SSR Journal of Multidisciplinary (SSRJM)

OPEN ACCESS

Volume 2, Issue 5, 2025 Homepage: https://ssrpublisher.com/ssrjm/ ISSN: 3049-1304
Email: office.ssrpublisher@gmail.com

Assessment of Palm Oil Mill Effluent-Induced Alterations on Soil Physicochemical Dynamics in Umuapu, Imo State

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Received: *19.06.2025* | ***Accepted:*** *09.07.2025* | ***Published:*** *12.07.2025*

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DOI: *10.5281/zenodo.15868385*

Abstract **Original Research Article**

Palm Oil Mill Effluent (POME) is a high-strength organic waste that poses significant environmental risks, particularly in regions where untreated discharge into terrestrial ecosystems is common. This study evaluates the impact of POME on soil physicochemical properties in Umuapu, Ohaji, Imo State, Nigeria a semi-rural community experiencing intensified artisanal palm oil production. A total of 12 composite soil samples were collected from effluent-impacted and control sites and analyzed for key parameters including pH, electrical conductivity (EC), total nitrogen, organic carbon, moisture content, and contaminant levels, following APHA and AOAC standard protocols. Results revealed marked alterations in soil properties due to effluent exposure. Soils near POME discharge points exhibited increased pH (up to 5.37), EC (500.10 µS/cm), total nitrogen (3.12%), and organic carbon (19.60%), indicating substantial organic enrichment and nutrient loading. However, elevated oil and grease concentrations (up to 700.86 mg/kg) and chloride levels (92.22 mg/kg) were observed, suggesting significant contamination risks. Temperature elevations (up to 36.10 °C) and increased moisture content in effluent-impacted soils reflect thermal and hydrophilic characteristics of POME, which may disrupt microbial dynamics and reduce soil aeration. The findings underscore the dualistic nature of POME impacts enhancing fertility parameters while simultaneously introducing environmental stressors such as salinity, hydrocarbon pollution, and potential groundwater contamination. This study provides critical localized data on POME-induced soil alterations, informing future remediation strategies and policy frameworks aimed at sustainable agro-industrial practices. Effective management of POME discharge is essential to safeguard soil health, agricultural productivity, and environmental quality in palm oil-producing regions.

Keywords: Palm Oil Mill Effluent, POME, Soil Contamination, Physicochemical Properties, Organic Waste, Imo State, Nigeria, Nutrient Loading, Oil And Grease, Chloride Levels, Environmental Impact, Agro-Industrial Waste, Soil Fertility.

Citation: Anele, B. C., Okorite, G.-W., Chikwem, F., Anioke, F. C., & Ede, P. C. (2025). Assessment of palm oil mill effluent-induced alterations on soil physicochemical dynamics in Umuapu, Imo State. *SSR Journal of Multidisciplinary (SSRJM)*, *2*(5), 14-20.

1. INTRODUCTION

Palm oil production is a cornerstone of the agricultural economy in many tropical nations, including Nigeria. However, its environmental footprint particularly the discharge of palm oil mill effluent (POME) has become a growing concern. POME is a high-strength organic waste characterized by elevated levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD), total solids, and acidic pH, making it a significant environmental pollutant when released untreated into the environment (Ahmad et al., 2003; Igwe & Onyegbado, 2007). In Nigeria, especially in semi-rural communities like Umuapu Ohaji in Imo State, unregulated disposal of POME directly onto land remains a common practice due to the lack of effective treatment infrastructure and environmental policies (Nwaugo et al., 2008).

The soil is a dynamic component of the terrestrial ecosystem, and its physicochemical properties such as pH, organic matter, cation exchange capacity (CEC), nutrient content and microbial activity are critical indicators of its health and productivity. When POME is indiscriminately applied to soil, it can lead to significant alterations in these properties. For instance, several studies have reported acidification of soil, elevation of heavy metal concentrations, excessive nutrient loads, and disruption of microbial communities in soils exposed to untreated POME (Agamuthu et al., 2010; Eze et al., 2018). While in some cases, POME has shown potential to improve soil fertility due to its organic and nutrient-rich composition, long-term application often results in nutrient imbalances, reduced aeration, and contamination of both surface and groundwater sources (Aigbodion & Iyasele, 2017).

In the Niger Delta region, where Umuapu Ohaji is situated, the combination of high rainfall, porous soils, and shallow aquifers further exacerbates the mobility and ecological consequences of effluent infiltration (Anoliefo et al., 2006). Despite the socio-economic importance of palm oil processing in this region, there is a dearth of localized data assessing the cumulative impact of POME on soil physicochemical parameters, particularly under field conditions typical of artisanal mills. This represents a significant gap in the environmental management literature and poses a challenge for the implementation of site-specific remediation and policy interventions.

In Umuapu, Ohaji, within Imo State, the proliferation of palm oil mills has intensified, yet there is limited empirical data evaluating the environmental consequences of POME discharge on soil physicochemical dynamics in this locale. Understanding these impacts is essential for devising effective soil management and remediation strategies, thereby safeguarding agricultural sustainability and environmental health (Adeniyi et al., 2019).

This study aims to comprehensively assess the alterations induced by Palm Oil Mill Effluent on the physicochemical properties of soils in Umuapu, offering critical insights into the environmental ramifications of palm oil processing waste and informing sustainable agro-industrial practices.

2. MATERIALS AND METHODS

2.1: Study Area

Umuapu is a rural community located in Ohaji Local Government Area of Imo State, Nigeria, situated at approximately 5.3833° N latitude and 7.0167° E longitude. The area is predominantly agrarian, with the majority of inhabitants engaged in small-scale farming and artisanal palm oil production. The local economy heavily relies on oil palm cultivation and processing, with numerous palm oil mills operating within the community. This agricultural focus shapes the land use pattern, contributing to both livelihood sustenance and environmental challenges such as soil contamination from palm oil mill effluents.

2.2 Sample Collection

Soil samples were systematically collected from sites impacted by Palm Oil Mill Effluent (POME) within the Umuapu community in Ohaji/Egbema Local Government Area of Imo State, Nigeria. The study area was selected based on its proximity to a medium-scale palm oil processing facility with known discharge of untreated or partially treated effluent directly into the surrounding environment.

A stratified sampling technique was adopted to ensure representativeness of both impacted and control sites. A total of 12 composite soil samples were collected: 9 from effluent-impacted sites at varying distances (0 m, 10 m, and 20 m) from the effluent discharge point and 3 from uncontaminated control sites located over 200 meters away from any known effluent source. The sampling depth was standardized at 0–20 cm, aligning with previous studies indicating that the topsoil is most susceptible to effluent infiltration and alteration (Okafor et al., 2020; Adeniyi et al., 2019).

Each composite sample was derived by mixing five subsamples collected within a 1 m² quadrant using a stainless steel auger to reduce the influence of localized variability. Samples were immediately placed in labeled polyethylene bags, stored in an ice chest, and transported to the laboratory for physicochemical analysis within 24 hours of collection. Prior to analysis, the soil samples were air-dried at room temperature, homogenized, and passed through a 2 mm sieve to remove debris and standardize particle size (Akinbile & Yusoff, 2012).

2.3: Physicochemical Analysis of Soil Samples

The collected soil samples were subjected to laboratory analysis to evaluate their physicochemical properties. All procedures followed standardized analytical methods as described by the American Public Health Association (APHA, 2017) and the Association of Official Analytical Chemists (AOAC, 2016), ensuring accuracy and comparability.

2.3.1 Soil pH and Electrical Conductivity

Soil pH was determined in a 1:2.5 soil-to-distilled water suspension using a calibrated digital pH meter. Electrical conductivity (EC), indicating salinity, was measured in the same suspension using a conductivity meter (Okafor et al., 2020).

2.3.2 Organic Carbon and Organic Matter

Organic carbon was analyzed using the Walkley-Black wet oxidation method. The percentage of organic matter was estimated by multiplying the organic carbon value by the van Bemmelen factor (1.724), based on the assumption that organic matter contains approximately 58% carbon (Akinbile & Yusoff, 2012).

2.3.3 Total Nitrogen

Total nitrogen (TN) was determined using the

Kjeldahl digestion technique, which involves acid digestion, distillation, and titration to quantify nitrogen content in the soil (Adeniyi et al., 2019).

2.3.4 Available Phosphorus

Available phosphorus was extracted using the Bray-1 method, suitable for acidic soils, and measured colorimetrically with the molybdenum blue method at 882 nm wavelength using a spectrophotometer (Nwoko & Ogunyemi, 2010).

2.3.5 Exchangeable Cations and Cation Exchange Capacity

Exchangeable cations (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) were extracted using 1.0 M ammonium acetate (pH 7.0). Calcium and magnesium were determined by atomic absorption spectrophotometry (AAS), while potassium and sodium were analyzed using a flame photometer. Cation exchange capacity (CEC) was computed by summing the exchangeable bases and exchangeable acidity (Ogunlade et al., 2011).

2.3.6 Particle Size Distribution (Soil Texture)

Soil texture was determined using the hydrometer method after dispersing soil particles with sodium hexametaphosphate. The proportions of sand, silt, and clay were classified based on the USDA soil textural triangle (ASTM, 2016).

3. RESULTS

Table 1 presents the physicochemical properties of soil samples from four locations near a palm oil mill in Umuapu, Ohaji, Imo State, Nigeria. Soil pH ranged from moderately acidic (5.37 in Umudokoyi) to strongly acidic (4.09 in Ihie). Electrical conductivity (EC) was highest in Akano (500.10 µS/cm), indicating higher soluble salt content. Soil temperature varied significantly, with Akano (36.10 °C) and Umudokoyi (35.20 °C) notably warmer than Umubuehi (25.10 °C) and Ihie (23.30 °C).

Table 1: Soil physicochemical properties of samples from Palm Oil Mill Industry in Umuapu, Ohaji Imo State, Nigeria

Parameters	Akano	Umudokoyi	Umubuehi	Ihie
pH	5.24	5.37	4.52	4.09
EC(µS/cm)	500.10	39.03	280.23	370.12
Tempt (°C)	36.10	35.20	25.10	23.30

Table 2 summarizes the nutrient and organic content of soil samples from the study area. Umudokoyi recorded the highest total nitrogen (3.12%) and nitrate (0.79%) levels, indicating greater nitrogen enrichment. Phosphorus content peaked in Ihie (1.23%), while Akano had the highest total organic carbon (19.60%) and organic matter (23.20 mg/kg), suggesting higher organic input or residue accumulation.

Table 2: Soil Nutrient and Organic content from Palm Oil Mill Industry in Umuapu, Ohaji, Imo State, Nigeria

Parameters	Akano	Umudokoyi	Umubuehi	Ihie
Total Nitrogen (%)	2.24	3.12	2.12	0.93
Nitrate (NO3-) (%)	0.52	0.79	0.60	0.28
Phosphorus (%)	1.06	0.90	0.49	1.23
TOC (%)	19.60	16.40	13.06	12.05
TOM(mg/kg)	23.20	26.26	21.02	19.41

Keys: TOC: Total Organic Carbon, TOM: Total Organic Matter

Table 3 highlights soil contaminants and chemical properties across the sampled sites. Umudokoyi exhibited the highest levels of chloride (92.22 mg/kg) and oil & grease (700.86mg/kg), indicating significant contamination. Alkalinity was highest in Umubuehi (67.00 mg/kg), while total moisture content ranged from 12.48% in Ihie to 20.04% in Akano. These variations reflect differing levels of pollutant exposure and soil retention capacity.

Table 3: Soil Contaminants and Chemical Properties from Palm Oil Mill Industry in Umuapu, Ohaji, Imo State, Nigeria

Parameters	Akano	Umudokoyi	Umubuehi	Ihie
Alkalinity (mg/kg)	38.00	36.00	67.00	34.32
Total moisture (%)	20.04	18.32	14.05	12.48
Chloride(mg/kg)	20.32	92.22	77.05	31.25
Oil & Grease (mg/kg)	420.25	700.86	500.53	400.

4. DISCUSSION

4.1: Soil Physicochemical Properties of Samples from Palm Oil Mill Industry in Umuapu, Ohaji Imo State, Nigeria

The physicochemical properties of soils from palm oil mill effluent (POME)–impacted zones in Umuapu reveal significant alterations in pH, electrical conductivity (EC), and temperature, reflecting the cumulative and site-specific influence of effluent disposal on soil quality and ecological function.

The pH values range from moderately acidic (5.37 at Umudokoyi and 5.24 at Akano) to strongly acidic (4.52 at Umubuehi and 4.09 at Ihie), highlighting a distinct pH elevation at sites closest to effluent disposal zones. While all soils remain within the acidic spectrum typical of tropical ultisols, the relatively higher pH at Akano and Umudokoyi suggests buffering due to effluent-derived alkaline organic compounds. These values exceed the typical baseline pH of acid forest soils in southeastern Nigeria, which ranges from 3.9–4.8, as reported by Osodeke and Eze (2011). Similarly, Nwoko and Ogunyemi (2010) observed a moderate increase in soil pH following POME application in Ibadan, attributed to the hydrolysis of organic acids and release of basic cations such as Ca^{2+}, K^{+}, and Mg^{2+} during decomposition (Nwoko & Ogunyemi, 2010).

The increase in pH, though modest, is ecologically significant. Acidic soils, particularly below pH 5.0, often suffer from aluminum toxicity, phosphorus fixation, and microbial inhibition. Therefore, the slight elevation in pH at effluent-impacted sites could foster improved microbial activity and nutrient availability, supporting findings by Okonokhua et al. (2007), who observed enhanced microbial respiration and enzyme activities at mildly acidic conditions post-effluent treatment (Okonokhua et al., 2007). However, these benefits are contingent on controlled effluent dosing; excessive or chronic effluent exposure may disrupt pH balance or induce salinity-related antagonism.

Electrical conductivity (EC), an indirect measure of soil salinity and ionic strength, displayed elevated values at Akano (500.10µS/cm) and Umudokoyi (390.03µS/cm), compared to Umubuehi (280.23µS/cm) and the control site Ihie (370.12µS/cm). These values are markedly higher than natural background levels (typically <200 µS/cm in lowland forest soils), confirming ionic enrichment due to POME residues (Anoliefo & Edegbai, 2000).The EC values are within tolerable thresholds for most crops (<700µS/cm), yet their upward trajectory signals potential for salinity accumulation, especially under high evapotranspiration or low leaching conditions, as also emphasized by Adeleke et al. (2022) in their study on effluent-affected soils in Ogun State (Adeleke, et al., 2022).

High EC has implications for soil structure and plant nutrient uptake. Elevated salinity may induce osmotic stress, reducing water absorption by roots and exacerbating drought conditions in marginally humid areas. Moreover, the altered soil ionic balance can promote the competitive exclusion of essential nutrients such as calcium and potassium by sodium ions, leading to nutrient imbalances. Such risks underscore the importance of routine monitoring and site-specific salinity management.

Temperature data further illustrate the thermal impact of effluent discharge. Soils at Akano (36.10°C) and Umudokoyi (35.20°C) recorded markedly higher surface temperatures than Umubuehi (25.10°C) and Ihie (23.30°C), likely due to the thermal properties of discharged POME, which is often released at elevated temperatures (50–80°C) from mills (Ahmad et al., 2003). These findings align with observations by Okwute and Isu (2007), who reported persistent heat loading in soils within 10–20 meters of effluent drains, resulting in increased microbial respiration and volatilization losses (Okwute & Isu, 2007).

While elevated temperatures may stimulate microbial decomposition and short-term mineralization, sustained soil heating can reduce water retention, denature soil enzymes, and suppress microbial diversity particularly of mesophilic and symbiotic species critical for nutrient cycling (Brady & Weil, 2016). These shifts could destabilize soil food webs, reduce nutrient-use efficiency, and ultimately degrade soil fertility.

4.2: Soil Nutrient and Organic Content from Palm Oil Mill Industry in Umuapu, Ohaji Imo State, Nigeria

The nutrient and organic content data from the study locations clearly demonstrate the profound influence of palm oil mill effluent (POME) discharge on soil fertility parameters. Total nitrogen (TN) values from Akano (2.24%), Umudokoyi (3.12%), and Umubuehi (2.12%) substantially exceed that of the control site Ihie (0.93%), suggesting a high deposition of organic-rich effluent and subsequent nitrogen mineralization. These values are considerably higher than those reported by Nwoko and Ogunyemi (2010), who recorded nitrogen values between 0.15% and 0.88% in POME-treated soils in Ibadan, Nigeria, pointing to more intense contamination or prolonged effluent exposure in the Umuapu region (Nwoko, & Ogunyemi, 2010)..

The nitrate (NO_3^-) profile further substantiates this conclusion. Elevated nitrate levels in Umudokoyi (0.79%) and Akano (0.52%) indicate rapid nitrification, consistent with the oxygenated aerobic breakdown of nitrogenous organic matter, as similarly reported by Okwute and Isu (2007) in Kogi State, where nitrate levels increased after POME application (Okwute & Isu,2007). However, the elevated nitrate concentrations raise ecological concerns, particularly regarding nitrate leaching into groundwater a risk highlighted by Okonokhua et al. (2007), who emphasized the potential for nitrate pollution in regions with permeable sandy soils and high rainfall (Okonokhua et al., 2007).

Phosphorus levels exhibited a non-linear trend. While Akano (1.06%) and Umudokoyi (0.90%) maintained high phosphorus levels, Umubuehi (0.49%) recorded lower concentrations than the control site Ihie (1.23%). This deviation suggests potential phosphorus immobilization or fixation in certain microenvironments. Similar phosphorus inconsistency was reported in studies by Afangide et al. (2022), where microbial uptake and chemical precipitation in acidic soils were suggested to limit bioavailable phosphorus despite high organic input.

Total organic carbon (TOC) concentrations were markedly elevated in POME-impacted soils: Akano (19.60%), Umudokoyi (16.40%), and Umubuehi (13.06%) compared to the control (12.05%). These values reflect an abundance of undecomposed or partially decomposed organic residues from the effluent. Such enrichment mirrors findings by Okwute et al. (2023), who reported a TOC range of 14.2–18.5% in POME-polluted soil amended with compost, emphasizing that effluent alone is capable of elevating carbon stocks in soils.

Total organic matter (TOM) follows a similar pattern, with concentrations peaking at Umudokoyi (26.26mg/kg) and Akano (23.20mg/kg). These figures are consistent with studies conducted in the Niger Delta, where POME application increased TOM by over 40% within three weeks (Anoliefo & Edegbai, 2000). Organic matter plays a vital role in nutrient retention, soil aggregation, and microbial activity; however, excessive accumulation can also result in oxygen deficiency and reduced nitrification in poorly drained soils.

4.3: Soil Contaminants and Chemical Properties from Palm Oil Mill Industry in Umuapu, Ohaji Imo State, Nigeria

The observed alkalinity values (38.0–86.0mg/kg) in Umudokoyi and Umubuehi significantly exceed those of the control Ihie (34.3mg/kg), suggesting an elevated buffering capacity in soils influenced by POME deposition. This aligns with Nta et al. (2020), who documented higher total alkalinity in POME-contaminated agricultural soils relative to uncontaminated counterparts alkalinity can initially mitigate acidification; however, without proper management, subsequent neutralization of soil acidity may consume buffering agents, destabilizing pH and nutrient availability (Okolie et al., 2019).

Moisture content across POME-impacted sites (14.05–20.04%) notably surpassed the control (12.48%), reflecting the hydrophilic nature of residual organics and oil in effluent, which enhances water retention. Similar outcomes were reported by Maduwuba (2024), with moisture reaching 21–35% in POME soils. While higher moisture may benefit plant growth in dry seasons, elevated residual moisture combined with oil films risks pore clogging, reduced aeration, and anaerobic microzones potentially impairing root respiration and microbial nitrification processes (Maduwuba, 2024).

Chloride concentrations show a clear effluent gradient: from 20.3mg/kg at Akano to 92.2 mg/kg at Umudokoyi, all superseding the control's 31.3mg/kg chloride. This mirrors studies in the Niger Delta showing increased soil salinity and chloride content post-POME discharge (Nta et al., 2020). Accumulated chloride poses risks of osmotic stress to crops and potential groundwater salinization, emphasizing the need for salinity profiling near agricultural zones (Aleruchi et al, 2023).

Oil and grease levels are alarmingly high in effluent-affected areas ranging from 420mg/kg (Akano) to 700.9mg/kg (Umudokoyi), compared with 400.3mg/kg in the control. Okolie et al. (2023) observed similarly elevated grease concentrations up to 3500mg/kg in POME soils, while Williams (2018) reported over 165000mg/L in raw effluent. Persistently high hydrocarbon residues can obstruct soil porosity, reduce infiltration, and inhibit biochemical processes vital for nutrient cycling. Moreover, they may generate phytotoxic conditions detrimental to crop uptake and yield (Williams, 2018).

5. CONCLUSION

This study has demonstrated that the indiscriminate discharge of palm oil mill effluent (POME) significantly alters the physicochemical properties of soils in Umuapu, Imo State. Observed changes such as increased acidity, elevated salinity, enrichment in organic matter, and hydrocarbon contamination pose long-term risks to soil fertility, crop productivity, and environmental sustainability. These findings underscore the urgent need for regulated effluent management in artisanal palm oil-producing communities.

6. RECOMMENDATIONS

1. Establish localized effluent treatment systems for artisanal palm oil mills to reduce direct discharge of untreated POME.
2. Enforce environmental monitoring and compliance policies targeting soil and water quality near processing sites.
3. Promote the use of eco-friendly remediation strategies, such as bioremediation and phytoremediation, to rehabilitate impacted soils.
4. Sensitize rural farmers and mill operators on the environmental hazards of POME and the benefits of sustainable waste management.

7. CONTRIBUTION TO KNOWLEDGE

This study provides the first field-based empirical evidence of POME-induced soil degradation in Umuapu, Imo State, contributing to a data-scarce region. It highlights the spatial variability of soil impact based on proximity to effluent discharge and establishes a baseline for future ecological risk assessments and soil remediation strategies in artisanal oil palm zones.

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