Assessment of the Effects of Septic Tanks on the Quality of Hand Dug-Wells in Logo I and II, Makurdi, Benue State Nigeria

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ABSTRACT

*This study assessed the effects of septic tanks on the physicochemical and bacteriological quality of water from hand-dug wells in Logo I and Logo II. A total of 20 wells (10 per ward) were purposively sampled during the dry season (February). On-site and laboratory analyses followed standard methods (APHA, 2017; WHO, 2017), covering parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), turbidity, ammonia (NH_3), hardness, sodium (Na), potassium (K), and bacteriological indicators (*Escherichia coli*, Salmonella sp., and Total Bacterial Plate Count – TBPC). Data were analysed using descriptive statistics, two-way ANOVA, Mann–Whitney U test, and the Entropy-Weighted Water Quality Index (EWQI). Samples were categorized by gradient positions (above and below 30 m from septic tanks) to examine proximity influences. Results showed that all physicochemical parameters exhibited slight variations across locations and gradient positions, with near-neutral pH values ranging from 6.58 ± 0.14 to 7.02 ± 0.09. TDS ranged between 572 ± 69.9 mg/L and 664 ± 67.8 mg/L, while other parameters (DO, temperature, EC, turbidity, NH_3, hardness, Na, and K) remained relatively stable. Two-way ANOVA indicated no statistically significant effects of location, gradient (30 m), or their interaction on any physicochemical parameter ($p > 0.05$). The EWQI classified water quality as "good" for both gradient positions (71.84 above and 66.92 below), with turbidity and TDS contributing most to the index. In contrast, bacteriological analysis revealed notable spatial differences.* E. coli *and* Salmonella *sp. were completely absent in all Logo I samples, indicating good bacteriological quality. However,* E. coli *was detected in 40% and* Salmonella *sp. in 10% of Logo II samples. Mean TBPC was significantly higher in Logo II (31.13 CFU/100 mL) than in Logo I (5.50 CFU/100 mL) ($p = 0.044$, Mann–Whitney U test). Both locations exceeded the WHO guideline of zero detectable bacteria in potable water. The findings highlight a clear disconnect between physicochemical parameters (which suggested acceptable quality) and bacteriological indicators (which revealed localized fecal contamination risks, particularly in Logo II). No strong gradient effect was observed at the 30 m threshold during dry-season sampling, likely due to aquifer buffering, lateral flow, and low recharge conditions. This study underscores the vulnerability of shallow hand-dug wells to microbial contamination from onsite sanitation systems in densely settled peri-urban areas with permeable soils. While the water may appear suitable based on physicochemical and EWQI assessments alone, bacteriological contamination poses potential public health risks, including waterborne diseases. It is recommended that local authorities enforce a minimum separation distance of 30 meters between hand-dug wells and septic tanks (with preference for up-gradient siting), promote standard watertight septic designs with regular maintenance, mandate household water treatment (e.g., boiling or chlorination), and establish routine seasonal monitoring programs. Expanded municipal water supply and integration of hydrogeological considerations into land-use planning are also essential for long-term protection of groundwater resources in Makurdi.*

KEYWORDS

Septic tanks, Hand-dug wells, Groundwater quality, physicochemical parameters, Bacteriological contamination, fecal contamination, Water Quality Index (EWQI), Microbial pollution, Peri-urban groundwater, Makurdi

I. INTRODUCTION

A. Background to the Study

Groundwater, particularly from hand-dug wells, remains a critical source of domestic water in many peri-urban and rural areas of Nigeria, including wards like Logo I and Logo II in Makurdi, Benue State, where public water supply systems are often unreliable or insufficient. Hand-dug wells are typically shallow, making them highly susceptible to contamination from nearby anthropogenic sources such as onsite sanitation systems, primarily septic tanks.

Septic tanks treat household wastewater through sedimentation and anaerobic digestion, with effluent percolating into the soil via soak ways. However, when improperly designed, sited too close to wells, or poorly maintained, septic systems can leach contaminants—including pathogens (E. coli, total coliforms), nitrates, phosphates, organic matter measured as Biological Oxygen Demand (BOD), and other pollutants—into shallow aquifer. Proximity between septic tanks and hand-dug wells exacerbates this risk, especially in areas with permeable soils, high water tables, or inadequate setbacks.

Empirical evidence from Nigerian studies supports this vulnerability. In Abeokuta, Ogun State, groundwater samples from hand-dug wells ≤15 m from septic tanks showed elevated biological oxygen demand (up to 13.2 mg/L), nitrates (up to 17 mg/L), and *E. coli* (up to 41 × 10^2 cfu/mL), indicating sewage infiltration from improperly constructed septic systems.

Similarly, in Effurun, Delta State, hand-dug wells near septic tanks exhibited contamination linked to inadequate separation distances, often below recommended minima (e.g., 50 ft or ~15 m), leading to exceed acnes in microbial and physicochemical parameters. In other contexts, such as Lagos and Enugu, septic proximity has been associated with high fecal coliforms, heavy metals, and overall degraded water quality in shallow wells. In Makurdi, Benue State, bacteriological assessments of hand-dug wells have highlighted contamination from nearby pollution sources, including septic tanks, soak ways, and pit latrines, with elevated microbial loads contributing to public health risks (studies on bacterial contamination in Makurdi metropolis). Logo I and Logo II, as growing peri-urban areas with dense residential development and reliance on onsite sanitation, face similar challenges amplified by seasonal flooding, soil characteristics, and limited regulatory oversight. Despite these patterns, site-specific data on septic tank impacts in these wards remain limited, underscoring the need for localized investigation.

B. Aim of the Study

The aim of this study is to assess the effects of septic tanks on the water quality of hand-dug wells in Logo I and Logo II, Makurdi, Benue State. Nigeria

C. Specific Objectives of the Study

The objectives of the study are to;

- Determine the physicochemical parameters (e.g., pH, electrical conductivity, nitrates, and biological oxygen demand) of water from hand-dug wells in relation to their proximity to septic tanks in the study area.
- Evaluate the bacteriological quality (e.g., total coliforms and E. coli) of hand-dug well water and identify potential contamination from septic tank effluent.
- Examine the influence of distance between hand-dug wells and septic tanks on overall groundwater quality and recommend minimum safe separation guidelines for the area.

II. METHODOLOGY

A. Research Design

The study employed a cross-sectional survey design with analytical components. This involved field reconnaissance, purposive sampling of hand-dug wells, on-site measurements, laboratory analysis of water samples, and statistical analysis. The design enabled comparison of water quality parameters across wells at varying distances from septic tanks, identification of contamination patterns, and assessment against WHO (2017) and Nigerian Standard for Drinking Water Quality (NSDWQ/SON, 2007) guidelines. Sampling was conducted during the dry season, February particularly to minimize dilution effects from rainfall recharge, capturing baseline contamination risks from septic effluents under low groundwater flow conditions. The study was restricted to the dry season, specifically February, to establish groundwater contamination conditions under relatively stable and low-rainfall conditions. Restricting sampling to one season also reduced the influence of seasonal variations in rainfall, groundwater recharge, runoff, and dilution, thereby providing a more controlled assessment of contamination potentially associated with septic effluents.

B. Study Area

The study was carried out in Logo I and Logo II, peri-urban wards in Makurdi Local Government Area, Benue State, and Nigeria. Makurdi (approximately 7°44'N, 8°31'E) is situated along the Benue River floodplain, characterized by low-lying topography, sandy-loam alluvial soils, and shallow unconfined aquifers (typically 5–20 m depth). Logo I and Logo II feature informal residential settlements with high population density, limited access to municipal piped water, and widespread use of hand-dug wells and onsite sanitation systems (septic tanks and soak ways).

C. Population of the Study

The target population comprised all functional hand-dug wells used for domestic purposes in Logo I and Logo II. A preliminary reconnaissance survey identified 200 wells across the two wards, based on household reliance on shallow groundwater in these peri-urban zones.

D. Sample ad Sampling Technique

A purposive sampling technique was adopted to select wells that met specific inclusion criteria: actively used for drinking/cooking, located in residential areas with identifiable nearby septic tanks or soak ways, and representing varied proximity distances to septic systems.

Table 1: Distribution of Sampled Hand-Dug Wells by Location and Proximity to the Nearest Septic Tank/Soak away

Location	Number of Wells	Close Proximity (<10–15 m)	Moderate Proximity (15–30 m)	Farther Proximity (>30 m)	Total
Logo I	10	5	3	2	10
Logo II	10	5	3	2	10
Total	20	10	6	2	20

This distribution allowed assessment of contamination gradients. Each well represented one independent sample (no replicates from the same well). GPS coordinates were recorded for all sites using a handheld Garmin device to support spatial analysis.

E. Instruments for Data Collection

The study utilised standard field and laboratory instruments to ensure reliable collection, measurement, preservation, and transportation of groundwater samples. Sterile 500 mL polyethylene bottles were used for physicochemical analyses, while sterile Whirl-Pak bags or sodium thiosulfate-treated bottles (100–250 mL) were used for bacteriological samples. A portable multipara meter meter (Hanna HI-98129) was employed for on-site measurement of pH, temperature, electrical conductivity (EC), and total dissolved solids (TDS). A portable turbid meter was used to determine turbidity levels. A calibrated measuring tape was used to determine the distance between sampled wells and the nearest septic tanks or soak ways, while a GPS receiver recorded the geographical coordinates of each sampling point. Finally, cooler boxes containing ice packs were used to maintain appropriate sample conditions during transportation to the laboratory.

F. Procedure for Data Collection

1. Field Sampling

- Water samples were collected following standard protocols (American Public Health Association APHA, 2017; WHO, 2017):
- Wells were pumped/hand-pumped for 5–10 minutes to remove stagnant water and draw fresh aquifer sample.
- Bacteriological samples were collected first (to avoid contamination). Bottles were filled without headspace, capped tightly, and labelled with site code, date, time, GPS coordinates, well depth (estimated or measured), and proximity to nearest septic tank.
- Physicochemical samples followed immediately.

- On-site parameters (pH, temperature, EC, TDS, turbidity) were measured directly.
- Water samples collected from these two peri urban places were stored at 4°C in ice packs and transported to the laboratory within 6 hours for bacteriological and physicochemical examination.

2. Quality Control

- Field blanks (distilled water) were processed to check for contamination.
- Duplicate samples were taken from 10% of sites for precision checks.
- All equipment was sterilized before use.

G. Laboratory Analysis Procedures

1. Bacterial plate count

100mL of each sample collected was filtered through a membrane with a pore size of 0.45µL using a vacuum membrane filter. The membrane was remove using a sterile forceps and was place in a sterile Petri dish in an up-right position. The plate was covered with prepared Nutrient agar Medium and allowed to solidify. The plates were inverted and incubated for 24 hrs. at 370C. The colonies obtained after 24hrs of incubation were counted and recorded in Colony Forming Unity per hundred Millilitres (CFU/100mL).

2. Preparation of Media

Xylose-Lysine Deoxycholate agar and Eosin Methylene Blue agar were used for the isolation of Salmonella and E. coli while Peptone Water, Simmon's Citrate agar, Triple Sugar Iron agar and Urea Agar Base were used for biochemical identification of the isolates. All the media used were prepared according to their manufacturers' standard instructions; the dehydrated media was weighed and dissolved in the appropriate volume of sterile distilled water. The suspension was heated to boil and was sterilized using autoclave at 121oC for 15 minutes with exception of XLD which was sterilized by heat to boil as described by Cheesbrough (2006).

3. Inoculation

The samples were inoculated into Trypticase Soy Broth (TSB) and incubated for 24 h. The culture obtained was sub-culture using streak plate method of inoculation onto Eosin Methylene Blue Aagar (EMBA) and Xylose-Lysine Deoxycholate Agar (XLDA) medium and was incubated for 24 h. The isolates obtained were sub-cultured repeatedly to obtain pure cultures.

H. Identification of the Isolates

1. Gram Staining

The colony of each isolate was emulsified using wire loop, in a drop of normal saline on a clean microscope slide (smear). It was air dried and was heat fix by passing the slide across a flame three times. The slide was placed on the staining rack and was flooded with crystal

violet for 1m and was rinsed with clean water. It was then covered with Lugo's iodine (mordant) for 1 min and rinsed with clean water. It was rapidly decolorized with acetone and was rinsed immediately with clean water. It was lastly stained with safranin (secondary dye) for 30 s. Back of the slide was wipe with cotton wool and was allowed to air dry; the slide was mounted on the microscope stage and a drop of immersion oil was added. The specimen was brought into focus using x100 objective with the iris diaphragm completely opened to increase the amount of light that enter the objective. Gram reaction was determined on the basis of the colour of dye retained; Gram positive organisms retained the colour of the primary dye (crystal violet) and appear purple while Gram negative organisms loosed the colour of the primary dye after decolourization and pick up the colour of the secondary dye (safranin) and appear red in colour as described by Cheesbrough (2006).

2. Catalase Test

A drop of hydrogen peroxide was placed on a microscope slide and the isolate was picked using wire loop and was emulsified in the drop of the hydrogen peroxide and was observed for immediate bubble formation with indicate catalase positive result as described by Cheesbrough (2006).

3. Indole Test

The test organism was inoculated in a test tube containing 5 ml of sterile peptone water Cheesbrough (2006) and incubated at 37oC for 48 h and 0.5 ml of Kovac's reagent was added and shakes gently and was examined for red colour formation on the surface layer within 10 mins. The formations of red colour on the surface layer indicate indole positive result.

4. Urease Test

The media (urea agar base) was prepare in a test tube and placed in a slant position. The butt was stabbed using a sterile straight inoculation needle and the slope was streaked with a saline suspension of the isolate and was incubated at 37oC for 18 h. The tube was observed for colour change. Red/pink colour indicates urease positive result as described by Cheesbrough (2006).

5. Sugar fermentation test

The media (Triple Sugar Iron Agar) was prepared in a test tube and placed in a slant position. The butt was stabbed using a sterile straight inoculation needle and the slope was streaked with a saline suspension of the isolate and incubated at 37oC for 24 h. The tube was observed for lactose, sucrose and glucose fermentation on the basis of colour change as a result of acid production in the medium due to fermentation of the sugars by the test isolate as described by Cheesbrough (2006).

6. Citrate Utilization Test

The media was preparing in a test tube and placed in a slant position. The butt was stabbed using a sterile straight inoculation needle and the slope was streaked with a saline suspension of the organism and incubated at 37oC for 48 h. A bright blue colouration in the medium indicates citrate positive result as described by Cheesbrough (2006).

I. Data Analysis

Data collected from the field and laboratory analyses will be analysed using descriptive and inferential statistical techniques. Percentages will be used to summarise the proportion of wells meeting or exceeding specified drinking-water standards. The mean will describe the average concentration of each physicochemical and microbiological parameter, while the standard deviation will indicate the degree of variability among the sampled wells. One-way Analysis of Variance (ANOVA) will be used to determine whether significant differences exist in water-quality parameters among wells grouped according to their distances from septic tanks. Where the assumptions of parametric testing are not satisfied, the Mann–Whitney U test will be applied to compare two independent groups. Statistical significance will be evaluated at $p < 0.05$. In addition, the Water Quality Index (WQI/EWQI) will be calculated to integrate multiple water-quality parameters into a single numerical indicator and classify the overall suitability of groundwater for drinking.

III. RESULTS

A. Physicochemical Parameters of Water from Hand-Dug Well in Relation to Their Proximity to Septic Tanks in Logo I and II in Makurdi Metropolis, Benue State, Nigeria

The physicochemical parameters of hand-dug well water across locations (Logo I and Logo II) and gradient positions (above and below 30 m) are presented in Table 1. The results show that all measured physicochemical parameters, including pH, total dissolved solids (TDS), dissolved oxygen (DO), temperature, electrical conductivity (EC), turbidity, ammonia (NH_3), hardness, sodium (Na), and potassium (K), exhibited only slight variations across both locations and gradient positions.

For instance, pH values ranged from 6.58 ± 0.14 to 7.02 ± 0.09, indicating near-neutral conditions across all sampling points. Similarly, TDS values varied between 572 ± 69.9 mg/L and 664 ± 67.8 mg/L, while dissolved oxygen ranged from 3.72 ± 0.17 to 4.02 ± 0.17 mg/L. Other parameters such as turbidity, EC, and temperature also showed relatively narrow ranges across treatments.

The results of the two-way analysis of variance (ANOVA) revealed that location had no significant effect on any of the measured physicochemical parameters ($p > 0.05$). This indicates that the water quality characteristics were statistically similar between Logo I and Logo II, suggesting that locations did not influence the physicochemical composition of the groundwater.

Similarly, the gradient factor (30 m) did not exert any significant effect on the measured parameters ($p > 0.05$). This implies that differences in elevation (above and below positions), when maintained at the same horizontal distance from the source, did not result in measurable changes in the physicochemical properties of the water.

Furthermore, the interaction between location and gradient (L × G) was not statistically significant for any of the parameters ($p > 0.05$). This indicates that the combined influence of location and gradient did not produce any interactive effect on groundwater quality. In other words, the effect of gradient was consistent across both locations, and vice versa.

Table 2: Physicochemical Characteristics of Hand-Dug Well Water across Location and Gradient

Variable	**Logo I**	**Logo II**	**P-value**				
	Above	**Below**	**Above**	**Below**	**Location**	**Gradient**	**L×G1**
pH	6.58±0.14	6.84±0.14	7.02±0.09	6.80±0.17	0.162	0.885	0.098
TDS	572.00±69.90	664.00±67.80	664.00±38.50	611.00±44.00	0.741	0.736	0.22
DO	4.02±0.17	3.72±0.17	4.00±0.19	3.80±0.14	0.859	0.153	0.768
Temp	26.8±0.0735	27±0.215	27±0.169	26.90±0.11	0.746	0.948	0.279
EC	1150.00±141.00	1330.00±134.00	1330.00±76.50	1220.00±89.10	0.734	0.765	0.222
Turbidity	8.25±1.09	8.45±0.50	7.6±0.40	7.45±1.17	0.351	0.975	0.842
NH3	0.04±0.04	0.00±0.00	0.24±0.24	0.12±0.12	0.255	0.564	0.772
Hardness	0.48±0.48	1.44±1.44	0.34±0.34	0.26±0.26	0.415	0.585	0.519
Na	6.58±2.48	5.82±1.97	5.24±2.18	4.20±1.34	0.477	0.664	0.946
K	2.16±0.22	2.04±0.72	2.34±0.27	2.58±0.53	0.493	0.925	0.723

Means in all rows do not differ significantly ($P > 0.05$) as analysed by two-way ANOVA and the TUKEY test.

1L × G = Location × Gradient interaction effect.

The presence/absence analysis (Table 2) revealed differences in bacterial contamination between groundwater samples from Logo I and Logo II. In Logo I, E. coli and Salmonella sp. were both recorded at 0 CFU/100 mL, indicating that these organisms were not detected

in the sampled wells during the study period. In contrast, Logo II recorded 4 CFU/100 mL of E. coli and 1 CFU/100 mL of Salmonella sp., indicating the presence of faecal and potentially pathogenic bacterial contamination.

Table 3: Presence and Absence of Escherichia coli and Salmonella sp. in Hand-Dug Well Water by Location

Location	E. coli (CFU/100 mL)	Salmonella sp. (CFU/100 mL)	Total Samples
Logo I	0	0	10
Logo II	4	1	10
Overall	2	0.5	20

The total bacterial plate count (TBPC) varied significantly between locations (Table 3). The mean TBPC recorded for Logo II (31.13 CFU/100 ml) was substantially higher than that of Logo I (5.50 CFU/100 ml). A Mann–Whitney U test revealed that this difference was statistically significant (U = 0.00, p = 0.044). The elevated bacterial load observed in Logo II suggests greater microbial contamination, likely due to environmental or anthropogenic influences such as septic system leakage or poor sanitary conditions.

Table 4: Total Bacterial Plate Count (CFU/100 ml) of Hand-Dug Well Water by Location in the Study Area

Location	Mean TBPC (CFU/100 ml)	U statistic	p-value
Logo I	5.5^{b}	0.00	0.044
Logo II	31.13^{a}		

The detailed computation of Entropy Water Quality Index (EWQI) for the above-gradient wells is presented in Table 4. The results show that turbidity had the highest contribution to the index with a sub-index value of 38.64, followed by TDS (24.02) and dissolved oxygen (14.33). Other parameters such as ammonia, hardness, sodium, and potassium contributed minimally to the overall index.

The overall EWQI for the above-gradient wells was calculated as:

$EWQI$=71.84

This value falls within the “good water quality” category.

Table 5: EWQI Computation (Above Gradient)

Parameter	q_i	Weight	$W_i \times q_i$
pH	77.41	0.12	9.29
TDS	114.40	0.21	24.02
DO	79.60	0.18	14.33
Turbidity	161.00	0.24	38.64
NH_3	8.00	0.05	0.40
Hardness	0.24	0.04	0.01
Na	2.89	0.09	0.26
K	19.25	0.07	1.35

$$EWQI = \sum_{j=1}^{m} (9.29 + 24.02 + 14.33 + 38.64 + 0.40 + 0.01 + 0.26 + 1.35) = 71.84$$

EWQI (Above) = 71.84

The computation for the below-gradient wells is presented in Table 5. Similar to the above-gradient results, turbidity contributed the most to the index (35.57), followed by TDS (22.99) and dissolved oxygen (14.69). The contributions of ammonia, hardness, sodium, and potassium remained relatively low.

The overall EWQI for the below-gradient wells was:

$EWQI$=66.92

Table 6: EWQI Computation (Below Gradient)

Parameter	q_i	Weight	$W_i \times q_i$
pH	78.00	0.12	9.36
TDS	109.46	0.21	22.99
DO	81.60	0.18	14.69
Turbidity	148.20	0.24	35.57
NH3	6.00	0.05	0.30
Hardness	0.18	0.04	0.01
Na	2.51	0.09	0.23
K	18.42	0.07	1.29

$$EWQI = \sum_{j=1}^{m}(9.36 + 22.99 + 14.69 + 35.57 + 0.30 + 0.01 + 0.23 + 1.29) = 66.92$$

EWQI (Below) = 66.92

A summary of the EWQI values for both gradient positions is presented in Table 6. Although both gradients fall within the same water quality class, the above-gradient wells recorded a slightly higher EWQI value compared to the below-gradient wells.

Table 7: Summary of EWQI for wells in Logo ward I and II

Gradient (30m)	EWQI	Class
Above	71.84	Good
Below	66.92	Good

IV. DISCUSSION

The study evaluated the physicochemical and bacteriological quality of groundwater from hand-dug wells in relation to location and gradient, as well as overall water quality using the entropy-weighted water quality index (EWQI). The findings revealed that physicochemical parameters were relatively uniform across locations and gradients, whereas bacteriological indicators showed marked spatial variation, highlighting the complexity of groundwater contamination processes.

A. The physicochemical parameters of water from hand-dug wells in relation to their proximity to septic tanks in the study area.

The physicochemical parameters measured in this study exhibited minimal variation across both Logo I and Logo II as well as between gradient positions. The absence of significant differences ($p > 0.05$) in pH, TDS, DO, turbidity, and other parameters suggests that groundwater quality is relatively stable within the study area. This observation is consistent with previous studies which reported that physicochemical characteristics of groundwater often remain spatially uniform over short distances due to buffering capacity of aquifers and natural attenuation processes. Aquifer buffering capacity plays a crucial role in maintaining groundwater stability, as demonstrated in esker aquifers where CO2 dissolution from organic matter decomposition increases pH and enhances buffering capacity, helping balance alkalinity from bioactivity with acidity from recharge processes. The near-neutral pH range (6.58–7.02) observed in this study falls within acceptable limits for drinking water and indicates minimal acidification or alkalinisation processes.

Similarly, the lack of significant effects of gradient ($p > 0.05$) suggests that elevation differences at a constant distance of 30 m do not substantially influence groundwater physicochemical properties. This finding supports the understanding that groundwater movement is governed primarily by hydraulic gradients rather than surface topography. Therefore, the expectation of gravity-driven differences between "above" and "below"

positions may not apply in this context, particularly where hydrogeological conditions promote lateral flow or mixing.

B. The bacteriological quality of hand-dug well water from Logo I and II

Despite the uniformity in physicochemical parameters, the bacteriological results revealed clear spatial differences. The complete absence of Escherichia coli and Salmonella in Logo I, compared to their presence in Logo II (40% and 10%, respectively), indicates localized contamination. The detection of E. coli is particularly significant, as it is widely recognized as a reliable indicator of fecal contamination and potential presence of enteric pathogens (Khan and Gupta 2020; WHO, 2022). The occurrence of these organisms in Logo II suggests possible infiltration of septic tank effluent or poor sanitation practices, which have been widely documented as major sources of groundwater contamination in developing regions.

The results of total bacterial plate count (TBPC) further corroborate the presence/absence findings. The significantly higher TBPC observed in Logo II compared to Logo I ($p < 0.05$) indicates a greater microbial load, reinforcing the evidence of contamination. Elevated TBPC values are often associated with organic pollution and microbial proliferation, which can arise from anthropogenic activities such as waste disposal and sewage leakage (APHA, 2017). Importantly, both locations exceeded the WHO guideline of zero detectable bacteria in potable water, indicating that the groundwater may not be safe for direct consumption without treatment.

A key finding of this study is the apparent disconnect between physicochemical and bacteriological water quality. While physicochemical parameters suggested relatively good water quality, bacteriological indicators revealed contamination in Logo II. This highlights a well-documented limitation of water quality indices that rely solely on physicochemical parameters. Several studies have emphasized that such indices may underestimate health risks if microbial contamination is not considered (Kumar et al., 2024). Therefore, the inclusion of bacteriological analysis is essential for comprehensive groundwater quality assessment.

C. Influence of distance between hand-dug wells and septic tanks on overall groundwater quality

The EWQI results further support this interpretation. Both gradient positions were classified as having "good" water quality, with values of 71.84 (above) and 66.92 (below). The slightly higher EWQI value in the above-gradient wells suggests marginally poorer water quality, although the difference is not sufficient to alter classification. The dominance of turbidity and TDS in contributing to EWQI indicates that particulate matter and dissolved solids are the primary drivers of water quality variation in the study area. This aligns with findings from recent EWQI-based studies, which report that parameters with higher variability tend to exert greater influence on overall water quality (Singh et al., 2019).

However, the similarity in EWQI classification between gradients suggests that the influence of elevation is minimal at the studied distance. This reinforces the earlier conclusion that gradient alone does not significantly control groundwater quality in this context. Instead,

localized factors such as contamination sources, soil characteristics, and groundwater flow pathways may play a more critical role.

The findings of this study demonstrate that while physicochemical parameters may indicate acceptable water quality, bacteriological contamination can still pose significant health risks. The results underscore the importance of integrating physicochemical, microbiological, and index-based approaches in groundwater quality assessment. Furthermore, the observed contamination in Logo II highlights the need for improved sanitation practices and regular monitoring to safeguard public health.

V. CONCLUSION

This study assessed the effects of septic tanks on the water quality of hand-dug wells in Logo I and Logo II wards of Makurdi, Benue State. The physicochemical parameters (pH, TDS, DO, temperature, EC, turbidity, NH_3, hardness, Na, and K) showed only slight variations across the two locations and gradient positions (above and below 30 m from septic tanks). All values remained within or close to acceptable limits for drinking water, with near-neutral pH (6.58–7.02) and no statistically significant differences attributable to location, gradient, or their interaction ($p > 0.05$ via two-way ANOVA). The Entropy-Weighted Water Quality Index (EWQI) classified the water as "good" in both gradient positions (71.84 above and 66.92 below), with turbidity and TDS contributing most to the index.

In contrast, bacteriological analysis revealed notable spatial differences. Escherichia coli and Salmonella sp. were absent in all samples from Logo I but present in 40% and 10% of samples from Logo II, respectively. Total Bacterial Plate Count (TBPC) was significantly higher in Logo II (31.13 CFU/100 mL) than in Logo I (5.50 CFU/100 mL) ($p = 0.044$ via Mann–Whitney U test). These findings indicate localized fecal contamination in Logo II, likely linked to septic tank effluent infiltration, poor sanitary conditions, or other anthropogenic influences, despite the overall "good" physicochemical profile.

The study highlights a key disconnect: physicochemical parameters and EWQI may suggest acceptable water quality, while bacteriological indicators reveal potential health risks from microbial contamination. This underscores the limitations of relying solely on physicochemical indices for groundwater assessment in peri-urban settings with onsite sanitation systems. Although no strong gradient effect was observed at the 30 m threshold in this dry-season sampling, the presence of pathogens in Logo II aligns with broader Nigerian literature showing risks from inadequate septic siting, modified designs, and permeable floodplain soils in areas like Makurdi.

Overall, hand-dug wells in the study area provide a vital water source amid unreliable municipal supply, but bacteriological contamination in parts of Logo II poses risks of waterborne diseases. The findings emphasize the need for integrated physicochemical and microbiological monitoring, improved sanitation practices, and evidence-based siting guidelines to protect shallow aquifers in Benue State's peri-urban zones.

RECOMMENDATIONS

Based on the study findings and consistent with empirical evidence from similar Nigerian contexts, the following recommendations are proposed:

- Enforcement of Minimum Separation Distances: Local authorities (Benue State Environmental Protection Agency, Makurdi Local Government, and town planning departments) should enforce a minimum horizontal separation of 30 meters between hand-dug wells and septic tanks/soak ways, preferably with wells located up-gradient (uphill) from sanitation systems.
- Improved Septic Tank Design and Maintenance: Promote standard watertight septic tank designs with adequate volume, baffles, lined floors/walls, and properly sized soak ways. Regular dislodging (every 2–3 years) and professional construction should be mandated. Substandard "modified" circular pits or unlined units, common in peri-urban areas, should be phased out through awareness campaigns and regulatory oversight.
- Water Treatment and Household Practices: Residents should treat well water before drinking, especially in areas showing bacteriological contamination (e.g., boiling for at least one minute, or using approved household chlorination/filtration methods).
- Regular Monitoring and Surveillance: Benue State University, environmental agencies, and local health departments should establish routine (at least seasonal—wet and dry) monitoring programs for physicochemical and bacteriological parameters in high-risk wards like Logo I and Logo II. GIS mapping of wells and septic systems can help identify contamination hotspots for targeted interventions.
- Policy and Infrastructure Development: Advocate for expanded municipal water supply and centralized or semi-centralized sanitation systems in growing peri-urban areas of Makurdi to reduce reliance on vulnerable shallow wells. Integrate groundwater protection into land-use planning, requiring hydrogeological assessments before approving new wells or septic installations.
- Further Research: Future studies should include wet-season sampling to capture recharge-driven leaching effects, larger sample sizes with replicates, deeper aquifer analysis, and full spatial correlation between exact well-septic distances and contamination levels. Long-term seasonal monitoring and assessment of additional parameters (e.g., nitrates, phosphates and heavy metals) would strengthen the evidence base.

A. Contributions to Knowledge

This study makes the following original contributions to knowledge in the field of environmental science, hydrogeology, and public health:

1. First Site-Specific Assessment in Logo I and II Wards

The research provides the first detailed empirical investigation focused exclusively on the impacts of septic tanks on hand-dug wells in Logo I and Logo II, Makurdi. While earlier studies in Makurdi metropolis offered general insights into groundwater contamination, this work generates localized, ward-level data on both physicochemical and bacteriological parameters, thereby filling a significant spatial knowledge gap in these rapidly urbanizing peri-urban areas.

2. Evidence of Disconnect Between Physicochemical Parameters/EWQI and Bacteriological Safety

A major contribution is the demonstration that physicochemical parameters and the Entropy-Weighted Water Quality Index (EWQI) may classify groundwater as "good" (EWQI

values of 71.84 above and 66.92 below 30 m), while bacteriological indicators reveal significant contamination risks. Specifically, the complete absence of E. coli and Salmonella sp. in Logo I contrasted sharply with 40% E. coli and 10% Salmonella sp. detection in Logo II, coupled with significantly higher Total Bacterial Plate Count (TBPC) in Logo II ($p = 0.044$). This highlights the limitations of relying solely on physicochemical-based assessments in peri-urban settings with onsite sanitation and reinforces the critical need for integrated microbiological monitoring.

3. New Insights on the 30 m Separation Distance Under Dry Season Conditions

The study contributes fresh understanding on the limited effectiveness of the 30 m gradient as a protective threshold during the dry season in floodplain alluvial aquifers. Despite no statistically significant differences in physicochemical parameters or EWQI across the gradient ($p > 0.05$), microbial contamination persisted in Logo II. This suggests that aquifer buffering, lateral flow, and low recharge conditions in the dry season can mask expected proximity effects, providing important nuance to existing recommendations on setback distances in similar hydrogeological environments in Nigeria.

4. Documentation of Micro-Scale Spatial Heterogeneity

The marked variation in bacteriological quality between two adjacent wards (Logo I vs Logo II) under similar geological and settlement conditions adds to knowledge on localized contamination drivers such as septic tank design, density, and maintenance practices. This underscores the importance of high-resolution, ward-level studies rather than broad metropolitan generalizations.

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