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Analysis of Physicochemical Properties of Soils in Sub-Saharan Region of Sokoto State, Nigeria

***S. A. Yarima[1] and A. M. Danjuma[2]**
[1]Department of Environmental Science Education, Shehu Shagari University of Education, Sokoto
[2]Department of Science Laboratory Technology, Umaru Ali Shinkafi Polytechnic, Sokoto
*Correspondence Author: yarimausman@gmail.com, 08032304044
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Abstract
This study investigates the physicochemical properties of soils in Gwadabawa Local Government, Sokoto State, Nigeria, focusing on their implications for hydrocarbon degradation and environmental management. Soil samples were collected from the top 0–15 cm layer across various sites and analyzed for parameters including pH, electrical conductivity (EC), phosphate content, and particle size distribution. The results indicated that the soils are slightly acidic, which fosters microbial activity essential for the natural biodegradation of hydrocarbons. The EC values suggested low salinity and ion concentration, indicating minimal hydrocarbon contamination at the sampled sites. However, low phosphate levels could limit microbial enzymatic processes critical for effective hydrocarbon degradation. The physical analysis revealed predominantly sandy soils with an average sand content of 66.62%, silt at 25.32%, and clay at 8.44%. This sandy texture enhances permeability and hydrocarbon mobility, increasing the potential for contaminants to spread through the soil profile and potentially reach groundwater. While the soil structure supports oxygen and nutrient penetration vital for microbial activity, the low clay content reduces the soil's capacity to adsorb and immobilize hydrocarbons, complicating remediation efforts.

Keywords: *Hydrocarbon degradation, physicochemical properties, sandy texture, microbial activity, contamination management.*

Introduction

Soil serves as a fundamental resource for agricultural productivity, ecological sustainability, and environmental remediation. Its physicochemical properties play a critical role in determining its health, fertility, and capacity to support biological and chemical processes (Adewale *et al*., 2021). In sub-Saharan Africa, particularly in Sokoto State, Nigeria, understanding soil characteristics is pivotal for sustainable land use and effective environmental management. This knowledge becomes even more critical when addressing environmental challenges such as hydrocarbon contamination, which can severely impact soil quality, groundwater resources, and ecosystem health.

The physicochemical properties of soil, including pH, electrical conductivity (EC), phosphate content, and particle size distribution (sand, silt, clay percentages), directly influence nutrient availability, microbial activity, and soil's ability to degrade hydrocarbons (Gowthamchand *et al*., 2023; Ogwu, 2024). Soil pH is a critical determinant of microbial activity and nutrient availability, as most microorganisms thrive in specific pH ranges. Similarly, EC provides an indication of salinity and ion concentration, which can impact soil structure and microbial communities. Phosphate content is particularly significant for hydrocarbon degradation, as microbial enzymatic processes often rely on the availability of phosphorus as a nutrient source (Das and Chandran, 2011; Fan *et al*., 2020; Singh *et al*., 2023).

In the context of Sokoto State, sandy soils are predominant, characterized by high permeability that can increase the risk of contaminant mobility and potential groundwater pollution. While the sandy texture facilitates oxygen and nutrient penetration, essential for microbial activity, it also presents challenges for hydrocarbon remediation due to its limited adsorption capacity. Consequently, understanding the interplay between these properties is crucial for developing strategies to mitigate hydrocarbon contamination and improve soil health in the region.

This study focuses on the physicochemical properties of soils in Gwadabawa Local Government, Sokoto State, Nigeria, to evaluate their implications for hydrocarbon degradation and environmental management. By analyzing parameters such as pH, EC, phosphate content, and particle size distribution, this research aims to provide insights into soil health, its suitability for supporting microbial activity, and its potential to facilitate or hinder the remediation of hydrocarbon contaminants.

Materials and Methods

Soil samples were systematically collected from the top 0–15 cm layer at multiple locations within Gwadabawa Local Government, ensuring a representative assessment of the area. Each sample was carefully labeled, sealed in pre-sterilized polyethylene bags to prevent contamination, and promptly transported to the laboratory for detailed physicochemical analysis.

The collected samples underwent analysis using established standard methodologies to evaluate critical soil parameters:

Soil pH: Measured via the potentiometric method using a calibrated pH meter. Calibration with standard buffer solutions ensured precision, offering reliable insights into the soil's acidity or alkalinity, a key determinant of microbial activity and nutrient availability (Eckert and Sims, 1995).

Electrical Conductivity (EC): Determined with a conductivity meter, with values expressed in µS/cm. This parameter provided an understanding of soil salinity and ion concentration, which influence soil fertility and microbial processes (Sikora and Moore, 2014).

Phosphate (PO_4): Quantified using the colorimetric method, with results reported in mg/kg. This method accurately assessed phosphorus levels, an essential nutrient for microbial enzymatic activity, particularly in hydrocarbon degradation processes (Donohue and Heckendorn, 1996).

Particle Size Distribution: Assessed using a density meter to determine the proportions of sand, silt, and clay. This analysis provided detailed insights into soil texture, which affects permeability, water retention, and the potential for hydrocarbon mobility or containment (Paterson *et al*., 2021)

Descriptive statistics, including means and standard errors, were calculated for each parameter to summarize the soil characteristics across sampling sites. The results were benchmarked against established standards to evaluate their implications for microbial activity, hydrocarbon degradation potential, and environmental management.

Table 1. Summary of Analytical Method

S/N	Parameter	Method of Analysis
1	pH	Potentiometry
2	EC (µS/cm)	Conductometry
3	PO_4 (mg/kg)	Colorimetry
4	% Sand	Density Meter
5	% Silt	Density Meter
6	% Clay	Density Meter

Results and Discussion

Chemical Properties of Soil

The chemical properties of the soil are summarized in Table 2. The mean pH of 6.3240 indicates slightly acidic conditions, conducive to microbial activity essential for hydrocarbon degradation. This acidity can be attributed to organic acid production by hydrocarbon-degrading microbes. The EC value of 58.5600 µS/cm reflects low salinity and minimal ion concentration, suggesting minimal contamination or early-stage hydrocarbon presence. However, the phosphate content of 0.1280 mg/kg is significantly low, potentially limiting microbial enzymatic activity due to nutrient deficiency. Phosphorus supplementation may be required to enhance microbial efficiency for hydrocarbon remediation.

Table 2. Chemical Properties of Soil

S/N	Parameter	Mean ± SE
1	pH	6.324
2	EC (µS/cm)	58.56
3	PO_4 (mg/kg)	0.128

Physical Properties of Soil

Table 3 highlights the soil's sandy texture, with sand comprising 66.62%, silt 25.32%, and clay only 8.44%. This composition enhances soil permeability, facilitating hydrocarbon mobility and increasing the risk of contaminant migration to deeper layers or groundwater. The low clay content limits the soil's adsorption capacity, complicating containment efforts. Moderate silt content offers some water retention, but the dominance of sand suggests conditions favoring hydrocarbon dispersion rather than localized accumulation. These characteristics underscore the challenges associated with hydrocarbon remediation in such soil environments.

Table 3. Physical Properties of Soil

S/No.	Parameter	Mean (%)
1	% Sand	66.62
2	% Silt	25.32
3	% Clay	8.44

Discussion

The results of this study provide valuable insights into the physicochemical properties of soils in Gwadabawa Local Government and their implications for hydrocarbon degradation and environmental management. The interplay between chemical and physical properties reveals a dual-edged scenario: while certain conditions favor microbial activity essential for biodegradation, others pose significant challenges for hydrocarbon containment and remediation.

Microbial Activity and Hydrocarbon Degradation

The slightly acidic pH (mean 6.3240) creates a favorable environment for hydrocarbon-degrading microbial communities. This pH level aligns with optimal conditions for microbial activity, where organic acids produced during microbial metabolic processes can further enhance hydrocarbon breakdown (Karishma, 2024). Additionally, the low electrical conductivity (EC) of 58.5600 µS/cm reflects minimal salinity and ion concentration, conditions that are generally supportive of microbial growth and activity (Zhu *et al.*, 2024). However, the significantly low phosphate content (0.1280 mg/kg) is a critical limitation. Phosphorus is an essential nutrient for microbial enzymatic functions, and its deficiency could significantly impair the efficiency of hydrocarbon degradation (Narayanan, 2023). To optimize microbial activity, phosphorus supplementation or the application of phosphorus-rich amendments may be necessary.

Hydrocarbon Mobility

The predominance of sand in the soil texture (66.62%) enhances permeability and facilitates the mobility of hydrocarbons through the soil profile (Wu *et al.*, 2024). This high permeability increases the risk of contaminants migrating to deeper soil layers or even reaching groundwater reserves, posing significant environmental risks. The low clay content (8.44%) exacerbates this issue by reducing the soil's capacity to adsorb hydrocarbons, which typically bind to fine clay particles (Sattraburut *et al.*, 2024). While the moderate silt content (25.32%) provides some water retention, it is insufficient to counterbalance the high sand content's permeability. This physical composition highlights the need for targeted strategies to mitigate contaminant dispersion.

Environmental Implications

The combined chemical and physical properties of the soil present a complex scenario for environmental management. On the one hand, the favorable pH and low salinity support microbial degradation processes, providing a natural mechanism for hydrocarbon remediation. On the other hand, the sandy texture and low clay content increase the risk of contaminant spread, complicating containment and remediation efforts. Effective management strategies must address these dual challenges. Key interventions could include:

Nutrient Supplementation: Addressing phosphorus deficiencies through the addition of phosphorus-rich fertilizers or bioavailable phosphate compounds to enhance microbial efficiency.

Hydrocarbon Containment: Incorporating organic or inorganic amendments, such as biochar or bentonite clay, to increase soil adsorption capacity and reduce hydrocarbon mobility.

Monitoring and Remediation: Implementing consistent monitoring protocols to track contaminant levels and adopting bioremediation techniques that leverage the soil’s natural microbial communities.

Conclusion

The physicochemical properties of soils in Gwadabawa Local Government provide valuable insights into their potential for hydrocarbon degradation and environmental management. The slightly acidic pH and low EC values create favorable conditions for microbial activity, but the low phosphate levels and sandy texture pose challenges for effective remediation. Sustainable management strategies should prioritize nutrient supplementation, soil amendment to reduce permeability, and consistent monitoring to mitigate environmental risks and enhance the soil’s capacity for hydrocarbon containment and degradation.

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