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Ekene Jude Nwankwo
Department of Civil Engineering, University of Nigeria, Nsukka, Nigeria

Celestine Odenigbo
Department of Civil Engineering, Enugu State University of Science and Technology, Enugu, Nigeria

Corresponding Author:
Ekene Jude Nwankwo
Department of Civil Engineering, University of Nigeria, Nsukka, Nigeria

Quality difference between sachet and bottled water produced under the same conditions

Ekene Jude Nwankwo and Celestine Odenigbo

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Abstract

The study investigated the physicochemical and microbial qualities of freshly produced packaged water in Nsukka, Nigeria in a way that reveals the effect of the filling and sealing processes on the final water quality. The result shows that the physicochemical parameters were largely within standards, except for a few packaged water that violated the standards for pH (7%), iron (Fe) (39%), and conductivity (32%). More than 70% and 3% of the packaged water tested positive for total coliform and *E. coli* respectively, which suggest inadequate disinfection and recent faecal contamination. The uniformity of the physicochemical parameters among sachet and bottled water collected from the same brand suggests that the filling and sealing processes either have similar or no effect on the physicochemical properties. Microbial parameters of packaged water from the same brand were less uniform but still within the same confident limits. Better surveillance and stricter supervision by the regulatory authorities, including insistence on full compliance with the general hygiene provisions, are required to put an end to the proliferation of unsafe packaged water and the associated life-threatening illnesses.

Keywords: Physicochemical, coliform, *E. coli*, water quality, packaged water, Nigeria

1. Introduction

Among the member states of the United Nation, Nigeria ranks third in the number of deaths due to consumption of unsafe water, with more than 68 annual deaths per 100 000 persons, most of them being children under the age of five [1]. Package water is generally perceived as a safer alternative to other sources of drinking water, including municipal water supplies. At a slightly higher cost, it is readily available as a convenient and healthy drinking water source associated with affluence and good living. The consumption of packaged water is rapidly increasing in developing countries, especially where municipal water supply is of doubtful quality. It has become an integral part of water security towards the realization of the water target of the Sustainable Development Goals (SDGs) [2]. However, evidence questioning the microbial integrity of the street-vended packaged water continues to accumulate, especially in low- and middle-income countries. Unacceptable levels of microbial pathogens have been found in street-vended packaged water by independent studies in Nigeria and beyond [3, 4]. Organisms that have been isolated include both enteric and pathogenic microorganisms implicated in fatal disease conditions and illnesses such as bacillary dysentery, gastroenteritis, diarrhoea, cryptosporidiosis, giardiasis, shigellosis, etc. [5, 6]. These organisms are not only indicators of inadequate water treatment; they may also be due to hygiene-related re-contamination during the filling and sealing processes [7].

Street-vended packaged water is usually in the form of sachet or bottled water. In the Nigerian context, “Sachet water” is mainly used to refer to water mechanically sealed in a 500 mL polyethylene pouch, while “bottled water” refers to packaged water corked in 500 – 1500 mL polyethylene terephthalate containers. The consumption of sachet water is higher than bottled water because sachet water is relatively cheaper and can be found in virtually all the towns and villages of Nigeria. However, bottled water is generally perceived to be safer than sachet water but could cost as much as 15 times more. The odds of contamination are generally higher in sachet water when compared with bottled water [8, 9]. Differences in the filling and handling practices by different manufacturers, together with the level of compliance with the general hygiene provisions may explain this discrepancy [10].

Because of the high sensitivity of water to microbial and chemical contamination, it is difficult to consistently avoid re-contamination of packaged water during the filling and sealing processes of previously treated water [11]. Besides hygienic designs and other aseptic considerations, the risk of contamination can be practically minimized by proper decontamination of packaging materials and preventing contact with the filler valve. Decontamination of packaging materials is usually achieved through the use of gaseous hydrogen peroxide (H_2O_2) or peracetic acid (PAA) [11]. For bottled water, the room that contains the filling and capping equipment is a "high risk" area because this is where water and packaging materials are exposed to the environment again after decontamination. Air blown into sachet bags to force them open before filling is known to be a source of microbial contamination [12].

The objectives of this study were to assess the microbial integrity of packaged water produced in Nsukka and to assess the effect of packaging processes on the re-contamination risk of sachet and bottled water. The question of whether there are peculiarities with the filling and sealing processes of sachet and bottled water that predispose them to different risks of recontamination has not been answered. This study tries to answer this question by assessing and comparing the physicochemical and microbial qualities of freshly packaged sachet and bottled water filled from the same treated water storage vessel.

2. Materials and Method

2.1 Description of the Study Area

The study was conducted in Nsukka, Enugu State, Nigeria. Nsukka is located within latitudes 6.86° N and 6.83° N of the Equator, and longitudes 7.36° E and 7.42° E of Greenwich Meridians. The region is known for abundant rainfall, receiving about 1500 mm of rainfall from May to October and a prolonged dry season lasting from November to March. Most households in Nsukka rely on rainwater during the rainy period and their general perception is that rainwater is of better quality than other sources [13]. During the dry period, water supply in Nsukka and its environs is a serious concern. The major sources of water supply during this period are hand-dug wells and tanker-vended borehole water because there are no surface water bodies [14, 15]. Recent quality monitoring of phreatic groundwater in Nsukka reported widespread contamination that could be traced to anthropogenic sources such as solid waste dumps, pit latrines, septic tanks, and fertilizer application and recommended extensive treatment before consumption [14]. Borehole water is generally of better quality than well water and may require minimal treatment before consumption [16]. The depths of boreholes in Nsukka range from 50 to 240 m [17].

2.2 Sample Collection, Examination, and Analysis

Ten pieces of bottled water and Ten pieces of sachet water were collected from nine different packaged water production companies (Ecaison, Galaxy, Jives, Legacy, Lion, O'gala, Samah, Solace, and Touche) within Nsukka and environs between March and May 2022 immediately after production. An effort was made to collect sachet and bottled water samples whose water came from the same storage vessel and went through the same treatments but with separate filling and sealing processes for sachet and bottled water so that any differences observed in the final water quality between the sachet and the bottled water groups could be attributed to the filling and sealing processes. The samples were transported in an ice-packed cooling box to the Sanitary Laboratory of the University of Nigeria, Nsukka for microbial and physicochemical examination within 1 h of collection. The physicochemical and bacteriological examinations were carried out by a certified technologist based on Standard Methods for the Examination of Water and Wastewater [18]. Other standard analytical methods were employed as dimmed appropriate. All the field and laboratory equipment were kept sterile by either autoclaving or rinsing with sterilized water before use to prevent contamination. Samples were extracted through the use of a sterile hypodermic syringe after the outer surface of the collection point had been swabbed with ethanol for decontamination purposes. To ensure the reliability of the analysis and increase confidence in the results, control samples and blanks were prepared and analyzed along with the main samples. The following water quality parameters were measured: Total coliform (MPN), *E. coli* (MPN), hardness, alkalinity, sulphate (SO_4^{2-}), chloride (Cl^-), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), calcium (Ca), turbidity, electrical conductivity (EC), total dissolved solids (TDS) and pH. Table 1 shows the analytical methods used in measuring these parameters. The descriptive statistics, including the test of significant difference, were all carried out in Microsoft Excel (2016). The samples were analyzed following the analytical methods described in APHA [18] Standard Methods for the Examination of Water and Wastewater as shown in Table 1.

Table 1: Analytical methods for the determination of physicochemical and microbial properties of packaged water based on APHA [18]

Parameter	Principle	Standard Method	Equipment
Total coliform	Most probable number	APHA 9221 A	Multiple-tube fermentation technique
E. coli	Most probable number	APHA 9221 F	Multiple-tube fermentation technique/ Fluorogenic method
pH	Electrometry	APHA 4500H+ B	HANNA pH meter
Turbidity	Turbidimetry	APHA 2130 B	HANNA turbidity meter
Electrical Conductivity	None Electrometry	APHA 2510 B	Conductivity meter
Calcium	EDTA Titrimetry	APHA 3500-Ca B	Titration
Potassium	Photometry	APHA 3500-K B	Flame Photometry
Magnesium	EDTA Titrimetry	APHA 3500-Mg B	Titration
Sodium	Photometry	APHA 3500-Na B	Flame photometer
Chloride	None Argentometry	APHA 4500Cl-	Titration
Sulphate	Turbidimetry	APHA 4500 SO_4^{2-} E	UV-Visible Spectrophotometer
Total hardness	EDTA Titrimetry	APHA 2340 B	Titration
Alkalinity	Potentiometric titration	APHA 2320 B	Titration/pH meter
Iron	Phenanthroline colourimetry	APHA 3500-Fe A	HACH DR 890 Colourimeter

3. Results and Discussion

3.1 Physicochemical Quality and Health Implications

Tables 2 – 4 show the result of the physicochemical quality of the sampled packaged water together with the Nigerian Industrial Standards (NIS) and World Health Organisation (WHO) guidelines for drinking water. The pH of all the sachet and bottled water collected from Jives, Lion, Touche, Galaxy, and Ecasion were within the recommended guideline values of 6.5 – 8.5 recommended by NIS and WHO. Two out of the 10 sachet water collected and two out of the 10 bottled water collected from Jives slightly fell below the allowable lower limit of 6.5. Only two sachet water collected from Solace fell below 6.5; all the bottled water from Solace were within the guideline values. Also, two of the sachet water collected from the Samah were below the allowable lower limit, but the pH of all the bottled water from this brand were within the limits. Three sachet water and 3 bottled water from Legacy also fell below the guideline values. No samples fell above the 8.5 upper limit. The mean pH values of all the sachet and bottled water brands were within the guideline values. In all, about 7% of all the sampled packaged water violated the pH guidelines. Even though pH has no health impact and health-based guidelines, it is an important operational parameter that can interfere with disinfection and clarification of water [19]. Brands using chlorine for disinfection are required to keep the pH level of water below 8 for disinfection to be effective. pH values lower than 7 can cause excessive corrosion which can impart taste and interfere with the appearance of water.

The alkalinity of all the packaged water varied from 4.28 to 34.15 mg/L of $CaCO_3$. Alkalinity, a measure of excess concentration of bases, helps to minimize changes in pH by neutralizing the effect of added acidic substances. Alkalinity has no guidelines because the concentration of alkalinity as $CaCO_3$ is not of health concern at levels found in drinking water.

Table 2: Mean and standard deviation of physicochemical properties of Ecaison, Galaxy, and Jives

Brand	Ecaison		Galaxy		Jives		NIS	WHO 2011
Parameter	Sachet Water	Bottled water	Sachet water	Bottled water	Sachet Water	Bottled water		
pH	7.1 ± 0.084	7.07 ± 0.045	7.58 ± 0.141	7.54 ± 0.108	6.6 ± 0.015	6.59 ± 0.005	6.5 – 8.5	6.5 – 8.5
Turbidity (NTU)	1.38 ± 0.01	1.41 ± 0.01	1.41 ± 0.01	1.43 ± 0.01	1.04 ± 0.02	1.12 ± 0.01	5	5
Electrical Conductivity (µS/cm)	402.58 ± 1.07	403.16 ± 1.01	162.74 ± 5.68	160.1 ± 8.98	129.35 ± 0.76	128.8 ± 0.72	1000	250
TDS (mg/L)	250.81 ± 6.023	260.84 ± 6.052	95.54 ± 4.532	93.67 ± 5.865	77.87 ± 2.152	76.89 ± 1.773	500	-
Calcium (mg/L)	3.38 ± 0.07	3.37 ± 0.08	7.84 ± 0.11	7.83 ± 0.1	0.93 ± 0.1	0.98 ± 0.08	-	-
Potassium (mg/L)	9.46 ± 0.25	9.56 ± 0.36	9.93 ± 0.4	9.81 ± 0.45	3.16 ± 0.39	2.92 ± 0.33	-	-
Magnesium (mg/L)	0.64 ± 0.06	0.66 ± 0.05	1.84 ± 0.05	1.81 ± 0.04	0.33 ± 0.08	0.37 ± 0.07	0.2	-
Sodium (mg/L)	11.4 ± 0.2	11.6 ± 0.27	9.54 ± 0.22	9.41 ± 0.26	7.77 ± 0.48	7.4 ± 0.42	200	200
Chloride (mg/L)	13.18 ± 0.13	13.35 ± 0.15	17.36 ± 0.3	17.47 ± 0.31	5.12 ± 0.24	5.13 ± 0.36	250	250
Sulphate (mg/L)	12.32 ± 0.27	12.3 ± 0.19	3.34 ± 0.06	3.35 ± 0.07	2.86 ± 0.05	2.89 ± 0.07	100	500
Total hardness (mg/L)	11.07 ± 0.30	11.13 ± 0.22	27.14 ± 0.4	27.01 ± 0.35	3.69 ± 0.44	3.95 ± 0.29	150	-
Alkalinity (mg $CaCO_3$/L)	4.43 ± 0.05	4.65 ± 0.07	16.02 ± 0.02	16.19 ± 0.06	4.35 ± 0.05	4.53 ± 0.07	-	-
Iron (mg/L)	0.12 ± 0.01	0.12 ± 0.01	0.16 ± 0.01	0.17 ± 0.01	0.19 ± 0.02	0.19 ± 0.01	0.3	0.3

Table 3: Mean and standard deviation of physicochemical properties of Legacy, Lion, and O'gala

Brand	Legacy		Lion		O'gala		NIS	WHO 2011
Parameter	Sachet Water	Bottled Water	Sachet Water	Bottled water	Sachet Water	Bottled water		
pH	6.56 ± 0.198	6.51 ± 0.162	7.29 ± 0.033	7.31 ± 0.046	6.58 ± 0.076	6.56 ± 0.073	6.5 – 8.5	6.5 – 8.5
Turbidity (NTU)	1.46 ± 0.01	1.5 ± 0.01	0.69 ± 0.12	0.91 ± 0.03	0.76 ± 0.1	0.93 ± 0.05	5	5
Electrical Conductivity (µS/cm)	258.81 ± 0.73	258.37 ± 1.2	263.87 ± 20.22	269.59 ± 22.3	106.97 ± 1.01	106.43 ± 1.14	1000	250
TDS (mg/L)	170.81 ± 5.004	170.53 ± 4.251	227.09 ± 16.248	236.57 ± 1.568	72.31 ± 2.392	72.27±2.078	500	-
Calcium (mg/L)	2.8 ± 0.09	2.8 ± 0.07	4.45 ± 0.08	4.39 ± 0.06	15.74 ± 0.82	15.75 ± 0.79	-	-
Potassium (mg/L)	11.25 ± 0.35	11.1 ± 0.26	28.3 ± 0.33	28.5 ± 0.31	4.71 ± 0.45	4.55 ± 0.48	-	-
Magnesium (mg/L)	1.76 ± 0.05	1.74 ± 0.07	0.2 ± 0.07	0.17 ± 0.08	0.55 ± 0.07	0.56 ± 0.08	0.2	-
Sodium (mg/L)	13.44 ± 0.3	13.34 ± 0.27	16.92 ± 0.22	16.82 ± 0.25	6.87 ± 0.48	7.01 ± 0.49	200	200
Chloride (mg/L)	28.93 ± 0.34	28.81 ± 0.33	24.58 ± 0.36	24.7 ± 0.33	14.67 ± 0.22	14.61 ± 0.19	250	250
Sulphate (mg/L)	2.85 ± 0.06	2.84 ± 0.07	10.21 ± 0.2	10.21 ± 0.22	6.78 ± 0.11	6.81 ± 0.1	100	500
Total hardness (mg/L)	14.21 ± 0.31	14.12 ± 0.3	11.93 ± 0.37	11.69 ± 0.3	41.59 ± 2.03	41.65 ± 2	150	-
Alkalinity (mg $CaCO_3$/L)	13.92 ± 0.06	14.13 ± 0.06	7.12 ± 0.05	7.28 ± 0.04	18.55 ± 0.14	19.35 ± 0.17	-	-
Iron (mg/L)	0.25 ± 0.02	0.24 ± 0.02	0.26 ± 0.01	0.26 ± 0.01	0.32 ± 0.02	0.31 ± 0.01	0.3	0.3

Table 4: Mean and standard deviation of physicochemical properties of Samah, Solace, and Touche

Brand	Samah		Solace		Touche		NIS	WHO 2011
Parameter	Sachet Water	Bottled Water	Sachet water	Bottled water	Sachet Water	Bottled water		
pH	6.62 ± 0.125	6.66 ± 0.092	6.6 ± 0.125	6.68 ± 0.079	6.91 ± 0.109	6.96 ± 0.092	6.5 – 8.5	6.5 – 8.5
Turbidity (NTU)	1.01 ± 0.04	1.1 ± 0.02	2.76 ± 0.02	2.8 ± 0.01	2.04 ± 0.01	2.04 ± 0	5	5
Electrical Conductivity (µS/cm)	228.71 ± 1.17	228.03 ± 1.39	215.38 ± 2.03	216.55 ± 2.32	172.86 ± 8.64	174.88 ± 9.28	1000	250
TDS (mg/L)	144.32 ± 4.546	144.33 ± 3.634	198.59 ± 5.271	199.87 ± 3.624	157.98 ± 7.994	159.54 ± 9.828	500	-
Calcium (mg/L)	5.93 ± 0.09	5.95 ± 0.07	7.52 ± 0.07	7.55 ± 0.08	2.24 ± 0.06	2.22 ± 0.07	-	-
Potassium (mg/L)	6.61 ± 0.38	6.57 ± 0.36	8.99 ± 0.23	9.05 ± 0.23	3.66 ± 0.37	4.23 ± 0.37	-	-
Magnesium (mg/L)	0.33 ± 0.08	0.3 ± 0.05	0.86 ± 0.09	0.83 ± 0.07	0.26 ± 0.06	0.26 ± 0.07	0.2	-

Sodium (mg/L)	19.46 ± 0.13	19.29 ± 0.21	8.57 ± 0.22	8.68 ± 0.19	15.17 ± 0.21	15.2 ± 0.28	200	200
Chloride (mg/L)	21.1 ± 0.4	21.04 ± 0.38	11.39 ± 0.15	11.48 ± 0.2	9.35 ± 0.16	9.33 ± 0.17	250	250
Sulphate (mg/L)	9.08 ± 0.12	8.97 ± 0.13	0.66 ± 0.1	0.61 ± 0.08	9.36 ± 0.11	9.41 ± 0.15	100	500
Total hardness (mg/L)	16.16 ± 0.46	16.1 ± 0.21	22.34 ± 0.42	22.28 ± 0.27	6.68 ± 0.37	6.62 ± 0.31	150	-
Alkalinity (mg $CaCO_3$/L)	32.13 ± 0.52	33.61 ± 0.39	20.46 ± 0.04	20.73 ± 0.12	6.28 ± 0.1	6.64 ± 0.07	-	-
Iron (mg/L)	0.33 ± 0.02	0.32 ± 0.02	0.67 ± 0.04	0.67 ± 0.04	0.98 ± 0.08	0.95 ± 0.07	0.3	0.3

Total hardness for all the packaged water varied from 3.18 to 44.96 mg/L, which is below the maximum recommended by NIS. World Health Organisation (WHO) does not have a fixed standard for hardness because the taste threshold and public acceptability of hardness may vary from one place to another depending on the associated cation. However, consumers may tolerate hardness in excess of 500 mg/L. While hardness due to calcium ion becomes perceptible between 100 – 300 mg/L, hardness due to magnesium ions begins to impart taste at a lower concentration of 100 mg/L.

The concentrations of calcium, magnesium, sodium, potassium and iron among the tested packaged water are in the ranges of 0.82 – 17.1 mg/L, 0.06 – 1.95 mg/L, 6.15 – 19.66 mg/L, and 2.52 – 28.83 mg/L, 0.11 – 1.09 mg/L, respectively. Although there are no health-based guidelines for these cations, their over concentration may interfere with the taste and general acceptability of water. Calcium and magnesium are essential minerals and insufficient intake of either mineral can undermine health. Adequate magnesium intake has been particularly associated with a reduced risk of cardiovascular disease [20]. Nigeria Industrial Standards (NIS) stipulated a maximum magnesium concentration of 0.2 mg/L to avoid taste in water. The ability of sodium to impart taste to water depends on the associated cation and water temperature. The average taste threshold for sodium at room temperature is about 200 mg/L. Potassium is beneficial to humans, and levels found in drinking water pose no threat to human health. A daily total intake of 3000 mg of potassium is recommended [19]. The iron concentration among the packaged water ranges from 0.11 to 1.09 mg/L, which is an indication that some packaged water violated the guidelines value of 0.3 mg/L. Seven of the 10 Galaxy sachet water, seven of the 10 Galaxy bottled water, nine of the 10 Samah sachet water, seven of 10 Samah bottled water, and all packaged water from Lion and Touche violated the iron guideline. In all, about 39% of all the sampled packaged water violated the guidelines for iron. Iron has no negative health impact and may even help the transport of oxygen in the blood [21]. However, the reddish-brown precipitate of iron (III) produced upon oxidation of iron may interfere with the acceptability of water. High concentrations of iron are usually recorded in packaged water companies where water distribution systems are made of iron and corrosion is left unchecked.

The turbidity of all the sachet and bottled water were below the guideline maximum of 5 NTU. However, more than 75% (138 of 180) of the sachet and bottled water recorded a turbidity value greater than 1 NTU. Turbidity of less than 1 NTU is important for effective disinfection [22]. This is because the colloidal particles that cause turbidity in water could shield organisms, interfering with the mechanisms of disinfection. This interference is especially more so for manufacturers that use physical disinfection methods, such as ultraviolet (UV) radiation, that depend on the ability of water to transmit light. Turbidity is an excellent indicator of microbial contamination and increasing cases of gastrointestinal infection have been associated with water of high turbidity [23]. Turbidity can also have a negative impact on the acceptability of water if the cloudiness due to turbidity is visible (> 4 NTU) [22].

The TDS of all the packaged water samples varied between 68.63 to 281.1 mg/L, which is within the guideline values of NIS and WHO. Water is no longer palatable when its TDS value reaches 600 mg/L, a taste that becomes significant and increasingly unacceptable as TDS values approach 1000 mg/L. Extremely low concentrations of TDS can also render the taste of water unacceptably flat and insipid [24]. The EC values varied between 104.81 to 404.71 µs/cm, which is within the guideline value of NIS but violets the guideline value of WHO. Out of the 9 brands of packaged water samples tested, only three brands (Lion, Legacy, and Ecaison) violated the WHO’s guidelines. For Lion, eight of the 10 sachet water and nine of the 10 bottled water exceeded the WHO’s guideline value. All the samples from Legacy and Ecaison violated the WHO’s EC standard. In all, about 32% of the sampled packaged water violated WHO’s standard for EC. TDS and EC are both indicators of water salinity and are mainly used to gauge the level of seawater intrusion [25, 26] While TDS measures the amount of dissolved solids in water, EC measures the proportion of dissolved ionized solids and the ability of these ions to conduct electric current. TDS is positively correlated to EC and can be used to predict its value within ±10% accuracy [27].

The sulfate and chloride concentrations of all the packaged water varied from 0.54 to 12.71 mg/L and from 4.67 to 29.37 mg/L respectively, which are below the allowable maximum values recommended by NIS and WHO. Sulfate and chloride are among the taste- and odour-causing anions that are not easily removed from water by conventional treatment processes. High concentrations of sulfate cause detectable taste in water, and very high concentrations could have a laxative effect on unaccustomed consumers. The ability of sulfate to impart taste depends on the associated cation. The taste threshold of sulfate concentration ranges from 250 mg/L for sodium sulfate to 1000 mg/L for calcium sulfate. Although chloride begins to impart taste to water when its concentration is more than 250 mg/L, the taste threshold of chloride is also dependent on the associated cation, ranging from 200 – 300 mg/L for sodium, potassium and calcium chloride. High sulfate and chloride concentration is an indicator of saline, sewage and industrial waste intrusion.

3.2 Bacteriological Quality and Health Implications

Table 5 shows the most probable number (MPN) per 100 mL for total coliform and *E. coli* for all the packaged water used in the experiments. Total coliform was detected in virtually all the brands except Jives and Lion. Total coliform was particularly detected in six of the 10 O’gala sachet water, five of the 10 O’gala bottled water, eight of the 10 Solace sachet water, nine of the 10 Solace bottled water, six of the 10 Touche sachet water, all the 10 Touche bottled water, seven of the 10 Galaxy sachet water, all the 10 Galaxy bottled water, all the 10 Samah sachet water, four of the 10 Samah bottled water, eight of the 10 Legacy sachet water, all the Legacy bottled water, and all the Ecaison sachet and bottled water. In all, about 70% of the packaged water tested positive for total coliform. Even though the coliform group comprises all the non-spore-forming, Gram-negative bacteria that can ferment lactose with gas production within 24 h at 35 – 37 ºC, including microorganisms that have been implicated in deadly disease condition and illnesses such as bacillary dysentery, gastroenteritis, diarrhoea, etc., they are not used as an indicator of faecal contamination. However, total coliform is used as an indicator of inadequate treatment, regrowth, biofilm formation, or ingress of foreign material into the distribution system. They should be absent in packaged water or tap water immediately after disinfection [19].

Table 5: Most probable number (MPN index/100 mL) of total coliform (TC) and *E. coli* (EC) for all the packaged water

S/B	Ecaison		Galaxy		Jives		Legacy		Lion		O'gala		Samah		Solace		Touche	
	TC	EC	TC	EC	TC	EC	TC	EC	TC	EC	TC	EC	TC	EC	TC	EC	TC	EC
S	110	<2	<2	<2	<2	<2	4	<2	<2	<2	<2	<2	49	<2	5	<2	<2	<2
S	240	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	14	<2	2	<2	<2	<2
S	350	<2	2	<2	<2	<2	4	<2	<2	<2	<2	<2	23	<2	<2	<2	<2	<2
S	150	5	2	<2	<2	<2	2	<2	<2	<2	23	<2	2	<2	<2	<2	<2	<2
S	180	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	2	<2	2	<2	7	<2
S	280	23	2	<2	<2	<2	5	<2	<2	<2	5	<2	39	<2	6.8	<2	12	<2
S	920	4	2	<2	<2	<2	4	<2	<2	<2	4	<2	41	<2	12	<2	9.2	<2
S	70	6.1	2	<2	<2	<2	2	<2	<2	<2	6.1	<2	47	<2	4	<2	15	<2
S	23	2	2	<2	<2	<2	12	<2	<2	<2	2	<2	94	<2	5	<2	17	<2
S	210	11	2	<2	<2	<2	15	<2	<2	<2	11	<2	23	<2	2	<2	23	<2
B	70	2	23	<2	<2	<2	4	<2	<2	<2	2	<2	<2	<2	2	<2	13	<2
B	94	2	5	<2	<2	<2	4	<2	<2	<2	2	<2	<2	<2	23	<2	23	<2
B	84	<2	13	<2	<2	<2	6	<2	<2	<2	<2	<2	<2	<2	23	<2	23	<2
B	220	<2	5	<2	<2	<2	12	<2	<2	<2	<2	<2	<2	<2	<2	<2	23	<2
B	79	<2	23	<2	<2	<2	14	<2	<2	<2	<2	<2	8	<2	13	<2	4	<2
B	140	5	14	<2	<2	<2	11	<2	<2	<2	5	<2	2	<2	31	<2	6	<2
B	170	2	43	<2	<2	<2	4	<2	<2	<2	2	<2	5	<2	47	<2	8.1	<2
B	150	2	13	<2	<2	<2	4	<2	<2	<2	2	<2	<2	<2	17	<2	11	<2
B	94	<2	17	<2	<2	<2	14	<2	<2	<2	<2	<2	<2	<2	21	<2	34	2
B	70	<2	14	<2	<2	<2	17	<2	<2	<2	<2	<2	2	<2	25	<2	58	4

S – sachet water, B – bottled water, TC – Total coliform, EC – *E. coli*

E. coli was detected in two Touche bottled water, six Ecaison sachet water, and five Ecaison bottled water. In all, about 3% of all the packaged water tested positive for *E. coli*. *E. coli* is a subset of total coliform group that lives in the gut of mammals and can ferment lactose at elevated temperature (44.5 ºC), producing specific enzymes. *E. coli* is a model microorganism used as an indication of recent faecal contamination. It must not be detected in water intended for human consumption [22]. However, the absence of *E. coli* does not necessarily indicate freedom from enteric protozoa and viruses which are known to be more resistant to disinfection. Despite this limitation, monitoring microbial quality using *E. coli* or thermotolerant coliforms provides firm assurance about the safety of drinking water due to their abundance in raw water ($10^2 – 10^4$ per litre) [22].

3.3 Effect of Filling and Sealing on the Quality of Packaged Water

The results showed that as much as the packaged water from different brands had different chemical compositions and characteristics attributable to several factors, including water source and difference in treatment, packaged water collected from the same brand showed similar and consistent physicochemical characteristics. These characteristics were basically the same for sachet and bottled water of the same brand, which is an indication that the water emanated from the same storage vessel and that the packaging processes had similar or no effect on the physicochemical properties of the packaged water. The total coliform and *E. coli* population among packaged water obtained from the same brand was more varied than the physicochemical parameters; however, the range of these variations mostly falls within the same confidence limits of MPN index/100 mL as given in Table 9221: IV of APHA [18]. Therefore, the risk of recontamination during filling and sealing is basically the same for sachet and bottled water.

Perhaps, a better method of assessing the effect of filling and packaging processes on the final quality of packaged water would be to test water samples immediately before and after packaging. However, the packaged water manufacturers only allowed restricted access to their facilities. Most manufacturers were sceptical of the purpose of the study and were unforthcoming about the treatment processes they use lest they reveal proprietary information or expose their company to espionage. Therefore, the author relied on the information provided by the company staff and whatever information that could be gleaned by inspection at the different levels of the water treatment processes. For example, the veracity of the information regarding if the packaged water came from the same storage vessel could not be independently verified. However, a deliberate effort was made to collect sachet and bottled water samples immediately after packaging, presuming the water came from the same source and went through the same treatment processes. This presumption was partially confirmed by the uniformity of the physicochemical parameters between the sachet water group and the bottled water group and within each group.

4. Conclusions

The study investigated the physicochemical and microbial qualities of freshly produced packaged water in Nsukka, Nigeria and, by comparing the quality with national and international drinking water standards, found that about 70% of packaged water produced in Nsukka is not fit for human consumption. Widespread contamination with total coliform suggests inadequate treatment, growth of biofilms in distribution systems, or ingress of foreign materials. The detection of *E. coli* in some of the packaged water, especially Ecaison, suggests recent faecal contamination. The uniformity of the physicochemical parameters measured among sachet and bottled water collected from the same manufacturer and filled from the same storage vessel suggests that the filling and sealing processes of packaged water may have no effects on the final water quality. However, the microbial parameters were less uniform than the physicochemical parameters, suggesting that the filling and sealing processes may have more impact on the microbial quality. The variations in microbial parameters within brands were mostly found to be within the same confidence limits. If Nigeria is to successfully tackle the problem of infant diarrhoea deaths, regulatory authorities must step up their activities to ensure compliance with the guidelines and general hygiene provisions for treating, storing, filling, and sealing packaged water. If possible, packaged water should be labelled to include the physicochemical and microbial qualities of the water.

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