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BACTERIOLOGICAL EVALUATION AND PHYSICOCHEMICAL COMPLIANCE OF PACKAGED WATER SOLD IN ILORIN, NIGERIA

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ABSTRACT

This study evaluated the quality of sachet and bottled water sold in Ilorin, Nigeria. Water samples were procured from selling points, and their physicochemical and bacteriological quality was assessed using standard methods. The results showed that the respective physicochemical parameters for sachet and bottle waters: temperature (26.6 °C and 23.9 °C), electrical conductivity (142.0 µs/cm and 111.0 µs/cm), total dissolved solids (68.5 mg/L and 58.0 mg/L), pH (7.5 and 7.3), and salinity (0.05 and BDL) of both sachet and bottled water samples respectively were within the permissible range recommended by the World Health Organization (WHO). Bacteriological analysis revealed that total heterotrophic bacterial counts ($52.5^{*Z} \pm 4.7$ and $35.0^{Z} \pm 0.9$) for sachet and bottled water samples were within WHO limits; however, total coliform counts ($51.50^{*Z} \pm 2.6$ and $33.5^{Z} \pm 1.5$) exceeded the acceptable range of 0 CFU/mL. Seven bacterial isolates identified were *Pseudomonas aeruginosa*, *Klebsiella* spp., *Proteus* spp., *Enterobacter* spp., *Salmonella* spp., *Shigella* spp. and *Bacillus subtilis*. The number of bacterial isolates in bottled water was higher, with Klebsiella spp. being the most prevalent. The findings suggest varying degrees of microbiological contamination, indicating that some packaged water samples are not of the highest quality. These results highlight the need for stricter monitoring and quality control measures to ensure the safety of packaged water.

Keywords: Packaged water quality, Bacteriological contamination, Physicochemical parameters, Coliform bacteria, Water safety monitoring

INTRODUCTION

Water is a fundamental natural resource essential for the sustenance and development of any society. It ranks as the second most crucial life-sustaining element, after air, and is indispensable for all living organisms. Humans can survive only a few days without water. Beyond sustaining life, water is a medium for metabolic activities in plants and animals, supporting vital processes such as growth, development, and survival. Additionally, it plays a critical role in agricultural, commercial, and industrial activities (Maishanu *et al*., 2024).
The World Health Organization (WHO) defines safe drinking water as water that, when consumed over a lifetime, poses no significant risk to human health, even considering individual sensitivity variations. However, in many developing countries, access to safe potable water remains a persistent challenge. The quality of drinking water is a crucial factor affecting human health and socio-economic stability. For water to be life-sustaining, it must be free from biological, chemical, and physical contaminants (Jimoh and Kolawole, 2021). Unfortunately, increasing population growth and anthropogenic activities are polluting drinking water sources, leading to a reduced availability of potable water. In underdeveloped regions, this has resulted in high mortality rates due to waterborne diseases (Adesakin *et al*., 2022).
Fecal bacterial indicators, such as *Escherichia coli* and *Klebsiella* spp., are transmitted via the fecal-oral route and are commonly used to evaluate the risk of waterborne diseases associated with contaminated water. Alarmingly, billions of people worldwide rely on drinking water sources contaminated with fecal matter (Bivins *et al*., 2020). According to WHO and UNICEF reports, approximately 748 million people lack access to quality drinking water. In Nigeria alone, over 60 million people face water scarcity, with 53% residing in rural areas and 28% in urban centers. Waterborne diseases account for an annual mortality of 4 million children in developing countries, with global adult deaths estimated at 2.3 billion (WHO and UNICEF, 2017).
Access to safe drinking water is hindered by a combination of environmental, infrastructural, and socio-economic factors. Rapid population growth and urbanization have outpaced the capacity of water supply systems, while pollution from industrial, agricultural, and domestic sources continues to degrade water quality. Inadequate and poorly maintained infrastructure in many regions exacerbates these challenges, allowing contaminants to enter water supplies. In rural and remote areas, geographical barriers and limited infrastructure make it difficult to provide clean water, leaving communities dependent on unsafe sources.
Economic and governance issues further contribute to the problem. Many low-income countries lack the financial resources to develop and maintain water infrastructure, while weak governance and corruption hinder effective policy implementation and regulation. Climate change has also intensified water scarcity, with altered rainfall patterns and increased droughts depleting freshwater resources. In conflict zones, displacement and infrastructure destruction disrupt access to potable water, increasing reliance on unsafe sources and elevating the risk of waterborne diseases (Ngene *et al*., 2021).
Cultural and behavioural factors also contribute to water quality issues. In some communities, traditional methods of water collection and storage can heighten the risk of contamination, while poor hygiene practices, such as open defecation, further compromise water quality (Cassivi *et al*., 2021). Addressing these complex challenges necessitates coordinated efforts that include infrastructure development, stricter regulations enforcement, public education, and international collaboration to ensure universal access to safe drinking water.

In Nigeria, public water agencies have faced significant challenges in maintaining water quality over the past four decades. Factors such as poor source water quality, inadequate facility management, unhygienic production practices, and a lack of government commitment have exacerbated the situation (Isukuru *et al*., 2024). These issues have led to a rising demand for and increased prices of safe drinking water. In response, the production of sachet water, commonly referred to as "pure water," has become widespread. Sachet water is relatively affordable and is consumed extensively throughout Nigeria and West Africa. However, despite regulatory oversight from the National Agency for Food and Drug Administration and Control (NAFDAC), some sachet water brands do not meet microbiological safety standards. Poor handling and non-compliance with production guidelines further complicate these challenges.

Ilorin, the capital of Kwara State, is located in north-central Nigeria at coordinates 4.5420°E, 8.4800°N. As of 2024, it ranks among Nigeria's ten most populous cities, covering an area of approximately 3,500 km² with an estimated population of 1.1 million. Despite its growing population, the city's water supply remains critically inadequate. The agency responsible for water provision faces numerous obstacles, including ageing infrastructure and limited resources, which hinder its ability to meet the increasing demand for potable water (Mokuolu *et al*., 2023). These inadequacies in public water supply have intensified the dependence on packaged water as a vital source of drinking water for households and businesses.

Numerous studies in developing countries have assessed water sources' microbiological and physicochemical quality, with a major focus on water sources such as boreholes, wells, and municipal water systems (Sila, 2019; David *et al*., 2023; Assouani *et al*., 2024). Nonetheless, there has been limited attention to packaged water in Ilorin, Nigeria, despite its increasing consumption as an alternative to tap and well water.

These packaged water products are ubiquitous in homes, schools, offices, and social gatherings, and are distributed via trucks and tricycles before being stored in shops for sale. However, improper storage practices can negatively affect the bacteriological quality of the water, increasing the risk of waterborne diseases (Umoafia *et al*., 2023). Consequently, this study focuses on the comparative assessments of packaged water sold in Ilorin.

MATERIALS AND METHODS

Study Area

This study was conducted in the Ilorin metropolis, the capital city of Kwara State, located in the North Central zone of Nigeria. The metropolis comprises three local government areas: Ilorin East, Ilorin West, and Ilorin South. Figure 1 presents the map showing the retail points of selected sachet water analyzed, situated at coordinates 8.5373° N (latitude) and 4.5444° E (longitude). Ilorin, often referred to as Nigeria's "gateway city" due to its strategic location between the northern and southern regions, covers an approximate land area of 100 km² (Mohammed, 2006).

The city is bordered by Asa Local Government Area to the west, Ifelodun Local Government Area to the east, and Moro Local Government Area to the north. Ilorin is predominantly inhabited by Yoruba and Fulani ethnic groups. The primary water sources in the area include rivers, wells, and boreholes, which serve as critical resources for domestic and commercial activities.

Sample Collection

A total of 20 sachets and 10 bottles of water from NAFDAC-registered brands were purchased within the Ilorin metropolis. The sachets were labelled A1 to A20, while the bottles were labelled B1 to B10. All samples were transported to the Microbiology Laboratory at the Department of Microbiology, Kwara State University, Malete, for analysis.

Analyses of Water samples

The physicochemical and bacteriological parameters of water samples were determined in triplicate using the standard technique. The physicochemical parameters determined were the pH, temperature, electrical conductivity (EC) and total dissolved solids (TDS) with the aid of a multiparameter probe meter (Model JQ006) as described by Nuri and Adamu, (2023).

Bacteriological Analyses of Water Samples

The media used for the bacteriological evaluation of the water samples were nutrient agar (NA) for total heterotrophic counts, MacConkey agar (MAC) for total coliform counts, *Salmonella-Shigella* Agar (SSA) for *Salmonella* and *Shigella* counts, and eosin methylene blue agar (EMB) for faecal coliform counts. All media were prepared according to the manufacturer's instructions.

The bacterial content of the water samples was determined using the membrane filtration technique. A 100 mL water sample was filtered through a 0.45 µm Millipore filter to trap bacteria. The filter was then aseptically placed on the prepared agar plates. Plates for total bacterial and coliform counts were incubated at 37°C for 24 hours, while plates for faecal coliform counts were incubated at 44.5°C for 24 hours. Colony counts were expressed as colony-forming units (CFU) per 100 mL of water (APHA, 2005).

Identification, and Characterization of Bacterial Isolates

The bacterial groups were identified based on their colonial morphology and biochemical characteristics (Cheesbrough, 2010). The colonial morphology considered were the shape, appearance, and pigmentation. Pure cultures were obtained by sub-culturing isolated colonies. Biochemical tests, including Gram staining, catalase, urease, citrate utilization, oxidase, and indole tests.

Statistical Analyses

All the data collected were subjected to statistical analysis using a pair samples t-test on IBM_SPSS statistical software version 23.

RESULTS AND DISCUSSION

Table 1: Physicochemical properties of packaged water samples sold in Ilorin

Parameters	Water Samples		WHO Standard
	Sachet	Bottle	
Temperature (°C)	26.6 ± 1.00	23.9 ± 2.90	25- 30
EC (μs/cm)	142.0 ± 1.23	111.0 ± 1.0	< 1000
pH	7.5 ± 0.40	7.3 ± 0.55	6.5 – 8.5
TDS (mg/L)	68.5 ± 6.50	58.0 ± 4.80	< 300
Salinity (mg/L)	0.05 ±0.05	BDL	< 1000

Keys: The values were presented in mean plus or minus the standard errors of mean; WHO - World Health Organization, BDL – Below detection limit

Table 2: Bacteriological qualities of packaged water sold in Ilorin

Bacterial count	Sachet water	Bottled water	WHO Standard
THBC (CFU/100mL)	$52.5^{*Z} \pm 4.7$	$35.0^{Z} \pm 0.9$	≤ 100
TCC (CFU/100mL)	$51.50^{*Z} \pm 2.6$	$33.5^{Z} \pm 1.5$	0.0
TFC (CFU/100mL)	0.00	0.0	0.0

Keys: The results were presented in mean plus/minus standard error of means; Mean value with asteric (*) in the same row showed significantly higher value ($p<0.05$); Mean value in the same row with superscript "z" indicates the value above the recommended range by the WHO; THBC – Total heterotrophic bacterial count, TCC – Total coliform count, TCC – Total faecal coliform count, WHO – World Health Organization

Table 3: Morphological characteristics of the isolated bacteria from water samples

Isolates	Elevation	Margin	Colour	Shape
A	Flat	Irregular	Green	Rod
B	Raised	Entire	Gray	Rod
C	Flat, Spreading	Irregular	Light yellow	Rod
D	Raised, Convex	Entire	Cream	Rod
E	Flat, Raised	Entire	Slight yellow	Rod
F	Flat, Raised	Entire	Colourless	Rod
G	Raised Convex	Entire	Light yellow	Rod

Table 4: Biochemical Characteristics of the Isolated Bacteria from Water Samples

Isolates	Gram Reaction	Urease test	Catalase test	Citrate test	Oxidase test	Indole test	Probable organisms
A		-	+	+	+	+	*Pseudomonas aeruginosa*
B		+	+	+	+	+	*Klebsiella* spp.
C		+	+	+	-	-	*Proteus* spp.
D		-	+	+	-	-	*Enterobacter* spp.
E		-	+	+	-	-	*Salmonella* spp.
F		-	+	-	-	-	*Shigella* spp.
G	+	+	+	-	+	+	*Bacillus subtilis*

Legend: + - Positive, - = Negative

Table 5: Frequency of the occurrence of bacterial species in both sachet and bottled water

Bacterial Isolates	Frequency (%)	
	Sachet	Bottled
Pseudomonas aeruginosa	8 (25.8)	0 (0)
Klebsiella spp.	10 (32.3)	7 (17.1)
Proteus spp.	0 (0)	9 (21.9)
Enterobacter spp.	4 (12.9)	6 (14.6)
Salmonella spp.	3 (9.6)	5 (12.2)
Shigella spp.	6 (19.4)	0 (0)
Bacilus subtilis	0 (0)	9 (21.9)
Total	31 (100)	41 (100)

RESULTS AND DISCUSSION

The results on the physicochemical properties of sachet and bottled water samples sold in Ilorin is presented in Table 1. Sachet water had a slightly higher temperature (26.6°C) compared to bottled water (23.9°C), although both values were within the WHO's recommended range of 25-30°C. Reports have shown that higher temperatures above the recommended range could significantly alter water composition and potentially introduce toxic substances from the packaged materials (Ahmed *et al*., 2021; Dewangana *et al.*, 2023).

Sachet water exhibited higher electrical conductivity (EC) and total dissolved solids (TDS) values, measuring 142.0 μs/cm and 68.5 mg/L, respectively, compared to bottled water, which recorded 111.0 µs/cm and 58.0 mg/L. Both water types remained within the WHO's acceptable limits of 1000 µs/cm for EC and 300 mg/L for TDS, indicating suitable mineral content. EC and TDS are essential parameters for evaluating potable water quality (Kur *et al*., 2019). EC reflects a liquid's capacity to conduct an electric charge, affected by the concentration of dissolved ions, ionic strength, and temperature. Higher EC values are directly linked to increased levels of dissolved ions, minerals, salts, and potential impurities in water (Kur *et al*., 2019). A previous study by Joshua *et al*. (2019) reported elevated EC values in sachet water from the Sabon Gari Local Government Area in Kaduna State, ranging from 131.5 to 210.5 µs/cm.

TDS quantifies the number of ions in water, including substances like organic matter, calcium, sodium, nitrates, and carbonates. Water with TDS concentrations below 1000 mg/litre is generally considered acceptable, though this can vary by circumstance. High TDS levels can lead to taste issues and excessive scaling in water pipes, heaters, boilers, and appliances. Conversely, low TDS concentrations may be considered unacceptable due to a flat taste and potential corrosiveness to water supply systems. A study by Devesa *et al* (2018) examined the effects of TDS levels on the sensory perception of water, including taste and consumer preferences. The study concluded that significant changes in TDS (>150 mg/L) are required for most consumers to notice a difference in taste and that higher TDS levels tend to decrease consumer liking due to changes in water taste and texture.

The pH values for both types of water were neutral and within the WHO permissible range of 6.5 to 8.5 for drinking water, with values ranging from 6.7 to 7.9. This indicates conditions ranging from slightly acidic to slightly alkaline, suitable for consumption. Similarly, Sule et al. (2017) reported pH values between 6.5 and 8.0 in sachet water sold in the Ilorin metropolis, reflecting compliance with international standards.

Salinity levels were minimal, with sachet water recording 0.05 ± 0.05 mg/L, while bottled water had salinity levels below detection limits. Both values are significantly lower than the WHO threshold of 1000 mg/L, indicating minimal risk of salinity-related health issues (Rosinger *et al*. 2021). Low salinity in drinking water not only enhances taste but also reduces the risk of scaling in pipes and appliances. This aligns with the findings by Opafola *et al*. (2020), who also observed minimal salinity in packaged water across several urban areas in Southwestern Nigeria.

The bacteriological analysis results, summarized in Table 2, revealed that sachet water had a higher microbial load than bottled water. The total heterotrophic bacterial count (THBC) in sachet water was 52.5 CFU/100 mL, compared to 35.0 CFU/100 mL in bottled water, with both values falling within the WHO guideline of ≤100 CFU/100 mL. However, the total coliform count (TCC) was significantly higher in sachet water (51.5 CFU/100 mL) than in bottled water (33.5 CFU/100 mL), both exceeding the WHO limit of 0.0 CFU/100 mL, indicating potential contamination risks. No total faecal coliforms (TFC) were detected in either sample, meeting the WHO's stringent standard for faecal contamination.

These findings are consistent with studies like Okoye *et al*. (2022), which reported higher microbial loads in sachet and bottled water in Southeast Nigeria due to insufficient quality control. Similarly, Akpen *et al*. (2018) and Opafola *et al*. (2020) documented coliform contamination in packaged water from various regions, attributing it to lapses during production or post-production handling. Such contamination raises critical concerns about the effectiveness of water treatment processes and highlights the need for stricter regulatory oversight and improved hygiene practices throughout the supply chain.

A total of seven bacterial genera identified in the water samples were *Pseudomonas aeruginosa*, *Klebsiella* spp., *Proteus* spp., *Enterobacter* spp., *Salmonella* spp., *Shigella* spp., and *Bacillus subtilis* (Table 3). The isolated bacteria exhibited diverse biochemical characteristics. *Pseudomonas aeruginosa* showed positive reactions for catalase, citrate, oxidase, and indole tests, reflecting its metabolic versatility. Other isolates, such as *Klebsiella* spp., *Proteus* spp., *Enterobacter* spp., *Salmonella* spp., *Shigella* and *Bacillus subtilis* had variable biochemical profiles, highlighting their adaptability. All the isolates were negative for Gram reaction (87.5 %), except *Bacillus subtilis*, which is the only Gram-positive isolate (12.5 %) and was detected only in bottled water. These findings align with Abdulsalam and Sule (2020), who reported the dominance of Gram-negative bacteria in water samples.

The frequency distribution of bacterial species revealed higher contamination in bottled water (41 isolates) than in sachet water (31 isolates). *Klebsiella* spp. was the most frequently occurring isolate in both water types (32.3% in sachet and 17.1% in bottled water). *Pseudomonas aeruginosa* and *Shigella* spp. were detected only in sachet water, while *Bacillus subtilis* and *Proteus* spp. were exclusive to bottled water (Table 4). These differences reflect variations in microbial contamination sources and handling practices for the two water types. This study indicated varying degrees of microbiological contamination, suggesting that some sachet and bottled water samples were not of optimal microbiological quality.

CONCLUSION

This study assessed the physicochemical and bacteriological qualities of sachet and bottled water available in Ilorin. Both types were within the WHO guidelines for key physicochemical parameters (temperature, electrical conductivity, total dissolved solids, pH, and salinity). However, sachet water showed slightly higher levels of electrical conductivity, total dissolved solids, and temperature compared to bottled water, indicating a greater concentration of dissolved ions and minerals. While these values remained within acceptable limits, ongoing monitoring is crucial for long-term compliance.

Bacteriological analysis revealed significant contamination in both sachet and bottled water, with total coliform counts exceeding WHO standards. Seven genera of bacteria were identified, primarily Gram-negative. The presence of potentially pathogenic bacteria, such as *Pseudomonas aeruginosa*, *Salmonella spp.*, and *Shigella spp*., raises public health concerns and highlights deficiencies in water treatment and handling practices.

These findings emphasize the necessity for stricter quality control measures and regulatory enforcement in the production and distribution of packaged water. Continuous monitoring and enhanced hygiene practices are recommended to safeguard the safety and quality of drinking water for consumers.

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