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Article

Evaluating the ecological consequences of heavy metal contamination in soil induced by spent engine oil and palm oil mill effluents for sustainable development

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Abstract: This study assessed the ecological consequences of heavy metal contamination in soil induced by spent engine oil (SEO) and palm oil mill effluents (POME) in Ebonyi State, Nigeria. Concentrations of zinc, nickel, mercury, manganese, lead, iron, copper, chromium, and cadmium were analyzed across contaminated and uncontaminated sites. The research, conducted at Ebonyi State University's Presco Campus, employed rigorous sampling and analytical methods. Results revealed that soil contaminated with spent engine oil effluent exhibited elevated mean concentrations of zinc, nickel, manganese, lead, iron, copper, chromium, and cadmium compared to the palm oil mill effluent and control sites. Conversely, mercury concentrations were higher in soil contaminated with palm oil mill effluent. Comparative analyses highlighted unique dynamics, such as lead concentrations being highest at the control site, challenging general trends observed for other metals. Importantly, none of the mean concentrations exceeded the WHO acceptable limits at the time of the study, indicating compliance with internationally recognized safety thresholds. The findings underscore the need for tailored environmental management strategies, considering specific contaminants associated with each effluent type. Continuous monitoring is crucial to ensure sustained adherence to safety standards and prevent potential future exceedances. This study contributes a valuable understanding of the nuanced ecological impact of industrial effluents on soil quality in Nigeria, emphasizing the importance of sustainable practices for environmental protection.

Keywords: ecological consequences; heavy metal; contamination; soil; spent engine oil; palm oil mill; effluents; sustainable development

1. Introduction

In the pursuit of industrialization and economic growth, developing nations often grapple with the environmental consequences of industrial activities. One significant environmental challenge is the contamination of soil with heavy metals, a consequence of various industrial effluents. Heavy metal contamination poses a severe threat to ecosystems, public health, and overall sustainable development [1,2]. This study focuses on evaluating the ecological consequences of heavy metal contamination in soil induced by two prevalent industrial effluents—spent engine oil and palm oil mill effluents—in the context of achieving sustainable development goals.

Rapid industrialization, population growth, and increased urbanization have led to intensified industrial activities, contributing to the release of diverse pollutants into the environment [3,4]. Among these pollutants, heavy metals stand out due to their persistence and potential for bioaccumulation in ecosystems, causing long-term environmental and health concerns. Heavy metals, including zinc (Zn), nickel (Ni), mercury (Hg), manganese (Mn), lead (Pb), iron (Fe), copper (Cu), chromium (Cr), and cadmium (Cd), are often associated with industrial processes and can contaminate soil through various pathways, including direct discharge or accidental spills [5,6]. Of particular concern are spent engine oil and palm oil mill effluents, which are common byproducts of the automotive and agro-industrial sectors, respectively [4,7,8]. These effluents contain a complex mixture of organic and inorganic compounds, including heavy metals, and when not managed properly, can result in widespread environmental contamination. The ecological consequences of heavy metal contamination in soil extend beyond the immediate vicinity of industrial sites, affecting terrestrial and aquatic ecosystems, as well as human populations through the food chain.

Understanding the ecological consequences of heavy metal contamination in soil induced by spent engine oil and palm oil mill effluents is imperative for several reasons. Firstly, heavy metals are non-biodegradable and can persist in the environment for extended periods, leading to cumulative effects on soil quality and ecosystem health. Secondly, the potential for bioaccumulation of heavy metals in plant and animal tissues raises concerns about their entry into the food chain, posing risks to human health. Thirdly, the impact of heavy metal contamination on biodiversity, soil fertility, and overall ecosystem functioning has broader implications for sustainable development [9–12].

Sustainable development, as articulated in the United Nations' Sustainable Development Goals (SDGs), seeks to balance economic growth, social well-being, and environmental protection. Achieving sustainable development requires a comprehensive understanding of the interconnections between industrial activities, environmental health, and societal well-being [13,14]. Therefore, assessing the ecological consequences of heavy metal contamination in soil aligns with the broader goal of fostering sustainable practices in industrial processes [15]. The motivation for undertaking the study is rooted in the critical intersection of industrial activities, environmental sustainability, and human well-being. In the pursuit of economic development, many developing nations, including Nigeria, have witnessed a surge in industrialization, resulting in increased production and utilization of various substances, some of which have adverse environmental consequences.

SEO and POME are two prominent industrial effluents that have raised environmental concerns due to their potential to introduce heavy metals into the soil. These heavy metals, including zinc, nickel, mercury, manganese, lead, iron, copper, chromium, and cadmium, are notorious for their persistence and potential toxicity. The lack of proper waste management practices in industrial processes often leads to the direct discharge of these effluents into the environment, resulting in soil contamination. The motivation for this study is also underscored by the need to comprehend the specific ecological consequences of heavy metal contamination associated with SEO and POME. While prior research has explored the impact of industrial effluents on soil quality [16], a comprehensive investigation focusing on the intricate dynamics of these two prevalent effluents is notably lacking. This gap in the literature emphasizes the urgency to address the nuanced environmental implications of SEO and POME, especially in the context of achieving sustainable development goals.

Existing literature underscores the gaps that motivate this study. For instance, a study by Ilyas et al. [17] highlighted the general environmental impact of industrial effluents but did not specifically delve into the unique consequences associated with SEO and POME. Similarly, the work of Golia [18] discussed heavy metal contamination in soils but did not provide a detailed analysis of the ecological repercussions specific to these two prevalent effluents. Furthermore, while studies such as those by Long et al. [19] and Pushpanjali et al. [20] have investigated the effects of industrial activities on soil quality, they did not distinctly address the potential variations in heavy metal concentrations induced by SEO and POME. This highlights a critical knowledge gap regarding the specific ecological consequences of these effluents, hindering the development of targeted mitigation strategies.

This study's significance lies in bridging critical knowledge gaps regarding the specific ecological consequences of heavy metal contamination in soil induced by spent engine oil (SEO) and palm oil mill effluents (POME). Existing literature lacks detailed analyses of the unique repercussions associated with these prevalent effluents, hindering the development of targeted mitigation strategies. By evaluating the ecological impact of SEO and POME, this study contributes vital understanding for informed environmental management and sustainable development, addressing a crucial need for understanding and addressing the distinctive challenges posed by these industrial byproducts.

More specifically, the motivation for this study is intricately linked to the broader goal of achieving sustainable development. Sustainable development, as encapsulated in the United Nations' Sustainable Development Goals (SDGs), requires a harmonious balance between economic growth, environmental conservation, and social well-being. Understanding the ecological consequences of heavy metal contamination induced by SEO and POME is crucial for advancing this balance. The potential impacts on soil quality and biodiversity have far-reaching consequences, affecting ecosystem services, agricultural productivity, and human health. By comprehensively evaluating the specific heavy metal concentrations associated with SEO and POME, this study seeks to provide an understanding that can inform sustainable practices in the industrial sector. The aim is to mitigate environmental degradation while fostering economic growth, aligning with SDGs such as responsible consumption and production (Goal 12) and environmental protection (Goal 15).

2. Methods

The study was conducted at Ebonyi State University's Presco Campus in Abakaliki, Nigeria, situated within the Guinea Savannah zone. The region experiences bimodal rainfall, with a mean annual temperature ranging from 29 ℃ to 30 ℃. The undulating terrain features irregular river valleys, ridges, and a dendritic drainage pattern. The study area includes open savannah woodland with a diverse array of species, including woody trees, shrubs, herbs, palms, climbers, and tall grasses. Two habitats were stratified for insect assessment, employing handheld sweep nets and pitfall traps. A 0.23 km line transect was established at each site, and six transect walks were conducted, each lasting 30 min. Sweep net sampling occurred twice weekly during morning and evening hours along predetermined transects, while 12 pitfall traps were distributed in various habitats. Insects captured were preserved using a wide-mouthed jar containing ethyl acetate. Preservation methods included direct pinning for larger insects and pickling for specimens unable to be pinned. Laboratory identification utilized keys from reputable sources. Descriptive statistics was employed for data analysis.

The inclusion of zinc (Zn), nickel (Ni), mercury (Hg), manganese (Mn), lead (Pb), iron (Fe), copper (Cu), cobalt (Co), chromium (Cr), and cadmium (Cd) in the study is crucial for a comprehensive assessment of ecological consequences. These heavy metals, commonly found in spent engine oil and palm oil mill effluents, pose distinct environmental risks. Zn, Ni, and Cd are known for soil toxicity, while Hg is a potent bio-accumulative neurotoxin. Mn, Pb, and Fe can impact plant growth and human health, and Cu, Co, and Cr exhibit varying degrees of environmental persistence. Studying these metals is essential for understanding the multifaceted ecological impact, facilitating targeted remediation strategies, and ensuring sustainable development in affected areas.

3. Results

Table 1 revealed that soil contaminated with spent engine oil effluent recorded the highest mean concentrations for zinc (0.33 ± 0.365 mg/kg) while the palm oil effluent site had the least (0.05 ± 0.061 mg/kg). There was no significant difference in the mean concentration of zinc among the three sites ($P = 0.196$). However, the concentrations of zinc were lower than the WHO-acceptable limit. The result in **Table 1** revealed that soil contaminated with spent engine oil effluent recorded the highest mean concentrations for nickel (27.07 ± 25.955 mg/kg) while the control site had the least (3.48 ± 0.556 mg/kg). There was no significant difference in the mean concentration of nickel among the three sites ($P = 0.22$). However, the concentrations of nickel were lower than the WHO acceptable limit.

Table 1. Mean concentration of heavy metals of the contaminated and uncontaminated sites.

Heavy metals	Sites			Reference (WHO) mg/kg	Remark
	POME	SEO	Control		
Zn	$0.05^{a} \pm 0.061$	$0.33^{a} \pm 0.365$	$0.08^{a} \pm 0.077$	300	Satisfactory
Ni	$17.69^{a} \pm 16.504$	$27.07^{a} \pm 25.955$	$3.48^{a} \pm 0.556$	50	Satisfactory
Hg	$0.24^{a} \pm 0.002$	$0.17^{a} \pm 0.173$	$0.16^{a} \pm 0.018$	1.0	Satisfactory
Mn	$1.12^{a} \pm 1.298$	$3.86^{a} \pm 4.209$	$2.87^{a} \pm 2.674$	2000	Satisfactory
Pb	$0.00^{a} \pm 0.000$	$0.01^{a} \pm 0.012$	$0.23^{b} \pm 0.046$	85	Satisfactory
Fe	$0.63^{a} \pm 0.724$	$2.41^{a} \pm 2.781$	$0.65^{a} \pm 0.207$	50,000	Satisfactory
Cu	$0.56^{a} \pm 0.618$	$3.07^{a} \pm 3.479$	$0.57^{a} \pm 0.632$	100	Satisfactory
Co	$0.06^{a} \pm 0.069$	$0.51^{a} \pm 0.59$	$0.39^{a} \pm 0.464$	19	Satisfactory
Cr	$0.10^{a} \pm 0.114$	$0.25^{a} \pm 0.046$	$0.24^{a} \pm 0.11$	100	Satisfactory
Cd	$0.05^{a} \pm 0.058$	$1.84^{a} \pm 3.24$	$0.31^{a} \pm 0.338$	3	Satisfactory

Rows sharing similar superscripts are not significantly different at $p > 0.05$; key: POME = palm oil mill effluent; SEO = spent engine oil; control = uncontaminated site.

Table 1 revealed that soil contaminated with palm oil mill effluent recorded the highest mean concentrations for mercury (0.24 ± 0.002 mg/kg) while the control site had the least (0.16 ± 0.018 mg/kg). There was no significant difference in the mean concentration of mercury among the three sites (*P* = 0.49). However, the concentrations of mercury were lower than the WHO-acceptable limit. The result in **Table 1** revealed that soil contaminated with spent engine oil effluent recorded the highest mean concentrations for manganese (3.86 ± 4.209 mg/kg) while the palm oil mill effluent site had the least (1.12 ± 1.298 mg/kg). There was no significant difference in the mean concentration of nickel among the three sites (*P* = 0.45). However, the concentrations of manganese were lower than the WHO-acceptable limit.

The result showed that the soil from the control site recorded the highest mean concentrations for lead (0.23 ± 0.046 mg/kg) while the palm oil mill effluent site had the least (0.00 ± 0.000 mg/kg) (**Table 1**). There was a significant difference in the mean concentration of lead among the three sites (*P* = 0.00). However, the concentrations of lead were lower than the WHO acceptable limit. The result in **Table 1** revealed that soil contaminated with spent engine oil effluent recorded the highest mean concentrations for iron (2.41 ± 2.78 mg/kg) while the palm oil mill effluent site had the least (0.63 ± 0.724 mg/kg). There was no significant difference in the mean concentration of iron among the three sites (*P* = 0.27). However, the concentrations of iron were lower than the WHO-acceptable limit.

The result in **Table 1** revealed that soil contaminated with spent engine oil effluent recorded the highest mean concentrations for copper (3.07 ± 3.479 mg/kg) while the palm oil mill effluent site had the least (0.56 ± 0.618 mg/kg). There was no significant difference in the mean concentration of iron among the three sites (*P* = 0.19). However, the concentrations of copper were lower than the WHO acceptable limit. **Table 1** also revealed that soil contaminated with spent engine oil effluent recorded the highest mean concentrations for copper (0.51 ± 0.59l mg/kg) while the palm oil mill effluent site had the least (0.06 ± 0.069 mg/kg). There was no significant difference in the mean concentration of cobalt among the three sites (*P* = 0.36). However, the concentrations of cobalt were lower than the WHO-acceptable limit.

The result in **Table 1** also showed that soil contaminated with spent engine oil effluent recorded the highest mean concentrations for chromium (0.25 ± 0.046 mg/kg) while the palm oil mill effluent site had the least (0.10 ± 0.114 mg/kg). There was no significant difference in the mean concentration of chromium among the three sites (*P* = 0.09). However, the concentrations of chromium were lower than the WHO-acceptable limit. The result in **Table 1** also showed that soil contaminated with spent engine oil effluent recorded the highest mean concentrations for cadmium (1.84 ± 3.24 mg/kg) while the palm oil mill effluent site had the least (0.05 ± 0.058 mg/kg). There was no significant difference in the mean concentration of cadmium among the three sites (*P* = 0.39). However, the concentrations of cadmium were lower than the WHO-acceptable limit.

4. Discussions

The comprehensive analysis of soil contaminants across multiple sites reveals intriguing patterns, providing an understanding of the environmental impact of industrial effluents in Nigeria. The concentration of various heavy metals, including zinc, nickel, mercury, manganese, lead, iron, copper, chromium, and cadmium, was assessed across sites with different effluent types. In terms of zinc concentrations, soil contaminated with spent engine oil effluent exhibited the highest mean values, showcasing the potentially detrimental effects of such contamination. This finding aligns with the work of Peter [16], who similarly highlighted the impact of engine oil effluents on soil quality. In contrast, the palm oil effluent site recorded the least zinc concentrations, suggesting a comparatively lower environmental impact, as emphasized by the findings of Lai et al. [21]. Similar trends were observed for nickel concentrations, with soil contaminated by spent engine oil effluent displaying the highest mean values. Notably, the control site exhibited the least nickel concentrations, indicating the absence of contaminating factors. This aligns with the observations in a related study by Hu et al. [22] and Khademi et al. [23], reinforcing the persistence of nickel in soils impacted by industrial activities.

Mercury concentrations followed a different pattern, with soil contaminated by palm oil mill effluent recording the highest mean values. In contrast, the control site exhibited the least mercury concentrations. This finding is consistent with the work of Isaiah and Blessing [4], who emphasized the role of palm oil mill effluents in elevating mercury levels in soil, posing potential environmental risks. Manganese concentrations displayed a distinct pattern, with soil contaminated by spent engine oil effluent exhibiting the highest mean values. In contrast, the palm oil mill effluent site recorded the least manganese concentrations. This aligns with a related study by Ikhajiagbe et al. [1] and Salam et al. [8], which emphasized the impact of engine oil effluents on soil manganese levels. Lead concentrations portrayed an interesting contrast, with soil from the control site recording the highest mean values and the palm oil mill effluent site having the least. This contradicts the general trend observed for other metals, highlighting the unique dynamics of lead contamination [3,24] further explored lead contamination in soils, emphasizing the importance of understanding site-specific factors influencing metal concentrations.

Iron concentrations exhibited a pattern similar to zinc and nickel, with soil contaminated by spent engine oil effluent displaying the highest mean values. In contrast, the palm oil mill effluent site recorded the least iron concentrations. This consistency across multiple metals underscores the pervasive impact of engine oil effluents on soil quality [7]. Copper concentrations mirrored the trends observed for zinc, nickel, and iron, with soil contaminated by spent engine oil effluent exhibiting the highest mean values. In contrast, the palm oil mill effluent site recorded the least copper concentrations. This aligns with the findings of Oriomah et al. [6], who emphasized the role of engine oil effluents in elevating copper levels in soils.

Chromium concentrations followed a similar pattern, with soil contaminated by spent engine oil effluent displaying the highest mean values. In contrast, the palm oil mill effluent site recorded the least chromium concentrations. This finding is consistent with the observations of Dhal et al. [25], reinforcing the specific impact of engine oil effluents on soil chromium levels. Cadmium concentrations exhibited a pattern akin to that of other metals, with soil contaminated by spent engine oil effluent displaying the highest mean values. In contrast, the palm oil mill effluent site recorded the least cadmium concentrations. This is in line with the work of Wang et al. [10], who emphasized the potential risks associated with cadmium contamination in soils impacted by industrial activities.

Despite the variations in metal concentrations across sites, it is noteworthy that none of the mean concentrations exceeded the WHO-acceptable limits. This is a positive outcome, suggesting that, at the time of the study, the levels of contaminants in the soil were within internationally recognized safety thresholds. Continuous monitoring, as advocated by Ogunbileje et al. [5], Obasi et al. [26], and Emmanuel et al. [27], remains crucial to ensure sustained compliance with these standards and prevent any future exceedance. The comparative analysis of heavy metal concentrations in soils impacted by spent engine oil and palm oil mill effluents highlights the diverse environmental implications of industrial activities in Nigeria. The patterns observed for each metal underscore the need for tailored environmental management strategies to mitigate specific contaminants and protect soil quality.

5. Recommendations for sustainable practices in the industrial sector: Mitigating heavy metal contamination in soil

To address the ecological consequences of heavy metal contamination induced by spent engine oil (SEO) and palm oil mill effluents (POME) for sustainable development, it is crucial to advocate for and implement comprehensive strategies within the industrial sector.

1) Effective waste management practices: A cornerstone of sustainable industrial practices lies in effective waste management. Industries should invest in advanced treatment facilities to ensure that effluents, particularly those containing heavy metals, undergo thorough processing before release. This not only aligns with responsible production practices (SDG 12) but also safeguards environmental health by preventing the direct discharge of pollutants into soil and water.
2) Circular economy principles: Embracing circular economy principles is pivotal for reducing the generation of harmful effluents. By adopting practices that prioritize the reuse and recycling of waste materials, industries contribute to the sustainable use of resources. This not only aligns with responsible consumption (SDG 12) but also minimizes the environmental impact of industrial activities.
3) Cleaner production technologies: Investing in cleaner production technologies is essential for minimizing the environmental footprint of industrial processes. Technologies that inherently generate fewer pollutants, including heavy metals, contribute to responsible production practices. This investment aligns with SDG 12 by promoting efficient resource use and reducing the environmental impact of production.
4) Eco-friendly alternatives: Industries should actively explore and adopt eco-friendly alternatives to replace or minimize the use of heavy metal-containing substances. This not only addresses environmental protection (SDG 15) but also

fosters innovation in sustainable practices, positioning industries as leaders in responsible production.

5) Corporate social responsibility (CSR) programs: CSR programs that focus on environmental conservation and community engagement contribute to responsible consumption and production (SDG 12). By allocating resources for community education on the hazards of heavy metal contamination, industries actively participate in sustainable development initiatives.
6) Collaboration with regulatory bodies: Collaborating with regulatory bodies ensures that industries stay informed about and adhere to evolving environmental standards. This collaboration aligns with responsible production practices (SDG 12) and demonstrates a commitment to compliance with global environmental goals.
7) Employee training: Investing in employee training creates a workforce that is conscious of its role in mitigating heavy metal contamination. By fostering a culture of responsibility and awareness, industries contribute to responsible consumption (SDG 12) and empower their employees to actively participate in sustainable practices.
8) Industry-wide collaboration: Fostering collaboration within industrial sectors is crucial for sharing best practices and collectively working towards minimizing environmental impact. Industry-wide initiatives contribute to responsible consumption and production (SDG 12) by creating a united front for sustainable industrial practices.
9) Continuous monitoring and improvement: Continuous monitoring of heavy metal concentrations is essential for informed decision-making. This practice, aligned with responsible production (SDG 12), enables industries to adapt their strategies in real time, ensuring continuous improvement in environmental stewardship.

6. Conclusion

In conclusion, our study evaluating the ecological consequences of heavy metal contamination in soil induced by spent engine oil (SEO) and palm oil mill effluents (POME) provides a comprehensive understanding of the environmental impact of these industrial activities in Nigeria. The analysis of various heavy metals, including zinc, nickel, mercury, manganese, lead, iron, copper, chromium, and cadmium, across contaminated and uncontaminated sites has revealed intricate patterns with implications for soil quality and ecological health.

The elevated concentrations of zinc, nickel, mercury, manganese, lead, iron, copper, chromium, and cadmium in soils contaminated with spent engine oil effluent underscore the potential detrimental effects of this particular industrial activity. These findings align with existing research, reinforcing the persistent nature of certain heavy metals in soils affected by industrial effluents. Notably, the study has contributed to the body of knowledge by highlighting the unique dynamics of lead contamination, where the control site exhibited the highest mean values, emphasizing the importance of site-specific factors in heavy metal distribution.

Despite the observed variations in metal concentrations across sites, the reassuring result is that, at the time of the study, none of the mean concentrations exceeded the WHO acceptable limits. This suggests a level of compliance with internationally recognized safety thresholds, providing a positive outlook on the current state of soil quality in the study area. However, the study emphasizes the importance of continuous monitoring, as advocated by previous researchers, to ensure sustained adherence to these standards and prevent potential future exceedances.

The diverse patterns observed for each metal across different sites underscore the need for tailored environmental management strategies. Mitigation measures should consider the specific contaminants associated with each industrial effluent and the unique ecological dynamics of the affected area. It is crucial for regulatory bodies and industries to work collaboratively to implement effective waste management practices that minimize the ecological consequences of heavy metal contamination in soils.

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