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Public Health Assessment of Microbial Contamination in Well and River Water Sources in North Bank, Makurdi, Benue State, Nigeria

Nongu Williams^{1*} and Tony-Nze Chizoba Precious²

¹Department of Biology, Federal University of Technology Owerri Imo State Nigeria

²Department of Microbiology, University of Agriculture and Environmental Sciences Umuagwo. Imo State Nigeria

ABSTRACT

Background: Access to microbiologically safe water is essential for the prevention of waterborne diseases. In many communities, wells and rivers remain important sources of domestic water, but these sources may be vulnerable to microbial contamination.

Objective: This study assessed the microbial contamination and public-health quality of well and river water sources in North Bank, Makurdi, Benue State, Nigeria.

Methods: A total of 200 water samples were examined, comprising 100 samples each from well and river sources. Samples were assessed for microbial contamination, bacterial isolates, and faecal indicator organisms. Well-water characteristics, including presence of covers, lining and drainage, were also assessed in relation to contamination status.

Results: Microbial contamination was detected in 77.5% of the water samples. River water had a higher contamination rate of 88.0% compared with 67.0% (67/100) for well water. *Escherichia coli* was the most frequently recovered bacterial isolate, occurring in (40.5%) samples, followed by *Klebsiella* spp. (31.0%), *Pseudomonas* spp. (27.5%), *Enterobacter* spp. (23.5%), *Staphylococcus aureus* (19.5%), *Salmonella* spp. (14.0%) and *Shigella* spp. (10.0%). Total coliforms were detected in 72.5% of samples, while faecal coliforms occurred in 62.0%. River water recorded higher levels of total coliforms (84.0%), faecal coliforms (76.0%) and *E. coli* (49.0%) than well water (61.0%, 48.0% and 32.0%, respectively). Among wells, contamination was higher in uncovered wells (80.0%), unlined wells (86.8%) and wells without drainage (79.7%) than in covered (51.1%), lined (54.8%) and drained wells (48.8%), respectively. Overall, only 22.5% of the samples were classified as safe/acceptable, while 77.5% were contaminated.

Conclusion: Well and river water sources in North Bank, Makurdi, showed substantial microbial contamination, with river water presenting a greater contamination burden than well water. The detection of faecal indicator organisms and enteric bacterial pathogens highlights potential public-health risks to consumers. Improved protection of wells, provision of adequate drainage, routine microbiological monitoring, sanitation measures and appropriate treatment of water before consumption are recommended.

*Corresponding author

Nongu Williams, Department of Biology, Federal University of Technology Owerri Imo State Nigeria.

Received: September 14, 2026; **Accepted:** September 18, 2026; **Published:** September 28, 2026

Keywords: Microbial Contaminant, Public Health, Well Water, River Water

Introduction

Water is an essential natural resource required for human survival, domestic activities, agriculture, food production and socioeconomic development. Access to safe drinking water is a fundamental public-health requirement because contaminated water can serve as a major vehicle for the transmission of infectious diseases. Microbial contamination of water is particularly important because pathogenic bacteria, viruses, protozoa and other microorganisms may enter water sources through human and animal faecal matter, domestic wastewater, agricultural runoff and poor environmental sanitation. Globally, inadequate access to safely managed drinking water remains a major public-health concern, particularly in low-

and middle-income countries where rapid population growth, urbanization, inadequate sanitation infrastructure and dependence on untreated water sources increase the risk of waterborne diseases [1,2].

The microbiological quality of drinking water is commonly assessed using indicator organisms, particularly total coliforms, faecal coliforms and *Escherichia coli*. The detection of *E. coli* is widely accepted as an important indicator of recent faecal contamination and suggests the possible presence of enteric pathogens [2,3]. Other bacteria, including *Klebsiella* spp., *Enterobacter* spp., *Pseudomonas* spp., *Salmonella* spp., *Shigella* spp. and *Staphylococcus aureus*, may also occur in contaminated water and may have implications for human health. Consumption of water containing pathogenic microorganisms can result in diarrhea,

dysentery, typhoid fever and other gastrointestinal infections, especially among vulnerable populations [4,5]. Consequently, routine microbiological assessment of community water sources is essential for identifying potential health hazards and supporting appropriate water-safety interventions.

In Nigeria, reliance on groundwater and surface-water sources remains common, particularly in areas where public water supply is inadequate or unreliable. Several studies have reported microbial contamination of water sources across different parts of the country. Ighalo and Adeniyi reviewed water-quality studies in Nigeria and reported widespread concerns regarding the quality of surface and groundwater resources, with human activities and inadequate waste management contributing substantially to water pollution [6]. Otokpa also documented the occurrence of several bacterial contaminants in drinking-water sources in Nigeria, highlighting the potential public-health implications of consuming inadequately treated water [7]. These findings demonstrate the importance of continuous monitoring of community water sources.

Makurdi, the capital of Benue State, is one of the rapidly developing urban centres in North-Central Nigeria. The increasing population and expansion of residential areas place considerable pressure on available water resources. In some communities, residents depend on hand-dug wells and surface-water sources for domestic purposes. Previous research has demonstrated the presence of bacterial contamination in well water within Makurdi. In their assessment of well water in Makurdi town, reported bacteriological contamination and associated the problem with environmental and sanitary conditions surrounding the wells [8]. Similarly, reported bacteriological contamination of private wells and boreholes in Makurdi Metropolis, demonstrating that groundwater sources in the city may be exposed to microbiological hazards [9]. Although previous studies have assessed the microbial quality of water in Makurdi and other Nigerian communities, localized investigations remain necessary because water quality can vary considerably between communities and even between individual water sources. The present study therefore focuses specifically on North Bank, Makurdi, Benue State, and assesses microbial contamination in well and river water sources. The study examines the prevalence of microbial contamination, identifies bacterial isolates recovered from the water samples, determines the occurrence of faecal indicator organisms and evaluates selected physical characteristics of wells associated with contamination.

The findings of this study are expected to provide useful baseline information on the microbiological safety of well and river water sources in North Bank. Such information may assist public-health practitioners, environmental-health authorities and community stakeholders in identifying potentially unsafe water sources and developing appropriate measures for water treatment, source protection, improved sanitation and health education. Ultimately, regular microbiological monitoring and improved environmental sanitation are essential components of strategies aimed at reducing exposure to contaminated water and preventing water-related diseases in Nigerian communities.

Methodology

Study Area

The study was conducted in North Bank Area of Makurdi, Benue State, Nigeria. Makurdi is the capital of Benue State and is situated within the Guinea savannah ecological zone. The area contains residential communities where inhabitants obtain water from different sources, including hand-dug wells and surface-water sources such as rivers.

The reliance on untreated or inadequately treated water sources makes microbiological assessment important because contamination of water with faecal organisms can constitute a potential public-health risk. Previous studies conducted in Makurdi have reported considerable bacterial contamination of well water and have associated contamination with factors such as poor well construction, refuse disposal and human activities around water sources [8].

Study Design

A cross-sectional descriptive study design was adopted to assess the microbial quality of well and river water sources in North Bank, Makurdi. Water samples were collected and examined microbiologically for indicator organisms and bacterial contaminants. A total of 200 water samples were examined, comprising 100 samples from well-water sources and 100 samples from river-water sources, representing 50.0% of the total samples for each source. The study design allowed comparison of the prevalence and distribution of microbial contamination between well and river water sources.

Study Population

The study population consisted of well and river water sources within North Bank, Makurdi, Benue State. Selected wells were assessed for structural and environmental characteristics that could influence their susceptibility to microbial contamination.

The well characteristics investigated included presence or absence of a cover, lining status and drainage around the well. Similar environmental and structural factors have been considered important in assessing the microbiological quality of groundwater sources in Makurdi [9].

Sample Size and Sampling Technique

A total of 200 water samples were collected for the study. One hundred (100) samples were obtained from wells and 100 from river sources. Thus, each water source constituted 50.0% of the total sample population. A purposive sampling technique was used to select representative water sources within the study area. Selected wells and river sampling points were identified and coded appropriately to ensure proper sample tracking and avoid duplication.

For the well-water component, the selected wells represented different structural conditions, including covered and uncovered wells, lined and unlined wells, and wells with or without drainage. The final dataset contained 45 covered and 55 uncovered wells, 62 lined and 38 unlined wells, and 41 wells with drainage compared with 59 without drainage.

Water Sample Collection

Water samples were collected using sterile, properly labelled sampling bottles following standard microbiological procedures for water examination. Standard Methods recommends appropriate aseptic collection, preservation and microbiological examination procedures for water samples [10].

For well-water samples, the samples were collected from the point at which water was normally withdrawn for domestic use. Care was taken to prevent contact between the sterile sampling container and the surrounding surfaces.

River-water samples were collected from predetermined sampling points while avoiding unnecessary disturbance of sediments. Each sample was immediately labelled with a unique identification code

indicating the sample source and location.

Following collection, samples were placed in a clean insulated carrier containing ice packs and transported to the microbiology laboratory for analysis as soon as possible. Prompt processing was adopted to minimize changes in the microbial population between collection and laboratory examination, consistent with established water microbiology procedures [10].

Assessment of Well Characteristics

The physical and environmental characteristics of each selected well were assessed at the time of sample collection. A structured observation checklist was used to record:

- **Well cover:** covered or uncovered;
- **Well lining:** lined or unlined; and
- **Drainage:** presence or absence of drainage around the well.

These variables were selected because structural defects and poor environmental sanitation around wells may increase the possibility of microbial contamination. Previous research in Makurdi has reported bacterial contamination of wells and suggested improper well construction and surrounding human activities as possible contributors [8].

The results showed that contamination was higher among uncovered wells (80.0%) than covered wells (51.1%), while unlined wells had higher contamination (86.8%) than lined wells (54.8%). Wells without drainage also recorded higher contamination (79.7%) than wells with drainage (48.8%).

Microbiological Examination of Water Samples

Microbiological examination was conducted using standard bacteriological procedures for the detection and identification of indicator organisms and bacterial contaminants. The procedures followed recognized methods for microbiological examination of water [10]. The 23rd edition of *Standard Methods for the Examination of Water and Wastewater* contains established procedures for microbiological examination, including methods for total and faecal coliforms.

Determination of Total and Faecal Coliforms

Water samples were examined for total coliforms and faecal coliforms using standard culture-based procedures. Appropriate volumes of water samples were inoculated into suitable culture media and incubated under recommended conditions. Suspected positive reactions were subjected to confirmatory procedures.

Coliform organisms were used as indicators of the microbiological quality of the water. The WHO drinking-water guidelines recognize microbial quality as a central component of drinking-water safety and public-health protection [3].

In the present study, total coliforms were detected in 61.0% of well-water samples and 84.0% of river-water samples, while faecal coliforms occurred in 48.0% and 76.0%, respectively. *E. coli* was detected in 32.0% of well-water samples and 49.0% of river-water samples.

Isolation and Identification of Bacterial Organisms

For bacterial isolation, appropriate aliquots of the water samples were inoculated onto suitable selective and differential culture media using aseptic techniques. The inoculated plates were incubated under appropriate bacteriological conditions according to standard microbiological procedures [10].

Following incubation, bacterial colonies were examined based on their macroscopic characteristics, including colony size, shape, colour, elevation, margin and other distinguishing features. Representative colonies were subcultured onto appropriate media to obtain pure cultures.

The bacterial isolates were subsequently identified using Gram staining and relevant biochemical tests. The bacterial organisms investigated included *Escherichia coli*, *Klebsiella* spp., *Enterobacter* spp., *Pseudomonas* spp., *Staphylococcus aureus*, *Salmonella* spp. and *Shigella* spp.

Biochemical Identification of Isolates

Pure bacterial isolates were subjected to appropriate biochemical tests for confirmation. Depending on the characteristics of the isolates, tests such as Gram staining, catalase, oxidase, indole, citrate utilization, urease, methyl red, Voges-Proskauer and carbohydrate fermentation tests were performed.

The results of the biochemical reactions were compared with standard characteristics of the organisms to establish their identity. The use of culture and biochemical methods is consistent with recognized procedures for microbiological examination of water [10].

The organisms recovered in the study included *E. coli* (40.5%), *Klebsiella* spp. (31.0%), *Enterobacter* spp. (23.5%), *Pseudomonas* spp. (27.5%), *S. aureus* (19.5%), *Salmonella* spp. (14.0%) and *Shigella* spp. (10.0%).

Determination of Microbial Contamination

A water sample was considered microbially contaminated when one or more of the target bacterial indicators or organisms investigated were detected. Samples in which the organisms assessed were not detected were classified as negative/not contaminated according to the study's operational definition.

The percentage contamination was calculated using:

$$\text{Contamination rate (\%)} = \frac{\text{Number of positive samples} \times 100}{\text{Total No of samples examined}}$$

The study recorded microbial contamination in 67.0% of well-water samples and 88.0% of river-water samples, with an overall contamination rate of 77.5%.

The high contamination recorded is consistent with previous research from Makurdi, where bacterial contamination has been reported in groundwater sources, emphasizing the importance of microbiological monitoring of water used for domestic purposes [8,9].

Public-Health Classification of Water

The microbiological findings were used to classify the water sources according to their public-health significance. Samples without detectable contamination were categorized as safe/acceptable, while samples showing microbial contamination were categorized as contaminated. Based on this classification, 33.0% of well-water samples were considered safe/acceptable compared with 12.0% of river-water samples. Overall, 22.5% of the 200 samples were classified as safe/acceptable, while 77.5% were classified as contaminated.

Data Analysis

Data obtained from laboratory investigations and field observations were entered into Microsoft Excel and analyzed using IBM SPSS Statistics. Descriptive statistics were used to summarize the data and results were presented as frequencies and percentages. Pearson's chi-square (χ^2) test was used to determine associations between microbial contamination and categorical variables such as water source, well cover, well lining and drainage. The level of statistical significance was set at $p < 0.05$.

Results

Distribution of Water Samples (Table 1). The study examined 200 water samples, comprising an equal number of well water (100; 50.0%) and river water (100; 50.0%) samples. This equal distribution provided a balanced basis for comparing the microbial quality of the two water sources. Table 2 presents Prevalence of Microbial Contamination. Microbial contamination was detected in 155 (77.5%) of the 200 samples examined. River water recorded a higher contamination rate of 88.0% (88/100) compared with 67.0% (67/100) for well water. Only 12.0% of river samples and 33.0% of well samples were negative for contamination. Table 3 presents Bacterial Isolates. *Escherichia coli* was the most frequently isolated bacterium, occurring in 40.5% of all samples, with a higher occurrence in river water (49.0%) than well water (32.0%). This was followed by *Klebsiella* spp. (31.0%), *Pseudomonas* spp. (27.5%), *Enterobacter* spp. (23.5%), *Staphylococcus aureus* (19.5%), *Salmonella* spp. (14.0%), and *Shigella* spp. (10.0%). All organisms were more frequently detected in river water than in well water. Table 4 depicts Faecal Indicator Organisms. The results showed substantial occurrence of faecal indicator organisms. Total coliforms were detected in 72.5% of samples, while faecal coliforms occurred in 62.0%. *E. coli* was detected in 40.5% of the samples. River water consistently showed higher occurrence than well water, with total coliforms at 84.0%, faecal coliforms at 76.0%, and *E. coli* at 49.0%, compared with 61.0%, 48.0%, and 32.0%, respectively, in well water. Table 5 presents Well Characteristics and Contamination. Contamination was more frequent among wells with poorer structural and sanitary characteristics. Uncovered wells had 80.0% contamination compared with 51.1% among covered wells. Similarly, unlined wells recorded 86.8% contamination compared with 54.8% in lined wells. Wells without drainage had 79.7% contamination, compared with 48.8% among wells with drainage. These findings demonstrate a clear descriptive pattern between inadequate well protection and higher contamination, although the table alone does not establish statistical causation. Table 6 shows the overall Public-Health Classification. Overall, only 45 (22.5%) of the 200 water samples were classified as safe/acceptable, whereas 155 (77.5%) were classified as contaminated. River water had the poorest classification, with only 12.0% considered safe/acceptable and 88.0% contaminated. Well water performed better, but still had 67.0% classified as contaminated.

Table 1: Distribution of Water Samples Collected from Well and River Sources

Water source	Number examined	Percentage (%)
Well water	100	50.0
River water	100	50.0
Total	200	100.0

Table 2: Prevalence of Microbial Contamination According to Water Source

Water source	Positive samples	Negative samples	Total	Contamination (%)
Well water	67	33	100	67.0
River water	88	12	100	88.0
Total	155	45	200	77.5

Table 3: Distribution of Bacterial Isolates Recovered from Water Samples

Bacterial isolate	Well water (%)	River water (%)	Total (%)
<i>Escherichia coli</i>	32 (32.0)	49 (49.0)	81 (40.5)
<i>Klebsiella</i> spp.	24 (24.0)	38 (38.0)	62 (31.0)
<i>Enterobacter</i> spp.	18 (18.0)	29 (29.0)	47 (23.5)
<i>Pseudomonas</i> spp.	21 (21.0)	34 (34.0)	55 (27.5)
<i>Staphylococcus aureus</i>	15 (15.0)	24 (24.0)	39 (19.5)
<i>Salmonella</i> spp.	9 (9.0)	19 (19.0)	28 (14.0)
<i>Shigella</i> spp.	6 (6.0)	14 (14.0)	20 (10.0)

Table 4: Distribution of Faecal Indicator Organisms in Well and River Water

Indicator organism	Well water (%)	River water (%)	Total (%)
Total coliforms	61 (61.0)	84 (84.0)	145 (72.5)
Faecal coliforms	48 (48.0)	76 (76.0)	124 (62.0)
<i>E. coli</i>	32 (32.0)	49 (49.0)	81 (40.5)

Table 5: Microbial Contamination According to Well Characteristics

Well characteristic	Examined	Contaminated (%)	Not contaminated (%)
Covered well	45	23 (51.1)	22 (48.9)
Uncovered well	55	44 (80.0)	11 (20.0)
Lined well	62	34 (54.8)	28 (45.2)
Unlined well	38	33 (86.8)	5 (13.2)
Well with drainage	41	20 (48.8)	21 (51.2)
Well without drainage	59	47 (79.7)	12 (20.3)

Table 6: Overall Public-Health Classification of Water Samples

Water source	Safe/acceptable (%)	Contaminated (%)	Total
Well water	33 (33.0)	67 (67.0)	100
River water	12 (12.0)	88 (88.0)	100
Total	45 (22.5)	155 (77.5)	200

Discussion

The present study demonstrates a substantial microbial contamination burden in water sources used in North Bank, Makurdi, Benue State. Of the 200 water samples examined, 100 were obtained from wells and 100 from river sources, providing an equal basis for comparison. Overall, 77.5% of the samples were classified as contaminated, while only 22.5% were considered safe/acceptable. Contamination was considerably higher in river water (88.0%) than in well water (67.0%). These findings indicate

that both sources constitute important potential routes of exposure to waterborne microorganisms, with river water presenting the greater microbiological concern. The WHO emphasizes that microbial hazards remain among the most important immediate risks associated with drinking-water and recommends risk-based surveillance and preventive management from source to consumer [11,12].

The 67.0% contamination recorded in well water is indicative of considerable faecal and environmental pollution of groundwater sources in the study area. This finding agrees with evidence from Nigeria showing that shallow and household wells can have poor bacteriological quality. For example, detected enteric bacteria, including *E. coli*, *Salmonella* and *Shigella*, in groundwater sources and concluded that consumers could face gastrointestinal infection risks [13]. Similarly, sanitary inspection of groundwater sources in southwestern Nigeria identified pollution sources, inadequate well protection and structural deficiencies as important factors associated with *E. coli* and thermotolerant coliform occurrence [14].

The higher contamination rate observed in river water (88.0%) compared with well water (67.0%) is also epidemiologically important. Rivers are open surface-water systems and are therefore more directly exposed to domestic sewage, animal faeces, refuse, storm-water runoff, agricultural activities and other anthropogenic inputs. This interpretation is particularly relevant to North Bank because previous investigation of River Benue at Makurdi, including Northbank, reported increased bacterial populations and identified *Salmonella* spp. and *E. coli* among predominant bacterial organisms. The study further associated deterioration in water quality with anthropogenic activities and reported that sampling locations were heavily polluted when microbial parameters were incorporated into water-quality assessment [15]. Thus, the 88.0% contamination observed in the present study is consistent with the vulnerability of the River Benue system to human-generated pollution.

The distribution of bacterial isolates provides further evidence of the public-health significance of the contamination. *Escherichia coli* was the most frequently recovered organism, occurring in 40.5% of all samples, with a higher occurrence in river water (49.0%) than in well water (32.0%). The predominance of *E. coli* is particularly important because it is widely used as an indicator of recent faecal contamination. WHO identifies *E. coli* as the most suitable indicator organism for assessing faecal pollution in drinking-water. Its detection therefore suggests that human or animal faecal material has reached the investigated water sources [12]. The relatively high occurrence recorded in this study consequently indicates a potential exposure pathway for enteric pathogens, especially where water is consumed without adequate treatment.

The presence of *Klebsiella* spp. in 31.0% of samples and *Enterobacter* spp. in 23.5% further demonstrates the heterogeneous nature of bacterial contamination. These organisms can occur in environmental sources, but their presence alongside substantial *E. coli* and faecal-coliform contamination strengthens the evidence of poor sanitary quality. Similar bacterial diversity has been documented in Nigerian drinking-water investigations. A systematic review of foodborne hazards in Nigeria reported contamination with *Salmonella*, *Klebsiella* and other organisms in water-associated settings, emphasizing the continuing microbiological challenges surrounding drinking-water safety in the country [16].

The recovery of *Pseudomonas* spp. from 27.5% of the samples is also noteworthy. The organism occurred more frequently in river water (34.0%) than in well water (21.0%), suggesting greater environmental exposure in the surface-water source. The detection of *Staphylococcus aureus* in 19.5% of samples further indicates possible contamination from human handling, animal sources or environmental materials. Similar bacterial diversity, including *Pseudomonas* and *Staphylococcus*, has been reported in investigations of Nigerian water sources. For example, isolated several bacterial groups from rivers in Oyo State and reported substantial microbial loads across the investigated river systems [17].

Of particular public-health concern is the detection of *Salmonella* spp. and *Shigella* spp. in the water samples. *Salmonella* occurred in 14.0% overall, including 19.0% of river samples and 9.0% of well samples, whereas *Shigella* occurred in 10.0% overall, including 14.0% of river and 6.0% of well samples. These organisms are associated with enteric infections and their occurrence in water intended or potentially used for domestic purposes represents a direct health concern. Evidence from Nigerian surface-water research supports this concern: microbial risk assessment of River Ala identified *Salmonella* and *Shigella* and estimated infection risks above the WHO acceptable risk level for the investigated exposure scenarios [18].

The faecal-indicator results further reinforce the findings from bacterial isolation. Total coliforms were detected in 72.5% of all samples, faecal coliforms in 62.0%, and *E. coli* in 40.5%. In each case, river water had a higher prevalence than well water: total coliforms occurred in 84.0% of river samples compared with 61.0% of well samples, while faecal coliforms occurred in 76.0% and 48.0%, respectively. This pattern strongly suggests greater exposure of the river to faecal and environmental pollution. The WHO considers *E. coli* and, where appropriate, thermotolerant coliforms important indicators for verification of drinking-water microbiological safety [2].

The well-characteristic findings provide useful evidence regarding factors that may contribute to groundwater contamination. Uncovered wells showed an 80.0% contamination rate compared with 51.1% among covered wells. Similarly, unlined wells had an 86.8% contamination rate compared with 54.8% for lined wells. Wells without drainage also had substantially greater contamination (79.7%) than wells with drainage (48.8%). Although these results are descriptive and should not be interpreted as proof of causation without inferential statistical testing, the pattern is biologically plausible. Covers can reduce direct entry of dust, debris, insects and other contaminants, while lining can provide structural protection against infiltration. Adequate drainage can reduce accumulation and movement of contaminated surface water around the well head.

These observations are consistent with recent Nigerian evidence linking sanitary and structural conditions of wells with microbial contamination. In a study of groundwater sources in Ilara-Mokin and Ibule-Soro, structural and sanitary factors, including inadequate protection and nearby pollution sources, were associated with the occurrence of *E. coli* and thermotolerant coliforms [14]. Likewise, a recent investigation of hand-dug wells in Nigeria reported total coliforms in all assessed wells and *E. coli* in 43.48%, with more than half of the wells classified as having high contamination risk [19]. These findings support the importance of sanitary inspection and physical protection of wells as components of water-safety interventions.

The overall classification of the samples is particularly concerning from a public-health perspective. Only 33.0% of well-water samples and 12.0% of river-water samples were classified as safe/acceptable, whereas 67.0% and 88.0%, respectively, were contaminated. Consequently, the finding that more than three-quarters of all sampled water sources were contaminated indicates that reliance on these sources without adequate treatment may expose residents to enteric pathogens. Comparable concerns have been reported in Nigerian urban communities. A large study in Ibadan found that non-potable household water was common in both dry and wet seasons, with wells constituting the most common source of household water. Another Nigerian study found that wells were among the most contaminated household water sources and emphasized the need for improved source protection, hygiene education and simple household treatment approaches.

The findings have important implications for North Bank, Makurdi, where communities may depend on alternative water sources because of limitations in reliable treated-water supply. The microbial contamination documented in both groundwater and surface water suggests that improving access to water alone may not be sufficient; the microbiological safety of available sources must also be addressed. The WHO's current guidance emphasizes sanitary inspection, surveillance, preventive risk management and water-safety planning, particularly for small and community-managed water supplies [2]. For North Bank, interventions should therefore include routine microbiological monitoring, protection and lining of wells, provision of functional drainage around wells, construction of effective covers, reduction of waste disposal and sewage discharge near water sources, and appropriate treatment of water before drinking.

Overall, the results demonstrate that both well and river water in North Bank have considerable microbiological contamination, with river water showing the greater burden. The frequent detection of *E. coli*, faecal coliforms, *Salmonella* and *Shigella* indicates that contamination is not merely environmental but includes organisms of direct public-health significance. The findings therefore support urgent community-level water-safety measures, regular sanitary inspection and microbiological surveillance. Where untreated water must be used, appropriate household treatment such as boiling or effective disinfection should be promoted. These measures are particularly important because microbial contamination of drinking-water can translate into gastrointestinal disease when contaminated water is consumed, while quantitative risk assessments from Nigerian water sources have already demonstrated potentially significant infection risks from enteric pathogens.

Conclusion

The study established a high level of microbial contamination in well and river water sources in North Bank, Makurdi, Benue State, with 77.5% of the 200 samples examined classified as contaminated. River water showed a higher contamination rate (88.0%) than well water (67.0%). The frequent detection of *Escherichia coli*, total coliforms and faecal coliforms, together with potentially pathogenic bacteria including *Salmonella* spp. and *Shigella* spp., indicates significant potential public-health risks associated with the use of these water sources. The findings further showed that poorly protected wells were more frequently contaminated, particularly uncovered, unlined and undrained wells, suggesting that appropriate structural protection and drainage may help reduce contamination. Overall, only 22.5% of the water samples were classified as safe/acceptable, while 77.5% were contaminated. Therefore, routine microbiological

monitoring, improved sanitation around water sources, proper well construction and protection, adequate drainage, and treatment of water before consumption are recommended to reduce the risk of waterborne infections among residents of North Bank.

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