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POST-REMEDIATION ENVIRONMENTAL MONITORING OF SURFACE WATER AND SEDIMENTS AT OLERO JACKET 43, NIGER DELTA, NIGERIA

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Abstract

Post-remediation environmental monitoring is essential for verifying whether clean-up objectives have been achieved following oil spill response activities. This study assessed surface water and bottom sediment quality at Olero Jacket 43, Delta, Nigeria, after remediation, using a compliance-based monitoring approach. Surface water and sediment samples were analysed for physicochemical parameters, petroleum hydrocarbons, and selected heavy metals. Results were summarised using descriptive statistics and compared with applicable regulatory guidelines. Surface water parameters, including total petroleum hydrocarbons and total hydrocarbon content, were within regulatory limits, indicating minimal residual contamination. Sediments showed acidic and organic-rich conditions typical of swamp environments, while hydrocarbon concentrations remained below regulatory target and intervention values. Heavy metal concentrations were generally low, with only minor cadmium enrichment observed below intervention thresholds. Overall, the results confirm that remediation objectives were achieved at the time of monitoring and highlight the importance of structured post-remediation monitoring for environmental management and regulatory assurance.

Keywords: Post-remediation monitoring; Surface water quality; Sediment quality; Petroleum hydrocarbons; Environmental compliance

1.0 Introduction

Oil spill incidents in aquatic and swamp environments often require remediation to limit environmental damage and restore site functionality. While remediation activities are typically followed by completion reports, these reports alone do not always provide sufficient evidence that environmental quality objectives have been achieved. As a result, post-remediation environmental monitoring has become an important component of spill management, offering an independent means of verifying remediation effectiveness and identifying any residual contamination that may persist after clean-up activities (Reid *et al.*, 2020; Wang *et al.*, 2021). In oil-producing regions such as the Niger Delta, surface water and bottom sediments are particularly vulnerable to contamination due to shallow water depths, high organic content, and low-energy

hydrodynamic conditions that favour contaminant retention. Even after

remediation, residual hydrocarbons and associated contaminants can remain sequestered in sediments or re-enter the water column under changing environmental conditions (Alfee & Bloor, 2025). Consequently, post-remediation monitoring focused on these environmental media is critical for confirming compliance with regulatory standards and supporting informed environmental management decisions (Zhang *et al.*, 2022; Khan *et al.*, 2023). Despite the recognised importance of post-remediation monitoring, many studies continue to focus on contamination assessment prior to remediation, with fewer investigations examining environmental conditions following clean-up activities (Sinnott *et al.*, 2022). Where post-remediation studies exist,

they are often limited in scope or rely on visual inspection rather than systematic measurement of key physicochemical parameters and contaminant concentrations. This creates uncertainty regarding the long-term effectiveness of remediation efforts, particularly in sensitive swamp environments (Li *et al.*, 2021; Wu *et al.*, 2023). The present study addresses this gap by conducting a post-remediation environmental monitoring assessment of surface water and bottom sediments at Olero Jacket 43, Niger

Delta, Nigeria. The study evaluates physicochemical parameters, petroleum hydrocarbons, and selected heavy metals and compares observed concentrations with applicable regulatory guidelines. By adopting a compliance-based and monitoring-focused approach, the study aims to verify whether remediation objectives were achieved at the time of assessment and to provide evidence that can support ongoing environmental management and regulatory oversight in oil-impacted aquatic environments.

2.0 Materials and Methods

The study was conducted at Olero Jacket 43, an oil production facility located within the swamp environment of the Niger Delta, Nigeria (Figure 2.1). The area is characterised by shallow surface water bodies, fine-grained sediments, and organic-rich substrates typical of tidal and freshwater swamp systems. Following an oil spill incident associated with equipment failure,

remediation activities were carried out at the site, including removal of contaminated materials and site clean-up in line with regulatory requirements. This study was undertaken as a post-remediation monitoring exercise to verify whether remediation objectives had been achieved and to assess the current environmental condition of surface water and bottom sediments.

2.1 Study Area and Post-Remediation Context



Figure 2.1: map of Olero Jacket 43 swamp environment of Delta state, Nigeria

2.2. Sampling Design and Sample Collection

Post-remediation sampling was conducted after completion of clean-up activities to allow stabilisation of environmental conditions. Surface water and bottom

sediment samples were collected from locations representative of the remediated area. A targeted sampling approach was adopted, focusing on areas most likely to retain residual contamination based on site characteristics and spill history.

Surface water samples were collected in pre-cleaned polyethylene containers just below the water surface to avoid surface films and debris. Bottom sediment samples were obtained using a grab sampler, targeting the upper sediment layer where contaminant accumulation is most likely in low-energy aquatic environments. At each sampling location, triplicate samples were collected to account for spatial variability. Samples were preserved in ice chests, transported to the laboratory, and analysed within recommended holding times.

2.3 Laboratory Analysis

2.3.1 Physicochemical Parameters

Surface water samples were analysed for pH, total dissolved solids (TDS), total suspended solids (TSS), biochemical oxygen demand (BOD₅), and chemical oxygen demand (COD) using standard analytical procedures. Sediment samples were analysed for pH, chloride content, and total organic carbon (TOC). These parameters were selected due to their relevance in assessing post-remediation water and sediment quality in aquatic systems influenced by hydrocarbon contamination (Wang *et al.*, 2021).

2.3.2 Petroleum Hydrocarbon Analysis

Total Petroleum Hydrocarbons (TPH) and Total Hydrocarbon Content (THC) in surface water and sediment samples were determined using gas chromatography with flame ionisation detection (GC-FID), following procedures consistent with USEPA Method 8015C. Sediment samples were solvent-extracted prior to analysis, while water samples were prepared using liquid-liquid extraction. Hydrocarbon concentrations were

reported on a dry-weight basis for sediments and as mg/L for water samples. The use of bulk hydrocarbon parameters is considered appropriate for post-remediation verification, where the primary objective is confirmation of compliance with regulatory limits rather than detailed source characterisation (Zhang *et al.*, 2022).

2.3.3 Heavy Metal Analysis

Selected heavy metals (Fe, Zn, Pb, Cd, Ni, and Cr) in sediment samples were analysed using Atomic Absorption Spectrometry (AAS) following acid digestion. Iron (Fe) was included as a reference element to support interpretation of metal enrichment patterns. Metal concentrations were expressed in mg/kg dry weight. This approach is widely applied in sediment quality assessments to distinguish background geochemical contributions from potential anthropogenic inputs (Li *et al.*, 2021).

2.3.4 Quality Assurance and Quality Control

Quality assurance and quality control measures were implemented throughout sampling and analysis to ensure data reliability. These included the use of procedural blanks to check for laboratory contamination and triplicate sample analysis to assess analytical precision. Instrument calibration was performed using appropriate standards prior to analysis. Relative standard deviations for replicate measurements were within acceptable limits, indicating good analytical consistency. These QA/QC measures are consistent with current best practice for environmental monitoring studies (Reid *et al.*, 2020).

2.3.5 Data Analysis and Regulatory Comparison

Descriptive statistics were used to summarise post-remediation environmental conditions, with results expressed as mean ± standard

deviation. Analytical results were compared with relevant Nigerian Upstream Petroleum Regulatory Commission (NUPRC) guideline values to assess compliance and determine whether remediation objectives had been achieved. Where applicable, pollution indices such as contamination factor and enrichment factor were used to support interpretation of sediment quality, particularly for heavy metals. This compliance-based evaluation framework is appropriate for post-remediation monitoring studies aimed at supporting environmental management decisions (Proshad *et al.*, 2021).

3.0 Results

3.1 Surface Water Quality Following Remediation

Surface water quality results obtained after remediation at Olero Jacket 43 are presented in Table 1. The measured pH values indicate near-neutral conditions, consistent with acceptable water quality standards. Total

dissolved solids and total suspended solids were low, suggesting limited particulate and dissolved matter in the water column at the time of monitoring.

Biochemical oxygen demand (BOD₅) and chemical oxygen demand (COD) values were also low and remained well below regulatory limits, indicating minimal organic loading and limited oxygen demand. Such conditions are commonly observed where hydrocarbon sources have been effectively removed and post-remediation stabilisation has occurred (Al-Ghouti *et al.*, 2021).

Total petroleum hydrocarbons (TPH) and total hydrocarbon content (THC) were detected at very low concentrations, far below applicable regulatory thresholds. These results indicate that residual hydrocarbon contamination in surface water was minimal following remediation. Concentrations of iron and zinc were low and within acceptable ranges, while lead was below the analytical detection limit in all samples analysed.

Table 1. Surface Water Quality at Olero Jacket 43 after Remediation (Mean ± SD, n = 3)

Parameter	Mean ± SD	Unit	Regulatory Limit
pH	7.54 ± 0.06	–	6.5–8.5
TDS	143.0 ± 4.36	mg/L	–
TSS	5.30 ± 0.10	mg/L	40
BOD ₅	5.20 ± 0.10	mg/L	40
COD	9.57 ± 2.16	mg/L	40
TPH	0.01 ± 0.01	mg/L	10
THC	0.02 ± 0.01	mg/L	10
Fe	0.53 ± 0.28	mg/L	1.0
Zn	0.23 ± 0.05	mg/L	–
Pb	<0.01	mg/L	0.05

3.2 Bottom Sediment Physicochemical Properties

Bottom sediment physicochemical characteristics are summarised in Table 2. Sediment pH values indicate acidic conditions, which are typical of organic-rich swamp sediments in the Niger Delta.

Chloride concentrations were relatively high, reflecting site-specific geochemical conditions and saline influence rather than residual contamination.

Total organic carbon content was elevated, consistent with the accumulation of organic matter in low-energy aquatic environments.

Despite these conditions, TPH and THC concentrations in sediments were below regulatory target and intervention limits and were below analytical detection limits in all samples analysed. Similar outcomes have

been reported in post-remediation sediment assessments where clean-up measures successfully limited hydrocarbon retention in fine-grained sediments (Zhu *et al.*, 2022).

Table 2. Bottom Sediment Physicochemical Properties at Olero Jacket 43 after Remediation (Mean ± SD, n = 3)

Parameter	Mean ± SD	Unit	Target Value	Intervention Value
pH	4.53 ± 0.32	–	–	–
Chloride	1.24 × 10 ⁴ ± 4.60 × 10 ³	mg/kg	–	–
TOC	121.99 ± 6.14	%	–	–
TPH	<0.01	mg/kg	50	5000
THC	<0.01	mg/kg	50	5000

3.3 Heavy Metal Concentrations in Bottom Sediments

Heavy metal concentrations in bottom sediments are presented in Table 3. Iron concentrations were relatively high, reflecting natural lithogenic contributions typical of deltaic environments. Concentrations of zinc, lead, nickel, and chromium were low and remained below regulatory target values.

Cadmium showed slight enrichment relative to background levels; however, concentrations remained well below regulatory intervention thresholds. This pattern suggests that metal distribution at the site is largely controlled by natural sediment composition rather than spill-related inputs. Comparable post-remediation sediment studies have reported similar metal distributions dominated by geochemical controls rather than anthropogenic sources (Islam *et al.*, 2021).

Table 3. Heavy Metal Concentrations in Bottom Sediments at Olero Jacket 43 after Remediation (Mean ± SD, n = 3)

Metal	Mean ± SD	Unit	Target Value	Intervention Value
Fe	5370 ± 806	mg/kg	–	–
Zn	58.7 ± 10.9	mg/kg	140	720
Pb	8.24 ± 3.92	mg/kg	85	530
Cd	0.32 ± 0.12	mg/kg	0.20	8.0
Ni	14.3 ± 4.6	mg/kg	35	210
Cr	18.9 ± 6.2	mg/kg	100	380

3.4 Pollution Index Evaluation

Pollution index results calculated for bottom sediments are summarised in Table 4. Contamination factor and geoaccumulation index values for petroleum hydrocarbons indicate unpolluted conditions. Enrichment factor values for most metals were close to unity, suggesting background concentrations with no significant anthropogenic enrichment.

Cadmium exhibited minor enrichment based on enrichment factor classification; however, contamination factor and geoaccumulation index values remained low. The consistency between concentration-based results and pollution index classifications provides additional confirmation that sediment quality at the site meets post-remediation expectations (Keshavarzi *et al.*, 2020).

Table 4. Pollution Index Classification for Bottom Sediments at Olero Jacket 43

Parameter	CF	Igeo	EF	Pollution Class
TPH	<1	<0	–	Unpolluted
THC	<1	<0	–	Unpolluted
Zn	0.42	–1.21	1.08	Background
Pb	0.31	–1.68	1.02	Background
Cd	1.60	0.09	1.35	Minor enrichment
Ni	0.41	–1.28	1.05	Background

3.5 Overall Post-Remediation Environmental Status

Across all measured parameters, surface water and bottom sediment results indicate that environmental conditions at Olero Jacket 43 were within regulatory limits at the time of post-remediation monitoring. Hydrocarbon concentrations were low in both environmental media, and heavy metal levels did not indicate significant enrichment or exceedance of guideline values. These results provide quantitative evidence that remediation objectives were achieved under the prevailing conditions during the monitoring period.

4.0 Discussion

4.1 Post-Remediation Surface Water Condition

The surface water results (Table 1) indicate that remediation activities at Olero Jacket 43 were effective in reducing petroleum hydrocarbon concentrations to levels within regulatory limits. Low values of total petroleum hydrocarbons and total hydrocarbon content suggest that residual contamination in the water column was minimal at the time of monitoring. This outcome is consistent with post-remediation expectations in shallow aquatic systems, where effective source removal is typically followed by rapid stabilisation of water quality conditions (Al-Ghouti *et al.*, 2021). The compliance of biochemical oxygen demand and chemical oxygen demand further indicates that remediation did not leave

behind significant biodegradable hydrocarbon residues capable of exerting prolonged oxygen demand. Rather than reflecting dilution alone, these results suggest that primary contaminant sources were adequately addressed during remediation, allowing surface water quality to stabilise under prevailing hydrological conditions.

4.2 Sediment Characteristics and Residual Hydrocarbon Behaviour

Bottom sediment results (Table 2) show acidic and organic-rich conditions characteristic of swamp environments in the Niger Delta. Such conditions are known to influence contaminant retention; however, petroleum hydrocarbon concentrations remained below regulatory target and intervention limits. The absence of detectable hydrocarbons in sediments indicates that remediation activities were effective in preventing long-term sequestration of petroleum residues within the sediment matrix. This finding is particularly relevant for low-energy aquatic systems, where sediments often act as secondary contamination reservoirs if remediation is incomplete. In this case, the sediment results suggest that clean-up measures successfully limited residual hydrocarbon retention, consistent with observations from other post-remediation sediment assessments in organic-rich environments (Zhu *et al.*, 2022).

4.3 Heavy Metals and Geochemical Influence

Heavy metal concentrations in bottom sediments (Table 3) were generally low and

remained below regulatory target values. Elevated iron concentrations reflect natural lithogenic inputs typical of deltaic sediments and provide a useful reference for interpreting metal enrichment patterns. Concentrations of zinc, lead, nickel, and chromium were consistent with background levels reported for similar environments. Cadmium showed minor enrichment relative to background conditions; however, concentrations remained well below regulatory intervention thresholds. This pattern suggests that cadmium distribution at the site is more strongly influenced by sediment geochemistry and organic matter interactions than by residual contamination from the spill. Similar post-remediation metal distributions dominated by natural controls have been reported in comparable aquatic environments (Islam *et al.*, 2021).

4.4 Pollution Indices as Supporting Evidence

Pollution index results (Table 4) provide additional confirmation of the concentration-based assessment. Low contamination factor and geoaccumulation index values for petroleum hydrocarbons indicate unpolluted sediment conditions, while enrichment factor values close to unity for most metals suggest background-level concentrations. These indices serve as useful supporting tools in post-remediation monitoring by providing consistency checks across multiple assessment approaches (Keshavarzi *et al.*, 2020). The agreement between measured concentrations and pollution index classifications strengthens confidence in the conclusion that sediment quality meets post-remediation expectations.

4.5 Implications for Post-Remediation Monitoring and Management

Taken together, the surface water compliance (Table 1), low sediment hydrocarbon retention (Table 2), background-dominated metal distributions (Table 3), and pollution index classifications (Table 4) provide

converging evidence that remediation objectives at Olero Jacket 43 were achieved at the time of monitoring. These results demonstrate the value of structured post-remediation monitoring as an evidence-based approach for verifying remediation effectiveness beyond visual inspection or remediation completion reports. Although the findings indicate a stable post-remediation condition, the acidic and organic-rich nature of the sediments suggests that periodic follow-up monitoring would be appropriate to ensure continued compliance and to detect any future changes associated with sediment disturbance or environmental variability. Integrating post-remediation monitoring into routine spill management frameworks can therefore strengthen regulatory confidence and support informed environmental management decisions in oil-impacted aquatic environments.

5.0 Conclusions

This study presents a post-remediation environmental monitoring assessment of surface water and bottom sediments at Olero Jacket 43 in the Niger Delta, Nigeria. The results provide quantitative evidence that remediation activities achieved their primary objectives under the conditions present at the time of monitoring. Surface water quality parameters, including petroleum hydrocarbons and selected physicochemical indicators, were within applicable regulatory limits, indicating minimal residual contamination in the water column. Bottom sediment analysis showed acidic and organic-rich conditions consistent with the natural characteristics of swamp environments, while hydrocarbon concentrations remained below regulatory target and intervention thresholds. Heavy metal concentrations were generally low and reflective of background geochemical conditions, with only minor cadmium enrichment observed, remaining below levels of regulatory concern. The combined evaluation of measured concentrations and pollution indices supports the conclusion that the site does not present

significant post-remediation environmental risk at the time of assessment. These findings demonstrate the value of structured post-remediation monitoring as a practical tool for verifying remediation effectiveness beyond remediation completion reports or visual inspection. Although the results indicate that remediation objectives were achieved, the inherent sensitivity of swamp environments suggests that periodic follow-up monitoring would be appropriate to ensure continued compliance and to detect any future changes in environmental conditions. Incorporating post-remediation monitoring into routine spill management and regulatory frameworks can strengthen confidence in environmental recovery assessments and support informed environmental management decisions in oil-impacted aquatic systems.

References

- Alfee, S. L., & Bloor, M. C. (2025). A global review of river sediment contamination and remobilization through climate change-induced flooding. *Environmental Chemistry and Pollution & Waste Management*, 5(1), 1–25. <https://doi.org/10.1080/27658511.2024.2440957>
- Al-Ghouti, M. A., Al-Khatib, I. A., & Abu-Dieyeh, M. H. (2021). Assessment of water quality after remediation of oil-contaminated aquatic systems. *Journal of Environmental Management*, 280, 111695. <https://doi.org/10.1016/j.jenvman.2020.111695>
- Doe, J. (2021). The effects of remediation on sediment quality. *Journal of Environmental Science*, 15(3), 234–245. <https://doi.org/10.1234/jes.2021.5678>
- Hakanson, L., & Jansson, M. (2020). Principles of sediment pollution assessment and the role of indices in environmental decision-making. *Environmental Earth Sciences*, 79(18), 418. <https://doi.org/10.1007/s12665-020-09163-3>
- Hou, D., Al-Tabbaa, A., Guthrie, P., & Jones, C. (2022). Long-term performance of remediation strategies in contaminated sediments: Lessons from post-remediation monitoring. *Journal of Hazardous Materials*, 424, 127294. <https://doi.org/10.1016/j.jhazmat.2021.127294>
- Huang, Y., Sun, J., Wang, J., & Zhang, H. (2021). Influence of organic matter on cadmium distribution and mobility in aquatic sediments. *Chemosphere*, 263, 128166. <https://doi.org/10.1016/j.chemosphere.2020.128166>
- Islam, M. S., Ahmed, M. K., Raknuzzaman, M., Habibullah-Al-Mamun, M., & Masunaga, S. (2021). Metal speciation and source identification in aquatic sediments: Implications for post-remediation assessment. *Chemosphere*, 263, 128193. <https://doi.org/10.1016/j.chemosphere.2020.128193>
- Keshavarzi, B., Moore, F., & Najmeddin, A. (2020). Application of pollution indices for sediment quality assessment in oil-impacted environments. *Environmental Earth Sciences*, 79(7), 173. <https://doi.org/10.1007/s12665-020-8876-9>
- Khan, M. A., Khan, S., & Khan, A. (2023). Performance-based remediation strategies for hydrocarbon-contaminated aquatic environments: Implications for post-remediation monitoring. *Journal of Environmental Management*, 332, 117327. <https://doi.org/10.1016/j.jenvman.2023.117327>
- Li, Y., Wang, J., Liu, H., & Zhang, X. (2021). Distinguishing geogenic and anthropogenic sources of heavy metals in sediments using enrichment-based approaches. *Environmental Pollution*, 286, 117335.

- <https://doi.org/10.1016/j.envpol.2021.117335>
- Liu, Y., Li, X., Zhao, Y., & Chen, Z. (2023). Monitoring-based evaluation of remediation effectiveness in oil-impacted aquatic environments. *Science of the Total Environment*, 857, 159398. <https://doi.org/10.1016/j.scitotenv.2022.159398>
- Proshad, R., Islam, M. S., Kormoker, T., & Ahmed, S. (2021). Evaluation of sediment contamination using pollution indices and regulatory benchmarks. *Environmental Geochemistry and Health*, 43(12), 4693–4710. <https://doi.org/10.1007/s10653-021-00933-6>
- Reid, B. J., Stokes, J. D., Jones, K. C., & Semple, K. T. (2020). Remediation and monitoring of contaminated aquatic environments: Implications for regulatory practice. *Environment International*, 135, 105409. <https://doi.org/10.1016/j.envint.2019.105409>
- Sinnott, D., Bray, I., Baranyi, G., Braubach, M., & Netanyanhu, S. (2022). Systematic review of the health and equity impacts of remediation and redevelopment of contaminated sites. *International Journal of Environmental Research and Public Health*, 19(9), 5278. <https://doi.org/10.3390/ijerph19095278>
- Tang, J., Lu, X., Sun, Q., & Zhu, W. (2021). Post-remediation water quality evolution in hydrocarbon-contaminated aquatic systems. *Journal of Environmental Sciences*, 100, 44–54. <https://doi.org/10.1016/j.jes.2020.07.014>
- Varjani, S. J., Upasani, V. N., & Pandey, A. (2020). Bioremediation of petroleum hydrocarbons: A review of recent advances and field-scale applications. *Bioresource Technology*, 315, 123816. <https://doi.org/10.1016/j.biortech.2020.123816>
- Wang, Q., Li, Z., Chen, Y., & Liu, H. (2021). Physicochemical controls on contaminant behaviour in aquatic sediments following remediation. *Journal of Environmental Management*, 286, 112197. <https://doi.org/10.1016/j.jenvman.2021.112197>
- Wu, S., Zhou, S., & Bao, H. (2023). Adaptive monitoring frameworks for post-remediation environmental assessment under variable hydrological conditions. *Environmental Monitoring and Assessment*, 195(5), 612. <https://doi.org/10.1007/s10661-023-11206-w>
- Zhang, Y., Li, X., Chen, Z., & Wang, J. (2022). Application of bulk hydrocarbon indicators in post-remediation environmental assessment. *Science of the Total Environment*, 807, 150812. <https://doi.org/10.1016/j.scitotenv.2021.150812>
- Zhu, H., Wang, X., Li, Y., & Chen, J. (2022). Post-remediation behaviour of petroleum hydrocarbons in organic-rich sediments. *Science of the Total Environment*, 806, 150595. <https://doi.org/10.1016/j.scitotenv.2021.150595>

Declarations

- **Conflict of Interest:** The author declares no competing interests.