Global Journal of Engineering and Technology Advances

eISSN: 2582-5003

Cross Ref DOI: 10.30574/gjeta

Journal homepage: https://gjeta.com/

(Research Article)

Groundwater Contamination Dynamics in Peri-Urban Nigeria: Insight from Septic Tank Proximity and Water Quality Index

Erewari Ukoha-Onuoha, Davidson D. Davis * and Samuel Deinte

Department of Agricultural and Environmental Engineering, Faculty of Engineering, Rivers State University PMB 5080, Port Harcourt, Nigeria.

Global Journal of Engineering and Technology Advances, 2026, 26(03), 027-035

Publication history: Received on 17 January 2026; revised on 02 March 2026; accepted on 04 March 2026

Article DOI: https://doi.org/10.30574/gjeta.2026.26.3.0046

Abstract

This study examines the relationship between septic tank proximity and groundwater contamination in Aluu, a developing peri-urban community in Rivers State. Six water samples from boreholes were analyzed for physicochemical parameters (pH, total dissolved solids, alkalinity, and heavy metals: lead, cadmium, and chromium) and microbes (total coliform and *E. coli*). Bacteria indicator ratio and weighted arithmetic water quality index (WA-WQI) were employed to assess effluent infiltration and suitability for human consumption. Results revealed that 67% of sampled boreholes failed to meet the minimum 20-meter separation distance from septic tanks as set by the Nigerian Industrial Standard (NIS) guidelines. While heavy metals and total dissolved solids (TDS) remained within permissible standards, all samples exceeded Nigerian Standard for Drinking Water Quality (NSDWQ) limits for total coliform and E. coli. Biochemical oxygen demand (BOD) exceeded guidelines in some samples, suggesting organic pollution. WA-WQI scores classified samples as very poor (76.32), poor (51.25 – 68.03) and good (48.58). Cd and BOD were identified as the major chemical pollutants with Cd and BOD having contributory shares of 41.03 to 59.05 % and 34 to 43.76 % respectively. All other chemical parameters had contributory share of 6.94 to 23.14%. The total coliform to E. coli ratio for all samples was low (2 to 5.7:1) confirming septic effluent infiltration. Correlation analysis did not directly link proximity as the major factor responsible for effluent infiltration. The study recommends groundwater evaluation in peri-urban areas, and treatment of all water samples before consumption.

Keywords: Groundwater Quality; Septic Tanks; Peri-Urban Areas; Niger Delta; Water Quality Index; Microbial Contamination

1. Introduction

One very important challenge faced by peri-urban dwellers in the Niger Delta region of Nigeria is access to potable water. The major source of drinking water in this region is groundwater, but this source is highly threatened by saltwater intrusion and substandard town planning. Saltwater intrusion is due to the diverse aquatic ecosystem of the region. The region is characterized by the presence of freshwater and brackish water (Edegbene et al., 2025, Molua et al., 2024, Onyena et al., 2021). Saltwater intrusion, though a natural phenomenon, is aggravated by man's activities such as sea-level rise due to climate change and reversal of the hydraulic gradient caused by groundwater over-exploitation (Eyankware et al., 2025, Aghogho et al., 2024, Abija et al., 2021, Ketabchi et al., 2016).

Peri-urban areas often lack standard town planning because they are developed by individual efforts. These areas lack centralized water supply and wastewater treatment systems. Individual residents supply water for themselves from shallow boreholes (Udom and Nwankwo, 2022, Efeotor and Akpokodje, 2020). Additionally, residents use on-site domestic wastewater disposal systems such as septic tanks.

* Corresponding author: Davidson D. Davis

Septic tanks are sites of anaerobic reactions, but they are often constructed with little or no regard to such reactions. For most households, nearly all sewerage systems and structures are designed to terminate in septic tanks. And with a high average annual rainfall and loose sandy soil, quick recharge of aquifer is also associated with pollutant migration in the region (Akpan and Edet, 2018, Edet and Okereke, 2014). The proximity of septic systems to boreholes and hand dug wells may promote infiltration of septic tank effluent into the boreholes (Amadi et al., 2012). Meanwhile studies on groundwater pollution in the region are mostly focused on large scale industrial pollution from oil and gas exploration activities (Oyebamiji et al., 2025, Ola et al., 2024, Ikenna and Chukwudozie, 2024). This tends to eclipse the persistent domestic contamination that affects daily household water security especially in newly developing peri-urban settlements (Nwankwoala and Udom, 2011).

This research examines this gap by studying water quality and septic tank distance in a developing peri-urban area. By combining location data and lab tests on water samples, it aims to: (i) find the amount and spread of key pollutants (microbes and heavy metals) in groundwater; (ii) find a link between pollution levels and distance to septic tanks using water quality index and relationship between bacterial indicators. The results should give valuable proof for public health work, help communities manage their water better, and help change environmental rules to protect the vital groundwater that millions in the Niger Delta rely on.

2. Materials And Method

2.1. Study Area and Sampling Site Selection

This study was carried out in Aluu as shown in Figure 1. Alu, a peri-urban area, is located in Ikwerre Local Government Area of Rivers State of Nigeria. It is a clan in the upland fringes of the eastern Niger Delta hinterland and has a land area of about 10,000 square kilometers. By the 1991 census, its population was about 19,000. However, due to the presence of several government establishments in the clan, a great population explosion has occurred, placing the clan as one of the most densely populated communities in Ikwerre Local Government Area. As a tropical region, the climate of Aluu is characterized by a wet and dry season. Its good tropical climate and surplus arable land permit occupations like farming, fishing and hunting. Thus, the Alu people are predominantly agriculturists.

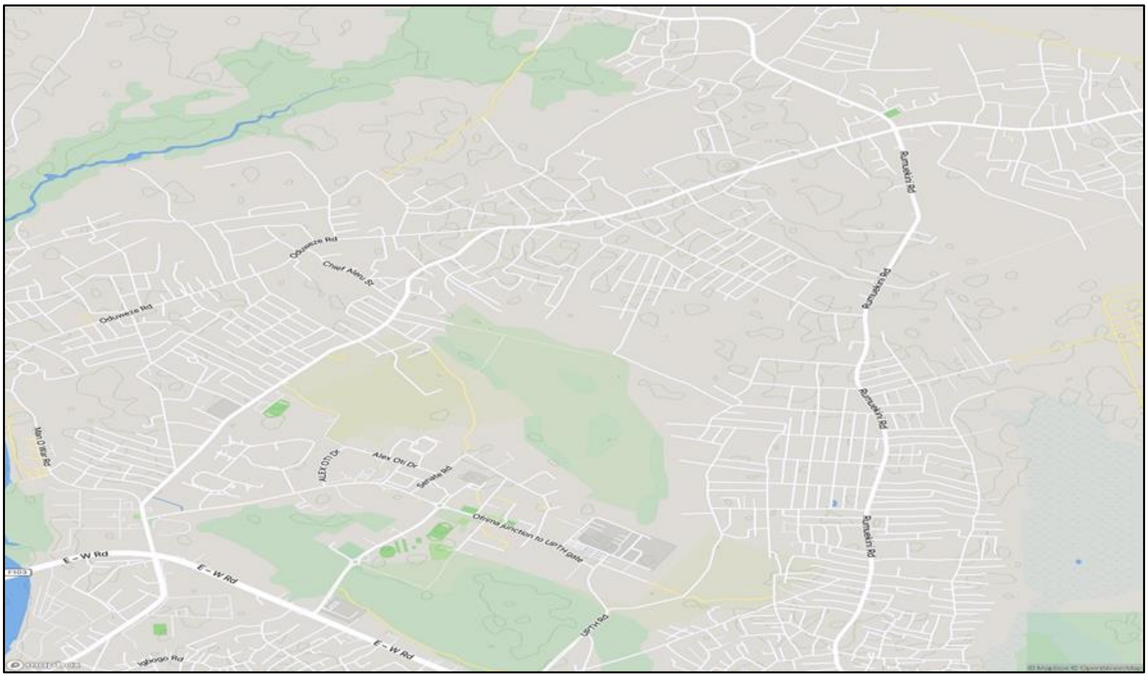

Figure 1 Map showing Alu and its neighboring environs

Field trips were made to the study location. The primary purpose of the initial visits was to have a general survey of the study area, familiarize with local authorities and residence caretakers, and select sampling points. The visit also enabled a feasibility study to be carried out on the required resources to accomplish effective sampling and a schedule for the collection of samples.

2.2. Water Sample Collection

At the commencement of the sample collection, the horizontal distance between the boreholes and the septic tanks was measured using a measuring tape. Six samples were taken, and all samples were taken from boreholes within the range of 5.3 m – 25 m. Sampling was limited to this range because of the denial of access by most resident owners and caretakers.

Water samples were collected using sampling bottles. The sampling bottles were rinsed thrice with distilled water and sample water before filling. The collected samples were then properly labelled, placed in an ice box and taken to the laboratory for analysis. Chemical properties, including pH, alkalinity, total dissolved solids (TDS), biochemical oxygen demand (BOD), and heavy metals, were analyzed. Microbial analyses for total coliform and E. coli were also done. Heavy metals analyzed include Pb, Cd, and Cr. All analyses were carried out following standard procedures and methods. TDS and pH were measured using a handheld multi-parameter tester (pH-W3988), while an Atomic Absorption Spectrophotometer (Shimadzu AA-6650) was used for heavy metal analysis. Microbial analysis was achieved using the membrane filtration method, according to the APHA standard (APHA, 2017).

2.3. Determination of Water Quality Index

The weighted arithmetic water quality index (WA-WQI) was used to describe the quality of each water sample and also describe the effect of septic tank distance on borehole pollution. The calculation of the WA-WQI was done without alkalinity, total coliform, and E. coli. From Equation 1, the inclusion of total coliform and E. coli with a permissible limit of zero in the calculation of WA-WQI will give an undefined answer. Also, in the Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines, no limit was set for alkalinity.

$$WA - WQI = \frac{\sum(W_n Q_n)}{\sum W_n}$$

Where Q_n is the quality rating for each measured parameter, and W_n is the assigned unit weight for each parameter. Table 1 illustrates the interpretation of the numeric values. Considering the microbial contamination of water samples, the relationship between the two indicator bacteria was used.

Table 1 WA-WQI Rating of Composite Scores

Range	Category/Status	Description
0-25	Excellent water	Very good quality; suitable for drinking without treatment
26-50	Good water	Acceptable for drinking; minor treatment may be needed
51-75	Poor water	Not fit for direct drinking; requires significant treatment
76-100	Very poor water	Only suitable for irrigation or industrial purpose after treatment
>100	Unfit for drinking	Unsuitable for human consumption; needs extensive purification

3. Results and Discussions

3.1. Water quality

The distances between the six septic tanks and boreholes are presented in Table 2. Using the Nigerian Industrial Standard (NIS) guidelines for code of practice for water well construction (NIS, 2010), about 67% of these boreholes did not meet the minimum separation distance of 20 m between borehole and septic tank. This implies that water from these boreholes may be prone to contamination and may not be fit for consumption.

Table 2 Borehole water quality

Sample ID	S-1	S-2	S-3	S-4	S-5	S-6
Distance (m)	5.3	8.36	12	15	20	25
pH	6.89	6.42	6.78	6.31	6.97	6.58
Alkalinity (mg/l)	110.43	150.26	124.90	89.21	162.17	136.19
TDS (mg/l)	52.13	34.77	81.65	28.95	72.14	40.73
Pb (mg/l)	0.0031	0.0039	0.0018	0.0051	0.0029	0.0042
Cd (mg/l)	0.0020	0.0014	0.0030	0.0020	0.0015	0.0020
Cr (mg/l)	0.0042	0.0076	0.0090	0.0053	0.0094	0.0048
BOD (mg/l)	5.27	4.89	6.91	6.25	5.66	6.42
Total Coliform (cfu/100 ml)	25	13	42	10	74	86
E. coli (cfu/100 ml)	10	8	18	5	13	15

The recorded mean values of pH show that all samples except S-2 and S-4 were within the Nigerian Standard for Drinking Water Quality (NSDWQ) guideline of 6.5-8.5 (NSDWQ, 2015). Samples S-2 and S-4, with pH values of 6.42 and 6.31, respectively, were slightly acidic. The pH of S-2 and S-4 were similar to the works of Ogbonna and Emenike (2021). The TDS values were all lower than the NSDWQ maximum allowable limit of 500 mg/l. Several works have also reported low TDS within the study area and nearby environment (Asomaku, 2023; Ogbonna and Emenike, 2021; Eze and Eze, 2015). The comparison between the pH values of the sample and the TDS shows a high positive correlation (r=0.82). The high correlation suggests that geochemical properties of the substrata materials may be responsible for the variation in pH values. This is supported by the moderate to high alkalinity (89.21 to 162. 17 mg/l). According to Shuaibu et al. (2024) groundwater alkalinity is suggestive of the presence of carbonate rocks. The pH, TDS, and alkalinity values with respect to the distance between the septic tank and the borehole are generally disproportionate. This is similar to the work of Eze and Eze (2015) and Adesakin et al. (2020). The disproportionation of these parameters resulted in the low correlation values as shown in Table 3. The low correlation (r = 0.39) between pH and alkalinity may be due to the influence of dissolved chemicals such as carbon dioxide, organic acids, sulfate, and nitrate. Saalidong et al. (2022), reported that the strength of correlation between pH and alkalinity could be weakened by the multifaceted reactions of dissolved substances in the water. Also, the low correlation (r = 0.36) between TDS and alkalinity may be attributed to the difference in the measured substances. Whereas TDS is a measure of all dissolved solids, including salts, minerals, and organic matter, alkalinity only includes acid-neutralizing ions like carbonate, bicarbonate, and hydroxide. Therefore, variance in TDS does not always translate to equal variance in alkalinity.

The studied heavy metals in the work were all within the acceptable limits of the NSDWQ guideline. Pb, Cd, and Cr are reported to have maximum allowable limits (MAL) of 0.01 mg/l, 0.003 mg/l, and 0.05 mg/l, respectively, to be fit for potable water. All samples recorded values lower than these guideline values, except Cd for the S-3 sample, which was at the threshold value (Table 2). Concentrations of heavy metals in the samples ranged between 0.0018 – 0.0051 mg/l, 0.0014 – 0.003 mg/l, and 0.0042 – 0.0090 mg/l for Pb, Cd, and Cr, respectively.

Pb has a strong inverse correlation with pH and TDS. The strong inverse correlation between pH and Pb is typical of groundwater unpolluted with heavy metals. Pb is highly soluble at pH < 6 (Jebril et al., 2024) while minimum solubility occurs at near neutral pH (6 – 8) (Pierrard et al., 2002). The pH values of the water samples in this study ranged between 6.31 and 6.97, which did not favour Pb solubility. Cr showed good direct correlation with TDS and alkalinity, suggesting that both TDS and Cr may be from a similar source, and with high alkalinity, this source may be geogenic (Izbicki et al., 2015). Cd showed moderate direct correlation (r = 0.5) with TDS and strong direct correlation (r = 0.81) with BOD. This is similar to the report of Gworek, et al. (2021), and this illustrates that both BOD and Cd may be from a similar source (Kubier et al., 2019).

BOD in groundwater is a direct indication of organic pollution. Common sources of organic pollution in groundwater are septic or sewage leaks and landfill leachates. The NSDWQ and WHO maximum value for BOD in drinking water is 6mg/l. From the results shown in Table 2, samples S-3, S-4, and S-6 had values above the set standard, while samples S-1, S-2, and S-5 were just below the permissible limit. Samples S-2 and S-5, with 8.36 m and 25 m distances between septic tanks and boreholes, reported the lowest and highest BOD values, respectively.

Table 3 Pearson's Correlation Matrix between Distance of Septic Tank and Water Parameters

	Distance	**pH**	**Alkalinity**	**TDS**	**Pb**	**Cd**	**Cr**	**BOD**	**Total Coliform**	**E. coli**
Distance	1									
pH	-0.02624	1								
Alkalinity	0.295161	0.390702	1							
TDS	0.014193	0.819259	0.359566	1						
Pb	0.24463	-0.78454	-0.36295	-0.93793	1					
Cd	-0.07636	0.145082	-0.44283	0.498051	-0.50261	1				
Cr	0.072205	0.324652	0.627719	0.675297	-0.59916	0.064653	1			
BOD	0.494658	-0.0197	-0.31674	0.354473	-0.1832	0.805551	0.101151	1		
Total Coliform	0.815086	0.488131	0.551659	0.408725	-0.24132	0.01507	0.178354	0.362103	1	
E. coli	0.347877	0.592695	0.410227	0.780348	-0.75517	0.58101	0.412229	0.565079	0.704895	1

Coliform bacteria are a broad group of bacteria naturally found in the environment and in the wastes of warm-blooded animals, including humans. It is therefore commonly used to assess water quality and determine potential risks to public health. Table 2 shows the presence of coliform as total coliform and E. coli. According to the NSDWQ guideline, there should be no count of coliform in drinking water. While E. coli bacteria in water samples serve as indicators of faecal contamination, total coliform (TC) is indicative of environmental bacteria. The presence of E. coli in the water samples, therefore, suggests an infiltration from the septic tank to the borehole. However, the high direct correlation ($r = 0.82$) between TC and distance and the low correlation ($r = 0.35$) between E. coli and distance do not illustrate an influence of the proximity of the septic tank distance to the borehole. This does not negate the possibility of infiltration of septic tank effluent into boreholes; it suggests the presence of cracks/leaks in septic tanks, poor well construction and integrity, as well as water table level and seasonal flooding as other contributing factors to the infiltration (Amadi and Aghogho, 2019; Edet and Okereke, 2014; Etu-Efeotor and Akpokodje, 2020; Nwankwoala and Harry, 2012; Udom and Nwankwoala, 2022; Ugbaja and Edet, 2020). Moreover, a moderate correlation ($r = 0.56$) between BOD and E. coli was observed, illustrating a possible similar source.

3.2. Overall Chemical Water Quality Determination

Table 4 shows that only one sample (S-5) was of good quality, while the remaining were of poor and very poor quality. This implies that, except for sample S-5, all other water samples require extensive treatment to improve the water quality before consumption.

Table 4 Water quality indices based on chemical parameters

Sample ID	Sub-index of Cd	Contributive share, %	Sub-index of BOD	Contributive share, %	Sub-index of others	Contributive share, %	WA-WQI	Water quality Classification
S-1	30.04	54.18	19.79	35.70	5.61	10.12	55.44	Poor
S-2	21.03	41.03	18.36	35.82	11.86	23.14	51.25	Poor
S-3	45.07	59.05	25.95	34.00	5.3	6.94	76.32	Very Poor
S-4	30.04	44.16	23.47	34.50	14.52	21.34	68.03	Poor
S-5	22.53	46.38	21.26	43.76	4.79	9.86	48.58	Good
S-6	30.04	46.52	24.11	37.34	10.42	16.14	64.57	Poor

As shown in Table 4, the major pollutants are Cd and BOD, with Cd having a contributory share ranging from 41.03 to 59.05 % and BOD having a contributory share ranging from 34 to 43.76 %. The identification of BOD and Cd as the major pollutants, in addition to their strong direct correlation as shown in Table 3, substantiates the possible infiltration of septic tank effluent into the boreholes.

Cd, having a contributory share of 21.03 – 45.07 % and presented as a major pollutant of the water samples, invalidates the fact that the concentration of Cd in all water samples was within the permissible range. However, this is possible because of the emphasis the WA-WQI places on health risk pollutants. With the WA-WQI, it was observed the water quality is more influenced by health risk pollutants such as heavy metals than TDS, electrical conductivity, turbidity, colour and chloride even when these parameters may be above their permissible limits (Ukoha-Onuoha et al., 2025). It is such that concentrations of Cd in water samples, though below the MAL value, were either close to or exactly the same as the MAL value (Table 2).

3.3. Overall Microbial Water Quality Determination

The microbial water quality was assessed using the ratio of the two bacterial indicators - total coliform and E. coli. Beyond the presence of coliform bacteria in a water sample, the total coliform to E. coli ratio is informative about the source of contamination. While a low ratio is suggestive of recent faecal pollution of warm-blooded animals, high ratio is indicative of an environmental origin. This implies that water with a low ratio could contain disease-causing microbes and so serve as a higher sanitary risk. Conversely, a high ratio infers low sanitary risk with minimal disease-causing bacteria (Meays et al., 2004, LeChevallier, 2003, Ashbolt, 2001). Although there are no specific threshold values in standard guidelines or any available literature, a threshold value of ≤6:1 was introduced for the low ratio based on the interpretations of well water test results as reported by Leeds, Grenville, and Lanark District Health Unit (2017).

In this study, the total coliform to E. coli ratio ranged between 2.0 and 5.7:1, as shown in Figure 2. These ratios are less than 6:1. This corroborates the fact that there was infiltration of septic tank effluent into the boreholes and that there is a compromise of the sanitary integrity of the boreholes. These boreholes are therefore high-risk boreholes and so they are not suitable for drinking without treatment to deactivate microbes.

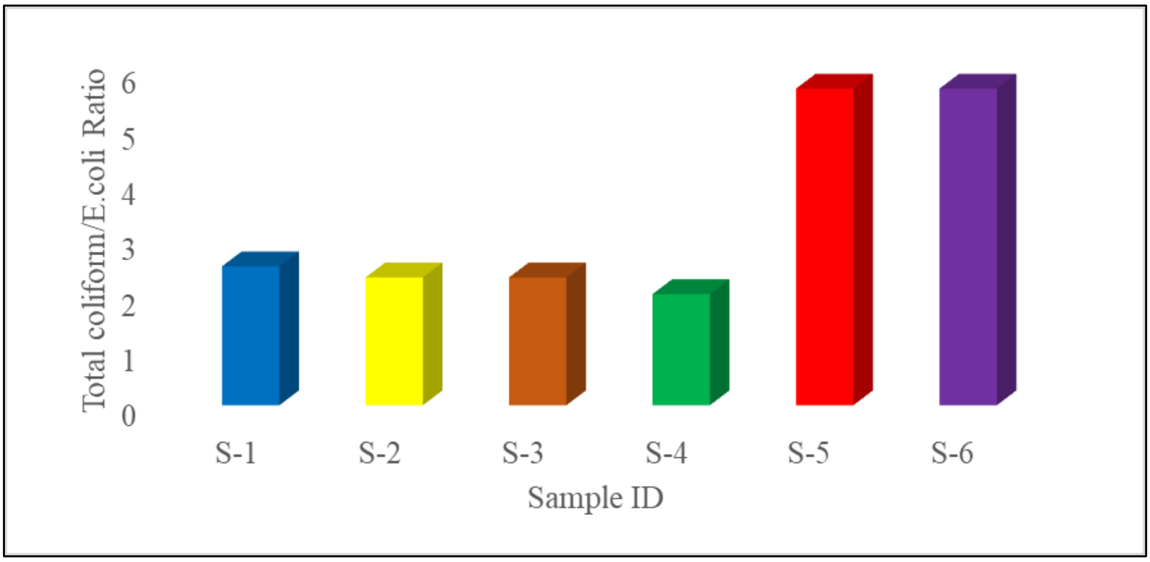

Figure 2 Sanitary Risk Ratio of Total Coliform to E. coli

4. Conclusion

This study showed the infiltration of septic tank effluent into boreholes within a spacing distance of 5.3 to 25 m. The presence of total coliform and E. coli, and the ratio of both indicator microbes, expressed this phenomenon. The use of the weighted arithmetic water quality index showed all water samples to be of poor quality except S-3. BOD and Cd were identified as the major chemical pollutants, although all heavy metals in this study were within the safe zone as recommended by the NSDWQ. A high direct correlation between BOD and Cd and a moderate correlation between BOD and Cd suggest that both pollutants have a similar origin - septic tank. Pearson's correlation matrix did not link pollution levels with spacing between septic tanks and boreholes. It is therefore recommended that in the assessment of the impact of septic tanks on boreholes, spacing should not be the only factor considered. But also cracks/leaks in septic tanks, poor well construction, and borehole integrity, as well as seasonal flood should be considered. Also, water should be treated before use.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Abija, F. A., Marshall, H. I., and Udom, G. J. (2021). Sources of salinization and investigation of salt water intrusion into coastal aquifers in parts of the Niger Delta, Nigeria. Journal of Hydrogeology and Hydrologic Engineering. 10(7), 1-7.

[2] Adesakin, T. A., Oyewale, A. T., Bayero, U., Mohammed, A. N., Aduwo, I. A., Ahmed, P. Z., Abubakar, N. D., and Barje, I. B. (2020). Assessment of bacteriological quality and physico-chemical parameters of domestic water sources in Samaru community, Zaria, Northwest Nigeria. Heliyon, 6. e04773. https://doi.org/10.1016/j.heliyon.2020.e04773

[3] Aghogho, O., Chucks, E. J., and Chukwuemeka, O. E. (2024). Investigation of saltwater intrusion into freshwater aquifers in some estuary environment in Niger Delta. Journal of Water Resources and Ocean Science, 13(4), 94–104. https://doi.org/10.11648/j.wros.20241304.11

[4] Akpan, I. O., and Edet, A. E. (2018). Assessment of impact of septic tank systems on groundwater quality in Calabar, South-Eastern Nigeria. Global Journal of Geological Sciences, 16, 1–12.

[5] Amadi, A. N., and Aghogho, O. (2019). Aquifer vulnerability and groundwater quality in the coastal sands of the Niger Delta Basin, Nigeria. Journal of African Earth Sciences, 160, 103618. https://doi.org/10.1016/j.jafrearsci.2019.103618

[6] Amadi, A. N., Olaschinde, P. I., and Yisa, J. (2012). Assessment of the impact of septic tanks on groundwater quality in parts of Port Harcourt, Nigeria. Journal of Environmental Science and Engineering, 1(3), 1–5.

[7] APHA (American Public Health Association). (2017). Standard methods for the examination of water and wastewater (23rd ed.). APHA, AWWA, WEF.

[8] Ashbolt, N. J. (2001). Microbial contamination of drinking water and disease outcomes in developing regions. Toxicology, 198(1–3), 229–238. https://doi.org/10.1016/j.tox.2004.01.030

[9] Asomaku, S. O. (2023). A Quality assessment of groundwater sourced from nearby abandoned landfills fromIndustrial City in Nigeria:Water pollution indices approach. HydroResearch, 6:130-137. https://doi.org/10.1016/j.hydres.2023.03.002

[10] Edegbene, A. O., Yaagoubi, S. E., and Ovie, T. T. E. (2025). Macroinvertebrates functional feeding groups (FFGs) of forested streams draining urban catchments in the Niger Delta: identifying and classifying vulnerable and tolerant FFGs. Chemistry and Ecology, 41(3), 354-374. https://doi.org/10.1080/02757540.2024.2432895

[11] Edet, A. E., and Okereke, C. S. (2014). Hydrogeological and hydrochemical character of the regolith aquifer, northern Obudu Plateau, southern Nigeria. Hydrogeology Journal, 22(6), 1265–1286. https://doi.org/10.1007/s10040-014-1139-8

[12] Etu-Efeotor, J. O., and Akpokodje, E. G. (2020). Hydrogeochemical investigation of shallow groundwater in the peri-urban areas of Warri, Niger Delta. Journal of Mining and Geology, 56(1), 1–14.

[13] Eyankware, M. O., Mba-Otike, M. N., Odesa, G. E., Chukwusa, F. O., Osisanya, W. O., Eyankware-Ulakpa, R. O., Akakuru, O. C. and Komolafe, N. P. (2025). Saline intrusion in Niger Delta coastal aquifers, drivers, hydrogeological dynamics and mitigation strategies. Discover Geoscience, 3:150, 1-28. https://doi.org/10.1007/s44288-025-00264-w

[14] Eze, C. L. and Eze, E. M. (2015). Investigation of Possible Groundwater Contamination from Septic System Siting in Port Harcourt, Nigeria. Journal of Natural Sciences Research, 5(10), 83-87

[15] Izbicki, J.A., Wright, M.T., Seymour, W.A., McCleskey, R.B., Fram, M.S., Belitz, K., and Esser, B.K. (2015). Cr(VI) occurrence and geochemistry in water from public-supply wells in California. Applied Geochemistry, 63, 203-217. http://dx.doi.org/10.1016/j.apgeochem.2015.08.007

[16] Ikenna, S. J. and Chukwudozie, O. S. (2024). Groundwater quality assessment in crude oil-impacted communities in Ogoniland in the Niger Delta using the Water Quality Index (WQI). International Journal of Research in Engineering, Science and Management. 7(9), 1-5

[17] Jebril, N. M. T., Al-Mamoori, N. H. O., Alhussainy, O. A. M. H., Sadeq, F. M. S., Alkareem, H. A., and AL-Taee, S. A. R. (2024). Theoretical Determination of Lead Availability and Speciation in Laboratory-Prepared Groundwater. IOP Conference Series: Earth and Environmental Science, 1371(2), 022011. https://doi:10.1088/1755-1315/1371/2/022011

[18] Ketabchi H, Mahmoodzadeh D, Ataie-Ashtiani B, Simmons C. T. (2016). Sea-Level Rise Impacts On Seawater Intrusion In Coastal Aquifers: Review And Integration. Journal of Hydrology. 535:235–55. https://doi.org/10.1016/j.jhydrol.2016.01.083

[19] Kubier, A., Wilkin, R.T., and Pichler, T. (2019). Cadmium in soils and groundwater: A review. Applied Geochemistry, 108, 104388. https://doi.org/10.1016/j.apgeochem.2019.104388

[20] LeChevallier, M. W. (2003). Conditions Favouring Coliform and HPC Bacterial Growth in Drinking-water Distribution Systems. In: Bartram, J. et al. (Eds.), Heterotrophic Plate Counts and Drinking-water Safety. IWA Publishing / WHO.

[21] Leeds, Grenville and Lanark District Health Unit. (2017). Sample Results. https://healthunit.org/health-information/drinking-water/sample-results . Accessed 9th January 2026

[22] Meays, C. L., Broersma, K., Nordin, R., and Mazumder, A. (2004). Source tracking fecal bacteria in water: a critical review of current methods. Journal of Environmental Management, 73(1), 71–79. https://doi.org/10.1016/j.jenvman.2004.06.001

[23] Molua, O. C., Ogholaja, E. R., and Akpoyibo, O. (2024). Identification of groundwater-dependent wetlands physical and hydrological characteristics and ecosystem relationship in Nun River, Niger Delta Region, Nigeria. Journal of Applied Sciences and Environmental Management, 28(8), 2299–2308. https://www.ajol.info/index.php/jasem/article/view/275499

[24] Nigerian Industrial Standard (NIS). (2010). Code of practice for water well construction. Standards Organisation of Nigeria (SON). Abuja, Nigeria.

[25] Nigerian Standard for Drinking Water Quality (NSDWQ). (2015). Standards Organisation of Nigeria (SON). Abuja, Nigeria.

[26] Nwankwoala, H. O., and Harry, M. T. (2012). Investigations of groundwater quality and sanitation in Yenagoa, Bayelsa State, Nigeria. International Journal of Scientific and Engineering Research, 3(8), 1–9.

[27] Nwankwoala, H. O., and Udom, G. J. (2011). Studies on the impact of septic tank systems on groundwater quality in Yenagoa, Bayelsa State, Nigeria. International Journal of Science and Nature, 2(3), 500–506.

[28] Ola, I., Drebenstedt, C., Burgess, R. M., Mensah, M., Holth, N., Okoroafor, P., and Kulls, C. (2024). Assessing petroleum contamination in parts of the Niger Delta based on a sub-catchment delineated field assessment. Environmental Monitoring Assessment, 196:585. https://doi.org/10.1007/s10661-024-12743-7

[29] Ogbonna, V. A. and Emenike, A. C. (2021). An Assessment Of Reclaimed Wetland Groundwater Quality In Omuoko Aluu, Ikwerre Local Government Area, Rivers State, Nigeria. International Research Journal of Modernization in Engineering Technology and Science, 3(10), 1132-1139.

[30] Onyena, A. P., Nkwoji, J. A. and Chukwu, L. O. (2021). Evaluation of hydrochemistry and benthic macroinvertebrates in Chanomi Creek, Niger Delta Nigeria. Regional Studies in Marine Science, 46, 101907. https://doi.org/10.1016/j.rsma.2021.101907

[31] Oyebamiji, A. R., Hoque, M. A., and Whitworth, M. (2025). Regional assessment of groundwater contamination risk from crude oil spillages in the Niger Delta: A novel application of the source-pathway-receptor model. Earth Systems and Environment. 9:117–133. https://doi.org/10.1007/s41748-024-00416-x

[32] Pierrard, J. C., Rimbault, J., and Aplincourt, M. (2002). Experimental study and modelling of lead solubility as a function of pH in mixtures of ground waters and cement waters. Water Research, 36(4), 879-890. https://doi.org/10.1016/S0043-1354(01)00307-4

[33] Saalidong, B. M., Aram, S. A., Otu, S. and Lartey, P. O. (2022). Examining The Dynamics of The Relationship Between Water Ph And Other Water Quality Parameters In Ground And Surface Water Systems. PlosOne 17(1): e0262117. https://doi.org/10.1371/journal.pone.0262117

[34] Shuaibu, A., Kalin, R. M., Phoenix, V., Banda, L. C., Lawal, I. M. (2024). Hydrogeochemistry and Water Quality Index for Groundwater in the Komadugu-Yobe Basin Sahel Region. Water, 16, 601. https://doi.org/10.3390/w16040601

[35] Udom, G. J., and Nwankwoala, H. O. (2022). Groundwater resource management and vulnerability in the Niger Delta: A review. International Journal of Environment and Climate Change, 12(11), 1560–1575.

[36] Ugbaja, A. N., and Edet, A. E. (2020). Contamination vulnerability and health risk assessment of groundwater in the Quaternary sands of the Niger Delta Basin. Environmental Earth Sciences, 79(13), 329. https://doi.org/10.1007/s12665-020-09067-3

[37] Ukoha-Onuoha, E., Anucha, C., Oji, P. (2025). Investigation of Coastal Groundwater Quality Using Weighted Arithmetic Water Quality Index and Entropy Weighted Water Quality Index Methods. Umudike Journal of Engineering and Technology (UJET), 11(2), 90 – 95. https://doi.org/10.33922/j.ujet_v11i2_12