Research Article

Domestic Water Accessibility, Physicochemical, Heavy Metal and Bacteriological Water Quality of Well Water in Enugu Metropolis

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Abstract

Evaluating the quality of domestic water is essential in ensuring public health and safety. This study assessed the availability of domestic water sources within Enugu metropolis and examined the physicochemical, heavy metal, and bacteriological quality of well water in comparison with water quality standards. Following standard procedures, well water samples were collected randomly, six from each of the three local government areas in Enugu metropolis, giving a total of eighteen samples. Physicochemical parameters (pH, temperature, conductivity, and total dissolved solids) were determined using appropriate meters, heavy metals were assessed using atomic absorption spectroscopy, and bacteriological quality and *Vibrio* presence were estimated using the standard plate count technique. Results indicate that many households in Enugu depended on untreated well water for their domestic needs. The pH of the water samples ranged from 5.90-7.10, temperature 25.5-26.8 °C, conductivity and total dissolved solids 35.50-436.00 mg/l, and 23.44-282.95 mg/l, respectively. Iron had the highest detection rate, and its values ranged between 1.09 and 2.58 mg/l, whereas arsenic was not detected at all. *E. coli* and total coliform counts were in the range of 4.0×10^0 cfu/ml to 1.7×10^1 cfu/ml, and 1.2×10^1 cfu/ml to 2.0 10^1 cfu/ml; while *Vibrio* counts ranged, 0×10^0 to 5×10^0 cfu/ml. All the assessed parameters had values within the standard permissible limit, except for pH, iron and bacterial counts. Well water in Enugu metropolis is not suitable for domestic use without treatment that improves the bacteriological quality. We recommend point-of-use water disinfection techniques such as solar pasteurization and the use of chlorine.

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1. INTRODUCTION

Water quality remains a global concern and a contemporary issue of discussion. The availability of sustainable, safe water directly or indirectly affects all the United Nations Sustainable Development Goals (UN-SDGs). However, exponential population growth, industrialization and climate change are adversely affecting the already scarce water sources [1]. According to the joint monitoring progress on household drinking water, sanitation and hygiene, 2.2 billion people worldwide still lack safely managed drinking water [2], including 115 million people who still depend on collecting surface water for drinking and other domestic uses [2]. In many sub-Saharan African countries, including Nigeria, many households obtain domestic water from surface water (streams, rivers, lakes, and canals), groundwater (hand-dug wells and boreholes), springs, or roof-harvested rainwater [3]. Unfortunately, these water sources are usually susceptible to faecal contamination from human and animal origins, requiring water quality assessment.

The quality of water is assessed by determining the physicochemical and microbiological properties of the water and comparing results with water quality standards [4-6]. Water that does not meet the stipulated permissible limits is declared as unsafe and not suitable for human use without treatment. The use of unsafe water puts human life at risk. It is a huge challenge to mankind and constitutes one of the greatest risks to public health and well-being. Unsafe water constitutes a 'one health' problem, affecting man, animals, and the environment. Unsafe water is more prominent in developing countries where there is poor management of solid and liquid waste from sewage, municipal and household sources, hospitals, industries, and agriculture and livestock. Waste from these anthropogenic sources may render water sources microbiologically contaminated and chemically polluted. On the other hand, safe drinking water is essential for sustainable health and wellbeing, for socioeconomic growth and sustainable development. It is necessary for all domestic activities, including drinking, food processing and food preparation, bathing, washing, cleaning, irrigation and livestock farming. As such, the UN-SDG 6 seeks to ensure safe drinking water for all by 2030. Further, the World Health Organization declares access to safe drinking water fundamental to public health, poverty reduction, environmental safety, and socio-economic development https://www.who.int/health-topics/water-sanitation-and-hygiene-wash#tab=tab_1

In Nigeria, particularly in Enugu State, access to municipal water supply is limited. Although the government (both state and federal) has made huge efforts to provide safe (potable) water to its citizens, access to pipe-borne water continues to be scarce and unreachable to the common masses [6], causing people to rely on unimproved and untreated water sources to meet their domestic water needs. The consequences are dire, as waterborne infections/diseases remain a recurring issue.

In a retrospective study conducted in Enugu [7], the incidence of waterborne diseases increased progressively, with typhoid fever and diarrhoea being the most prevalent. In another study involving the assessment of stool samples collected from households, 85.4% of stool from healthy individuals contained at least one waterborne pathogen [3]. According to reports from the Nigeria Centre for Disease Control, within the first eight months of 2021, about 31,000 suspected cholera cases, including 311 confirmed cases and 800 deaths, were reported from 22 states in Nigeria, including Enugu State https://ncdc.gov.ng/news/337/cholera-in-nigeria%3A-urgent-call-to-strengthen-water%2C-sanitation-and-hygiene-%28wash%29. In our recent work, waterborne pathogen Vibrio cholerae was molecularly identified from Asata River water samples, and quantitative microbial risk assessment recorded more than 0.5% risk of cholera infection for those who depended on the untreated water [8]. Nevertheless, continuous water quality surveillance is paramount to ensuring water safety and mitigating the incidences of waterborne diseases. This study aims to provide information on the water accessibility, physicochemical, and bacteriological quality of well water sourced for domestic uses in Enugu metropolis. Further discussing the suitability of the water for safe human use based on water quality standards.

2. METHODOLOGY

Description of the study area and sampling sites

Enugu metropolis is the capital city of Enugu State, Nigeria. It consists of three local government areas (LGAs): Enugu-East, Enugu-North, and Enugu-South. The various residential areas that make up Enugu urban include Coal Camp, Uwani, Asata, Independence Layout, New Heaven, Emene, GRA, Abakpa, and Trans-Ekulu. The residential areas can be categorized into urban, suburban, and urban slums. Enugu has a population of about 816,000 persons and is located on longitude 7º30'53.5"E-7º34'40.54" E and latitude 6º24'14.62"N-6º24'26.94" N, and at an altitude of 152 meters above sea level [9]. Enugu urban has a tropical wet climate, with a mean temperature of 27 °C and rainfall of about 1500mm – 2100mm. Rainy seasons span from March to October [9, 10], as affirmed by the meteorological data of over 96 years, indicating that intense rainfall starts sometime in March and ceases in October.

Study design

This study incorporated a survey design using a well-structured questionnaire titled "Assessment of domestic water availability and use within Enugu metropolis". The questionnaire was administered via Google Forms and was used to gather information on the availability of domestic water used by households within Enugu metropolis. It captured data on the main and alternative sources of water available to households, the purpose(s) the source water serves, and household water treatment options available.

Water sample collection

Water samples were collected based on standard practice, aseptically from domestic water sources using 500 mL sterile glass bottles. Water sample collection was stratified to cover the three LGAs within Enugu urban. In all, a total of 18 well water samples were randomly collected, six each from Enugu-North, Enugu-South, and Enugu-North. The collected well water samples were placed in an insulated box with frozen refrigerant packs while being transported to the laboratory for analysis. All samples were analyzed within 6 hours of sample collection.

Sample processing and water quality analysis

Determination of physicochemical parameters of the water samples

Selected physicochemical parameters (pH, temperature, conductivity (EC), total dissolved solids (TDS) of the water samples were determined according to standard methods [11] using the appropriate meters/standard instruments. The hydrogen ion concentration, pH was determined using the pHep® pocket-sized pH meter (HANNA HI–98107, USA) previously calibrated with buffer solution. Temperature was measured using mercury-in-glass environmental thermometer in °C, and conductivity measured with the DiST Conductivity/TDS meter (HANNA HI – 98107, USA) calibrated with potassium chloride.

Determination of heavy metal concentration in the water sample

The determination of heavy metals: copper (Cu), iron (Fe), cadmium (Cd), chromium (Cr), lead (Pb), manganese (Mn), and arsenic (Ar) was done using atomic absorption spectrophotometry (Buck Scientific 210 AAS) according to standard methods [11]. One hundred millilitres (100 ml) of each water sample were digested by adding 3 ml of nitric acid. The mixture was allowed to stand for 30 minutes at 30 °C. The resulting solution was filtered with Whatman filter paper, and the filtrate was analysed in the AAS, and readings were taken and recorded.

Determination of bacteriological indicators of water quality

The bacteriological quality of the water samples was determined using standard quantitative microbiological procedures and on an appropriate bacteriological agar plate medium. Briefly, following tenfold serial dilution of the water sample, 1 ml of the chosen dilution was placed on a sterile petri dish containing solidified agar media and spread. Chromocult Coliform Agar (CCA) (Merck, Germany) was used for the detection and enumeration of E. coli and total coliform [9]. The CCA, with its combination of two chromogenic substances, can specifically and simultaneously detect E. coli and other coliforms on the basis of specific colony colors [12]. The inoculated plates were incubated at 35 ºC for 24 hours. All samples were analyzed in triplicate. After 24 hours of incubation, colonies on plates were counted and recorded as cfu/ml. Typical colonies appearing blue to violet were counted and recorded as E. coli, while colonies appearing salmon (pink) to red were recorded as other coliforms. The total coliform counts comprise the sum of all blue to violet (E. coli) and salmon to red (other coliforms) colonies [12].

Detection and quantification of presumptive Vibrio in the water samples.

The detection and quantification of Vibrio colonies were carried out following the standard microbiological streak plate technique. To enhance the growth of presumptive Vibrio colonies, a modified sample enrichment procedure [13] was employed. Briefly, water samples measuring 2 ml were inoculated into 2 ml of sterile alkaline peptone water (APW, Merck-KGaA, Germany) in test tubes and incubated for 6-8 hours. Thereafter, using the spread plate method, 1 ml of the enriched culture was inoculated onto TCBS agar medium (Oxoid, UK) and incubated for 24 hours at 35 °C. After incubation, developed colonies were counted and recorded.

Identification of bacterial species

The target bacteria isolates were isolated from the selective media: CCA and TCBS agar medium, respectively and subcultured on a general-purpose media (nutrient agar). Pure colonies were further characterized and identified using cultural morphology, gram staining and microscopy and biochemical as described previously [14]. The biochemical tests include oxidase, catalase, indole, motility, Voges-Proskauer, methyl red and sugar fermentation.

Statistical analysis

All statistical analysis was performed using SPSS version 20 software. Descriptive statistics (mean, standard deviation) were used to present the results of triplicate experiments of physicochemical and bacteriological counts and mean results compared with set standard values. Charts were plotted using Microsoft Excel 2019 software.

3. RESULTS

The physicochemical and bacteriological parameters of well water used for domestic purposes in Enugu metropolis were studied to ascertain the water quality status and suitability in ensuring public health and safety. Mean values of water quality indicators were evaluated and compared with recommended standards for drinking water.

Survey investigation

The results on the main domestic water sources available to households in Enugu metropolis are presented in Figure 1. The result indicates that 30.4% of Enugu residents rely on protected hand-dug wells and tanker-truck providers, respectively, for their daily water needs. Dependence on unprotected/tube-fetched (15.2%) and state-provided pipe-borne water (10.9%) follows closely. The result in Figure 2 indicates that the water sources were used mainly for cooking/food preparation (82.6%) and other household activities, including drinking (39.1%). Further, 67.4% of households in Enugu metropolis use the domestic water supply without any form of treatment (Figure 3). Meanwhile, 19.6% treat the water before drinking (Figure 3).

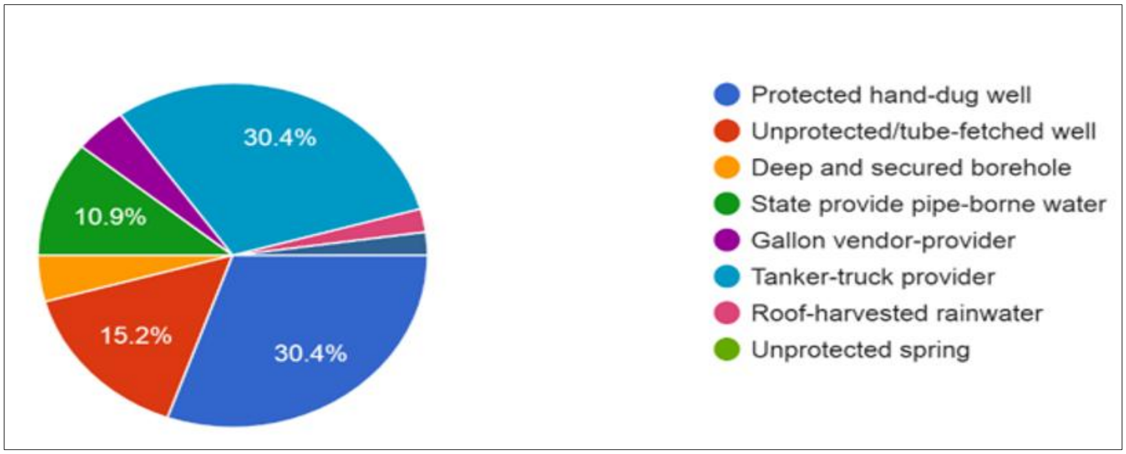

Figure 1: Main sources of domestic water available in Enugu metropolis

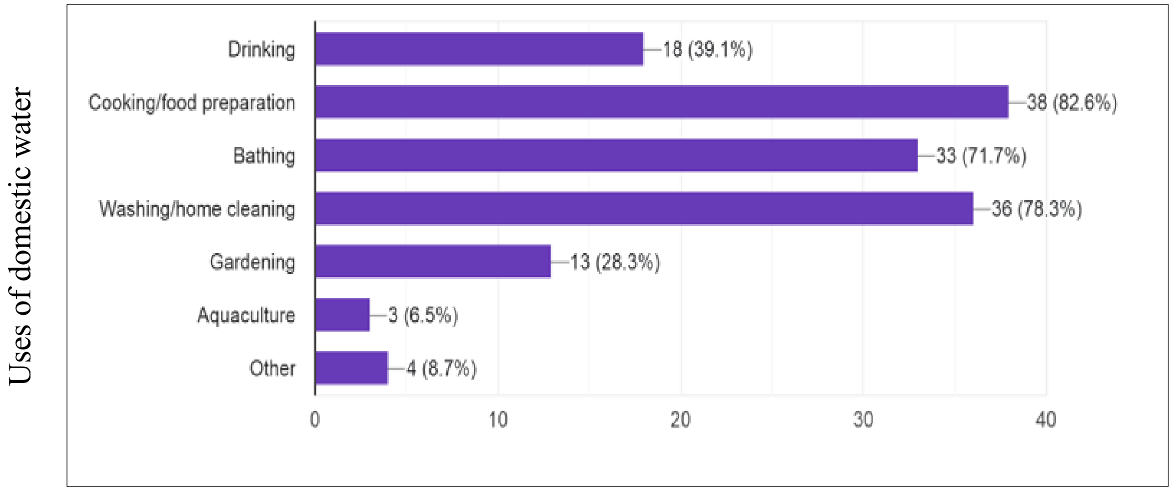

Figure 2: Major uses of domestic water in Enugu metropolis

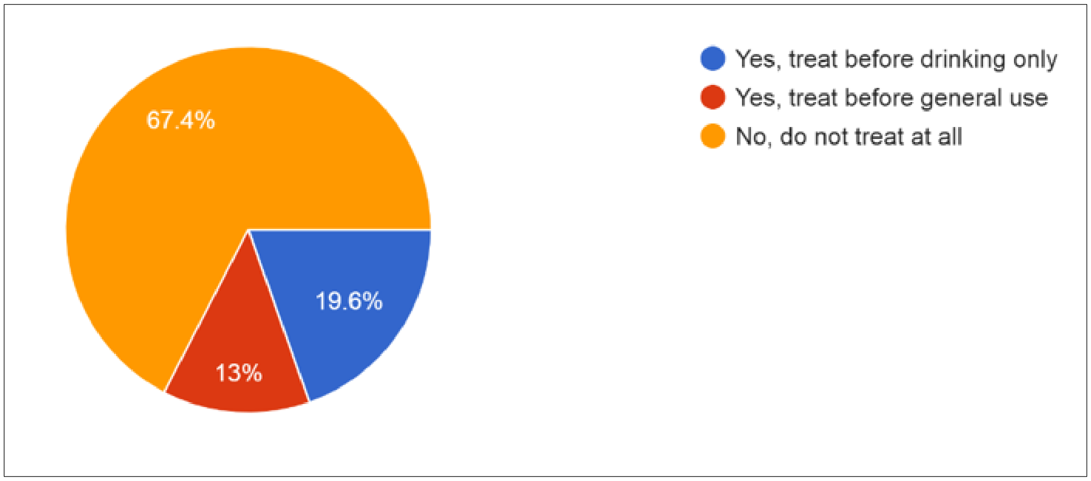

Figure 3: Application of water treatment to domestic water.

Physiochemical and bacteriological water quality indicators
Physiochemical and bacteriological water quality indicators

The results of physicochemical water quality indicators show that the water temperature maintained the ambient temperature range, 25-27 °C. (Figure 2). The pH of the water samples in this study was slightly acidic and ranged from 5.9 to 7.1. Conductivity and TDS presented a similar trend (Figure 4). Their values varied greatly between samples, but none of the values were above 500 mg/L and 300 mg/L, respectively (Figure 4). Heavy metals were detected in the water samples in minute quantities. In all the water samples, iron was the most prevalent and ranged from 1.09 to 2.59 mg/l followed by manganese (0.02 to 0.12). Lead and chromium were detected in traceable limits in many of the water samples. However, arsenic was not detected in any of the water samples (Figure 5). Counts of *E. coli* and total coliform were detected and recorded in all the water samples, but *Vibrio* species were detected sparingly (Figure 6). The *E. coli* counts ranged from 4.0×10^{0} cfu/ml to 1.7×10^{1} cfu/ml while total coliform counts ranged from 1.2×10^{1} cfu/ml to 2.0 10^{1} cfu/ml. Regarding counts of *Vibrio* species, it ranged from 0×10^{0} to 5×10^{0} cfu/ml (Figure 6).

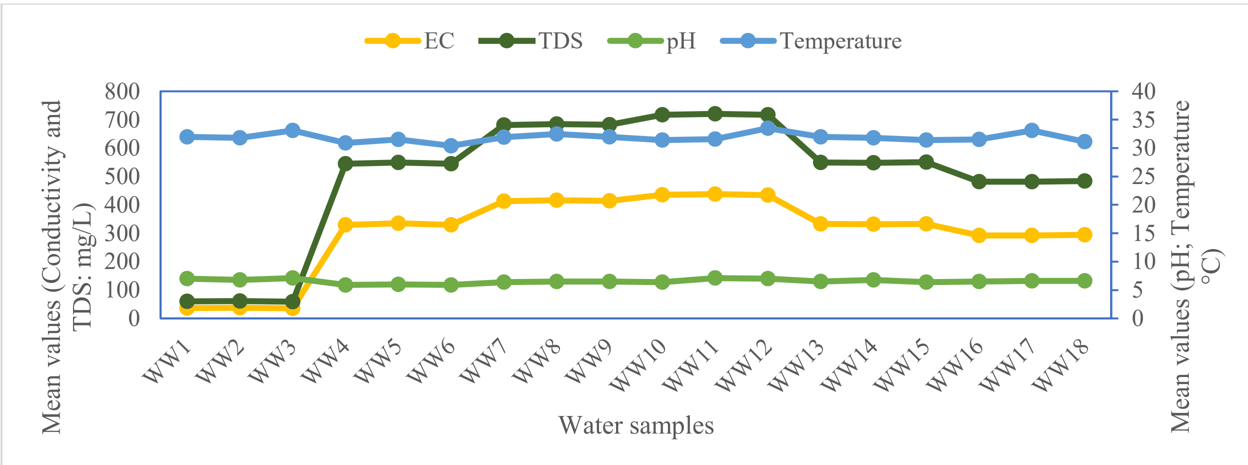

Figure 4: Physicochemical water quality indicator of domestic well water in Enugu metropolis

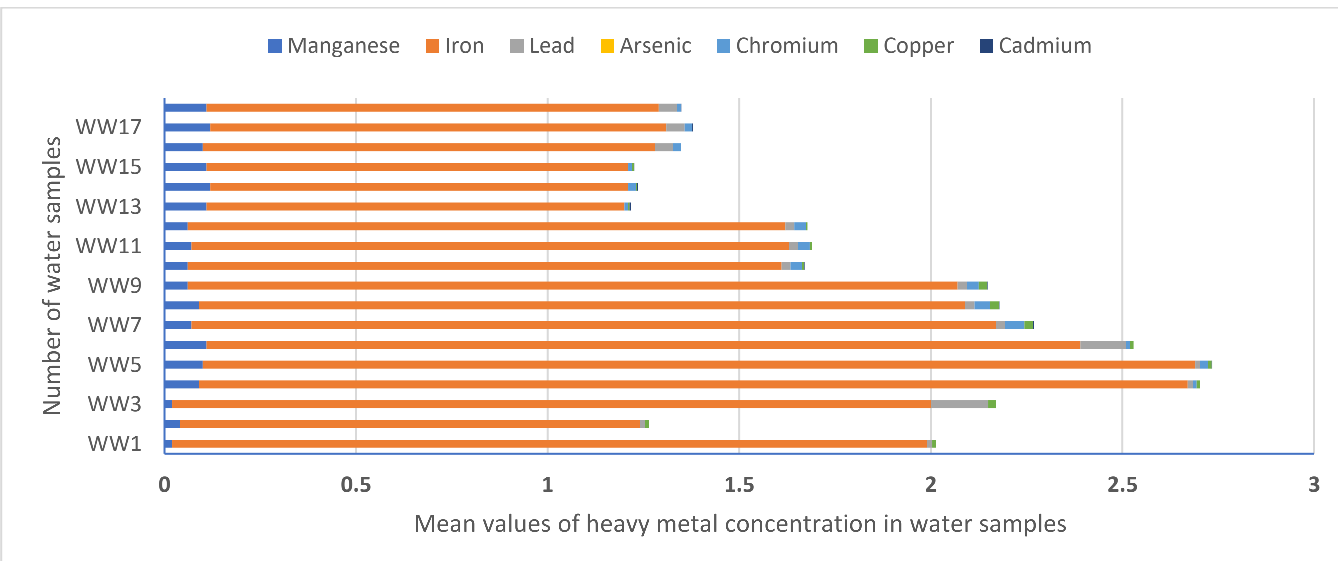

Figure 5: Heavy metal content of domestic well water in Enugu metropolis

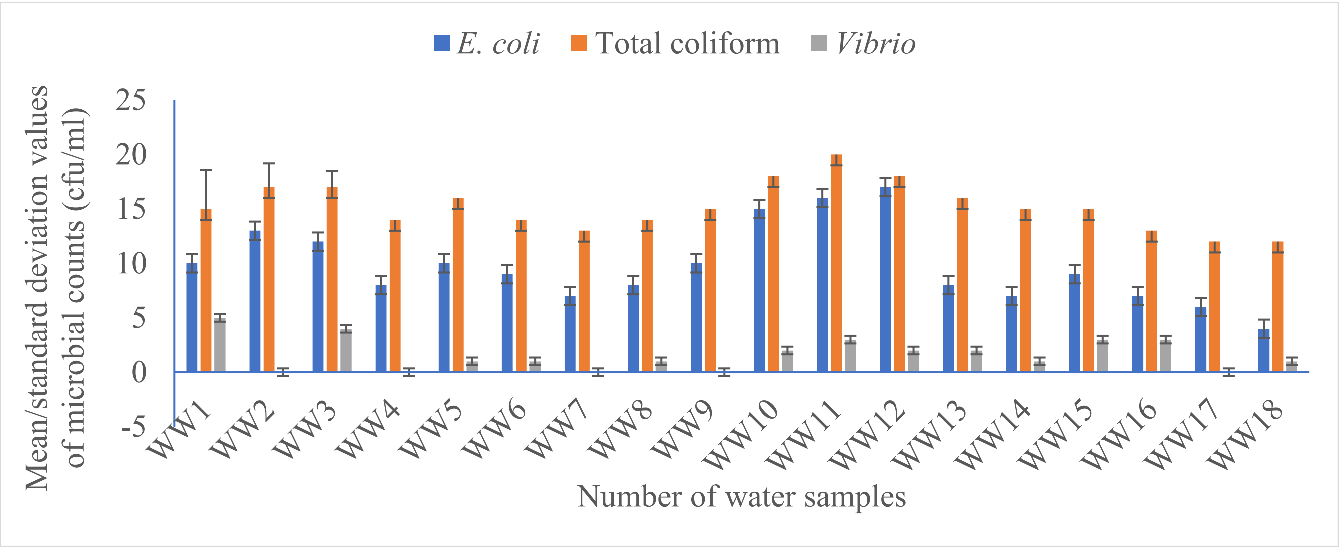

Figure 6: Bacterial counts in domestic well water in Enugu metropolis

Table 1 presents the results of bacterial identification using cultural morphology, gram staining and microscopy and biochemical tests. The isolates were identified as *E. coli* and *Vibrio cholerae*, respectively. oxidase, catalase, indole, motility, Voges-Proskauer, methyl red and sugar fermentation.

Table 1: Bacterial species identified in domestic well water in Enugu metropolis

Growth on selective media	Growth on nutrient agar	Gram reaction and microscopy	Motility	Catalase	Oxidase	Indole	Methyl red	VP	Glucose fermentation	Possible *Vibrio* species
Dark blue to violet colony on CCA	Small circular pinkish colony.	Gram -ive short rods in singles.	+	+	-	-	+	_	+/Gas	*E. coli*
2-3 mm raised yellow colony on TCBS	Large raised yellow colony.	Gram -ive comma/curved shape.	+	-	+	+	+	_	+/Gas	*V. cholerae*

[**CCA: Chromocult coliform agar;** +: positive reaction; -: negative reaction; Gas: gas production]

Comparative estimation of domestic well water for suitability to drinking water standards.

Overall mean values of domestic well water in Enugu metropolis were evaluated and compared with the stipulated value for drinking water as stated in the Nigerian standard for drinking water and the WHO guideline for drinking water quality (Table 2). Results indicate that all physicochemical parameters were within the stipulated standard values except for pH, which was slightly acidic (Table 2). Also, apart from iron, all the heavy metals assessed in this study were below the standard maximum permissible limit. On the other hand, the bacteria species assessed in this study were detected at a count not suitable for safe drinking water (Table 2).

Table 2: Water quality indicators of domestic well water in Enugu metropolis in comparison with water quality standard

Parameters (unit)	Overall Water samples (N = 18)		Water quality standards	
	Range (Min-Max)	Mean ± SD	SON (2015)	WHO (2017)
pH	5.9 – 7.1	6.5 ± 0.4	6. 5 – 8.5	6.5 – 8.5
Temperature (°C)	24.5 – 26.5	25.3 ± 0.6	Ambient	Ambient
Conductivity (µS/cm)	35.5 – 438.0	307.3 ± 134.6	1000	1000
Total dissolve solids (mg/L)	23.4 – 283.0	199.3 ± 87.3	500	500
Manganese (mg/L)	0.000 – 0.021	0.007 ± 0.007	0.2	0.2

Iron (mg/L)	1.09 – 2.59	1.68 ± 0.52	0.3	0.3
Lead (mg/L)	0.00 – 0.15	0.03 ± 0.03	0.01	0.01
Arsenic (mg/L)	0.00 – 0.00	0.00 ± 0.00	0.01	0.01
Chromium (mg/L)	0.00 – 0.05	0.02 ± 0.01	0.05	0.05
Copper (mg/L)	0.000 – 0.023	0.009 ± 0.007	1.0	1.0
Cadmium (mg/L)	0.000 – 0.003	0.001 ± 0.001	0.003	0.003
E. coli count (cfu/ml)	4.0×10^0 - 1.7×10^1	$9.8 \times 10^0 \pm 3.5 \times 10^0$	Zero	Zero
Total coliform count (cfu/ml)	1.2×10^1 - 2.0×10^1	$1.5 \times 10^1 \pm 2.2 \times 10^0$	10 (equivalent 1.0×10^0)	Zero
Vibrio count (cfu/ml)	0.0×10^0 - 5.0×10^0	$1.6 \times 10^0 \pm 1.5 \times 10^0$	Zero	Zero

4. DISCUSSION

Adequate access to safe drinking water is a fundamental human right. It is vital for sustainable human health and wellbeing [5]. While safe drinking water is regarded as water that is free of indicator bacteria and priority chemicals, domestic water is described as water that is available to households and is used for drinking, cooking, bathing, washing, food processing, livestock watering and others [2]. Our study shows that only 11% of households in Enugu metropolis have access to pipe-borne water, which, of course, is the most reliable, treated and safe water source for household use. This finding portrays an unfortunate situation that is not peculiar to only residents of Enugu metropolis. In Nigeria, the government (both federal and state) is responsible for providing potable water to the citizens and has made huge efforts; yet, access to pipe-borne water continues to be scarce and unreachable to the common masses [6].

The limited access to pipe-borne water has caused many households to rely on other sources of water to meet their domestic water needs. The nearest alternative, as shown in our study, is groundwater resources, which are achieved mainly through hand-dug facilities. The majority of households in Enugu metropolis depend on well water (either a protected hand-dug well (30.4%) or an unprotected/tube-fetched well (15.2%). The finding seems similar to the findings from other states of the federation. For instance, statistics show that 75% of urban and 45% of rural dwellers depend on groundwater resources for their domestic water needs [10]. Tanker-truck-provided water recorded the second major source of domestic water in Enugu metropolis after well water. From interviews and observations, many tanker-truck providers source the “supply water” from deep groundwater facilities (boreholes) or from surface waters within the state. These water sources are used by households for various purposes, including drinking (39%) and food preparation (83%). Although hand-dug groundwater and tanker-truck-provided water are reported to be prone to chemical and faecal pollution [10, 15, 16], many households (67%) still use the water without any form of treatment. The consequences can be dire, as many illnesses and deaths are attributed to the use of unsafe water [17].

In this study, the conductivity, total dissolved solids, and temperature of all domestic well waters assessed were within the limits stipulated for safe drinking water. This is not surprising, as many studies have shown that physicochemical parameters of water within Enugu metropolis are usually within compliant limits [9, 15, 18]. The assessed physicochemical parameters have no direct health risk consequences, but they are important operational water quality parameters, and when detected above the stipulated limits, may affect the acceptability of drinking water [4, 5]. Water with TDS values above 1000 mg/L becomes unpalatable and offensive to consumers because it causes scaling in pipes, boilers/heaters, and other household appliances [5]. Our findings, which showed a similar trend between conductivity and total dissolved solids, are in concordance with the already established relationship between conductivity and TDS [5]. As recorded in similar other studies [16], the higher the TDS, the higher the conductivity. This is so because conductivity is a function of dissolved salts and ions in water samples [19]. Although pH values found in water do not cause health risks, alkaline pH above 8.0 causes problems during water treatment [5]. In our study, pH values were slightly acidic, and most were within the permissible limits. This finding is encouraging as the water can be treated with utmost satisfaction, producing the required free residual chlorine. Iron and manganese were the most detected heavy metals in our study, with iron having values above the permissible limit. Our finding agrees with the findings of [18], who reported iron values in groundwater to be above the WHO acceptable standard. The reason could be as a result of the abundant nature of iron in the Earth’s crust and indiscriminate disposal of condemned iron substances into the environment. In the same light, manganese is found in abundance in the Earth’s crust [5]. This could explain the seemingly perceptible levels of manganese in this study. Both metals (iron and manganese) do not have adverse health consequences; rather, they are essential elements required by humans and animals [5].

Bacteriological quality of water has always been a major cause of concern worldwide. According to standards for drinking water, indicator bacteria (*E. coli* and faecal coliforms) should not be present in the domestic water supply. In our study, counts of *E. coli* were recorded in all the water samples. This is an indication of recent faecal contamination and a possibility that pathogens may be present in the water samples [20]. The detection of *Vibrio* species in our study concords with the statement that *E. coli* detection in water means a possibility of pathogen presence. *Vibrio* species are pathogens that cause varying severity of infections when consumed via drinking water [8]. *Vibrio* infections range from asymptomatic infection to self-limiting gastroenteritis to disease outbreaks involving hundreds to thousands of people, as is the case.

The mean count value of *E. coli* detected in this study is 1.7×10^1 cfu/ml. This count is high when compared with the "zero count" required by the standards for drinking water. The unhygienic use of "well buckets" could be responsible for the introduction or reintroduction of faecal contaminants into the wells, and as such, may have accounted for the high *E. coli* counts recorded. Comparable counts of *E. coli* in well water have been recorded in several recent studies in Nigeria [16, 21]. and other African countries [19]. In addition, these findings explain the burden of diarrhoea and other waterborne diseases in Nigeria and the Enugu metropolis [7, 22]. According to [23], inadequate access to potable water supply coupled with poor access to water, sanitation, and hygiene (WASH) contributes to 88% of Nigeria's disease burden. Over the years, thousands of lives have been lost to waterborne diseases, including diarrhoea, cholera, dysentery, typhoid fever, hepatitis A, and even polio. This tragic loss is attributed to the lack of a municipal water supply, which has resulted in a reliance on untreated and unimproved water sources [17].

Nevertheless, water samples in our study had acceptable values of physicochemical water quality parameters that boost effective water treatment. Although the bacteriological quality of the water was unacceptable, bacterial contaminants can easily be eliminated and the water made potable by simple household water treatment methods [24]. So, with appropriate interventions, households could significantly improve their water quality and reduce the incidence of waterborne diseases. Implementing basic water treatment solutions, such as solar pasteurization, filtration, and chlorination, could lead to substantial health benefits for the population.

5. CONCLUSION

This study shows the non-availability of potable water in Enugu metropolis and the dependency on groundwater (hand-dug wells) and tanker-truck-provided water. Despite the reliance on these unimproved sources of water, many households use the water for food preparation, washing/home cleaning, bathing, and drinking without any form of treatment. Although the physicochemical properties of the water were within the compliance limit, except for pH and iron in the case of heavy metals, the bacteriological quality is not acceptable. The detection of *E. coli* and *Vibrio* species in the water suggests faecal contamination and pathogen presence, signifying that the water is not suitable for domestic use without treatment for the elimination of bacterial contaminants. By understanding this shortfall in bacteriological quality, we promote the practice of affordable point-of-use household treatment measures such as the use of solar pasteurization, filtration, and chlorination (water guard). Further, we encourage households to mitigate the introduction or reintroduction of contaminants into the well by adopting the pipe and pump method of water abstraction from wells. The government should rise up to the challenges and put in more efforts to reticulate the municipal water supply in the metropolis.

Limitations of the study

The study was conducted during the dry season (December 2024 to February 2025). So, seasonal variations in water quality were not evaluated, and the bacteria detected in the study were not characterized at the genetic level. The study did not screen for the presence of chemical ions such as nitrate, nitrite, sulphate, and others. It focused mainly on the routine operational water quality parameters.

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