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Comparative Bacterial Load and Morphological Assessment of Gram-Negative Bacteria in Surface and Groundwater Sources in Patigi, Kwara State, Nigeria

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Abstract

Microbial contamination of drinking-water sources remains a major public health challenge in many low- and middle-income settings, where populations often depend on untreated or minimally treated surface water and groundwater systems. This study compared the bacterial load and morphological characteristics of Gram-negative bacteria recovered from surface water obtained from River Kpata and groundwater obtained from borehole sources in Patigi, Kwara State, Nigeria. Water samples were collected aseptically and analysed using serial dilution and culture on nutrient agar, MacConkey agar, and eosin methylene blue (EMB) agar. Bacterial loads were expressed as colony-forming units per milliliter (CFU/mL), while colony appearance on selective media and Gram staining were used for characterization of isolates. Statistical analysis was performed using Welch's t-test to account for unequal variances between the two sample groups. Results showed a mean bacterial load of 5.05×10^7 CFU/mL in River Kpata and 1.37×10^6 CFU/mL in borehole water. Although the river water exhibited a higher mean load, the difference between the two sources was not statistically significant ($p = 0.3276$), largely because of wide variation within the river samples. MacConkey agar showed both lactose-fermenting and non-lactose-fermenting colonies, while Gram staining confirmed the predominance of Gram-negative rods. The findings indicate that both water sources may be microbiologically compromised and that reliance on physical appearance alone may underestimate health risks. The study underscores the need for regular surveillance of community water sources, improved environmental sanitation around boreholes, and public health education on safe water handling and treatment in Patigi, Kwara State, Nigeria.

Keywords: Water quality, Gram-negative bacteria, bacterial load, microbial contamination, groundwater, public health

Introduction

Access to safe drinking water is a fundamental determinant of public health globally. Water is required not only for hydration but also for food preparation, domestic hygiene, sanitation, and disease prevention. When water sources are contaminated, they become efficient vehicles for the transmission of enteric and environmentally persistent microorganisms. In many developing regions, the burden of unsafe water falls most heavily on households that depend on nearby rivers, wells, and boreholes whose quality is neither routinely monitored nor consistently protected from contamination. Despite improvements in water infrastructure in many countries, microbial contamination continues to pose significant risks in low- and middle-income countries (World Health Organization [WHO], 2022; World Health Organization & UNICEF, 2023).

The microbiological safety of water is especially important because contamination may occur at several stages, including at the point of collection, during transport, during storage, or as a result of poor sanitation practices in the surrounding environment. Surface waters are particularly susceptible to contamination due to direct exposure to environmental pollutants, agricultural runoff, animal activity, indiscriminate waste disposal, open defecation, and other anthropogenic influences. By contrast, groundwater is often perceived as cleaner because subsurface filtration can reduce the burden of particulate matter and some microorganisms. However, groundwater sources are not automatically safe. They may still be compromised through infiltration, poor borehole construction, damaged casings, contaminated catchment zones, and

unhygienic activities around collection points (Bain et al., 2014).

In many communities, the consequences of unsafe water extend beyond acute illness alone. Recurrent exposure to contaminated water can contribute to absenteeism from school and work, increased household spending on treatment, reduced trust in local water infrastructure, and cumulative social burdens on caregivers. Where households must choose between distant safer sources and nearby but questionable water points, convenience frequently shapes behaviour more strongly than laboratory evidence. This makes localized studies especially important, because interventions are more likely to succeed when they are based on familiar sources that residents actually use (Edokpayi et al., 2018; World Health Organization & UNICEF, 2023).

In public health microbiology, Gram-negative bacteria occupy an important position because many of them are associated with faecal contamination, gastrointestinal disease, opportunistic infections, and the deterioration of water quality. Members of the family Enterobacteriaceae, in particular, are widely used as indicators of sanitary quality because their presence in water frequently reflects environmental exposure to human or animal waste (Edberg et al., 2000; Odonkor & Ampofo, 2013). Although indicator organisms do not provide a complete picture of water safety, they remain highly useful in routine surveillance where time, equipment, and financial resources may be limited.

Culture-based methods continue to be valuable in such settings because they provide a practical means of estimating microbial load and differentiating broad groups of organisms on the basis of growth characteristics. Selective and differential media such as MacConkey agar and EMB agar are commonly used in water microbiology to distinguish lactose fermenters from non-lactose fermenters and to support the preliminary recognition of enteric Gram-negative organisms. These approaches remain standard for introductory microbial assessment in resource-limited laboratory settings (Cheesbrough, 2006). While molecular and biochemical methods can generate greater precision, culture-based analysis is still a relevant first step for community-level surveillance and for identifying water sources that require intervention (Adefisoye & Okoh, 2017).

The present study is situated within the context of Patigi, a community in Kwara State, Nigeria, where households may depend on a mixture of surface water and groundwater for everyday use. In such communities, the quality of available water sources has direct implications for household health, educational attendance, productivity, and the broader burden of preventable disease. A comparison between river water and borehole water is important because it helps to clarify whether groundwater sources commonly regarded as safer are in fact substantially better than exposed surface waters under local conditions.

This study therefore aimed to compare the bacterial load and morphological characteristics of Gram-negative bacteria in selected surface and groundwater sources in Patigi, Kwara State, Nigeria. Beyond generating basic microbial counts, the study sought to provide evidence that can support local health awareness, environmental sanitation, and future water quality monitoring. By framing the findings within a public health and community-development perspective, the work also aligns with the wider interdisciplinary concerns of environmental wellbeing, health protection, and local infrastructure management. In addition, the study was intended to provide a baseline that can support later work on seasonal variation, household exposure pathways, and the relationship between community water practices and health outcomes. Such baseline studies are especially valuable in environments where routine institutional water testing is limited, because they supply locally grounded evidence that can inform both research and immediate preventive action.

Materials and Methods

Study Area

The study was conducted in Patigi, Kwara State, Nigeria. Patigi is a riverine and residential environment in which access to water may involve a combination of natural surface sources and constructed groundwater systems. Sampling sites included River Kpata, which served as the surface-water source, and selected borehole sources located within residential areas, which represented groundwater. The choice of these sources was informed by their practical significance to the local population and by the need to compare water bodies that differ in exposure, protection, and likely routes of contamination.

River Kpata is directly exposed to environmental events and human activities occurring within and around its catchment area. Such activities may include washing, bathing, agricultural runoff, refuse disposal, and movement of people and animals near the riverbank. Borehole sources, on the other

hand, are expected to benefit from some degree of natural filtration by soil layers, yet they may still be threatened by poor drainage, surface seepage, inadequate siting relative to contamination sources, and ineffective sanitary protection. The comparison of these two water categories therefore provides a useful framework for examining local assumptions about water safety.

Study Design

The study adopted a comparative laboratory-based design. Surface-water and groundwater samples were evaluated using the same microbiological procedures in order to permit direct comparison of microbial load and colony characteristics. The use of replicate samples allowed for descriptive statistical summary and inferential analysis of differences between the two source categories. The design focused on preliminary bacteriological assessment rather than species-level confirmation and therefore emphasised load estimation and morphological characterization of Gram-negative isolates.

Sample Collection

Water samples were collected aseptically in sterile containers. Care was taken to minimize external contamination during sampling, handling, and transportation to the laboratory. For surface water, sampling was performed in a manner intended to capture representative water from the selected point while avoiding obvious debris that could interfere with plating. For borehole water, collection followed routine hygienic sampling practice, with attention to obtaining water directly from the source into sterile containers.

Multiple replicate samples were analysed per site to allow for robust statistical comparison. Immediately after collection, samples were labelled appropriately according to source and handled in a way that preserved their microbiological integrity before analysis. Because bacterial counts can change when samples are improperly stored, timely processing was considered important to reduce distortion of the observed microbial burden.

The sample collection procedure was designed to preserve comparability between sources. Containers used for sampling were kept sterile until the moment of use, and care was taken to avoid touching the inner surfaces or lids during handling. Samples were labelled immediately in order to maintain source identity throughout the analytical process. These procedural details are important in water microbiology because even small lapses in handling can introduce contaminants that misrepresent the actual microbial status of the source being studied.

The decision to use replicate samples was also important from an interpretive standpoint. Single-sample assessments may be misleading because water contamination is rarely perfectly uniform. Replication improves the descriptive quality of results and allows the analysis to reflect variability within each source category. In the present study, that variability proved especially informative for understanding why the river showed a high mean count alongside a broad spread of values.

Microbiological Analysis

Serial dilutions were prepared for each sample in order to obtain countable plate ranges. Dilution is essential in water microbiology because undiluted samples, particularly those with heavy contamination, may produce confluent growth that prevents reliable enumeration. By distributing organisms across a dilution series, the analyst is able to select plates with clearly separated colonies suitable for counting and subsequent morphological observation.

Aliquots from appropriate dilutions were inoculated onto the following media:

- Nutrient agar (NA)
- MacConkey agar
- Eosin methylene blue (EMB) agar

Nutrient agar served as a general-purpose medium for broad bacterial recovery. MacConkey agar was used to favour the growth of Gram-negative enteric bacteria and to distinguish lactose fermenters from non-lactose fermenters. EMB agar provided additional differential support for recognizing coliform-like colony behaviour and related Gram-negative organisms. Plates were incubated at ambient laboratory temperature for 48–72 hours, after which visible colonies were examined and enumerated.

Enumeration of Bacterial Load

Bacterial counts were calculated using the standard formula:

CFU/mL = (Colony count × Dilution factor) / Volume plated

The resulting values were expressed as colony-forming units per milliliter (CFU/mL). This approach provides an estimate of the viable bacterial population in the tested water sample. Although plate counts do not detect all microorganisms present, they remain

useful for identifying heavily contaminated sources and for comparing relative levels of microbial burden across sampling groups.

Identification of Isolates

Identification in this study was based on preliminary microbiological features rather than definitive species confirmation. Colony morphology was assessed in relation to size, colour, surface appearance, and lactose fermentation characteristics on MacConkey agar. Gram staining was then used to confirm the presence of Gram-negative rods among predominant isolates. This two-step approach allowed the study to focus on the broad occurrence of Gram-negative bacterial contamination without overstating taxonomic precision.

The decision to rely on morphology and staining reflected the practical conditions of many teaching and public health laboratories, where routine surveillance often begins with basic but informative methods. While biochemical profiling and molecular assays would strengthen species identification, the present study aimed primarily to assess whether the sampled water sources showed bacteriological evidence of compromise and whether the organisms recovered were consistent with Gram-negative contamination patterns of public health interest. This approach also reflects the reality of many local laboratories, where low-cost screening methods remain the most feasible first line of investigation. In practice, such methods can help identify when a water source requires urgent attention, further confirmatory testing, or public health intervention, even before a complete taxonomic profile of the isolates is obtained.

Quality Considerations

Standard aseptic precautions were maintained throughout sample handling, dilution, inoculation, incubation, and microscopy. Media selection was aligned with the objective of recovering general bacteria and obtaining preliminary differentiation of Gram-negative isolates. Replicate sampling and uniform treatment of both sample categories were adopted to improve comparability. These measures do not eliminate all sources of laboratory variation, but they help reduce avoidable error and improve confidence in the general pattern of findings.

Statistical Analysis

Data were expressed as mean ± standard deviation (SD). Because of the unequal variances observed between the two groups, Welch's t-test was used to determine the significance of differences between river and borehole water samples. Statistical significance was set at $p < 0.05$. The use of Welch's test was appropriate because it is less sensitive than the classical Student's t-test to unequal group variances and differing sample dispersion, making it suitable for the observed distribution of bacterial loads.

Results

Bacterial Load Comparison

The bacterial loads of the sampled sources are summarized in Table 1. The mean bacterial load for River Kpata was 5.05×10^7 CFU/mL ± 1.11×10^8 CFU/mL, while the borehole water recorded a mean of 1.37×10^6 CFU/mL ± 2.51×10^6 CFU/mL. The minimum and maximum values further demonstrate the broad spread of counts observed within the sample groups, especially for the river samples.

Table 1: Summary of bacterial loads across sampling sites

Source	Min (CFU/mL)	Max (CFU/mL)	Mean ± SD (CFU/mL)
River Kpata	3.56×10^3	2.76×10^8	$5.05 \times 10^7 \pm 1.11 \times 10^8$
Borehole	3.20×10^2	5.80×10^6	$1.37 \times 10^6 \pm 2.51 \times 10^6$

The descriptive pattern indicates that river water carried a substantially higher average microbial burden than borehole water. However, the river data also showed marked variability, suggesting that contamination intensity was not uniform across replicate samples. Borehole water, though generally lower in count, still contained measurable bacterial populations at levels of concern for untreated domestic use (Olasoji et al., 2019; Oloruntoba & Sridhar, 2017).

Welch's t-test revealed that the difference in bacterial load between the river and borehole sources was not statistically significant ($t(5.01) = 1.08$, $p = 0.3276$). This result suggests that, within the limits of the

sampled data, the observed difference in mean counts could not be interpreted as statistically conclusive at the 5% significance level. The large spread in values, particularly among river samples, appears to have reduced the statistical power of the comparison.

Colony Characteristics and Microscopy

On MacConkey agar, both lactose-fermenting (pink) and non-lactose-fermenting (colorless) colonies were observed. The occurrence of these two broad colony types suggests that the sampled waters contained a mixture of Gram-negative organisms with differing metabolic characteristics. Lactose-fermenting colonies are often associated with coliform-like organisms, whereas non-lactose-fermenting colonies may represent other environmental or enteric Gram-negative bacteria of sanitary interest.

Gram staining confirmed that the predominant isolates were Gram-negative rods. This finding supports the interpretation that the sampled water sources contained bacterial populations consistent with the target group of the study. Although species-level identification was beyond the scope of the current work, the combination of colony morphology and Gram reaction provided preliminary evidence of microbiological contamination of potential public health importance.

Visual Representation

The comparison of bacterial loads is presented in Figure 1. The graphical presentation provides a clearer appreciation of the magnitude of difference between surface water and groundwater while also illustrating variation within the data. In practical terms, the figure supports the descriptive conclusion that river samples tended to cluster at higher bacterial loads than borehole samples, even though the statistical test did not show a significant difference at the chosen threshold.

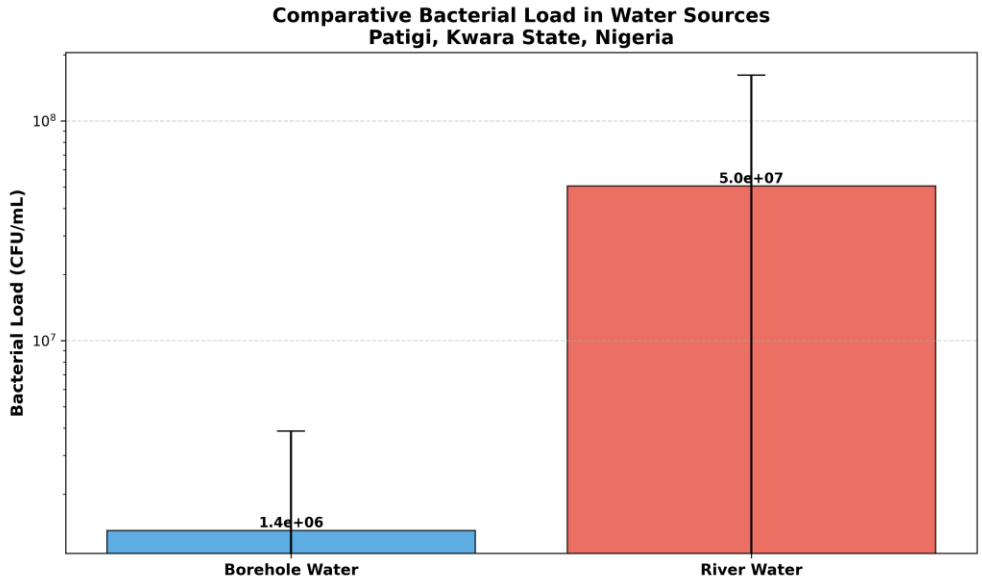


Figure 1: Log-scale comparison of bacterial load across water sources in Patigi.

Discussion

The findings of this study indicate a clear descriptive pattern of greater microbial burden in surface water than in groundwater in Patigi. This outcome is consistent with the environmental realities of exposed water bodies, which are more vulnerable to direct contamination from runoff, organic waste, human activity, and animal contact. Surface water typically reflects the cumulative impact of surrounding land use and sanitation practices. Where environmental protection is weak, river systems may function as recipients of multiple contamination inputs, producing fluctuating microbial loads across time and location. In communities where a river serves several domestic purposes, each contact point can become a route of contamination or recontamination. Consequently, the microbiological quality of surface water often mirrors the broader sanitation condition of

the surrounding environment rather than a single isolated event.

The higher mean bacterial count recorded for River Kpata is therefore unsurprising from a microbiological standpoint. What is particularly important, however, is that borehole water also showed measurable bacterial contamination at levels that should not be ignored. Groundwater is often perceived within communities as inherently safe, but such perceptions may encourage consumption without further treatment. The present findings caution against that assumption. Even if groundwater is comparatively less exposed than river water, poor construction, proximity to contamination sources, seepage pathways, and inadequate sanitary control around boreholes can allow microorganisms to enter systems that users believe are protected.

The lack of statistical significance between the two source categories should be interpreted carefully. It does not mean that the two sources are equivalent in practical terms. Rather, it indicates that within this dataset the difference in mean bacterial load was accompanied by a degree of variability large enough to weaken statistical certainty. In field-based microbiological studies, high variability is common because contamination is affected by numerous local conditions, including recent rainfall, usage patterns, point-source pollution, water turbulence, and sampling position. Consequently, statistical non-significance should not be used to dismiss evident sanitary concerns, especially when absolute bacterial loads remain high.

The observed mixture of lactose-fermenting and non-lactose-fermenting colonies provides further insight into the nature of contamination. Lactose fermentation on MacConkey agar is commonly associated with organisms used as indicators of faecal pollution and sanitary compromise, while non-lactose-fermenting colonies may point to other Gram-negative bacteria that thrive in aquatic or contaminated environments. The coexistence of these colony types suggests a heterogeneous microbial population rather than isolated contamination by a single group. This diversity is important because it implies that both environmental contamination and faecal-associated contamination pathways may be contributing to the microbiological profile of the studied waters.

The predominance of Gram-negative rods after staining reinforces the public health relevance of the results. Gram-negative bacteria are of concern not only because several important enteric pathogens fall within this broad grouping, but also because many opportunistic species can survive in moist environments and persist in poorly managed water systems. In practical public health terms, the recovery of Gram-negative rods from untreated household water sources should prompt caution, especially where water is consumed directly or used with minimal treatment.

The borehole findings deserve particular attention in relation to community behaviour. In many settings, households may reserve river water for washing and other domestic activities while depending on borehole water for drinking. If borehole water is assumed to be safe merely because it is clearer or sourced underground, people may overlook microbiological hazards that are not visible to the naked eye. The present study therefore contributes not only to scientific documentation but also to risk communication. It highlights the difference between apparent cleanliness and microbiological safety.

These findings can also be interpreted in light of broader literature on drinking-water contamination in resource-limited settings. Unsafe water conditions frequently arise from a combination of infrastructure limitations, environmental exposure, weak monitoring systems, and behavioural practices. The World Health Organization has emphasized the persistent health burden linked to contaminated drinking water, particularly in settings where protective infrastructure and surveillance remain inadequate (World Health Organization [WHO], 2022; World Health Organization & UNICEF, 2023). Similarly, evidence from global assessments shows that improved-source classification alone does not guarantee microbiological safety, since groundwater systems may still be affected by faecal contamination and related sanitary failures (Bain et al., 2014; Edokpayi et al., 2018). The current study reflects these broader concerns at the local level in Patigi.

The present work also supports the continuing usefulness of culture-based screening in community water surveillance. Although biochemical and molecular techniques would generate more specific organism identification, culture-based methods remain practical and informative in many institutional and public health laboratories. The ability to quantify viable bacterial load, observe lactose fermentation behaviour, and confirm Gram reaction provides actionable evidence for preliminary decision-making. This is especially important where laboratories must prioritise rapid, affordable methods to screen multiple environmental samples.

From a public health policy perspective, the findings suggest that both source protection and household-level intervention are necessary. For

surface water, strategies may include reducing indiscriminate waste disposal, restricting contaminating activities near collection points, and educating residents about the risks of untreated river water. For borehole systems, attention should be given to siting, drainage, apron design, structural maintenance, and hygiene around fetching areas. At household level, boiling, filtration, chlorination, or other accessible treatment practices can reduce risk where central treatment is unavailable.

An additional implication of the study is the need to view water safety as an interdisciplinary issue. Microbiological contamination is not only a laboratory concern; it is also linked to environmental management, social behaviour, infrastructure quality, public education, and local governance. In this sense, the study speaks to the wider mission of an interdisciplinary journal by showing how a microbiological finding can inform community health planning, environmental stewardship, and everyday household decision-making.

Comparison With Similar Public Health Patterns

Although the present study did not attempt an extensive literature review, its general pattern is consistent with a recurrent public health observation: exposed surface water often carries heavier and less predictable microbial contamination than protected groundwater, while poorly maintained groundwater sources may still fall below acceptable safety expectations. This pattern is particularly relevant in settings where improved water infrastructure is unevenly distributed and where communities alternate between multiple water sources depending on season, accessibility, or cost. The descriptive difference observed here between River Kpata and the borehole samples therefore fits a broader understanding of how exposure, sanitation, and source protection shape bacteriological risk (Olasoji et al., 2019; Oloruntoba & Sridhar, 2017; Adomi et al., 2025).

Another useful point of comparison concerns the interpretation of indicator-type findings. In many environmental health studies, the recovery of organisms consistent with Gram-negative enteric contamination is treated as a warning sign even when pathogen-specific confirmation is unavailable. The same logic applies here. The present results should not be read narrowly as a laboratory curiosity; rather, they point to conditions under which harmful organisms could also occur, persist, or be periodically introduced. For that reason, the study remains relevant to local health planning even without full organism identification.

Environmental and Social Dimensions of Water Use

Water quality is shaped not only by physical source type but also by the social systems that surround water collection and use. If a river is used for washing, bathing, agricultural activity, and other daily practices, contamination pressure is likely to increase. Likewise, if households queue at a borehole with shared containers, place vessels on unclean ground, or store water in poorly covered receptacles, a source that begins with lower contamination can still contribute to exposure. The health value of a water source therefore depends on a chain of protection that runs from the environment of the source to the point of household use.

This broader perspective is important for community-level interventions. A borehole may be structurally present in a neighbourhood yet still fail to deliver safe water if drainage is poor, wastewater pools nearby, animals have unrestricted access, or maintenance is irregular. Similarly, residents may continue to depend on surface water even when safer alternatives exist if cost, distance, queuing time, or convenience become barriers. These realities help explain why a microbiological study can also contribute to conversations about behaviour, infrastructure, and local policy.

Implications for Research, Practice, and Policy

For researchers, the present study provides a basis for designing more detailed investigations into water safety in Patigi. Future work could compare wet and dry season contamination profiles, assess additional physicochemical parameters, examine household storage practices, and identify specific bacterial species or resistance traits among recovered isolates. Such extensions would deepen understanding of contamination sources and improve the targeting of interventions.

For practitioners and local institutions, the study offers evidence that can support routine surveillance and community outreach. Educational campaigns should not only tell residents that water may be unsafe; they should also explain why, when, and how contamination occurs, and what low-cost protective actions are available. Regular flushing and sanitary inspection of boreholes, proper waste disposal near riverbanks, and the promotion of household treatment options are practical measures that can be implemented even before major infrastructure upgrades are achieved.

For policy actors, the findings underline the importance of integrating water safety into local development planning. Access to safer water influences school attendance, household productivity, healthcare burden, and overall quality of life. Investments in environmental sanitation, drainage management, protected water points, and public awareness therefore have benefits that extend beyond microbiology alone. By placing a local laboratory finding within this wider frame, the present study supports the view that safe water is both a scientific and developmental priority.

Public Health Implications

The bacterial levels observed in both water categories imply potential exposure to preventable health risks among users of these sources. Where contaminated water is used for drinking, food preparation, or washing of utensils, the probability of waterborne disease transmission increases. Children, older adults, and individuals with weakened immunity are especially vulnerable to adverse outcomes associated with unsafe water. Even where illness is not immediately recognized as water-related, repeated exposure to contaminated sources can contribute to the wider disease burden within a community.

The findings therefore justify stronger public sensitization regarding routine water treatment before consumption. They also support the need for periodic monitoring by local institutions, schools, health authorities, and community stakeholders. Public health messaging should emphasize that water clarity or underground origin does not guarantee bacteriological safety. Practical guidance on boiling, safe storage, hand hygiene, and protection of water points can provide immediate benefit while broader infrastructure improvements are pursued.

This implication is especially relevant for students, traders, food vendors, and households that depend on daily water collection from nearby sources. In such contexts, even modest improvements in source protection and household treatment can produce meaningful health gains. The study therefore supports not only laboratory follow-up, but also practical community action aimed at reducing routine exposure to microbiologically unsafe water.

Comparison With Broader Nigerian and Regional Evidence

The pattern observed in this study also resonates with findings reported from other low- and middle-income settings in which exposed surface waters tend to show heavier microbial contamination than groundwater, while groundwater remains vulnerable when protection is inadequate. Studies from different parts of Nigeria and sub-Saharan Africa repeatedly suggest that source classification alone does not determine microbiological safety. Rather, sanitation conditions, proximity to waste disposal, livestock activity, drainage quality, and the integrity of the water source itself often play decisive roles in shaping bacterial burden. The current findings from Patigi therefore fit a wider public health picture in which groundwater may be safer in relative terms but still unsafe in absolute terms when users depend on it without treatment.

This broader comparison is important because it strengthens the interpretation of the present results beyond a purely local observation. If similar contamination profiles have been described elsewhere, then the situation in Patigi should be understood not as an isolated anomaly but as part of a recurring challenge facing communities where water infrastructure, environmental sanitation, and routine surveillance remain insufficient. In this sense, the study contributes to an evidence base that supports preventive action even where laboratories cannot yet identify every isolate to species level. It confirms that simple bacteriological assessment can still reveal meaningful risks and should not be dismissed as merely preliminary.

Another point of comparison concerns the role of variability. Several field-based water studies report wide fluctuations in counts across apparently similar samples, especially for rivers and other exposed sources. Such variability reflects the dynamic nature of environmental contamination. Rainfall events, sediment disturbance, domestic activity at collection points, and episodic waste input can all alter microbial load over short periods. The broad dispersion recorded in the river samples in this study is therefore plausible and epidemiologically meaningful. It suggests that a single apparently moderate reading may provide false reassurance if monitoring does not continue across time.

Why the Findings Matter Beyond the Laboratory

One reason this study is worth expanding for an interdisciplinary readership is that water quality is not only a microbiological issue. It is also a social, economic, and developmental issue. When households depend on contaminated sources, the consequences extend into education, productivity, household spending, and care burdens. Children who experience recurrent diarrhoeal disease may miss school days, caregivers may lose time from work, and families may

incur treatment costs that could have been prevented through safer water access. A microbiological study therefore has implications that extend well beyond the laboratory bench.

The results also matter because they challenge common assumptions that are often embedded in everyday decision-making. In many communities, river water may be recognized as risky, but borehole water may be treated as safe without further thought. Yet the present findings suggest that this perceived contrast can be misleading. Relative safety does not always equal actual safety. If a borehole is poorly sited or poorly maintained, or if contamination occurs during fetching and storage, the practical health advantage of groundwater can be reduced. This is why community education should not only encourage the use of improved sources; it should also explain the conditions under which those sources remain safe or become unsafe.

For institutional stakeholders, the study highlights the need for low-cost but regular surveillance. Universities, public health units, environmental officers, and community associations can all play a role in sustaining periodic water monitoring. Even modest testing programmes that rely on culture-based techniques can identify trends, reveal high-risk sources, and support evidence-based public health messaging. In settings where budgets are limited, such surveillance can still provide substantial value because it helps direct attention to the sources most in need of intervention.

Practical Intervention Pathways for Patigi

The present findings suggest several realistic intervention pathways. First, source protection should be treated as a priority. For River Kpata, this means reducing contaminating activities near collection points, discouraging refuse disposal along the riverbank, and promoting cleaner practices where households continue to rely on the river for domestic purposes. Protective education is particularly important because the river may remain in use even if boreholes exist, whether because of convenience, queue length, cost, or habit.

Second, borehole management should be strengthened. Boreholes are often seen as completed infrastructure once installed, but their safety depends on continued maintenance. Drainage around the apron, prevention of stagnant wastewater, structural integrity of the installation, and control of nearby contamination sources all influence microbiological quality. Community leaders and institutions that oversee water points should therefore treat borehole hygiene as an ongoing responsibility rather than a one-time construction matter.

Third, household-level treatment remains essential. Until reliable routine monitoring and source protection are assured, users should be encouraged to boil, filter, chlorinate, or otherwise treat water before drinking. Just as important, treated water should be stored hygienically in clean, covered containers to avoid recontamination after collection. These measures may appear simple, but they are often the most immediately achievable public health response where centralized water treatment is absent.

Finally, risk-communication strategies should be tailored to local realities. Public advice is more likely to be followed when it acknowledges what households actually do. If residents use different sources for drinking, cooking, and washing, health messages should address each use clearly. If women, children, or vendors are the main collectors and handlers of water, outreach should engage those groups directly. Effective intervention depends not only on identifying contamination but also on translating the evidence into messages and practices that communities can realistically adopt.

Limitations

This study was limited to culture-based morphological identification and did not include biochemical confirmation or molecular characterization of isolates. As a result, the findings should be interpreted as evidence of preliminary Gram-negative contamination rather than definitive identification of specific pathogenic species. The number of sampling points and the observed variability in counts also limit the extent to which the results can be generalized beyond the studied sources.

Another limitation is that sampling was conducted within a restricted study frame and therefore may not capture seasonal fluctuations in microbial burden. Water quality can vary substantially with rainfall, runoff intensity, usage patterns, and environmental events. Consequently, a single study period provides an important snapshot but not a complete annual picture. In addition, the study did not include parallel physicochemical measurements such as pH, turbidity, temperature, dissolved solids, or residual disinfectant status, all of which could enrich interpretation of the microbial findings. Future studies should incorporate broader temporal coverage, larger sample sizes, biochemical tests such as IMViC, and molecular approaches where feasible.

Recommendations

Based on the findings, regular microbiological assessment of both surface water and borehole water in Patigi is recommended. Environmental sanitation measures should be strengthened around riverbanks and borehole points in order to reduce contamination pressure. Community education campaigns should promote household treatment of drinking water and discourage the assumption that groundwater is automatically safe. Future researchers should expand the work through seasonal sampling, broader geographic coverage, and confirmatory identification techniques that can establish the specific organisms involved and their likely sources.

In institutional terms, collaboration between local health officers, educational institutions, environmental agencies, and community leaders would strengthen any response arising from these findings. Universities and local laboratories can support periodic monitoring, while public health educators can translate laboratory results into understandable guidance for households. Community ownership is equally important: where residents understand the risks and participate in protecting water points, interventions are more likely to be sustained over time. This makes local engagement a practical component of long-term water safety.

Conclusion

Both surface and groundwater sources in Patigi showed evidence of microbial contamination. River Kpata recorded a higher mean bacterial load than the sampled borehole sources, but the difference between the two categories was not statistically significant, largely because of substantial variability in the river samples. Nonetheless, the presence of Gram-negative rods and the recovery of both lactose-fermenting and non-lactose-fermenting colonies indicate that the microbial quality of both water sources deserves public health attention.

The study demonstrates that groundwater sources regarded as safer than surface water may still carry notable bacteriological risk when sanitary protection is inadequate. It also shows that descriptive microbiological evidence can be highly informative even when inferential differences are not statistically significant. In practical terms, the findings call for improved source protection, routine water quality monitoring, public education on household water treatment, and expanded future investigation using more specific identification methods. Strengthening these areas will help reduce the likelihood of waterborne illness and support safer community water use in Patigi and similar settings.

Taken together, the results reinforce a simple but important public health message: communities should not rely on assumption, appearance, or source type alone when judging the safety of water intended for domestic use. Local evidence remains essential. By documenting contamination in both river and borehole samples, the present study provides a practical basis for action within Patigi and offers a model for similar community-based investigations in other parts of Nigeria where comparable water-use patterns exist.

Author Contributions

Usman Abiola Mohammed: Conceptualization, data analysis, writing, supervision.

Yakubu Amina: Data collection, laboratory analysis, manuscript review.

Conflict of Interest

The authors declare no conflict of interest.

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