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PHYSICO-CHEMICAL ANALYSIS AND ANTIBIOTIC SUSCEPTIBILITY PROFILE OF GRAM-NEGATIVE BACTERIA ISOLATED FROM STORAGE TANKS WATER IN A TERTIARY INSTITUTION IN NIGERIA

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ABSTRACT

The physicochemical parameters and antibiotic susceptibility profile of Gram-negative bacteria in storage tanks water samples were studied. The pH was measured with pH meter and Temperature using mercury-in-glass thermometer. The measurements of Conductivity and Total Dissolved Solid (TDS) in water samples were done using a Bantec-510 Electrical Conductivity meter, Biological Oxygen Demand (BOD_5) and Dissolved Oxygen (DO) were tested using DO meter. Alkalinity and Acidity were measured using titrimetric method. Gram-negative bacteria were isolated by spread plate method and identified by cultural, morphological and biochemical characterization. Susceptibility of isolates to antibiotics was determined using Kirby-Bauer disc diffusion technique. Temperature of the water samples ranged from 24.0 - 27.5^{O}C with an average value of 27.7^{O}C. The pH value ranged between 5.7 and 9.4. Conductivity values ranged between 20.2 and 39.2 µS/cm respectively. DO values ranged from 0.8 to 1.9 mg/mL across the water samples. The BOD and TDS values ranged from 0.2 - 0.4 mg/mL and 18.3 – 30.2 mg/mL, respectively. Six (6) Gram negative bacteria were recovered and identified from the water samples. The frequency and percentage occurrence of the bacteria include *Enterobacter intermedius* {2(33%)}, *Salmonella bongori* {1(16.67%)}, *Klebsiella pneumoniae* {1(16.67%)}, *Citrobacter diversus* {1(16.67%)}, and *Klebsiella* sp. {1(16.67%)}. Antibiotic susceptibility greatly varied among the bacterial isolates as all displayed total sensitivity to ceftriaxone and ciprofloxacin, but were resistant to chloramphenicol. All the bacteria were sensitive to cefuroxime and cefotaxime except *Klebsiella* species. The isolates showed varying resistance against meropenem and ceftazidime. Five (83.33%) of the bacteria were multiple antibiotic-resistant types with multiple antibiotic resistance index (MARI) values greater than 0.2. and exhibited various MAR patterns. In conclusion, some of the physicochemical parameters analyzed fall within the permissible limit recommended for drinking water. However, the presence of multiple antibiotic resistant Gram negative - bacteria in the water samples analyzed may constitute health hazards in humans.

Keywords: Drinking water, Physico-chemical parameters, Gram negative bacteria, Storage tanks, Antibiotics resistance.

INTRODUCTION

Water is a vital resource and fundamental necessity for all individuals, often used for domestic purposes such as drinking, bathing and food preparation (Fahes *et al.,* 2025). Consumption of contaminated water can negatively affect human health (Nawaz *et al.,* 2023). Furthermore, poor environmental hygiene can lead to gastrointestinal infections, inhibiting nutrient absorption and malnutrition, significantly affecting children and vulnerable individuals (Rodriguez *et al.,* 2011; Mshida *et al.,* 2018). Having access to safe and adequate water makes it easier to practice hygiene, which is essential for preventing acute respiratory infections, diarrheal illnesses, and many other neglected tropical diseases (WHO, 2023). Sixty percent of people in poor countries lack access to safe drinking water. It has also been reported by the World Health Organization (WHO) in 2020 that about 25% of the people lacked safely managed drinking water in their homes (WHO 2021). Sources, distribution, transit, and, depending on the circumstances, handling in home or commercial settings are some of the ways that water can get contaminated (Manga *et al.*, 2021). Increased availability to safe drinking water would surely have a major positive influence on human health because drinking water contaminated with microorganisms, particularly those from excrement, poses a considerable risk to human health (Luvhimbi, 2022). In addition, Most of the microbes that grow in drinking water require essential physicochemical conditions such as temperature, dissolved oxygen and other organic matter that aids their growth under a favorable environmental condition. Physico-chemical parameters play a major ecological role in nature; they are essential element for microbes'

growth. Therefore, Water quality is a complex subject, which determines the quality of water and comprises of physical, chemical, hydrological and biological characteristics of water (Adesakin *et al.*, 2022).

Reports have shown that water-borne infections emanating from the consumption of contaminated water are common in developing countries. Most of the water-borne diseases in human beings are caused by unhygienic water supplies used for drinking purposes that cause infections like dysentery, diarrhoea, cholera, typhoid, etc (Atobatele and Owoseni, 2023). It has been reported that about 20% of the world's population experiences scarcity of safe drinking water, and over 5 million people die every year from illnesses associated with drinking water due to inadequate sanitation (Karnwal *et al.*, 2017). Gram negative bacteria are known to be a prominent cause of water-borne diseases in humans. Pathogens such as *Salmonella, Escherichia, Shigella, Vibrio* and *Campylobacter* have been identified in poorly treated water. Interestingly, some opportunistic pathogens including *Aeromonas, Pseudomonas* and coliforms are also present in water (Borchardt *et al.*, 2003). Antibiotic resistance threatens global health, food security, and development; cutting across anyone, age, and country. Some diseases including water-borne illnesses such as typhoid fever and cholera may be difficult to treat due to antibiotic resistance (WHO, 2018).

The study investigates the physico-chemical and Gram-negative bacterial qualities of storage tanks water in a tertiary institution, and determines the antibiotic susceptibility of the bacterial isolates.

MATERIALS AND METHODS

Study Area

The study was conducted at the Anchor University, Lagos, a rapidly expanding university with more than 2000 residents, situated in Ayobo community in the Alimosho Local Government Area on the outskirts of Lagos, Nigeria, with coordinates of 6°36'38 N; 3°17'45 E. According to the 2006 population census, Alimosho is the most populous LGA in Lagos State, with 1,319,571 residents (NBS, 2012), while Ayobo is primarily a residential neighborhood. Lagos State is a coastal region that borders the Atlantic Ocean and is one of the 36 states in the nation. The state contains 787 km^2 of inland water and 3,577 km^2 of land. Despite having one of the highest densities of people in Nigeria, Lagos is the state with the smallest land area (Mogaji, 2020).

Sample collection

Sample collection was done at the Anchor University, Lagos, between March and April, 2024. Water samples were taken from six distinct storage tanks using 50 cl sterile polythene stoppered bottles. The samples were immediately transported to the Microbiology Unit laboratory of the Biological Sciences Department for physico-chemical and bacteriological analyses. Bacteriological analyses of the water samples were performed following standard procedures.

Physico-chemical analysis of water samples

The Physicochemical parameters of water quality were analyzed according to APHA (2014).
A mercury-in-glass thermometer was used to measure the Temperature, and a water quality tester model (EZ-9909SP) was used to assess the Conductivity and Total Dissolved Solids (TDS). A dissolve oxygen meter (a water quality tester) was used to assess the Dissolved Oxygen (DO), and a Biochemical Oxygen Demand (BOD_5) analysis was performed on the fifth day after the water had been incubated for five days. The titration method was used to measure acidity and alkalinity, whereas the pH meter was used to measure pH.

Isolation and Characterization

Isolation of bacteria was carried out using spread plate method. Less than one milliliter (0.1 mL) of serial diluted water sample was spread on cooled MacConkey agar plates, incubated at 37^{O}C for 24 hours. Pure culture of isolates was obtained by subculturing on fresh Nutrient agar plates incubated at 37^{O}C for 24 hours. The isolates were stored on nutrient agar slants at 4^{O}C. Preliminary identification of Gram-negative bacterial isolates was by cultural, morphological and physiological characterization by observing certain characteristics such as colour, consistency, elevation, Gram's reactions, shape, size etc. (Olutiola *et al.*, 2000). Further identification of isolates was carried out by biochemical

characterization using various biochemical tests with reference to the Bergey's Manual of Determinative Bacteriology (Holt *et al.*, 1994).

Gram's Staining

The procedure outlined by Cheesbrough (2006) was followed while performing the Gram staining method. In short, a tiny colony was selected using a wire loop that had been disinfected, spread out on a sanitized glass slide, and then heated gently to fix it. After a minute of applying the crystal violet solution, the slide was rinsed under running water, and then our mordant (iodine) was added. Finally, it was gently washed under running water. After 10 seconds of washing with acetone alcohol as the decolorizer, safranin was applied, and the counterstain was left to stain for a minute. After being cleaned with running water and allowed to air dry, the slides were inspected using a 100x objective microscope.

Triple Sugar Iron (TSI) Test

Based on their physiological capacity to metabolize lactose and/or sucrose, Gram negative enteric bacteria were subjected to the triple sugar iron (TSI) test. Appropriate quantity of TSI agar was measured, dissolved in water, homogenized, dispensed into test tubes and autoclaved. The sterile medium was removed, allowed to cool and solidify as a slant with a deep butt surface. Sterile inoculating wire was gently used to inoculate a pure 24 hours old bacterial colony into the slant, and also streaked on the surface. The tubes were incubated at 37^{O}C for 24 - 48 h. The medium was examined for colour change in case of sugar fermentation, and H_2S production by the test bacterial isolates after 48 h.

Oxidase Test

Filter paper was moistened with a few drops of 1% tetramethyl-phenylenediaminene-dihydrochloride. With the aid of a sterile wire loop, an inoculum was taken from the culture and smeared on a filter paper. Oxidase production was indicated by the development of a purple colour within 5 to 10 seconds. No development of purple colour indicated a negative (Olutiola *et al.,* 2000).

Citrate Test

A loopful of 24 hours old culture of the inoculum was streaked on the entire slant of the Citrate agar plate, incubated at 37°C for 24 hours. A positive citrate test result was indicated by growth on the medium and a color change from green to blue in the Citrate agar while a negative citrate test result was indicated by no growth on the medium or growth with no color change (the medium remained green).

Catalase Test

The catalase test is used to determine the production of catalase, an enzyme that breaks down hydrogen peroxide (H_2O_2) to release oxygen and water. The catalase reaction is evident by the rapid formation of bubbles. A drop of 3% H_2O_2 was made on a microscopic glass slide after which a sterile inoculating loop was used to pick a pure bacterial colony and smeared in the H_2O_2 on the slide, evolution of the oxygen bubbles was observed. No bubbles formation indicated a negative result.

Indole test

Sterile Peptone water (British Drug House Ltd, Poole England) was inoculated with a loopful of broth culture of the organism and incubated at 37^{O}C for 48 hours. Production of indole was determined by adding 0.5 mL Kovac's reagent, the tubes were shaken and allowed to stand. Positive result was indicated by the formation of a red surface layer of the medium, while orange-yellow colour indicated a negative test for indole (Olutiola *et al.,* 2000).

Methyl Red and Voges Proskauer Test

Appropriately labelled tubes containing sterile MR-VP broths (British Drug House Ltd, Poole England), were aseptically inoculated with a loopful of 24 hours old culture of the inoculum, incubated for 48 hours at 37^{O}C. The MR-VP of each tube was divided into 2 in fresh clean test tubes and labelled MR and VP. To the test tubes labelled MR, was added methyl red, red colour change indicated positive reaction while yellow colour change depicted negative reaction. To the test tube labelled VP, 0.5 ml of 6% α-naphthol solution and 0.5 ml of 16% potassium hydroxide (KOH) were added, and the tubes were vigorously agitated then left for 5 min to check for its reaction. Red colouration indicated positive reaction i.e. acetoin production and negative reaction is depicted by no colour change (Olutiola

et al., 2000).

Antimicrobial Susceptibility Test.
The Kirby-Bauer disk diffusion method was used to determine the antibiotic susceptibility of the isolates on Mueller-Hinton plate agar plate, using Gram negative multiple disc (BIOMARK Laboratories, code number BDR009) containing various concentrations of antibiotics namely Gentamicin (GEN) 10 µg, Cefuroxime (CRX) 30 µg, Chloramphenicol (CHL)10 µg, Ceftriaxone (CTR) 30 µg, Cefotaxime (CTX)30 µg, Ciprofloxacin (CIP)5µg, Amikacin (AMK) 30 µg, Vancomycin (VAN) – 30 µg, Ceftazidime (CPZ) – 30 µg, and Meropenem (MEM) - 10 µg. The 0.5 McFarland standardized inoculum (10^8CFU/mL) was seeded onto the sterile Mueller-Hinton agar plates. The antibiotic disc was firmly placed on the plates using a sterile forcep and allowed to stay on the workbench for 30 minutes to allow for proper diffusion of the antibiotics. The plates were incubated at 37^{O}C for 24 hours. The diameter of zone of inhibition was measured with a transparent ruler in milliliter and interpreted as susceptible (S), Intermediate (I), and Resistance (R) according to the Clinical Laboratory and Standard Institute (2018). Multiple antibiotic resistance was determined using the multiple antibiotic resistance (MAR) index formular.

Multiple Antibiotic Resistance (MAR) Index Calculation
Multiple antibiotic resistance (MAR) index was calculated and interpreted.

$$MAR\ Index = {}^{a}/_{b}$$

Where a = the number of antibiotics to which an isolate is resistant

b = the total number of antibiotics to which the isolate is exposed/tested

RESULTS
Table 1 shows the mean physico-chemical values of the water samples. Temperature ranged from 24.0 - 27.5^{O}C, with an average value of 27.7^{O}C. The pH value ranged between 5.7 and 9. 4, while DO values ranged from 0.8 - 1.9 mg/mL across the water samples. The BOD and TDS values ranged from 0.2 - 0.4 mg/mL and 18.3 – 30.2 mg/mL, respectively.

Table 1: Mean Physico-chemical values of water samples

Water sample	**BH**	**GH1**	**GH2**	**CF**	**SP**
pH	8.7±0.5	5.7±1.2	7.6±0.4	9.4±0.2	6.5±1.6
Conductivity (µS/cm)	29.1±1.2	39.2±3.5	22.2±2.1	39.2±0.3	20.2±2.8
Temperature (°C)	28.0±2.4	29.0±1.5	28.5±3.2	28.0±0.5	27.0±3.3
TDS (mg/L)	25.4±0.3	28.0±.0.9	18.0±2.8	30.2±0.6	18.3±0.2
Acidity (mg/L)	6.5±1.2	6.0±0.2	5.6±1,6	7.0±2.8	6.0±1.2
Dissolved Oxygen (mg/L)	0.8±0.5	1.6±0.3	2.0±0.8	0.8±1.9	1.6±0.8
BOD (mg/L)	0.2±0.01	0.2±0.1	0.2±0.1	0.3±1.1	0.4±0.2
Alkalinity (mg/L)	7.3±1.4	7.0±0.2	7.2±1.3	7.4±1.4	7.0±1.7

KEY: BH – Boys' hostel, GH1 – Girls' hostel 1, GH2 – Girls' hostel 2, CF - Cafeteria, SP - Sport Centre.

Table 2 shows the biochemical characteristics of the identified bacteria. Six (6) Gram negative bacteria were recovered and identified from the water samples. The frequency and percentage occurrence of the bacteria include *Enterobacter intermedius* {2 (33%)}, *Salmonella bongori* {1(16.67%)}, *Klebsiella pneumoniae* {1(16.67%)}, *Citrobacter diversus* {1(16.67%)}, and *Klebsiella* sp. {1(16.67%)}.

Table 2. Biochemical characteristics of the bacterial isolates from Storage tanks water samples.

							TSI			
GR	**CIT**	**CAT**	**IND**	**OXI**	**MR**	**VP**	**Slant/Butt**	**Gas**	**H2S**	**Probable bacteria**
-	+	+	-	+	+	+	Y/Y	+	-	*Enterobacter intermedius*
-	+	+	-	+	+	+	R/Y	+	+	*Salmonella bongori*
-	+	-	-	+	+	-	Y/Y	+	-	*Klebsiella pneumoniae*
-	+	+	+	+	+	+	Y/Y	+	-	*Citrobacter diversus*
-	+	+	+	-	+	+	Y/Y	+	-	*Klebsiella* sp.
-	+	+	-	+	+	+	Y/Y	+	-	*Enterobacter intermedius*

Key: GR: Gram's reaction, VP: Voges Proskauer, MR: Methyl Red, Y= Yellow (acid production), R: Red (no acid production)

Tables 3 shows the antibiotic susceptibility profile of the bacterial isolates from the water samples. Antibiotic susceptibility greatly varied among the bacterial isolates as all displayed total sensitivity to ceftriaxone and ciprofloxacin, but were resistant to chloramphenicol. All the bacteria were sensitive to cefuroxime and cefotaxime except *Klebsiella* species.

Table 3. Antibiotic Susceptibility Profile of the Bacterial Isolates form storage tanks water samples.

	GEN	MEM	VAN	CRX	CTR	AMK	CPZ	CHL	CTX	CIP
Enterobacter intermedius	R	R	R	S	S	R	R	R	S	S
Klebsiella sp.	R	R	R	R	S	R	R	R	R	S
Salmonella bongori	R	S	S	S	S	S	S	R	S	S
Enterobacter intermedius	R	S	R	S	S	R	S	R	S	S
Klebsiella pneumoniae	R	R	S	S	S	R	R	R	S	S
Citrobacter diversus	S	R	R	S	S	R	S	R	S	S

Gentamicin (GEN) 10 µg, Cefuroxime (CRX) 30 µg, Chloramphenicol (CHL)10 µg, Ceftriaxone (CTR) 30 µg, Cefotaxime (CTX)30 µg, Ciprofloxacin (CIP)5µg, Amikacin (AMK) 30 µg, Vancomycin (VAN) – 30 µg, Ceftazidime (CPZ) – 30 µg, and Meropenem (MEM) - 10 µg.

Table 4 displayed the percentage antibiotic resistance of the bacterial isolates. All the bacterial isolates were 100% resistant to chloramphenicol. Similarly, all isolate showed resistance to gentamycin and amikacin, except *Citrobacter diversus* and *Salmonella bongori,* respectively. Varying resistance was recorded against meropenem and ceftazidime by the isolates.

Table 4. Frequency (%) of Antibiotic Resistance of the Bacterial Isolates from storage tanks water samples

	GEN	MEM	VAN	CRX	CTR	AMK	CPZ	CHL	CTX	CIP
Enterobacter intermedius (2)	100	50	100	0	0	100	50	100	0	0
Klebsiella sp. (1)	100	100	100	100	0	100	100	100	100	0
Salmonella bongori (1)	100	0	0	0	0	0	0	100	0	0
Klebsiella pneumoniae (1)	100	100	0	0	0	100	100	100	0	0
Citrobacter diversus (1)	0	100	100	0	0	100	0	100	0	0

Gentamicin (GEN) 10 µg, Cefuroxime (CRX) 30 µg, Chloramphenicol (CHL)10 µg, Ceftriaxone (CTR) 30 µg, Cefotaxime (CTX)30 µg, Ciprofloxacin (CIP)5µg, Amikacin (AMK) 30 µg, Vancomycin (VAN) – 30 µg, Ceftazidime (CPZ) – 30 µg, and Meropenem (MEM) - 10 µg.

Table 5 shows the multiple antibiotic resistance patterns of the bacterial isolates from the storage tanks water samples. . Five (83.33%) of all the bacteria isolates exhibited MAR pattern in this study. Varying multiple antibiotic resistance patterns comprising between four and eight

different antibiotics were displayed. The MARI values of the MAR isolates ranged between 0.4 and 0.8. This observation showed that the bacterial isolates were obtained from an environment with high antibiotics.

Table 5. Multiple Antibiotic Resistance Patterns of the Bacterial Isolates from the storage tanks water samples

S/N	Bacteria	Resistance profile	MARI
1	*Enterobacter intermedius*	GEN, MEM, VAN, AMK, CPZ, CHL	0.6
2	*Enterobacter intermedius*	GEN, VAN, AMK, CHL	0.4
3	*Klebsiella* sp.	GEN, MEM, VAN, CRX, AMK, CPZ, CHL, CTX	0.8
4	*Klebsiella pneumoniae*	GEN, MEM, AMK, CPZ, CHL	0.5
5	*Citrobacter diversus*	MEM, VAN, AMK, CHL	0.4

Gentamicin (GEN) 10 µg, Cefuroxime (CRX) 30 µg, Chloramphenicol (CHL)10 µg, Ceftriaxone (CTR) 30 µg, Cefotaxime (CTX)30 µg, Ciprofloxacin (CIP)5µg, Amikacin (AMK) 30 µg, Vancomycin (VAN) – 30 µg, Ceftazidime (CPZ) – 30 µg, and Meropenem (MEM) - 10 µg.

DISCUSSION

The physico-chemical characteristics showed that the total dissolved solids value in each storage water sample was within the WHO-expected limit of 1000 mg/L. One important determinant of water clarity is total dissolved solids. Dissolved solids will raise the temperature of the water and lower the amounts of dissolved oxygen (DO). The quantity of oxygen needed for the microbial metabolism of organic molecules in water is known as the biological oxygen demand. The biological oxygen requirement in each storage tank was found to be within the WHO standard. The presence of fecal pollution or particulate and dissolved organic carbon from both human and animal sources are determinants of the level of biological oxygen demand. The findings from this study indicated that the average temperature of the storage water tanks in these study areas was 27.7 °C, with a range of 24.0-27.5 °C. The physico-chemical parameters of the study showed that, with the exception of the storage water sample at BH and CF (Boys' hostel and Cafeteria), where the pH values were 8.7 and 9.4, all other samples exhibited pH values within the WHO-expected limit of 8.5. Increased pH in the water samples may be due to the presence of alkaline minerals, microbial activity, algae growth, which may release substances like ammonia or carbonates. According to the findings of the study, the average EC for every location varied between 20.02 and 39.2 µS/cm, which is less than the 300 µS/cm standard drinking water guideline (WHO, 2015). Accordingly, they were all below the threshold of no risk, which is consistent with Omoboye *et al.* (2023). The ability of a solution to conduct electric current is measured by its electrical conductivity (EC) (Aniyikaiye *et al.*, 2019). The conductivity rises with increasing ion concentration because ions in solution carry the electrical current. As a result, it is among the primary criteria used to assess whether water is suitable for firefighting and irrigation.

The isolation of *Enterobacter intermedius*, *Salmonella bongori*, *Klebsiella pneumonia*, *Citrobacter diversus*, and *Klebsiella* species in this study is consistent with the reports from other previous studies. Since groundwater (borehole) is the main source of water for the storage tanks, this can be ascribed to inadequate routine cleaning of the tanks and the fact that the majority of the biota would have entered the water from the environment. Omoboye *et al.* (2023) reported ground water sources around Ayobo, Lagos as reservoir of potential pathogenic microorganisms, which is in tandem with the result of this study. These bacteria are either pathogenic or opportunistic in nature which may pose significant health risks to those consuming water from the storage tanks. Some of these bacteria have been reported in water samples from in previous studies (Akani *et al.,* 2021). Intriguingly, 83.3% of the bacteria isolated in this study had MARI value greater than 0.2, an indication that the bacterial isolates were obtained from an environment with high antibiotic use, as reported by Woh *et al.* (2023).

All the Gram-negative bacterial isolates in this study exhibited 100% resistance to chloramphenicol, as such treatment with this antibiotic may not be successful. About 83% of the Gram-negative bacteria isolated in this study exhibited multi-drug resistance which further raises concern about possible difficulty in treating water-borne illnesses from the consumption of the water investigated in this study. The presence of MAR Gram-negative bacteria in groundwater (well water) has been reported by Atobatele and Owoseni (2023) and Omoboye *et al.* (2023). Numerous investigations have demonstrated the significance of environmental conditions (such as soil or water) on the natural cycle of antibiotic, either because environmental bacteria can produce antibiotic resistance mechanisms or because pathogens and commensals from humans and animals can contaminate the environment (Ouyan *et al.*, 2024; Liu *et al.*, 2024; Can *et al.,* 2024). Hospital effluents, urban sewage, livestock farm wastewater, and agricultural wastewater all contain antibiotics at sub-inhibitory quantities in the environment, which promotes the selection of resistant strains. This could lead to the dissemination of antibiotic resistance genes among pathogenic microorganisms.

Furthermore, multiple antibiotics resistant bacteria have been discovered in drinking water, groundwater, and surface water across several nations (Hafiane *et al.*, 2024). There is unmistakable proof that the presence of MAR bacteria in water samples increases the difficulty of treating illnesses caused by the pathogenic bacteria (Sharma *et al.*, 2024; Saibu *et al.*, 2024).

CONCLUSION

Human consumption water is expected to be free of objectionable physical, chemical, and microbial contaminants. Some of the physicochemical parameters of the water samples analyzed in the study fall within the permissible level recommended for drinking water. However, the presence of multiple antibiotic resistant Gram-negative bacteria in the water samples analyzed may constitute health hazards in humans.

RECOMMENDATION

Due to the occurrence of MAR Gram-negative bacteria in the water samples investigated, regular cleaning and disinfection of storage tanks, boiling of water before use, continuous monitoring and avoiding contamination of water are recommended.

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CONFLICT OF INTERESTS

The authors declare that there are no conflicts of interest related to this article.

AUTHORS' CONTRIBUTIONS

Faith Nwamah and Helen Omoboye collected and analyzed water samples. Helen Y. Omoboye supervised the research work and wrote the manuscript.

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