Hydrocarbon Contamination and Physicochemical Degradation of Groundwater in Artisanal Refining Hotspots of Gokana LGA, Rivers State, Nigeria

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Abstract
This study assessed the impact of artisanal refining ("kpo-fire") activities on groundwater quality in two communities (Lewe and Bodo) of Gokana Local Government Area, Rivers State, Nigeria. Groundwater is the primary drinking water source for these communities, yet artisanal refining has introduced petroleum hydrocarbons into shallow aquifers. A comparative and analytical research design was employed, involving field sampling from boreholes and laboratory analysis of physicochemical parameters, total petroleum hydrocarbons (TPH), and polycyclic aromatic hydrocarbons (PAHs). Results were benchmarked against EGASPIN standards. The findings revealed severe contamination. pH values (4.89 in Lewe; 5.33 in Bodo) fell below the EGASPIN range of 6.5–8.5, while dissolved oxygen (2.45 mg/L and 2.36 mg/L, respectively) was below the minimum of 5 mg/L. TPH concentrations (4.228 mg/L in Lewe; 3.777 mg/L in Bodo) exceeded the EGASPIN limit of 0.05 mg/L by approximately 85 and 76 times, respectively. Naphthalene was detected in both communities; fluorene only in Lewe. Lewe consistently recorded higher contamination than Bodo, with statistically significant differences ($p < 0.05$) for pH, electrical conductivity, turbidity, TPH, and total PAH. The study concludes that artisanal refining has severely degraded groundwater quality in Gokana LGA, posing significant public health and environmental risks. Immediate provision of safe drinking water, environmental remediation, and strengthened governance are recommended.

Keywords: *Artisanal refining, groundwater contamination, total petroleum hydrocarbons, polycyclic aromatic hydrocarbons, Gokana LGA, Niger Delta*

1. Introduction

Groundwater is a critical source of drinking water for millions of people in Nigeria, particularly in the Niger Delta region, where surface water is often polluted by oil-related activities. In Rivers State, groundwater serves as the primary source of potable water for rural and peri-urban communities due to limited access to treated municipal supplies (Nwankwoala & Omofuophu, 2020). However, the rise of artisanal refining, locally known as "kpo-fire," has introduced severe environmental challenges, especially contamination of groundwater resources. Artisanal refining involves the crude, makeshift distillation of stolen crude oil using rudimentary equipment, which releases hydrocarbons and toxic by-products into surrounding soils and aquifers (Ugwueze et al., 2024).

The Niger Delta has long been recognised as one of the most environmentally degraded oil-producing regions globally, with petroleum hydrocarbons being a major pollutant of water bodies (Ite et al., 2018). Studies in Rivers State, such as those conducted in Bonny Island, have revealed elevated levels of hydrocarbon contaminants in groundwater, posing risks to human health and ecological systems (Nwankwoala & Omofuophu, 2020). Hydrocarbon pollution is particularly concerning because compounds such as benzene, toluene, and polycyclic aromatic hydrocarbons (PAHs) are carcinogenic and can persist in groundwater for decades, making remediation difficult (Erifeta et al., 2024). Recent investigations in Delta State, geographically contiguous to Rivers State, demonstrated that artisanal refinery sites significantly increase hydrocarbon concentrations in groundwater and sediments, with microbial density also altered due to toxic exposure (Tudararo-Aherobo & Bright, 2023). These findings highlight the transboundary nature of artisanal refining impacts across the Niger Delta. In Rivers State, where artisanal refining is widespread, the contamination of aquifers threatens not only water quality but also food security, as groundwater is used for irrigation and aquaculture (Adeniran et al., 2023). Despite the growing body of evidence on hydrocarbon contamination in the Niger Delta, systematic studies quantifying the extent of groundwater contamination specifically linked to kpo-fire activities in Gokana LGA remain limited. This lack of data hampers effective policymaking, community awareness, and remediation efforts. Therefore, this study seeks to fill that gap by investigating the extent of groundwater pollution attributable to artisanal refining in selected communities of Gokana LGA, Rivers State. The specific objectives were to: (i) evaluate the physicochemical properties of groundwater in communities affected by artisanal refining; (ii) determine the concentrations of TPH and PAHs in groundwater samples; and (iii) compare the levels of these parameters between the affected communities.

2. Methodology

2.1 Study Area

The study was conducted in Gokana Local Government Area (LGA) of Rivers State, Nigeria. Gokana LGA covers approximately 166 km^2 and is situated in the eastern part of the state within the Ogoni cultural area; its administrative headquarters are in Kpor. The LGA has a population of approximately 228,828 (NPC, 2006), with groundwater serving as an important domestic water source. Hydrogeologically, Gokana LGA exhibits the typical Niger Delta setting of shallow aquifers, numerous rivers and tributaries, and high annual rainfall, conditions that increase the vulnerability of groundwater to surface-derived contaminants (Nwankwoala et al., 2023). Two communities, Lewe and Bodo, were purposively selected for this study because they represent contamination hotspots within the LGA where artisanal refining activities are prevalent.

2.2 Research Design

The study adopted a comparative and analytical research design involving field sampling and laboratory analysis. Groundwater samples were collected from boreholes that serve as primary drinking water sources in each community. The design allowed for systematic measurement of physicochemical parameters and petroleum hydrocarbons, enabling comparison between the two communities and benchmarking against regulatory standards.

2.3 Sampling Strategy and Groundwater Sampling

A purposive sampling approach was employed to select sampling points. Groundwater samples were collected from boreholes located close to artisanal refining sites as well as those farther away, to capture spatial variation in contamination levels. Samples were collected using sterile polyethylene bottles pre-rinsed with distilled water and the groundwater itself. Hydrocarbon

samples were stored in amber glass bottles to prevent photodegradation and kept under refrigeration until laboratory analysis. Physicochemical parameters such as pH, electrical conductivity (EC), turbidity, and dissolved oxygen (DO) were measured in situ using portable meters. Chain-of-custody procedures were strictly followed, with detailed documentation of sampling locations and environmental conditions.

2.4 Laboratory Analysis

Laboratory analyses were undertaken to evaluate the physicochemical properties and petroleum hydrocarbon concentrations in groundwater samples. All procedures followed standard laboratory protocols and internationally recognised methods. pH, EC, and DO were measured in situ using portable digital meters. Turbidity and total dissolved solids (TDS) were analysed under controlled laboratory conditions. For petroleum hydrocarbons, the analysis focused on total petroleum hydrocarbons (TPH) and polycyclic aromatic hydrocarbons (PAHs). Gas Chromatography-Mass Spectrometry (GC-MS) was employed to detect and quantify PAHs, while Infrared Spectrophotometry was used to measure TPH concentrations. The results were benchmarked against the Nigerian regulatory standards (EGASPIN) to determine whether concentrations exceeded safe thresholds.

2.5 Data Analysis

Data analysis combined descriptive statistics (means, standard deviations, ranges) and inferential statistics. An independent samples t-test was used to compare mean values of each parameter between the two communities. Analysis of Variance (ANOVA) was applied to assess variability within each community across multiple sampling points. Statistical significance was set at $p < 0.05$. All analyses were performed using standard statistical software.

3. Results

3.1 Physicochemical Properties of Groundwater

Table 1 presents the results of physicochemical analysis for Lewe and Bodo communities alongside the EGASPIN regulatory limits.

Table 1: Physicochemical Parameters of Groundwater in Lewe and Bodo Communities

S/N	Parameters	LEWE	BODO	EGASPIN
1	pH	4.89	5.33	6.5 – 8.5
2	Temperature (°C)	25.7	25.9	Ambient
3	Electrical Conductivity (µS/cm)	70	30	NS
4	Total Dissolved Solids (mg/L)	35	30	5,000
5	Turbidity (NTU)	0.54	0.17	10
6	Dissolved Oxygen (mg/L)	2.45	2.36	5

NS – Not Stated. Source: Laboratory Results, 2026

The pH values recorded were 4.89 for Lewe and 5.33 for Bodo. Both values fall below the EGASPIN permissible range of 6.5–8.5, indicating that the groundwater in both communities is acidic. The pH in Lewe was lower than that in Bodo, suggesting greater acidity in the Lewe community. Temperature readings were 25.7°C for Lewe and 25.9°C for Bodo, within ambient temperature ranges. Electrical conductivity was measured at 70 µS/cm in Lewe and 30 µS/cm in Bodo; the higher conductivity in Lewe indicates a greater concentration of dissolved ions.

TDS concentrations were 35 mg/L in Lewe and 30 mg/L in Bodo, both well below the EGASPIN limit of 5,000 mg/L. Turbidity levels were 0.54 NTU in Lewe and 0.17 NTU in Bodo, both below the EGASPIN limit of 10 NTU, though Lewe recorded higher turbidity. Dissolved oxygen concentrations were 2.45 mg/L in Lewe and 2.36 mg/L in Bodo, both below the EGASPIN recommended minimum of 5 mg/L, indicating low oxygen levels typical of water bodies affected by organic pollution.

3.2 Total Petroleum Hydrocarbons (TPH) in Groundwater

Table 2 presents the TPH concentrations recorded in Lewe and Bodo.

Table 2: Total Petroleum Hydrocarbons (TPH) Concentrations in Groundwater

S/N	Sample I.D.	TPH (mg/L)
1	LEWE	4.228
2	BODO	3.777
	EGASPIN	0.05

Source: Laboratory Results, 2026

The TPH concentration in Lewe was 4.228 mg/L, while Bodo recorded 3.777 mg/L. Both values are significantly higher than the EGASPIN permissible limit of 0.05 mg/L. The TPH level in Lewe exceeded the regulatory limit by approximately 85 times, while Bodo exceeded it by approximately 76 times. These results indicate severe hydrocarbon contamination of groundwater in both communities. The higher TPH concentration in Lewe suggests that this community experiences greater exposure to petroleum hydrocarbon pollution than Bodo.

3.3 Polycyclic Aromatic Hydrocarbons (PAHs) in Groundwater

Table 3 presents the PAH results for Lewe and Bodo communities.

Table 3: Polycyclic Aromatic Hydrocarbons (PAHs) Concentrations in Groundwater

S/N	Parameters	Lewe (mg/L)	Bodo (mg/L)
1	Naphthalene	2.59×10^{2}	2.38×10^{2}
2	Acenaphthene	ND	ND
3	Acenaphthene	ND	ND
4	Fluorene	2.08×10^{2}	ND
5	Anthracene	ND	ND
6	Phenanthrene	ND	ND
7	Fluoranthene	ND	ND
8	Pyrene	ND	ND
9	Benz(a)anthracene	ND	ND
10	Chrysene	ND	ND
11	Benzo(b)fluoranthene	ND	ND
12	Benz(k)fluoranthene	ND	ND
13	Benz(a)pyrene	ND	ND
14	Indeno(1,2,3-cd)pyrene	ND	ND
15	Dibenz(a,h)anthracene	ND	ND
16	Benzo(g,h,i)perylene	ND	ND
	Total PAH	**4.67×10^{2}**	**2.38×10^{2}**

ND = Not Detected. Source: Laboratory Results, 2026

Only two PAH compounds were detected in the groundwater samples. Naphthalene was detected in both communities at concentrations of 2.59×10^{2} mg/L in Lewe and 2.38×10^{2} mg/L in Bodo. Fluorene was detected only in Lewe at a concentration of 2.08×10^{2} mg/L. All other

PAH compounds analysed were below detection limits in both communities. The total PAH concentration was 4.67×10^2 mg/L in Lewe and 2.38×10^2 mg/L in Bodo. The higher total PAH concentration in Lewe is attributable to the additional presence of fluorene. The detection of naphthalene in both communities indicates the presence of light molecular weight petroleum hydrocarbons in the groundwater. The absence of heavier PAH compounds such as benzo(a)pyrene suggests that the contamination is predominantly from lighter petroleum fractions.

3.4 Comparative Analysis of Groundwater Quality Between Communities

Table 4 presents a comparative summary of groundwater quality parameters in Lewe and Bodo.

Table 4: Comparative Summary of Groundwater Quality Parameters in Lewe and Bodo

Parameter	Lewe	Bodo	EGASPIN Limit	Observation
pH	4.89	5.33	6.5 – 8.5	Both below limit; Lewe more acidic
Temperature (°C)	25.7	25.9	Ambient	Similar in both
EC (µS/cm)	70	30	NS	Higher in Lewe
TDS (mg/L)	35	30	5,000	Both within limits
Turbidity (NTU)	0.54	0.17	10	Both within limits; higher in Lewe
DO (mg/L)	2.45	2.36	5	Both below limit
TPH (mg/L)	4.228	3.777	0.05	Both exceed limit; higher in Lewe.
Total PAH (mg/L)	4.67×10^2	2.38×10^2	—	Higher in Lewe

Source: Researcher's compilation, 2026

The comparative analysis reveals that Lewe consistently recorded higher concentrations of contaminants than Bodo across most parameters. The pH was lower (more acidic) in Lewe (4.89) compared to Bodo (5.33). Electrical conductivity, turbidity, TPH, and total PAH were all higher in Lewe than in Bodo. Dissolved oxygen was slightly higher in Lewe (2.45 mg/L) than in Bodo (2.36 mg/L), though both were below the regulatory limit. Both communities recorded pH values below the EGASPIN permissible range, TPH concentrations far exceeding the regulatory limit, and dissolved oxygen levels below the recommended minimum. These findings indicate that groundwater in both communities is contaminated and unsuitable for drinking without treatment. However, the degree of contamination is more severe in Lewe than in Bodo.

3.5 Statistical Analysis

Statistical tests were conducted to determine whether the differences in groundwater quality parameters between Lewe and Bodo communities are statistically significant. An independent samples t-test was used to compare the mean values of each parameter between the two communities. Table 5 presents the results of the t-test for the key parameters.

Table 5: Summary of Independent Samples t-test Results

Parameter	t-value	p-value	Significance (p < 0.05)
pH	5.82	0.004	Significant
Temperature	0.91	0.412	Not Significant
EC	4.76	0.009	Significant
TDS	1.23	0.286	Not Significant
Turbidity	3.45	0.026	Significant
DO	0.67	0.538	Not Significant
TPH	6.14	0.003	Significant
Total PAH	4.89	0.008	Significant

Source: Researcher's Computation, 2026

The t-test results show statistically significant differences between Lewe and Bodo for pH, electrical conductivity, turbidity, TPH, and total PAH. This indicates that the groundwater quality in Lewe is significantly more contaminated than in Bodo for these parameters. No statistically significant differences were found for temperature, total dissolved solids, and dissolved oxygen, suggesting that these parameters are relatively similar across the two communities. ANOVA results indicated significant variability within each community for TPH and PAH concentrations across different sampling points, confirming that contamination is not uniform but varies spatially within the communities. This spatial heterogeneity is consistent with the proximity of sampling points to artisanal refining sites.

4. Discussion

4.1 Physicochemical Properties of Groundwater

The groundwater in Lewe and Bodo is acidic, with pH values of 4.89 and 5.33, both below the EGASPIN range of 6.5–8.5. Similar acidity (pH 5.2–6.8) was reported in Afam, Rivers State, and attributed to hydrocarbon infiltration and organic acid release during petroleum degradation (Igwe et al., 2021). The lower pH in Lewe indicates more intense contamination. Acidic groundwater increases the solubility and mobility of toxic metals such as lead and cadmium, raising exposure risks (Erifeta et al., 2024). Electrical conductivity was 70 µS/cm in Lewe and 30 µS/cm in Bodo. The higher value in Lewe reflects greater dissolved ion content from hydrocarbon degradation products and leaching of refining residues (Okonkwo et al., 2023). TDS remained low (35 and 30 mg/L), typical of shallow Niger Delta aquifers with rapid rainfall recharge (Osuamkpe et al., 2025), but low TDS does not indicate safe water because petroleum hydrocarbons do not dissociate into ions. Turbidity was below the EGASPIN limit of 10 NTU in both communities (0.54 and 0.17 NTU), though higher in Lewe. The difference suggests more suspended refining residues and contaminated soil particles at Lewe. Dissolved oxygen was 2.45 mg/L in Lewe and 2.36 mg/L in Bodo, both below the 5 mg/L minimum. Low DO is characteristic of organic pollution, as microbial hydrocarbon degradation consumes oxygen and creates anaerobic conditions (Ogidi & Omirose, 2025).

4.2 Total Petroleum Hydrocarbons in Groundwater

TPH concentrations were 4.228 mg/L in Lewe and 3.777 mg/L in Bodo, exceeding the EGASPIN limit of 0.05 mg/L by 85 and 76 times, respectively. These values agree with earlier reports of TPH above permissible limits in Niger Delta artisanal refining hotspots (Erifeta et al., 2024; Nwankwoala & Omofuophu, 2020). Petroleum hydrocarbons contain toxic compounds such as benzene, toluene, ethylbenzene, and xylene, which are linked to leukaemia, neurological damage, and immune suppression (Aleku et al., 2024). Chronic consumption of this water poses a serious health risk, and hydrocarbons can persist in aquifers for decades (Adeniran et al., 2023).

4.3 Polycyclic Aromatic Hydrocarbons in Groundwater

Naphthalene was detected in both communities (2.59×10^2 mg/L in Lewe; 2.38×10^2 mg/L in Bodo), and fluorene only in Lewe (2.08×10^2 mg/L). Total PAH was 4.67×10^2 mg/L in Lewe and 2.38×10^2 mg/L in Bodo. The presence of light molecular weight PAHs indicates petroleum-derived contamination. The absence of heavier compounds such as benzo(a)pyrene suggests contamination from lighter petroleum fractions. Naphthalene is volatile and relatively biodegradable; its presence indicates recent or ongoing input. Fluorene is more resistant to degradation, and its detection only in Lewe may reflect differences in crude composition or contamination age.

4.4 Comparison of Groundwater Quality Between Communities

Lewe recorded higher contamination than Bodo for pH, electrical conductivity, turbidity, TPH, and total PAH, with statistically significant differences ($p < 0.05$). This spatial variation agrees with Ukaigwe et al. (2025), who reported heterogeneous groundwater quality around artisanal refining sites in Rivers State. The differences may arise from a higher density of refining sites in Lewe, shallower or more permeable aquifers, closer proximity of water sources to refining operations, or weaker waste containment practices. ANOVA showed significant within-community variability for TPH and PAH, confirming that contamination varies with distance from refining sites. Dissolved oxygen was slightly higher in Lewe (2.45 mg/L) than in Bodo (2.36 mg/L) despite higher hydrocarbon levels in Lewe. This may reflect differences in microbial activity or recharge rates, or the influence of temperature and atmospheric exchange on DO. Both values remain below the regulatory minimum, indicating organic pollution in both communities.

5.0 Conclusion

This study assessed the impact of artisanal refining ("kpo-fire") activities on groundwater quality in Gokana Local Government Area, Rivers State, Nigeria. The investigation revealed that groundwater in both Lewe and Bodo communities is severely contaminated with petroleum hydrocarbons and exhibits significant physicochemical degradation. The pH values were below the EGASPIN permissible range, dissolved oxygen levels were below the recommended minimum, and TPH concentrations exceeded the regulatory limit by approximately 85 and 76 times in Lewe and Bodo, respectively. The detection of naphthalene in both communities and fluorene in Lewe confirms petroleum-derived contamination of the aquifers. The comparative analysis showed that Lewe is more severely contaminated than Bodo, with statistically significant differences for pH, electrical conductivity, turbidity, TPH, and total PAH. The study concludes that groundwater in both communities is grossly contaminated and unsuitable for drinking without advanced treatment. Immediate provision of safe water alternatives and environmental remediation are urgently recommended.

References

Adeniran, M. A., Oladunjoye, M. A., & Doro, K. O. (2023). Soil and groundwater contamination by crude oil spillage: A review and implications for remediation projects in Nigeria. *Frontiers in Environmental Science, 11*, 1137496. https://doi.org/10.3389/fenvs.2023.1137496

Aleku, D. L., Biester, H., & Pichler, T. (2024). Pipeline-related residential benzene exposure and groundwater natural attenuation capacity in the eastern Niger Delta, Nigeria. *Environments, 11*(10), 221.

Erifeta, E. K., Ezugwu, M. O., Erifeta, G. O., & Akhimien, F. A. (2024). Evaluation of total petroleum hydrocarbon (TPH) in groundwater in the Niger Delta region of Nigeria. *International Journal of Novel Research and Development, 9*(11), 252.

Igwe, O., Ngwoke, M., Ukah, B. U., & Ubido, O. E. (2021). Assessment of the physicochemical qualities of groundwater and soils around oil-producing communities in Afam, Port Harcourt, Niger Delta, Nigeria. *Applied Water Science, 11*(74). https://doi.org/10.1007/s13201-021-01379-9

Ite, A. E., Harry, T. A., Obadimu, C. O., Asuaiko, E. R., & Inim, I. J. (2018). Petroleum hydrocarbons contamination of surface water and groundwater in the Niger Delta region of Nigeria. *Journal of Environment Pollution and Human Health, 6*(2), 51–61. https://doi.org/10.12691/jephh-6-2-2

NPC. (2006). *2006 Population and Housing Census*. National Population Commission, Abuja.

Nwankwoala, H. O., & Omofuophu, E. (2020). Investigation of hydrocarbon contaminant levels and groundwater quality assessment in parts of Bonny Island, Rivers State, Nigeria. *Central Asian Journal of Environmental Science and Technology Innovation, 1*(1), 61–70.

Nwankwoala, H. O., Abam, T. K. S., & Giadom, F. D. (2023). Challenges of groundwater development and supply in the Niger Delta, Nigeria. *Journal of Water Resource and Protection, 15*, 247–275.

Ogidi, M. A., & Omirose, N. Y. (2025). Assessment of physicochemical parameters in groundwater quality in Ikere-Ekiti, Nigeria. *IRE Journals, 8*(8), 45–56.

Okonkwo, C. N., Eze, P. N., & Nwankwo, I. C. (2023). Oil and gas activities and environmental degradation in the Niger Delta: A review. *Journal of Environmental Management, 345*, 118765. https://doi.org/10.1016/j.jenvman.2023.118765

Osuamkpe, N. B., Tamunobereton-ari, I., Amakiri, A. R. C., & Amonieah, J. (2025). Assessment of groundwater potential and vulnerability in Rivers State, Nigeria, using integrated geophysical, geological and geospatial techniques. *International Journal of Energy and Water Resources, 9*(7), 2325–2347. https://doi.org/10.1007/s42108-025-00345-9

Tudararo-Aherobo, L., & Bright, M. (2023). Assessment of the impacts of artisanal refinery of crude oil on surface water, groundwater and sediment quality at Obi-Ayagha community in Delta State, Nigeria. *International Journal of Scientific Research in Science and Technology, 10*(3), 325–336. https://doi.org/10.32628/IJSRST52310325

Ugwueze, M. I., Asua, S. A., Mbadah, S. A., Ezeme, P. E., Atime, P. L., Oboiji, J. N., & Ngwu, E. C. (2024). The state and criminalisation of artisanal oil refining in Nigeria. *Society, 61*(4), 547–559. https://doi.org/10.1007/s12115-024-00990-w

Ukaigwe, O. B., Nwachukwu, E., Patricks, C., & Ugwoha, E. (2025). Spatial evaluation of water quality of surface and groundwater around artisanal refining polluted area in Emohua LGA, Rivers State. *GPH-International Journal of Applied Science, 8*(6), 01–22. https://doi.org/10.5281/zenodo.15805836