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Mapping Contamination Hotspots: A GIS-Based Assessment of Groundwater Quality in Hand-Dug Wells across Emughan Clan, Abua/Odual Local Government Area, Rivers State, Nigeria

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ABSTRACT

Groundwater from hand-dug wells is the principal source of domestic and drinking water for rural communities in the Niger Delta, including Emughan Clan of Abua/Odual Local Government Area, Rivers State, Nigeria. Although earlier work has assessed well water quality in isolated villages within Emughan Clan — notably a single-village study of Egunughan community by Akinfolarin and Ebianna (2016) — no study has previously evaluated groundwater quality across the clan as a whole. This study therefore represents the first clan-wide assessment of groundwater quality in Emughan Clan, examining the physicochemical, heavy metal and bacteriological quality of well water from seven communities — Owerewere, Aminigboko, Emesu, Okoboh, Egunughan, Obaranyi and Emabuh — and compared the results with the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015). Of the 45 functional hand-dug wells identified during a reconnaissance survey, 21 were classified as major functional wells, from which seven were purposively selected, one per community, for sampling. Water samples were collected in triplicate from each well on a single sampling occasion and analysed in the laboratory for pH, temperature, total dissolved solids (TDS), total suspended solids (TSS), chloride, sulphate, nitrate, iron, lead and faecal coliform. Results showed that temperature (28.08 °C), pH (7.28), TDS (155.66 mg/L), TSS (25.82 mg/L), chloride (50.46 mg/L), sulphate (38.02 mg/L) and nitrate (22.63 mg/L) were within NSDWQ limits across all communities. However, iron exceeded the 0.3 mg/L threshold in Obaranyi (0.337 mg/L), and lead exceeded the 0.01 mg/L limit in every community sampled, ranging from 0.018 mg/L in Emesu to 0.109 mg/L in Obaranyi (grand mean 0.057 mg/L). Faecal coliform was detected in all seven samples, in violation of the NSDWQ requirement of zero coliform per 100 mL. These findings indicate that, despite acceptable physicochemical characteristics, the well water in Emughan Clan is microbiologically unsafe and contaminated with lead at levels of public health concern, rendering it unsuitable for direct human consumption without treatment. The study recommends routine water quality monitoring, protection of well heads from surface contamination, discouragement of open defecation near water sources, and the provision of treated pipe-borne water as an alternative, safer supply.

Keywords: groundwater quality; hand-dug wells; heavy metals; faecal coliform; NSDWQ; Niger Delta; Emughan Clan

1. INTRODUCTION

Access to safe drinking water remains one of the most pressing public health challenges in rural Nigeria, where a large proportion of the population depends on unprotected or semi-protected groundwater sources

such as hand-dug wells for domestic use (WHO, 2022). In riverine and wetland communities of the Niger Delta, the shallow water table makes hand-dug wells the most accessible and affordable source of water, yet this same shallow depth exposes them to contamination from surface run-off, pit latrines, agrochemicals and saline intrusion (Iloba et al., 2022).

Emughan Clan, located in Abua/Odual Local Government Area of Rivers State, is one such community where pipe-borne water supply is largely absent, and residents rely almost exclusively on hand-dug well water for drinking, cooking and other domestic purposes. A reconnaissance survey identified 45 functional hand-dug wells in the clan, of which 21 were classified as major wells serving substantial portions of the population. Prior investigations of well water quality within Emughan Clan have been limited to isolated, single-village assessments. For instance, Akinfolarin and Ebianna (2016) evaluated the physicochemical quality of hand-dug well water in Egunughan community alone, one of the villages within Emughan Clan, but did not extend the assessment to neighbouring communities or to the clan as a coherent hydrogeological and administrative unit. Consequently, the overall quality of groundwater across Emughan Clan has not been systematically documented at the clan level, despite growing concern over the impact of oil and gas activities, poor sanitation practices, and geogenic influences on shallow aquifers in the wider Niger Delta region (Ideriah et al., 2012; Izah et al., 2016). This study addresses that gap by providing the first multi-community, clan-wide assessment of groundwater quality in Emughan Clan, incorporating spatial (GIS-based) mapping of contaminant distribution across all seven sampled communities.

Groundwater quality is typically evaluated using physicochemical parameters (pH, temperature, total dissolved solids, total suspended solids, chloride, sulphate and nitrate), trace/heavy metals (such as iron and lead), and microbiological indicators (faecal coliform), each of which is regulated under the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015). Elevated heavy metal concentrations, particularly lead, are of significant toxicological concern because lead is a cumulative neurotoxicant with no known safe level of exposure, especially in children (WHO, 2022). Similarly, the presence of faecal coliform bacteria is a direct indicator of contamination by human or animal waste and signals the potential presence of pathogens responsible for diarrhoeal and other waterborne illnesses (Adejuwon, 2025).

This study therefore assessed the physicochemical, heavy metal and bacteriological quality of hand-dug well water from seven representative communities in Emughan Clan, and evaluated the extent of compliance with NSDWQ limits. The specific objectives were to: (i) determine the physicochemical characteristics of the well water; (ii) determine the concentrations of iron and lead in the water; (iii) assess the bacteriological quality of the water using faecal coliform as an indicator; and (iv) compare the results obtained with NSDWQ standards to evaluate the suitability of the water for human consumption.

2. MATERIALS AND METHODS

2.1 Study Area

Emughan Clan is located within Abua/Odual Local Government Area of Rivers State, in the Niger Delta region of southern Nigeria. Abua/Odual LGA lies approximately between latitudes 4°45′N and 5°00′N and longitudes 6°25′E and 6°45′E, and is bordered by Ahoada West and Ahoada East to the north-east, and Degema and Akuku-Toru to the south (Figure 1). The area is characterised by a low-lying, flood-prone terrain typical of the Niger Delta, with a shallow water table that makes hand-dug wells the dominant means of water abstraction. Seven communities within Emughan Clan — Owerewere, Aminigboko, Emesu, Okoboh, Egunughan, Obaranyi and Emabuh — were selected for this study (Figure 2).

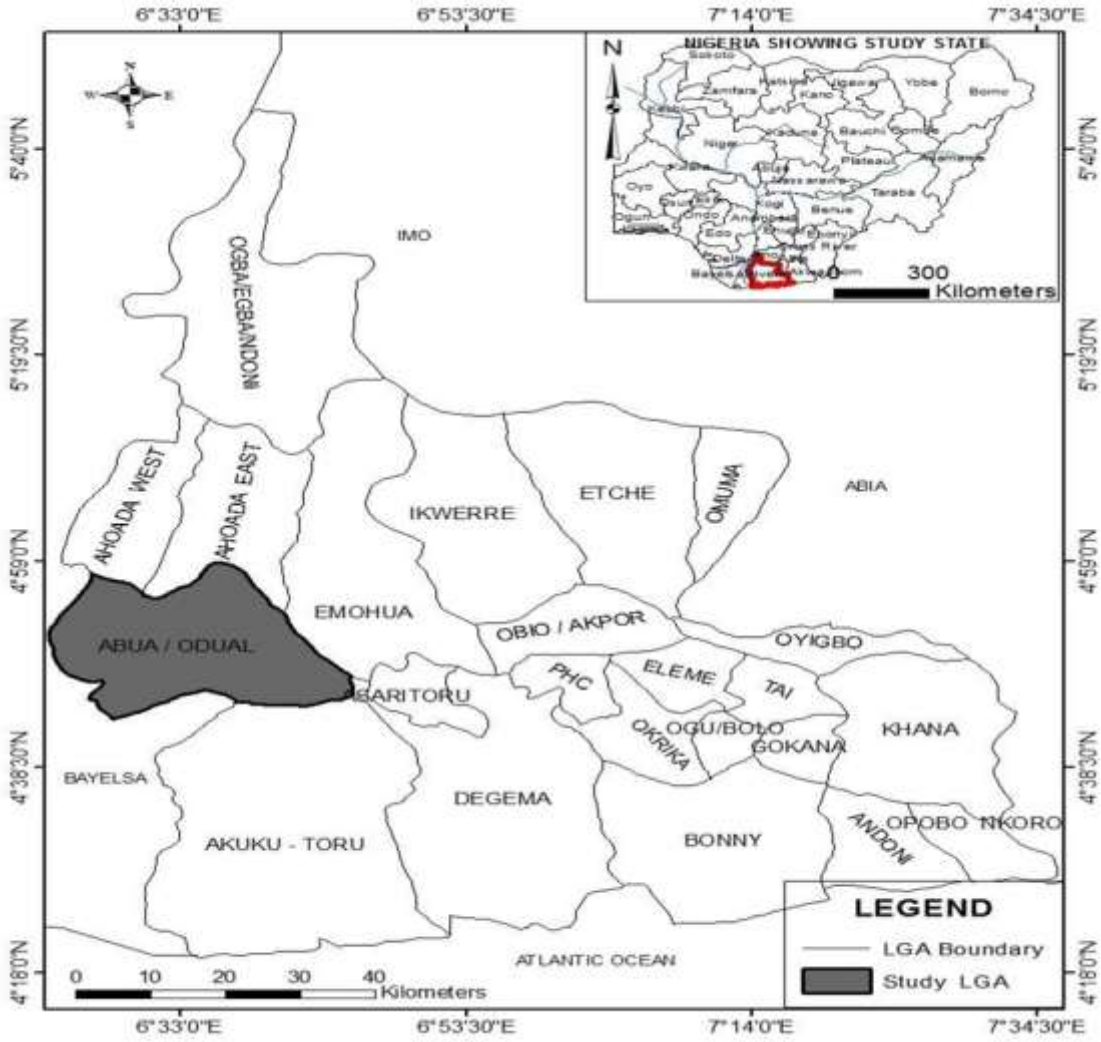

Figure 1. Map of Rivers State showing Abua/Odual Local Government Area.

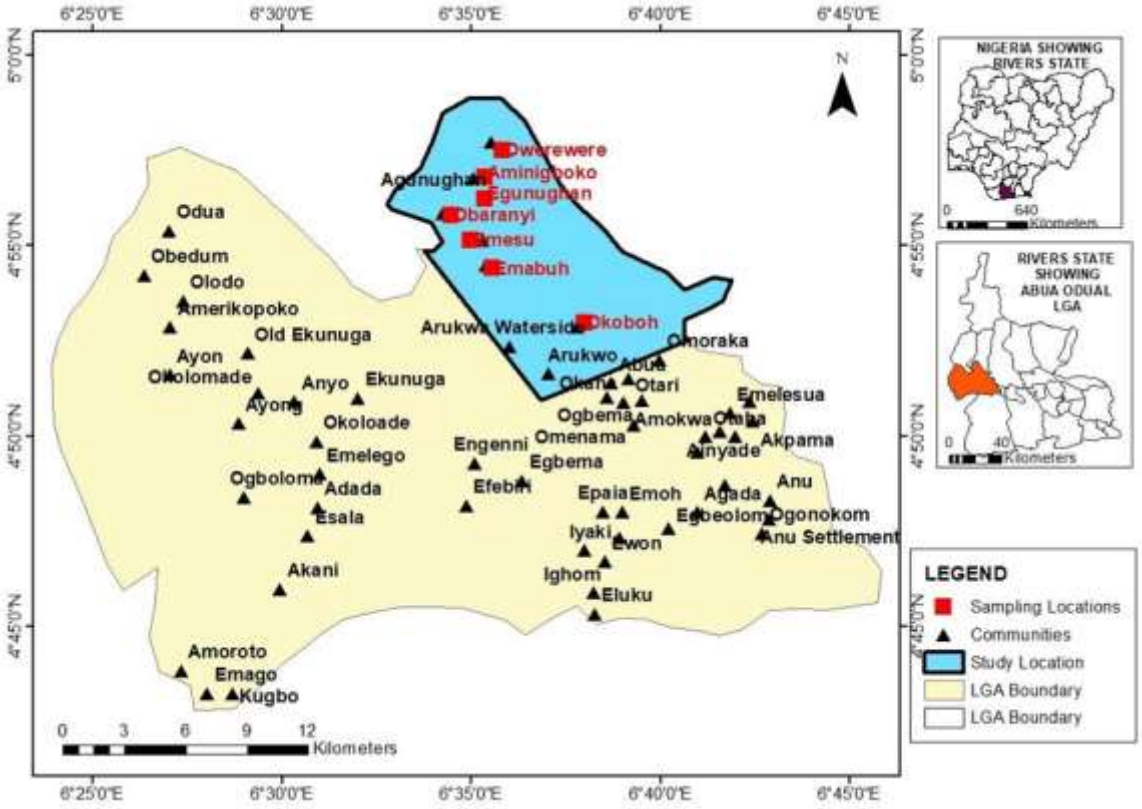

Figure 2. Map of Emughan Clan showing the seven well water sampling locations.

2.2 Well Inventory and Sample Selection

A reconnaissance/feasibility survey of the study area identified a total of 45 functional hand-dug wells, of which 21 were classified as major functional wells based on frequency of use, depth and structural condition. From these 21 major wells, seven were purposively selected, one per community, to represent the spatial spread of Emughan Clan (Table 1). The geographic coordinates of each sampling point were recorded with a hand-held Global Positioning System (GPS) receiver (Table 2).

S/N	Community	No. of Wells Sampled	Replicates
1	Owerewere	1	3
2	Aminigboko	1	3
3	Emesu	1	3
4	Okoboh	1	3
5	Egunughan	1	3
6	Obaranyi	1	3
7	Emabuh	1	3

Table 1. Sampling frame of hand-dug wells in Emughan Clan.

S/N	Community	Geographic Coordinates
1	Owerewere	N04°57'31" E006°35'50"
2	Aminigboko	N04°56'48" E006°35'22"
3	Emesu	N04°55'09" E006°34'60"
4	Okoboh	N04°52'59" E006°37'60"
5	Egunughan	N04°56'54" E006°35'23" (field record)
6	Obaranyi	N04°55'34" E006°45'48"
7	Emabuh	N04°58'43" E006°49'42"

Table 2. Geographic coordinates of the sampled wells.

2.3 Sample Collection and Handling

Water samples were collected from the seven wells on a single sampling day in 2021 to minimise the influence of temporal variation on inter-community comparison. At each well, samples were collected in triplicate using pre-cleaned, sterilised polyethylene bottles that had been rinsed with the sample water prior to collection. Separate sterile bottles were used for the microbiological samples. Samples for heavy metal analysis were acidified with a few drops of concentrated nitric acid to a pH below 2 to prevent metal precipitation. All samples were labelled, placed in an ice-packed cooler, and transported to the laboratory within 24 hours of collection for analysis, in line with standard methods for the examination of water and wastewater (APHA, 2017).

2.4 Laboratory Analysis

Ten parameters were determined for each sample: pH, temperature, total suspended solids (TSS), total dissolved solids (TDS), chloride, sulphate, nitrate, iron, lead and faecal coliform. pH and temperature were measured in situ and confirmed in the laboratory using a calibrated pH/temperature meter. TDS and TSS were determined gravimetrically. Chloride was determined by argentometric (Mohr) titration, sulphate by the turbidimetric method, and nitrate by the ultraviolet spectrophotometric screening method. Iron and lead concentrations were determined using Atomic Absorption Spectrophotometry (AAS). Faecal coliform was enumerated using the membrane filtration technique, with counts expressed as colony-forming units (CFU). All analyses followed standard methods described by the American Public Health Association (APHA, 2017).

2.5 Data Analysis

Descriptive statistics (mean and standard deviation) were computed for the triplicate measurements at each well, and grand means were computed across the seven communities for each parameter. All mean values were compared against the permissible limits stipulated by the Nigerian Standard for Drinking Water Quality (NSDWQ, 2015; SON, 2015) to determine compliance status. Values exceeding the NSDWQ limit were flagged as non-compliant.

2.6 Spatial Analysis and GIS Mapping

To visualise the spatial distribution of each water quality parameter across Emughan Clan, the geographic coordinates of the seven sampling wells were imported into a Geographic Information System (GIS) environment together with the corresponding mean parameter values. Spatial interpolation was performed to generate continuous surfaces depicting the predicted variation of each parameter between sampling points across the study area, and the resulting surfaces were classified into five graduated colour classes (green indicating the lowest values and red the highest) for ease of visual interpretation. This approach allowed the identification of zones of elevated contamination that may not be apparent from point-based tabular data alone, and complements the descriptive statistics presented in Section 3.

3. RESULTS

3.1 Physicochemical Characteristics

The mean concentrations (± standard deviation) of the physicochemical parameters analysed are presented in Table 3. Across the seven communities, temperature ranged from 27.18 °C in Aminigboko to 28.80 °C in Egunughan, with a grand mean of 28.08 °C, below the NSDWQ threshold of 30 °C. pH values ranged from 6.69 in Owerewere to 7.90 in Emabuh, with a grand mean of 7.28, falling within the NSDWQ permissible range of 6.5–8.5. TDS ranged from 118.21 mg/L (Okoboh) to 180.32 mg/L (Emabuh), and TSS ranged from 16.16 mg/L (Owerewere) to 37.94 mg/L (Obaranyi); both parameters were well below the NSDWQ limit of 500 mg/L in all communities. Chloride (32.25–58.63 mg/L), sulphate (30.49–42.98 mg/L) and nitrate (12.55–34.74 mg/L) were likewise below their respective NSDWQ limits of 250 mg/L, 100 mg/L and 50 mg/L in every community sampled.

Community	pH	Temp. (°C)	TDS (mg/L)	TSS (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	NO_3^- (mg/L)
Owerewere	6.69±0.04	27.71±0.06	141.13±1.16	16.16±1.05	56.75±5.6	38.3±1.23	28.39±0.99
Aminigboko	7.3±0.03	27.18±0.01	148.82±2.97	20.56±1.4	58.63±1.19	39.1±0.21	26.15±1.5
Emesu	6.98±0.02	28.58±0.07	173.51±1.8	30.61±1.11	57.3±0.34	34.87±1.25	12.55±0.21
Okoboh	7.89±0.02	28.15±0.03	118.21±2.75	21.11±0.88	38.92±1.01	40.89±2.08	13.16±0.04
Egunughan	6.93±0.03	28.8±0.02	173.83±2.39	26.99±1.9	32.25±0.72	42.98±1.57	34.74±0.05
Obaranyi	7.25±0.04	28.15±0.03	153.82±1.45	37.94±0.48	52.63±0.4	39.49±0.46	26.75±1.34
Emabuh	7.9±0.08	27.98±0	180.32±2.26	27.38±0.67	56.77±0.1	30.49±0.97	16.67±0.14
Grand Mean	**7.28**	**28.08**	**155.66**	**25.82**	**50.46**	**38.02**	**22.63**
NSDWQ Limit	**6.5 – 8.5**	**≤ 30**	**≤ 500**	**≤ 500**	**≤ 250**	**≤ 100**	**≤ 50**

Table 3. Mean (± SD) physicochemical characteristics of well water by community, compared with NSDWQ limits.

3.2 Heavy Metals and Bacteriological Quality

Table 4 presents the mean concentrations of iron and lead, and the faecal coliform counts, for each community. Iron concentrations ranged from 0.098 mg/L (Owerewere) to 0.337 mg/L (Obaranyi). Only Obaranyi exceeded the NSDWQ limit of 0.3 mg/L for iron; the remaining six communities were within the permissible limit. In contrast, lead concentrations exceeded the NSDWQ limit of 0.01 mg/L in all seven communities, ranging from 0.018 mg/L in Emesu to 0.109 mg/L in Obaranyi, with a grand mean of 0.057 mg/L — more than five times the permissible limit. Faecal coliform was detected in every sample, with mean counts ranging from 12.00 (Egunughan) to 28.00 (Okoboh) colonies, corresponding to CFU values well above the NSDWQ requirement of zero coliform per 100 mL. The consistent presence of faecal coliform across all seven wells indicates widespread microbiological contamination of the shallow aquifer in Emughan Clan.

Community	Fe (mg/L)	Pb (mg/L)	Fecal Coliform (mean count)	Fecal Coliform (CFU/mL)
Owerewere	0.0983±0.0013	0.0607±0.0004	20.33	2.0×10^{-5}
Aminigboko	0.143±0.0028	0.0458±0.0033	16	1.6×10^{-5}
Emesu	0.1309±0.0012	0.018±0.001	16.33	1.6×10^{-5}

Okoboh	0.2092±0.0006	0.0635±0.0002	28	2.8×10^{-5}
Egunughan	0.1439±0.0001	0.0125±0.0002	12	1.2×10^{-5}
Obaranyi	0.3368±0.0004	0.1087±0.0002	24.67	2.5×10^{-5}
Emabuh	0.1725±0.0005	0.0924±0.0024	15	1.5×10^{-5}
Grand Mean	**0.1764**	**0.0574**	**18.9**	**Present**
NSDWQ Limit	**≤ 0.3**	**≤ 0.01**	**Nil**	**0 CFU/100 mL**

Table 4. Mean concentrations of iron and lead, and faecal coliform counts, by community, compared with NSDWQ limits.

3.3 Spatial Pattern of Contamination

Obaranyi consistently recorded the highest concentrations of both iron (0.337 mg/L) and lead (0.109 mg/L), as well as one of the highest faecal coliform counts (24.67), suggesting a localised zone of elevated contamination possibly linked to well construction, proximity to contamination sources, or underlying geology. Okoboh recorded the highest faecal coliform count (28.00) despite comparatively low heavy metal concentrations, pointing to sanitation-related rather than geogenic contamination at that location. These spatial differences suggest that contamination sources in Emughan Clan are not uniform and may require community-specific mitigation strategies.

3.4 Spatial Distribution Maps

To further examine the spatial variability of groundwater quality across Emughan Clan, interpolated surfaces were generated in GIS for each parameter (Figures 3–12). The maps show that chloride, sulphate and nitrate concentrations were generally elevated across the cluster of communities in the northern part of the clan (Owerewere, Aminigboko, Egunughan, Obaranyi, Emesu and Emabuh), with comparatively lower values toward Okoboh in the south, while faecal coliform showed the reverse pattern, increasing from the northern cluster toward Okoboh. Iron and lead concentrations were both distinctly elevated at the western extremity of the study area around Obaranyi, consistent with the point data identifying Obaranyi as the most contaminated location for these two parameters. Temperature and pH were comparatively lower around the Aminigboko–Egunughan axis and increased toward the south-eastern part of the clan near Okoboh, while TDS and TSS were highest around the Emesu–Emabuh and Obaranyi areas respectively. Collectively, these maps indicate that contamination in Emughan Clan is not spatially uniform, with the western and southern margins of the clan (Obaranyi and Okoboh, respectively) emerging as zones of particular concern for heavy metals and faecal contamination.

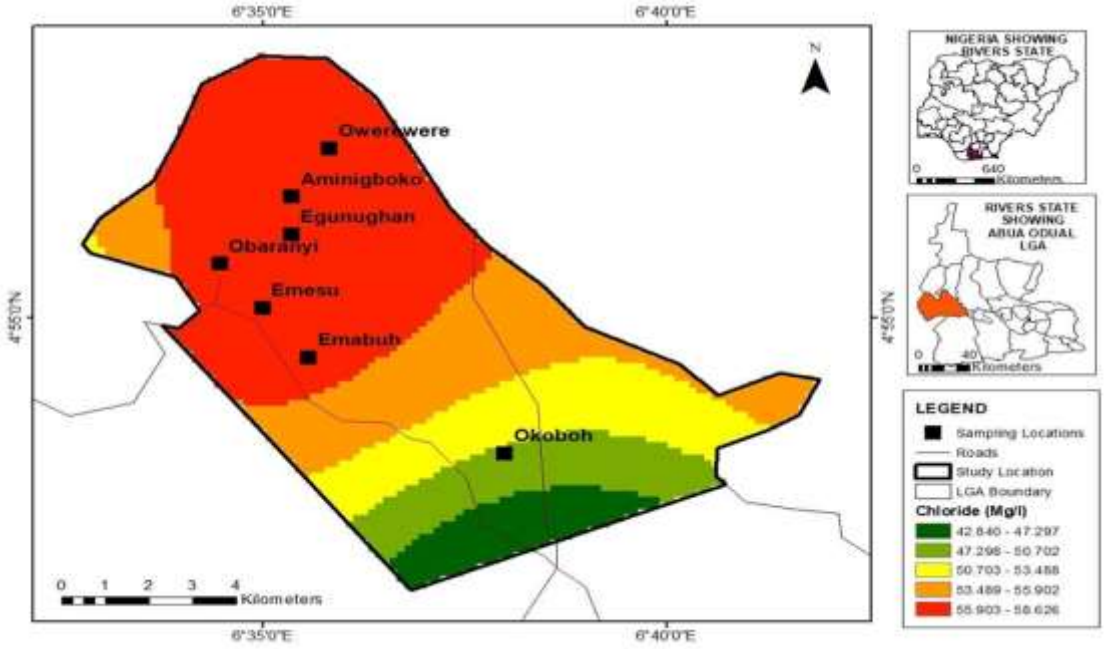

Figure 3. Spatial distribution of chloride (mg/L) across Emughan Clan.

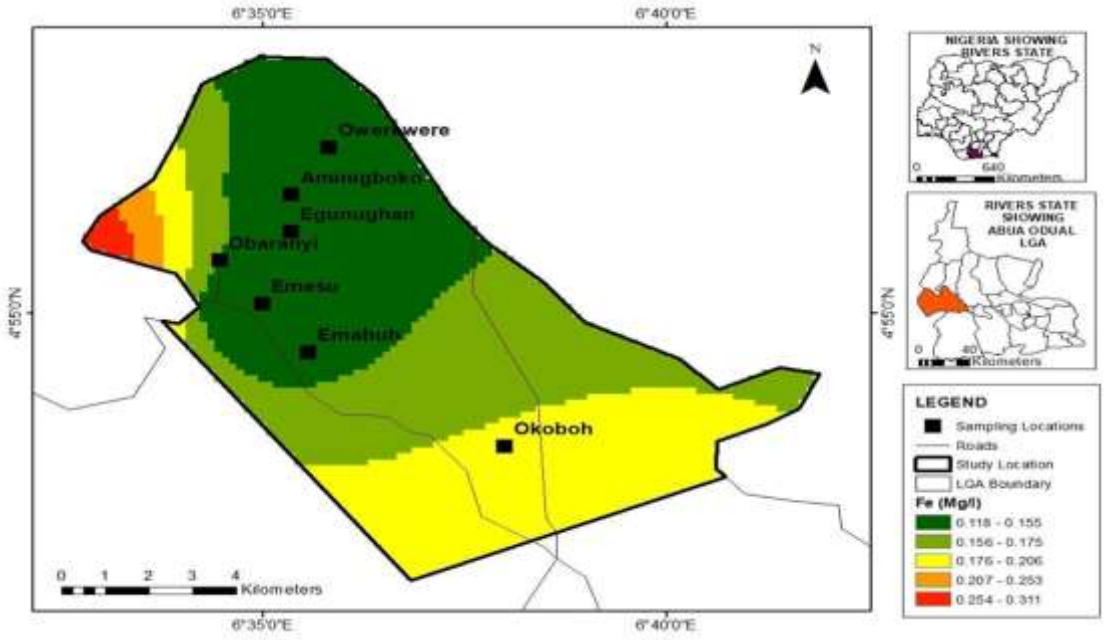

Figure 4. Spatial distribution of iron (mg/L) across Emughan Clan.

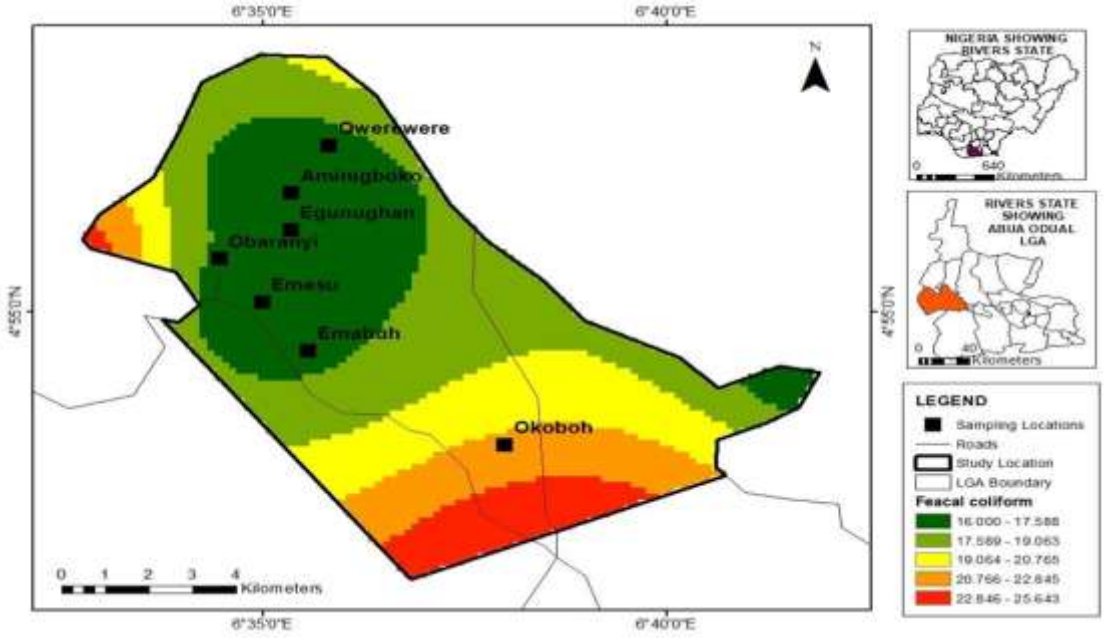

Figure 5. Spatial distribution of faecal coliform across Emughan Clan.

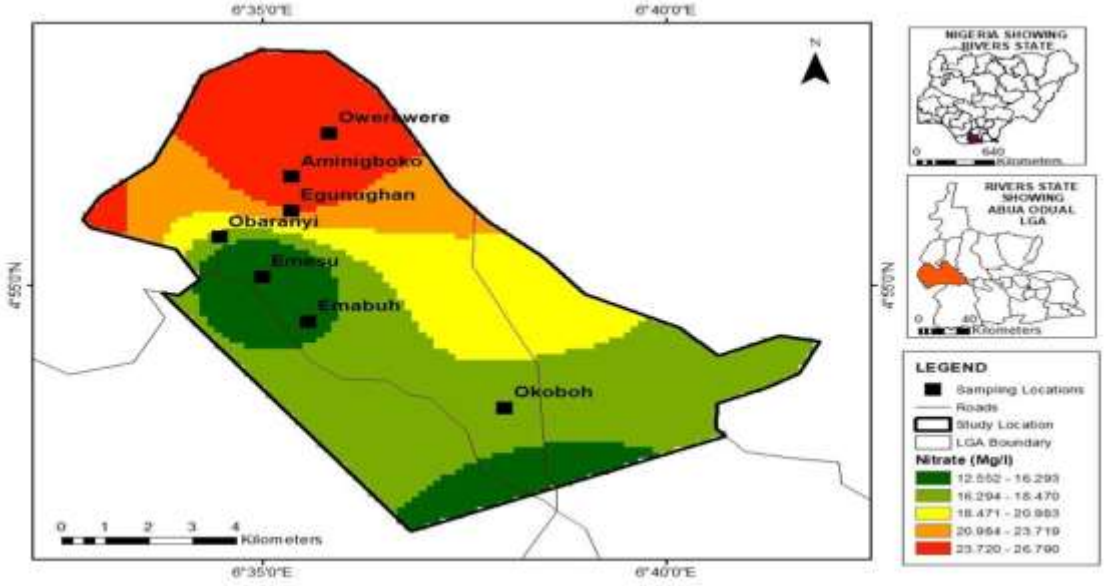

Figure 6. Spatial distribution of nitrate (mg/L) across Emughan Clan.

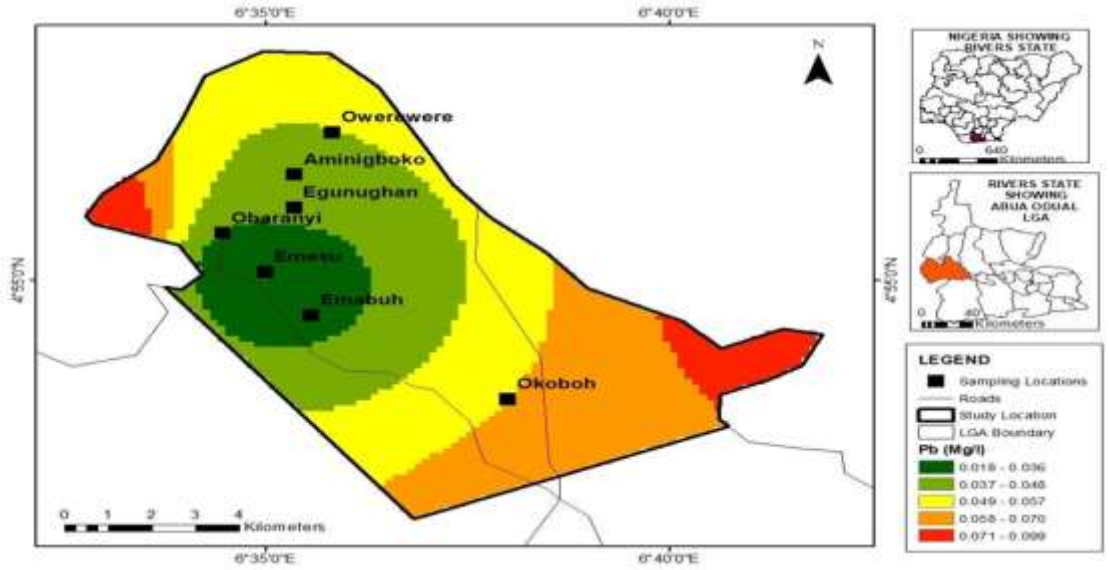

Figure 7. Spatial distribution of lead (mg/L) across Emughan Clan.

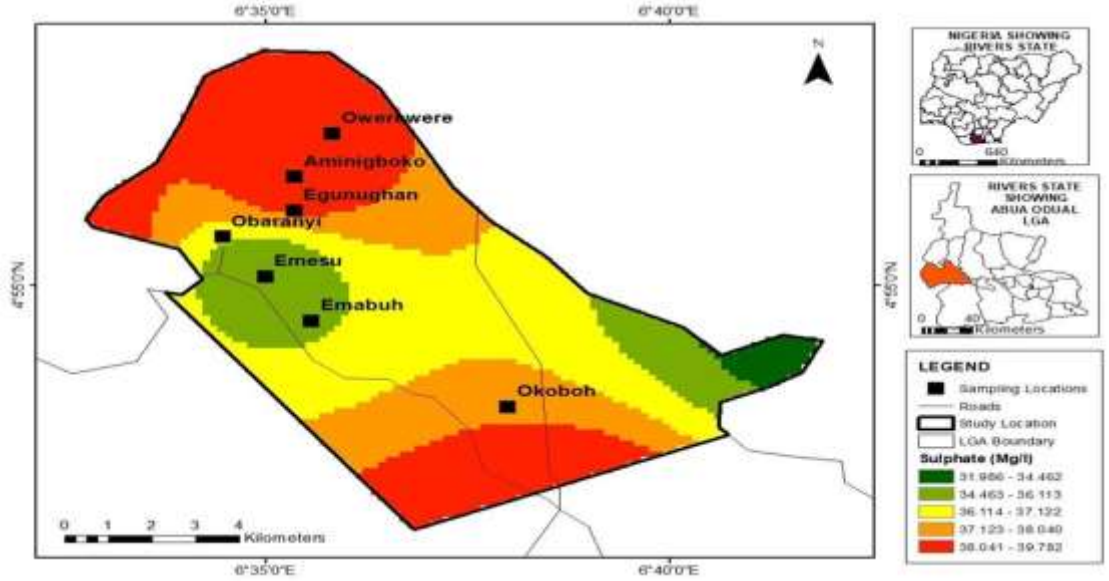

Figure 8. Spatial distribution of sulphate (mg/L) across Emughan Clan.

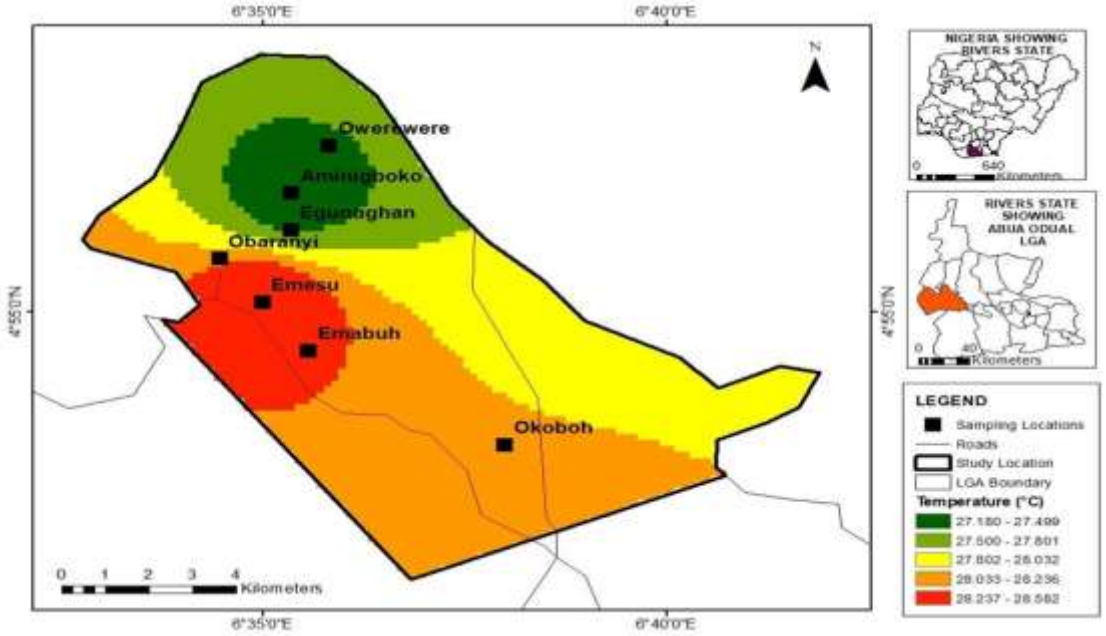

Figure 9. Spatial distribution of temperature (°C) across Emughan Clan.

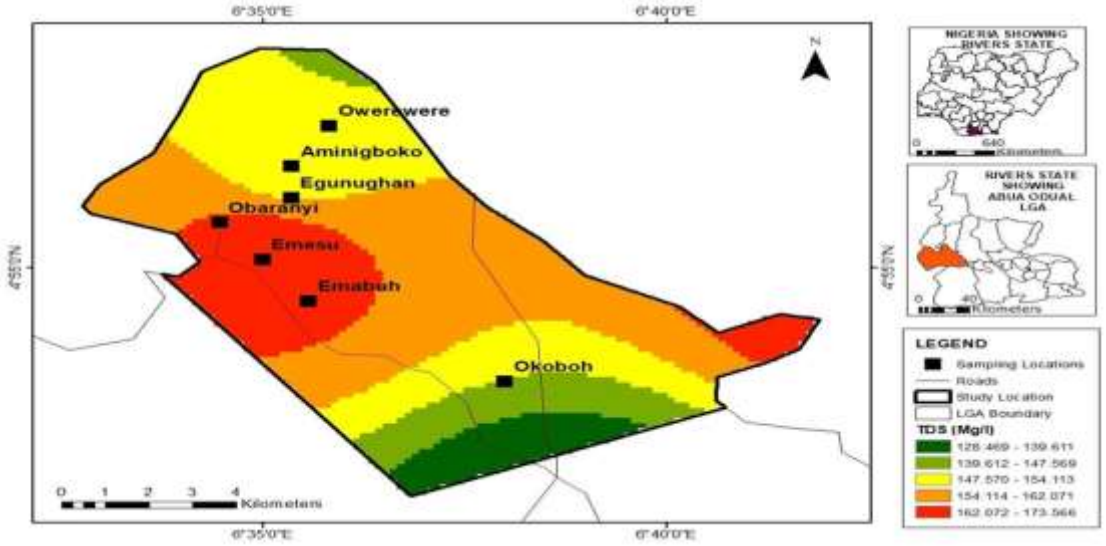

Figure 10. Spatial distribution of total dissolved solids (mg/L) across Emughan Clan.

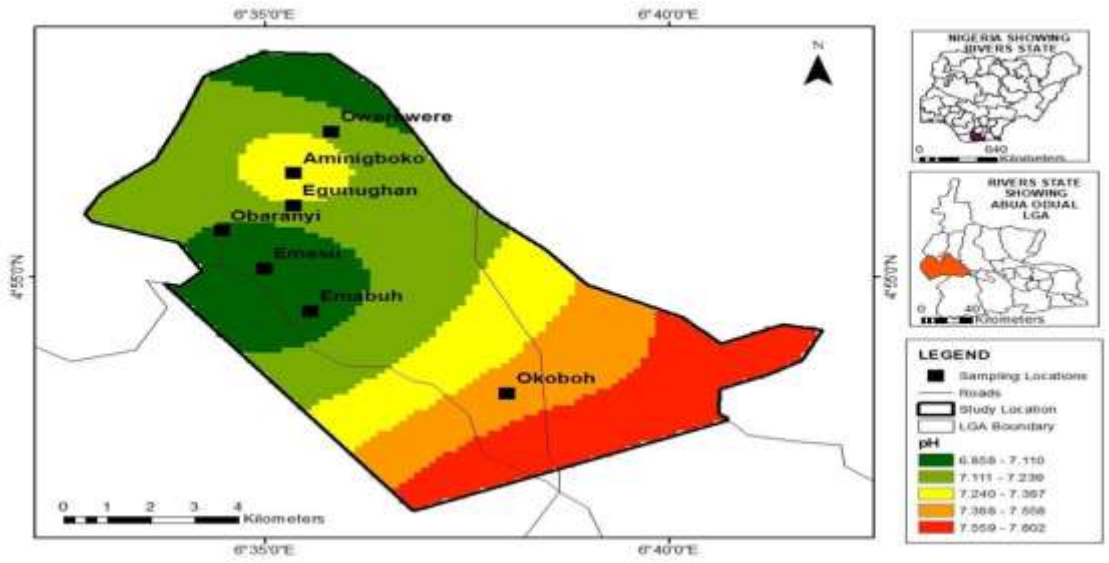

Figure 11. Spatial distribution of pH across Emughan Clan.

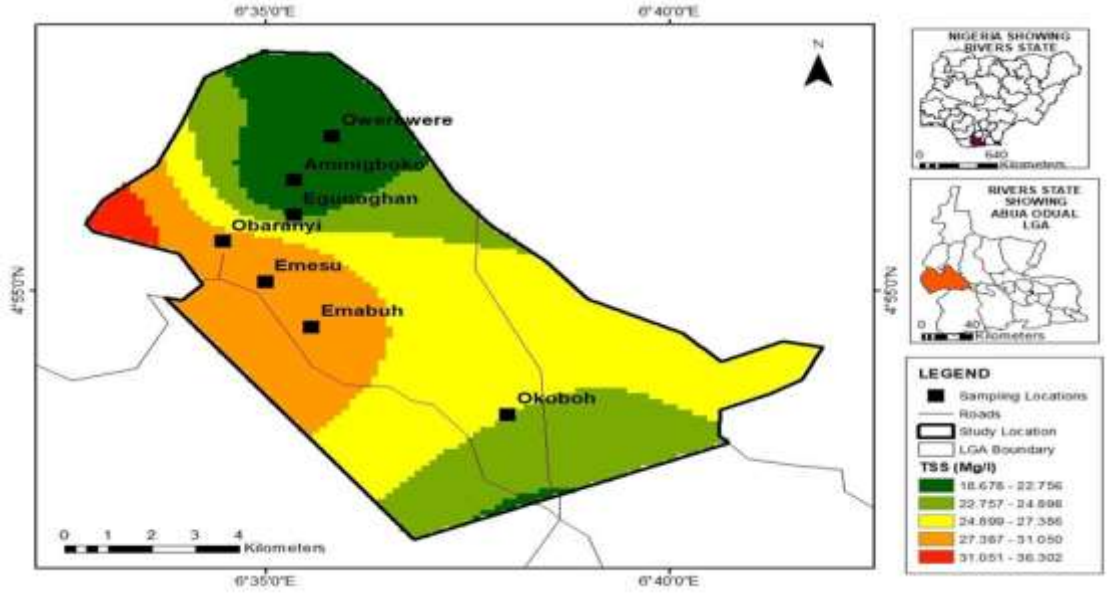

Figure 12. Spatial distribution of total suspended solids (mg/L) across Emughan Clan.

4. DISCUSSION

The physicochemical results obtained in this study are consistent with findings from other groundwater assessments in the Niger Delta, where pH, temperature, TDS, TSS, chloride, sulphate and nitrate levels in shallow hand-dug wells are typically within NSDWQ limits, reflecting the generally low mineral content of the sandy, unconsolidated aquifer material characteristic of the region (Iloba et al., 2022; Ideriah et al., 2012). The near-neutral pH values recorded across all seven communities are favourable, as they reduce the tendency for the leaching of metals from plumbing or well-lining materials and support a stable environment for microbial indicator testing.

The elevated iron concentration recorded in Obaranyi, though isolated to a single community, is consistent with the naturally iron-rich, lateritic and alluvial soils common in parts of the Niger Delta,

which can contribute geogenic iron to shallow groundwater (Izah et al., 2016). While iron is not classified as acutely toxic at the concentrations recorded, it can impart undesirable taste, odour and staining to water and may indicate broader mineral leaching processes at that location.

The most significant finding of this study is the widespread exceedance of the NSDWQ lead limit across all seven communities. Lead contamination in shallow hand-dug wells has been linked in the literature to factors such as leaching from corroding pipes or fittings, proximity to unregulated waste dumps, agrochemical residues, and, in oil-producing areas, contamination associated with petroleum-related activities (Adejuwon, 2025; Izah et al., 2016). Given that lead is a cumulative toxicant with well-documented adverse effects on neurological development in children and on renal and cardiovascular systems in adults even at low exposure levels (WHO, 2022), the concentrations recorded in this study — up to nearly eleven times the NSDWQ limit in Obaranyi — represent a serious public health concern that warrants further source-tracing investigation.

The universal detection of faecal coliform across all sampled wells corroborates similar findings across rural Niger Delta communities, where hand-dug wells are frequently sited close to pit latrines, soak-away pits, and areas affected by open defecation, and are typically uncovered or poorly protected from surface run-off (Adejuwon, 2025). This pattern of contamination is consistent with poor sanitary protection of well heads rather than with any single point source, underscoring the need for improved well construction standards and hygiene practices in the study area.

Overall, while the well water in Emughan Clan is physicochemically acceptable by NSDWQ standards, its microbiological contamination and elevated lead content render it unsuitable for direct human consumption without treatment. This is broadly consistent with the wider pattern reported for hand-dug wells across the Niger Delta, where physicochemical compliance frequently coexists with microbiological and heavy metal non-compliance (Iloba et al., 2022).

The spatial distribution maps (Figures 3–12) extend the earlier single-village assessment of Akinfolarin and Ebianna (2016), which was confined to Egunughan community, by showing how contamination varies across Emughan Clan as a whole. Rather than being uniformly distributed, elevated iron and lead concentrations were concentrated around Obaranyi, while faecal contamination intensified toward Okoboh, indicating that different communities within the same clan may be exposed to different dominant contamination pathways — geogenic or infrastructural in the case of Obaranyi, and sanitation-related in the case of Okoboh. This spatial heterogeneity would not have been apparent from a single-village study and underscores the value of a clan-wide, multi-community sampling design for guiding targeted, community-specific interventions rather than a uniform clan-wide response.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study provides the first clan-wide assessment of groundwater quality in Emughan Clan, Abua/Odual Local Government Area, Rivers State, extending beyond the isolated, single-village assessments previously conducted within the clan. By evaluating the physicochemical, heavy metal and bacteriological quality of hand-dug well water across seven communities, the study offers a more representative picture of groundwater conditions throughout Emughan Clan. The results show that while physicochemical parameters (pH, temperature, TDS, TSS, chloride, sulphate and nitrate) were generally within NSDWQ limits, lead was found to exceed the permissible limit in all seven communities, and faecal coliform was detected in every sample. Iron exceeded the permissible limit in one community (Obaranyi). These findings indicate that the hand-dug well water widely relied upon in Emughan Clan is not fit for direct consumption in its untreated state, owing to microbiological contamination and elevated lead concentrations.

5.2 Recommendations

Based on the findings, the following are recommended:

i. Well heads should be properly protected (raised aprons, covers and adequate distance from latrines and waste disposal sites) to reduce surface and faecal contamination.
ii. Open defecation should be actively discouraged, and community sanitation facilities improved, to reduce faecal loading of the shallow aquifer.
iii. The source of lead contamination, whether from geogenic, anthropogenic, or infrastructural sources, should be investigated further through targeted soil and source-tracing studies, particularly in Obaranyi.
iv. Point-of-use water treatment (e.g., boiling, chlorination, or filtration) should be encouraged as an interim measure pending infrastructural improvement.
v. Government and relevant agencies should prioritise the provision of treated pipe-borne water at strategic, accessible locations within Emughan Clan as a safer long-term alternative to hand-dug well water.
vi. Routine, periodic water quality monitoring of wells in the area should be institutionalised to track changes in contamination levels over time.

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