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Microbial Quality and Mineral Content of Water Consumed in Ho Municipality of Volta Region, Ghana

G. Aboagye [1*], P.G. Akpaloo [1], T.A. Avle [2]

1. Department of Nutrition and Dietetics, School of Allied Health Sciences, University of Health and Allied Sciences, Ho, Volta Region, Ghana
2. Department of Nursing, School of Nursing and Midwifery, University of Health and Allied Sciences, Ho, Volta Region, Ghana

HIGHLIGHTS

- Bottled water had the highest acceptability than sachet and tap water.
- Physical parameters were within the recommended limits.
- Mineral composition of the samples was generally within acceptable limits.

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Acronyms and abbreviations
CFU=Colony Forming Unit
HPC=Heterotrophic Plate Count
NTU=Nephelometric Turbidity Unit

ABSTRACT

Background: Water quality and safety are fundamental to human development and well-being. Therefore, the purpose of this study was to determine the bacteriological and mineral content of water in Ho, the capital city of the Volta Region of Ghana.
Methods: Sachet, bottled, and tap water were sampled from January to February in 2019 due to the high rate of consumption and their presumed quality which were taken at random from five different locations throughout the municipality. Water quality assessment protocols were utilized to ascertain the bacteriological as well as mineral contents of the samples, whilst ANOVA was used to determine statistical difference and significance at $p<0.05$.
Results: The maximum Heterotrophic Plate Count for tap water was $9.95\pm0.64\times10^5$ Colony Forming Unit (CFU)/ml, for sachet water was $7.46\pm0.09\times10^6$ CFU/ml, and for bottled water was $1.10\pm0.56\times10^5$ CFU/ml, all obtained on nutrient agar. For MacConkey agar, maximum growth was $2.94\pm0.03\times10^6$, $9.42\pm1.67\times10^6$, and $2.31\pm0.77\times10^5$ CFU/ml for tap, sachet, and bottled water, respectively. The Xylose Lysine Deoxycholate Agar indicated maximum growth of $1.84\pm0.34\times10^3$, $5.72\pm0.06\times10^6$, and $5.50\pm2.12\times10^4$ CFU/ml for tap, sachet, and bottled water, respectively.
The physical parameters such as pH, turbidity, color, and conductivity were within the recommended limits set by the Ghana Standards Authority. However, tap water recorded the highest turbidity, bottled water recorded the highest and least pH and turbidity, respectively. Moreover, the mineral analysis revealed high levels of phosphate (PO_4^{3-}), chloride (Cl^-), and sodium (Na) in bottled water, and total iron (Fe) was relatively high in several tap and sachet water samples, the latter item also recorded the highest for ammonia (NH_3).
Conclusions: Overall, the tap, sachet, and bottled water samples exhibited varied levels of microbial, and mineral contents whilst the physical parameters were relatively within the recommended levels. The sachet and tap water were the least wholesome in comparison with the bottled water samples.

* Corresponding author (G. Aboagye)
E-mail: gaboagye@uhas.edu.gh
ORCID ID: https://orcid.org/0000-0002-2725-2676

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Introduction

Water quality and safety are fundamental to human development and well-being. Water quality can be compromised by the presence of infectious agents, toxic chemicals, and radiological hazards (WHO, 2023). The United Nations General Assembly, in 2010, emphasized the need for humans to sufficient, continuous, safe, acceptable, physically accessible, and affordable water for personal and domestic use (Hall et al., 2014).

Unfortunately, in developing countries such as ones in the sub-Saharan Africa, access to sufficient, safe, acceptable, physically accessible, and affordable water is still a major challenge (Makokove et al., 2022). Approximately, 880 million individuals still have no access to safe water, the lowest coverage found in sub-Saharan Africa (World Health Organization and Unicef, 2008). Contaminated water can transmit diseases such as diarrhoea, cholera, dysentery, typhoid, and polio diseases and is estimated to cause 502,000 diarrhoeal deaths annually (WHO, 2023). Waterborne disease such as diarrhoea, causes 1.5 million deaths in a year, prominently to children in developing countries (World Health Organization and Unicef, 2008).

The World Health Organization (WHO) estimates that nearly 10% of the global burden of disease could be prevented by improving water supply, sanitation, hygiene, and management of water resources (WHO, 2023). In light of this information, there have been attempts to make water safer and better purified for consumption. Among these attempts are the construction of boreholes and wells, provision of tap water and packaged water. According to the 2014 Ghana Demographic Health Survey, 6 in 10 households in Ghana obtain drinking water from an improved source, including a piped source within the dwelling, yard or plot, a public tap, standpipe, tube well or borehole; a hand pump, protected well or protected spring, and rainwater, with additional 10 and 30% of households relying on unimproved and bottled or sachet water sources, respectively (Ghana Statistical Service, 2011). In Ho municipality, households derive their drinking water from diverse sources, including standpipes, borehole/pump/tube well, and river or stream. The largest proportion of households (33.0%) rely on pipe borne water outside dwelling as their main source of drinking water. A little above one-quarter (25.6%) of households have pipe borne water inside their dwelling. Regarding main source of water for other domestic use, pipe borne water is regarded as the main source for 53.7% of households, followed by the use of public tap/standpipe by 17.2% of households. Unfortunately, preliminary assessment of the type of water sources in households indicated that approximately 10% of them in Ho Municipality rely on unprotected water sources i.e. unprotected wells and springs, rivers/streams, dugout/pond/lake/dam/canal, etc. as their main sources of drinking water.

It is worth noting that treated water, which is meant to be safer than raw surface water, fails always to meet the standards of potability, coupled with a decline in access to urban pipe water due to increase in population size (Mor and Griffiths, 2011; World Health Organization and Unicef, 2014). Sachet water has, therefore, emerged as a significant private sector innovation to fill West African gaps in urban household drinking water security, particularly among the urban poor (Stoler et al., 2012).

The most common source of drinking water in the urban areas is sachet water (43%), followed by public tap or standpipe (23%). In rural households, the most common source of drinking water is tube well or borehole (41%), followed by public tap or standpipe (19%) (Appiah-Effah et al., 2021). The most notable change in access to drinking water sources between 2008 and 2014 is the increase in the proportion of households using sachet water from 8 to 29% in the past 6 years (Ghana Statistical Service, 2011). On the other hand, the proportion of households that use drinking water from public tap or standpipe or tube well or borehole has decreased from 57% in 2008 to 44% in 2014, most likely due to switching to sachet water in the later survey (Ghana Statistical Service, 2011). Packaged water is the fastest growing beverage category in the world (WHO, 2008). Consumers may possess various reasons for purchasing packaged drinking water, such as taste, convenience or fashion; for many consumers, however, safety and potential health benefits are fundamental considerations (WHO, 2008). For some consumers, it is a healthy alternative to tap water and other beverages (WHO, 2008).

Several studies have revealed that the chemical and microbiological qualities of some packaged water are in violation of acceptable standards, and may not conform to national standards as expected by the consumers (Osei et al., 2013). Microbiological quality of drinking water is of great health concern to all people owing to the potential of drinking water as carrier of microbial pathogens and cause of subsequent illness in both developed and emerging economies of the world (Ngwai et al., 2010).

Unfortunately, the rapid growth and unknown scope of formal and informal sachet water production combined with lack of resources for adequate enforcement of its regulation in Ghana, has rendered Food and Drugs Board (FDB) registration somewhat voluntary (Stoler et al., 2012). Therefore, this research, being first of its kind, was performed to determine the microbial quality, mineral content as well as other infectious agents present in the water consumed by the people of Ho municipality of the Volta Region of Ghana.

Materials and methods

Sampling method

The highly patronised drinking water sources in the municipality i.e. sachet, bottled, and tap water were sampled from January to February in 2019. The sachet and bottled water were bought from various selling locations in the municipality whilst the tap water samples were obtained from selected households in the municipality.

Two sachets from each of the five brands of sachet water samples, two bottles also from each of five brands of bottled water samples and two tap water samples from five selected households were obtained from the municipality. In all, 10 each of sachet, bottled, and tap water totalling 30 samples were analysed for microbiological quality, whereas, duplicates of 1 L from the same sources were analysed for mineral content. It is noteworthy that each of the sachet, bottled, and tap water samples obtained and analysed for the study measured 500 ml. Since the sachet and bottled water samples were sealed from purchase, prevention of contamination of the tap water was ensured by the use of clean, sterile, nonreactive borosilicate glass bottle to fetch the tap water samples midstream. A 2 cm headspace was permitted in the glass bottle to facilitate mixing by shaking before analysis.

Microbiological quality

Total and faecal coliforms were tested using the membrane filtration method (Nalgene Filter, Fisher Scientific, UK) (Burk, 2024). The water samples were filtered through a 0.45 µm of the afore-mentioned filter paper, homogenized, and serially diluted in sterile distilled water to 10^{-5} and pour plated in a petri dish with various microbial nutrients (nutrient agar, MacConkey agar, and Xylose Lysine Deoxycholate Agar (XLDA) (all from Oxoid Ltd, Basingstoke, Hampshire, England, UK) for general microbial growth, identification of Gram-negative bacteria and *Salmonella* and *Shigella* species, respectively. The plates were incubated at 37 ºC for 24 h (Sanders, 2012). The colonies were thereafter enumerated and identified.

Mineral analysis

A multiparameter photometer was utilized to ascertain the chemical parameters including nitrite (NO^-_2), nitrate (NO^-_3), phosphate (PO_4^{3-}), sulphate (SO_4^{2}-), fluoride (F^-), and manganese (Mn) by using the methods stated in the 23rd edition of standard methods for the examination of water and wastewater (Rice et al., 2017). Findings were compared with the Ghana Standards Authority reference values (Ghana Standards Authority, 2021) to determine whether the samples conformed to acceptable standards based on the recommendations of Ghana Standards Authority (Ghana Standards Authority, 2021).

Physical parameters

Some physical parameters were considered such as color, temperature, pH, and turbidity to specify the acceptable level of the various samples. For color, the colorimeter (Koehler Instrument K88,900/K88,990 Bomb Calorimeter, USA) was employed in which alteration in color after application of the sample to the equipment was noted and recorded. Afterwards, a mercury-in-glass thermometer was applied to consider the temperature of the samples by dipping into the samples. For pH measurement, a pH meter (AS ONE 2-8140-01 KR5E As Pro pH Meter, Singapore) was dipped into the samples and record made of the reading, and for turbidity, a turbidimeter (Extech TB400 Turbidity Meter, USA) was used (Bhawan, 2007). All the readings were accomplished in triplicates. Other parameters such as alkalinity and chloride (Cl^-) were tested, using the titration technique by Patil et al. (2012), where accurately measured volumes of the analyte were placed in an Erlenmeyer flask using a pipette along with few drops of the indicator. The standardized solution was placed in the burette and its volume recorded as the initial volume. The solution was then dispensed until a complete color change was observed. The final volume of the solution was then recorded and the measurement repeated in triplicates. The difference in volume of the final and initial values was recorded as the titre value, and the final color was also recorded for the parameters as described by RACI (2019).

Statistical analysis

After obtaining results of the parameters that were determined, the triplicate values were meaned, and standard deviations ascertained using GraphPad Prism v9.0. The degree of variability between the water samples was also ascertained using an analysis of variance at $p<0.05$.

Results

Table 1 demonstrates the Heterotrophic Plate Count (HPC) of the drinking water on three various media which were applied to determine their presence in the water system. In addition, the findings were compared with the Ghana standards reference values for water quality to ascertain their acceptability.

Table 1: Heterotrophic Plate Count (HPC) of drinking water on three different media; nutrient agar, MacConkey agar, and Xylose Lysine Deoxycholate Agar (XLDA).

Type of sample	Sample	Nutrient agar average CFU/ml	MacConkey agar average CFU/ml	XLDA average CFU/ml	Comments
Tap water	A	1.00E±03	2.10E±03	3.65E±03	not acceptable
	B	9.95E±05	2.94E±06	1.84E±06	not acceptable
	C	4.05E±04	1.54E±04	1.14E±04	not acceptable
	D	2.50E±03	0.00E±00	5.00E±02	not acceptable
	E	1.50E±03	2.51E±05	8.00E±03	not acceptable
Sachet water	A	2.25E±05	0.00E±00	0.00E±00	not acceptable
	B	1.10E±05	3.45E±05	1.74E±05	not acceptable
	C	7.46E±06	9.42E±06	5.72E±06	not acceptable
	D	1.30E±05	0.00E±00	0.00E±00	not acceptable
	E	4.50E±04	0.00E±00	0.00E±00	not acceptable
Bottled water	A	1.10E±05	3.00E±03	1.05E±04	not acceptable
	B	2.50E±04	2.31E±05	5.50E±04	not acceptable
	C	7.00E±03	1.50E±05	5.50E±04	not acceptable
	D	0.00E±00	5.00E±02	0.00E±00	not acceptable
	E	0.00E±00	0.00E±00	0.00E±00	acceptable

E=value (x) times exponent of 10
CFU=Colony Forming Unit

Analysis of variance for the samples revealed a significant difference ($p<0.05$; $p=0.0308$) between them.

There was a significant difference ($p<0.05$; $p=0.0055$) observed between the samples with 4 out of 5 samples recording counts above the recommended limits.
Table 1 represents the HPC of *Salmonella* and *Shigella* in bottled water samples. Forty percent of the samples recorded no counts of *Salmonella* and *Shigella* while the remaining 60% had counts above the recommended limits. Analysis of variance between the samples indicated a significant difference ($p<0.05$; $p=0.0101$). Samples D and E recorded no counts while sample A recorded the least, with no significant difference between samples B and C.

Total and fecal coliforms

Using the membrane filtration method, total and fecal coliforms were tested on all the different samples. The results were negative in all the test samples. Therefore with regards to coliforms, all the different water samples conformed to standards set for coliforms in drinking water. The Ghana Standards Authority has set reference values to allow for some amount of coliforms of less than 1 Colony Forming Unit (CFU)/ml in water that will not be detrimental to health. There was growth on the media but less than the 1 CFU/ml standard set by the Ghana Standards Authority.

Physical parameters

The hazy appearance of water is referred to as turbidity. It is a measurement of light's ability to move through water. It is caused by suspended material in water including clay, silt, organic material, plankton, and other particulates. Temperature influences palatability, viscosity, solubility, smell, and chemical reactions. Water is colored by organic waste degraded from flora and inorganic matter such as dirt, stones, and boulders. Foreign matter, such as organic contaminants, inorganic compounds, or dissolved gasses, can generate taste and odor in water. These resources could be regarded as natural, domestic, or agricultural.

Based on conducted tests, using the methods outlined in the 23rd edition of standard methods for the examination of water and wastewater, the physical parameters such as acidity or alkalinity (pH), turbidity, color, and conductivity were within the recommended limits set by the Ghana Standards Authority as illustrated in Table 2. Sample E, a sample of bottled water recorded the highest pH among all the samples while sample A, a sample of tap water recorded the highest color. Generally, bottled water recorded the lowest values for turbidity with sample A of sachet water recording the highest turbidity. Salinity, being a measure of all the salts dissolved in water, and temperature on the other hand, did have no reference values to compare with those of the test samples.

Mineral analysis

Table 3 exhibits the levels of several selected minerals in the samples of water used for the study. All minerals were measured in mg/L. The difference between the values of the various minerals for the three different types of water failed widely to vary although (PO_4^{3-}), Cl^-, and sodium (Na) levels were observed to be relatively higher in bottled water. Aside sample E of tap water and sample C of sachet water which were higher than the level recommended for total iron (Fe), other samples were within recommended limits for all the tested minerals. Sample E of tap water exceeded the recommended limit for Fe by 3.5 (1.04/0.3) while sample C of sachet water exceeded by 1.5 (0.44/0.3). Further, some samples recorded Mn levels although within the normal range, close to the recommended limit. Sample A of tap water for instance, recorded 0.39 for Mn with the recommended limit being 0.40. Sample B of sachet water had the highest value for ammonia (NH_3) as well.

Table 2: Physical parameters of tap, sachet, and bottled water samples

Type of water	**Sample**	**pH 6.50-8.50**	**Conductivity (mS/m) 100.00**	**Salinity (ppt)**	**Color (HU) 15.00**	**Temperature (°C)**	**Turbidity (NTU) 5.00**
Tap water	SA	7.32	9.00	0.00	2.50	28.50	0.77
	SB	7.45	10.00	0.01	0.00	28.60	0.49
	SC	7.54	9.00	0.00	0.00	27.20	0.50
	SD	7.43	10.00	0.01	0.00	28.00	0.54
	SE	7.30	9.00	0.00	0.00	28.00	0.57
Sachet wateer	SA	7.81	10.00	0.01	0.00	26.80	0.80
	SB	7.00	4.00	0.00	0.00	27.30	0.37
	SC	7.72	9.00	0.00	0.00	28.30	0.74
	SD	7.61	9.00	0.00	0.00	26.40	0.53
	SE	7.61	9.00	0.00	0.00	26.40	0.53
Bottled water	SA	7.73	5.00	0.00	0.00	28.00	0.24
	SB	7.14	3.00	0.00	0.00	27.40	0.30
	SC	7.55	12.00	0.01	0.00	27.70	0.23
	SD	7.17	11.00	0.01	0.00	26.40	0.36
	SE	8.11	10.00	0.01	0.00	26.60	0.30

HU=Haze Units; NTU=Nephelometric Turbidity Unit.

Table 3: Mineral content of tap, sachet, and bottled water samples

Type of water source	**Sample ID**	**Alkalinity**	**TDS (1000.00)**	**Total Hardness (500.00)**	**Chloride (Cl^-) (250.00)**	**Bicarbonate (HCO_3^-)**	**Carbonate (CO_3^{2-})**	**Fluoride (F^-) (1.50)**	**Nitrate (NO_3^-) (50.00)**	**Nitrite (NO_2^-) (3.00)**	**Ammonia (NH_3) (1.50)**	**Sulphate (SO_4^{2-}) (250.00)**	**Sodium (Na) (200.00)**	**Total iron (Fe) (0.30)**	**Manganese (Mn) (0.40)**	**Phosphate**
Tap water	SA	10.00	4.50	30.00	10.00	12.2	0.00	0.38	0.04	0.00	0.04	0.00	6.49	0.16	0.39	0.48
	SB	10.00	5.00	30.00	5.00	12.2	0.00	0.64	0.39	0.01	0.00	1.00	3.25	0.12	0.27	0.22
	SC	10.00	4.50	50.00	5.00	12.2	0.00	0.82	0.68	0.01	0.10	2.00	3.25	0.13	0.09	0.46
	SD	10.00	5.00	50.00	5.00	12.2	0.00	0.57	2.13	0.00	0.10	0.00	3.25	0.13	0.06	0.91
	SE	10.00	4.50	40.00	5.00	12.2	0.00	0.49	0.55	0.01	0.09	0.00	3.25	**1.04**	0.16	3.11
Sachet water	SA	0.50	5.00	30.00	10.00	0.61	0.00	0.34	0.00	0.01	0.01	2.00	6.49	0.09	0.23	0.28
	SB	10.00	4.50	30.00	5.00	12.20	0.00	0.52	0.07	0.02	0.27	2.00	3.25	0.16	0.34	0.15
	SC	10.00	4.50	30.00	5.00	12.20	0.00	0.52	1.73	0.02	0.07	4.00	6.49	**0.44**	0.33	0.15
	SD	10.00	2.00	40.00	5.00	12.20	0.00	0.40	0.00	0.00	0.02	1.00	3.25	0.03	0.20	0.22
	SE	10.00	4.50	30.00	10.00	12.20	0.00	0.54	0.00	0.00	0.02	1.00	3.25	0.03	0.20	0.83
Bottled water	SA	10.00	1.50	30.00	5.00	12.20	0.00	0.36	0.25	0.01	0.15	1.00	9.74	0.02	0.01	6.40
	SB	10.00	5.00	20.00	10.00	12.20	0.00	0.62	0.27	0.01	0.20	2.00	3.25	0.03	0.14	9.00
	SC	10.00	2.50	40.00	15.00	12.20	0.00	0.55	1.12	0.00	0.12	0.00	9.74	0.01	0.12	2.10
	SD	10.00	6.00	30.00	15.00	12.20	0.00	0.77	0.65	0.00	0.11	0.00	9.74	0.14	0.01	5.20
	SE	10.00	5.50	40.00	15.00	12.20	0.00	0.69	1.03	0.00	0.11	0.00	6.49	0.00	0.06	2.50

TDS=Total Dissolved Solids

Discussion

Growth of microorganisms in water after treatment is normally referred to as "regrowth". The principal determinants of regrowth are temperature, availability of nutrients (from the water and/or materials in contact with water), and lack of residual disinfectant (Bartram et al., 2003; Douterelo et al., 2016). The HPC of 86.67% of the water samples cultured on nutrient agar, which promotes the growth of various organisms, was above 500 CFU/ml, the recommended limit for finished treated public water for distribution (WHO, 2008), according to the study's findings, as presented in Table 1. Fifty to hundred CFU/ml is the recommended limit for packaged water (sachet and bottled) according to the international packaged water quality specifications. It is undesirable to have high microbial counts in water due to the likelihood of an increased presence of pathogens and the possibility of these organisms access to foods or drinks, which could lead to adverse effects (Ojo et al., 2008). On MacConkey agar test for Gram-negative organisms, 66.67% of the samples recorded counts above the acceptable limit (Table 1). Furthermore, according to Table 1, 33.33% of the samples cultured on XLDA for *Salmonella* and *Shigella* species were within recommended limits with the remaining 66.67% having counts above the recommended limits. A research detected high amounts of heavy metals in drinking water in Kampala, Uganda's capital city, including lead (Pb), zinc (Zn), Fe, copper (Cu), cadmium (Cd) ,and chromium (Cr). Similarly, such substances have been separated in natural water reservoirs such as lakes, marshes, fish, and beef and milk (Kasozi et al., 2019). Fe was found in the water samples tested in this study, even though they failed to exceed the Ghana Standards Authority's reference values (2021). The three different sources of water sampled for this study (i.e. tap, sachet, and bottle) were significantly different ($p<0.05$) with regards to the microbial count of the various assessed parameters. On all three media, *p*-values were less than 0.05 indicating a significant difference between the samples. This significant difference between the samples could be attributed to the inherent properties of species of organisms which grew on each media from the different samples. The different samples were from various brands and several brands such as sample C of sachet water recorded the highest HPC on all three media whereas sample E of sachet water recorded the lowest HPC. Further, this case applies to bottled water where sample B recorded high counts of Gram-negative organisms as well as *Salmonella-Shigella*, and sample A, the highest of all microorganisms while, sample E recorded the lowest counts. The difference could have originated from hygienic practices during treatment and packaging employed by the producers. This observation was also made by Stoler et al. (2012) who purported that hygienic practices by manufacturers of processed water are major factors affecting water quality.

Water pumps draw directly from a piped-connection of municipality treated water during the production of sachet water (Stoler et al., 2012), however, some sachet water had counts that were higher than those recorded for tap water, making hygiene the next point of concern. All tap water samples originated from the identical distribution point or source of supply although collected from different locations in the municipality. Although all samples recorded various counts of organisms on all three media, the difference may be attributed to either bacterial re-growth or contamination in the distribution system which may happen as several bacteria, e.g. *Legionella* and *Pseudomonas aeruginosa* grow in piped water distribution systems. Elevated HPC occurs during distribution particularly in stagnant parts of piped distribution systems (Bartram et al., 2003; Wang et al., 2012) when the water leaving the treatment plant contains acceptable levels of HPC. However, levels of the HPC in the water distribution system exceeded the recommended limit, so bacterial regrowth in the distribution system could be suspected (Bartram et al., 2003). Due to high plate counts of Gram-negative bacteria, *Salmonella* and *Shigella* as well as other organisms, all of the tap and sachet water samples were found to be unacceptable with regard to the established standards of water quality. Additionally, 80% of bottled water sample counts were also deemed unacceptable since they revealed counts that exceeded the set limits. According to a study conducted in Malaysia, major sources of microbial contamination of any potable water are due to inadequate sanitation and unhygienic practices (Rahmanian et al., 2015). In the current investigation, *Escherichia coli* was observed in all test sites with modest levels of contamination in borehole water. However, at the night-dam outflow, the counts exceeded 1,000 CFU/100 ml, indicating a rise with post-treatment movement and storage of treated effluent (Kgopa et al., 2021). Meanwhile, several researchers discovered that most household stored water samples tested positive for *E. coli* than the source water samples in a study performed in Nigeria which investigated the bacteriological quality of drinking water at a water collection source and the point of consumption. Additionally, another study acquired identical results in Malawi. These findings suggest that water handling techniques have an impact on water quality after it is generally collected from safe sources (Makokove et al., 2022). High demand for packaged water has led to the establishment of small scale enterprises engaged in the production of packaged water without due regard to hygienic practices in the production processes (Oyedeji et al., 2010).

Bottled water may be derived from 'pristine' sources or processed water. They may contain or have added carbon dioxide that would restrict potential growth, but typically no long-lasting disinfectant residual was present. The finished product is often exposed to elevated temperatures over a period of days to weeks before consumption. Microorganisms naturally present in water are a normal part of the microbiota of bottled water that meet appropriate safety norms. This may account for high HPC counts post distribution (Bartram et al., 2003). The high counts of tap water could be related to the formation of biofilms in the pipes. Microbial re-growth and the release of microorganisms from the biofilms during distribution may account for the high HPC (over 1,000 CFU/ml) in the tap water samples (Bartram et al., 2003). According to available research, in the absence of faecal contamination, there is no direct relationship between HPC values in drinking-water and human health effects in the population at large (Bartram et al., 2003). According to a South African study, out of ten bottled water samples, 8 (80%) indicated HPC within the recommended limits of less than 100 CFU/ml, values ranging from 0 as the lowest to 11 as the highest for the 8 bottles, this declared South African bottled water as generally safe (Ehlers et al., 2004), which is similar to a study in Zimbabwe which also declared bottled water processed and bottled in Zimbabwe as safe. The Zimbabwe study revealed that 4 out of 60 (6.7%) samples of bottled water exceeded the recommended HPC limits. Although locally-produced bottled water is safe microbiologically based on the study, it is necessary to continue with precautionary measures as any lapse in hygiene may lead to microbial proliferation (Okagbue et al., 2002). Similarly, a study conducted in Ghana proved that majority of the samples taken from botled water are safe for drinking (Osei et al., 2013). Another study performed in Accra, Ghana, came to the conclusion that while bottled water in Ghana is generally safe, HPC levels must still be kept under control to ensure that the quality stays acceptable (Osei et al., 2013). Moreover, sachet water cannot be described as generally safe, according to the authors. The results obtained in this study are not in line with the former statement but agrees with the latter. A study conducted in Uganda proved bottled water to be safe for drinking as compared to open well water, tap water, and other water sources. The reason for the high contamination of the open well water and stored water was due to contamination from rain water or the soil (Kasozi et al., 2019).

Chemical analysis of water samples was necessary to guarantee the quality, compliance with established quality criteria and efficiency of operation of water treatment plants and distribution systems (Ojo et al., 2008). The pH of all samples was found to be within the normal range with sample E of bottled water which recorded zero counts of various organisms, whereas Gram-negative organisms and *Salmonella* as well as *Shigella* had the highest pH (8.11). With no counts recorded for bottled water, sample E could be related to its alkalinity because unlike low pH which leads to corrosion of metal pipes and plumbing system, alkaline water indicates disinfection in water, this result was in accordance with a research carried out in Malaysia where the pH of tap water within acceptable ranges (Rahmanian et al., 2015). With the exception of temperature and residual chlorine, during the summertime, mean values of pH and alkalinity were comparable with the high mean of total bacteria. According to research, high pH of water (above 8.5) is connected with large numbers of bacteria such as HPC in distribution pipes (Mohammed et al., 2021).

With the main exception of nitrate, the majority of chemicals found in drinking water are only harmful to human health after prolonged exposure rather than just a few months. Nitrate concentrations that are high could harm pregnant women, adults, and kids (WHO, 2008). All chemical parameters including nitrate were within acceptable ranges with the exception of total Fe which exceeded the recommended ranges in samples E of tap water and C of sachet water whereas, a study in Bissau found high levels of NO^-_2 and Fe in well water, the study was conducted in shallow and tube well water, in the wet and dry seasons (Bancessi et al., 2020). Another study carried out in Malaysia discovered heavy metals in drinking water (Rahmanian et al., 2015). Although Fe is not suspected of causing direct health effects through its presence in drinking water, it may cause severe discoloration of water, which may lead to consumers turning to other microbiologically unsafe sources of drinking water and may also frequently cause operational problems (Thompson et al., 2007). This study found high Fe in a sample that was tested and is in accordance with a study conducted in Uganda, where Fe was highest in well water and lowest in bottled water (Kasozi et al., 2019). Fe might be high due to contamination by rain water or the Fe rich soil.

Turbidity readings in shallow wells ranged from 14.43 Nephelometric Turbidity Unit (NTU) in the dry season to 19.96 NTU in the rainy season, well over the Nigeria Standard for Drinking Water Quality (NSDWQ) limit value of five. Most shallow wells extract water with buckets, which enhances turbidity. As observed in a study carried out in Guinea-Bissau (Bancessi et al., 2020) compared to the current study where the turbity values of tap, bottled, and sachet water were not statistically significant.

Conclusion

Interesting results were obtained from analyzing the tap, sachet, and bottled water samples 'physical, mineral, as well as microbial parameters. Color, pH, turbidity, and temperature were generally within acceptable limits in all the sample types. Turbidity levels ranged from 14 to approximately 20 NTU, and significantly differed in microbial load. The mineral content was high in total Fe and NH_3, and microbial species were present at significant loads. The microbial load recorded was high in tap water than sachet and bottled water. Although total Fe was high in some of the sachet and tap water samples, the physical parameters were in acceptable levels and the mineral content was low.

Since sachet and tap water were the least potable for microbial load and safety, sachet water production should be closely monitored so that consumers can make choices for water products that would limit their exposure to water-borne diseases. However, the consumption of bottled water is recommended due to its low record of water-borne microbes.

Author contributions

G.A. developed the research concept and provided resource support for the collection of data; P.G.A. collected the samples and contributed to the analysis of the data; G.A. and T.A.A. provided critical comments on the reviewed manuscript before approval by all the authors. All authors designed the methodology, and contributed to the interpretation of findings and preparation of the manuscript for publication.

Conflicts of interest

The authors declare that there is no conflict of interest.

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Ethical Consideration

All the necessary ethical considerations were fulfilled, and a certificate for research ethics was issued by the Institute of Health Research, University of Health and Allied Sciences. Certficate Identification Number: UHAS-REC A.4 [246] 18-19.

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