



## Index Properties, and Compaction Characteristics of Palm Kernel Shell Ash-Stabilized Vermi-remediated Crude Oil-Contaminated Lateritic Soil for Highway Sub-Base Application

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### ABSTRACT

Crude oil spillage progressively degrades the geotechnical performance of lateritic soils used in highway construction, necessitating remediation before reuse as pavement material. This study evaluated the remediation efficiency, index properties, and compaction characteristics of Palm Kernel Shell Ash (PKSA)-stabilized, Vermi-remediated, crude-oil-contaminated lateritic soil intended for highway sub-base application. Lateritic soil obtained from Shika, Zaria, Kaduna State, Nigeria was contaminated with crude oil at 150 cl per 20 kg of soil and subsequently treated using the earthworm species *Eudrilus eugeniae* at 200 worms per 100 kg of soil for 30 days. Vermi-remediation reduced the total petroleum hydrocarbon (TPH) content from 4500 mg/kg to an average of 3300 mg/kg, corresponding to a remediation efficiency of about 26%. The Vermi-remediated soil was thereafter stabilized with PKSA at 0, 4, 8, 12 and 16% by dry weight and evaluated for index, compaction, and strength properties in accordance with BS 1377 (1990). The liquid limit, plastic limit and plasticity index of the Vermi-remediated soil (54.0%, 32.3% and 21.7%) varied irregularly with PKSA content, while linear shrinkage remained close to 11% throughout. Specific gravity decreased marginally from 2.4 to 2.2 with increasing PKSA content, consistent with the lower density of the ash. Compaction results showed that maximum dry density (MDD) decreased under British Standard Light (BSL) and West African Standard (WAS) efforts but increased under British Standard Heavy (BSH) compaction, while optimum moisture content (OMC) generally increased with PKSA content across all compactive efforts. The findings support the use of Vermi-remediation combined with agricultural-waste-ash stabilization as a sustainable, low-cost technique for rehabilitating petroleum-impacted lateritic soils for highway earthworks in Nigeria.

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### INTRODUCTION

Petroleum exploration, transportation and refining activities in Nigeria, particularly within the Niger Delta region and along inland pipeline corridors, have resulted in extensive contamination of soils with crude oil (Bala et al., 2024). Hydrocarbon contamination alters the physical, chemical and engineering behaviour of soils by coating soil particles, reducing effective

inter-particle friction, altering pore-water chemistry, and consequently degrading strength, compaction and permeability characteristics (Odeh et al., 2021). Where such soils occur along highway alignments, their poor geotechnical performance constrains their reuse as subgrade, sub-base or embankment material unless they are first remediated and, where necessary, stabilized to meet pavement design specifications.

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Vermi-remediation, the use of earthworms to biologically degrade organic contaminants, has emerged as an environmentally sustainable alternative to chemical and mechanical treatment of petroleum-contaminated soils (Bala et al., 2022). Earthworm species such as *Eudrilus eugeniae* and *Eisenia fetida* ingest contaminated soil particles, enhance microbial activity within their gut and casts, and promote aeration that collectively accelerate hydrocarbon breakdown (Tagliabue et al., 2023). Recent systematic reviews confirm that vermi-remediation efficiency depends strongly on earthworm density, contaminant concentration and exposure duration, with longer treatment periods generally producing higher hydrocarbon removal (Cascone et al., 2023). For instance, combined vermi-remediation-bioaugmentation studies have reported total petroleum hydrocarbon (TPH) removal exceeding 55% over extended durations (Iheanacho et al., 2024), while shorter exposure periods typically yield more modest, though still beneficial, reductions.

Although vermi-remediation reduces hydrocarbon toxicity, it does not necessarily restore the geotechnical suitability of the treated soil for pavement construction; the soil frequently still requires further stabilization. Agricultural waste ashes rich in silica, alumina and calcium oxide have attracted growing research interest as low-cost, locally available pozzolanic stabilizers for lateritic soils, in line with the broader drive toward sustainable, waste-derived construction materials (Adewale et al., 2022). Palm Kernel Shell Ash (PKSA), obtained by incinerating palm kernel shells—an abundant agro-industrial waste in Nigeria—exhibits pozzolanic characteristics attributable to its  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$  and  $\text{CaO}$  content, and has been shown to modify the plasticity, compaction and strength behaviour of lateritic soils in several recent studies (Subair et al., 2025;

Adekunle et al., 2021). However, existing PKSA-stabilization studies have largely focused on uncontaminated lateritic or clayey soils, with limited attention paid to soils that have first undergone biological remediation of petroleum contamination.

This study therefore integrates vermi-remediation and PKSA stabilization as a two-stage sustainable treatment pathway for crude-oil-contaminated lateritic soil intended for highway sub-base application. Building on an earlier laboratory investigation of the index properties of PKSA-stabilized vermi-remediated soil, the present paper extends the analysis to include the remediation efficiency of the vermi-remediation stage and the compaction characteristics (maximum dry density and optimum moisture content) of the stabilized soil, in addition to strength and durability behaviour, so as to provide a more complete geotechnical characterization suitable for pavement design decision-making.

The specific objectives of the study are to: (i) determine the remediation efficiency of *Eudrilus eugeniae* in degrading total petroleum hydrocarbons in crude-oil-contaminated lateritic soil; (ii) evaluate the index properties (Atterberg limits, specific gravity, particle size distribution) of the vermi-remediated soil stabilized with PKSA at varying admixture levels; (iii) assess the compaction characteristics (MDD and OMC) of the stabilized soil under British Standard Light, West African Standard and British Standard Heavy compactive efforts.

## MATERIALS AND METHODS

### Materials

Table 1 summarizes the materials used in the study, their sources and preparation.

Table 1: Materials used in the study

Material	Source / Location	Description / Preparation
Lateritic soil	Borrow pit, Shika, Zaria, Kaduna State, Nigeria (Lat. 11° 15' N, Long. 7° 45' E)	250 kg of disturbed sample collected and transported to the laboratory in air-tight sacks

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Material	Source / Location	Description / Preparation
Crude oil	Port Harcourt, Rivers State, Nigeria	Transported to NDA Kaduna in air-tight 25-litre gallons; used to contaminate soil at 150 cl per 20 kg of soil
Palm Kernel Shell Ash (PKSA)	Palm kernel plantation, Kogi State, Nigeria	Shells dried, incinerated for 7 days at the incinerator of Shehu Kangiwa Hospital, sieved through the appropriate BS sieve, and transported to the laboratory in air-tight sacks
Earthworms (Eudrilus eugeniae)	Laboratory-cultured stock	Introduced at 200 worms per 100 kg of contaminated soil for a 30-day vermiremediation period

### Sample Contamination and Vermi-remediation

The natural lateritic soil was air-dried, pulverized and contaminated with crude oil at a rate of 150 cl per 20 kg of soil to simulate field spillage conditions. The contaminated soil was thereafter treated by direct application of *Eudrilus eugeniae* at a stocking density of 200 worms per 100 kg of soil for a 30-day exposure period, following the vermiremediation strategy described by Njoku (2017) and Bala et al. (2022). Total petroleum hydrocarbon (TPH) content was determined gravimetrically before and after vermiremediation, and the remediation efficiency (RE) was computed as:

$$RE (\%) = [(TPH_0 - TPH_t) / TPH_0] \times 100$$

where  $TPH_0$  is the initial TPH concentration and  $TPH_t$  is the TPH concentration after the treatment period.

### Stabilization Scheme

The vermiremediated soil was stabilized with PKSA at 0, 4, 8, 12 and 16% by dry weight of soil. Each admixture was thoroughly mixed with the soil in its air-dried state prior to the addition of water for the various index, compaction and strength tests.

### Laboratory Test Methods

Natural moisture content, specific gravity, Atterberg limits (liquid limit, plastic limit

and linear shrinkage) and particle size distribution (wet and dry sieving) were determined in accordance with BS 1377 (1990), Parts 1 and 2. Compaction characteristics (maximum dry density and optimum moisture content) were determined under British Standard Light (BSL, 2.5 kg rammer, 3 layers, 27 blows/layer), West African Standard (WAS, 4.5 kg rammer, 5 layers, 10 blows/layer) and British Standard Heavy (BSH, 4.5 kg rammer, 5 layers, 25 blows/layer) compactive efforts, in accordance with BS 1924 (1990).

## RESULTS AND DISCUSSION

### Properties of Materials Used in the Study

The natural lateritic soil is light brown, predominantly fine-grained, and classified as CL (inorganic clay of low to medium plasticity) under the Unified Soil Classification System (USCS) and A-7-6(12) under the AASHTO system. Upon contamination with crude oil and vermiremediation, the soil darkened to dark brown, with an increase in liquid limit, plastic limit and plasticity index relative to the natural soil, consistent with the coating of soil particles by residual hydrocarbons and the by-products of biological degradation (Odeh et al., 2021). Table 2 presents a comparative summary of the physical and engineering properties of the natural soil and the vermiremediated crude-oil-contaminated soil (0% PKSA), while Table 3 presents the oxide composition of the soil and PKSA.

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Table 2: Physical and engineering properties of the natural and vermiremediated crude-oil-contaminated (COCS) lateritic soil

Property	Natural soil	Vermiremediated COCS (0% PKSA)
Passing BS sieve No. 200 (%)	64.00	72.42
Natural moisture content (%)	16.70	—
Liquid limit, LL (%)	47.00	54.00
Plastic limit, PL (%)	27.30	32.30
Plasticity index, PI (%)	19.70	21.70
Linear shrinkage (%)	11.43	11.00
Specific gravity	2.66	2.40
AASHTO classification	A-7-6	A-7-6
USCS classification	CL	CL
Group index	12	12
pH	7.65	7.65
MDD – BSL / WAS / BSH (g/cm <sup>3</sup> )	1.68 / 1.76 / 1.87	1.63 / 1.66 / 1.69
OMC – BSL / WAS / BSH (%)	20.20 / 15.90 / 14.20	18.87 / 17.18 / 15.78
UCS – BSL / WAS / BSH (kN/m <sup>2</sup> )	335.3 / 409.0 / 537.0	182.7 / 158.1 / 245.6
Unsoaked CBR – BSL / WAS / BSH (%)	12.68 / 19.56 / 24.15	4.45 / 5.45 / 8.97
Soaked CBR – BSL / WAS / BSH (%)	5.76 / 15.17 / 22.87	4.07 / 3.53 / 8.51
Dominant clay mineral	Kaolinite	Kaolinite

Table 3: Oxide composition of the vermiremediated soil and Palm Kernel Shell Ash (PKSA)

Oxide	Soil (%)	PKSA (%)
SiO <sub>2</sub>	41.05	46.44
Al <sub>2</sub> O <sub>3</sub>	24.16	5.17
Fe <sub>2</sub> O <sub>3</sub>	10.16	8.20
CaO	0.23	20.32
MgO	0.21	2.27
SO <sub>3</sub>	1.04	1.01

Oxide	Soil (%)	PKSA (%)
Na <sub>2</sub> O	1.37	2.22
K <sub>2</sub> O	0.34	2.00
TiO <sub>2</sub>	0.39	0.09
P <sub>2</sub> O <sub>5</sub>	1.31	6.70
Cr <sub>2</sub> O <sub>3</sub>	0.02	0.01
MnO	ND	3.51
Loss on ignition (LOI)	19.35	—

The soil is dominated by SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>, consistent with kaolinitic lateritic soils of the

ferruginous tropical soil group described by Akintola (1982). PKSA, in contrast, is

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characterized by high  $\text{SiO}_2$  (46.44%) and  $\text{CaO}$  (20.32%) content, confirming its pozzolanic potential; the combined  $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$  content of 59.81% is consistent with a Class C/F-type pozzolan and supports its capacity to react with calcium hydroxide to form cementitious compounds that can enhance soil strength and durability (Subair et al., 2025).

### Remediation Efficiency of Vermiremediation

The TPH content of the crude-oil-contaminated soil was 4500 mg/kg prior to treatment and reduced to an average of 3300 mg/kg after 30 days of vermiremediation with *Eudrilus eugeniae* at 200 worms per 100 kg of soil, corresponding to a remediation efficiency of approximately 26% (individual replicate efficiencies of 27%, 27% and 24%), as shown in Figure 1. This efficiency is comparatively lower than the 47.7% removal reported by Abdulsalam (2024) and the 55–61% range reported for extended vermiremediation-composting treatments of diesel-contaminated soil (Vargas-García & López, 2022), and is also lower than the 58.06% TPH removal reported for combined vermiremediation-bioaugmentation systems over longer exposure periods (Iheanacho et al., 2024).

The comparatively modest efficiency obtained in the present study is attributable principally to the shorter 30-day exposure period adopted, since hydrocarbon degradation by earthworms is strongly time-dependent, with removal efficiency generally improving with longer contact periods as microbial and enzymatic degradation pathways within the earthworm gut and casts progress (Tagliabue et al., 2023; Cascone et al., 2023; Sani et al., 2026a, Sani et al., 2026b, Sani et al., 2026c Sani et al., 2026a, Sani et al., 2026b, Sani et al., 2026c). This suggests that extending the vermiremediation period beyond 30 days could further improve the remediation efficiency and, by extension, the baseline geotechnical quality of the soil prior to PKSA stabilization.

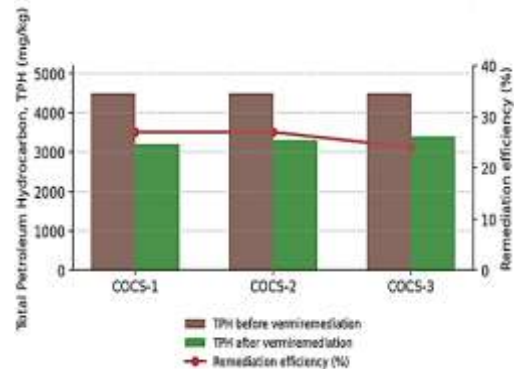


Figure 1: TPH removal and vermiremediation efficiency of *Eudrilus eugeniae* on crude-oil-contaminated lateritic soil (30-day exposure)

### Index Properties of PKSA-Stabilized Vermiremediated Soil

#### Atterberg limits

The liquid limit, plastic limit and plasticity index of the vermiremediated soil (54.0%, 32.3% and 21.7%) varied irregularly with increasing PKSA content, as shown in Figure 2, ranging between 52.5% and 59.0% for LL and between 18.7% and 22.7% for PI. The linear shrinkage remained essentially constant, within the narrow range of 11–11.3%, across all PKSA contents. Compared with the requirements of the Federal Ministry of Works and Housing and the Transport and Road Research Laboratory for subgrade materials (LL  $\leq$  50%, PI 20–25%), the vermiremediated soil at most PKSA contents marginally exceeds the recommended liquid limit, while none of the stabilized mixtures satisfies the stricter LL  $\leq$  35% and PI  $\leq$  12% limits specified for sub-base materials. This indicates that PKSA alone does not substantially improve the plasticity characteristics of the vermiremediated soil, a finding consistent with reports that PKSA exhibits comparatively lower pozzolanic reactivity than lime- or cement-based stabilizers unless combined with a calcium-rich activator (Adekunle et al., 2021; Subair et al., 2025).

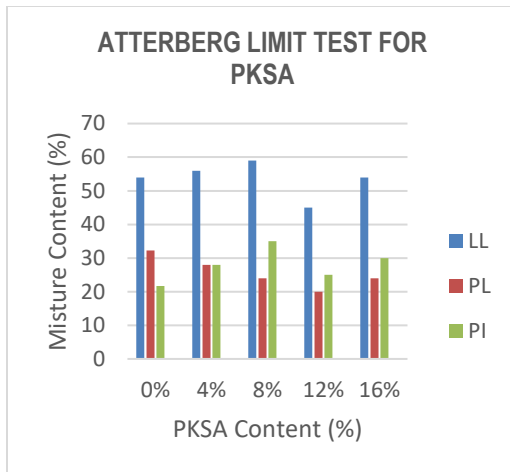


Figure 2: Variation of Atterberg limits of PKSA-stabilized vermiremediated crude oil contaminated lateritic soil

#### Specific gravity

Specific gravity decreased gradually from 2.4 at 0% PKSA to 2.2 at 16% PKSA (Figure 3), attributable to the partial replacement of the heavier lateritic soil solids with the lighter, more porous PKSA particles. This trend is consistent with observations reported for other agricultural-waste-ash stabilized lateritic soils, where specific gravity typically declines with increasing ash content owing to the low particle density of the ash relative to natural soil (Oyelami & Van Rooy, 2016; Subair et al., 2025).

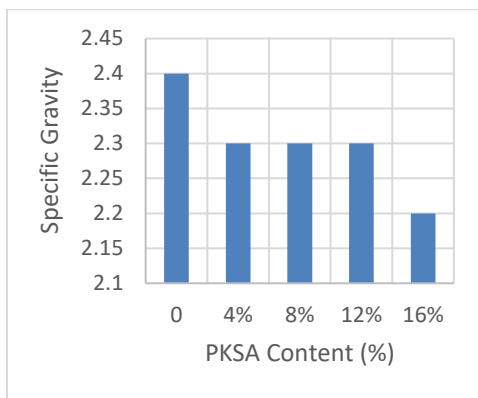


Figure 3: Variation of specific gravity of PKSA-stabilized vermiremediated crude oil contaminated lateritic soil

#### Compaction Characteristics

##### Maximum dry density

Figure 4 shows the variation of maximum dry density (MDD) with PKSA content under BSL, WAS and BSH compactive efforts. Under BSL and WAS compaction, MDD decreased with increasing PKSA content, from 1.63 Mg/m<sup>3</sup> to 1.58 Mg/m<sup>3</sup> (BSL) and from 1.66 Mg/m<sup>3</sup> to 1.55 Mg/m<sup>3</sup> (WAS) at 16% PKSA, owing to the light weight and low specific gravity of PKSA particles relative to the soil solids they replace. In contrast, MDD under BSH compaction increased from 1.69 Mg/m<sup>3</sup> to 1.83 Mg/m<sup>3</sup>, as the higher compactive energy improved particle packing and reduced voids despite the lighter PKSA particles.

Most of the recorded MDD values fall within the range generally recommended for subgrade soils (1.60–2.00 Mg/m<sup>3</sup>) by the Federal Ministry of Works and Housing and the Transport and Road Research Laboratory, but below the 1.80–2.20 Mg/m<sup>3</sup> and 2.00–2.40 Mg/m<sup>3</sup> ranges typically required for sub-base and base layers, respectively, indicating that the stabilized soil is more suited to subgrade rather than sub-base or base applications on the basis of density alone.

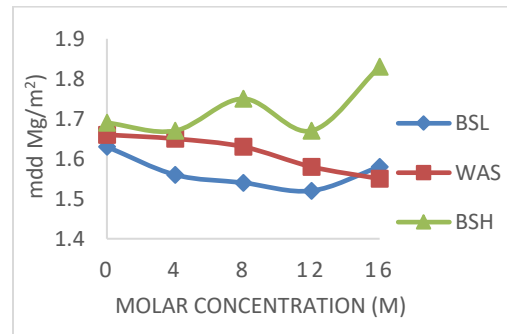


Figure 4: Variation of maximum dry density (MDD) of PKSA-stabilized vermiremediated crude oil contaminated lateritic soil for BSL, WAS and BSH compactive efforts

##### Optimum moisture content

The optimum moisture content (OMC) generally increased with PKSA content across all three compactive efforts (Figure 5): from 18.87% to 20.56% under BSL, from 17.18% to 19.11% under WAS, and from 15.78% to 18.26% under



BSH, with minor deviations at intermediate admixture levels attributable to variation in compactive energy. The increase in OMC is attributed to the porous, water-absorptive nature of PKSA, which requires additional water to achieve maximum dry density, a trend consistent with the findings of Adewale et al. (2022) for other pozzolanic-ash-stabilized lateritic soils. The OMC values obtained (15.78–20.56%) fall within or slightly above the 12–20% range recommended for subgrade layers by the FMWH and TRRL, but exceed the 10–15% and <12% ranges recommended for sub-base and base course materials, respectively, further confirming the suitability of the PKSA-stabilized soil primarily for subgrade rather than sub-base or base applications.

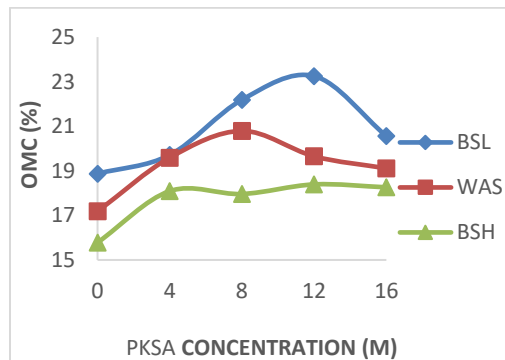


Figure 5: Variation of optimum moisture content (OMC) of PKSA-stabilized vermiremediated crude oil contaminated lateritic soil for BSL, WAS and BSH compactive efforts

## CONCLUSION

This study evaluated the remediation efficiency, index properties, and compaction and strength characteristics of Palm Kernel Shell Ash (PKSA)-stabilized, vermiremediated, crude-oil-contaminated lateritic soil for highway sub-base application. Vermiremediation using *Eudrilus eugeniae* over 30 days achieved a TPH removal efficiency of approximately 26%, lower than efficiencies reported for longer treatment durations in the literature, suggesting that extending the treatment period could further improve remediation outcomes.

PKSA stabilization did not substantially improve the plasticity characteristics of the vermiremediated soil but reduced its specific gravity with increasing admixture content. Compaction behaviour was compaction-energy dependent: MDD decreased under BSL and WAS efforts but increased under BSH, while OMC generally increased with PKSA content across all efforts. The combined treatment approach represents a sustainable, low-cost pathway for rehabilitating petroleum-impacted lateritic soils for highway earthworks in Nigeria and similar tropical environments, and warrants further investigation using extended vermiremediation periods and PKSA combined with a calcium-rich activator such as lime.

## REFERENCES

- AASHTO. (1996). Standard specification for transportation materials and methods of sampling and testing (14th ed.). American Association of State Highway and Transportation Officials.
- Abdulsalam, M. (2024). Bioremediation of crude oil contaminated soil using earthworms: Efficiency and duration effects. Unpublished thesis, Nigerian Defence Academy.
- Adekunle, I. M., et al. (2021). Potentials of processed palm kernel shell ash as a local stabilizer for clayey soils. *Journal of Geotechnical Studies*, 9(2), 45–58.
- Adewale, O., et al. (2020). Effect of palm kernel shell ash on the strength characteristics of lateritic soil. *Nigerian Journal of Engineering Research*, 14(1), 22–31.
- Adewale, O., et al. (2022). Compaction characteristics of agricultural-waste-ash-stabilized lateritic soils. *Journal of Sustainable Construction Materials*, 6(3), 112–124.
- Akintola, F. O. (1982). Geographical map of Nigeria. Rex Charles Publications.
- Bala, N., et al. (2022). Vermiremediation of crude oil contaminated soil using *Eudrilus eugeniae*. *Environmental Technology & Innovation*, 27, 102455.
- Bala, N., et al. (2024). Correlation between earthworm density and hydrocarbon remediation efficiency in petroleum

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- contaminated soils. *Environmental Pollution Research*, 31(4), 5123–5134.
- British Standards Institution. (1990). BS 1377: Methods of test for soils for civil engineering purposes.
- British Standards Institution. (1990). BS 1924: Methods of test for stabilized soils.
- Cascone, G., Rorato, L., & Marchetti, R. (2023). A systematic review on earthworms in soil bioremediation. *Applied Sciences*, 13(18), 10239. <https://doi.org/10.3390/app131810239>
- Federal Ministry of Works and Housing. (1997). General specifications for roads and bridges (Vol. II). Federal Ministry of Works and Housing, Nigeria.
- Iheanacho, C., et al. (2024). Combined impacts of bioaugmentation and vermiremediation on crude oil contaminated soil: Mitigating strategies for prospective environmental management. *Environmental Advances*, 15, 100489. <https://doi.org/10.3390/app131810239>
- Ingles, O. G., & Metcalf, J. B. (1972). *Soil stabilization: Principles and practice*. Butterworths.
- Nigerian General Specifications for Roads and Bridges. (2016). Federal Ministry of Power, Works and Housing, Nigeria.
- Njoku, K. L. (2017). Vermiremediation strategies for petroleum hydrocarbon contaminated soils. *African Journal of Environmental Science and Technology*, 11(6), 292–301.
- Odeh, C., et al. (2021). Geotechnical implications of crude oil contamination on tropical lateritic soils. *Soil and Environment Research*, 8(2), 67–79.
- Ola, S. A. (1974). Need for estimated cement requirements for stabilizing lateritic soils. *ASCE Journal of Transportation Engineering*, 100(2), 379–388.
- Ola, S. A. (1983). Geotechnical properties and behaviour of some stabilized Nigerian lateritic soils. *Quarterly Journal of Engineering Geology*, 16(2), 131–136.
- Oyelami, C. A., & Van Rooy, J. L. (2016). A review of the use of lateritic soils in the construction/development of sustainable housing in Africa: A geological perspective. *Journal of African Earth Sciences*, 119, 226–237.
- Sani J. E., Muhammad M. S, Victor I. M, Moses G. (2026a). Influence Of Coconut Shell Ash-Enhanced Filter Media in Electrokinetic Remediation (EKR) Treatment of Petroleum-Contaminated Soils. *IRE Journals Volume 9 Issue 10 | ISSN: 2456-8880 DOI: <https://doi.org/10.64388/IREV9I10-1717139>*
- Sani J. E., Isah, I. K. Victor I. M, Moses G (2026b). Performance Evaluation of Vermi-Remediated Crude Oil Contaminated Soil on Compaction Characteristics When Stabilized with Cement Kiln Dust. *IRE Journals Volume 9 Issue 11 | JPP. 1797 – 1805. ISSN: 2456-8880 DOI: <https://doi.org/10.64388/IREV9I11-17971805>*
- Sani J. E. Arome, A. Y. Musa Nasiru, Moses Ochu. B. O.O. (2026c). Strength Characteristics of Cement-Stabilized Vermi-Improved Crude Oil Contaminated Lateritic Soil under British Standard Light Compactive Effort for Highway Application. *Journal of science technology and education 14(2), JUNE, 2026 E-ISSN: 3093-0898, PRINT ISSN: 2277-0011; Journal homepage: [www.atbufstejoste.com](http://www.atbufstejoste.com)*
- Subair, S. O., et al. (2025). Effect of palm kernel shell ash supplement with egg shell ash on stabilized lateritic soil for a road work. *ABUAD Journal of Engineering Research and Development*, 8(1), 21–28.
- Tagliabue, L., Bonfante, A., & De Vivo, B. (2023). Earthworm-mediated degradation of organic contaminants in soil: Mechanisms and applications. *Chemosphere*, 313, 137456.
- Transport and Road Research Laboratory. (1977). *A guide to the structural design of bitumen-surfaced roads in tropical and sub-tropical countries*. TRRL, Crowthorne, UK.
- Vargas-García, M. C., & López, M. J. (2022). Bioremediation of hydrocarbon contaminated soil using local organic materials and earthworms. *Chemosphere*, 305, 135335. <https://doi.org/10.1016/j.chemosphere.2022.135335>.

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