean level of 2.66 ± 0.83 NTU and were all within the recommended limit. The turbidity results match the work of (Meride and Ayenew, (2016) whose results were 0.98 NTU. The turbidity values are also in line with bottled water findings from Malaysia (Chain *et al*. 2007) and Kampala (Halage et al. 2015) which were 0.1 – 1.68 NTU, and 0.00 NTU respectively.

Alkalinity result ranged from 3.00 ± 11.79 to 73.00 ± 2.65 mg/L with a mean value for alkalinity of 46.91 ± 15.91 mg/L. All values of alkalinity fall within the UNBS permissible limit. This result is in line with the findings Molefe *et al*. (2018) who had 3.27 ± 0.06 mg/L in bottled water samples. Nitrogen in bottled water also ranged from 0.018 0.006mg/L to 0.328 ± 0.120mg/L with a mean value of 0.177 ± 0.120mg/L. All the values of Nitrogen were within the permissible limit. Phosphorus results ranged from 0.032 ± 0.005 to 0.072 ± 0.002 mg/L with a mean value of 0.049 ± 0.013. All the samples within the UNBS permissible limit. Phosphorus when present in drinking water causes rapid growth of algae. This brings about water pollution.

Results for Chloride ranged from 0.00 ± 0.00 to 17.67 ± 0.5 mg/L with a mean value for chloride of 4.30 ± 4.75 mg/L. All the samples fell within the UNBS recommended permissible limit. This result is in line with research findings made in Greece by Venire, *et al*., (2006). The study also matched the findings of Oyelude *et al*., (2012) who recorded 0.50 mg/L in packaged water in south-western Nigeria. The total hardness of the bottled water samples was between 28.27 ± 1.81 to 64.67 ± 0.64 mg/L with a mean value of 43.13 mg/L. These results are in line with the findings of Oluyege *et al*., (2014) whose value is log29.20 mg/L. It is also consistent with the findings of Molefe *et al.* (2010) who had 1.80 ± 0.23 mg/L.

4.1.2 Physicochemical properties of Handtied water samples

The results of the physicochemical properties of the bottle water samples are presented in Table 4.2, the mean ± standard deviation of the pH, Electrical conductivity (EC), colour, Turbidity, Alkalinity, Nitrogen, Phosphorus, Total hardness and Chloride for the 9 Handtied water samples were presented. Results of pH of the Handtied water samples ranged from 6.60 ± 0.20 to 7.47 ± 0.12 with a mean pH level of 7.04 ± 0.25, the pH values fell within the permissible range of the UNBS guidelines. These results were in line with findings of Abdul *et al*., (2014) who had 6.41 to 6.61 The study consistent with the findings of Oluyege *et al*., (2014) in Nigeria who had7.2. The findings also concur with another study findings of Molefe *et al.*, (2018) from Maseru, Lesotho who had 7.42 ± 0.10. pH is very important parameter in which variation from the limits too low or too high can alter the test of the water. Electrical conductivity of Handtied water ranged from 161.00 ± 38.30 µS/cm to 493.33 ± 10.26 µS/cm and a mean electrical conductivity value of 257.41 ± 137.14 µS/cm. All the values for the EC fell within the safe limit of 1500 µS/cm. The study is in line with the findings of Sasikaran, (2012) in Sri Lanka, who got a ranged of 22 – 253 µS/cm, in handtied in Sri Lanka.

The Color of the handtied samples ranged from 2.10 ± 0.00TCU to 6.97 ± 0.15TCU with a mean value for color of 3.36 ± 2.18TCU. The colour of the samples were within the UNBS permissible limit of 15 TCU. Turbidity results ranged from 1.67 ± 0.72 NTU to 5.70 ± 2.43

NTU with a mean value for turbidity of 3.92 ± 1.56 NTU. These results are consistence with the findings of Abdul *et al*., (2014) in Kumasi, Ghana, who had a range of 0.31 NTU to 1.14 NTU. It is also in line with the study conducted by Chain *et al*., (2007) in Malaysia, who had 0.0352-0.1680 NTU. The result also corresponds to the work of Oluyege *et al.*, (2014) in Nigeria, where they recorded 10-66 mg/L. Alkalinity result ranged from 23.67 ± 1.53 mg/L to 146.00±10.58 mg/L with a mean alkalinity of 58.19 ± 37.63 mg/L which are also within the recommended limit (UNBS). The results for Nitrogen showed a ranged of 0.369 ± 0.033mg/L to 0.016 ± 0.000mg/L with mean level of nitrogen of 0.244 ± 0.104mg/L. The values of Nitrogen in all the samples fell within the recommended limits.

This concurs with the result obtained in the study conducted at Sri Lanka, by Sasikaran *et al*., (2012) who had 0.21- 4.19mg/L. For Phosphorus, the results ranged from 0.013 ± 0.000mg/L to 0.109 ± .039mg/L with a mean phosphorus level of 0.051 ± 0.033mg/L. This is in line with findings of Adeyemi *et al*., (2010) who conducted his research in Nigeria and got 0.001-0.020mg/L. Chloride results ranged from 2.00 ± 0.00mg/L to 11.67 ± 0.58 mg/L with mean value for chloride of 5.04 ± 2.78 mg/L. the level of chloride in all the samples were within the recommended limit. This study is in line with another study conducted at Wondo genet campus, Ethiopia, by Meride and Ayenew, (2016) who got a ranged from 53.07 mg/L. It is similar to another study conducted at Maseru, Lesotho by Molefe *et al.*, (2018) whose results ranged from 0.02 ± 0.02 to 0.08 ± 0.04 mg/L. Total hardness, results revealed the ranged of 36.33 ± 2.89mg/L to 87.33 ±3.06mg/L with a mean total Hardness level of 53.23 ±16.91mg/L. All the parameters determined fell within the permissible limit of the UNBS. The results are similar to the findings made by (Abdul *et al*., 2014) who had 8.0 – 30.0mg/L.

4.1.3 Physicochemical of properties of sachet and spring water samples

The results of the physicochemical properties of the bottle water samples are presented in Table 4.3, the mean ± standard deviation of the pH, Electrical conductivity (EC), colour, Turbidity, Alkalinity, Nitrogen, Phosphorus, Total hardness and Chloride for the 6sachet and spring water samples were presented.

pH results in sachet water showed ranged from 6.70 ± 0.10 to 8.90 ± 0.00, with a mean value of 7.02 ± 0.76. This result implied that the water samples were almost neutral. This result is in line with the findings of Halage *et al*., (2015) who had 6.8-7.8 ± 0.3; also concurs with that of Abdul *at al*., (2014) in Kumasi Ghana who got 6.41 - 6.61. The study is consistent with the work of Oluyege *et al*., (2014) on the bacteriological density and physicochemical properties of bottled and sachet water in Nigeria who had pH: 7.17. The electrical conductivity results, showed ranged from 166.00 ± 38.31µS/cm to 194.33 ± 6.66µS/cm. with a mean electrical conductivity of 175.56 ± 25.94µS/cm while the spring water ranged from 284.00 ± 18.00µS/cm to 480.33 ± 30.92 µs/cm with a mean of 213.94 ± 129.83 µS/cm and total mean of 213.94 ± 129.83 µS/cm. Electrical conductivity was higher in the spring water because no treatment was made since it is directly from the source.

This is in accordance with work of Abdul et al., 2014 in Kumasi Ghana who obtained a ranged of 110.1µS/cm – 262.0 µS/cm; also with that of Oluyege *al*., (2014), in Nigeria who had a ranged of 0.01–0.16µS/cm; concurs with that of Adeyemi *et al*., (2010) in Nigeria who also got 100 - 210 µS/cm. The Colour results in sachet water ranged from 1.10 ±0.00TCU to 2.70 ± 0.00TCU with mean value of 2.10 ± 0.79TCU. While colour in the spring water samples, ranged from 3.33 ± 0.35TCU to 7.00 ± 0.00TCU. This is similar to the findings of Yadev *et al*., (2013) findings whose result was colorless; Adeyemi *et al*., (2010) also had colorless in his results; is in lined with the findings of Abdul *et al*., (2014) in Kumasi, Ghana, where he got a ranged of 0.00 to 174 Hz. Colour is high in the spring water samples because no filtering was.

Turbidity result in sachet water samples showed a ranged of 3.23 ± 0.25 mg/L to 3.50 ± 0.50 mg/L mg/L. While in the spring water: the ranged were from 3.40 ± 0.53 mg/L to 4.83 ± 1.76 mg/L with a mean value of 2.18 + 2.19 TCU. All the sachet and spring water samples were within the permissible limit. The result were in lined with the findings of Abdul *et al*., (2014) in Kumasi, Ghana, where he got a ranged of 0.31 NTU – 1.14 NTU; it also concurs with findings of Adeyemi *et al*. (2010) who had 0.001-0.06 NTU; consistent with Halage *et al*., (2015) whose researched on PDW in Kampala and got 0.00 NTU. Alkalinity result in sachet water revealed the ranged from 25.00 ± 0.00 mg/L to 59.33 ± 1.15mg/L with mean alkalinity of 37.00 mg/L while spring water sample ranged from 49.33 ± 1.15 mg/L to 155.00 ± 5.00 mg/L with a mean values of 85.44 ± 52.25 mg/L, and total mean value for alkalinity of 54.12 ±32 mg/L.7654.12 ±32.76 mg/L, all fall within the recommended limit of 50.0 mg/L by UNBS.

The result concurs with the findings made by Abdul *et al*., (2014) who did his work in Kumasi Ghana and got 8.0 to 18.0 mg/L. Results for nitrogen revealed the ranged from 0.219 ± 0 .194 mg/L to 0.271 ± 0.323mg/L in sachet water sample with a mean nitrogen of 0.242 ± 0.190 mg/L_{CaCO_3}. All the samples were within the recommended limit as described by UNBS. This result was in accordance with the results obtained by Molefe *et al*. (2018) made his findings in Maseru, Lesotho and got values range from0.04 ± 0.00 mg/L to 0.07 ± 0.00 mg/L. The results of phosphorus in sachet water samples ranged from 0.032 ± 0.005 mg/L to 0.042 ± 0.003 mg/L with mean phosphorus value of 0.037 ± 0.006 mg/L. While results in spring water samples the range is from 0.024 ± 0.004 mg/L to 0.036 ± 0.003 mg/L with a mean of 0.046 ± 0.022 mg/L. The values of phosphorus in all the sachet and spring water samples fall within the UNBS permissible limit. These results found to similar to the findings of Abdul *et al*., (2014) in Kumasi, Ghana, and got a ranged of 0.42 - 4.50 mg/L.

Result presented for Chloride in sachet water samples ranged from 3.00 ± 0.00 mg/L to 11.67 ± 0.58 mg/L with mean value of chloride of 2.45 ± 0.36 mg/L. While the spring water samples ranged from 4.00 ± 0.00 mg/L to 7.00 ± 0.00 mg/L, with a mean chloride value of 5.08 ± 4.66 mg/L; and total mean value for sachet and spring water samples of 5.08 ± 4.66 mg/L; all the sachet and spring water samples fall within the permissible limit. This result is in line with the findings of Abdul *et al*., (2014) and got 6.0 mg/L to 14.0 mg/L. The result for total hardness in sachet water revealed the ranged from 44.08 ± 15.14 mg/L to 45.93 ± 2.50 mg/L, with mean value for total hardness of 43.75 ± 8.92 mg/L; while in the spring water samples Total Hardness ranged from 72.57 ± 7.35 mg/L to 81.60 ± 8.63 mg/L with value for total Hardness of 50.58 mg/L; all the parameters tested for sachet and spring water samples fall within the recommended limit. This concurs with the findings of Uduma and Uduma, (2014) who had a ranged of 6.0 mg/L to 18.0 mg/L; also, in line with Adeyemi *et al*., (2010) conducted his research on spring water in Nigeria and got a ranged from 40 mg to 90 mg/L.

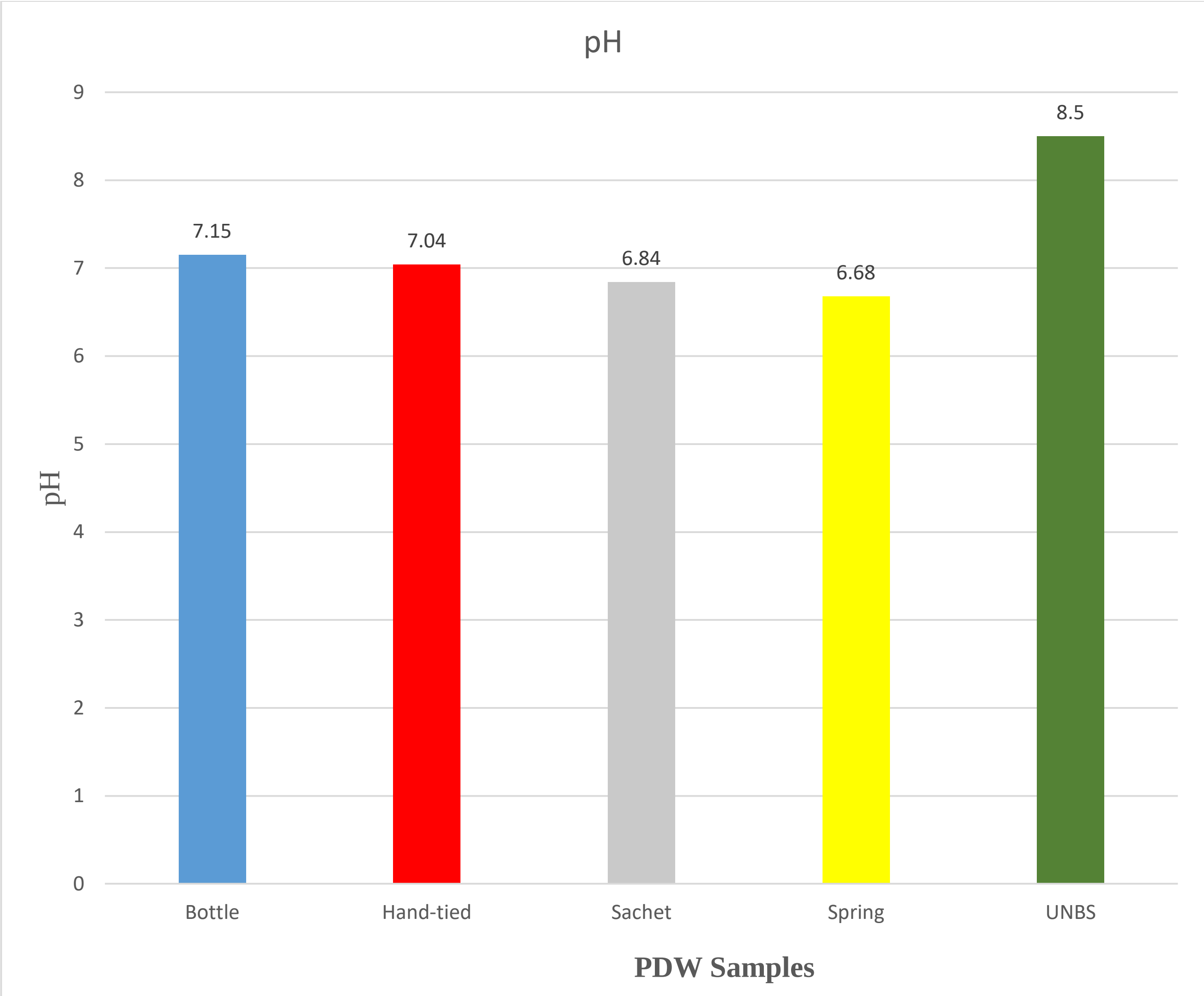


Figure 4.1: The level of pH in PDW samples

The results of the pH in the bottled water samples are presented in Figure 4.1, the mean ± standard deviation of the pH, Electrical conductivity (EC), colour, Turbidity, Alkalinity, Nitrogen, Phosphorus, Total hardness and Chloride for the PDW samples were presented.

Figure 4.1 revealed that the mean level of pH in the Bottled water samples Except for Sample BJ in the Bottled water sample, the value was below the UNBS permissible limit. The taste of the water at this pH level would be blighted. The pH range were in the order of Bottled water > Handtied > sachet > spring water samples. The pH values were all within the permissible limit of UNBS.

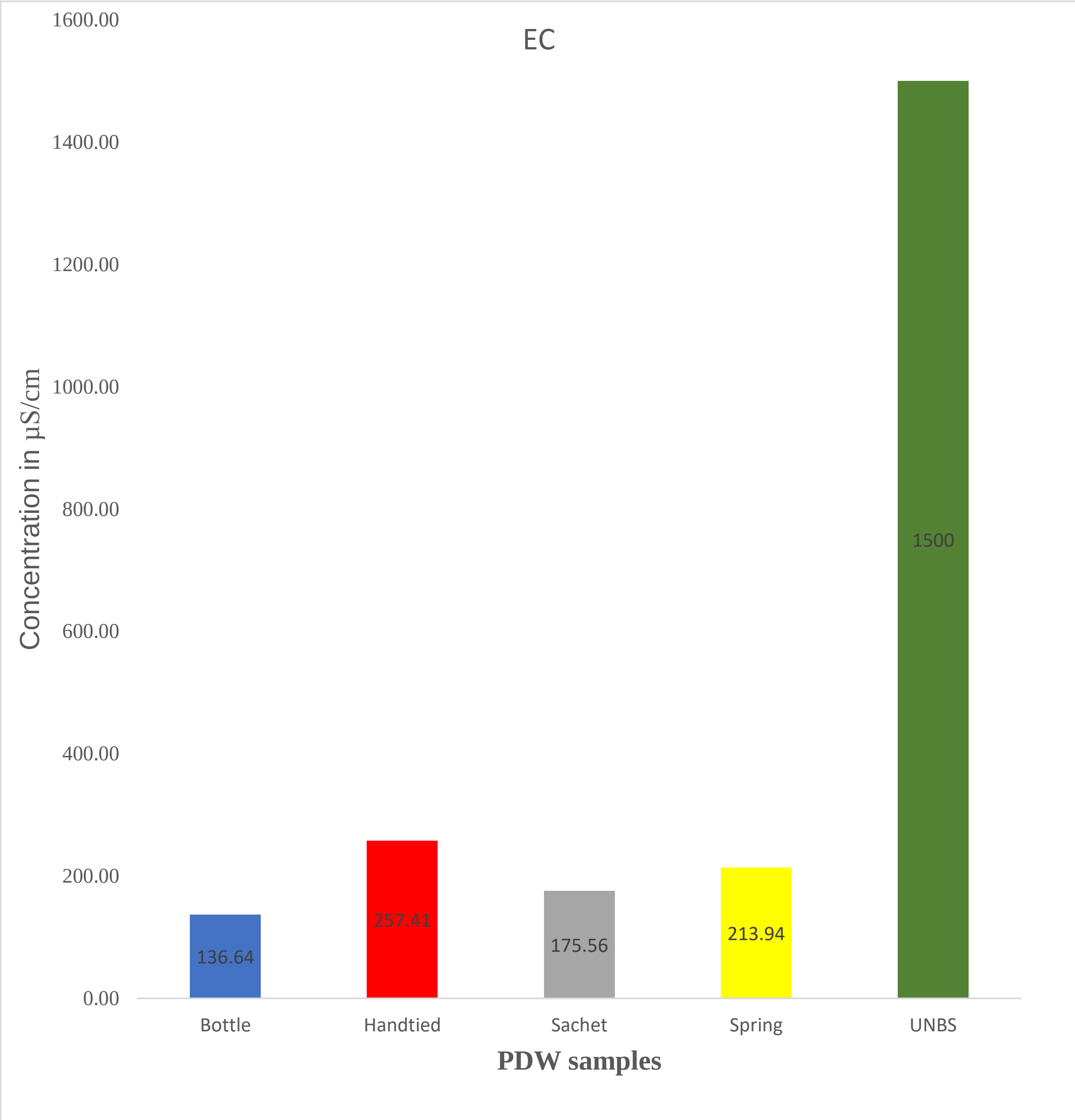


Figure 4.2 Electrical Conductivity of the PDW sample

The results presented in figure 4.2 Electrical Conductivity revealed that handtied > spring water > Sachet water > Bottled water sample. All the samples were within the permissible limit as guided by the UNBS.

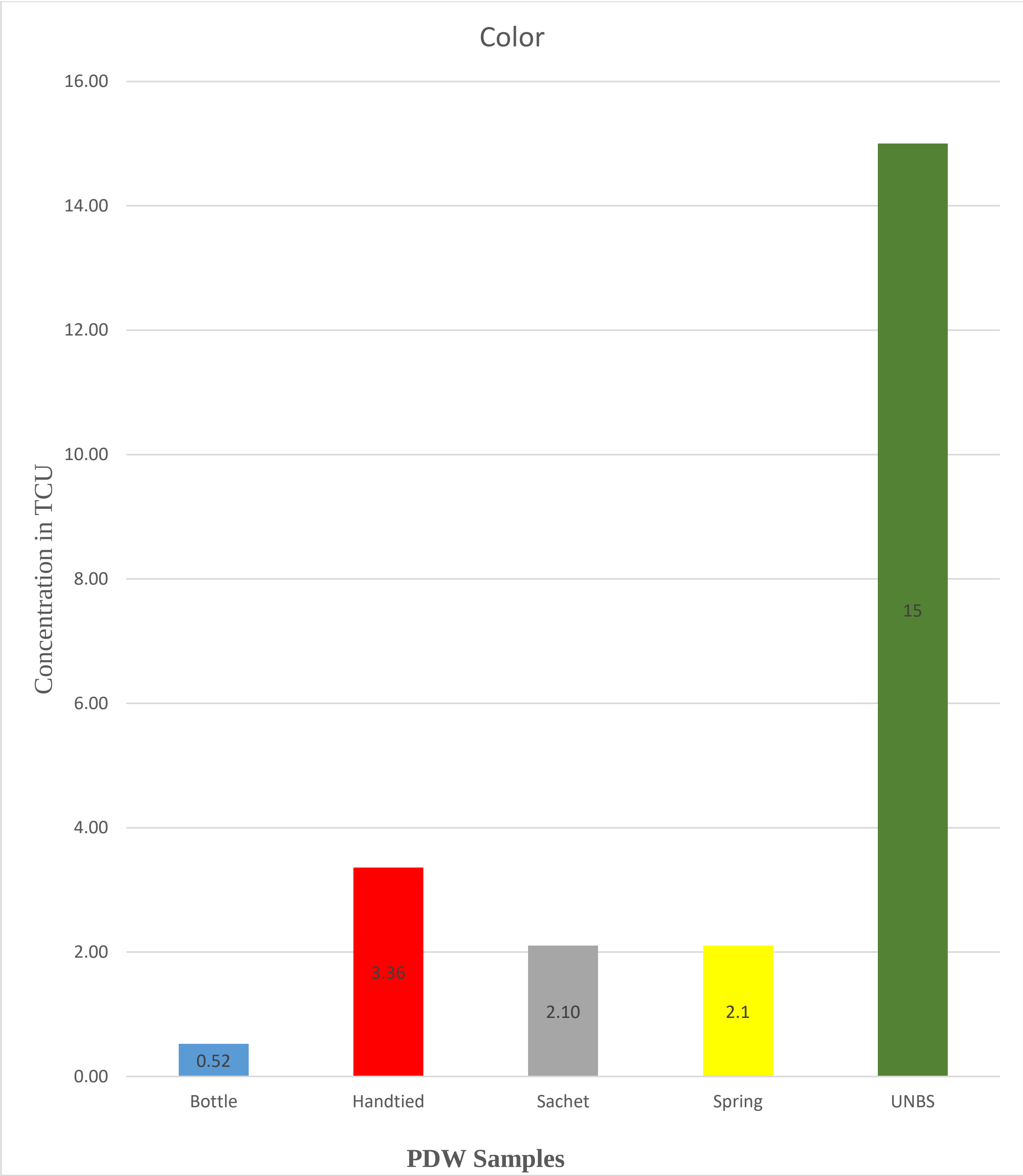


Figure 4.3: Colour level in PDW Samples

Figure 4.3 Colour level in PDW revealed that spring > Handtied> sachet >bottled water. All the samples were within the permissible limit as guided by the UNBS.

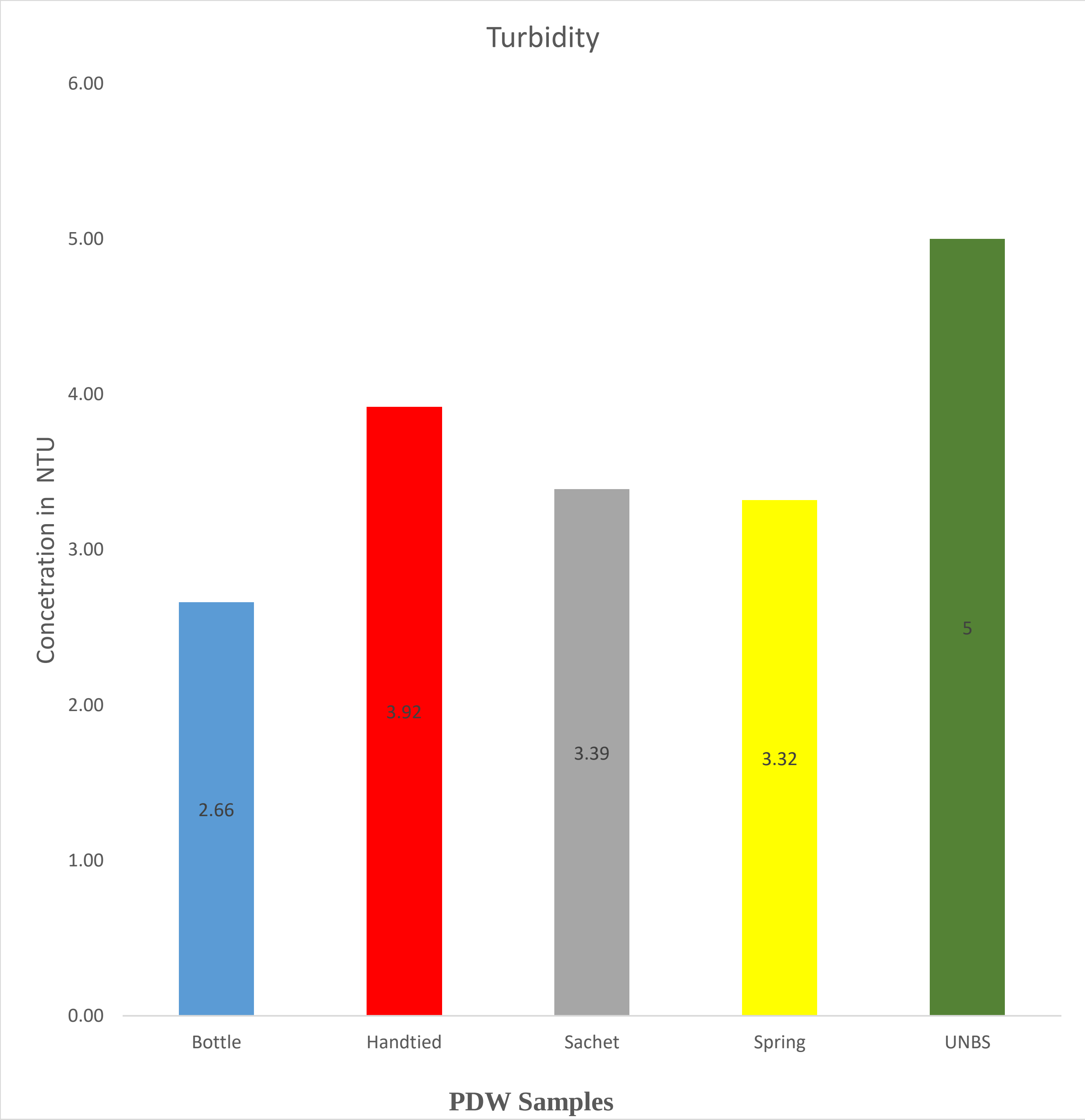


Figure 4.4: Turbidity of the PDW samples.

Turbidity results showed significant variations in the various samples, Handtied water > spring water > sachet water >bottled water. All the samples were within the permissible limit as guided by the UNBS.

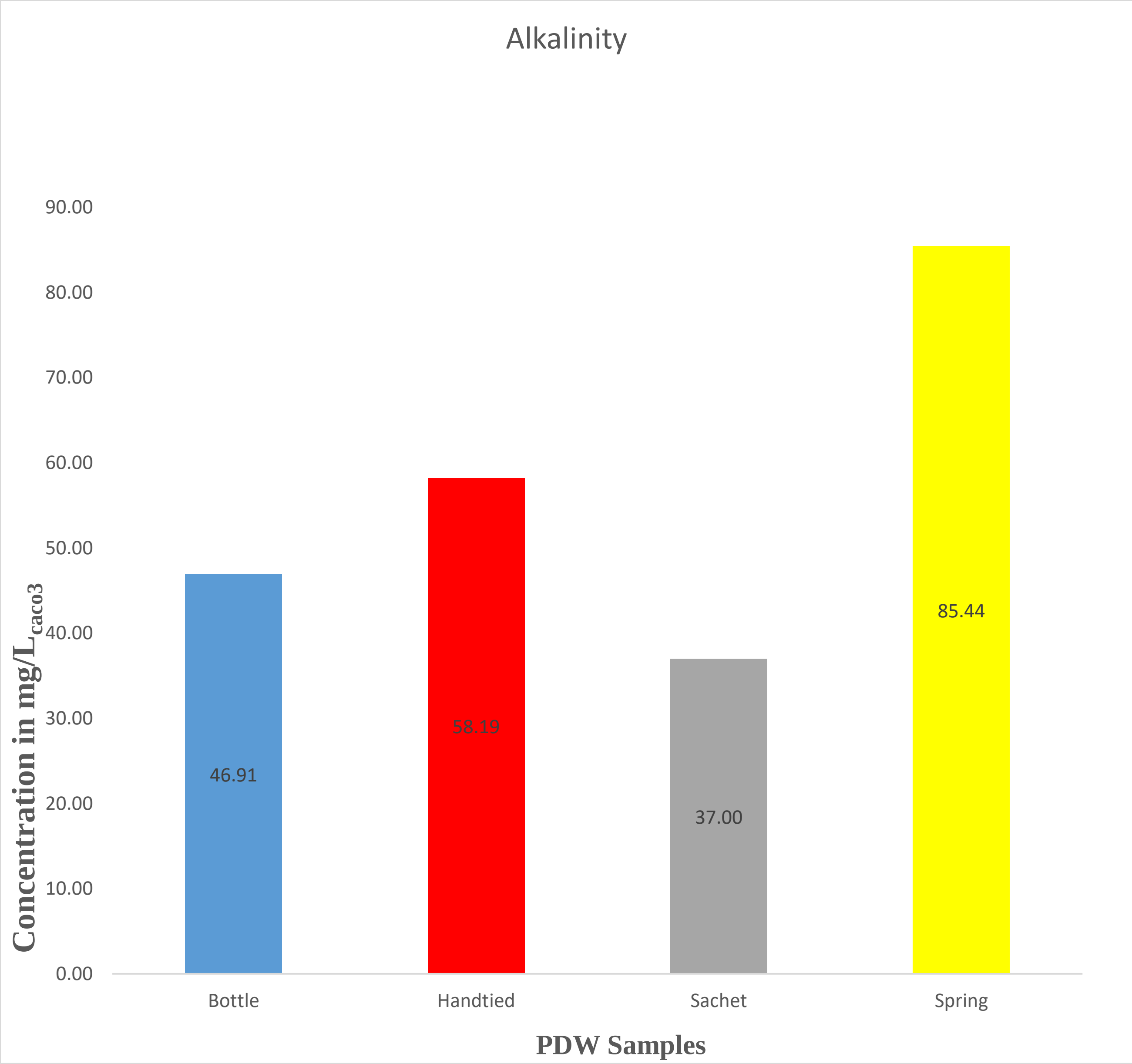


Figure 4.5 alkalinity in PDW samples.

For alkalinity, spring water was the highest, followed by the Hand –tied, bottled water and the least was the sachet water. All the samples were within the permissible limit as guided by the UNBS.

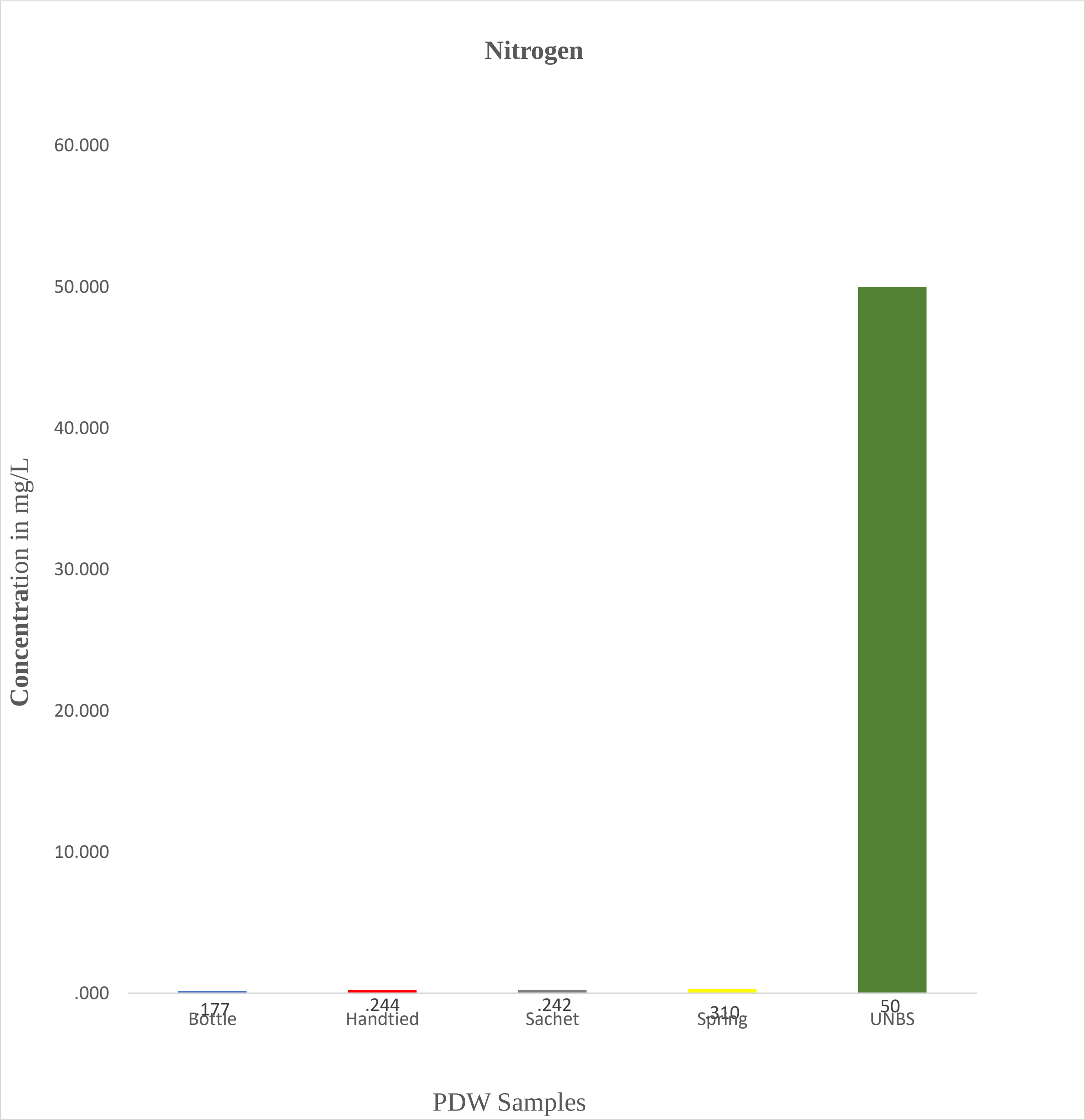


Figure 4.6 Level of Nitrogen in PDW

Result for nitrogen also revealed that spring water >handtied water > sachet water >bottled water which is also expected. All the samples were within the permissible limit as guided by the UNBS.

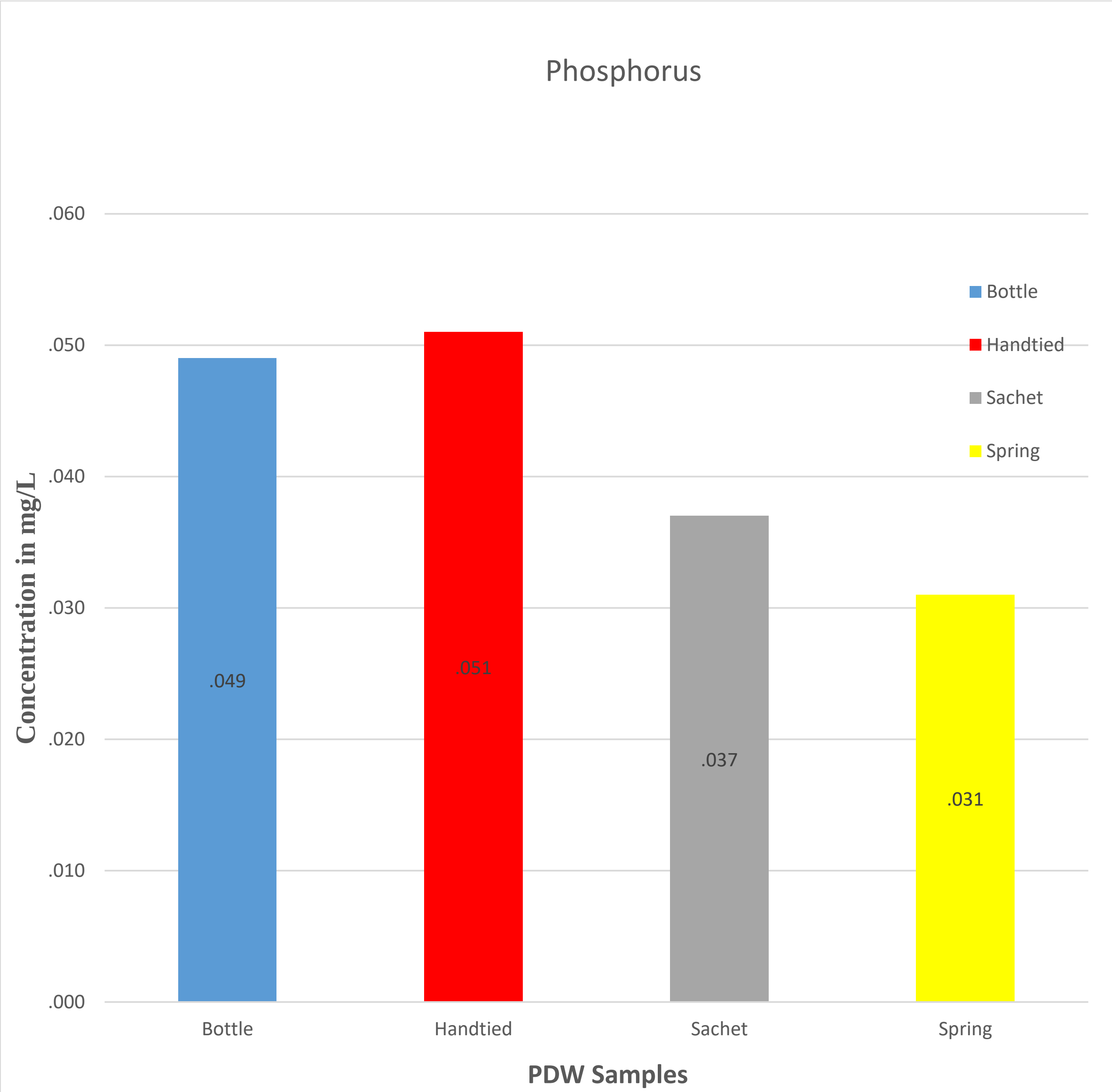


Figure 4.7 Level of Phosphorus in PDW samples

Phosphorus results revealed that handtied water had the highest value followed by bottled water, then sachet water while the least was spring water. All the parameters were within the permissible limit of the UNBS DW guidelines.

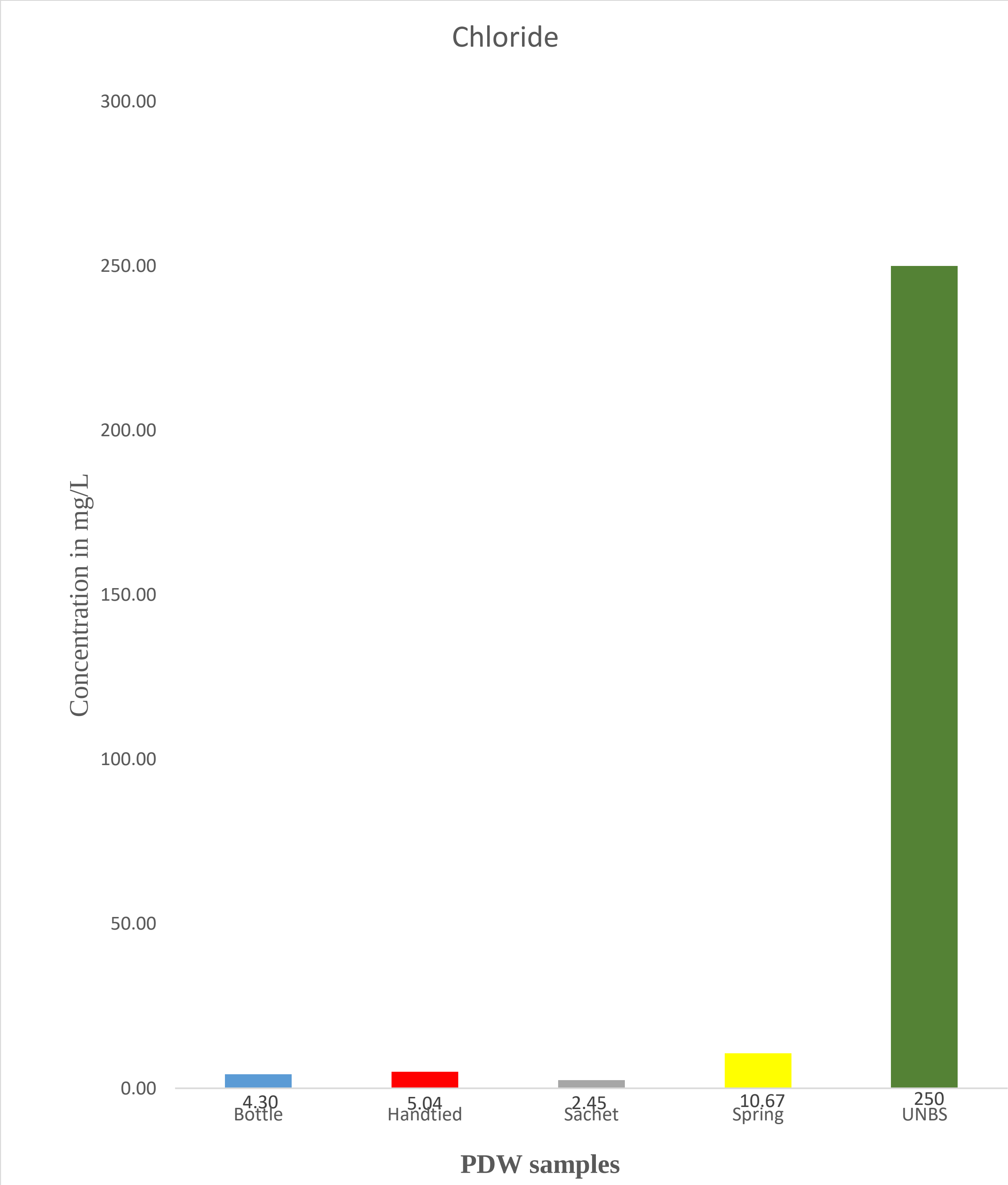


Figure 4.8 Level of Chloride (mg/L)

Chloride also varied as spring water was still the highest followed by the handtied and bottled water and the least was sachet water. All the samples were within the permissible limit as guided by the UNBS.

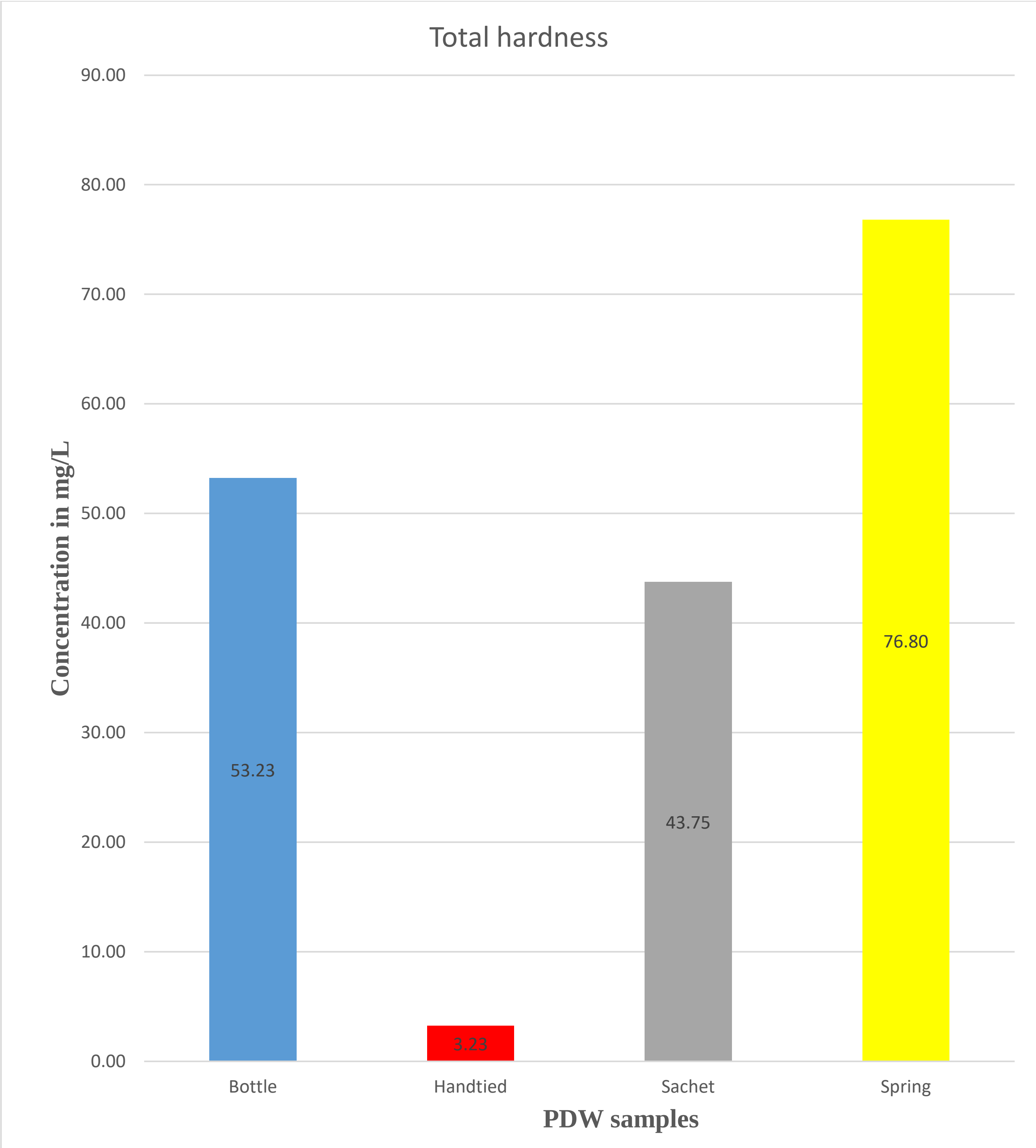


Figure 4.9 Level of total hardness in PDW Samples

Result presented in Figure 4.9 for Total Hardness revealed that spring water as the highest followed by the Bottled water, sachet and hand tied, having the least level. All the parameters determined were within the recommended limit of the UNBS.

4.1.4 Comparison of the physicochemical parameters in PDW samples

The results of the physicochemical properties of the bottle water samples are presented in Figure (4.1 - 4.9), the mean ± standard deviation of the pH, Electrical conductivity (EC), colour, Turbidity, Alkalinity, Nitrogen, Phosphorus, Total hardness and Chloride for the 6 sachet and spring water samples were presented.

Figure 4.1 revealed that the mean level of pH in the samples were in the order of Bottled water >Handtied water> sachet water> spring water samples. The pH values were all within the permissible limit of UNBS. Figure 4.2 showed that electrical conductivity varies in the different PDW samples as follows: spring water >Handtied water> sachet water> bottled water. Figure 4.3 Colour level also revealed that spring >Handtied water> sachet water>bottled water. All the values were within the permissible limit of UNBS. Figure 4.4 Turbidity results showed significant variations in the various samples, Handtied water > spring water > sachet water >bottled water. However, all the values were within the permissible limit of UNBS. Figure 4.5 Result for alkalinity, spring water > Hand –tied > bottled water> sachet water. All the values were within the permissible limit of UNBS.

Figure 4.6 Result for nitrogen also revealed that spring water >handtied water > sachet water >bottled water which is also expected. The values were within the permissible limit of UNBS. Figure 4.7 Phosphorus results revealed that handtied water >bottled water> sachet water > spring water. All the values were within the permissible limit of the UNBS DW guidelines. Figure 4.8 Results for Chloride also varied as spring water >Handtied water > bottled water> sachet water. All the values were within the permissible limit of the UNBS DW guidelines. Figure 4.9 Results for the Total Hardness showed that spring water >handtied water>sachet water> bottled water. All the values determined were within the recommended limit of the UNBS 2011 DW guidelines.

Table 4.1.Fecal contamination in CFU/ml for bottled water samples.

Bottle	TPC	TC	*E. Coli*
BA	$1.01 \times 10^5 \pm 7.17 \times 10^4$	0.00 ± 0.00	0.00 ± 0.00
BB	$7.13 \times 10^5 \pm 4.95 \times 10^5$	0.00 ± 0.00	0.00 ± 0.00
BC	$6.67 \times 10^0 \pm 5.77 \times 10^0$	0.00 ± 0.00	0.00 ± 0.00
BD	$5.83 \times 10^5 \pm 2.62 \times 10^5$	0.00 ± 0.00	0.00 ± 0.00
BE	$4.07 \times 10^1 \pm 3.05 \times 10^1$	0.00 ± 0.00	0.00 ± 0.00
BF	$5.00 \times 10^0 \pm 0.00 \times 10^0$	0.00 ± 0.00	0.00 ± 0.00
BG	$5.33 \times 10^0 \pm 5.03 \times 10^0$	0.00 ± 0.00	0.00 ± 0.00
BH	$2.00 \times 10^4 \pm 1.40 \times 10^4$	0.00 ± 0.00	0.00 ± 0.00
BI	0.00	0.00	0.00
BJ	$5.80 \times 10^1 \pm 2.99 \times 10^1$	10.00 ± 5.00	0.00 ± 0.00
BK	$3.80 \times 10^1 \pm 2.00 \times 10^1$	0.00 ± 0.00	0.00 ± 0.00
Mean± SD	$1.29 \times 10^5 \pm 2.89 \times 10^5$	0.91 ±3.18	0.00 ± 0.00
UNBS	**100**	**0**	**0**

TPC = Total plate count, TC = Total coliform and *E. coli* + Escherichia coli. Bottled were coded BA-BK

4.2 Microbial properties of PDW

The result of the Microbial properties of the bottled, handtied, spring and sachet drinking water samples tested in this study are presented in table 4.1, 4.2, and 4.3 respectively. The microbial properties tested includes Total Plate Count (TPC), Total Coliform (TC), and *Escherichia coli (E. coli).*

4.2.1 Microbial properties of bottled water sample

Table 4.2 Fecal contamination in CFU/ml for Handtied Drinking Water sample.

Handtied	**TPC**	**TC**	***E. Coli***
HA	$1.46 \times 10^5 \pm 1.02 \times 10^5$	0.00 ± 0.00	0.00 ± 0.00
HB	$1.24 \times 10^3 \pm 1.85 \times 10^2$	0.00 ± 0.00	0.00 ± 0.00
HC	$3.40 \times 10^5 \pm 9.64 \times 10^4$	9.00 ±26.46	0.00 ± 0.00
HD	$3.33 \times 10^0 \pm 5.77 \times 10^0$	0.00 ± 0.00	0.00 ± 0.00
HE	$2.23 \times 10^4 \pm 2.06 \times 10^4$	553±4.16	0.00 ± 0.00
HF	$4.40 \times 10^4 \pm 7.94 \times 10^3$	0.00 ± 0.00	0.00 ± 0.00
HG	$1.39 \times 10^5 \pm 3.16 \times 10^4$	0.00 ± 0.00	0.00 ± 0.00
HH	$2.37 \times 10^5 \pm 1.53 \times 10^5$	0.00 ± 0.00	0.00 ± 0.00
HI	$1.09 \times 10^6 \pm 9.24 \times 10^5$	0.00 ± 0.00	1.60 ±2.89
Mean± SD	$2.25 \times 10^5 \pm 4.23 \times 10^5$	71.48 ± 210.58	1.30 ± 3.82
UNBS	**100**	**0**	**0**

TPC = Total plate count, TC = Total coliform, *E. coli* = *Escherichia coli.*Handtied (boiled) water were coded HA-HI, CFU/ml = Coliform forming unit per ml

4.2.2 Microbial properties of handtied water samples in CFU/ml

The results of the TPC in the handtied water samples, except for $3.33 \times 10^0 \pm 5.77 \times 10^0$ CFU/ml from sample HD which falls within the recommended permissible limit, but the remaining samples were all contaminated with TPC above UNBS permissible limit. TPC ranged from $3.33 \times 10^0 \pm 5.77 \times 10^0$ CFU/ml to $1.09 \times 10^6 \pm 9.24 \times 10^5$ CFU/ml with the mean TPC values of $2.25 \times 10^5 \pm 4.23 \times 10^5$ CFU/ml. The results for total coliform ranged from 0.00 CFU to $5.53 \times 10^2 \pm 4.16 \times 10^2$ CFU/ml with a mean value for TC of 71.48 ± 210.58 CFU. This implies that all the samples were contaminated with certain microbes. Results for *E. coli* revealed that only one sample was contaminated with 11.67 ± 2.89 CFU/ml from sample HI.

This study is consistent with the findings of Obiri-Danso *et al*., (2003) in Kumasi Ghana who had 7.33 x 10^{12} CFU/ml; is in line with another study conducted in Nigeria by Alaoye and Onilude, (2009) and got 1.62Log CFU/ml. However, sample HC and HE were found contaminated with the TC. All other samples were within the UNBS permissible limit. In a study carried out by Obiri-Danso *et al.* (2003) on the microbiological evaluation of drinking water in Ghana, the authors reported that the water samples were of poor quality. According to them, the occurrence of indicator organisms in the water constitutes a serious threat to the community, and they called for strict observance of good manufacturing practices.

The result is in accordance with the results obtained by Abdul *et al.*, (2014) from Kumasi Ghana who acquired 0.00 - 552 CFU/ml.; also in line with Halage *et al*., (2015) from Kampala who had 0.00 – 65.00 CFU/ml; also similar to the findings of Oluyege *et al.*, (2014) in Nigeria which came out with Log_{10} (5.00 – 5.48)CFU/ml; is also consistent with study conducted in Nigeria by Oyedeji *et al.* (2010) who had TPC ranged from 5-200 CFU/ml and TC from 2-140 CFU/ml.

Table 4.3 Microbial Properties in CFU/ml for Sachet and Spring Water Samples.

Sachet	TPC	TC	*E. Coli*
SA	$4.67 \times 10^{2} \pm 2.61 \times 10^{2}$	0.00 ± 0.00	0.00 ± 0.00
SB	$1.34 \times 10^{3} \pm 3.15 \times 10^{2}$	0.00 ± 0.00	0.00 ± 0.00
SC	$5.67E+01 \pm 4.16 \times 10^{1}$	0.00 ± 0.00	0.00 ± 0.00
Mean ± SD	$6.20 \times 10^{2} \pm 6.03 \times 10^{2}$	0.00 ± 0.00	0.00 ± 0.00
Spring	**TPC**	**TC**	***E. Coli***
SPA	$3.57 \times 10^{4} \pm 1.37 \times 10^{4}$	20.00 ± 0.000	0.00 ± 0.00
SPB	$2.92 \times 10^{5} \pm 1.52 \times 10^{5}$	2.53 ± 0.924	0.00 ± 0.00
SPC	$1.76 \times 10^{5} \pm 6.29 \times 10^{4}$	33.33±11.550	0.00 ± 0.00
Mean ± SD	$1.68 \times 10^{5} \pm 1.39 \times 10^{5}$	26.22 ± 9.400	0.00 ± 0.00
UNBS	**100**	**0**	**0**

TPC = total plate count, TC = Total coliform, *E. coli* = *Escherichia coli*, Sachet water were coded 'S' and has a ranged from SA – SC; while spring water were coded 'SP' and had a ranged from SPA – SPC

4.2.3 Microbial properties of sachet and spring water samples

The results of the microbial properties of the sachet and spring water samples presented in Table 4.6. The mean ± standard deviation of the TPC, TC and *E. coli* for the 6 sachet and spring water samples were presented.

Results for the Total Plate Count (TPC) in sachet water samples ranged from $5.67 \times 10^{1} \pm 4.16 \times 10^{1}$ CFU/ml to $1.34 \times 10^{3} \pm 3.15 \times 10^{2}$ CFU/ml with a mean value for TPC of $6.20 \times 10^{2} \pm 6.03 \times 10^{2}$ CFU/ml. Sample SC passed the TPC test which fell below the permissible limit of 100 CFU/ml while the rest were contaminated. There were no total coliform and *E. coli* detected in sachet water. This result differs from the results obtained by Halage *et al.* (2015) who obtained 0.00-65.00 CFU/ml for sachet water in Kampala. While the result for TPC in spring water revealed that all the samples were contaminated with the total plate count and total coliform. There was no *E. coli* detected in spring water samples. A similar work conducted in Kampala by Halage *et al*. (2015) who got a ranged of 0.00 to 65.00 CFU/ml. Another similar work conducted in Kumasi Ghana on Physicochemical and Microbial properties of Sachet

Water in the Kumasi Metropolis of Ghana by Abdul *et al.* (2014) who had total coliform at a ranged from 0.00-552 CFU/ml. The study is in line with another study conducted in Nigeria by Oyelude *et al.* (2012) who had TC ranged from 12 CFU/ml - 168 CFU/ml.

4.3 Trace Metal analysis.

The results of the trace metals analysis for bottled water, handtied, sachet and spring water samples presented in Table 4.7. The mean ± standard deviation of the Pb, Cu, Fe, Mn and Zn. for the bottled water samples were presented.

4.3.1 Trace metal concentrations in bottled water samples

Lead results for bottle water samples ranged from 0.000 ± 0.000 to 0.012 ± 0.002 mg/L with a mean value for lead of 0.006 ± 0.006 mg/L. Three samples were slightly higher than the UNBS permissible limit of 0.01 mg/L and these were sample BA, BD and BK. The presence of lead in these samples can be attributed to human activities around the location of the water sources. All other samples for lead were within the UNBS recommended limit. The results differ from the finding of Yusif *et al.* (2018) form Nigeria, whose result was undetected in all the samples. Similar to the study conducted by Eman *et al*. (2011) in Egypt, who arrived with 13.57± 1.78 µg/L. Result for Copper ranged from 0.01 ± 0.001 to 0 006 ± 0.001 mg/L with a mean value for copper of 0.003 ± 0.002 mg/L. This finding differs from the findings of Yusif *et al*. (2018) form Nigeria whose values for copper ranged from 0.802 ± 500 to 3.032 ± 0.400 mg/L. This result also consistent with the findings of Uduma and Uduma, (2014) where the authors reported value for copper ranged from 1.0 – 1.5 mg/L.

The results for Iron in Table 4.4, ranged from 0.000 ± 0.000 mg/L to 0.079 ± 0.016 mg/L with mean Iron value of 0.026 ± 0.024 mg/L. All the results for Iron fell within the UNBS recommended limit. This result differs from the findings of Eman *et al*., (2011) whose result was719.78 ± 118.13 mg/L; result of this work also concurs with the study conducted by Uduma and Uduma, 2014 where the authors reported a ranged for Iron of 0.01-1.0 mg/L. Results for Manganese also showed the ranged from 0.000 ± 0.000 mg/L to 0.007 ± 0.003 μg/L with mean value for manganese of 0.003 ± 0.002 mg/L. All the results for manganese fell within the UNBS recommended limit. The result concurs with the findings of Yusif *et al*. (2018), whose findings was in Nigeria and got 0.008 ± 0.100 mg/l, to 0.03 ± 0.100 mg/L.

Result for Zinc revealed the ranged from 0.007 ± 0.002 mg/L to 0.009 ± 0.007 mg/L with mean value for Zinc of 0.010 ± 0.005 mg/L. All the values fell within the UNBS recommended limit. This result agrees with the findings made by Yusif *et al*. (2018) in Nigeria where the authors reported the values for Zinc ranged from1.002 ± 0.100 mg/L to 3.513 ± 1.000 mg/L. This study is also in line with another study conducted in Nigeria by Uduma & Uduma, (2004) who investigated Zinc and Arrived with 2.50 mg/L.

4.3.2 Trace metal concentrations in handtied water samples

Lead concentrations in handtied water samples ranged from 0.002 ± 0.001 mg/L to 0.022 ± 0.021, with mean lead value of 0.011±0.010 mg/L. The result for lead is slightly above the UNBS recommended limit in samples HB, HC, HD, HE and HF with HB having the highest concentration. This can be attributed to battery work around the area or presence of automobile technical work within the water source. The result differs with the finding of Yusif *et al.*, (2018) form Nigeria whose values were undetected by the machine. This shows that the concentrations were too low, beyond the capacity of such model machine to detect from all the samples. Most of the water samples in the Handtied water sample were contaminated with slight amount of Lead probably, these contaminations occur due to human activities at the water sources. Results for copper showed the ranged from 0.004 ± 0.002 to 0.035 ± 0.017 mg/L. with mean copper value of 0.018 ± 0.014 mg/L. The result agreed to the findings of Yusif *et al.*, (2018) form Nigeria whose results were 0.802 ± 0.5000 to 3.032 ± 0.400 mg/L.

Results for Iron in Table 4.5, showed the ranged from 0.014 ± 0.006 to 0.091 ± 0.002 mg/L. All the parameters fall within the permissible limit. This is in line with the findings of Abdul *et al.* (2014) who conducted research in Kumasi Ghana on the Physicochemical and Microbial properties of Sachet Water in Kumasi Metropolis of Ghana and got 0.000 mg/L. Still in Table 4.5, result presented for Manganese revealed the ranged from 0.003 ± 0.001 mg/L to 0.021 ± 0.007 mg/L with mean value of0.010 ± 0.006 mg/L. This showed that all the parameters fall within the recommended safe limit. This result has showed similarity with a research conducted in Nigeria by Yusif *et al*., (2018) and got a ranged from 0.008 ± 0.100 to 0.030 ± 0.100 mg/L with mean value for manganese of 0.010 ± 0.006 mg/L. It is also in consistent with the study conducted in Cambodia by Buschmann *et al*., (2007) who had a range of0.1-0.9mg/L.

Results for zinc ranged from 0.004 ± 0.003 to 0.050 ± 0.035 mg/L with mean value for Zn of 0.026 ± 0.018 mg/L. All the results were within the UNBS recommended limit. This result is in line with findings of Yusif *et al*., (2018) who got 1.002 ± 0.100 to 3.513 ± 1.000 mg/L The result also concurs with the finding of Uduma and Uduma, (2014) who had 2.50 mg/L.

4.3.3 Trace metal concentration in sachet water samples

Results for lead range from 0.003 ±0.001 mg/L to 0.018 ±0.010 mg/L with mean value for lead of 0.013 ± 0.009 mg/L. The level of Lead in two of the sachet water samples (SB and SC) and one of the spring water sample (SPB) were found to be contaminated higher than the recommended UNBS limit. This may be attributed to the human activities taken place at around the water sources. However, one of the samples in sachet and two of the spring water samples were within the permissible limit. The result is in line with the work conducted by Uduma and

Uduma, (2014) who obtained the range for lead from 0.01 mg/L- 0.05 mg/L. The result is consistent with the findings of Eman *et al*. (2011) in Egypt, who had value for lead of 0.014 ± 0.002 mg/L.

Copper results range from 0.000 ± 0.000 mg/L to 0.004 ± 0.001 mg/L with mean value for copper of 0.001 ±0.002 mg/L. However, all the samples were within the UNBS recommended limit. The result is in lined with the findings of (Guler et al., 2007) who had 0.09 - 1.00 mg/L. The result is also in consistent the report from Uduma and Uduma, 2014 that got 1.0-1.5 mg/L (Cu). Result for Iron range from 0.018 ± 0.005 mg/L to 0.025 ± 0.008 mg/L with mean value for Iron of 0.021 ± 0.007 mg/L. All the samples fell within the permissible limit. This result concurs with the findings of Kashyap, (2016) who had a range for Iron from 0.075 ± 0.00 mg/L to 0.095 ± 0.00 mg/L .The result also is in line with the findings of Akpoborie & Ehwarimo, (2012) who had value for Iron of 0.00 – 0.003 mg/L.0.001 ± 0.001 mg/L to 0.002 ± 0.002 mg/L with mean value for Manganese of 0.002 ± 0.001 mg/L. This study is consistent with the work of Buschmann *et al*. (2007) who had a mean value for manganese of 0.097± 0.028 mg/L. This result showed similarity to the findings of Azlan et a*l.* (2012) who had0.05–0.21 mg/L.

Result for Zinc in sachet water sample range from 0.017 ± 0.003 mg/L to 0.024 ± 0.002 mg/L with mean value for Zinc of 0.021 ± 0.004 mg/L. All the samples were within the UNBS recommended limit. This result is in line with the findings of Uduma and Uduma, (2014) who got 2.50 mg/L. The result is in line with the findings of Azlan *et al*. (2012) who got values range from 0.002 mg/L 0.10 mg/L.

4.3.4 Trace metal concentrations in spring water samples

While, result for lead in the spring water samples range from 0.003 ± 0.001 mg/L to 0.013 ± 0.002 mg/L with mean value for lead of 0.008 ± 0.004 mg/L. The mean value for lead in spring water sample is within the recommended UNBS limit. This result is consistent with the findings of Akpoborie & Ehwarimo, (2012) in Nigeria who got 0.00 – 0.002 mg/L. The result is similar to the study conducted by Uduma & Uduma, (2014) who had 0.01 – 0.05 mg/L. Result for copper in the spring water samples range from 0.002 ± 0.001 to 0.005 ± 0.002 mg/L with mean value for copper of 0.003 ± 0.001 mg/L. All the values for copper in the spring water samples were within the recommended UNBS limit. This result is in line with the findings of Buschmann, (2007) who had a range for copper from 2.60 - 31.00 mg/L; also, in line with Uduma & Uduma, (2014) who had 1.00 – 1.50 mg/L.

Result for Iron in the spring water range from 0.015 ± 0.006 mg/L to 0.028 ± 0.012 mg/L with mean value for Iron of 0.022 ± 0.001 mg/L. All the values fell within the UNBS recommended limit. The result concurs with the findings of Eman *et al.* (2011) who had 833.60 ± 78.48 mg/L; also concurs with another study conducted by Bachmann *et al.* (2007) who obtained values for Iron range from < 0.05-10 mg/L with a mean value for iron of 1.0 mg/L. The result for Manganese in the spring water range from 0.075 ± 0.005 mg/L to 0.134 ± 0.009 mg/L with a mean value for manganese in the spring water of 0.097 ± 0.028 mg/L. All the result fell within the recommended UNBS limit. This study is in line with the findings of Buschmann et al., (2007) who had a range from <0.10 - 2.60 mg/L with a mean value for Manganese of 1.10 mg/L. Result for Zinc ranged from 0.017 ± 0.005 to 0.120 ± 0.016 mg/L with a mean value for Zinc of 0.053 ± 0.051 mg/L. The value for Zinc is within the recommended UNBS limit. This result is in line with the work of Uduma & Uduma, (2014) who got 0.03 – 1.00 mg/L. the study is consistent with the findings of Azlan *et al*., (2012) who had value for Zinc of 0.40 – 24.30 mg/L.

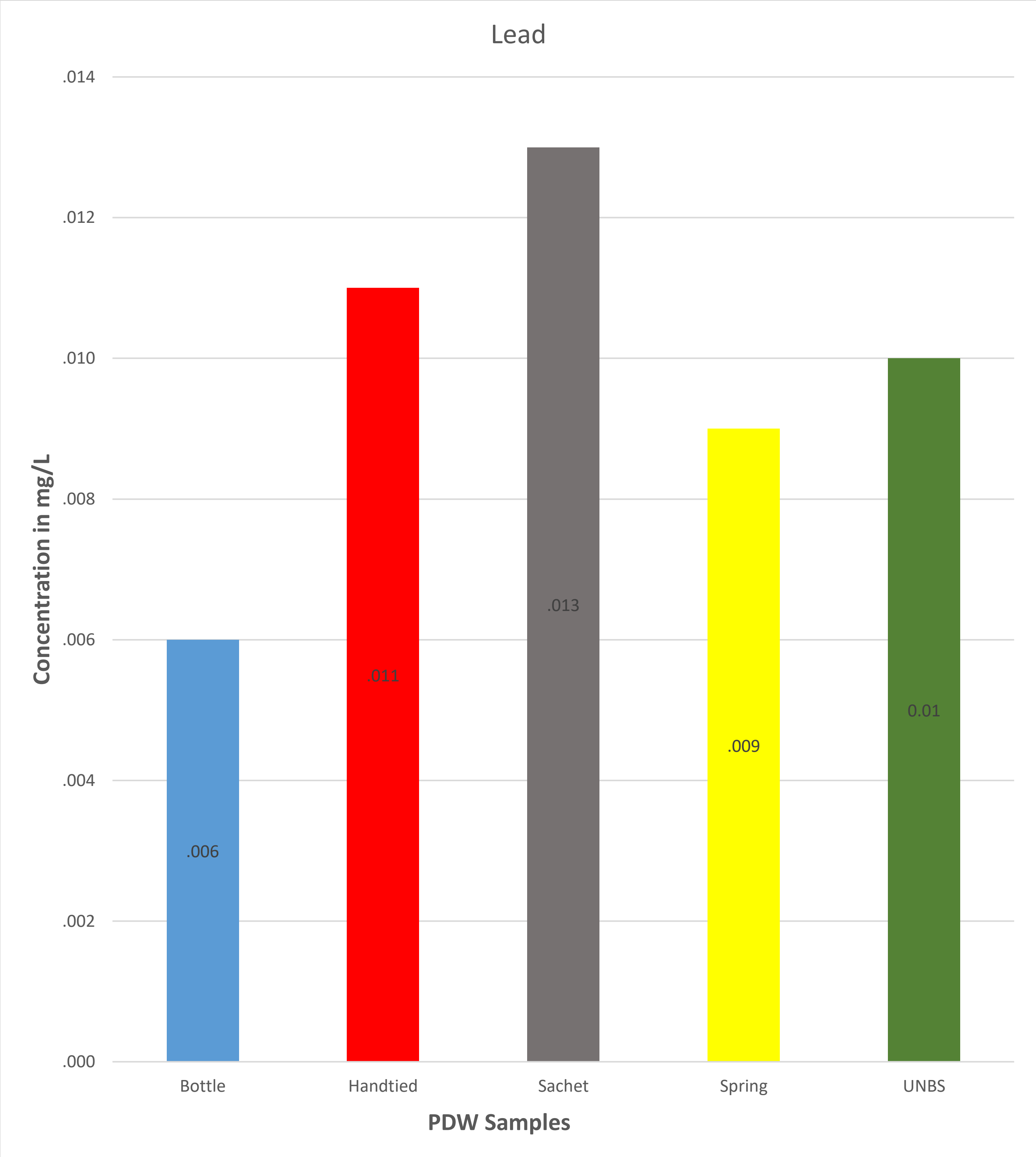


Figure 4.10 level of Lead in mg/L in PDW samples

Results presented in the chart above revealed the level of lead in PDW samples. The range is in the order: Sachet > Handtied > Spring > Bottled water sample. All the parameters determined were within the recommended limit of the UNBS.

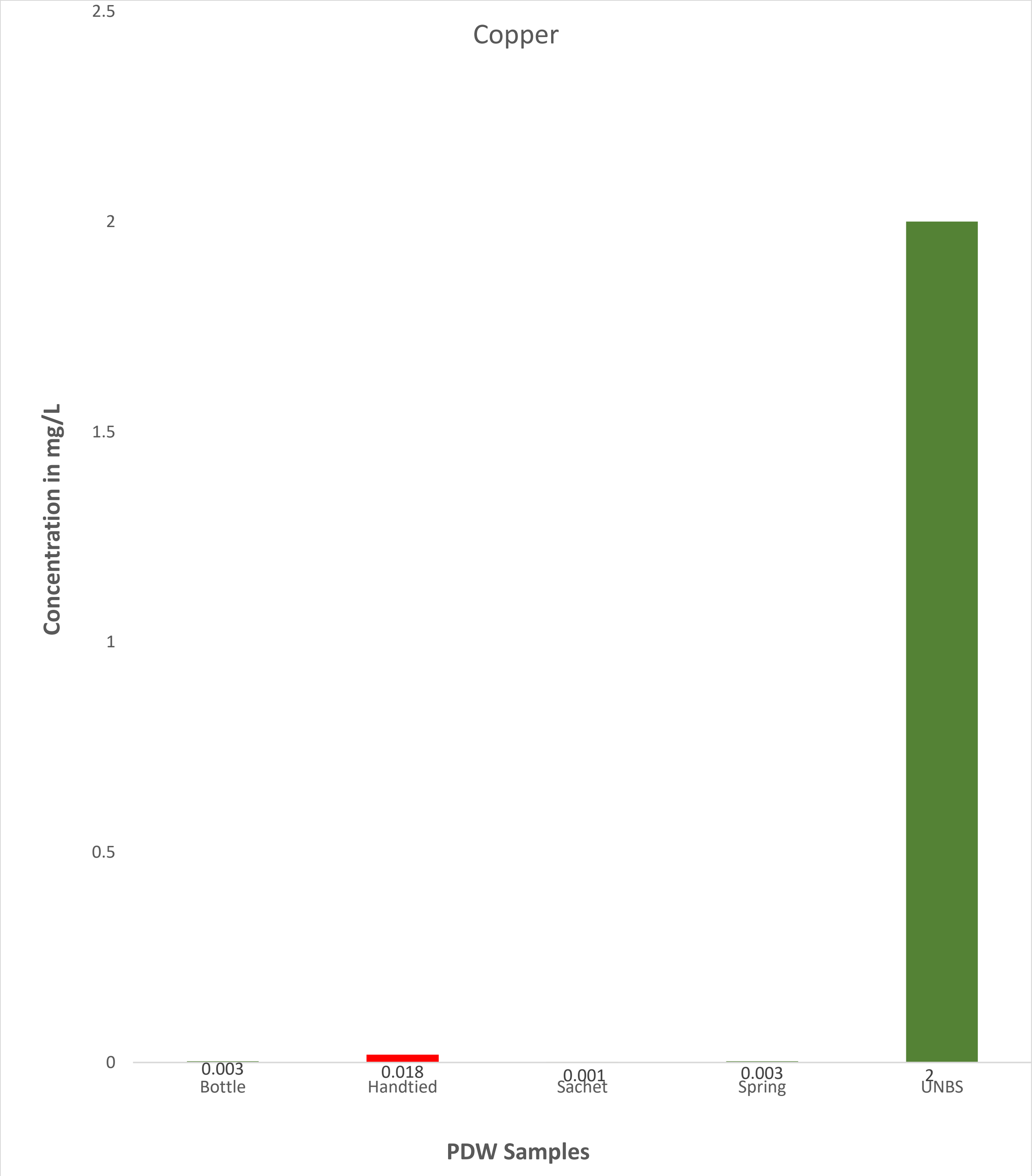


Figure 4.11 level of copper in mg/L in PDW Samples

Results presented in Figure 4.11 revealed the range of copper: Handtied >Bottled > Spring > Sachet water sample. All the parameters determined were within the recommended limit of the UNBS.

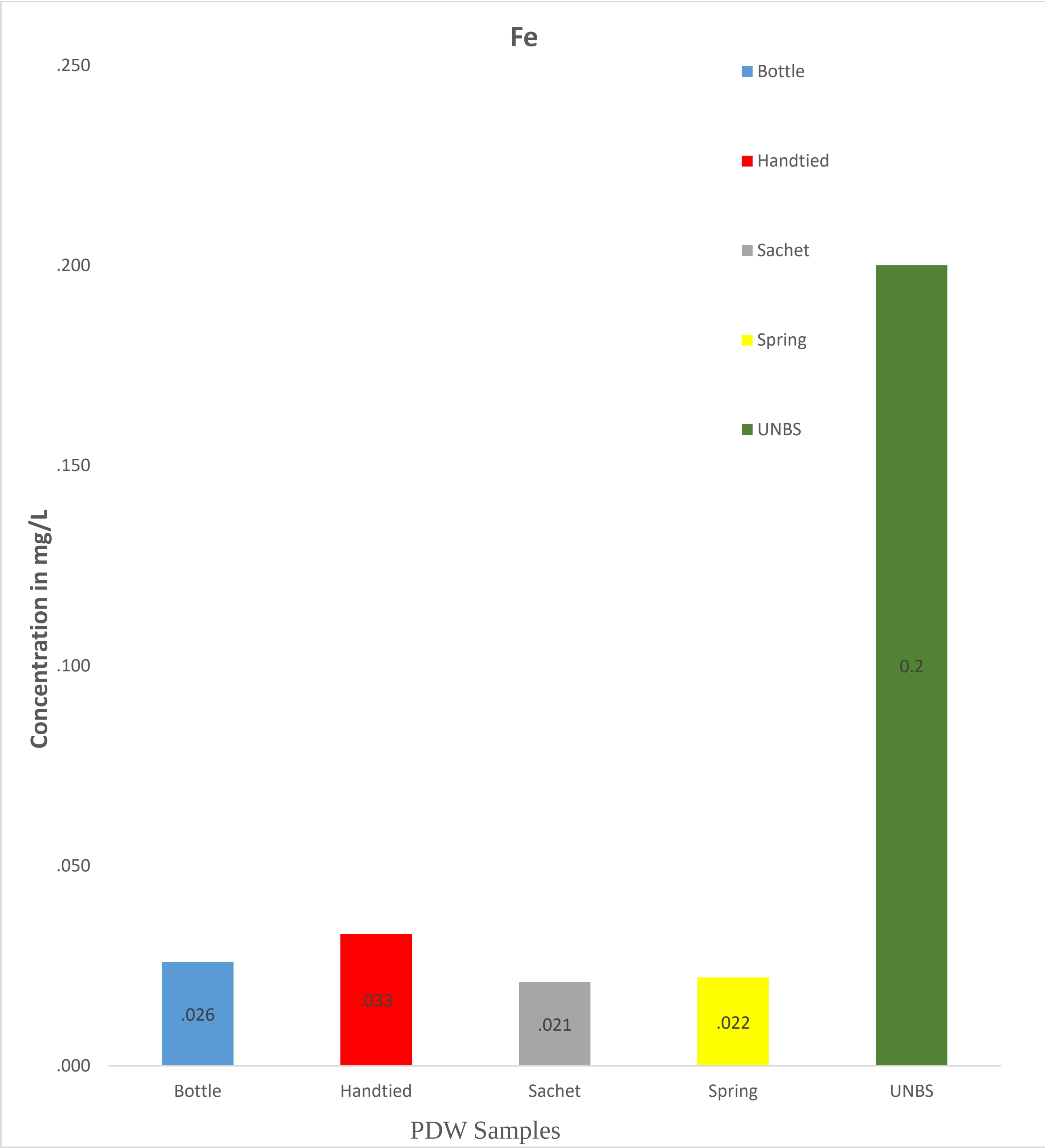


Figure 4.12 Level of Iron in mg/L in PDW Samples

Results presented in Figure 4.12 revealed the level of Iron in mg/L in the PDW Samples as follows: Handtied > Bottled> Sachet > Spring water Sample. All the parameters determined were within the recommended limit of the UNBS.

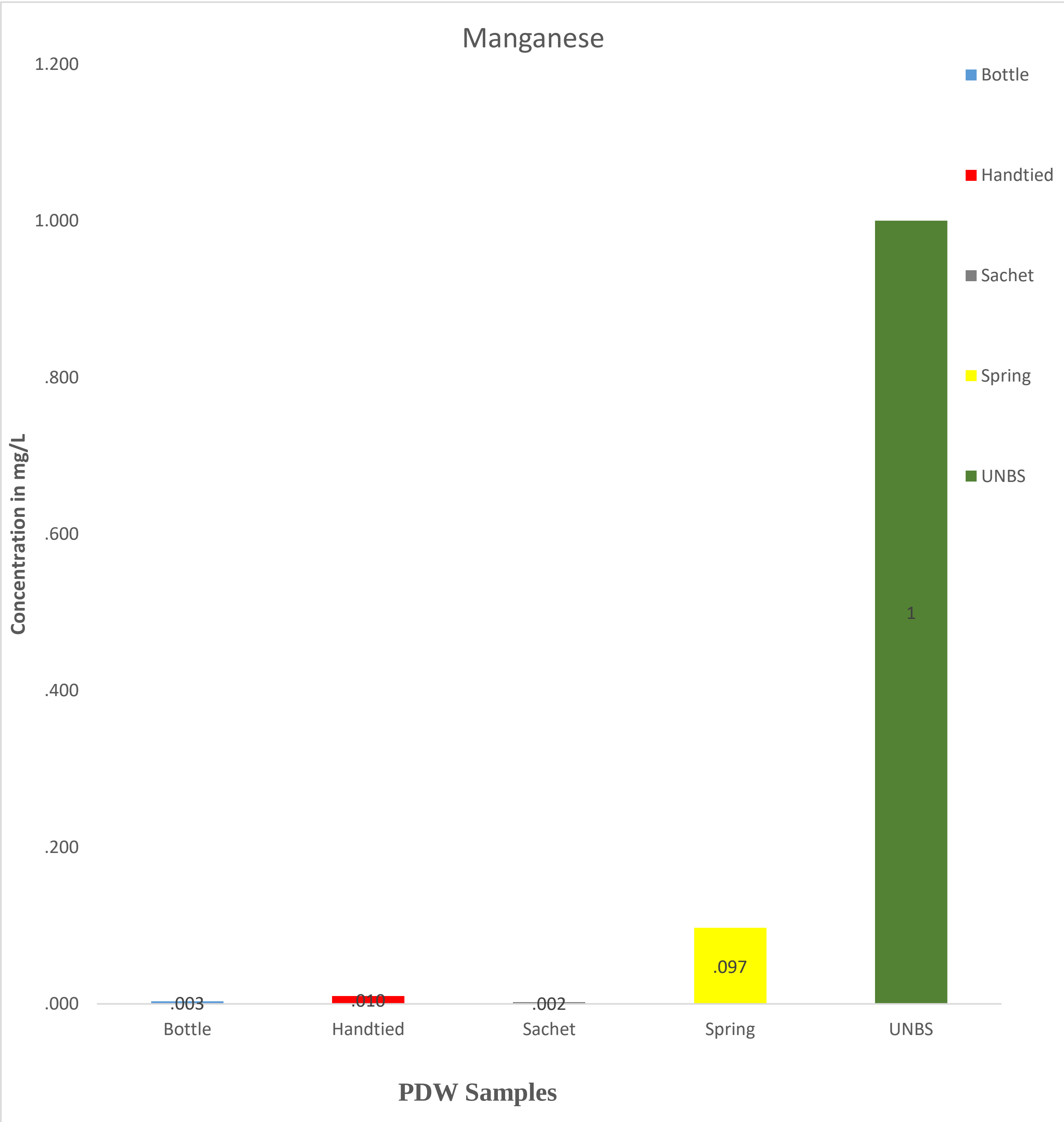


Figure 4.13 Level of Manganese in mg/L in the PDW Samples

Results presented for Manganese in Figure 4.13 revealed that Spring > Handtied water > Bottled > Sachet water Sample. All the parameters determined were within the recommended limit of the UNBS.

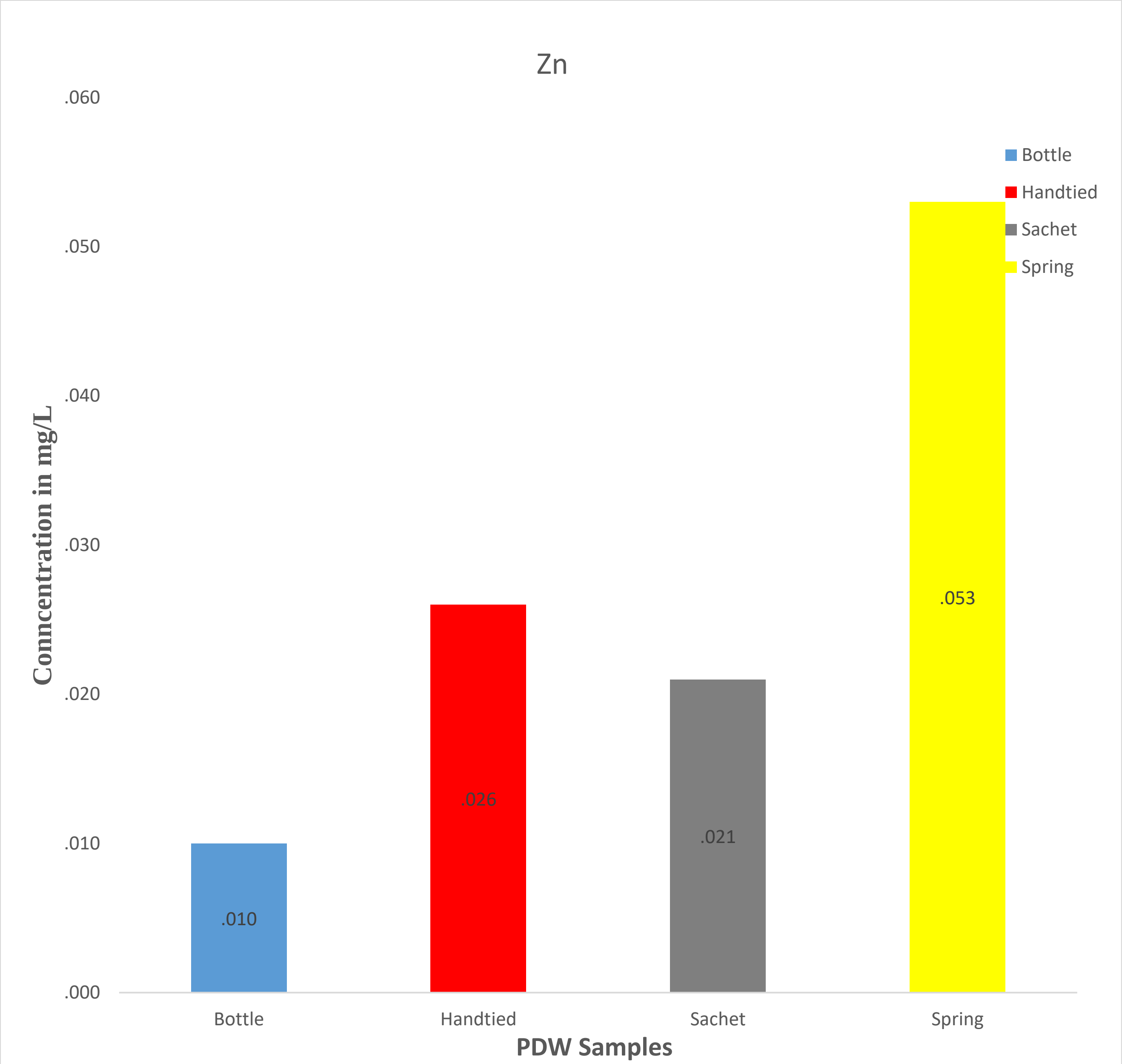


Figure 4.14 Level of Zinc in mg/L in the PDW Samples

The level of lead is in the order: sachet water > handtied > spring > bottle water. The level of copper result is in the order: Handtied > spring > Bottle > sachet water sample. For iron, is in the order: bottle > Handtied > spring > sachet water sample. For Manganese: spring water > handtied > bottle > sachet water sample. The result for Zinc is in the order: spring water sample > handtied > sachet > bottle water sample.

4.4 Data Analysis

4.4.1 Analysis of variance

Analysis of variance (ANOVA) was carried to test the hypothesis (H_o) that there were no significant difference in the levels of the parameters of the four PDW samples test. The results of the ANOVA test for the properties of the PDW samples are presented in Table 4.11. The values for the sum of squares, degree of freedom (Df), the mean square, F and significance level (Sig.) are also presented in Table 4.11.

Table 4:4 Analysis of Variance (ANOVA)

Parameters	Sum of Squares	Df	Mean Square	F	Sig.
PH	1.884	3	.628	1.101	.354
E.C.	591160.302	3	197053.434	20.635	.000
Colour	190.043	3	63.348	25.959	.000
Turbidity	26.963	3	8.988	6.873	.000
TPC	368395282580.468	3	122798427526.823	1.214	.311
T.C.	82349.130	3	27449.710	1.760	.162
E. coli	29.665	3	9.888	1.928	.132
Alkalinity	13630.938	3	4543.646	4.872	.004
Nitrogen	.155	3	.052	3.117	.031
P	.004	3	.001	2.670	.054
Cl	362.963	3	120.988	6.829	.000
T.H.	8630.596	3	2876.865	14.257	.000
Pb	.001	3	.000	3.589	.018
Cu	.004	3	.001	17.249	.000
Fe	.002	3	.001	1.104	.353
Mn	.067	3	.022	227.078	.000
Zn	.014	3	.005	11.045	.000

Parameters, Df = degree of freedom, Mean square, F= test and sig., pH, E.C electrical conductivity, TPC, TC = Total coliform, *E.coli* = *Escherichia coli*, P= Phosphorus, Cl = Chloride, T/H = Total hardness, Pb = Lead, Cu = copper, Fe = Iron, Mn = manganese, and Zn = Zinc.

The ANOVA results indicated that there were no significant differences in the levels of pH, TPC, TC, E. coli, P and Fe in the PDW samples. The implication of this finding is that care should be taken in the consumption of PDW samples, since parameters like TPC and TC have values greater than the recommended limit. This study also reported that there were significant differences in the level of microbial properties of sachet water samples. There were significant variations in the values of the EC, Colour, turbidity, alkalinity, and nitrogen, Cl, TH, Pb, Cu, Mn and Zn in the samples. To investigate where sources of the differences in parameter found in the PDW samples, pair wise multiple comparison was carried out using the Fischer Least Significant difference (LSD) post-hoc test at 0.05 confidence level. The results of the LSD test are presented in Table 4.5. Superscript a, b, c, were used to indicate significant differences between the parameters of PDW samples types. The values of the LSD errors are also presented.

Table 4.5: Multiple comparison by Least Significant Difference (LSD).

Parameter	PDW types	Error	Sig.
EC.	$Bottle^{a}Handtied^{a,c}$,$Sachet^{c}Spring^{b}$	250.3585	a = 0.000, b = 0.000, c = 0.033
Colour	$Bottle^{a}$, $Handtied^{,c}$, $Sachet^{b}Spring^{b,c}$	0.4054	a = 0.000,b = 0.000,c = 0.009,
Turbidity	$Bottle^{a}$, $Handtied^{ab}$, $Spring^{b}$	0.2967	a = 0.000,b = 0.000
Nitrogen	$Bottle^{a}$, $Handtied^{a}$, $Spring^{b}$	0.033357	a = 0.046,b = 0.046,
Chloride	$Bottle^{a}$, H-$tied^{b}$, $Sachet^{c}$,$Spring^{a,b,c}$	1.58280	a = 0.000,b = 0.001,c = 0.000
TH	$Bottle^{a}$, $Handtied^{b}$, $Spring^{ab}$	3.68621	a = 0.000,b = 0.008,
Lead	$Bottle^{c}$, $Handtied^{b}$, $Sachet^{ab}$	0.001987	a = 0.007,b = 0.007,
Manganese	$Bottle^{a}$,$Handtied^{c}$, $Sachet^{b}Spring^{abc}$	0.002581	a = 0.010, b = 0.010, c = 0.807,
Zinc	$Bottled^{a}$, $Handtied^{b}$ $sachet^{c}$, $Spring^{abc}$		a = 0.004,b = 0.004,c = 0.000

LSD = Least significant difference; EC = Electrical Conductivity; TH = Total hardness; Sig. = Significant; Superscript (a, b, c,) is significant at 0.05 Confidence level

ANOVA results for electrical conductivity (F: 3, p = 0.05) indicated significant differences, and the bulk of this difference comes from the spring water sample at (abc), where a = 0.000, b= 0.000, and c= 0.033 level of confidence. The sachet and bottle water samples show the least difference at c = 0.033 level of confidence. For colour results in the LSD, the significance difference obtained was from the bottle water sample which has the least colour on comparison to the other 3 samples. For the turbidity, the bulk difference comes from Hand tied at ab, where a = 0.000 and b = 0.000 confidence level. This is obvious because handtied and spring water samples do not used sophisticated filtering machines in order to effectively filter the water as they do for bottle and sachet water sample. For nitrogen LSD result showed that there is significant difference between bottle water and spring water samples.

This has showed the same in the results from Table 4.1 and 4.3 with mean values of 0.177 ± 0.120 and 0.051 ± 0.033mg/L respectively. LSD results for Chlorides showed significant difference between bottle, handtied and sachet at sig. = 0.000^{a}, 0.001^{b}, 0.000^{c}. However, there is interaction between bottle water and spring, handtied and spring, sachet and spring. The LSD results for the total hardness showed that there is significant difference in the level of total hardness between handtied and spring at sig. = 0.000^{a}, and 0.008^{b} the bulk of this difference can be seen in the results in Table 4.2 and 4.3 with the mean values of 53.23 ± 16.91 and 50.58 ± 17.49 mg/L.

The results from Table 4.1 and 4.3 showed the Lead mean values of 0.00 ± 0.00 mg/L for bottle and spring water samples while Handtied and sachet water mean values of 0.011 ± 0.010 mg/L and 0.013 ± 0.009 mg/L. The LSD results for lead showed that there is significant difference between bottle, handtied and sachet water samples. The bulk of these difference come from handtied and sachet at sig. = 0.007a, and 0.007b. However, there is significant interaction between bottle/handtied and bottle/ sachet. Post hoc ANOVA results for Manganese showed significant difference in the level of manganese in all the four different samples at sig. = 0.010^{a}, 0.010^{b}, 0.800^{c}, and 0.000^{d}. The bulk of this Differences lied with the sachet and bottle water being the least in manganese level. LSD results for zinc showed that there is significant difference in the level of zinc in the bottle, handtied, and sachet and spring water samples at 0.004^{a}, 0.004^{b}, 0.000^{c}. The bulk of these differences lied with the spring water. The value for zinc; Table 4.7 has 0.010 ± 0.005mg/L while the mean for the handtied from Table 4.8 of 0.026 ± 0.018 mg/L, sachet mean value of 021±.004 and the spring mean value of 0.053 ± .051 mg/L This showed that spring water sample carried the bulk of the difference at (abc).

Table 4.6, Pearson Correlations

	pH	E.C.	Color	Turb.	TPC	TC	*E. Coli*	Alk.	N	P	Cl	T/H	Pb	Cu	Fe	Mn	Zn
pH	1																
EC	-0.063	1															
Colour	-0.245*	0.502**	1														
Turb.	-0.067	0.140	0.407**	1													
TPC	0.231*	-0.036	0.125	0.290*	1												
TC	0.001	0.001	-0.082	0.071	-0.049	1											
E. coli	0.114	0.043	0.055	0.341**	0.487**	-0.044	1										
Alk.	0.116	0.207	0.061	0.414**	0.391**	-0.098	0.556**	1									
N	-0.150	0.253*	0.248*	0.180	0.174	-0.012	0.215	0.105	1								
P	0.153	0.124	-0.068	-0.242*	0.038	-0.211	0.072	-0.061	0.040	1							
Cl	0.015	0.506**	0.221	0.151	-0.044	0.018	-0.064	0.265*	0.185	-0.052	1						
T/H	-0.079	0.376**	0.384**	0.123	0.220	0.112	0.106	0.356**	0.075	-0.381**	0.293**	1					
Pb	0.045	0.121	0.097	-0.075	-0.139	0.271*	-0.173	-0.228*	0.106	-0.054	0.117	0.103	1				
Cu	-0.051	0.207	0.385**	0.270*	0.051	0.024	-0.082	-0.021	-0.050	-0.119	0.044	0.187	0.101	1			
Fe	0.299**	0.173	0.015	-0.086	-0.036	-0.020	0.020	0.059	0.025	0.220	-0.088	-0.168	0.162	-0.042	1		
Mn	-0.157	0.626**	0.437**	0.139	-0.012	0.008	-0.052	0.255*	0.302**	-0.174	0.330**	0.522**	-0.050	-0.079	-0.101	1	
Zn	-0.103	0.401**	0.605**	0.228*	0.196	-0.067	0.149	0.134	0.145	0.011	0.379**	0.292**	0.155	0.003	0.040	0.372**	1

Correlation is significant at 0.05 Confidence level, **correlation is significant at 0.001; EC = Electrical Conductivity in micro Siemens per centimeter (μS/cm), Color measured in True Colour Unit (TCU), Turb. = Turbidity Nephelometric Tessa Unit (NTU), Alkalinity in milligram per litre (mg/L), N = Nitrogen in milligram per litre (mg/L), P = Phosphorus, is measured in milligram per litre (mg/L), Cl = Chloride in milligram per litre (mg/L). TH = Total Hardness in milligram per litre (mg/L). (BA-BK) = codes for Bottled water. UNBS = Ugandan National Bureau of Standards

4.4.2 Pearson correlation analysis

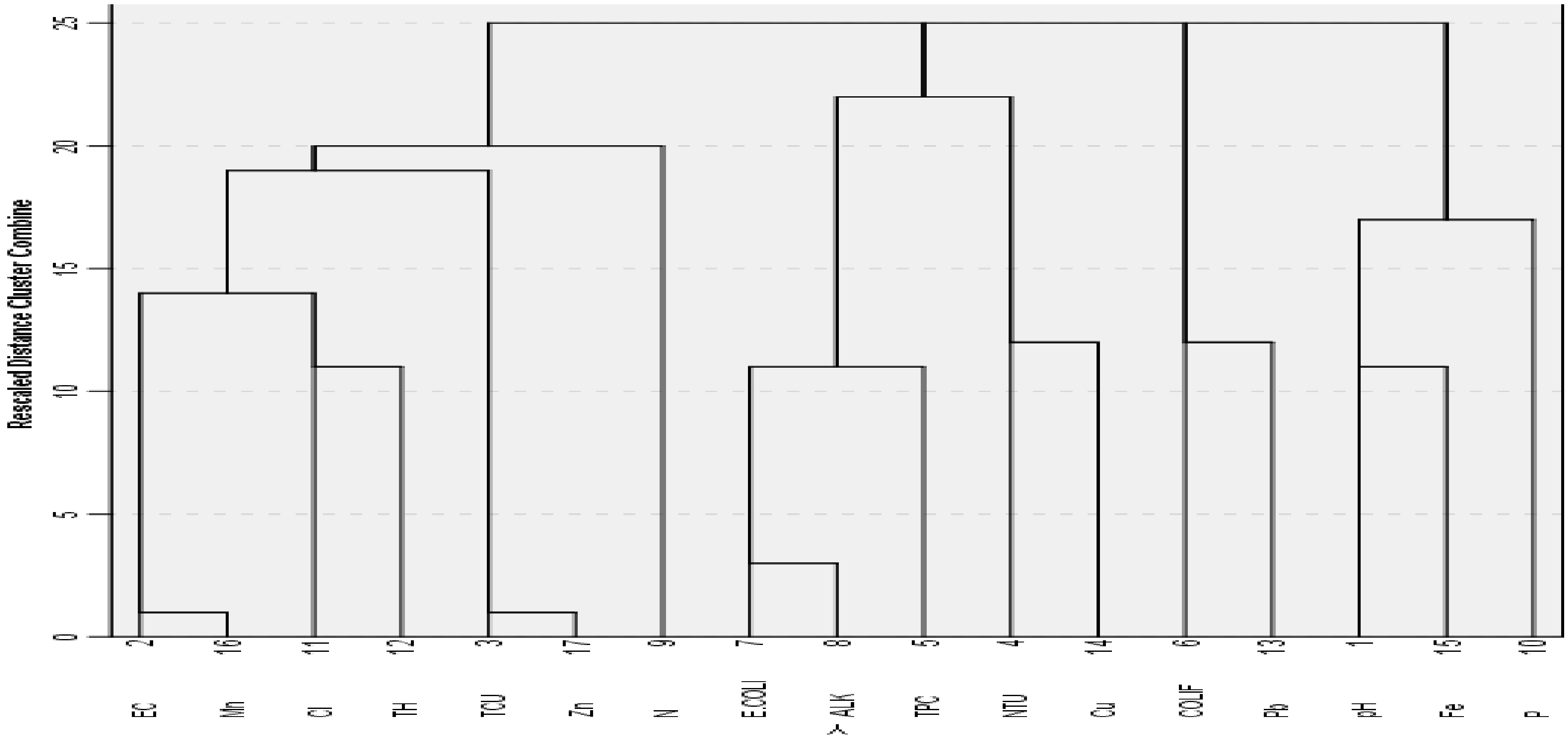
Pearson correlation analysis was carried out to see where there is an association in the properties of the drinking water samples. The result of the correlation analysis is presented in Table 4.6. The correlation was performed at $\alpha = 0.05$ and $\alpha = 0.01$ level in a 2-tailed test. From the correlation matrix in Table 4.6, pH and electrical conductivity were poorly and negatively correlated (-0.063). This is attributed to the fact as the concentrations of mobile ions in water increases, the water tends to become more acidic and hence a decrease in pH. This is contrary to the findings of Aris et al. (2013) who recorded strong positive correlation ($r = 0.742$) between pH and EC in bottled water samples in Malaysia. Colour correlated with pH and electrical conductivity at -0.245 and 0.502 confidence level respectively. While turbidity correlated with colour at 0.407 level of confidence and the total plate count correlated with pH and turbidity all at 0.231 and 0.290 level of confidence. *Escherichia coli* correlated with turbidity and TPC at 0.341 and 0.487level of confidence. Alkalinity was found correlated with turbidity, TPC and *E. coli* all at 0.414, 0.391 and 0.556 confidence level respectively. While nitrogen correlated with electrical conductivity and colour at 0.253 and 248 level of confidence respectively. Phosphorus was found correlated with turbidity at -0.242. However, Chloride correlated with electrical conductivity and alkalinity at 0.506 and 0.265 confidence level respectively. Total hardness correlated with electrical conductivity, colour, and alkalinity, and inversely correlated with phosphorus at 0.376 and 0.384, 0.356, 0.293 and -0.381 confidence level respectively.

Lead correlated with TC and inversely correlated with alkalinity at 0.271 and -0.228 level of confidence respectively. While Copper correlated with colour and turbidity at 0.385 and 0.270 confidence level respectively. There is also correlation in Iron with pH at 0.299 confidence level. Manganese correlated with electrical conductivity, colour, alkalinity and nitrogen at 0.626, 0.437, 0.255, 0.302, 0.330 and 0.522 confidence level respectively. There are correlations in zinc with electrical conductivity, colour and turbidity at 0.401, 0.605, 0.379, 0.292, 0.372 at 99% and 0.228 at 95%level of confidence respectively.

4.4.3 Dendrogram Centroid Linkage

Figure 4.4 is a dendrogram showing the distance of correlation by centroid linkage between the tested parameters of the PDW samples. The distance in relationship between the tested parameters is an indication of the closeness in correlation of the parameters. The distance between each parameter in the dendrogram was calculated using the variance by varimax rotation. The longer the distance between the parameters, the weaker the correlation. Strong positive correlation can be seen between EC and Manganese. This implies that the mean EC in the PDW samples was greatly influenced by the concentration of the metal in the samples. This is also confirmed in the correlation matrix of Table 4.13. The mean concentration of Chloride and the total hardness in the water also correlate closely with EC. Negative correlation can be found between the EC and the mean values of the pH, Fe, and phosphates in the PDW samples. This indicates that EC or mineral concentration of the drinking water samples can be increased by reducing the pH and, also phosphates in the water. A weak negative correlation is also visible in the correlation matrix. Colour and zinc were also closely linked. This implies zinc grossly influenced the colour of the samples. Another useful correlation is the linkage between the turbidity levels and the presence of Cu in the samples. Lead concentration in the samples correlates with the level of total coliform.

DENDROGRAM USING CENTROID LINKAGE



EC = Electrical Conductivity in micro Siemens per centimeter (µS/cm), Color measured in True Colour Unit (TCU), Turb. = Turbidity Nephelometric Tessa Unit (NTU), Alkalinity in milligram per litre (mg/L), N = Nitrogen in milligram per litre (mg/L), P = Phosphorus, is measured in milligram per litre (mg/L), Cl = Chloride in milligram per litre (mg/L). TH = Total Hardness in milligram per litre (mg/L). (BA-BK) = codes for Bottled water. UNBS = Ugandan National Bureau of Standards.

Figure 4.15 Dendrogram using centroid linkage of parameters in packaged drinking water

CHAPTER FIVE

5.0 Conclusion and Recommendations

5.1 Conclusion

Physicochemical properties analyzed in all the samples were within the recommended UNBS limit. Critical study of Handtied and spring water samples reveals that there is high contamination of the total plate count, total coliform, in the spring water sample, while the least were from the bottled water. As earlier discussed, no total coliform was detected in sachet water sample, *E. coli* was only found in one of the handtied water sample, but all other samples were free of the *E. coli*. Fecal contamination was in the order: bottled water < sachet<handtied< spring water sample. Spring water samples were highly contaminated with Total Plate Count and Total Coliform in all the samples.

Except for lead handtied and sachet water samples. The level of trace metals was within the UNBS recommended permissible limit.

In the final analysis the study concludes by arguing that Bottle water is the most portable and safety in all the PDW samples investigated. Equally, this study has enriched our understanding of the nature of the investigation of the Physicochemical, microbial, and trace metals properties of PDW sold in Kansanga.

5.2 Recommendations

1. The UNBS should strengthen their effort to ensure that the manufacturers keep to standards as is regulated by the agency.

2. One should know the hygiene status of the person/place that prepared the Hand-tied water before buying and even consuming.

3. There is need for manufacturers to put more effort during the processing, transportation and storage.

4. Effort should be made by the manufacturers to control the level of metals.

5. Sanitary practices be adopted to reduce the level of contaminants especially in Hand-tied and spring water,

6. Research should be done regularly for all hand-tied and sachet drinking water. As this may ensure regulation and safety in the future.

It is also recommended that more research should be conducted on toxic metals such as chromium, cadmium, arsenic, molybdenum and mercury as well as biological pathogens such as *Salmonella typi, Klebsiella, and Enterococcus spp., and Pseudomonas aeruginosa* should also be investigated.

Possession of hygiene certificates from UNBS by staff of organizations seeking a licensee for the production of sachet-packaged drinking water could be a useful criterion before approval is given.

5.3 Contribution to Knowledge

The study contributes toward validating as well as determination of the physicochemical, microbial parameters and some selected trace metals which are all water quality indicators. Handtied (boiled) water which is now competing with the sachet water is actually containing less microbes when comparing to the spring water. This research helps contributes by bridging the gap established in previous studies and could serve as a reference material for researchers. Finally, it opens a window upon which further research could be conducted.

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APPENDICES

Appendix 1: Results in Triplicates.

SN	ID	Rep	TPC	TC	*E. coli*	NTU	ALK.	Cl	TH	N	Pb	Cu	Fe	Mn	Zn	pH	E.C.	TCU	P
1	BA	1	159000	0	0	3.20	67.00	3.62	50.50	0.240	0.013	0.000	0.089	0.001	0.011	8.300	182.00	0.0	0.04
2	BA	2	21000	0	0	3.00	40.00	4.46	50.20	0.284	0.013	0.000	0.060	0.001	0.014	8.600	124.00	0.0	0.04
3	BA	3	124000	0	0	2.90	52.00	3.78	55.40	0.402	0.010	0.000	0.088	0.001	0.001	8.400	136.00	0.0	0.04
4	BB	1	1050000	0	0	3.50	60.00	2.62	30.60	0.246	0.001	0.006	0.011	0.006	0.015	7.600	96.00	0.0	0.06
5	BB	2	950000	0	0	3.40	60.00	2.78	33.40	0.272	0.012	0.005	0.021	0.004	0.010	7.800	97.00	0.0	0.06
6	BB	3	140000	0	0	3.40	60.00	4.6	30.30	0.465	0.001	0.006	0.014	0.005	0.015	7.800	96.00	0.0	0.06
7	BC	1	10	0	0	3.00	74.00	1.2	40.15	0.021	0.002	0.003	0.050	0.002	0.013	7.500	134.00	0.0	0.05
8	BC	2	0	0	0	3.20	75.00	1.22	40.40	0.246	0.001	0.002	0.040	0.003	0.019	7.700	141.00	1.0	0.05
9	BC	3	10	0	0	3.40	70.00	1.4	40.50	0.024	0.002	0.002	0.042	0.003	0.003	7.900	146.00	0.0	0.05
10	BD	1	880000	0	0	0.50	22.00	0.04	64.30	0.163	0.014	0.001	0.037	0.001	0.011	7.900	87.00	3.0	0.05
11	BD	2	480000	0	0	0.60	25.00	0	65.40	0.240	0.020	0.003	0.028	0.001	0.011	8.100	92.00	2.0	0.05
12	BD	3	3880000	0	0	0.50	25.00	0	64.30	0.240	0.001	0.002	0.027	0.001	0.001	7.700	96.00	2.0	0.05
13	BE	1	71	0	0	2.00	40.00	7.4	14.00	0.016	0.005	0.002	0.011	0.001	0.010	7.900	120.00	0.0	0.04
14	BE	2	10	0	0	1.40	43.00	6.44	60.30	0.013	0.005	0.003	0.011	0.001	0.008	7.900	131.00	0.0	0.04
15	BE	3	41	0	0	1.80	40.00	6.82	62.40	0.237	0.006	0.002	0.014	0.001	0.009	7.600	136.00	0.0	0.04
16	BF	1	5	0	0	3.00	52.00	18.2	45.20	0.222	0.009	0.003	0.013	0.003	0.014	7.400	300.00	0.0	0.06
17	BF	2	5	0	0	2.80	50.00	18.42	43.40	0.226	0.001	0.003	0.024	0.004	0.014	7.400	326.00	0.0	0.06
18	BF	3	5	0	0	2.80	54.00	16.84	43.00	0.217	0.009	0.002	0.033	0.004	0.014	7.400	335.00	0.0	0.06
19	BG	1	6	0	0	3.00	40.00	5.6	23.00	0.024	0.010	0.006	0.020	0.005	0.009	7.700	187.00	0.0	0.07
20	BG	2	0	0	0	3.00	40.00	5.62	34.80	0.063	0.002	0.007	0.020	0.007	0.007	7.800	196.00	0.0	0.07
21	BG	3	10	0	0	3.00	40.00	5.4	36.00	0.034	0.009	0.005	0.012	0.008	0.005	7.600	148.00	0.0	0.07
22	BH	1	30000	0	0	3.20	25.00	3.88	72.00	0.255	0.003	0.005	0.000	0.004	0.010	5.300	107.00	2.0	0.04
23	BH	2	4000	0	0	3.00	27.00	4.02	45.30	0.277	0.000	0.005	0.000	0.003	0.008	5.500	84.00	2.0	0.04
24	BH	3	26000	0	0	3.50	26.00	3.8	64.00	0.217	0.003	0.005	0.000	0.005	0.009	5.500	102.00	3.0	0.04
25	BI	1	0	0	0	3.00	60.00	2.04	32.40	0.047	0.000	0.004	0.078	0.006	0.013	7.200	126.00	0.0	0.06
26	BI	2	0	0	0	3.00	63.00	2	37.20	0.172	0.000	0.005	0.028	0.004	0.007	7.000	124.00	0.0	0.06
27	BI	3	0	0	0	2.60	64.00	2.42	36.40	0.317	0.000	0.004	0.006	0.005	0.001	7.200	104.00	0.0	0.06
28	BJ	1	70	5	0	2.50	30.00	1.24	43.30	0.240	0.005	0.007	0.023	0.004	0.009	4.700	92.00	1.0	0.03
29	BJ	2	24	10	0	2.30	31.00	1.44	48.00	0.240	0.005	0.005	0.003	0.004	0.006	4.700	88.00	0.0	0.03
30	BJ	3	80	15	0	2.20	34.00	1.22	32.20	0.240	0.005	0.005	0.003	0.001	0.009	4.400	77.00	1.0	0.03
31	BK	1	58	0	0	3.00	43.00	1.58	26.60	0.065	0.016	0.000	0.014	0.000	0.015	6.800	90.00	0.0	0.03
32	BK	2	38	0	0	3.00	50.00	1.62	28.00	0.122	0.001	0.001	0.014	0.000	0.015	6.800	84.00	0.0	0.03
33	BK	3	18	0	0	3.20	66.00	1.42	30.20	0.173	0.016	0.002	0.024	0.001	0.015	6.800	1252.00	0.0	0.03
34	HA	1	29000	0	0	3.50	50.00	3.54	34.00	0.202	0.002	0.021	0.091	0.010	0.026	6.400	712.00	5.6	0.06
35	HA	2	206000	0	0	3.40	54.00	3.52	32.00	0.240	0.009	0.005	0.092	0.010	0.026	6.600	174.00	4.9	0.06
36	HA	3	204000	0	0	3.40	50.00	3.48	32.00	0.216	0.009	0.017	0.089	0.004	0.030	6.800	345.00	5.5	0.06
37	HB	1	1130	0	0	2.80	52.00	11.5	61.00	0.386	0.015	0.002	0.014	0.260	0.017	6.900	482.00	3.4	0.06

38	HB	2	1450	0	0	2.50	50.00	11.04	64.00	0.289	0.045	0.042	0.044	0.013	0.012	6.900	502.00	3.4	0.06
39	HB	3	1130	0	0	2.40	88.00	11.82	68.00	0.329	0.005	0.031	0.016	0.024	0.017	7.000	496.00	3.4	0.06
40	HC	1	300000	120	0	4.50	98.00	2.62	88.00	0.016	0.021	0.022	0.016	0.003	0.042	7.100	206.00	2.5	0.02
41	HC	2	270000	80	0	4.10	90.00	2.76	84.00	0.016	0.010	0.025	0.011	0.002	0.052	7.100	194.00	2.4	0.02
42	HC	3	450000	70	0	3.80	62.00	2.8	90.00	0.163	0.010	0.042	0.019	0.003	0.012	7.200	225.00	2.4	0.02
43	HD	1	0	0	0	1.20	50.00	1.74	38.00	0.288	0.015	0.056	0.047	0.015	0.026	7.000	166.00	3.7	0.05
44	HD	2	0	0	0	1.30	50.00	1.54	38.00	0.202	0.002	0.002	0.027	0.010	0.026	7.000	302.00	0.0	0.05
45	HD	3	10	0	0	2.50	48.00	1.92	33.00	0.402	0.025	0.004	0.067	0.015	0.022	7.000	176.00	1.0	0.05
46	HE	1	20000	420	0	3.20	25.00	4.52	38.40	0.240	0.018	0.010	0.020	0.012	0.001	7.400	166.00	0.0	0.02
47	HE	2	3000	20	0	6.50	22.00	6.04	42.00	0.240	0.010	0.021	0.030	0.010	0.001	7.000	245.00	1.0	0.02
48	HE	3	44000	1020	0	3.20	25.00	4.78	60.60	0.240	0.024	0.003	0.030	0.008	0.008	7.000	194.00	1.0	0.02
49	HF	1	47000	0	0	5.20	22.00	5.36	44.30	0.255	0.015	0.013	0.021	0.010	0.083	6.900	194.00	7.1	0.02
50	HF	2	50000	0	0	5.00	25.00	5.24	43.40	0.255	0.015	0.011	0.011	0.005	0.013	6.900	119.00	6.8	0.02
51	HF	3	35000	0	0	5.50	24.00	5.42	43.20	0.255	0.013	0.026	0.021	0.008	0.053	6.800	170.00	7.0	0.02
52	HG	1	166000	0	0	3.50	30.00	7.05	61.20	0.337	0.018	0.023	0.042	0.006	0.026	7.000	146.00	2.1	0.01
53	HG	2	146000	0	0	3.20	30.00	7.12	60.10	0.163	0.011	0.004	0.032	0.008	0.022	7.000	234.00	2.1	0.01
54	HG	3	104000	0	0	3.00	33.00	7.2	60.00	0.202	0.001	0.034	0.022	0.010	0.023	7.100	164.00	2.1	0.01
55	HH	1	70000	0	0	5.00	50.00	3.78	56.00	0.216	0.003	0.031	0.011	0.008	0.012	7.200	191.00	6.0	0.02
56	HH	2	270000	0	0	5.50	55.00	3.84	42.00	0.240	0.002	0.021	0.021	0.010	0.010	7.200	232.00	6.0	0.02
57	HH	3	370000	0	0	4.60	50.00	3.96	41.00	0.240	0.002	0.054	0.010	0.012	0.014	7.120	188.00	5.8	0.02
58	HI	1	1500000	0	10	4.20	134.00	3.54	67.00	0.337	0.001	0.005	0.020	0.008	0.046	7.400	255.00	2.7	0.02
59	HI	2	34000	0	15	4.40	150.00	3.48	54.00	0.367	0.002	0.003	0.042	0.009	0.038	7.400	240.00	2.9	0.02
60	HI	3	1742000	0	10	8.50	154.00	4.04	62.00	0.402	0.002	0.004	0.020	0.006	0.036	7.600	232.00	2.7	0.02
61	SA	1	220	0	0	3.00	60.00	2.14	46.00	0.016	0.003	0.003	0.015	0.003	0.019	6.700	155.00	2.7	0.04
62	SA	2	740	0	0	3.50	60.00	2.16	48.40	0.402	0.004	0.005	0.025	0.002	0.013	6.600	155.00	2.7	0.04
63	SA	3	440	0	0	4.00	58.00	2.10	43.40	0.240	0.003	0.004	0.015	0.003	0.018	6.800	189.00	2.7	0.04
64	SB	1	10	0	0	3.50	25.00	2.74	47.30	0.202	0.018	0.000	0.022	0.002	0.022	6.900	210.00	1.1	0.04
65	SB	2	0	0	0	3.00	27.00	2.68	44.40	0.240	0.019	0.000	0.020	0.001	0.024	6.900	140.00	1.1	0.04
66	SB	3	1689	0	0	3.20	28.00	2.88	32.00	0.265	0.017	0.000	0.034	0.001	0.026	7.000	148.00	1.1	0.03
67	SC	1	1244	0	0	3.40	25.00	2.98	61.20	0.016	0.007	0.000	0.020	0.004	0.022	6.900	196.00	3.0	0.03
68	SC	2	90	0	0	3.30	25.00	2.14	32.44	0.634	0.019	0.000	0.022	0.002	0.022	6.900	187.00	2.1	0.03
69	SC	3	70	0	0	3.60	25.00	2.26	38.60	0.163	0.027	0.000	0.012	0.001	0.020	6.900	200.00	2.4	0.03
70	SPA	1	45000	20	0	4.00	50.00	1.64	74.60	0.340	0.002	0.003	0.021	0.126	0.016	7.000	446.00	4.0	0.04
71	SPA	2	42000	20	0	3.20	48.00	1.58	82.80	0.396	0.004	0.006	0.014	0.144	0.012	6.500	506.00	4.0	0.03
72	SPA	3	20000	20	0	3.00	50.00	1.54	71.30	0.329	0.004	0.005	0.010	1.310	0.022	6.900	489.00	4.0	0.03
73	SPB	1	325000	20	0	3.50	52.00	17.54	64.50	0.501	0.011	0.002	0.014	0.086	0.124	6.700	467.00	7.0	0.02
74	SPB	2	126000	20	0	3.30	50.00	12.42	78.90	0.010	0.014	0.002	0.036	0.078	0.102	6.900	422.00	7.0	0.03
75	SPB	3	425400	20	0	3.50	54.00	16.32	74.30	0.350	0.013	0.003	0.034	0.082	0.134	6.400	466.00	7.0	0.05
76	SPC	1	201000	20	0	5.00	155.00	18.52	82.40	0.465	0.008	0.003	0.010	0.081	0.012	6.500	302.00	3.7	0.03
77	SPC	2	104000	40	0	3.00	160.00	12.48	89.80	0.173	0.008	0.002	0.031	0.073	0.024	6.800	284.00	3.3	0.02
78	SPC	3	222000	40	0	6.50	150.00	13.36	72.60	0.225	0.009	0.003	0.025	0.072	0.028	6.400	266.00	3.0	0.02

Table 4.7: Physicochemical Properties of Bottled Water Samples.

Bottle	pH	EC (µS/cm)	Colour(TCU)	Turb.(NTU)	Alk. (mg/L)	N (mg/L)	P (mg/L)	Cl (mg/L)	T H (mg/L)
BA	8.43± 0.15	147.33± 30.62	0.00 ± 0.00	3.03± 0.15	53.00 ± 13.53	0.309± .084	0.041± .003	4.00 ± 0.00	52.03 ± 2.92
BB	7.73± 0.12	96.33 ± 0.58	0.00 ± 0.00	3.43± 0.06	60.00 ± 0.00	0.328± .120	0.064± .000	3.67 ± 1.15	31.43 ± 1.71
BC	7.70± 0.20	140.33 ± 6.03	0.33 ± 0.58	3.20± 0.20	73.00 ± 2.65	0.023± .002	0.048± .006	1.00 ± 0.00	40.35 ± 0.18
BD	7.90± 0.20	91.67 ± 4.51	2.33 ± 0.58	0.53± 0.06	24.00 ± 1.73	0.214± .044	0.050± .007	0.00 ± 0.00	64.67 ± 0.64
BE	7.80± 0.17	129.00 ± 8.19	0.00 ± 0.00	1.73± 0.31	41.00 ± 173	0.018± .006	0.041± .003	6.67 ± 0.58	45.57± 27.36
BF	7.40± 0.00	320.33± 18.18	0.00 ± 0.00	2.87± 0.12	52.00 ± 2.00	0.222± .005	0.063± .002	17.67±0.58	43.87 ± 1.17
BG	7.70 ± 0.10	177.00 ± 25.51	0.00 ± 0.00	3.00 ± 0.00	40.00 ± 0.00	0.040 ± .020	0.072 ± .002	5.67 ± 0.58	31.27 ± 7.18
BH	5.43 ± 0.12	97.67 ± 12.10	2.33 ± 0.58	3.23 ± 0.25	26.00 ± 1.00	0.250 ± .030	0.041 ± .003	4.00 ± 0.00	60.43± 13.70
BI	7.13 ± 0.12	118.00 ± 12.17	0.00 ± 0.00	2.87 ± 0.23	62.33 ± 2.08	0.179 ± .135	0.055 ± .009	2.00 ± 0.00	35.33 ± 2.57
BJ	4.60 ± 0.17	85.67 ± 7.77	0.67 ± 0.58	2.33 ± 0.15	31.67 ± 2.08	0.240 ± .000	0.035 ± .006	1.00 ± 0.00	41.17 ± 8.11
BK	6.80 ± 0.00	99.67 ± 22.14	0.00 ± 0.00	3.07 ± 0.12	53.00±11.79	0.120 ± .054	0.032 ± .005	1.67 ± 0.58	28.27 ± 1.81
MEAN ± SD	7.15 ± 1.12	136.64 ± 66.35	0.52 ± 0.94	2.66 ± 0.83	46.91 ± 15.91	0.177 ± .120	0.049 ± .013	4.30 ± 4.75	43.13± 14.16
UNBS	**5.5 - 8.5**	**1500**	**15**	**5**	-	**50**	-	**250**	-

EC = Electrical Conductivity in micro Siemens per centimeter (µS/cm), Color measured in True Colour Unit (TCU), Turb. = Turbidity Nephelometric Tessa Unit (NTU), Alkalinity in milligram per litre (mg/L), N = Nitrogen in milligram per litre (mg/L), P = Phosphorus, is measured in milligram per litre (mg/L), Cl = Chloride in milligram per litre (mg/L). TH = Total Hardness in milligram per litre (mg/L). (BA-BK) = codes for Bottled water. UNBS = Ugandan National Bureau of Standards.

Table.4.8 Physicochemical Properties of Hand tied Water Samples.

Hand tied	pH	E.C. (µS/cm)	Colour (TCU)	Turb.(NTU)	Alk. (mg/L)	N (mg/L)	P (mg/L)	Cl (mg/L)	TH (mg/L)
HA	6.60 ± 0.20	410.33±274.89	5.33 ±0.38	3.45 ± 0.05	51.33 ± 2.31	0.219± 0.019	0.069±0.015	3.67 ± 0.58	32.67 ± 1.15
HB	6.93 ± 0.06	493.33 ± 10.26	3.40 ± 0.00	2.57 ± 0.21	63.33 ± 21.39	0.335 ± 0.049	0.060±0.008	11.67±0.58	64.33 ± 3.51
HC	7.13 ± 0.06	208.33 ± 15.63	2.43 ± 0.06	4.13 ± 0.35	83.33 ± 18.90	0.016 ± 0.000	0.024±0.004	3.00 ± 0.00	87.33 ± 3.06
HD	7.00 ± 0.00	214.67 ± 75.80	0.67 ± 0.58	1.67 ± 0.72	49.33 ± 1.15	0.297 ± 0.100	0.109±0.039	2.00 ± 0.00	36.33 ± 2.89
HE	7.13 ± 0.23	201.67 ± 40.05	0.67 ± 0.58	4.30 ± 1.91	24.00 ± 1.73	0.240 ± 0.000	0.025±0.003	5.33 ± 0.58	47.00 ± 11.91
HF	6.87 ± 0.06	161.00 ± 38.30	6.97 ± 0.15	5.23 ± 0.25	23.67 ± 1.53	0.255 ± 0.000	0.077±0.007	5.00 ± 0.00	43.63 ± 0.59
HG	7.03 ± 0.06	181.33 ± 46.49	2.10 ± 0.00	3.23 ± 0.25	31.00 ± 1.73	0.234 ± 0.091	0.013±0.000	7.00 ± 0.00	60.43 ± 0.67
HH	7.17 ± 0.06	203.67 ± 24.58	5.93 ± 0.12	5.03 ± 0.45	51.67 ± 2.89	0.232 ± 0.014	0.027±0.007	4.00 ± 0.00	46.33 ± 8.39
HI	7.47 ± 0.12	242.33 ± 11.68	2.77 ± 0.12	5.70 ± 2.43	146.00 ± 10.58	0.369 ± 0.033	0.056±0.025	3.67 ± 0.58	61.00 ± 6.56
MEAN ± SD	**7.04 ± 0.25**	**257.41±137.14**	**3.36 ± 2.19**	**3.92 ± 1.56**	**58.19 ± 37.63**	**0.244 ± 0.104**	**0.051±0.033**	**5.04 ± 2.78**	**53.23 ± 16.91**
UNBS	**5.5 - 8.5**	**1500**	**15**	**5**	**-**	**50**	**-**	**250**	**-**

EC.= Electrical Conductivity measured in micro Siemens per centimeter (µS/cm), Color measured in True Colour Unit (TCU), Turbidity measured Nephelometric Tessa Unit (NTU), Alk. = Alkalinity in milligram per litre (mg/L), N = Nitrogen in milligram per litre (mg/L) P = Phosphorus, measured in milligram per litre (mg/L), Cl = Chloride in milligram per litre (mg/L). TH = Total Hardness in milligram per litre (mg/L). (HA-HI) = codes for Handtied water, UNBS = Ugandan National Bureau of Standards.

Table 4.9: Physicochemical Properties for sachet and spring water samples.

Sachet	pH	EC (µS/cm)	Colour (TCU)	Turb. (NTU)	Alk. (mg/L)	N (mg/L)	P (mg/L)	Cl (mg/L)	TH (mg/L)
SA	6.70 ± 0.10	166.33 ± 19.63	2.70 ± 0.00	3.50 ± 0.50	59.33 ± 1.15	0.219 ±0.194	0.042±0 .003	2.13 ± 0.03	45.93 ± 2.50
SB	6.93 ± 0.06	166.00 ± 38.31	1.10 ± 0.00	3.23 ± 0.25	26.67 ± 1.53	0.236±0.032	0.037±0.003	2.77±0.10	41.23 ± 8.13
SC	8.90± 0.00	194.33 ± 6.66	2.50± 0.46	3.43 ±0.15	25.00 ± 0.00	0.271±0.323	0.032±0.005	2.46 ± 0.45	44.08 ±15.14
Mean ± SD	**6.84 ± 0.12**	**175.56 ± 25.94**	**2.10 ± 0.79**	**3.39 ± 0.31**	**37.00 ± 16.79**	**0.242±0.190**	**0.037 ± .006**	**2.45± 0.36**	**43.75 ± 8.92**
Spring	**pH**	**EC (mg/L)**	**Colour (mg/L)**	**Turb. (NTU)**	**Alk. (mg/L)**	**N (mg/L)**	**P (mg/L)**	**Cl (mg/L)**	**TH (mg/L).**
SPA	6.80 ± 0.26	480.33 ± 30.92	4.00 ± 0.00	3.40 ± 0.53	49.33 ± 1.15	.355 ± .036	.036 ± .003	2.00 ± 0.00	76.23 ± 5.92
SPB	6.67 ± 0.25	451.67 ± 25.70	7.00 ± 0.00	3.43 ± 0.12	52.00 ± 2.00	.287 ± .251	.034 ± .013	15.33 ± 3.06	72.57 ± 7.35
SPC	6.57 ± 0.21	284.00 ± 18.00	3.33 ± 0.35	4.83 ± 1.76	155.00 ± 5.00	.288 ± .156	.024 ± .004	14.67 ± 3.79	81.60 ± 8.63
Total	6.68 ± 0.23	405.33 ± 94.45	4.78 ± 1.70	3.89 ± 1.16	85.44 ± 52.25	.310 ± .153	.031 ± .009	10.67 ± 6.95	76.80 ± 7.51
Mean ± SD	**7.02 ± 0.76**	**213.94±129.83**	**2.18 ± 2.19**	**3.32 ± 1.27**	**54.12 ± 32.76**	**.223 ± .134**	**.046 ± .022**	**5.08 ± 4.66**	**50.58 ± 17.49**
UNBS	**5.5 – 8.5**	**1500**	**15**	**5**	**-**	**50**	**-**	**250**	**-**

E.C = Electrical Conductivity in micro Siemens per centimeter (µS/cm), Color measured in True Colour Unit (TCU), Turb. =Turbidity Nephelometric Tessa Unit (NTU), Alkalinity in milligram per litre (mg/L), N = Nitrogen in milligram per litre (mg/L), P = Phosphorus, is measured in milligram per litre (m g/L), Cl = Chloride in milligram per litre (mg/L). TH = Total Hardness in milligram per litre (mg/L).(SA-SC) = codes for sachet water samples. (SPA-SPC) = codes for spring water samples, UNBS = Ugandan National Bureau of Standards.

Table 4.10: Trace Metals concentrations for the Bottled Water Samples

Bottle	Lead	Copper	Iron	Manganese	Zinc
BA	0.012 ± 0.002	0.000 ± 0.000	0.079 ± 0.016	0.001 ± 0.000	0.009 ± 0.007
BB	0.001 ± 0.000	0.006 ± 0.001	0.015 ± 0.005	0.005 ± 0.001	0.013 ± 0.003
BC	0.002 ± 0.001	0.002 ± 0.001	0.044 ± 0.005	0.003 ± 0.001	0.012 ± 0.008
BD	0.012 ± 0.010	0.002 ± 0.001	0.031 ± 0.006	0.001 ± 0.000	0.008 ± 0.006
BE	0.005 ± 0.001	0.002 ± 0.001	0.012 ± 0.002	0.001 ± 0.000	0.009 ± 0.001
BF	0.006 ± 0.005	0.003 ± 0.001	0.023 ± 0.010	0.004 ± 0.001	0.014 ± 0.000
BG	0.007 ± 0.004	0.006 ± 0.001	0.017 ± 0.005	0.007 ± 0.002	0.007 ± 0.002
BH	0.002 ± 0.002	0.005 ± 0.001	0.000 ± 0.000	0.004 ± 0.001	0.009 ± 0.001
BI	0.000 ± 0.000	0.004 ± 0.001	0.037 ± 0.037	0.005 ± 0.001	0.007 ± 0.006
BJ	0.005 ± 0.000	0.006 ± 0.001	0.010 ± 0.012	0.003 ± 0.002	0.008 ± 0.002
BK	0.011 ± 0.009	0.001 ± 0.001	0.017 ± 0.006	0.000 ± 0.001	0.015 ± 0.000
MEAN ± SD	**0.006 ± 0.006**	**0.003 ± 0.002**	**0.026 ± 0.024**	**0.003 ± 0.002**	**0.010 ± 0.005**
UNBS	**0.01**	**2.00**	**0.20**	**1.00**	**-**

UNBS = Uganda Bureau for standard, ‘BA-BK’ Bottled water sample code

Table 4.11: Trace Metals in mg/L for Hand tied Water samples

Hand tied	Lead	Copper	Iron	Manganese	Zinc
HA	0.007 ± 0.004	0.014 ± 0.008	0.091 ± 0.002	0.008 ± 0.003	0.027 ± 0.002
HB	0.022 ± 0.021	0.025 ± 0.021	0.025 ± 0.017	0.021 ± 0.007	0.015 ± 0.003
HC	0.014 ± 0.006	0.030 ± 0.011	0.015 ± 0.004	0.003 ± 0.001	0.035 ± 0.021
HD	0.014 ± 0.012	0.004 ± 0.002	0.047 ± 0.020	0.013 ± 0.003	0.025 ± 0.002
HE	0.017 ± 0.007	0.011 ± 0.009	0.027 ± 0.006	0.010 ± 0.002	0.004 ± 0.003
HF	0.014 ± 0.002	0.017 ± 0.008	0.018 ± 0.006	0.008 ± 0.003	0.050 ± 0.035
HG	0.010 ± 0.009	0.020 ± 0.015	0.032 ± 0.010	0.008 ± 0.002	0.024 ± 0.002
HH	0.002 ± 0.001	0.035 ± 0.017	0.014 ± 0.006	0.010 ± 0.002	0.012 ± 0.002
HI	0.002 ± 0.001	0.004 ± 0.002	0.027 ± 0.013	0.008 ± 0.002	0.040 ± 0.005
MEAN ± SD	**0.011 ± 0.010**	**0.018 ± 0.014**	**0.033 ± 0.025**	**0.010 ± 0.006**	**0.026 ± 0.018**
UNBS	**0.01**	**2.00**	**0.20**	**1.00**	**-**

UNBS = Uganda Bureau for Standard,handtied water (Boiled water) were coded as 'H' and has a ranged of HA- HI, UNBS = Ugandan National Bureau of Standard.

Table.4.12 Trace Metals in Mg/L for Sachet and Spring Water Samples

Sachet	Lead	Copper	Iron	Manganese	Zinc
SA	0.003 ±0.001	0.004 ± 0.001	0.018 ± 0.006	0.003 ± 0.001	0.017 ± 0.003
SB	0.018 ±0.001	0.000 ± 0.000	0.025 ± 0.008	0.001 ± 0.001	0.024 ± 0.002
SC	0.018 ±0.010	0.000 ± 0.000	0.018 ± 0.005	0.002 ± 0.002	0.021 ± 0.001
Mean ± SD	**0.013 ± 0.009**	**0.001 ±0.002**	**0.021 ± 0.007**	**0.002 ± 0.001**	**0.021 ± 0.004**

Spring	Lead	Copper	Iron	Manganese	Zinc
SPA	0.003 ± 0.001	0.005 ± 0.002	0.015 ± 0.006	0.134 ± 0.009	0.017 ± 0.005
SPB	0.013 ± 0.002	0.002 ± 0.001	0.028 ± 0.012	0.082 ± 0.004	0.120 ± 0.016
SPC	0.008 ± 0.001	0.003 ± 0.001	0.022 ± 0.011	0.075 ± 0.005	0.021 ± 0.008
Mean± SD	**0.008 ± 0.004**	**0.003 ± 0.001**	**0.022 ± 0.010**	**0.097 ± 0.028**	**0.053 ± 0.051**
UNBS	**0.01**	**2.00**	**0.20**	**1.00**	**---**

UNBS = Uganda Bureau for Standard,Sachet water sample coded ‘SA-SC’, Spring water sample coded: SPA – SPC.

Table 4.13 Bottled water. ***Samples, sources, manufacture and expiry dates***

S/N	**Trade Name**	**Code**	**Production Dates**	**Expiry Dates**
1	HEMA	BA	11/01/18	11/01/19
2	RAINDROP	BB	07/07/18	07/04/19
3	MIDLAND	BC	04/03/18	04/03/19
4	HILL WATER	BD	12/06/18	17/07/19
5	AQUASIPI	BE	12/06/18	11/06/19
6	HIGHLAND	BF	18/05/18	18/11/18
7	NIVANA	BG	20/05/18	20/02/19
8	DASANI	BH	05/06/18	20/02/19
9	VERO	BI	04/04/18	04/10/18
10	WAVAH	BJ	12/18	10/19
11	OKRA	BK	09/06/18	09/06/19

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