Physicochemical Quality and Petroleum Hydrocarbon Contamination of Groundwater in Illegal Bunkering Hotspots of Ogba/Egbema/Ndoni Local Government Area, Rivers State, Nigeria

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ABSTRACT

Groundwater contamination by petroleum hydrocarbons from illegal bunkering activities poses significant environmental and public health risks in the Niger Delta. This study assessed the physicochemical quality and petroleum hydrocarbon contamination (total petroleum hydrocarbons [TPH] and oil and grease) of groundwater in Ogba/Egbema/Ndoni Local Government Area (ONELGA), Rivers State. Groundwater samples were collected from four locations: three impacted sites (Points 1, 2, and 3) and one control site (Point 4). Physicochemical parameters were measured in situ, while TPH and oil and grease were determined using EPA Method 8015C and API-RP 45/EPA Methods 418.1 & 1664, respectively. Results showed acidic pH (4.62–6.21) at impacted sites compared to the near-neutral control (7.15), elevated electrical conductivity (1000–2256 µS/cm), low turbidity (0.24–0.41 NTU), reduced dissolved oxygen (5.50–5.80 mg/L), and low biochemical oxygen demand (0.3–0.7 mg/L). TPH concentrations (2.30–5.05 mg/L) exceeded the EGASPIN limit of 0.60 mg/L by up to 8.4 times, while oil and grease concentrations (3.10–16.60 mg/L) indicated substantial petroleum contamination. Point 1 exhibited the highest TPH and oil and grease levels, followed by Point 2 and Point 3, suggesting spatial variability linked to bunkering intensity. The control site showed no detectable petroleum hydrocarbons. The study concludes that illegal bunkering has significantly degraded groundwater quality in ONELGA, rendering it unsuitable for potable use without treatment. Recommendations include strengthened regulatory enforcement, targeted remediation of hotspots, provision of alternative water sources, and establishment of routine monitoring programmes.

Keywords: Groundwater quality, illegal bunkering, total petroleum hydrocarbons, oil and grease, physicochemical parameters, Niger Delta

1. INTRODUCTION

Groundwater is a vital resource for drinking, domestic, agricultural, and industrial purposes, particularly in regions where surface water is scarce or unreliable (Barbieri et al., 2023). In the Niger Delta region of Nigeria, groundwater constitutes the primary source of potable water for many communities due to its relative availability and perceived natural purity (Lapworth et al., 2022). However, groundwater resources in this region are increasingly threatened by anthropogenic activities, particularly those associated with petroleum exploration, production, and illegal oil bunkering (Ite et al., 2018).

Illegal oil bunkering, often locally referred to as "bunkery," involves the unauthorised tapping of oil pipelines, artisanal refining, and crude oil theft. These activities have become widespread in Rivers State and have resulted in the uncontrolled release of crude oil and its by-products into the environment (Chris et al., 2024). The clandestine nature of these operations often leads to unregulated spills, leakages, and discharges that contaminate soil, surface water, and groundwater (Umego et al., 2022). Unlike regulated petroleum operations, illegal bunkering lacks environmental safeguards, monitoring, or remediation measures, thereby exacerbating the environmental burden on already vulnerable ecosystems.

Ogba/Egbema/Ndoni Local Government Area (ONELGA) in Rivers State is a known hotspot for illegal bunkering activities. The area is characterised by extensive oil and gas infrastructure, including pipelines, flow stations, and artisanal refining sites, which are frequently targeted by illegal operators (Okoro et al., 2020). The region's hydrogeological setting, dominated by unconsolidated sandy aquifers of the Benin Formation, renders groundwater highly vulnerable to contamination from surface pollutants (Nwankwo & Ekine, 2022). Despite the known risks, there is a paucity of focused research on the physicochemical quality and petroleum hydrocarbon contamination of groundwater in ONELGA, particularly in areas affected by illegal bunkering.

Most existing studies in the Niger Delta have focused on PAH contamination, heavy metals, or general water quality in surface water and soils, with limited attention to bulk petroleum hydrocarbon parameters such as TPH and oil and grease in groundwater (Ite et al., 2018; Amaechi et al., 2022). TPH and oil and grease are important indicators of petroleum contamination because they encompass a broad range of hydrocarbon compounds, including aliphatic and aromatic fractions, some of which are toxic and carcinogenic (Anyanwu et al., 2023). Elevated levels of these parameters in groundwater indicate the presence of free-phase or emulsified petroleum products, which can impair water quality, affect treatment processes, and pose health risks to consumers (Obike et al., 2020).

This study, therefore, aimed to assess the physicochemical characteristics and petroleum hydrocarbon contamination (TPH and oil and grease) of groundwater in illegal bunkering hotspots of ONELGA, Rivers State. The specific objectives were to: (i) determine the physicochemical parameters (pH, electrical conductivity, turbidity, dissolved oxygen, and biochemical oxygen demand) of groundwater samples; (ii) quantify TPH and oil and grease concentrations in groundwater; and (iii) evaluate the spatial variability of these parameters across impacted sites and a control site. The findings are expected to provide baseline data for environmental management and public health interventions in the region.

2.0 METHODOLOGY

2.1 Study Area

The study was conducted in Ogba/Egbema/Ndoni Local Government Area (ONELGA), Rivers State, Nigeria. ONELGA is located in the Niger Delta region, approximately between latitudes 5°20′30.01″N and longitudes 6°39′20.02″E (Figure 1). The area is underlain by the Benin Formation, which comprises predominantly unconsolidated sands with minor clay intercalations, forming a high-yield aquifer system (Doust & Omatsola, 1990). The climate is humid tropical, with a rainy season from March to November and high annual rainfall, which promotes groundwater recharge but also facilitates contaminant infiltration (Nwaerema & Ikoro, 2021).

2.2 Sampling Design and Sample Collection

A cross-sectional sampling design was adopted. Four groundwater sampling points were selected: Point 1, Point 2, and Point 3 were located in communities previously identified as pollution hotspots due to illegal bunkering activities (Ebocha, Omoku, and Okwuzi), while Point 4 served as a control site in Ndoni, a relatively unpolluted area (Okoro et al., 2020). Samples were collected from hand-dug wells and boreholes using a stainless-steel groundwater sampler. Before collection, all glass containers were rinsed with the water to be sampled. Samples for TPH and oil and grease analysis were collected in amber glass bottles, sealed, and stored at 4°C until laboratory analysis.

2.3 In Situ Physicochemical Measurements

Physicochemical parameters were measured in situ immediately after sample collection. pH and temperature were measured using a Jenway Model 430 meter. Electrical conductivity (EC) was determined using a Hanna HI 9835 meter. Turbidity was measured using a portable turbidity meter (APHA 2130). Dissolved oxygen (DO) was measured using a Hanna HI98198 Optical Dissolved Oxygen Meter. Biochemical oxygen demand (BOD) was determined by the APHA 5210B method after incubation at 20°C for 5 days.

2.4 Laboratory Analysis of TPH and Oil and Grease

TPH concentrations were determined using EPA Method 8015C (gas chromatography with flame ionisation detection). Oil and grease concentrations were determined using API-RP 45/EPA Methods 418.1 & 1664

(gravimetric method after solvent extraction with n-hexane). All analyses were performed at Endpoint Laboratories Equipment Limited, Port Harcourt, Nigeria. Quality assurance and quality control measures included the use of procedural blanks, duplicate samples, and certified reference materials. The method detection limits were 0.05 mg/L for TPH and 0.05 mg/L for oil and grease.

2.5 Data Analysis

Descriptive statistics (mean, range, standard deviation) were used to summarise the data. Results were compared with the Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN) limits for groundwater. Spatial variability was assessed by comparing concentrations across the four sampling points.

3. RESULTS

3.1 Physicochemical Characteristics of Groundwater

The physicochemical parameters of groundwater samples are presented in Table 1. The pH values ranged from 4.62 to 7.15. Point 2 exhibited the lowest pH (4.62), indicating strongly acidic conditions, while Point 4 (control) showed a near-neutral pH of 7.15, which falls within the EGASPIN guideline range (6.50–8.50). Points 1 (6.21) and 3 (5.80) were also below the acceptable range. Electrical conductivity (EC) values ranged from 350 µS/cm at the control site to 2256 µS/cm at Point 1. The elevated EC values at Points 1 (2256 µS/cm), 2 (1000 µS/cm), and 3 (1450 µS/cm) suggest higher ionic concentrations in groundwater from bunkering-impacted areas compared to the control site. Turbidity values were generally low, ranging from 0.12 NTU at the control site to 0.41 NTU at Point 1, all well below the EGASPIN limit of 5 NTU. DO concentrations ranged from 5.50 mg/L to 7.20 mg/L, with the control site exhibiting the highest DO (7.20 mg/L). The lower DO values at Points 1 (5.50 mg/L), 2 (5.55 mg/L), and 3 (5.80 mg/L) may indicate oxygen consumption by microorganisms actively degrading petroleum hydrocarbons. BOD values ranged from 0.2 mg/L (control) to 0.7 mg/L (Point 1), with higher BOD at Point 1 suggesting the presence of biodegradable organic matter.

Table 1: Physicochemical Parameters of Groundwater Samples

Parameter	Point 1	Point 2	Point 3	Point 4 (Control)	EGASPIN Limit
pH	6.21	4.62	5.8	7.15	6.50–8.50
Electrical Conductivity (µS/cm)	2256	1000	1450	350	NS
Turbidity (NTU)	0.41	0.24	0.32	0.12	5
Dissolved Oxygen (mg/L)	5.5	5.55	5.8	7.2	NS
Biochemical Oxygen Demand (mg/L)	0.7	0.3	0.5	0.2	NS

NS = Not stated in EGASPIN guidelines. Source: Researcher's Laboratory Results, 2026.

3.2 Total Petroleum Hydrocarbon (TPH) Concentrations

TPH concentrations are presented in Table 2. TPH ranged from 2.30 mg/L at Point 3 to 5.05 mg/L at Point 1, with a mean of 3.97 mg/L across the three impacted sites. The control site showed TPH levels below the detection limit of 0.05 mg/L. All TPH concentrations at the impacted sites significantly exceeded the EGASPIN limit of 0.60 mg/L. The TPH concentrations at Points 1, 2, and 3 were 8.4, 7.6, and 3.8 times higher than the permissible limit, respectively. The spatial distribution of TPH showed a decreasing trend from Point 1 > Point 2 > Point 3.

Table 2: Total Petroleum Hydrocarbon (TPH) Concentrations

S/No.	Sample ID	Result (mg/L)	EGASPIN Limit (mg/L)
1	Point 1	5.05	0.6
2	Point 2	4.57	0.6

3	Point 3	2.3	0.6
4	Point 4 (Control)	< 0.05	0.6

Source: Researcher's Laboratory Results, 2026.

3.3 Oil and Grease Concentrations

Oil and grease concentrations are presented in Table 3. Oil and grease ranged from 3.10 mg/L at Point 3 to 16.60 mg/L at Point 1, with a mean of 8.50 mg/L across the three impacted sites. The control site showed oil and grease levels below the detection limit of 0.05 mg/L. Similar to TPH, the highest oil and grease concentration was recorded at Point 1 (16.60 mg/L), followed by Point 2 (5.80 mg/L) and Point 3 (3.10 mg/L). Although EGASPIN does not specify a limit for oil and grease in groundwater, the elevated concentrations observed are indicative of significant petroleum contamination.

Table 3: Oil and Grease Concentrations

S/No.	Sample ID	Result (mg/L)	EGASPIN Limit (mg/L)
1	Point 1	16.6	NS
2	Point 2	5.8	NS
3	Point 3	3.1	NS
4	Point 4 (Control)	< 0.05	NS

NS = Not stated in EGASPIN guidelines. Source: Researcher's Laboratory Results, 2026.

4. DISCUSSION

4.1 Physicochemical Parameters

The acidic pH values (4.62–6.21) recorded at the impacted sites contrast sharply with the near-neutral pH (7.15) at the control site, indicating that hydrocarbon contamination has contributed to groundwater acidification. Microbial degradation of petroleum hydrocarbons produces organic acids as metabolic by-products, leading to pH reduction (Atekwana et al., 2004). Additionally, the oxidation of reduced sulphur compounds commonly present in crude oil can generate sulphuric acid, further contributing to acidification (Bamforth & Singleton, 2005). Similar observations have been reported in other petroleum-impacted aquifers in the Niger Delta, where pH values ranging from 4.0 to 6.5 were recorded (Nwankwo & Ekine, 2022; Amaechi et al., 2022). The acidic environment has significant implications for contaminant mobility, as many heavy metals and organic pollutants become more soluble and bioavailable at lower pH values, potentially increasing the toxicity of the groundwater (Xia et al., 2020).

The elevated EC values at the impacted sites (1000–2256 µS/cm) compared to the control (350 µS/cm) suggest higher ionic concentrations, potentially from the dissolution of minerals and salts from geological formations, as well as the introduction of ionic species from petroleum hydrocarbons and their degradation products (Lubi & Akinluyi, 2022). Comparable EC values have been reported in groundwater from petroleum-impacted areas in the Niger Delta (Ite et al., 2018; Nwaogazie et al., 2018). The low turbidity values (0.12–0.41 NTU) indicate that the groundwater has undergone effective filtration through the unconsolidated sandy aquifers typical of the Niger Delta region (Doust & Omatsola, 1990). This suggests that particulate-associated contaminants are limited, and the primary concern is dissolved-phase pollutants. The lower DO values at the impacted sites (5.50–5.80 mg/L) compared to the control (7.20 mg/L) may indicate oxygen consumption by microorganisms actively degrading petroleum hydrocarbons (Lapworth et al., 2022). The low BOD values (0.3–0.7 mg/L) despite significant TPH concentrations suggest that the contamination is dominated by more recalcitrant compounds, such as PAHs and other persistent hydrocarbons, which resist biodegradation (Anyahara, 2021).

4.2 Total Petroleum Hydrocarbon Concentrations

The substantial exceedance of the EGASPIN limit for TPH (0.60 mg/L) at all impacted sites indicates significant petroleum hydrocarbon contamination in groundwater from bunkering-impacted areas. The TPH concentrations

observed in this study (2.30–5.05 mg/L) are comparable to those reported by Obike et al. (2020), who documented TPH concentrations ranging from 2.8 to 12.4 mg/L in groundwater from petroleum-impacted areas in the Niger Delta. The high TPH concentrations reflect the intensity of bunkering activities and associated contamination events in the study area. The uncontrolled release of crude oil and its by-products during illegal oil extraction and processing introduces substantial quantities of petroleum hydrocarbons into the environment, which subsequently contaminate groundwater resources (Chris et al., 2024). The spatial distribution of TPH (Point 1 > Point 2 > Point 3) suggests varying levels of contamination intensity across the study area. Point 1, with the highest TPH concentration (5.05 mg/L), appears to be the most severely impacted site, likely due to its proximity to bunkering activities or more favourable hydrogeological conditions for contaminant accumulation. Differences in the intensity and frequency of bunkering activities, local hydrogeological conditions, and the extent of natural attenuation may contribute to the observed spatial variability (Nwankwo & Ekine, 2022; Edet et al., 2021).

4.3 Oil and Grease Concentrations

The elevated oil and grease concentrations (3.10–16.60 mg/L) at the impacted sites are consistent with studies conducted in other petroleum-impacted areas in the Niger Delta. Obike et al. (2020) reported oil and grease concentrations up to 25.8 mg/L in groundwater from areas affected by oil spills in the region, while Lubi and Akinluyi (2022) documented concentrations ranging from 2.5 to 18.0 mg/L. The presence of oil and grease in groundwater indicates that the contamination is not limited to dissolved-phase hydrocarbons but also includes emulsified and free-phase oil, which can cause more persistent and challenging contamination (Anyanwu et al., 2023). The high oil and grease concentrations at the impacted sites can be attributed to the release of crude oil and its by-products during illegal bunkering activities. The clandestine nature of these operations often leads to unregulated spills and leakages, allowing petroleum hydrocarbons to infiltrate the soil and reach the groundwater (Chris et al., 2024). The detection of oil and grease in groundwater has significant implications for water quality and treatment. Oil and grease can cause aesthetic issues, such as unpleasant taste and odour, and can create films on water surfaces that impair oxygen transfer and affect aquatic organisms (Kristanti et al., 2022). The presence of emulsified oil in groundwater poses challenges for water treatment, as conventional treatment methods may not effectively remove oil and grease without advanced treatment techniques.

4.4 Relationship Between TPH and Oil and Grease

The spatial patterns of TPH and oil and grease were similar (Point 1 > Point 2 > Point 3), suggesting that these parameters are influenced by similar contaminant sources and transport processes. Both parameters reflect the bulk petroleum hydrocarbon load in groundwater, with oil and grease representing the hydrophobic fraction that is less soluble in water and tends to partition into organic matter or form emulsions (Anyanwu et al., 2023). The consistent pattern across the impacted sites reinforces the conclusion that Point 1 is the most heavily contaminated site, likely due to its proximity to active bunkering operations.

4.5 Implications for Groundwater Quality and Public Health

The exceedance of the EGASPIN limit for TPH and the elevated oil and grease concentrations have significant implications for groundwater quality and public health. TPH encompasses a broad range of hydrocarbon compounds, including aliphatic and aromatic hydrocarbons, many of which are toxic and can cause adverse health effects upon chronic exposure (Ite et al., 2018). The presence of elevated TPH concentrations in groundwater indicates that the water is unsuitable for drinking without treatment, as it may contain compounds that pose health risks to consumers. Short-term exposure to high TPH concentrations can cause acute health effects, including nausea, vomiting, and central nervous system depression (UNEP, 2017). Long-term exposure, even at relatively low concentrations, has been associated with chronic health effects, including liver and kidney damage, immune system impairment, and cancer (Coes, 2019).

The contamination of groundwater also has socioeconomic implications for the communities in ONELGA. Many local residents rely on groundwater for drinking and domestic use, and the contamination of this resource forces them to either consume unsafe water or incur additional costs to secure safe water supplies (Bubu-Davies et al., 2021). The economic burden of water treatment, healthcare costs associated with water-related illnesses,

and reduced agricultural productivity due to water quality constraints can exacerbate poverty and social inequality in the region (Ellah & Okoru, 2025).

4.6 Limitations of the Study

This study has some limitations. The sample size was small (four sampling points), which limits the generalizability of the findings. The sampling was conducted during a single period, and seasonal variations in groundwater quality were not assessed. Additionally, the study focused on a limited set of physicochemical parameters and petroleum hydrocarbon indicators; other contaminants, such as heavy metals and BTEX compounds, were not evaluated. Future studies should address these limitations by incorporating larger sample sizes, seasonal sampling, and a broader range of contaminants.

5. CONCLUSION

This study assessed the physicochemical quality and petroleum hydrocarbon contamination of groundwater in illegal bunkering hotspots of Ogba/Egbema/Ndoni LGA, Rivers State. The results revealed that groundwater at the impacted sites is acidic (pH 4.62–6.21), has elevated electrical conductivity (1000–2256 µS/cm), low turbidity, reduced dissolved oxygen, and low BOD compared to the control site. TPH concentrations (2.30–5.05 mg/L) significantly exceeded the EGASPIN limit of 0.60 mg/L by up to 8.4 times, and oil and grease concentrations (3.10–16.60 mg/L) confirmed substantial petroleum contamination. Point 1 was identified as the most severely impacted site, followed by Point 2 and Point 3. The control site showed no detectable petroleum hydrocarbons, confirming that the contamination is anthropogenic and linked to illegal bunkering activities. The study concludes that illegal bunkering has significantly degraded groundwater quality in ONELGA, rendering it unsuitable for potable use without treatment. Urgent interventions are required to mitigate further contamination and protect public health.

REFERENCES

1. Amaechi, J. U., Onweremadu, E. U., Uzoho, B. U., & Chukwu, E. D. (2022). Physicochemical properties of wetland soils affected by crude oil spillage in Niger Delta area, Nigeria. *International Journal of Plant & Soil Science, 34*(24), 109–121.
2. Anyahara, J. N. (2021). Effects of polycyclic aromatic hydrocarbons (PAHs) on the environment: A systematic review. *International Journal of Advanced Academic Research, 7*(3), 12–26.
3. Anyanwu, I. N., Beggel, S., Sikoki, F. D., Okuku, E. O., Unyimadu, J.-P., & Geist, J. (2023). Pollution of the Niger Delta with total petroleum hydrocarbons, heavy metals and nutrients in relation to seasonal dynamics. *Scientific Reports, 13*(1), 14079.
4. Atekwana, E. A., Werkema, D. D., Duris, J. W., Rossbach, S., Atekwana, E. A., Sauck, W. A., Cassidy, D. P., Means, J., & Legall, F. D. (2004). In-situ apparent conductivity measurements and microbial population distribution at a hydrocarbon-contaminated site. *Geophysics, 69*(1), 56–63.
5. Bamforth, S. M., & Singleton, I. (2005). Bioremediation of polycyclic aromatic hydrocarbons: Current knowledge and future directions. *Journal of Chemical Technology and Biotechnology, 80*(7), 723–736.
6. Barbieri, M., Barberio, M. D., Banzato, F., Billi, A., Boschetti, T., Franchini, S., Gori, F., & Petitta, M. (2023). Climate change and its effect on groundwater quality. *Environmental Geochemistry and Health, 45*(4), 1–16.
7. Bubu-Davies, O. A., Otene, B. B., & Ebini, M. V. C. (2021). Polycyclic aromatic hydrocarbon contamination in water, sediments and aquatic life of Nigerian inland and coastal waters. *Magnesium Research, 4*(2), 1–15.
8. Chris, D. I., Juliana, N. O., Wokeh, O. K., Mohamad Nor, A., Lananan, F., & Seong Wei, L. (2024). Comparative ecotoxicological study on the current status of artisanal crude oil-contaminated mangrove swamps in Rivers State, Southern Nigeria. *Heliyon, 10*(14), e34588.
9. Coes, A. L. (2019). *Assessment of polycyclic aromatic hydrocarbon concentrations in southern Lake Powell, Glen Canyon National Recreation Area, Arizona and Utah, 2016–17* (Scientific Investigations Report 2019-5065). U.S. Geological Survey.

10. Doust, H., & Omatsola, E. (1990). Niger Delta. In J. D. Edwards & P. A. Santogrossi (Eds.), *Divergent/Passive Margin Basins* (AAPG Memoir 48, pp. 201–238). American Association of Petroleum Geologists.
11. Edet, A., Nyong, E., Ukpong, A., & Edet, C. (2021). Evaluation and risk assessment of polycyclic aromatic hydrocarbons in groundwater and soil near a petroleum distribution pipeline spill site, Eleme, Nigeria. *Sustainable Water Resources Management, 7*(4), 1–15.
12. Ellah, C. C., & Okoru, A. (2025). The intersection of environmental degradation and crime in Nigeria: A case study of oil theft in Rivers State. *IIARD International Journal of Geography & Environmental Management, 11*(5), 54–57.
13. 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.
14. Kristanti, R. A., Hadibarata, T., Syafrudin, M., Yilmaz, M., & Abdullah, S. (2022). Microbiological contaminants in drinking water: Current status and challenges. *Water, Air, & Soil Pollution, 233*(6), 1–15.
15. Lapworth, D. J., Boving, T. B., Kreamer, D. K., Kebede, S., & Smedley, P. L. (2022). Groundwater quality: Global threats, opportunities and realising the potential of groundwater. *Science of The Total Environment, 811*, 152471.
16. Lubi, S. P., & Akinluyi, F. O. (2022). Groundwater hydrocarbon contamination spatial pattern in Opuama, Western Niger-Delta, Nigeria. *Environmental Earth Sciences, 81*(4), 1–14.
17. Nwaerema, P., & Ikoro, N. J. (2021). Characterisation of climate change communication: Implications for environmental sustainability in Ogba, Egbema, Ndoni Local Government Area of River State, Nigeria. *Randwick International of Social Science Journal, 2*(1), 1–11.
18. Nwankwo, C. N., & Ekine, A. S. (2022). Potential and level distribution pattern of groundwater in parts of Ogba/Egbema/Ndoni Local Government Area, Rivers State, Nigeria. *Journal of Applied Sciences and Environmental Management, 26*(6), 1023–1030.
19. Nwaogazie, I. L., Osamudiamen, O. P., & Oghenefejiri, B. (2018). Modelling groundwater quality index based on sensitivity analysis for wet and dry seasons in Obio/Akpor Local Government Area, Rivers State, Nigeria. *Nigerian Journal of Technology, 37*(3), 800–807.
20. Obike, A. I., Uwakwe, K. J., Abraham, E. K., Ikeuba, A. I., & Emori, W. (2020). Review of the losses and devastation caused by corrosion in the Nigerian oil industry for over 30 years. *International Journal of Corrosion and Scale Inhibition, 9*(1), 74–91.
21. Okoro, E. E., Okafor, I. S., Igwilo, K. C., Orodu, K. B., & Mamudu, A. O. (2020). Sustainable biogas production from waste in potential states in Nigeria – alternative source of energy. *Journal of Contemporary African Studies, 38*(4), 627–643.
22. Umego, C. F., Mboto, C. I., Asitok, A. D., Osaji, L. C., George, U. E., Edet, U. O., Mbim, E. N., Faleye, T. O., Adewumi, O. M., & Adeniji, J. A. (2022). Circulation of hepatitis B virus genotype-E among outpatients in tertiary hospitals in the Niger-Delta region of Nigeria. *African Health Sciences, 22*(1), 511–520.
23. UNEP (2017). United Nations Environment Programme. *UN Environment annual report 2017*. UNEP.
24. Xia, Y., Zhang, M., Tsang, D. C. W., Geng, N., Lu, D., Zhu, L., Igalavithana, A. D., Dissanayake, P. D., Rinklebe, J., Yang, X., & Ok, Y. S. (2020). Recent advances in control technologies for non-point source pollution with nitrogen and phosphorus from agricultural runoff: Current practices and future prospects. *Applied Biological Chemistry, 63*, 8.