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*Original Research Article*

# Quality Assessment of Sachet and Bottled Water Produced by a University and Selected Private Business Owners in Benin City, Nigeria

***[1]Ndukwe Maduka and [2]Henrietta Omokhele Obueh**

[1]Department of Microbiology, Faculty of Science, Federal University Otuoke, Yenagoa, Bayelsa State, Nigeria.
[2]Department of Biological Sciences, College of Science and Computing, Wellspring University, Benin City, Edo State, Nigeria.
*Corresponding Author's email: madukann@fuotuke.edu.ng
ORCID: https://orcid.org/0000-0003-1375-8665

**KEYWORDS**
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Toxic metals,
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**ABSTRACT**
Poor quality drinking water pose a public health risk to consumers and contribute to waterborne disease burden especially in developing countries. This study assessed the quality of sachet and bottled water produced by a university coded Uni and three private business owners (Lom, Olv and Tai) in Benin City, Nigeria. Microbiological analysis involved the use of traditional methods, while physicochemical properties, essential and toxic metals content of the samples (n = 24) were determined using standard methods. Kirby-Bauer disc diffusion method was used to test antibiotic susceptibility of the bacterial isolates. The total heterotrophic bacterial count and total fungal counts of the Uni brand of drinking water ranged between 2.48 - 2.64 and 2.00 - 3.70 $\log_{10}$CFU/mL, while other brands was 2.78 - 7.36 and 1.00 - 3.60 $\log_{10}$CFU/mL, respectively. No coliforms were detected in the Olv and Uni brands of drinking water. The physicochemical properties, essential and toxic metals content of the samples were below permissible limits stipulated by the World Health Organization (WHO) for drinking water, with some exceptions. Among the isolates, *Staphylococcus aureus* had the least multiple antibiotic resistant index of 0.0, whereas the highest involved *Proteus mirabilis* and *Escherichia coli* reported as 0.4 each. Although, the overall results indicate that the Uni branded product was relatively better than others, regulatory bodies such as National Agency for Food and Drug Administration and Control (NAFDAC) should intensify its efforts in monitoring the production, storage, and distribution of sachet and bottled water to ensure strict compliance with international standards.

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## INTRODUCTION

The health status of people living in a geographical area could be affected by quantity and quality of water available daily for drinking and domestic use (Mulualem et al., 2023). Large population of people living in developing countries lack access to safe drinking water (Onuguh et al., 2025). For that reason, about 80% of all diseases and more than 30% of deaths recorded in developing countries are linked to drinking water (Akpen et al., 2018). It is alarming to report that more than 66 million Nigerians are not provided



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with clean drinking water (Imam et al., 2023). This is a worrisome situation because water constitute about 60% of the total weight of average 70 kg man which is equivalent to 42 litres of water (Ekanem, et al., 2025). To stay healthy, Ugwuoha et al. (2023) reported that 3 litres of water, both in liquid and food should be consumed daily by an average man weighing between 53 - 63 kg.

Water is a resource that is abundant on earth and essential for the existence of all living things (Omada et al., 2025). The oceans constitute 97% of the total water on earth, while the remaining 3% is fresh water. Only 0.01% of fresh water is available for human use (Munteanu et al., 2021). Potable water is colourless, tasteless, odourless and completely free from harmful microorganisms, feacal matter, physical and chemical pollutants (Kılıç, 2021; Maduka et al., 2025). Different sources of drinking water available for millions of Nigerians especially rural dwellers are unsafe as a result of high level contamination (Ire et al., 2024; Isukuru et al., 2024). The quality of water is critical because drinking water contaminated with bacteria (*Vibrio cholerae*, *V. parahaemolyticus Streptococcus* spp., *Shigella dysenteriae*, S. *flexneri, S. boydii, S. sonnei*, *Micrococcus* spp., *Klebsiella* spp., *Escherichia coli* particularly serotypes 0148, 0157 and O124, *Enterobacter* spp., *Bacillus* spp., *Salmonella enterica, Pseudomonas aeruginosa*), protozoan parasites (*Giardia* spp. and *Cryptosporidium* spp.) and viruses (adenovirus, calciviruses, enterovirus, norovirus and reovirus) are associated with several diseases. They include cholera, typhoid fever, amoebic dysentery, Bacillary dysentery, *E. coli* diarrhea, salmonellosis, Balantidiasis, giardiasis, cryptosporidiosis, cyclosporiasis, campylobacteriosis, yersiniosis, polio, hepatitis A and gastroenteritis infections (Cabral, 2010; Manetu & Karanja, 2021; Meki et al., 2022; Ahiabor & Donkor, 2025). Although adults could experience waterborne diseases after drinking contaminated water, infants, young children, immunocompromised individuals and the elderly face the greatest risk (WHO, 2017). Annually, about 151, 700 children living in Nigeria, below 5 years old, die as a result of diarrhea linked to contaminated water and poor sanitation (Adamu et al., 2022). Cholera, dysentery, typhoid and poliomyelitis are gastrointestinal diseases responsible for about 485, 000 diarrhoeal deaths, annually. This ugly report is as a result of drinking water contaminated with fecal matter (Boas et al., 2025).

In developing countries, treated water is packaged by producers and sold to consumers using polyethylene terephthalate (PET) bottles and high density polyethylene (HDPE) film sachets. This product is patronized by millions of Nigerians daily (Aroh et al., 2013). Sachet and bottled water with different brand names are regarded as safe drinking water by the general public. The result of several studies on packaged drinking water sold in different parts of Nigeria is a bit worrisome because of the public health risks faced by consumers (Balogun et al., 2024; Ahaotu et al., 2025; Usman et al., 2026). The values reported for quality parameters of drinking water were above or below the limits recommended by the World Health Organization (WHO), National Agency for Food and Drug Administration and Control (NAFDAC) and Nigeria Standard for Drinking Water Quality (NSDWQ) (Kılıç, 2021; Umoafia et al., 2023). Dibua et al. (2007) reported that sachet water sold in Nsukka campus of the University of Nigeria, were contaminated with *Escherichia coli*, *Streptococcus* sp., *Micrococcus* sp., *Bacillus* sp., *Klebsiella* sp., *Staphylococcus* sp., *Pseudomonas* sp., *Actinomycetes* sp. and *Escherichia coli*. Recently, Ekanem et al. (2025) assessed the quality of different brands of packaged water sold within the premises of a university teaching hospital in southern part of Nigeria. The study reported that 60% and 20% of sachet and bottled water samples were unfit for drinking due to high level contamination, respectively.

Majority of the packaged drinking water consumed in Nigeria are produced by private business owners. In recent years, the Management of some universities in the country own water factories that produce sachet and bottled water for the general public. They have other business enterprise which includes hotels, guest houses, lockup shops, bakeries and gas stations. These are sources of internally generated revenue (IGR) for the universities (Ofoegbu & Alonge, 2016). Since the production of packaged table water is dominated by private business owners in Nigeria, majority of the research publications on quality assessment of plastic bottled and sachet water sold in different locations involve products from private business owners. Similar studies on bottled and sachet water produced by universities are very few. Fadipe et al. (2024) carried out overall assessment of water factory owned by Osun State University, to ascertain the level of compliance to good manufacturing practices (GMPs). The researchers reported that total coliforms ($1.0 \times 10^5$ CFU/mL) in raw water remain unchanged even after subjecting it to microfiltration and ozonation treatment. On the contrary, there was reduction in the values for all the physicochemical parameters of the treated water.

The Nigerian Industrial Standard (NIS) for drinking water listed several parameters and maximum limits permissible for all sources of water meant for human consumption. According to the NIS, routine monitoring parameters for drinking water include taste, odour, colour, turbidity, pH, conductivity, iron, nitrates, aluminum, residual chlorine, *Escherichia coli* and fluoride. The parameters categorized as inorganic constituents of water include nitrate, nitrite, sodium, sulphate, total dissolved solids, zinc, magnesium, hardness, lead, iron, chromium, copper, cadmium and few others (NIS, 2007). Based on the parameters recommended by the NIS, we compared the quality of sachet and bottled water produced by a selected public university and private business owners in Benin City, Nigeria. Antibiotic susceptibility test of bacterial isolates from the packaged water samples were also carried out.

## MATERIALS AND METHODS

### Sample Collection

Four (4) popular brands of plastic bottled and sachet water sold in Benin City, Nigeria were selected for this study. Three brands owned by private business owners were coded Lom, Tai and Olv, while the fourth owned by a public university is Uni. Three (3) samples of plastic bottled water and three (3) sachet water bearing the same brand name and manufacturer were randomly collected from eight (8) vendors in four (4) locations namely King Square, Uselu, Ugbowo and Ogba market. Each sample was visually inspected to ensure that it was properly sealed, labeled with NAFDAC registration number and within the product shelf life. The date of production is April - May, 2025. A total of 24 samples of bottled and sachet water were transported to the Microbiology and Biochemistry Laboratory, Wellspring University Benin City, within 2 hours, for analyses.

### Serial Dilution

One milllilitre (1 mL) of the water sample was poured inside 9 mL of sterile peptone water and gently shaken. Exactly 1 mL of solution from the stock solution was aseptically transferred to the next tube containing 9 mL sterile peptone water using a sterile pipette. Stepwise transfer of the sample from the second tube to the next was done using a sterile pipette. This procedure was repeated in subsequent tubes containing 9 mL sterile peptone water using a sterile pipette for each transfer until dilution $10^{-5}$ was reached (Ire et al., 2024).

### Determination of Total Heterotrophic Bacterial Count

One milliliter (1 mL) of dilution$10^{-4}$ and $10^{-5}$ of each water sample was inoculated into a freshly prepared nutrient agar plate in triplicate. The inoculated plates were placed in an inverted position inside an incubator set at 37 °C and incubated for 24 hours. After incubation of the culture plates, growth of distinct colonies was examined and enumerated using the standard formula stated below. The result was expressed in colony forming unit per milliliter (CFU/mL) (Umoafia et al., 2023).

$$\text{CFU/mL} = \text{no. of colonies} \times \frac{1}{dilution\ factor} \times \frac{1}{volume\ of\ sample\ plated}$$

### Determination of Total Fungal Count

A freshly prepared Saboraud dextrose agar was inoculated with 1 mL of dilution $10^{-4}$ and $10^{-5}$ of each water sample in triplicate. The plates inoculated with the sample were incubated at room temperature (25±2 °C) for 5 days. Examination and enumeration of colonies in the culture plates was carried out using the standard formula stated below. The result was expressed in colony forming unit per milliliter (CFU/mL) (Umoafia et al., 2023).

$$\text{CFU/mL} = \text{no. of colonies} \times \frac{1}{dilution\ factor} \times \frac{1}{volume\ of\ sample\ plated}$$

### Obtaining Pure Isolates

To obtain discrete colonies of bacteria, repeated sub-culturing was done using freshly prepared nutrient agar. Each pure culture was inoculated in nutrient agar slants in a sterile Bijoux sample bottles. The isolates were subcultured in freshly prepared medium until proper identification of each isolate has been concluded. A similar procedure was carried out using Saboraud dextrose agar as a growth medium to obtain pure culture of fungi.

### Identification of Bacterial Isolates

Gram staining and motility test on each isolate was performed. Biochemical tests which include citrate, coagulase, urease, catalase, oxidase, indole, triple sugar iron, methyl red and Voges-Proskauer test were also performed for each bacterial isolate. Bergey's Manual of Determinative Bacteriology was helpful in identification of the genera each bacterium belongs.

### Identification of Fungal Isolates

The morphology of the fungi growing on the Saboraud dextrose agar plate was noted. Lactophenol-cotton blue stain of the fungal isolate was carried out followed by microscopic examination of the stained organism. The fungal genera were identified using a standard procedure (Barnett & Hunter, 1972).

### Detection of Coliform Population

Two-step enrichment method was used to estimate the coliform population in the water samples. One hundred milliliter (100 mL) of each sample was filtered through 0.45 µm pore size membrane. The filter trapped with bacteria present in the water samples was first placed on a lauryl tryptose medium. Thereafter, it was transferred to the surface of M-Endo media. The lauryl tryptose medium and M-Endo media was incubated at 34 °C for 3 and 22 hours, respectively. After incubation, the total number of colonies in the media was determined (Yahaya et al., 2022).

### Determination of Physicochemical Parameters

The appearance and odour of the water samples were noted. This was followed by measurement of pH, temperature, electrical conductivity, dissolved oxygen, turbidity, total dissolved solids, total suspended solids, total hardness, salinity, chloride, nitrite, and sulphate of the water samples using standard methods (APHA, 1992; Ire et al., 2024).

### Determination of Minerals

Minerals such as magnesium, calcium, sodium, potassium, iron, and zinc content of the water samples were determined using standard methods (APHA, 1998).

### Determination of Heavy Metals

Chromium, cadmium, copper, and lead content of the water samples were determined using standard methods with slight modification. The Perkins Elmer atomic absorption spectrophotometer (Buck Scientific Model 200A/210) with a double beam and background corrector was used for heavy metal detection (APHA, 1998).

### Antibiotic Sensitivity of Bacterial Isolates

Standard method with slight modification was adopted in testing the susceptibility of each bacterial isolate against commonly used antibiotics (Umoafia et al., 2023). The antibiotic sensitivity disc used to test Gram positive bacterial isolates contain PEF - Pefloxacin; GTN - Gentamycin; APX - Ampiclox; ZCF - Zinnacef; AM - Amoxicillin; RPN - Rocephin; CPX - Ciprofloxacin; STY - Streptomycin; SXT - Septrin; ERY - Erythromycin, while SXT - Septrin; CH - Chloramphenicol; SP - Sparfloxacin; CPX - Ciprofloxacin; AM - Amoxicillin; AU - Augmentin; CN - Gentamycin; PEF - Pefloxacin; OFX - Tarivid; STY - Streptomycin is for Gram negative bacterial isolates. The diameter of zone of inhibition of each isolate against the antibiotic tested was measured and the result was interpreted based on the Clinical and Laboratory Standard Institute (CLSI) standard.

### Multiple Antibiotic Resistance (MAR) Index

It is calculated based on the number of antibiotics a known microorganism has demonstrated resistance divided by the total number of antibiotics the same microorganism has been exposed to during antibiotic susceptibility testing.

MAR index = $\frac{a}{b}$

Where: a = the number of antibiotics the microorganism demonstrated resistance

b = total number of antibiotics the microorganism was exposed to during the testing (Maduka et al., 2022).

### Statistical Analysis

The statistical analysis of the values obtained in this study was carried out using the Statistical Package for Social Sciences (SPSS, version 23.0). The values obtained after carrying out physicochemical, essential and toxic metals analyses of the sachet and bottled water samples were subjected to the Analysis of Variance (ANOVA) and the Duncan Multiple Range Comparison Test. The results for each brand of bottled and sachet water was expressed as means of triplicate determinations ± SD. Means were regarded to be significantly different at 5 %.

## RESULTS AND DISCUSSION

Table 1 shows the result of total heterotrophic bacterial count of bottled and sachet water samples from different producers. Among the four brands of packaged drinking water, the Tai and Uni brand of bottled/sachet water had the highest (6.72/7.36 $\log_{10}$CFU/mL) and lowest (2.48/2.64 $\log_{10}$CFU/mL) heterotrophic bacterial population, respectively. Three brands of sachet water (Tai, Olv and Uni) had higher heterotrophic bacterial population than the bottled water of the same brand. The total heterotrophic bacterial count (THBC) of the samples ranged between 2.48 - 7.36 $\log_{10}$CFU/mL. It is worthy to note that the THBC of Uni brand of bottled water (2.48 $\log_{10}$CFU/mL) and sachet water (2.64 $\log_{10}$CFU/mL) is lower than the values for other samples of bottled and sachet water. The World Health Organization (WHO) responsible for publishing and periodically updating international drinking water guidelines has not reached an agreement to adopt a numerical limit for heterotrophic plate count (HPC) as a quality parameter to determine the safety of drinking water. This current position by the WHO is because there is no potential harmful effect on human health directly linked to the HPC of drinking water. Nevertheless, the effectiveness of any water treatment process is evaluated using the HPC and several parameters recommended by national and international regulatory bodies (Molale-Tom et al., 2024). Low values of HPC shows that bacteria undesirable in drinking water such as *Escherichia coli* and *Pseudomonas* spp. is absent or below detection limit (Carabin et al., 2024).

Presented in Table 2 is the total coliform counts (TCC) of four brands of bottled and sachet table water. Lom brand of sachet water had the highest TCC (2 CFU/100 mL), followed by Lom brand of bottled water, Tai brand of bottled and sachet water (1 CFU/100 mL each). Coliforms were not detected in the Olv and Uni brands of bottled and sachet water. This result is in agreement with research findings by Chiwetalu et al. (2022) and Udokpoh et al. (2022) that reported absence of coliforms in sachet water samples produced in parts of Enugu and Kaduna States, respectively. With reference to the WHO standard for drinking water, the permissible limit of *Escherichia coli* and coliforms is 0 CFU/100 mL (Some et al., 2021; Chiwetalu et al., 2022). It is worrisome that the Tai and Lom brands of packaged drinking water did not meet the WHO standard for drinking water as a result of coliforms being present in the samples. Under normal circumstance, enteric pathogens will not multiply in water unless it is allowed to contaminate food products. Consequently, the population of enteric pathogens in the product increases. The general public especially immunocompromised individuals are most likely to experience waterborne diseases when they drink water heavily contaminated with coliforms (Zvidzai et al., 2007).

Recently, Fadipe et al. (2024) assessed the various treatment units in a water factory owned by Osun State University. The researchers reported that total coliform count (TCC) of raw water prior to treatments is 1 x $10^5$ CFU. After subjecting the raw water to microfiltration, the researchers reported that TCC of the treated water is 0 CFU. The result did not change after the water was subjected to sand and carbon filtration. Surprisingly, the TCC reported after ozonization of the water undergoing treatment is 1 x $10^5$ CFU. The researchers attributed this result to inadequate contact of ozone with the water. All the coliforms present in the treated water were eliminated after it was subjected to ultraviolet disinfection. Interestingly, *Escherichia coli* were not encountered in the treated water samples. This is contrary to the result reported in this study.

**Table 1: Total heterotrophic bacterial count ($log_{10}$CFU/mL) of sachet and bottled water**

| | Brands of packaged drinking water | | | |
|---|---|---|---|---|
| **Samples** | **Lom** | **Tai** | **Olv** | **Uni** |
| Bottled water | 5.34±0.03 | 6.72±0.02 | 2.78±0.03 | 2.48±0.03 |
| Sachet water | 4.30±0.01 | 7.36±0.05 | 3.96±0.02 | 2.64±0.02 |

Values show the means of triplicate analysis ±SD

**Table 2: Total coliform count (CFU/100 mL) of sachet and bottled water**

| | Brands of packaged drinking water | | | |
|---|---|---|---|---|
| **Samples** | **Lom** | **Tai** | **Olv** | **Uni** |
| Bottled water | 1.00±0.01 | 1.00±0.04 | 0.00±0.00 | 0.00±0.00 |
| Sachet water | 2.00±0.02 | 1.00±0.02 | 0.00±0.00 | 0.00±0.00 |

Values show the means of triplicate analysis ±SD

Table 3 shows the total fungal counts (TFC) of four brands of bottled and sachet water. The Uni brand of bottled water had the highest TFC (3.70 $log_{10}$CFU/mL), whereas the least involved 'Lom' and Tai brands of bottled and sachet water (1.00 $log_{10}$CFU/mL each). Information on heterotrophic plate count of fungi stipulated by relevant regulatory bodies for drinking water is lacking (Mhlongo et al., 2019). Fungal load in the four brands of packaged drinking water could be attributed to the source of water, effectiveness of water treatment, sanitary condition of the water factory, level of personal hygiene of workers and implementation of good manufacturing practices (GMPs) in the entire production and packaging processes. In a related study, Dibua et al. (2007) reported the presence of *Streptococcus* sp. *Micrococcus* sp., *Klebsiella* sp., *Bacillus* sp., *Pseudomonas* sp., *Staphylococcus* sp., *Escherichia coli*, Actinomycetes and yeasts in sachet water samples sold in University of Nigeria, Nsukka campus. Akharame et al. (2018) isolated *Staphylococcus epidermidis, Pseudomonas* sp., *Azotobacter* sp., yeast, *Penicillium italicum, P. oxalicum, Cladosporium* sp. and *Mucor* sp. from nine brands of bottled water sold in parts of Benin City, Nigeria.

**Table 3: Total fungal count ($log_{10}$CFU/mL) of sachet and bottled water**

| | Brands of packaged drinking water | | | |
|---|---|---|---|---|
| **Samples** | **Lom** | **Tai** | **Olv** | **Uni** |
| Bottled water | 1.00±0.02 | 1.00±0.05 | 2.15±0.02 | 3.70±0.03 |
| Sachet water | 1.00±0.02 | 1.00±0.04 | 3.60±0.03 | 2.00±0.04 |

Values show the means of triplicate analysis ±SD

Table 4 shows the six (6) bacterial species found in the four brands of bottled and sachet water. They were identified based on Gram staining reaction, biochemical characteristics and motility. The bacterial species include *Staphylococcus aureus, Escherichia coli, Bacillus cereus, B. subtilis, Streptococcus agalactiae* and *Proteus mirabilis*. Some of these bacterial isolates are associated with gastroenteritis. Consumption of food and water contaminated with large population of *S. aureus* could manifest symptoms in humans such as nausea, vomiting, and abdominal cramp (Maduka & Ugbogu, 2024). The presence of coliforms such as *E. coli* in some water samples is an indication of ineffective water treatment and post-treatment contamination of the packaged drinking water (Mukhopadhyay et al., 2012). According to Some et al. (2021), the presence of *E. coli* and *Streptococci* sp. in drinking water are strong indicators of sewage contamination.

The morphology, cellular structure and colonial characteristics of three (3) fungal species isolated from four brands of bottled and sachet water are presented in Table 5. The isolates identified include *Fusarium* sp., *Aspergillus niger* and *Rhizopus stolonifer*. The three fungal species encountered in the four brands of packaged drinking water have earlier been reported in some treated water samples. The presence of these fungal species in drinking water poses a public health risk to consumers because they are capable of producing mycotoxins that is carcinogenic and weakens the immune system (Mhlongo et al., 2019). In a related study, Dibua et al. (2007) reported the presence of *Streptococcus* sp. *Micrococcus* sp., *Klebsiella* sp., *Bacillus* sp., *Pseudomonas* sp., *Staphylococcus* sp., *Escherichia coli*, Actinomycetes and yeasts in sachet water samples sold in University of Nigeria, Nsukka campus. Akharame et al. (2018) isolated *Staphylococcus epidermidis, Pseudomonas* sp., *Azotobacter* sp., yeast, *Penicillium italicum, P. oxalicum, Cladosporium* sp. and *Mucor* sp. from nine brands of bottled water sold in parts of Benin City, Nigeria.

**Table 4: Gram staining, biochemical characteristics and motility test of bacteria isolated from bottled and sachet water**

| Source of isolate | Gram staining | Catalase | Oxidase | Coagulase | Indole | Motility | Urease | Methyl red | Voges-Proskauer | Citrate | Glucose | Lactose | Fructose | Probable organism |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tai (B) | -ve rod | + | + | + | + | + | + | - | - | - | + | + | + | *Escherichia coli* |
| Olv (B) | +ve cocci | + | + | + | - | + | + | + | + | - | + | + | + | *Staphylococcus aureus* |
| Olv (B) | -ve Rod | + | + | - | - | + | + | - | + | - | + | + | + | *Proteus mirabilis* |
| Olv (B) | +ve rod | + | + | + | - | + | + | + | + | - | + | + | + | *Bacillus subtilis* |
| Lom (S) | +ve rods | + | + | + | + | + | - | + | + | - | + | + | + | *Bacillus cereus* |
| Uni (S), Uni (B) | +ve cocci | - | + | + | - | - | - | + | + | - | + | + | - | *Streptococcus agalactiae* |

Key: -ve represent negative; +ve represent positive; B – Bottled water; S – Sachet water

**Table 5: Morphology, cellular structure and colonial characteristics of fungal isolates from bottled and sachet water**

| Isolate code | Colonial characteristics | Morphology and cellular structure | Probable organism |
|---|---|---|---|
| Olv (S), Uni (S) | Grey-whitish mycelium with sparse floccose | Microconidia was produced on branched conidiophores and it is oval shaped | *Fusarium* spp. |
| Olv (B), Uni (B), Lom (B and S), Tai (B and S) | White to yellow colonies. Rapidly turns dark brown to black when the conidia developed | Light yellow and brown vesicles. Phialides was seen growing radially along the whole periphery of phialides. The colour of the primary phialides and secondary vesicles are brownish. | *Aspergillus niger* |
| Uni (B) | The colonies are light grey. Grows rapidly and covers the Petri dish with dense cottony mycelia that produces mass of sporangia | Light brown, smooth walled and aseptate sporangiophore. It forms a bundle. Globose or sub-globose sporangia of which some of them were having a flattened base. The sporangia contain many whitish spores and later turn to black. | *Rhizopus stolonifer* |

B - Bottled water; S - Sachet water

Presented in Table 6 is the physicochemical properties of four brands of bottled and sachet water in comparison with the standard recommended by the World Health Organization (WHO). The pH of all the brands of bottled water did not fall within the range recommended by the WHO, with the exception of Uni brand of sachet water, Tai brand of bottled and sachet water. The salinity of all the samples of bottled and sachet water did not fall within the range recommended by the WHO. On the contrary, the following physicochemical properties of the packaged water samples which include appearance, odour, temperature, electrical conductivity, turbidity, total suspended solids, dissolved oxygen, total dissolved solids, $HCO_3^-$, $NO_3^-$, $SO_4^{2-}$, and total hardness were below the limits stipulated by the WHO.

In terms of odour and appearance, all the samples (sachet and bottled water brands) were odourless and clear, respectively. This result is in agreement with a related study that involved several brands of bottled and sachet water sold in parts of Edo State, Nigeria. The researchers reported that the odour and appearance of all the samples of packaged drinking water were unobjectionable and clear, respectively (Arhin et al., 2024).

The pH of bottled and sachet water produced by two privately-owned companies (Lom and Olv) did not fall within the range recommended by the WHO for drinking water. A similar result was reported in the Uni brand of bottled water (Table 6). Low pH contribute to sour taste of drinking water. According to Akinnibosun & Ugbawa (2017), consumption of water with pH < 6.5 is unsafe. Drinking water that is alkaline could cause serious disruption in nutrient absorption. The individuals involved might experience indigestion and malnutrition. On the other hand, drinking acidic water could cause vomiting, kidney disease, diarrhea, stomach cramp, liver disease and nausea. Water with pH lower than 6.0 is likely to contain toxic heavy metals above recommended limits which have health implications. The pH of groundwater which is usually used by water factories to produce packaged drinking water could be influenced by mineralogical and geochemical characteristic of rocks in a particular area (Odu et al., 2020). This factor could have contributed to the differences in pH values of the sachet and bottled water. The pH values reported in this study is not in agreement with the research findings by Ekanem et al. (2025). According to the researchers, the pH of different brands of sachet and bottled drinking water sold in a university teaching hospital is within the range recommended by the WHO.

The temperature of all the samples of sachet and bottled water were within the range of 27.70±0.44 - 30.90±0.87 °C. The result for the Uni brand of packaged water is slightly lower than other brands with few exceptions. All the results are within the permissible limit recommended by the WHO. In a related study, Akpen et al. (2018) reported lower values that ranged between 22.0 - 23.8 °C in samples of sachet and bottled water sold in Gboko, Benue State, Nigeria. The variation in the results could be attributed to the environmental conditions prevalent in the two locations where the sachet and bottled water samples were obtained. During storage of plastic bottled water for a long period, temperature alteration will promote the release of some harmful materials in the plastic bottles into drinking water which could be harmful to human health. In order to protect consumers' health, temperature of the environment where packaged drinking water is stored should be taken into consideration by producers, vendors, consumers and regulatory bodies (Ahmed et al., 2021).

Electrical conductivity (EC) of all the brands of sachet and bottled water were within the range of 28.00±2.00 - 430.00±2.65 μS$cm^{-1}$. The EC of the Uni brand of sachet water is higher than the values reported in other brands of packaged drinking water. According to scientists, human health is not directly impacted by conductivity, but high level conductivity is responsible for mineral taste of drinking water (Ahmad et al., 2021). According to Chukwuma et al. (2018), the conductivity of different brands of sachet and bottled water sold within the University of Port Harcourt community is within the range of 22.6 - 146.1 μS/cm and 63.5 - 169.1 μS/cm, respectively. Higher values of EC were reported in the bottled water (91.5 - 2130 μS/cm) and sachet water (1023 - 1814 μS/cm) sold within the premises of University of Uyo Teaching Hospital (Ekanem et al., 2025). EC is useful in evaluating the purity of water. It is a parameter that indicates the extent a particular aqueous solution will conduct electricity. Two main factors that influence EC of natural water are temperature and concentration of dissolved salts in water (Gapparov & Isakova, 2023).

The amount of salt (the larger part is chloride equivalent) which could render water unfit for drinking is reported as salinity (APHA, 1992). The salinity of all the brands of sachet and water bottled ranged between 0.013±0.003 - 0.194±0.002 mg/L. Although the level of salinity in the packaged drinking water is low, the values did not fall within the range recommended by the WHO. The salinity of sachet water coded Uni is higher than the values in other brands of packaged drinking water samples. Low salinity enhances the taste of drinking water and also reduces the risk of scaling in pipes and appliances. In parts of Ilorin Nigeria, Jimoh et al. (2025) reported that the salinity of 20 sachets of different brands of drinking water registered by NAFDAC is 0.05±0.05 mg/L, whereas the result for 10 samples of NAFDAC - registered bottled water is below detection limit.

Turbidity and total suspended solids (TSS) of all the brands of bottled and sachet water were below detection limit. The presence of varieties of particles in water results in cloudiness, which also influence its turbidity. Turbidity is an important parameter used in assessing the quality of drinking water (APHA, 1992). Another parameter known as TSS shows the level of suspended solids, organic and inorganic materials present in water. The presence of particles in water is responsible for cloudiness which influences its turbidity. Since the turbidity and TSS of the packaged drinking water samples were below detection limit, it is an indication that heavy contamination of the product did not occur (Alexander et al., 2019). The turbidity of all the brands of bottled and sachet water is not in agreement with the range of values (0.19 - 0.38 NTU) reported by Arhin et al. (2024) in a related study that involved different brands of bottled and sachet water sold in Edo State, Nigeria. Akpen et al. (2018) also reported that the turbidity of sachet water sold in Gboko, Benue State, Nigeria, is within the range of 0.00 - 0.85 NTU. The TSS of sachet and bottled water sold within University of Port Harcourt community is 0.05 mg/L (Chukwuma et al., 2018). This result is also not in agreement with our research findings.

The dissolved oxygen (DO) of all the samples of bottled and sachet water were within the range of 0.90±0.03 - 2.10±0.36 mg/L. According to Odu et al. (2020), DO indicate the level of free, non-compound oxygen present in water that influences the existence of microorganisms in the water. The Uni brand of sachet water and Lom brand of bottled water had the lowest (0.90±0.03 mg/L) and highest (2.10±0.36 mg/L) DO among the four brands of packaged drinking water, respectively. This result is an indication that the Uni brand of sachet water has lower population of microorganisms than other packaged water samples. This assertion is supported by the result presented in Table 1.

The total dissolved solid (TDS) of all the samples of packaged drinking water is within the range of 14.00±1.00 – 214.00±1.53 mg/L. The Uni brand of sachet water had the highest TDS among the brands of packaged drinking water, whereas Lom brand of bottled water was the least. According to Akpen et al. (2018), individuals who drink water that has low TDS are at risk of experiencing heart diseases, hypertension, goiter, ischemic and other health challenges. Total dissolved solid is a mixture of cations and anions present in water. It includes sulphate, bicarbonate, magnesium, phosphate, calcium, nitrate, organic ions and other ions (Chukwuma et al., 2018). Drinking water that has extremely low total dissolved solids has flat and insipid taste, and therefore, unacceptable (Islam et al., 2017). In a related study, Ekanem et al. (2025) reported that the TDS of sachet water and bottled water sold in Uyo, Akwa Ibom State, ranged between 473.0 – 832.0 mg/L and 146.3 – 975.0 mg/L, respectively.

The amount of $HCO_3^-$ in all the samples of packaged drinking water ranged between 42.70±0.31 - 115.90±0.19 mg/L. Among the samples of packaged water, the Uni brand of sachet water and Lom brand of bottled water had the highest and lowest $HCO_3^-$ content, respectively. A related study by Chukwuma et al. (2018) reported that the $HCO_3^-$ content of sachet and bottled water samples ranged between 34 - 40 mg/L and 35 - 40 mg/L, respectively.

The results obtained from this study showed that the concentration of $NO_3^-$ and $SO_4^{2-}$ in all the samples of packaged drinking water is within the range of 0.142±0.007 - 1.980±0.036 mg/L and 0.0030±0.0003 - 0.1180±0.0050 mg/L, respectively. The Uni brand of sachet water had the highest concentrations of $NO_3^-$ and $SO_4^{2-}$ among the sachet and bottled water samples. On the contrary, the Lom brand of bottled water had the lowest concentrations of $NO_3^-$ and $SO_4^{2-}$. In a related study that involved different brands of sachet and bottled water sold in a university teaching hospital, Ekanem et al. (2025) reported that the amount of $NO_3^-$ in the samples is within the range of 0.68 - 1.36 mg/L and 0.16 - 0.58 mg/L, respectively. The researchers also reported that the concentration of $SO_4^{2-}$ in sachet and bottled water samples is 0 mg/L or below detection limit (BDL).

Total hardness of the sachet and bottled water samples ranged between 1.50±0.26 - 35.50±0.09 mg/L. The Uni brand of sachet water had the highest result for total hardness, whereas the Lom brand of sachet water was the least. Total hardness of natural water is largely influenced by the level of dissolved magnesium and calcium salts. Seasonal variations greatly influence the total hardness of water. There are four categories of water hardness which include soft (0 - 60 mg/L), moderate (60 - 120 mg/L), hard (121 - 180 mg/L) and very hard (>180 mg/L) (Odu et al., 2020). Therefore, all the samples of sachet and bottled water evaluated in this study are regarded as soft water.

Physicochemical properties of bottled and sachet water samples evaluated in this study which include temperature, EC, turbidity, TSS, DO, TDS, $HCO_3^-$, $NO_3^-$, $SO_4^{2-}$ and total hardness were below the recommended WHO limits for drinking water (Table 6). There was significant differences ($p<0.05$) in the values obtained for each physicochemical parameter evaluated among the samples. According to Chiwetalu et al. (2022), the result for physicochemical properties and heavy metals content of sachet water produced in Enugu metropolis, met the WHO standard for drinking water. During the different stages of water treatment in a production factory, Fadipe et al. (2024) reported a reduction in the values of physicochemical properties of raw water which include total hardness, pH, Ca, Mg, $NO_3^-$, $SO_4^{2-}$, TDS, EC, K, Pb and Fe.

Essential and toxic metals concentrations in the four brands of packaged drinking water are presented in Table 7. Zn, Ca, Na, Mg, K, Cr, and Cu content in all the samples of bottled and sachet water were below the limits recommended by the WHO for drinking water. The amount of cadmium in all the samples of packaged drinking water was below detection limit (BDL). On the contrary, iron and lead content of all the samples of bottled and sachet water exceeded the limit recommended by the WHO.

Cadmium was not detected in all the samples of bottled and sachet water evaluated in this study. This is not in agreement with the report by Ahaotu et al. (2025) that detected Cd in 43 out of 51 samples of bottled water. It is worrisome that Pb content of all the samples of bottled and sachet water were above the limit recommended by the WHO for drinking water. In a related study, Maxwell et al. (2018) reported the presence of Pb (0.0232 - 0.3481 mg/L) in bottled water obtained from Lagos and its environs. Health risks individuals will face when they drink water contaminated with Pb above the permissible limit include cancer, anemia and kidney diseases (Ahaotu et al., 2025). The Fe content of the four brands of sachet and bottled water evaluated in this study also exceeded the limit recommended by the WHO for drinking water. Noticeable effect of high Fe content of water is change in colour from colourless to brown. A change in taste of food could be noticed after using the water for cooking (Odu et al., 2020). High Fe content of the four brands of sachet and bottled water is not in agreement with the report by Maxwell et al. (2018), which stated that Fe content of bottled water samples is within the range of 0.0046 - 0.0715 mg/L. Our results showed that Cr, Cd, K, Cu, Zn, Ca, Na, and Mg content of the four brands of bottled and sachet water did not exceed the permissible limits stipulated by the WHO for drinking water (Table 7).

Table 8 shows the antibiotic susceptibility profile of three (3) Gram positive bacterial species isolated from the bottled and sachet water samples. All Gram-positive bacterial isolates shared sensitivity to a common set of 7 antibiotics. Among the three Gram-positive isolates, only *Staphylococcus aureus* was sensitive to all the antibiotics tested. *Bacillus subtilis* was resistant to 3 out of 10 antibiotics, while *Streptococcus agalactiae* was resistant to 1 out of 10 antibiotics tested. Presented in Table 9 is the antibiotic susceptibility profile of two (2) Gram negative bacterial species isolated from the bottled and sachet water samples. All Gram-negative bacterial isolates shared sensitivity to a common set of 5 antibiotics. Each of the Gram-negative isolates was sensitive to 6 out of 10 antibiotics tested. On the contrary, each of the isolates was resistant to 4 out of 10 antibiotics tested. Table 10 shows the multiple antibiotic resistant patterns of bacterial isolates from bottled and sachet water sample. The results showed that *Bacillus subtilis, Escherichia coli* and *Proteus mirabilis* poses a high risk. On the contrary, *S. aureus* had no risk, while *Streptococcus agalactiae* had a low risk.

All the Gram positive bacterial isolates from the water samples were sensitive to antibiotics which include pefloxacin, gentamycin, ampiclox, rocephin, ciprofloxacin, septrin and erythromycin, while the Gram negative isolates involved sparfloxacin, gentamycin, tarivid and streptomycin. *Staphylococcus aureus* isolated from the packaged drinking water samples was sensitive to all the antibiotics tested and poses no risk. In a related study, Umoafia et al. (2023) reported that *Staphylococcus aureus* isolated from sachet water sold in Calabar metropolis was sensitive to all the antibiotics tested, with the exception of augmentin. The study also reported that *Escherichia coli* isolated from the water samples was sensitive to 7 out of 10 antibiotics tested. These results are substantially in agreement with our research findings. *Bacillus subtilis, Escherichia coli* and *Proteus mirabilis* isolated from the bottled and sachet water poses a high risk due to the number of antibiotics they were resistant to.

**Table 6: Physicochemical properties of bottled and sachet water from different producers**

| Parameters | Bottled and sachet water | | | | | | | | WHO Limit |
|---|---|---|---|---|---|---|---|---|---|
| | Lom (B) | Lom (S) | Tai (B) | Tai (S) | Olv (B) | Olv (S) | Uni (B) | Uni (S) | |
| Odour | Odourless | Odourless | Odourless | Odourless | Odourless | Odourless | Odourless | Odourless | No odour |
| Appearance | Clear | Clear | Clear | Clear | Clear | Clear | Clear | Clear | - |
| pH | 5.30±0.10$^{b}$ | 6.20±0.26$^{d}$ | 7.30±0.15$^{f}$ | 7.80±0.15$^{g}$ | 4.90±0.15$^{a}$ | 6.30±0.2$^{d}$ | 5.80±0.17$^{c}$ | 6.70±0.17$^{e}$ | 6.5-8.5 |
| Temperature (°C) | 29.00±0.26$^{b}$ | 28.40±0.46$^{ab}$ | 29.00±0.26$^{b}$ | 28.90±0.40$^{b}$ | 28.40±0.26$^{ab}$ | 30.90±0.87$^{c}$ | 28.80±0.89$^{b}$ | 27.70±0.44$^{a}$ | <40 |
| EC (µS$cm^{-1}$) | 28.00±2.00$^{a}$ | 30.00±1.00$^{a}$ | 253.00±1.73$^{d}$ | 74.00±2.00$^{c}$ | 377.00±2.65$^{f}$ | 56.00±2.00$^{b}$ | 349.00±1.73$^{e}$ | 430.00±2.65$^{g}$ | 1000 |
| Salinity (mg/L) | 0.013±0.003$^{a}$ | 0.014±0.002$^{a}$ | 0.114±0.004$^{d}$ | 0.033±0.003$^{c}$ | 0.171±0.003$^{f}$ | 0.025±0.002$^{b}$ | 0.157±0.006$^{e}$ | 0.194±0.002$^{g}$ | 200-250 |
| Turbidity (NTU) | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 5 |
| TSS (mg/L) | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 1000 |
| DO (mg/L) | 2.10±0.36$^{e}$ | 1.90±0.04$^{de}$ | 1.60±0.06$^{c}$ | 1.80±0.02$^{cd}$ | 1.10±0.04$^{ab}$ | 1.80±0.04$^{cd}$ | 1.30±0.02$^{b}$ | 0.90±0.03$^{a}$ | 5.0 |
| TDS (mg/L) | 14.00±1.00$^{a}$ | 15.00±1.73$^{a}$ | 125.00±2.65$^{d}$ | 37.00±2.31$^{c}$ | 188.00±4.00$^{f}$ | 28.00±2.65$^{b}$ | 174.00±3.46$^{e}$ | 214.00±1.53$^{g}$ | 500 |
| $HCO_3^-$ (mg/L) | 42.70±0.31$^{a}$ | 61.00±0.14$^{b}$ | 73.20±0.37$^{d}$ | 67.10±0.88$^{c}$ | 109.80±0.79$^{f}$ | 67.10±0.21$^{c}$ | 97.60±0.59$^{e}$ | 115.90±0.19$^{g}$ | 1000 |
| $NO_3^-$ (mg/L) | 0.142±0.007$^{a}$ | 0.190±0.003$^{b}$ | 0.720±0.009$^{e}$ | 0.481±0.006$^{d}$ | 1.772±0.004$^{g}$ | 0.331±0.006$^{c}$ | 1.532±0.010$^{f}$ | 1.98±0.036$^{h}$ | 5 |
| $SO_4^{2-}$ (mg/L) | 0.0030±0.0003$^{a}$ | 0.0050±0.0002$^{ab}$ | 0.0080±0.0005$^{b}$ | 0.0050±0.0003$^{ab}$ | 0.1030±0.0003$^{d}$ | 0.0050±0.0004$^{ab}$ | 0.0150±0.0040$^{c}$ | 0.1180±0.0050$^{e}$ | 400 |
| Total hardness (mg/L) | 1.70±0.20$^{a}$ | 1.50±0.26$^{a}$ | 16.60±0.10$^{d}$ | 3.90±0.03$^{c}$ | 30.50±0.05$^{f}$ | 2.90±0.05$^{b}$ | 28.70±0.05$^{e}$ | 35.50±0.09$^{g}$ | 150 |

Values show the means of triplicate analysis ±SD. Means with different superscript across the row are significantly different ($p<0.05$). Key: BDL- Below detection limit; B-Bottled; S-Sachet; EC-Electrical conductivity; TSS-Total suspended solids; DO-Dissolved oxygen; TDS-Total dissolved solids; (B) – Bottled water; (S) – Sachet water; WHO – World Health Organization

**Table 7: Essential and toxic metals concentration in bottled and sachet water from different producers.**

| | Bottled and sachet water | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Parameters | Lom (B) | Lom (S) | Tai (B) | Tai (S) | Olv (B) | Olv (S) | Uni (B) | Uni (S) | WHO Limit |
| Cr (mg/L) | 0.019±0.006$^{ab}$ | 0.013±0.003$^{a}$ | 0.017±0.007$^{ab}$ | 0.035±0.004$^{c}$ | 0.026±0.002$^{bc}$ | 0.021±0.004$^{ab}$ | 0.018±0.006 | 0.015±0.003 | 0.05 |
| Cd (mg/L) | BDL | BDL | BDL | BDL | BDL | BDL | BDL | BDL | 0.003 |
| Cu (mg/L) | 0.210±0.004$^{d}$ | 0.243±0.006$^{g}$ | 0.313±0.007 | 0.526±0.004$^{h}$ | 0.278±0.011$^{f}$ | 0.117±0.006$^{b}$ | 0.094±0.002$^{a}$ | 0.141±0.002$^{c}$ | 2.0 |
| Pb (mg/L) | 0.030±0.004$^{ab}$ | 0.040±0.008$^{b}$ | 0.012±0.004$^{a}$ | 0.100±0.006$^{a}$ | 0.017±0.003$^{ab}$ | 0.014±0.005$^{ab}$ | 0.010±0.003$^{a}$ | 0.010±0.003$^{ab}$ | 0.01 |
| Zn (mg/L) | 0.346±0.006$^{d}$ | 0.382±0.010$^{e}$ | 0.437±0.006$^{f}$ | 0.744±0.014$^{g}$ | 0.385±0.010$^{e}$ | 0.235±0.008$^{c}$ | 0.126±0.005$^{a}$ | 0.213±0.008$^{b}$ | 5.0 |
| Ca (mg/L) | 0.190±0.005$^{cde}$ | 0.170±0.006$^{bcd}$ | 0.210±0.010$^{def}$ | 0.240±0.015$^{f}$ | 0.220±0.008$^{ef}$ | 0.150±0.040$^{abc}$ | 0.110±0.030$^{a}$ | 0.130±0.040$^{ab}$ | 100 |
| Na (mg/L) | 0.020±0.002$^{b}$ | 0.020±0.007$^{b}$ | 0.030±0.003$^{c}$ | 0.040±0.006$^{d}$ | 0.030±0.006$^{c}$ | 0.010±0.003$^{a}$ | 0.020±0.005$^{b}$ | 0.020±0.004$^{b}$ | 20 |
| Fe (mg/L) | 1.047±0.036$^{b}$ | 1.126±0.048$^{b}$ | 1.824±0.046$^{d}$ | 3.168±0.050$^{e}$ | 1.422±0.042$^{c}$ | 0.326±0.030$^{a}$ | 0.312±0.032$^{a}$ | 0.341±0.041$^{a}$ | 0.3 |
| K (mg/L) | 2.330±0.320$^{bcd}$ | 2.460±0.138$^{cd}$ | 3.217±0.866$^{de}$ | 4.280±0.139$^{f}$ | 3.180±0.696$^{e}$ | 1.740±0.432$^{abc}$ | 1.280±0.148$^{a}$ | 1.630±0.505$^{ab}$ | 12 |
| Mg (mg/L) | 1.220±0.259$^{abc}$ | 1.180±0.115$^{ab}$ | 1.790±0.679$^{cd}$ | 2.190±0.112$^{d}$ | 1.36±0.261$^{bc}$ | 0.820±0.245$^{ab}$ | 0.730±0.223$^{a}$ | 0.940±0.277$^{ab}$ | 30 |

Values show the means of triplicate analysis ±SD. Means with different superscript across the row are significantly different ($p<0.05$). Key: BDL – Below detection limit; (B) – Bottled water; (S) – Sachet water; WHO – World Health Organization

**Table 8: Antibiotic susceptibility of Gram-positive bacterial isolates**

| Isolates | Antibiotics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | PEF (10 µg) | GTN (10 µg) | APX (30 µg) | ZCF (20 µg) | AM (30 µg) | RPN (25 µg) | CPX (10 µg) | STY (30 µg) | SXT (30 µg) | ERY (10 µg) |
| *Bacillus subtilis* | S | S | S | R | R | S | S | R | S | S |
| *Staphylococcus aureus* | S | S | S | S | S | S | S | S | S | S |
| *Streptococcus agalactiae* | S | S | S | S | R | S | S | S | S | S |

Key: PEF – Pefloxacin; GTN – Gentamycin; APX – Ampiclox; ZCF – Zinnacef; AM – Amoxicillin; RPN – Rocephin; CPX – Ciprofloxacin; STY – Streptomycin; SXT – Septrin; ERY – Erythromycin; S – Sensitive; R - Resistance

**Table 9: Antibiotic susceptibility of Gram negative bacterial isolates**

| | Antibiotics | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Isolates | SXT (30 µg) | CH (30 µg) | SP (10 µg) | CPX (10 µg) | AM (30 µg) | AU (10 µg) | CN (10 µg) | PEF (10 µg) | OFX (10 µg) | STY (30 µg) |
| *Escherichia coli* | R | R | S | S | R | R | S | S | S | S |
| *Proteus mirabilis* | S | R | S | S | R | R | S | R | S | S |

Key: SXT – Septrin; CH – Chloramphenicol; SP – Sparfloxacin; CPX – Ciprofloxacin; AM – Amoxicillin; AU – Augmentin; CN – Gentamycin; PEF – Pefloxacin; OFX – Tarivid; STY – Streptomycin; S – Sensitive; R – Resistance

**Table 10: Multiple antibiotic-resistant patterns of bacterial isolates from bottled and sachet water**

| Isolates | Resistance profile | a | B | MARI = $\frac{a}{b}$ | Standard (≤0.2) |
|---|---|---|---|---|---|
| *Bacillus subtilis* | ZCF, AM, STY | 3 | 10 | 0.3 | High risk |
| *Staphylococcus aureus* | None | 0 | 10 | 0.0 | No risk |
| *Streptococcus agalactiae* | AM | 1 | 10 | 0.1 | Low risk |
| *Escherichia coli* | SXT, CH, AM, AU | 4 | 10 | 0.4 | High risk |
| *Proteus mirabilis* | CH, AM, AU, PEF | 4 | 10 | 0.4 | High risk |

Key: ZCF - Zinnacef; AM – Amoxicillin; STY – Streptomycin; SXT – Septrin; CH – Chloramphenicol; AU – Augmentin; PEF – Pefloxacin; MARI - Multiple antibiotic-resistant index; a - Total number of antibiotics the organism is resistant to; b - Total number of antibiotics the organism was tested.

## CONCLUSION

Detection of six bacterial and three fungal species in the four brands of bottled and sachet water imply that water treatment was ineffective, and microbial contamination of the drinking water possibly occurred during production and handling. Coliform encountered in some samples is an indication that factory production of packaged drinking water occurred under poor hygienic conditions. Consequently, consumers of the contaminated bottled and sachet water could experience gastroenteritis, dysentery and vomiting. Most of the physicochemical properties, essential and toxic metals content of the packaged drinking water were below the limits recommended by the WHO for drinking water. Although, salinity and iron content of the packaged drinking water did not meet the standard recommended by the WHO for drinking water, a similar report with regards to lead content is worrisome due to its health implications. The bacterial isolates encountered in the packaged drinking water were sensitive to most of the antibiotics tested. In terms of multiple antibiotic resistance (MAR) index, the *Staphylococcus aureus* isolated from the packaged drinking water pose no risk. Overall health risks due to consumption of poor quality sachet and bottled water include waterborne and non-communicable diseases.

## RECOMMENDATIONS

To prevent outbreak of waterborne diseases linked to consumption of sachet and bottled water contaminated with pathogens, increase in public awareness, effective water treatment and strict implementation of good manufacturing practices (GMPs) in the water factories are recommended. There is urgent need for improved monitoring of the quality of packaged drinking water and enforcement of International Standards for production, storage and distribution of the product by NAFDAC and other relevant regulatory agencies to protect consumer safety.

## REFERENCES

Adamu, I., Andrade, F. C. D., & Singleton, C. R. (2022). Availability of drinking water source and the prevalence of diarrhea among Nigerian households. *American Journal of Tropical Medicine and Hygiene*, 107(4), 893-897. https://doi.org/10.4269/ajtmh.21-0901

Ahaotu, I., Echikwa, M., & Maduka, N. (2025). Bacteriological, physicochemical properties and heavy metals content of plastic bottled water sold in Obio-Akpor Local Government Area, Rivers State, Nigeria. *Ife Journal of*

*Science*, 27(2), 529-544. https://dx.doi.org/10.4314/ijs.v27i2.20

Ahiabor, W. K., & Donkor, E. S. (2025). Microbial safety of sachet water in Ghana: A systematic review. *Environmental Health Insights,* 19, 1-11. https://doi.org/10.1177/11786302241307830

Ahmad, W., Abu-Rayyan, A., Elhassan, N. E. E., Humaida, M. I. (2021). Measuring the health impact of drinking water sources in El-Fashir, Sudan. *Indian Journal of Forensic Medicine and Technology*, 15(1), 1640-1646.

Ahmed, A. T., Emad, M., & Bkary, M. A. (2021). Impacts of temperature alteration on the drinking water quality stored in plastic bottles. *Applied Water Science*, 11(167), 1-9. https://doi.org/10.1007/s13201-021-01505-2

Akharame, M. O., Ekhosuehi, A., Okolafor, F. I., & Sadoh, K. A. (2018). Effects of sunlight exposure on the quality parameters of bottled water. *Journal of Applied Science and Environmental Management*, 22(5), 769-774. DOI: https://dx.doi.org/10.4314/jasem.v22i5.32

Akpen, G. D., Kpoghol, I. S., & Oparaku, L. A. (2018). Quality assessment of sachet and bottled water sold in Gboko, Benue State, Nigeria. *Nigerian Journal of Technology*, 37(1), 241-248. http://dx.doi.org/10.4314/njt.v37i1.32

Alexander, P., Bwatanglang, I. B., & Daniel, J. (2019). Assessment of physicochemical and bacteriological parameters of borehole and hand dug well water in Michika and Environs, Adamawa State, Nigeria. *Microbiology Research Journal International*, 28(6): 1-11.

Arhin, E., Osei, J. D., Anima, P. A., Damoah-Afari, P., & Yevugah, L. L. (2024). The pH of drinking water and its human health implications: a case of surrounding communities in the Dormaa Central Municipality of Ghana. *Journal Healthcare Treatment Development*, 04(01), 15-26. https://doi.org/10.55529/jhtd.41.15.26

Aroh, K. N., Eze, E. M., Ukaji, D., Wachuku, C. K., Gobo, A. E., Abbe, S. D., Teme, S. C., & Igoni, A. H. (2013). Health and environmental components of sachet water consumption and trade in Aba and Port Harcourt, Nigeria. *Journal of Chemical Engineering and Materials Science*, 4(2), 13-22. https://doi.org/10.5897/JCEMS11.040

Akinnibosun, F. I., & Ugbawa, L. A. (2017). Comparative analysis of bottled and sachet water sold in urban and rural areas of Edo State, Nigeria. *Sierra Leone Journal of Biomedical Research*, 9(2): 19-27. https://dx.doi.org/10.4314/sljbr.v9i2.5

APHA (1998). American Public Health Association Standard Methods for the Examination of Water and Waste Water. 20th ed. Washington, DC, USA.

APHA (1992). Standard Methods for the Examination of Water and Waste Water. American Public Health Association (APHA), USA.

Balogun, M., Aruna, T., Akintayo, O., Imam, R., Shukurat, O., Lala, O., Kolawole, F., & Gbadebo, C. (2024). Quality assessment of different polyethylene-packaged groundwater in the Ilorin metropolis of Nigeria for compliance with standards. *Slovak Journal of Food Sciences*, 18: 366-385. https://doi.org/10.5219/1961

Barnett, E. O. I., & Hunter, B. B. (1972). Illustrated Genera of Imperfect Fungi. 3rd edition, Minnesota Burgess Publishing Company, Minneapolis, p. 241-252.

Boas, D.M. V., Junior, W. J. F. L., Nascimento, J., Leite, C., Matos, J., Paz, F., Ana, A. S. S., & Guimarães, A. G. (2025). Incidence of *Escherichia coli* in drinking water: a comparative of indoor and outdoor sources over four years across Bahia, Brazil. *Hygiene and Environment Health Advances*, 15, 1-10. https://doi.org/10.1016/j.heha.2025.100121

Cabral, J. P. (2010). Water microbiology. Bacterial pathogens and water. *International Journal of Environmental Research and Public Health*, 7, 3657-3703. https://doi.org/10.3390/ijerph

Carabin, A., Cassivi, A., Dorea, C., Rodriguez, M., & Huot, C. (2024). Heterotrophic plate counts (HPC) in drinking water distribution systems: a comprehensive review and meta-analysis. *Water Quality Research Journal*, 59(3), 1-33. https://doi.org/10.2166/wqrj.2024.027

Chiwetalu, U. J, Nebechukwu, A. C., & Attah, O. H. (2022). Quality assessment for some sachet water produced in Enugu metropolis, Enugu-Nigeria. *FUDMA Journal of Sciences*, 6(2), 81-87. https://doi.org/10.33003/fjs-2022-0602-926

Chukwuma, C. C., Ikwechi, C. C., & Ayalogu, E. O. (2018). Water quality of different brands of packaged water consumed within the University of Port Harcourt community. *Asian Journal of Biological Sciences*, 11: 152-156. https://doi.org/10.3923/ajbs.2018.152.156

Dibua, U. E., Esimone, C. O., & Ndianefo, P. C. (2007). Microbiological and physicochemical characterization of sachet water samples marketed in Nsukka campus of the University of Nigeria. *Bio-Research,* 5(1), 189-193.

Ekanem, A. M., Benson, S. A., Ekpuk, I. N., Amafaye, W. D., Akpan, I. E., Udo, A. A., Edem, S. A., David, E., Akpabio, K. O., & Nneamaka, A. A. (2025). Quality assessment of packaged water brands in a university teaching hospital in southern Nigeria. *Ibom Medical Journal,* 18(1), 187-195. https://doi.org/10.61386/imj.v18i1.607

Fadipe, O. O., Adeniran, V. A., Lawal, O. O., Kareem, M. A., & Adeosun, J. O. (2024). Quality assessment of a university-based packaged water factory. *LAUTECH Journal of Civil and Environmental Studies*, 12, 93-103. https://doi.org/10.36108/laujoces/4202.21.0101

Gapparov, A., & Isakova, M. (2023). Study on the characteristics of water resources through electrical conductivity: a case study of Uzbekistan. *IOP Conference Series: Earth and Environmental Science*, 1-8. https://doi.org/10.1088/1755-1315/1142/1/012057

Imam, N., Abdurrahman, N., Isah, L. A., & Lawal, O. S. (2023). Progress on drinking water quality monitoring in the northern part of Nigeria: A catalyst to achieving sustainable development goals. *FUDMA Journal of Science*, 7(2), 152-158. https://doi.org/10.33003/fjs-2023-0702-1472

Ire, F. S., Okoro, C. J., Ahaotu, I., Ire, E. S., & Maduka, N. (2024). Bacteriological and physicochemical analysis of drinking water sources in some parts of Nneato in Umunneochi Local Government of Abia State, Nigeria. *Scientia Africana*, 23(4), 211-222. https://dx.doi.org/10.4314/sa.v23i4.19

Islam, R., Faysal, S. M., Amin, M. R., Juliana, F. M., Islam, M. J., Alam, M. J., Hossain, M. N., & Asaduzzaman, M. (2017). Assessment of pH and total dissolved substances (TDS) in the commercially available bottled drinking water. *IOSR Journal of Nursing and Health Science,* 6(5), 35-40. https://doi.org/10.9790/1959-0605093540

Isukuru, E. J., Opha, J. O., Isaiah, O. W., Orovwighose, B., & Emmanuel, S. S. (2024). Nigeria's water crisis: abundant water, polluted reality. *Cleaner Water,* 2, 1-33. https://doi.org/10.1016/j.clwat.2024.100026

Jimoh, F. A., Ajao, A. T., Aborisade. W. T., Abdulsalam, Z. B., & Kolawole, M. O. (2025). Bacteriological evaluation and physicochemical compliance of packaged water sold in Ilorin, Nigeria. *FUDMA Journal of Sciences*, 9(1), 180-185. https://doi.org/10.33003/fjs-2025-0901-3015

Kılıç, Z. (2021). Water pollution: causes, negative effects and prevention methods. *Istanbul Sabahattin Zaim University Journal of the Institute of Science and Technology*, 3(2), 129-132.

Maduka, N., Igiebor, F. A., & Elum, O. (2022). Microbiological assessment of home-packed children's meal, antibiotic susceptibility and prevalence of intestinal parasites among pupils in selected schools in Benin City, Nigeria. *FUW Trends in Science and Technology Journal*, 7(3), 138-150.

Maduka, N., Obueh, H. O., & Unuagbon, H. I. (2025). The quality and health risk assessment of polyethylene packaged table water sunlight exposed and unexposed during storage. *FUDMA Journal of Science*, 9(8), 172-187. https://doi.org/10.33003/fjs-2025-0908-3792

Maduka, N., & Ugbogu, O. C. (2024). A review on microorganisms and mycotoxin contamination of selected 'swallow meals' - potential health risks to consumers. *Heliyon* 10, 1-24. https://doi.org/10.1016/j.heliyon.2024.e39311

Manetu, W. M., & Karanja, A. M. (2021). Waterborne disease risk factors and intervention practices: a review. *Open Access Library Journal*, 8, 1-11. https://doi.org/10.4236/oalib.1107401

Maxwell, O., Adewoyin, O. O., Joel, E. S., Okolie, S. T. A., Ayowe, O. E. A. A., & Arijaje, T. E. (2018). Potential health risks of heavy metal contents in bottled water from Lagos state and its environs, Nigeria. *IOP Conference Series: Earth and Environmental Science,* 173, 1-15. https://doi.org/10.1088/1755-1315/173/1/012021

Meki, C. D., Ncube, E. J., & Voyi, K. (2022). Community-level interventions for mitigating the risk of waterborne diarrheal diseases: a systematic review. *Systematic Reviews,* 11, 1-12. https://doi.org/10.1186/s13643-022-01947-y

Mhlongo, N. T., Tekere, M., & Sibanda, T. (2019). Prevalence and public health implications of mycotoxigenic fungi in treated drinking water systems. *Journal of Water and Health*, 17(4), 517-531. https://doi.org/10.2166/wh.2019.122

Molale-Tom, L. G., Olanrewaju, O. S., Kritzinger, R. K., Fri, J., & Bezuidenhout, C. C. (2024). Heterotrophic bacteria in drinking water: evaluating antibiotic resistance and the presence of virulence genes. *Microbiology Spectrum*, 12(2), 1-20. https://doi.org/10.1128/spectrum.03359-23

Mukhopadhyay, C., Vishwanath, S., Eshwara, V. K., & Shankaranarayana, A. S. (2012). Microbial quality of well water from rural and urban households in Karnataka, India: a cross-sectional study. *Journal of Infection and Public*

*Health,* 5, 257-262. https://dx.doi.org/10.1016/j.jiph.2012.03.004

Mulualem, Y., Kumie, A., Tefera, Y., Demsie, B., & Mengesha, S. D. (2023). Assessing the effect of sunlight exposure on physicochemical properties of bottled water in Addis Ababa, Ethiopia: An experimental observational study. *Scientific African*, 19, 1-11. https://doi.org/10.1016/j.sciaf.2022.e01454

Munteanu, C., Teoibas-Serban, D., Iordache, L., Balaurea, M., & Blendea, C. (2021). Water intake meets the water from inside the human body – physiological, cultural, and health perspectives – synthetic and systematic literature review. *Balneo and PRM Research Journal*, 12(3): 196-209. https://dx.doi.org/10.12680/balneo.2021.439

NIS (2007). Nigerian Industrial Standard (NIS). Nigerian Standard for Drinking Water Quality. p. 1-30.

Odu, N. N., Omunakwe, A. L., & Millicent, M. (2020). Comparative assessment on the physicochemical water quality of wells and boreholes in two Rivers State communities, Nigeria. *International Journal of Research Studies in Microbiology and Biotechnology,* 6(2), 5-20. https://doi.org/10.20431/2454-9428.0603002

Ofoegbu, F. I., & Alonge, H. O. (2016). Internally generated revenue (IGR) and effectiveness of university administration in Nigeria. *Journal of Education and Learning*, 5(2), 1-8. https://doi.org/10.5539/jel.v5n2p1

Omada, S. E., Anagwe, M. U., Boniface, E. O., Yisa, A. G., Samuel, S. A., & Osegbo, A. N. (2025). Assessment of the microbial quality of sachet water sold in Nyanya, Nasarawa State, Nigeria. *Sahel Journal of Life Sciences FUDMA*, 3(3), 97-104. https://doi.org/10.33003/sajols-2025-0303-12

Onuguh, I. C., Aaron, I. Y., Nnadozie, R. I., Oke, V. J., & Imade, O. S. (2025). Comparative determination of physicochemical and microbial quality of sachet drinking water sold in Okada, Edo State Nigeria. *International Journal of Chemistry, Mathematics and Physics*, 9(1), 1-6. https://dx.doi.org/10.22161/ijcmp.9.1.2

Some, S., Mondal, R., Mitra, D., Jain, D., Verma, D., & Das, S. (2021). Microbial pollution of water with special reference to coliform bacteria and their nexus with environment. *Energy Nexus,* 1, 1-9. https://doi.org/10.1016/j.nexus.2021.100008

Udokpoh, U. U., Abubakar, Z. S., & Yakasi, A. B. (2022). Variation in water quality indices of sachet water brands consumed in Kaduna State: consumers' perceptions. *Discovery*, 58(317), 441-452.

Ugwuoha, E., Udeh, N. U., & Kpaniku, D. (2023). Impact of municipal dumpsite on neighbouring boreholes in Igbogo community of Rivers State, Nigeria. *Asian Journal of Geological Research*, 6(1): 1-11.

Umoafia, N. E., Edet, U. O., Joseph, A. P., Henshaw, O. U., Mbim, E. N., Obeten, H., Edet, B. O., Edet, A., Ibor, O. R., Nkang, N., Louis, H., Nwaokorie, F. O., & Nkang, A. (2023). Impacts of sunlight exposure on physicochemical parameters, potential toxic metals, and microbial characteristics of sachet drinking water sold in Calabar metropolis, Nigeria. SN *Applied Sciences*, 5, 1-19. https://doi.org/10.1007/s42452-023-0558S-4

Usman, H. M., Faruk, M. U., & Yahaya, M. (2026). Bacteriological analysis of sachet water sold at Adamawa State University, Mubi Commercial. *International Research Journal of Innovations in Engineering and Technology*, 10(3), 118-123. https://doi.org/10.47001/IRJIET/2026.103015

WHO (2017) Guidelines for drinking-water quality: fourth edition incorporating the first addendum. Geneva: World Health Organization. Licence: CC BY – NC-SA 3.0 IGO. p 1-631.

Yahaya, T. O., Abdulganiyu, Y., Ologe, O., Muhammad, Z. K., Ibrahim, Y. Y., Haruna, A. J., & Adeniyi, T. J. (2022). Quality and safety assessment of borehole water around Simpson Transfer Loading Station in Lagos, Southwest Nigeria. Dutse *Journal of Pure and Applied Science,* 8(4), 20-35. https://dx.doi.org/10.4314/dujopas.v8i4a.3

Zvidzai, C., Mukutirwa, T., Mundembe, R., & Sithole-Niang, I. (2007). Microbial community analysis of drinking water sources from rural areas of Zimbabwe. *African Journal of Microbiology Research*, 1(6), 100-105.