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Assessment of the Bacteriological Quality of Commercially Packaged Table Water Sold in Port Harcourt, Nigeria

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ABSTRACT

The microbiological quality of commercially packaged drinking water is important to public health because contamination may occur during water treatment, packaging, storage and distribution. This study evaluated the total heterotrophic bacterial (THB) loads and bacterial diversity of commercially packaged table water sold in Port Harcourt, Rivers State, Nigeria. A descriptive cross-sectional study was conducted from January to December 2025, involving 480 samples representing ten brands collected monthly from four locations: Aba Road, Iwofe, Mile 1 and Mile 3. Bacterial loads were determined by standard culture techniques using nutrient agar, while selective and differential media were used for the recovery of presumptive bacterial groups. Purified isolates were characterised using cultural, morphological and biochemical methods. Mean THB counts varied across brands and sampling locations, ranging from 0.42 ± 0.08 to 5.5 ± 0.7 × 10^3 CFU/mL. Differences among brands were statistically significant at Aba Road (P = 0.026) and Mile 1 (P = 0.011), but not at Mile 3 (P = 0.496) or Iwofe (P = 0.481). Growth on Salmonella–Shigella agar was recorded in one sample, with a count of 2.50 × 10^2 CFU/mL A total of 144 bacterial isolates belonging to ten bacterial groups were recovered from the packaged table-water samples. Staphylococcus spp. were the most frequently recovered isolates, accounting for 46.5% of the total isolates, followed by Lactobacillus spp. (16.0%), Bacillus spp. (13.2%) and Proteus spp. (9.0%). Micrococcus spp. accounted for 6.3% isolates, while Salmonella spp. accounted for 4.9%. Other recovered organisms included Escherichia coli (2.1%), Klebsiella spp. (0.7%), Enterobacter spp. (0.7%) and Shigella spp. (0.7%). The findings demonstrate variations in heterotrophic bacterial loads and the occurrence of diverse culturable bacteria in the packaged-water samples examined. The recovery of presumptive enteric bacteria highlights the importance of routine microbiological monitoring, appropriate pathogen confirmation and effective quality control during water production, packaging and distribution.

Keywords: *Packaged drinking water; heterotrophic bacterial count; bacterial isolates; microbiological quality; Port Harcourt; Nigeria.*

Introduction

Safe drinking water is essential for human health, yet microbial contamination of water supplies remains a major cause of preventable diseases, particularly in developing countries. Waterborne pathogens are responsible for diseases such as diarrhoea, typhoid fever, cholera, and dysentery, which continue to contribute significantly to morbidity and mortality globally [1]. The greatest health risk associated with drinking water is the transmission of faecal pathogens, especially where water sources are contaminated with human or animal excreta [2].In Nigeria, packaged table water, commonly produced and sold in sachets or bottles, has become an important alternative source of drinking water because of its affordability, portability, and availability [3, 4]. The rapid growth of the sachet-water industry has improved access to drinking water in many urban and semi-urban communities. However, the microbiological safety of packaged water depends on the quality of the source water, effectiveness of treatment, hygiene during production and packaging, storage conditions, transportation, and handling by vendors and consumers [5, 6].Several studies in Nigeria have reported microbial contamination of sachet and bottled water, raising concerns about their suitability for consumption. Adewoye et al. [7], Adeyinka et al. [8], Anyamene and Ojiagu[9], Ezeugwunne et al. [10], and Omalu et al. [11] isolated various bacteria from packaged drinking water sold in different Nigerian cities. Such contamination may result from inadequate treatment, unhygienic handling, poor sanitation around water sources, or post-packaging contamination during storage and distribution [12, 13].Microbiological examination of drinking water is therefore necessary to determine its suitability for human consumption. Total heterotrophic bacterial count is widely used as an operational indicator of the general microbial load in water. It provides information on treatment efficiency, bacterial regrowth, and possible biofilm formation within treatment, storage, or distribution systems [14, 15]. Although heterotrophic bacteria are not all pathogenic, high counts may indicate inadequate disinfection, poor hygiene, or contamination after treatment (WHO, 2011).

The most important microbiological indicators of drinking-water safety are faecal indicator organisms, particularly *Escherichia coli* and thermotolerant coliforms. WHO [2] recommends that *E. coli* or thermotolerant coliform bacteria must not be detectable in any 100 mL sample of water intended for drinking. The presence of *E. coli* provides strong evidence of recent faecal contamination and suggests the possible presence of enteric pathogens, including *Salmonella* species, pathogenic *E. coli*, *Vibrio cholerae*, viruses, and protozoan parasites [2, 16].*Salmonella* and *Shigella* species are of particular public-health importance because they are associated with typhoid fever, gastroenteritis, and bacillary dysentery [17]. Their presence in packaged water may result from contamination of raw water, failure of disinfection, unhygienic handling, or post-packaging contamination. Other bacteria frequently recovered from packaged water, including *Staphylococcus*, *Bacillus*, *Proteus*, *Klebsiella*, *Enterobacter*, and *Micrococcus* species, may originate from environmental sources, human handling, or microbial biofilms within water-treatment and storage systems [11, 6].In Port Harcourt, Rivers State, the high demand for commercially packaged table water makes routine bacteriological assessment necessary. This study was therefore designed to evaluate the total heterotrophic bacterial loads, *Salmonella–Shigella* counts, and bacterial isolates from ten table-water brands sampled at Aba Road, Iwofe, Mile 1, and Mile 3 over a 12-month period. The findings will provide information on the microbiological quality of commercially available table water and support the need for improved treatment, hygienic packaging, and regular regulatory monitoring [18].

Materials and Methods

Study area

The study was conducted in Port Harcourt, Rivers State, Nigeria, a major urban centre in the Niger Delta region. The city is characterised by substantial commercial activity, high population density and dependence on alternative drinking-water sources, including commercially packaged table water. Samples were obtained from four locations: Mile 1, Iwofe, Aba Road and Mile 3, located at approximately 4°49′27″N latitude and 7°02′01″E longitude. It is one of Nigeria's largest metropolitan centers.

Study design and Sample collection

A laboratory-based study was conducted over a 12-month period (January to December 2025). A total of 480 packaged table-water samples representing ten different brands were collected from retail outlets across four selected locations within the study area. Ten brands were sampled from each of the four locations monthly throughout the 12-month sampling period, giving 40 samples per month and 480 samples in total. Samples were purchased from supermarkets, street vendors, wholesale distributors and retail shops to capture variations in brand availability and microbiological quality. Only bottles with intact seals and identifiable production and expiry dates were included. Information recorded for each sample included brand name, batch number, production date, expiry date, manufacturer's location and National Agency for Food and Drug Administration and Control (NAFDAC) registration number, where available. Each bottle was appropriately labeled and transported to the laboratory under aseptic conditions. Samples were processed within 24 hours of collection to minimise changes in the bacterial population before analysis.

Bacterial isolation

Bacterial isolation was performed using standard cultural techniques. The culture media employed included nutrient agar for the isolation of total heterotrophic bacteria, MacConkey agar for presumptive coliform bacteria, Salmonella–Shigella agar for presumptive Salmonella and Shigella, mannitol salt agar for presumptive *Staphylococcus*, thiosulphate–citrate–bile salts–sucrose (TCBS) agar for presumptive Vibrio, and eosin methylene blue agar for presumptive *Escherichia coli*. Culture media were prepared according to the manufacturers' instructions and sterilised by autoclaving at 121°C for 15 minutes, where applicable. A 1-mL aliquot of each water sample was transferred into 9 mL of sterile diluent to obtain a 10^{-1} dilution. Subsequently, 0.1 mL of the diluted sample was inoculated onto freshly prepared agar plates and spread evenly using a sterile bent-glass spreader. Inoculated plates were incubated at 35°C for 24 hours. Following incubation, colonies displaying distinct morphological characteristics were selected and purified through repeated subculturing on nutrient agar. The purified isolates were subjected to preliminary characterisation and subsequent biochemical identification. Bacterial identities were reported as presumptive based on their cultural, morphological and biochemical characteristics. Pure isolates were maintained in appropriate culture media for subsequent antibiotic susceptibility testing.

Characterisation and identification of bacterial isolates

Purified bacterial isolates were characterised using cultural, morphological and biochemical methods. Colony characteristics assessed included colour, shape, elevation, margin and consistency. Gram staining was performed to determine Gram reaction and cellular morphology. Biochemical characterisation included motility, catalase activity, methyl red and Voges–Proskauer reactions, carbohydrate fermentation involving glucose, fructose and sucrose, citrate utilisation, indole production and starch hydrolysis. The results of the morphological and biochemical tests were compared with standard identification criteria in Bergey's Manual of Determinative Bacteriology [19] to achieve presumptive identification of the bacterial isolates.

Results

Total heterotrophic bacterial counts of packaged table water

The mean total heterotrophic bacterial (THB) counts of the ten packaged-water brands across the four sampling locations are presented in Table 1. Bacterial loads varied among brands and sampling locations. Ad recorded the highest mean THB count at Mile 3, with 5.5 ± 0.7 x 10^3 CFU/mL, while Cw recorded the lowest mean count at Mile 1, with 0.42 ± 0.08 x 10^3CFU/mL.At Mile 3, the mean THB counts ranged from 1.5 ± 0.2 to 5.5 ± 0.7 x 10^3 CFU/mL. At Iwofe, the values ranged from 0.80 ± 0.3 to 4.1 ± 0.6 x 10^3 CFU/mL. At Aba Road, the counts ranged from 0.77 ± 0.1 to 4.9± 0.7 x 10^3 CFU/mL, while at Mile 1, they ranged from 0.42 ± 0.08 to 4.3 ± 0.3 x 10^3 CFU/mL. Differences in mean THB counts among the brands were statistically significant at Aba Road (P=0.026) and Mile 1 (P=0.011). However, the differences were not statistically significant at Mile 3 (P=0.496) and Iwofe (P=0.481).

Table 1: Mean total heterotrophic bacterial counts of packaged table-water brands across the four sampling locations

Water brand	Mile 3	Iwofe	Aba Road	Mile 1
Ad	5.5 ± 0.7	4.1 ± 0.6	4.9 ± 0.7	3.5 ± 0.4
Cw	2.8 ± 0.3	1.8 ± 0.3	1.3 ± 0.2	0.42 ± 0.08
Es	2.8 ± 0.3	2.9 ± 0.3	4.3 ± 0.4	4.3 ± 0.3
De	1.8 ± 0.3	0.80 ± 0.3	0.83 ± 0.2	0.87 ± 0.1
IA	2.6 ± 2.5	3.4 ± 0.4	1.9 ± 0.2	1.5 ± 0.2
IB	2.6 ± 0.3	2.5 ± 0.3	1.6 ± 0.2	1.1 ± 0.2
Jav	2.9 ± 0.3	2.4 ± 0.3	2.5 ± 0.4	2.1 ± 0.4
Ja	3.1 ± 0.4	1.9 ± 0.3	0.77 ± 0.1	1.5 ± 0.2
La	2.6 ± 0.3	2.0 ± 1.9	1.7 ± 1.5	1.2 ± 1.0
Ri	1.5 ± 0.2	1.3 ± 0.2	1.6 ± 0.2	1.3 ± 0.1
P-value	0.496	0.481	0.026	0.011

Values are mean ± standard deviation, expressed as ×10^3 CFU/mL.

Growth on Salmonella–Shigella agar was recorded in one sample, identified as Adex collected from Mile 3 in June, with a bacterial count of 2.50 x 10^2 CFU/mL. No growth was recorded on this medium in the other samples examined (Table 2).

Table 2: Bacterial count recorded on Salmonella–Shigella agar

Water brand	Sampling location	Sampling month	Count (CFU/mL)
Ad	Mile 3	June	2.50 × 10^2
All other brands and locations	—	—	No growth

Note: *Growth on Salmonella–Shigella agar represents a selective-medium result and does not, by itself, confirm the presence of Salmonella or Shigella.*

A total of 144 bacterial isolates belonging to ten bacterial groups were recovered from the packaged table-water samples. *Staphylococcus* spp. were the most frequently recovered isolates, accounting for 67 (46.5%) of the total isolates, followed by *Lactobacillus* spp. (23; 16.0%), *Bacillus* spp. (19; 13.2%) and *Proteus* spp. (13; 9.0%). *Micrococcus* spp. accounted for 9 (6.3%) isolates, while *Salmonella* spp. accounted for 7 (4.9%). Other recovered organisms included *Escherichia coli* (3; 2.1%), *Klebsiella* spp. (1; 0.7%), *Enterobacter* spp. (1; 0.7%) and *Shigella* spp. (1; 0.7%) (Table 3).

Table 3: Bacterial isolates recovered from packaged table-water samples

Bacterial isolate	Number	Percentage (%)
Staphylococcus spp.	67	46.5
Lactobacillus spp.	23	16.0
Bacillus spp.	19	13.2
Proteus spp.	13	9.0
Micrococcus spp.	9	6.3
Salmonella spp.	7	4.9
Escherichia coli	3	2.1
Klebsiella spp.	1	0.7
Enterobacter spp.	1	0.7
Shigella spp.	1	0.7
Total	**144**	**100.0**

Discussion

The microbiological quality of commercially packaged drinking water remains an important public health concern in Nigeria, where sachet and bottled water are widely consumed in urban communities. Variations in bacterial quality across locations suggest that source-water characteristics, treatment efficiency, production hygiene, packaging practices, and post-production handling all influence the safety of these products. Dada [3] highlighted the public health risks associated with the rapid expansion of the sachet-water industry, particularly where quality-control systems are inadequate. Similarly, Olaoye and Onilude[6] observed location-dependent bacterial contamination in sachet water from Western Nigeria, reinforcing the need for routine surveillance rather than assuming that registered products are consistently safe. The bacterial loads obtained in the present study are broadly comparable with those reported in earlier Nigerian investigations, although direct comparisons require caution because of differences in brands, sampling design, analytical methods, and reporting units. Olaoye and Onilude[6] recorded total bacterial counts of approximately 2.86–3.45 log CFU/mL in sachet water from Western Nigeria, while Oyedeji et al. [20] reported heterotrophic plate counts of 5–200 CFU/mL among sachet-water brands in Ibadan and Ile-Ife, with some brands also positive for coliforms and *Escherichia coli*. Such variation indicates that contamination is not uniform across Nigerian markets and may reflect geographical, temporal, and methodological differences .Findings from Port Harcourt are particularly relevant. Lawson et al. [21] recovered *Escherichia*, *Streptococcus*, *Micrococcus*, *Vibrio cholerae*, *Staphylococcus*, and *Bacillus* from table water sold on University of Port Harcourt campuses. The overlap between several of these genera and those isolated in the present study suggests similar culturable bacterial populations in packaged water within the metropolis, although differing sampling locations and study designs preclude conclusions about shared contamination sources. More recently, Oridikitorusinyaa et al. [18] reported higher bacterial loads in sachet than bottled water sold in Port Harcourt and isolated *E. coli*, *Salmonella*, *Aeromonas*, and *Proteus*, among other organisms. The detection of some of these groups in both investigations strengthens concerns about packaged-water safety in the area.The predominance of *Staphylococcus* in the present investigation aligns with earlier Nigerian reports. In a review of studies on packaged drinking water, Odeyemi [22] found *Staphylococcus* in 37.9% of the studies examined, while *Bacillus* and *Salmonella* were reported in 44.1% and 44.8%, respectively. These figures describe the proportion of studies reporting each genus, not the proportion of contaminated samples. Their repeated detection may be linked to environmental contamination, poor processing hygiene, or handling practices, although culture-based results alone cannot establish the source. *Bacillus* is commonly encountered in water and environmental samples because of its wide distribution in soil and dust and its ability to form resistant endospores. These traits may promote persistence in treatment and packaging environments. Lawson et al. [21] and Odeyemi [22] also reported *Bacillus* in packaged water from Port Harcourt and Nigeria, respectively. However, detecting this genus does not by itself indicate faecal pollution or pathogenicity, since *Bacillus* species vary widely in ecology and clinical significance.The recovery of *Proteus* is similarly consistent with Oridikitorusinyaa et al. [18], who isolated the genus from commercial drinking water in Port Harcourt. Although *Proteus* is associated with intestinal environments, it also occurs in other habitats; therefore, its presence alone is not definitive evidence of faecal contamination. Specific indicators, especially *E. coli*, remain essential for assessing faecal pollution. The detection of *E. coli*, *Klebsiella*, *Enterobacter*, *Shigella* and *Salmonella* is of particular safety relevance because some members of these groups inhabit the intestinal tract and certain species cause human infections. Oyedeji et al. [20] recovered *E. coli* from four of twenty sachet-water brands examined in Ibadan and Ile-Ife, while *Enterococcus faecalis* was found in two brands. In contrast, Udoh et al. [23], reviewing 52 Nigerian studies, estimated pooled prevalences of 12.38% for faecal indicator bacteria, 13.30% for *E. coli*, and 53.27% for total coliforms.

The much higher coliform prevalence underscores the need to distinguish general bacterial contamination from actual evidence of faecal pollution. The occurrence of *Salmonella* further supports the need for surveillance that includes enteric pathogens. Odeyemi [22] identified it among commonly reported genera in Nigerian packaged water, and Oridikitorusinyaa et al. [18] recovered it from products sold in Port Harcourt. Because presumptive identification based on cultural and biochemical tests can be uncertain, confirmatory biochemical or molecular methods are advisable. The isolation of *Micrococcus* and *Lactobacillus* illustrates the broader diversity of bacteria that may be cultured from packaged water. Lawson et al. [21] likewise reported *Micrococcus* in table water sold around the University of Port Harcourt. Differences in the organisms recovered across studies may arise from sampling strategies, culture media, incubation conditions, identification protocols, and product characteristics; therefore, interpretations should emphasize broad patterns rather than assume that variations directly reflect changes in contamination levels.

Generally, evidence from Port Harcourt and other parts of Nigeria indicates that heterotrophic bacteria, environmental organisms, and potentially significant enteric bacteria continue to occur in commercially packaged drinking water. The findings of Lawson et al. [21], Oridikitorusinyaa et al. [18], Oyedeji et al. [20], Odeyemi [22], and Udoh et al. [23] collectively support sustained microbiological monitoring. Effective quality assurance should combine routine heterotrophic and coliform testing with specific faecal indicators and pathogen detection, while also strengthening hygiene across source-water abstraction, treatment, packaging, storage, and distribution [24]. A national review similarly reported total coliform contamination in 53.27% of studies and *E. coli* in 13.30%, supporting the need for stricter regulatory oversight of sachet-water products.

Conclusion

This study demonstrated variations in heterotrophic bacterial loads and the occurrence of diverse culturable bacteria in commercially packaged table water sold in Port Harcourt, Rivers State, Nigeria. The recovered isolates included environmental and potentially important enteric bacterial groups. The presumptive recovery of *Escherichia coli* and the detection of bacterial growth on Salmonella–Shigella agar highlight the need for appropriate confirmatory procedures and routine microbiological monitoring of packaged drinking water. Improved quality control during water treatment, hygienic packaging, proper storage and effective monitoring throughout distribution are important for maintaining the microbiological quality of these products.

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