World Journal of Advanced Research and Reviews

eISSN: 2581-9615 CODEN (USA): WJARAI

Cross Ref DOI: 10.30574/wjarr

Journal homepage: https://wjarr.com/

(Review Article)

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Physicochemical and bacteriological assessment of the polyethene packaged sachet water (popularly called "pure water") as a major source of drinking water in Sagamu, Ogun State, Southwest, Nigeria

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World Journal of Advanced Research and Reviews, 2024, 21(03), 452–469

Publication history: Received on 22 January 2024; revised on 27 February 2024; accepted on 01 March 2024

Article DOI: https://doi.org/10.30574/wjarr.2024.21.3.0712

Abstract

This study aimed to evaluate the physicochemical and bacteriological characteristics of polyethylene-packaged sachet water, commonly known as "pure water," produced and distributed in the Sagamu local government area of Ogun State, Southwest Nigeria. The research involved analyzing sachet water samples from various producers, sources, and distributors to assess their quality. Samples were collected randomly from six different locations/towns within Sagamu Local Government and subjected to physicochemical and bacteriological analysis. The findings were compared with the permissible limits established by reputable organizations such as WHO, EPA, Canada, and NIS. The results indicated that most parameters fell within the acceptable range set by WHO, EPA, Canada, and NIS. However, the pH levels of the sachet water samples (ranging from 4.73 to 6.10) were found to be acidic, deviating from the expected range of 6.5 to 10.5. Additionally, while the Total Heterotrophic Bacteria count and Enteric Bacteria count were slightly lower than the permissible limits, with Total Enteric Bacteria ranging from 300 to 480 cfu/100ml (permissible limit <500cfu/100ml) and Enteric Bacteria ranging from 280 to 380 cfu/100ml. Recommendations derived from the study include advocating for water-producing industries to establish their raw water sources in contamination-free zones, encouraging the involvement of well-equipped private and government hospitals in monitoring and reporting on the water quality of packaging industries, promoting the provision of safe piped water by credible individuals within communities, and emphasizing the role of regulatory bodies like SON and NAFDAC in continuously assessing the production and packaging standards of drinking water across communities.

Keywords: Sachet Polyethene Water; Sagamu; Drinking Water; Enteric Bacteria Count; Total Heterotrophic Bacteria Count; Bacteriological; Heterotrophic plate count

1. Introduction

In Nigeria, sachet water, commonly known as "Pure Water," is the primary and most affordable source of water for households. It is heavily relied upon for rehydration and consumption after meals, with many perceiving it as pure and safe to drink. The sachet water business is highly profitable, and its demand is expected to remain high in the foreseeable future. The majority of government-supplied piped water systems have become non-functional due to rapid population growth, lack of maintenance, and deterioration of water production infrastructure. Consequently, the population depends entirely on purchasing water for drinking purposes, while relying on boreholes in their homes for laundry, washing, and cooking.

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Located in West Africa, Nigeria shares its borders with the Republic of Benin to the west, Cameroon and Chad to the east, and Niger to the north. To the south, its coastline extends along the Gulf of Guinea, and to the northeast, it shares a border with Lake Chad. Nigeria experiences four clearly defined seasonal changes in its climate, with the variations becoming more pronounced as one moves from the northern to the southern regions through the country's central belt. Sagamu, a conglomeration of thirteen (13) towns situated in Ogun State along the Ibu River and Eruwuru Stream between Lagos and Ibadan in southwestern Nigeria, holds significant geographical and economic importance. The constituent towns comprising Sagamu include Makun, Offin Sonyindo, Epe, Ibido, Igbepa, Ado, Oko, Ipoji, Batoro, Ijoku, Latawa, and Ijagba. As the capital of Remo Kingdom, Sagamu hosts the palace of the paramount ruler, the Akarigbo of Remo, which is located in the town of Offin. The presence of major multinational industries such as Lafarge, Nestle, Olam, Honey Well, Emzor, WASOL, International Breweries, Apple and Pears in the vicinity has contributed to the rapid development of Sagamu.

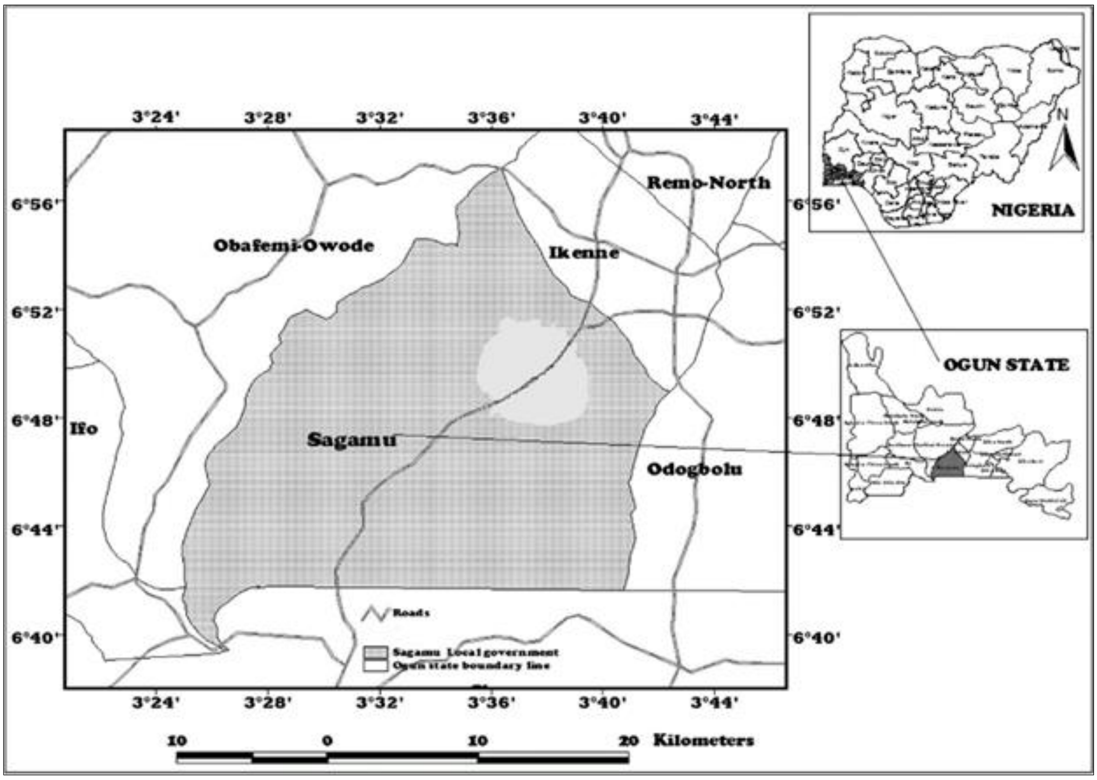

Figure 1 Map of Sagamu Oguntade et al., (2020)

1.1. Drinking Water in Sagamu

Drinking water, often referred to as portable water, is crucial for human health and wellbeing. It is safe for consumption and cooking purposes. The availability of quality drinking water is particularly vital in developing countries, where it remains a scarce resource. Portable water plays a pivotal role in sustaining life and fostering economic prosperity within communities. Access to safe, dependable, and easily accessible water is essential for maintaining public health, whether for drinking, household activities, food production, or recreational pursuits. Enhancing water supply and sanitation infrastructure, along with efficient water resource management, can significantly contribute to a country's economic advancement and alleviate poverty. Recognizing the significance of this resource, the UN General Assembly acknowledged the human right to water and sanitation in 2010. As per the World Health Organization (WHO) in 2019, every individual has the right to access sufficient, continuous, safe, acceptable, physically accessible, clean, and affordable water for personal and domestic use. The indispensable nature of water as a fundamental requirement for human existence cannot be overstated. This reality, which predates contemporary times, has been consistently affirmed since the evolution of early human species, such as 'homo abalis' and 'homo erectus,' and extends to the evolutionary periods of modern man's generic ancestral species, the 'homo sapiens.' During these epochs, human survival primarily depended on three critical elements: water, fire, and earth. Even more significantly than concrete, water is universally recognized as humanity's most utilized and consumed substance (Ibhadode et al., 2017).

1.2. Portable Water

Potable water, which is safe for drinking and household use, is facing a global decline in availability. The increasing demand for water is putting pressure on freshwater sources worldwide, while various contaminants pose risks to its safety and appeal for consumption. According to research conducted by Fluence Corp in 2019, more than two billion people lack access to potable water in their homes. Furthermore, 844 million people lack even the most basic drinking water services, with 263 million individuals needing to travel approximately 30 minutes per trip to obtain water. Alarmingly, 159 million people rely on water from exposed or untreated open surfaces. The consumption of unclean drinking water significantly contributes to diarrheal diseases, resulting in the deaths of approximately 800,000 children under the age of five annually, primarily in developing countries. Despite ongoing efforts, it is predicted that 90 countries will not achieve universal water coverage by 2030 (Fluence Corp, 2019). In their study assessing the quality of packaged sachet water in Kano Metropolis, Alhassan et al. (2008) examined the physicochemical parameters and found that the collected samples were tasteless, odourless, and colourless. They determined that the pH and total hardness were within the permissible limits set by the World Health Organization (WHO). However, the concentration of heavy metals exceeded the WHO permissible limit, with the exception of copper and zinc, which remained below the allowable thresholds. Similarly, Airaodion et al. (2019) conducted research on the quality assessment of sachet and bottled water in Ibadan, Nigeria. Their analysis included physical attributes, sachet water characteristics, bacteriological qualities, and mineral composition. They found that 90% of the analysis results complied with the guidelines established by the WHO and the Nigerian Industrial Standards (NIS) for quality water. The water samples tested in the studies conducted by Unegbu et al. (2017) in Owerri and Yusuf et al. (2015) in Zaria exhibited notable characteristics and properties. Unegbu et al. (2017) investigated the impact of storage on the physicochemical properties of sachet water distributed in Owerri. They observed that after eight weeks of storage, there was a decrease in oxygen, chlorine, alkalinity, and BOD (biological oxygen demand), while the temperature, calcium, magnesium, total hardness, total dissolved solids, and electrical conductivity increased. Yusuf et al. (2015) evaluated various parameters in sachet water quality in Zaria, including color, taste, odor, pH, chloride, potassium, calcium, electrical conductivity, oxygen demand (OD), biological oxygen demand (BOD), total dissolved solids (TDS), and coliform counts. Their findings indicated that the samples were odorless, tasteless, and colorless, with most physicochemical parameters falling within the permissible limits set by the WHO and NIS, except for coliform counts. Therefore, they concluded that sachet water in Zaria is relatively safe and meets the standards for human consumption.

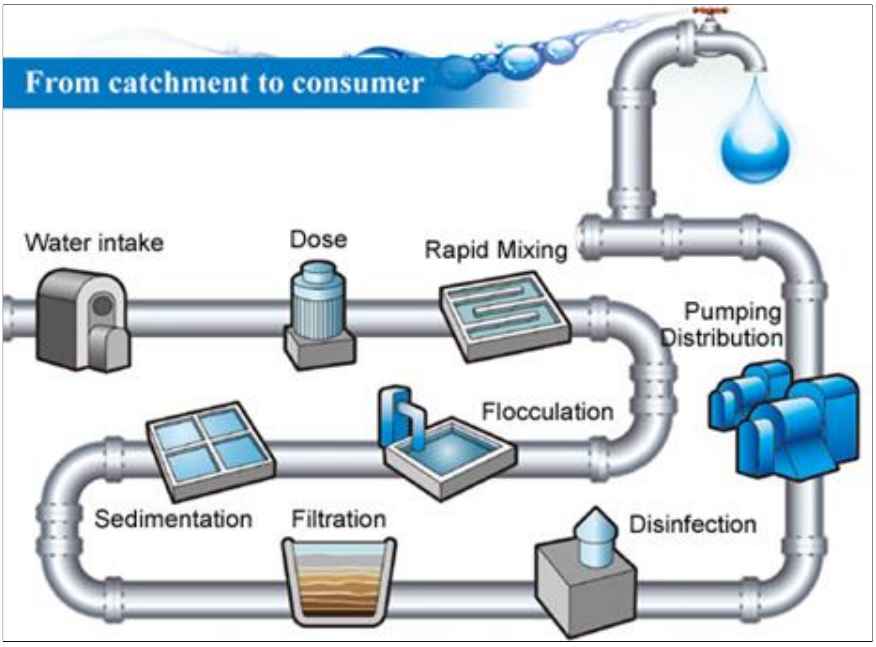

Figure 2 Water Purification process (Survival Life, 2016**)**

1.3. Water and Health

Drinking water, often referred to as portable water, is crucial for human health and wellbeing. It is safe for consumption and cooking purposes. The availability of quality drinking water is particularly vital in developing countries, where it remains a scarce resource. Portable water plays a pivotal role in sustaining life and fostering economic prosperity within communities. Access to safe, dependable, and easily accessible water is essential for maintaining public health, whether for drinking, household activities, food production, or recreational pursuits. Enhancing water supply and sanitation infrastructure, along with efficient water resource management, can significantly contribute to a country's economic advancement and alleviate poverty. Recognizing the significance of this resource, the UN General Assembly acknowledged the human right to water and sanitation in 2010. According to the World Health Organization (WHO) in 2019, every individual is entitled to sufficient, uninterrupted, safe, acceptable, physically accessible, clean, and affordable water for personal and domestic use.

1.4. Water Availability

While water covers more than two-thirds of the Earth's surface, the majority of it is saline and unsuitable for drinking. Only a small fraction, approximately 2.7% of the total water on Earth, is freshwater, and merely 1% of this freshwater, found in lakes, rivers, and groundwater, is readily accessible. Much of the available freshwater is inaccessible due to being located in deep aquifers or frozen in glaciers, constituting a mere 3% of the total freshwater resources. Desalination processes can convert seawater into freshwater, but this method is not universally adopted. Many countries face challenges regarding water availability. Some suffer from physical scarcity, lacking sufficient freshwater resources, while others may have abundant water resources but struggle with the high cost of extraction and distribution, leading to economic scarcity. Ensuring access to adequate, clean, and safe drinking water is essential for various users. However, there is no universally accepted definition of "safe drinking water." Generally, safe drinking water is understood to be water that poses no significant health risks over a lifetime of consumption. The water purification process involves several sequential steps, each increasing in severity to ensure the water becomes purer after production. These steps typically include sedimentation, filtration, and disinfection, among others. Different techniques are employed at each stage to effectively purify the water. During the disinfection phase, chemicals are utilized to eradicate bacteria and other microorganisms, rendering the water safe for consumption. Additionally, the treatment process often involves controlling acidity and adjusting the pH to meet standard specifications. Pure water is considered neutral, neither acidic nor basic, as water with extreme pH levels is not safe for human consumption. Commonly used chemicals for water filtration and purification include chlorine and its compounds, ozone, and ultraviolet radiation. Despite their effectiveness in cleaning the water and making it suitable for consumption, there is ongoing controversy regarding the overall health benefits of filtered water. In essence, the process of water purification involves taking water that has become polluted with harmful compounds and subjecting it to rigorous treatment to restore its cleanliness and safety for consumption. However, in this process, the water may lose a significant portion of its natural beneficial properties. While treating water with chemicals may ensure safe drinking and survival, it cannot fully replicate the benefits of fresh, natural water. Freshwater not only sustains life but also provides additional benefits to humans. Therefore, while water purification serves as a practical method to mitigate droughts and other dangers, it cannot fully compensate for the loss of clean water that humans have experienced and continue to face.

2. Literature review

Research on the safety of drinking sachet water, commonly known as 'Pure Water,' has been conducted across various regions in Nigeria, including the South West, South South, South East, Northern, and Middle Belt regions, as well as in Ghana. Studies have investigated various aspects such as physicochemical, chemical, physical, and microbiological properties of sachet water. Alhassan et al. (2008) conducted a study on the quality assessment of packaged sachet water around Kano Metropolis. Their analysis revealed that the samples collected were tasteless, odorless, and colorless, with pH and total hardness within WHO permissible limits. However, the concentration of heavy metals exceeded WHO limits, except for copper and zinc, which were below permissible levels. Airaodion et al. (2019) assessed the quality of sachet and bottled water in Ibadan, Nigeria. They found that 90% of the analysis results complied with WHO/NIS guidelines for quality water, with total coliforms, fecal coliforms, and enterococci absent in the water samples. Unegbu et al. (2017) studied the effect of storage on the physicochemical properties of sachet water in Owerri. They observed that after eight weeks of storage, oxygen, chlorine, alkalinity, and BOD decreased, while temperature, calcium, magnesium, total hardness, total dissolved solids, and electrical conductivity increased. Yusuf et al. (2015) evaluated the quality of sachet water in Zaria, focusing on various parameters including color, taste, odor, pH, chloride, potassium, calcium, electrical conductivity, oxygen demand (OD), biological oxygen demand (BOD), total dissolved solids (TDS), and coliform counts. Most physicochemical parameters were within WHO/NIS limits except for coliform counts, indicating that sachet water in Zaria is relatively safe for human consumption. Ojekunle et al. (2015) investigated the effect of storage on the physicochemical status and bacteriological quality of sachet water in Abeokuta metropolis. They found that all brands of water analyzed were physically and chemically wholesome, meeting WHO requirements and standards for drinking water. However, the majority of samples failed in microbiological assays when stored at ambient temperature for two months. Overall, while sachet water generally meets physicochemical standards for safe consumption, microbiological quality may vary, highlighting the importance of proper storage and handling to ensure water safety.

2.1. Effects of Chlorine on Human Health

There is growing concern about the potential health risks associated with chlorine in drinking water. Despite technological advancements, chlorine, often likened to bleach, is commonly used to treat water before consumption. The long-term effects of chlorinated drinking water have recently garnered attention, particularly regarding its potential carcinogenicity. According to the U.S. Council of Environmental Quality, individuals consuming chlorinated water face a 93% higher risk of cancer compared to those with non-chlorinated water sources. Chlorine reacts with natural compounds in water to form Trihalomethanes (THMs), known as chlorination byproducts. These byproducts can induce the production of free radicals in the body, leading to cell damage and carcinogenic effects. Although the concentrations of these carcinogens (THMs) in chlorinated water are typically low, cancer scientists believe that even these low levels contribute significantly to the development of most human cancers. Water can be sourced from various places such as lakes and wells, which may contain germs capable of causing illness. Furthermore, water can become contaminated with germs as it travels through extensive piping systems to reach communities. To combat germ contamination, water companies commonly add disinfectants, typically chlorine or chloramine, to eliminate disease-causing pathogens such as Salmonella, Campylobacter, and norovirus (EPA, 2000).

2.2. Bacteria (Enteric and Heterotrophs)

Enteric bacteria are microorganisms found in the intestines, colonizing the digestive tracts of various animals. While many of these bacteria are harmless or even beneficial, some can cause diseases, particularly in young children, individuals with weakened immune systems, or those encountering the microbe for the first time. Several enteric bacteria are commonly associated with human illnesses, including Salmonella, Campylobacter jejuni, pathogenic strains of Escherichia coli, and Shigella. Among preventive measures, thorough and regular handwashing with soap and warm water, especially after handling animals, particularly young ones with diarrhea, is highly effective in protecting against these pathogens (US Davis, 2020). Heterotrophs are a diverse group of microorganisms, including bacteria, molds, and yeasts, that utilize organic carbon sources for growth. They are commonly present in various water sources, including drinking water systems. The Heterotrophic Plate Count (HPC) test, also known as the Standard Plate Count, measures colony formation of heterotrophic bacteria on culture media in drinking water. This test helps assess the overall bacteriological quality of water in public, semi-public, and private water systems (Gandham, 2020). It's important to note that according to Health Canada guidelines, HPC results do not indicate water safety and should not be used to assess potential adverse human health effects. The World Health Organization (WHO, 2003) suggests that methods such as coliform testing are more reliable indicators of water sanitation conditions than HPC testing.

Table 1 Physicochemical and Microbiological Analyses of the samples

Parameter	Unit	Samples						Mean and STDV		Standard and Permissible Limits			
		SG1	SG2	SG3	SG4	SG5	SG6	Mean	STDV	WHO	Canada	EPA	NIS
Turbidity	*NTU*	0.12	0.12	0.08	0.16	0.12	0.08	0.11	0.03	0.3	0.1	0.2	5
pH		4.89	6.1	5.71	5.14	4.97	4.73	5.26	0.53	6.5 – 8.5	7.10 – 10.5	6.5 - 8.5	6.5 - 8.5
Alkalinity	*mg/l*	12	10	9	12	17	19	13.17	3.97	500	NA	NA	NA
T. Hardness	*mg/l*	5	6	3	6	4	3	4.50	1.38	<60	<80-100	NA	NA
Phosphate	*mg/l*	0.29	0.12	0.34	0.51	0.32	0.44	0.34	0.13	5	NA	5	5
Iron	*mg/l*	0.03	0.02	0.13	0.15	0.21	0.19	0.12	0.08	0.3	0.3	0.3	0.3
Calcium	*mg/l*	2.8	3.5	4.8	2.1	3.3	4.21	3.45	0.97	75	75	75	200
Nitrate	*mg/l*	2.5	2.2	2.3	2.31	0	2.4	1.95	0.96	50	50	45	50
Chloride	*mg/l*	12.8	18.6	17.8	26.7	18	28.3	20.37	5.93	250	250	250	250
THBC	*cfu/100ml*	400	300	420	520	470	450	426.67	74.74	<500	<500	<500	NA
EB	*cfu/100ml*	280	310	280	380	310	280	306.67	38.82	NA	NA	NA	NA

Notes: 1 EBC = 4.081NTU, EBC = European Brewery Convention, NTU: Nephelometric Turbidity Units; THBC – Total Heterotrophic Bacteria Count; EB – Enteric Bacteria Count; CFU – Colony Forming Unit; Data – All samples data in this table are calculated mean from five consecutive analyses; NA – Not Available

3. Water samples collection, Sample design and Water Preparation

3.1. Sample design and collection

Sachet water samples, commonly referred to as 'Pure Water,' were systematically collected from six distinct geographical locations within the Sagamu local government area. These samples were gathered and analyzed over a five-month period, and the average values for each site were calculated for the study. To ensure consistency and accuracy, the samples were preserved according to standard specifications before undergoing laboratory analyses. In this research, the identities of the sachet water brands were anonymized and will be identified solely by area codes labeled as SAG followed by numerical designations. The sampling locations included Makun along Awolowo market road, Ijagba, Sabo market area, Igbepa, Ipoji, and Ijoku, representing various villages in Sagamu. Upon collection, the samples were shielded from direct sunlight and promptly transported in a cooler box containing ice packs to maintain their integrity. All samples were then stored at a temperature of 4°C and analyzed within four hours of collection to minimize any potential alterations in their composition. Subsequently, the permissible limits and contaminant levels of the water samples were compared against established standards set by the World Health Organization (WHO), the United States Environmental Protection Agency (EPA), and the Nigeria International Standard (NIS). This comparison aimed to determine the level of compliance and assess the safety of the sachet water samples for public consumption.

4. Justification of this research

Sachet water, commonly referred to as "pure water," stands as the most economical, esteemed, and dependable source of drinking water in numerous Nigerian households. Extensive research and experiments have been conducted to evaluate the quality of sachet drinking water across Nigeria. However, relatively few studies have focused on assessing the quality of sachet drinking water in Ogun State, particularly in the region of Sagamu. This research endeavors to address this gap by presenting an assessment of the physicochemical and bacteriological properties found in polyethylene-packaged sachet water, commonly recognized as "pure water," which is both produced and distributed within the Sagamu Local Government Area of Ogun State, situated in the Southwest region of Nigeria.

5. Quality assurance

Special precautions were taken to ensure quality assurance throughout the research process. Firstly, all reagents utilized were of analytical grade, and the test kits were sourced from Merck Group in Germany, known for their high-quality laboratory supplies. For pH analysis, samples were promptly preserved in a cooler with ice to maintain their integrity and were analyzed within two hours of sampling to prevent any potential alterations in pH levels over time. Similarly, samples for coliform count and bacteria analyses were analyzed within two hours of sampling to minimize any changes in bacterial composition. Samples for the analysis of NO3-, phosphate, iron, calcium, nitrate, alkalinity, and chloride were also analyzed within two hours of sampling to ensure accurate results. To standardize the temperature conditions, all samples were attemperated to 20°C before analysis. Additionally, to prevent any contamination, all glassware used for the research was thoroughly washed and soaked overnight in chromic acid, ensuring cleanliness and accuracy in the analyses conducted.

6. Analyses of the sachet water samples

The pH meter utilized for measurements was the Thermofisher Scientific Orion Dual Star model, which was calibrated using buffer solutions of pH 4, 7, and 10 to ensure accuracy. The water samples were adjusted to a temperature of 20°C before testing. For pH analysis, the electrodes were rinsed with the water samples and then immersed into the samples, with the pH values subsequently recorded. Turbidity measurements were conducted using the Sigrist Haze Meter after the water samples were adjusted to 20°C. Alkalinity analysis involved titrating 100 ml of the water sample against 0.02N Sulphuric acid using methyl orange as an indicator. Total Hardness was determined by adding a Merck hardness tablet to 100 ml of the sample, followed by the addition of two drops of 32% Ammonia. The mixture was then titrated against Merck Titriplex B. For the analysis of Phosphate, Iron, Calcium, Nitrate, and Chloride, standard Merck reagents were used, and readings were obtained using a spectrophotometer (Spectroquant® Prove 600, Merck). Microbiological analyses, specifically for Total Heterotrophic Bacteria and Enteric Bacteria, involved culturing the samples using the membrane filter method within a laminar flow hood. The cultured samples were then transferred into an incubator and allowed to incubate at 28 ± 2°C for 48 hours, after which the plates were examined, and readings were taken.

6.1. Statistical and data analysis

Microsoft excel was utilized in the statistical/data analyses.

7. Results and discussion

7.1. Turbidity

In this study, no suspended solids were detected in the sachet water samples, and the maximum turbidity value for all samples was found to be 0.16 NTU, which aligns with findings by Airaodion et al., 2019, indicating values below 5.0 NTU. Notably, these results exceeded the specification set by Canada, which mandates a maximum turbidity of 0.1 NTU. Turbidity serves as a useful indicator of water purity, as elevated levels can suggest inadequate removal of pathogens in filtered water. According to the World Health Organization (WHO) guidelines on water quality and health, a desirable turbidity level for drinking water should be 0.3 NTU in 95% of monthly measurements, with none exceeding 1 NTU. Comparing this with the turbidity limits established by the Environmental Protection Agency (EPA) (0.2 NTU), Canada (0.1 NTU), and the Nigerian Industrial Standard (NIS) (5.0 NTU), it is evident that NIS allows for a broader range, as observed in the current research. Turbidity refers to the cloudiness of water resulting from suspended particles such as clay, silts, chemical precipitates like manganese and iron, and organic particles such as plant debris and organisms. The presence of cloudiness in sachet water raises concerns regarding safety, as it may signify the presence of pollutants detrimental to health. The Nigerian government has implemented regulations to ensure that drinking water, including sachet water, adheres to specific quality standards, including turbidity limits. However, enforcement of these regulations may pose challenges, and sachet water of questionable quality is frequently circulated in Nigeria. Consumers can safeguard themselves by procuring water from reputable sources, examining it for turbidity or other signs of contamination before consumption, and employing methods such as boiling or using water filters to eliminate impurities and reduce turbidity. As turbidity levels increase, water clarity decreases due to the scattering and absorption of transmitted light. Turbidity, typically measured in nephelometric turbidity units (NTU), serves as a practical parameter for assessing water quality. It can be measured using various tools such as online devices, benchtop and portable meters, or even turbidity tubes, especially in resource-limited settings or small communities. Turbidity values below 4 NTU may only be detectable using instruments; however, when levels reach 4 NTU or higher, the water may appear milky-white, muddy, red-brown, or black in suspension, potentially diminishing its acceptability for drinking-water (WHO, 2017). Based on these standards, it is evident that all water samples in this study meet the requirements and standards for turbidity.

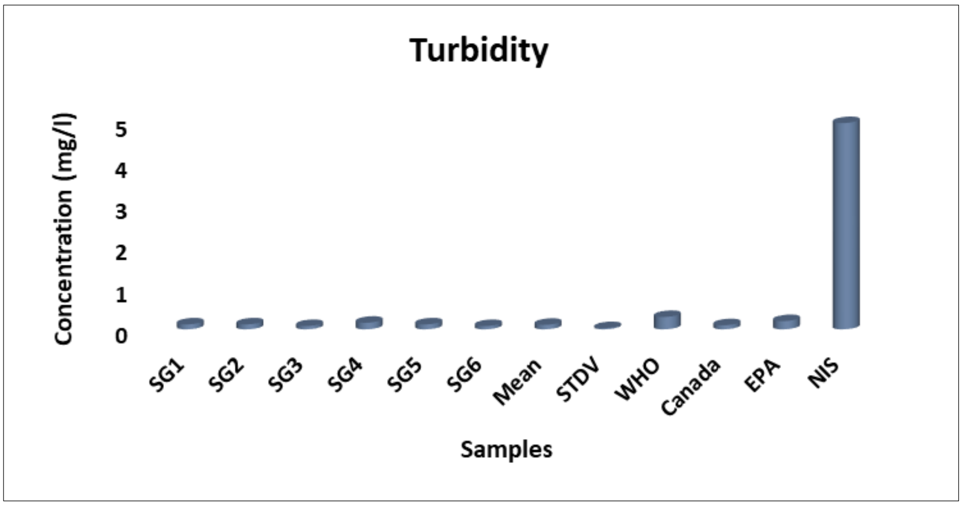

Figure 3 Turbidity of the water samples

7.2. pH

The pH of this study is not in conformance with the findings of Airaodion et al., 2019, in which they studied the quality of drinking sachet water in Ibadan, South West of Nigeria and found the pH to be in the range of 6.48 - 7.12 against 4.73 – 6.10 of this present studies in Sagamu, which the water tends to be very acidic and below the permissible limits for EPA, WHO, NIS and Canada. The sachet drinking water may not be safe for consumption due to its acidic nature.

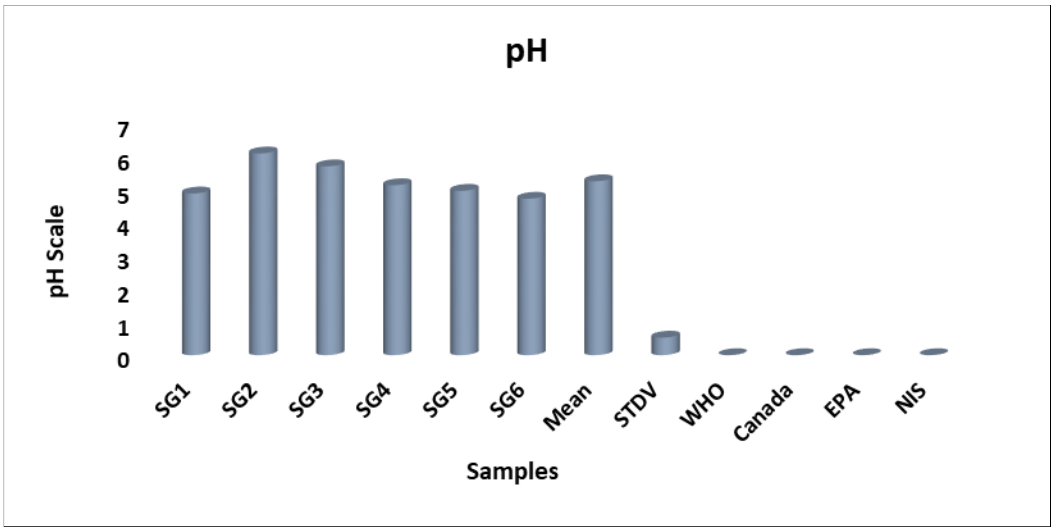

Figure 4 pH of the water samples

The pH of a solution is defined as the negative logarithm (base 10) of the hydrogen ion activity:

pH = -log (H+) …………………(Eqn 1)

In the equation Kw =[H+] × [OH−], ……………………..(Eqn 2)

Kw represents the ion product of water at a given temperature. At 25°C, the value of Kw is approximately $1.0\times10{-}14 mol^2/L^2$. This constant indicates the equilibrium concentration of hydrogen ions ([H+]) multiplied by the hydroxide ions ([OH−]) in pure water at that temperature.

where: [H+] is the equilibrium concentration or activity of hydrogen ions (mol/L); and [OH−] is the hydroxide ions or activity of hydroxide ions (mol/L).

Indeed, the activity of hydrogen ions, also known as effective concentration, refers to the ions that actively participate in a chemical reaction, which may differ from the actual concentration of ions present in a solution due to various factors such as ionic strength, complex formation, and temperature. A logarithmic scale, typically expressed as pH, is a convenient method for quantifying the ionic activities. pH represents the negative logarithm (base 10) of the hydrogen ion concentration ([H+]) in a solution. This logarithmic scale allows for a more manageable and standardized representation of the wide range of hydrogen ion concentrations found in aqueous solutions.

(-log10 [H+]) + (-log10 [OH−]) = -log10 Kw = 14 at 25°C …………….(Eqn 3)

Or pH + pOH = pKw ……………..(Eqn 4)

where:
pH = -log10 [H+]
pOH = -log10 [OH−]; and
pKw = -log10 Kw

Exposure to extreme pH values can lead to irritation of the eyes, skin, and mucous membranes. pH levels exceeding 11 have been linked to eye irritation, exacerbation of skin conditions, and potential gastrointestinal irritation in sensitive individuals. Similarly, exposure to low pH values can induce similar effects. pH levels below 4.0 have been associated with eye redness and irritation, with severity increasing as pH decreases. Below pH 2.5, irreversible and extensive damage to the epithelium may occur. Additionally, pH levels can influence the corrosion of metals and the efficiency of disinfection processes, indirectly impacting health (WHO, 1986).

The optimal pH for water varies depending on the water's composition and the materials used in the distribution system. However, it typically falls within the range of 6.5–9.5. The World Health Organization (WHO) recommends that the pH of drinking water should be between 6.5 and 8.5 to ensure its safety for human consumption. Similarly, the

Nigerian National Standard for Drinking Water specifies a pH range of 6.5 to 8.5 for all drinking water, including sachet water. Extreme pH values may arise from accidental spills, treatment breakdowns, or inadequately cured cement mortar pipe linings (WHO, 1996).

7.3. Total Alkalinity

The average total alkalinity values observed in this study, ranging from 9mg/l to 19mg/l, are well below the permissible limit of 500mg/l for drinking water as recommended by the World Health Organization (WHO, 2019). Unegbu et al. (2017) similarly reported total alkalinity levels in sachet water ranging from 3.71mg/l to 9.02mg/l, which is lower than the range found in the present study. Excessive alkalinity in water can potentially lead to adverse effects such as impaired digestion, exacerbation of kidney disorders, and dry, itchy skin. However, with the observed values falling well below permissible limits, the risk of such side effects is minimized in the water samples analyzed in this study.

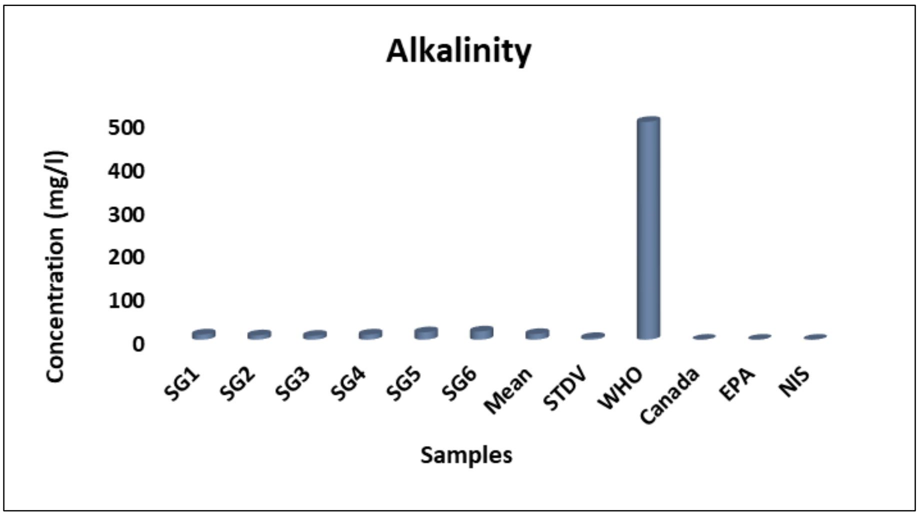

Figure 5 Alkalinity concentration in the water samples

Mildly elevated alkalinity levels are generally considered safe by experts, although there is limited research on the long-term effects (West, 2019). Alkalinity itself is not a chemical present in water; rather, it is a property of water influenced by the presence of certain chemicals such as bicarbonates, carbonates, and hydroxides. Alkalinity can be defined as the buffering capacity of a water body, representing its ability to neutralize acids and bases and maintain a relatively stable pH level (USGS, 2015). In Nigeria, groundwater often exhibits higher alkalinity levels compared to surface water sources like rivers and lakes. This is attributed to groundwater frequently encountering limestone, dolomite rock formations, and other minerals that can influence its alkalinity. However, accurately estimating the alkalinity levels of clean water in Nigeria without microbial or physicochemical analysis can be challenging. Understanding the quality of water and ensuring it meets the standards for drinking and other uses can be enhanced by knowledge of alkalinity levels.

7.4. Phosphate

The average phosphate concentrations observed in this study range from 0.12mg/l to 0.51mg/l, significantly below the permissible limit levels set by the World Health Organization (WHO), Nigerian Industrial Standard (NIS), and the Environmental Protection Agency (EPA). Phosphorus is a vital element essential for the growth of both plants and animals. However, in its elemental form, phosphorus can be highly toxic and prone to bioaccumulation. Phosphate exists in various forms, including orthophosphate, met-phosphate, and organically bound phosphate. Orthophosphates, produced through natural processes and found in sewage, are prevalent. Polyphosphates, used in boiler water treatment and detergents, transform into orthophosphates in water. Organic phosphates, originating from the breakdown of organic pesticides containing phosphates, are also significant in nature. These compounds may be present in solution, as particles, loose fragments, or within the bodies of aquatic organisms. Excessive phosphate runoff from agricultural soils due to rainfall can lead to environmental concerns. However, the phosphate levels observed in this study fall within safe limits and do not pose significant digestive health risks, as extremely high levels of phosphate intake may cause digestive problems (Kumar and Puri, 2012). Phosphate is a naturally occurring compound found in drinking water and is essential for various industrial processes and agricultural activities, particularly as a component of fertilizers. In Nigeria, the levels of phosphate in drinking water can vary depending on factors such as the water source, treatment methods, distribution systems, and the presence of farming activities in the vicinity. For example, urban areas of Sagamu may have lower levels of phosphate due to fewer farming activities compared to rural areas where subsistence farming is prevalent. Elevated levels of phosphate in drinking water can have adverse effects on both human health and the environment. In humans, excessive consumption of phosphate or exposure to high concentrations can be associated with an increased risk of cardiovascular disease, kidney problems, and bone disorders. To mitigate these risks, it is crucial for water treatment facilities in Nigeria to regularly monitor, assess, and test the concentrations of phosphate in their drinking water supply. If necessary, appropriate measures should be taken to reduce phosphate concentrations to ensure the safety and well-being of the population. This proactive approach can help safeguard public health and protect the environment from potential adverse effects associated with high phosphate levels in drinking water.

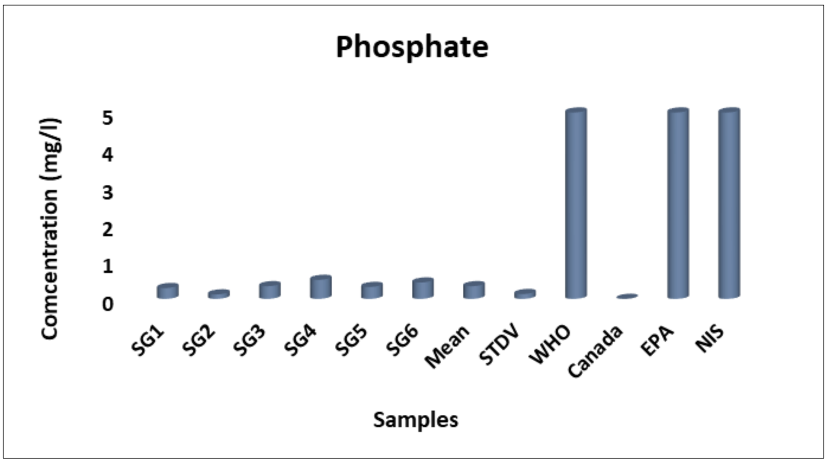

Figure 6 Phosphate concentration in the water samples

7.5. Total Hardness

The average total hardness of sachet water samples in Sagamu ranges from 3mg/l to 6mg/l, falling below the permissible limits set by both the WHO and Canada for total hardness in drinking water. Calcium and magnesium, the minerals contributing to total hardness, play essential roles in human health. Inadequate intake of these nutrients can lead to adverse health effects, making it vital to ensure sufficient daily intake. The total hardness of sachet water in Nigeria varies based on its water source and treatment method. Typically, sachet water in Nigeria is sourced from wells or boreholes, which can vary in hardness due to dissolved minerals like calcium and magnesium. The analysis of sachet drinking water in Sagamu suggests that sachet water in Nigeria generally exhibits low to moderate levels of hardness, as it undergoes basic filtration and disinfection processes. It's important to recognize that while low to moderate hardness levels are generally safe for consumption, elevated hardness levels can have adverse health effects and may damage household appliances like water heaters and washing machines. Therefore, monitoring and maintaining appropriate hardness levels in drinking water are crucial for ensuring both human health and the longevity of household equipment.

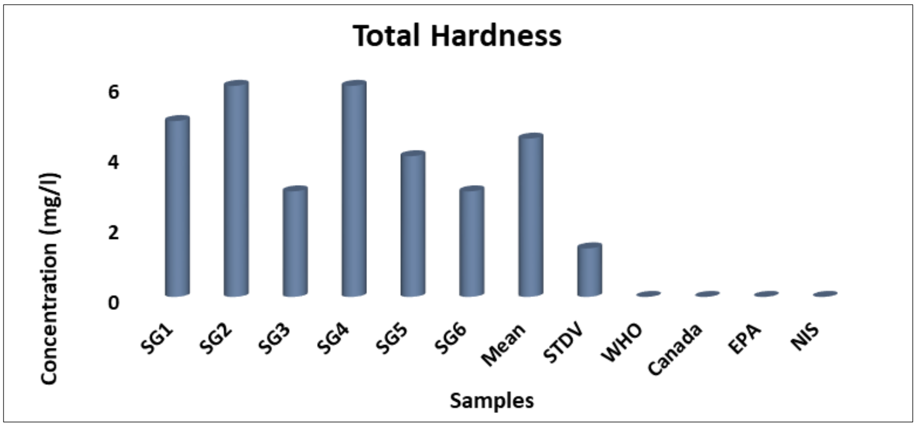

Figure 7 Total Hardness concentration in the water samples

7.6. Iron

The average iron concentration in the sachet water samples analyzed in this study falls within the range of 0.02 mg/l to 0.21 mg/l, consistent with findings by Airaodion et al., 2019, which reported iron concentrations ranging from 0.01 mg/l to 0.05 mg/l. Iron is an essential nutrient for human nutrition, with recommended daily intake varying based on factors such as age, sex, and physiological status. While iron is necessary for health, excessive intake can be harmful, with the average lethal dose estimated to be between 200–250 mg/kg of body weight. Even relatively low doses, such as 40 mg/kg of body weight, have been associated with fatalities. However, small concentrations of iron in sachet drinking water are generally considered safe. The presence of iron in sachet drinking water in Nigeria can result from various factors, including corrosion of metal pipes, leaching from soil or rock formations, and the presence of iron-rich minerals in the water source. While low concentrations of iron are typically safe, high levels can lead to negative health effects and may cause staining and other issues with household appliances and fixtures. Chronic iron overload, primarily associated with genetic disorders like hemochromatosis or diseases requiring frequent transfusions, can lead to adverse health effects. However, studies suggest that regular intake of iron supplements at recommended doses is unlikely to cause harm in healthy individuals. In summary, while iron is essential for health, it's important to monitor and control its concentration in drinking water to ensure it remains within safe limits and does not pose risks to human health or cause other undesirable effects.

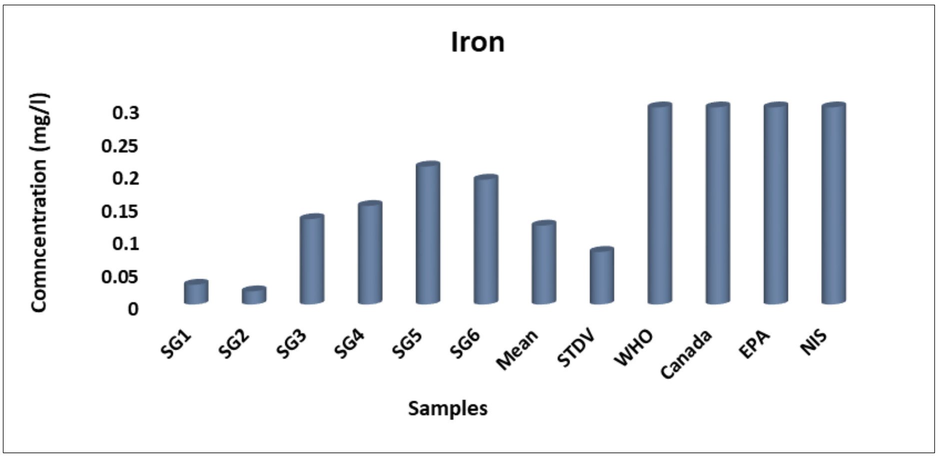

Figure 8 Iron concentration in the water samples

7.7. Calcium

The average concentration of calcium in the sachet water samples analyzed in this study ranged from 2.10 mg/l to 4.8 mg/l. This contrasts with the findings of Airaodion et al., 2019, which reported lower levels of calcium ranging from 0.4 mg/l to 0.09 mg/l. Additionally, Yusuf et al., 2015, found higher concentrations of calcium ranging from 2.1 mg/l to 48.58 mg/l in their research on sachet water in Zaria, Kaduna. However, all these results were below the permissible limits suggested by WHO, Canada, NIS, and EPA. Calcium is naturally present in water and can dissolve from various rocks such as limestone, marble, calcite, dolomite, gypsum, fluorite, and apatite. It is a determinant of water hardness due to its presence as Ca^{2+} ions. While calcium is an essential mineral for human health, excessive intake can have negative effects. The lethal oral dose of calcium is estimated to be between 5-50 mg/kg of body weight, and metallic calcium can cause skin corrosion upon contact with the skin, eyes, and mucous membranes. In addition to being present in water, calcium is found in many food sources such as dairy products, leafy greens, and nuts. Drinking water can contribute to calcium intake, but the amount varies depending on the water source and treatment process. Factors such as the source of the water, treatment methods, and packaging materials can influence the calcium content of sachet drinking water in Nigeria. Given the variability in calcium concentration and its importance for human health, it is essential to ensure that drinking water meets health standards for calcium content. Monitoring and regulating the calcium levels in drinking water can help protect public health and prevent adverse effects associated with excessive calcium intake.

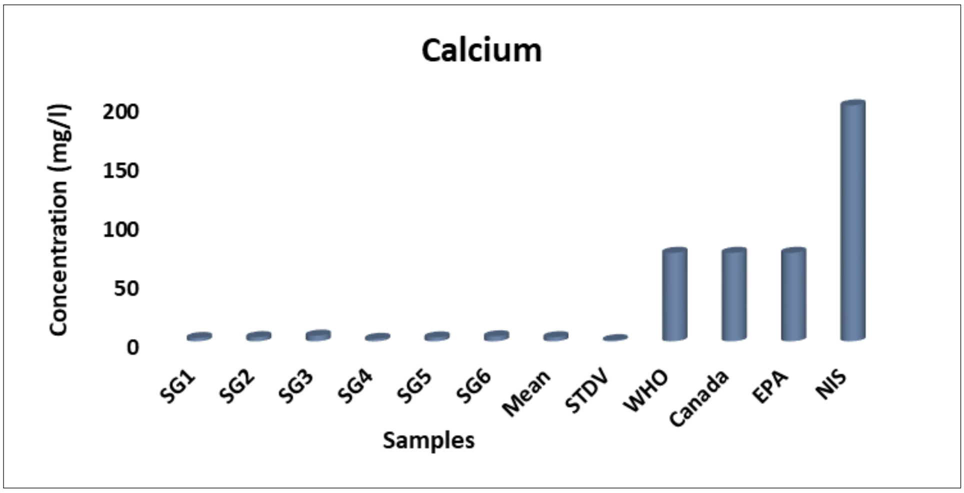

Figure 9 Calcium concentration in the water samples

7.8. Nitrate

The average nitrate concentration in the sachet water samples analyzed in this study falls within the range of 0.00 mg/l to 2.50 mg/l, which is well below the permissible limits. This finding is consistent with the research conducted by Ahimah and Ofosu (2012), who investigated nitrate levels ranging from 0.00 mg/l to 0.50 mg/l in sachet water in the Ghana metropolis. Similarly, Adeyeye et al. (2017) found lower levels of nitrate ranging from 0.080 mg/l to 0.32 mg/l in their research on sachet water in Ekiti, Nigeria. Nitrate contamination in groundwater is a common issue in rural areas, often originating from agricultural fertilization and leaching of human and animal waste into the groundwater. Regulation of nitrate levels in drinking water is important due to the potential health risks associated with excess nitrate intake. High nitrate levels can cause methemoglobinemia, also known as "blue baby" disease, particularly in infants. While nitrate levels that affect infants may not pose a direct threat to older children and adults, they can indicate the potential presence of other contaminants such as bacteria or pesticides. Drinking water standards for nitrate are often set based on a fraction of the level associated with no observed adverse health effects. However, there may be little margin of safety in these standards, as evidenced by a 1977 report from the National Academy of Science, which suggested a maximum no-observed adverse health effect level near 10 mg/l nitrate for preventing methemoglobinemia in infants. Overall, maintaining nitrate levels within permissible limits in drinking water is essential to protect public health, particularly vulnerable populations such as infants. Monitoring and regulating nitrate levels in drinking water sources can help mitigate potential health risks associated with nitrate contamination.

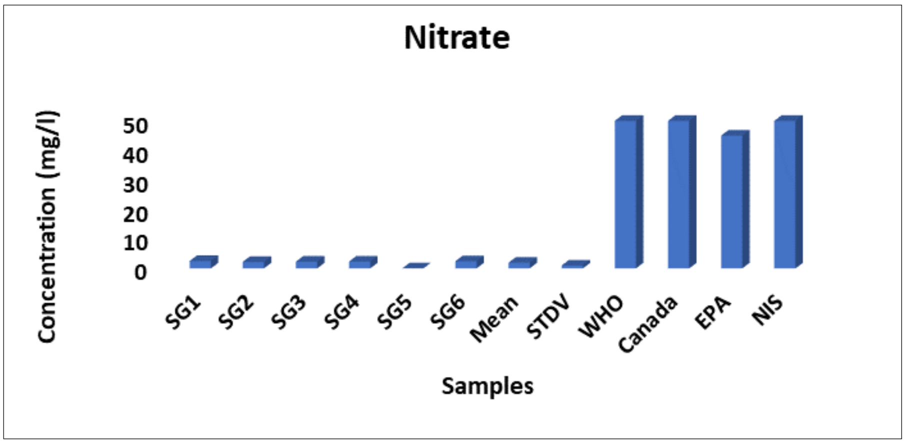

Figure 10 Nitrate concentration in the water samples

7.9. Chloride

The average range of chloride concentration in the sachet water samples analyzed in this study falls between 12.8 mg/l to 28.3 mg/l, which is below the permissible limits set by WHO, EPA, Canada, and NIS. These results are consistent with the findings of Adeyeye et al., 2017, who reported chloride concentrations ranging from 18.0 mg/l to 33.0 mg/l in sachet drinking water. Chloride is an essential nutrient for human health, and a normal adult human body contains approximately 81.7 g of chloride. The recommended dietary intake for adults is 9 mg of chloride per kg of body weight per day, equivalent to slightly more than 1 g of table salt per person per day. For children up to 18 years of age, a daily dietary intake of 45 mg of chloride is recommended. While chloride toxicity is rare in healthy individuals, excessive intake of chloride can have negative effects on health, particularly in cases of impaired sodium chloride metabolism, such as congestive heart failure. However, healthy individuals can tolerate large quantities of chloride intake if there is a concurrent intake of fresh water. In Sagamu, where sachet drinking water is commonly consumed, the levels of chloride in the sachet water are relatively low, indicating that the water is safe for consumption. It is important to continue monitoring and ensuring that drinking water meets health standards and guidelines for chloride levels to safeguard public health.

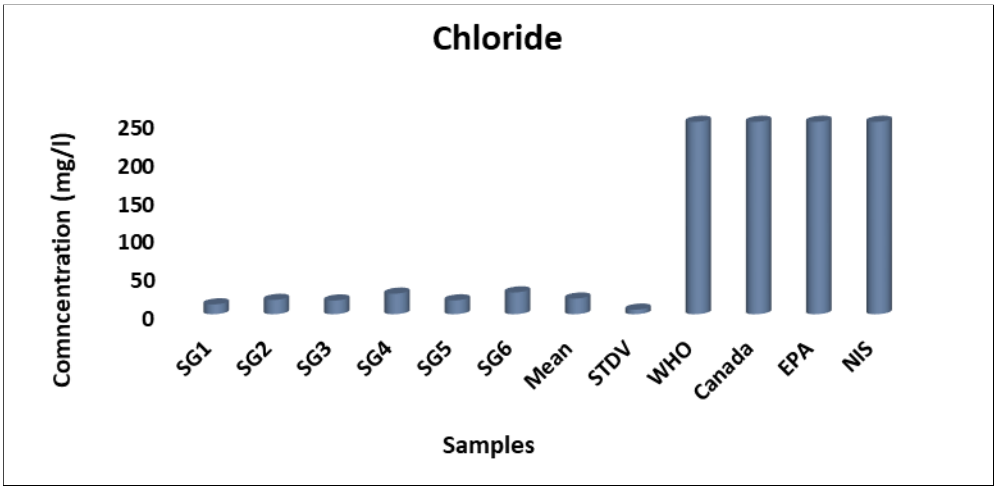

Figure 11 Chloride concentration in the water samples

7.10. Total Enteric Bacteria and Enteric Bacteria

Total enteric bacteria and enteric bacteria are terms used to describe bacteria that are commonly found in the gut of warm-blooded animals, including humans. While some species of enteric bacteria are beneficial and play a role in digestion, others can cause illness when present in drinking water. In sachet drinking water in Nigeria, the levels of total enteric bacteria and enteric bacteria may be influenced by various factors, including the source of the water, the hygiene practices of water production staff, the treatment processes used, and the quality of the packaging materials. It is important to ensure that these factors are carefully managed to prevent contamination of the water with harmful bacteria. The levels of total enteric bacteria and enteric bacteria in the sachet drinking water samples analyzed in this study are slightly below the permissible limits of less than 500 colony forming units (cfu) stipulated by WHO, Canada, and EPA. However, even low levels of fecal coliform bacteria in drinking water can indicate contamination with fecal material from humans or animals. This contamination can introduce pathogens or disease-causing bacteria and viruses into the water, posing a potential health risk to individuals who consume it. Waterborne diseases such as typhoid fever, viral and bacterial gastroenteritis, and hepatitis A can result from the ingestion of water contaminated with fecal coliform bacteria. The presence of fecal contamination in drinking water is therefore a cause for concern and indicates that there may be a potential health risk associated with exposure to this water. To mitigate the risk of fecal contamination in drinking water, it is essential to maintain high standards of hygiene and sanitation throughout the water production, treatment, and distribution process. Regular monitoring and testing of water quality are also important to ensure that drinking water meets safety standards and is free from harmful bacteria and contaminants.

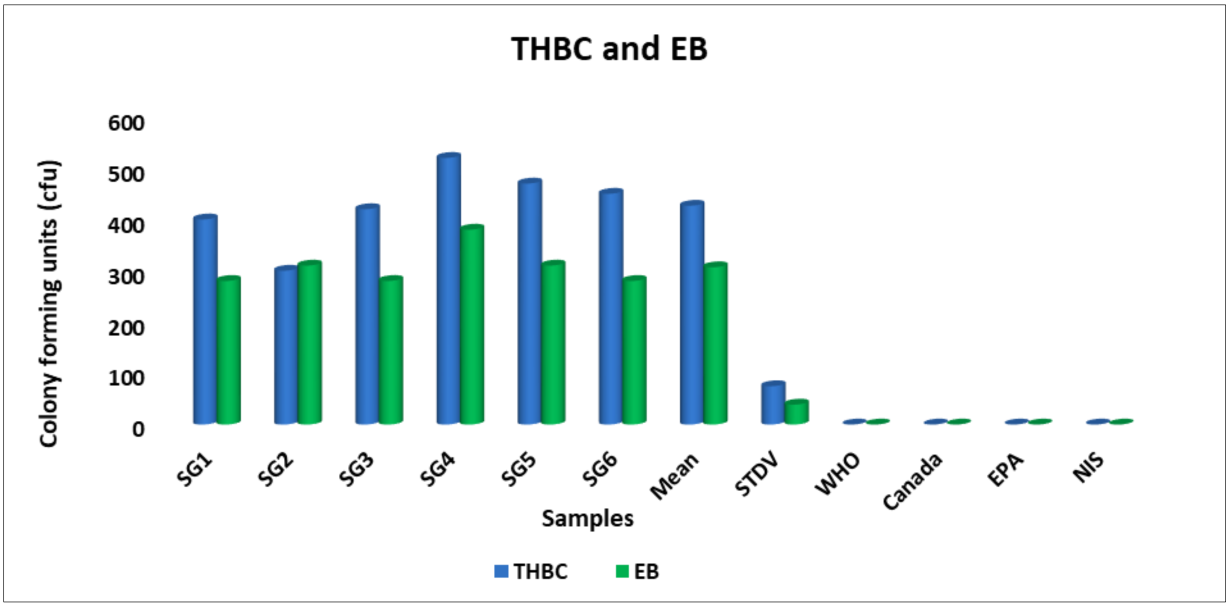

Figure 12 Total Heterotrophic Bacteria Count (THBC) and Enteric Bacteria Count (EB) measured in Colony Forming Unit (CFU)

8. Conclusion

The pH levels observed in this research, ranging from 4.73 to 6.10, do not meet the permissible limits recommended for drinking water, which typically fall between 6.5 and 10.5. This deviation from the acceptable range indicates acidity in the water samples, which is a cause for concern regarding water quality and safety. Ensuring proper acid control in water systems is crucial for water producers to maintain compliance with regulatory standards and provide safe drinking water to consumers. Acidity in drinking water can have adverse effects on human health and may also indicate potential issues with water treatment processes or water sources. To address acidity in water systems, water producers should implement measures such as pH correction or neutralization during the treatment process. Regular monitoring of pH levels and adjustments to treatment methods as needed are essential to ensure that the pH of drinking water remains within the acceptable range. Additionally, water producers should conduct thorough assessments of water sources and treatment facilities to identify any factors contributing to acidity in the water. By addressing these issues and implementing appropriate corrective measures, water producers can help ensure the delivery of safe and potable drinking water to consumers.

Turbidity - The observed turbidity levels ranging from 0.08 to 0.16 NTU fall within the permissible limits of 0.1 to 5.0 NTU. This indicates that the water samples have low turbidity, which is desirable for drinking water as it suggests clarity and minimal suspended particles. Alkalinity - The alkalinity levels ranging from 9 to 17 mg/l are significantly lower than the permissible limit of 500.00 mg/l. Low alkalinity is generally preferred in drinking water as it helps maintain stable pH levels and reduces the likelihood of corrosion in water distribution systems. Total Hardness - The total hardness levels ranging from 3 to 6 mg/l are well below the permissible limits of <60 to 100 mg/l. Low hardness levels indicate minimal concentrations of calcium and magnesium ions, which can prevent scale buildup in plumbing fixtures and appliances. Phosphate - The phosphate concentrations ranging from 0.12 to 0.51 mg/l are below the permissible limit of <5 mg/l. Phosphate levels within acceptable limits are desirable as excessive phosphate can contribute to eutrophication in water bodies. Iron - The iron concentrations ranging from 0.02 to 0.21 mg/l are below the permissible limit of <0.03 mg/l. Low iron levels are preferred in drinking water as excessive iron can cause aesthetic issues such as discoloration and unpleasant taste. Calcium - The calcium concentrations ranging from 2.10 to 4.80 mg/l are within the permissible limits of <75 to 200 mg/l. Calcium is an essential mineral in drinking water, and moderate levels contribute to overall water quality. Nitrate - The nitrate concentrations ranging from 0.00 to 2.50 mg/l are below the permissible limits of <45 to 50 mg/l. Elevated nitrate levels can pose health risks, particularly for infants, so it's important to monitor and maintain nitrate levels within safe limits. Chlorine - The chlorine concentrations ranging from 12.8 to 28.30 mg/l are below the permissible limit of <250 mg/l. Chlorine is commonly used as a disinfectant in drinking water treatment to control microbial contamination. The Total Enteric Bacteria count ranging from 300 to 480 cfu/100ml and the Enteric Bacteria count from 280 to 380 cfu/100ml of the water samples analyzed fall within or below the permissible limits established by WHO, EPA, Canada, and NIS. Although there were microbiological growths observed in the analyses, they remained below the permissible limits. However, if not managed properly, these growths could surpass the permissible limits set by EPA, NIS, Canada, and WHO, especially if the water is stored improperly before consumption. Therefore, it is crucial for water producers of sachet "Pure Water" to maintain proper hygiene conditions, ensure good sanitation practices, and prioritize personal hygiene. Additionally, if the borehole used for sourcing raw water is situated near a toilet or waste dump site, there is a risk of contamination. Proper treatment measures should be implemented to mitigate the potential contamination of fecal coliforms in the water supply.

Recommendations

Water production facilities should adhere to proper housekeeping practices and select raw water sources located away from latrines, chemical waste dump sites, and drainage systems to ensure safety. The government should engage reputable private hospitals equipped with laboratories to oversee and report on the analyses of each water factory in its vicinity. Additionally, qualified individuals with well-equipped laboratories should be engaged to manage the distribution of township water supply through pipelines to households in the surrounding areas and nearby communities, with water usage metering and monthly billing implemented. Regulatory bodies such as NAFDAC and SON should conduct regular assessments and monitoring of water production by each vendor. Individuals can also contribute by storing water appropriately and reporting any illegal practices by water production companies.

In summary, and from the research, discussions, and studies above, few recommendations for ensuring safer sachet drinking water in Nigeria are stated below.

- **Water source:** The source of the water used for sachet drinking water should be tested before starting production and tested regularly to ensure that it is free from harmful contaminants and meets health standards.
- **Treatment process:** The produced water should undergo proper treatment, such as filtration, chlorination, or ultraviolet disinfection, to reduce or remove harmful contaminants.
- **Packaging materials:** The nylon materials used for packaging sachet drinking water should be food grade, safe for food contact and should not pose a risk of contamination (degradable).
- **Quality control/assurance:** Regular laboratory testing should be performed to ensure that the water meets health standards such as the guidelines for total enteric bacteria, enteric bacteria, chlorine, calcium, and chloride levels.
- **Consumer education:** Consumers should understand and be educated about the importance of safe drinking sachet water and the risks associated with consuming contaminated or infected water.
- **Regulatory framework:** The government should implement and enforce strict regulations that will ensure safety in sachet drinking water and ensure that sachet drinking water meets health standards requirements and is safe for consumption.
- **Continuous monitoring:** The quality of sachet drinking water should be monitored continuously and efficiently to ensure that it remains safe for consumption.

If these recommendations are implemented, the risk of consuming contaminated sachet drinking water can be reduced, and consumers can be protected from the negative health effects of contaminated sachet water, popularly referred to as “*Pure Water*”.

Compliance with ethical standards

Acknowledgments

The authors gratefully acknowledge International Breweries Plc (A member of the Anheuser Busch Inbev) located in Sagamu, Ogun State, Nigeria. We extend our sincere appreciation for using their facilities to re-confirm most of the physicochemical properties discussed in this research. Their support and cooperation significantly contributed to the success of this study.

Disclosure of conflict of interest

No conflict of interest is to be disclosed.

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