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Bioremediation Potential of *Aspilia Africana* Manure in Engine Oil-Polluted Soils: Assessing Physico-Chemical and Heavy Metal Remediation Dynamics

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ABSTRACT

Background: Hydrocarbon contamination from spent engine oil poses significant environmental and agricultural risks, particularly in regions with limited access to advanced remediation technologies. This study evaluates the bioremediation potential of *Aspilia africana* manure, an underutilized plant resource, in restoring physicochemical properties and mitigating heavy metal contamination in engine oil-polluted soils.

Methods: Soil samples were artificially contaminated with 10% w/w used engine oil and amended with varying rates of *A. africana* manure (0.5–2.0 kg/pot) over 90 days. Physicochemical parameters (pH, organic carbon, nitrogen, phosphorus, cation exchange capacity) and heavy metal concentrations (Fe, Pb, Zn, Cu, Mn) were analyzed.

Results: Results indicated that *A. africana* manure significantly improved soil moisture retention (42.47% to 53.25%), neutralized acidity (pH 4.65 to 5.40), and enhanced nutrient availability (e.g., phosphorus increased from 0.11 to 1.57 mg/100g). Organic carbon content decreased due to enhanced microbial hydrocarbon degradation, while nitrogen levels rose with higher amendment rates. Heavy metal concentrations (Fe, Zn, Cu, Mn) declined by 15–50%, attributed to adsorption, complexation, and precipitation mechanisms facilitated by the manure's bioactive compounds. However, lead (Pb) concentrations unexpectedly increased (1.92 to 2.07 mg/100g), potentially due to inherent Pb in the manure or pH-mediated mobilization.

Conclusion: These findings demonstrate *A. africana* manure's efficacy in ameliorating hydrocarbon-polluted soils, particularly in resource-constrained settings. While effective for most metals, Pb dynamics warrant further investigation. This study advocates for the integration of regionally specific plant-based amendments into sustainable soil management practices, aligning with circular agricultural economies and environmental health priorities.

Keywords: Bioremediation; *Aspilia africana*; Engine oil contamination; Polluted Soil; Heavy metal

1.0 INTRODUCTION

Hydrocarbon contamination from engine oil remains a pervasive environmental challenge, particularly in regions with high vehicular traffic, industrial activity, or inadequate waste management infrastructure. Engine oil, a complex mixture of aliphatic and aromatic hydrocarbons, poses significant risks to soil ecosystems due to its persistence, toxicity, and capacity to disrupt soil physicochemical properties such as pH, cation exchange capacity (CEC), and

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organic matter content [1, 2, 3] which can have detrimental effects on soil health and plant growth. Studies have shown that the presence of spent engine oil contributes to a more acidic soil environment, which can affect nutrient availability and microbial activity [4, 5]. In some cases, the pH of the soil may not be significantly affected by oil contamination, depending on the type of oil and soil characteristics [6]. CEC generally decreases with increased levels of engine oil pollution. This reduction in CEC can limit the soil's ability to retain essential nutrients, increased nutrient leaching, thereby affecting plant growth and soil fertility [7]. Significant differences in CEC were observed between different soil types and treatments, indicating that the impact of engine oil on CEC can vary based on soil characteristics [6]. Engine oil contamination can lead to an increase in soil organic matter content due to the addition of hydrocarbons from the oil. However, this increase does not necessarily translate to improved soil health, as the hydrocarbons can be toxic to plants and soil organisms [4]. The presence of engine oil can also alter the balance of organic carbon and other organic parameters, affecting the overall soil quality [5]. While engine oil contamination generally has negative effects on soil physicochemical properties, the extent of these effects can vary based on soil type, oil concentration, and environmental conditions. Furthermore, used engine oils often contain heavy metals like lead (Pb), cadmium (Cd), and chromium (Cr), which accumulate in soils, threatening agricultural productivity and human health through bioaccumulation [8. 9, 10]. While the direct effects of engine oil on soil are significant, it is also important to consider the broader environmental implications. Engine oil can contaminate water bodies through runoff, affecting aquatic ecosystems and potentially entering the food chain, posing risks to human health. Additionally, volatilization of engine oil contributes to air pollution, exacerbating respiratory issues and climate change [8]. These interconnected impacts highlight the need for sustainable management practices to mitigate the environmental burden of engine oil pollution. Conventional remediation techniques, including soil washing and chemical oxidation, are frequently criticized for their high costs, secondary pollution risks, and failure to restore soil fertility [11]. These limitations have spurred interest in sustainable bioremediation strategies that leverage organic amendments to stimulate microbial degradation of hydrocarbons while immobilizing toxic metals [12]. Remediation strategies, such as the use of organic amendments like poultry manure, have shown potential in mitigating some of the adverse effects of oil contamination on soil properties [4, 13]. Bioremediation using plant-derived amendments, such as composts and manures, has emerged as a promising approach to address hydrocarbon-polluted soils. Organic amendments enhance microbial activity, improve soil structure, and supply nutrients that facilitate hydrocarbon degradation [4]. Recent studies highlight the potential of plant-based amendments rich in lignin and cellulose, such as Moringa oleifera and Tithonia diversifolia, to accelerate petroleum hydrocarbon breakdown while stabilizing heavy metals [14]. However, the dual capacity of organic amendments to concurrently remediate hydrocarbons and detoxify metals remains underexplored, particularly in the context of underutilized plant species with unique biochemical profiles. *Aspilia africana*, a tropical plant widely distributed across sub-Saharan Africa, holds untapped potential for bioremediation applications. Traditionally used in ethnomedicine, this species is noted for its high biomass yield, rapid growth, and rich phytochemical composition, including flavonoids, alkaloids, and organic acids [15]. These compounds may enhance microbial hydrocarbon degradation by serving as electron donors or chelating agents to immobilize heavy metals. Recent metabolomics analyses further reveal that A. africana biomass harbors bioactive compounds capable of stimulating microbial activity and chelating metal ions [16]. Preliminary investigations suggest that *Aspilia africana* biomass can reduce lead bioavailability in contaminated soils, though its efficacy in hydrocarbon-polluted environments remains unverified [17]. Despite these promising attributes, no study has systematically evaluated the integrative effects of *Aspilia africana* manure which is a byproduct of agricultural waste on soil physicochemical restoration and heavy metal dynamics in engine oil-polluted soils. Current research on organic soil amendments has predominantly focused on composts and biochar, with limited exploration of regionally specific plant manures that may offer cost-effective, culturally accessible solutions for low-income communities [18]. This gap is critical in regions like sub-Saharan Africa, where engine oil pollution disproportionately affects rural farmlands, yet remediation technologies remain underdeveloped.

This study investigated the bioremediation potential of *Aspilia africana* manure in engine oil-polluted soils, with a dual focus on restoring physicochemical properties and mitigating heavy metal contamination. We hypothesized that the manure's bioactive compounds and nutrient-rich matrix would synergistically enhance hydrocarbon mineralization by indigenous microbes while reducing metal bioavailability through adsorption and complexation. By integrating physicochemical and eco-toxicological analyses, this work advances the practical application of underutilized plant resources in sustainable soil management and aligns with global efforts to promote circular agricultural economies.

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2.0 MATERIALS AND METHODS

2.1 Materials

The following equipment and apparatus were used for this study: soxhlet apparatus, heating mantle, blender, autoclave, Bunsen burner, incubator, automatic weighing balance, refrigerator, water bath, and spectrophotometer. Glassware utilized included test tubes, Petri dishes, beakers, conical flasks, bijou bottles, glass rods, and slides. The reagents employed were distilled water, oxidase reagent crystal violet, safranine, hydrogen peroxide, absolute ethanol, 45% ethanol, Lugol's iodine, Kovac's reagent, petroleum ether, sulphuric acid, sodium hydroxide, anhydrous sodium sulphate, Mayer's reagent, Dragendoff reagent, ethyl acetate, ferrous sulphate, ferrous chloride, aluminum chloride, ammonia solution, olive oil, nutrient agar, and peptone water. Additional materials included Whatman No. 2 filter paper, aluminum foil, spatula, latex gloves, and cotton wool.

2.2 Methods

2.2.1 Study Area

The study was conducted at the Department of Chemistry Laboratory. Federal University, Otuoke, Nigeria. Soil samples were collected from field within the University premises that had no history of petroleum hydrocarbon contamination.

2.2.2 Collection of Soil Samples

Topsoil samples (0-20 cm depth) were collected randomly from five different points within the agricultural field using a soil auger. The collected samples were mixed thoroughly to obtain a composite sample, which was then passed through a 2-mm sieve to remove debris and stones. The homogenized soil sample was stored in clean polyethylene bags at room temperature prior to use in the experiment.

2.2.3 Collection of Used Engine Oil Samples

Used engine oil was collected from a local automobile repair workshop in Otuoke, Ogbia Local Government Area of Bayelsa State, Nigeria. The oil samples were obtained from multiple vehicles that had undergone oil changes. The collected oil was filtered through Whatman No. 2 filter paper to remove particulate matter and stored in dark glass bottles at room temperature until further use.

2.2.4 Collection of Aspilia africana Samples

Fresh, mature *Aspilia africana* plants were harvested from uncultivated areas around the university. Plant identification and authentication were performed at the Department of Plant Science. The collected plant materials, including leaves and roots, were thoroughly washed with distilled water to remove soil particles and other debris. The plants were air-dried at room temperature (28±2°C) for two weeks until constant weight was achieved. The dried plant materials were ground using a mechanical blender and sieved through a 2-mm mesh to obtain homogenized *A. africana* manure. The prepared manure was stored in airtight containers at room temperature prior to application.

2.2.5 Preparation of Used Engine Oil Contaminated and Aspilia africana Amended Soil Treatments

The experiment was set up in a completely randomized design with six treatments and three replicates. 2 kg of the homogenized soil was placed in each plastic pot (25 cm diameter × 30 cm height) with perforated bottoms to allow drainage. The soil in all pots, except the control, was contaminated with used engine oil at a concentration of 10% w/w (200 ml of used engine oil per 2 kg of soil). The contaminated soil was thoroughly mixed to ensure even distribution of the oil and left to equilibrate for one week before the application of *A. africana* manure. The experimental treatments were as follows: (1) Uncontaminated soil (negative control) (ii) Oil-contaminated soil without amendment (positive control/0% amendment) (iii) Oil-contaminated soil + 0.5 kg *A. africana* manure per pot (iv) Oil-contaminated soil + 1.0 kg *A. africana* manure per pot (v) Oil-contaminated soil + 1.5 kg *A. africana* manure per pot (vi) Oil-contaminated soil + 2.0 kg *A. africana* manure per pot. The *A. africana* manure was thoroughly mixed with the contaminated soil according to the treatment specifications. The pots were maintained at 60% water holding capacity throughout the 90-day experimental period by regular addition of distilled water. The pots were kept under ambient conditions (temperature range: 25-30°C; relative humidity: 65-80%) in a semi-controlled environment.

2.2.6 Analysis of Soil Physical and Chemical Characteristics

The soil samples were air-dried at room temperature for two weeks and crushed to pass through a 2-mm mesh sieve. Soil particle size distribution analysis was conducted using the hydrometer method according to the procedures outlined [19]. Soil moisture content was determined gravimetrically by drying soil samples at 105°C to constant weight. Soil pH was measured in a 1:1 soil-to-water ratio using a glass electrode pH meter (Mclean, 1982). Organic carbon content was determined by the wet dichromate acid oxidation method [20] and organic matter content was calculated by multiplying the percentage organic carbon by a factor of 1.724. Total nitrogen was determined using the modified Kjeldahl distillation method [21]. Available phosphorus was extracted with Bray solution II and determined by the molybdenum blue colorimetric method [22] using a spectrophotometer at 660 nm wavelength.

Exchangeable bases (Ca, Mg, K, and Na) were extracted with 0.05 N NH_4OAc buffered at pH 7.0. The concentrations of K and Na in the extracts were determined using a flame photometer, while Ca and Mg were determined by the EDTA titration method 19]. Total exchangeable acidity (H^+ and Al^{3+}) was extracted with 1N KCl and determined by titration with 0.05N NaOH using phenolphthalein as an indicator. Effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable bases and total exchangeable acidity. The percentage base saturation was calculated as the percentage of the sum of exchangeable bases divided by ECEC.

2.2.7 Determination of Heavy Metal Contents of Soil

One gram of each sieved soil sample was digested using the nitric/perchloric acid digestion procedure [23]. Briefly, soil samples were placed in digestion tubes, and 10ml of concentrated HNO_3 was added. The mixture was heated at 145°C for 1 hour, after which 5ml of concentrated $HClO_4$ was added. Heating continued until the appearance of white fumes, followed by cooling and filtering through Whatman No. 42 filter paper. The filtrate was made up to 50ml with distilled water.

The concentrations of heavy metals (Fe, Pb, Zn, Cu, and Mn) in the digests were determined using an atomic absorption spectrophotometer (UnicamSolaar32 model) following standard procedures. [24] Standard solutions of the metals were prepared from their respective salts for instrument calibration. Metal concentrations were expressed in mg/100g of soil.

2.3 Statistical Analysis

All data were subjected to one-way analysis of variance (ANOVA) using SPSS software (version 23.0).

3.0 RESULTS AND DISCUSSION

3.1 Physical Properties of Used Engine Oil Contaminated Soil Remediated with *Aspilia africana* Manure

The physical properties of used engine oil contaminated soil remediated with *Aspilia africana* manure are presented in Table 1and Figure 1. The results show that the soil texture was predominantly sandy loam, with the sand fraction ranging from 67.23% to 67.82% across all treatments. The unpolluted soils (control) showed a slight decrease in sand content (67.55%) compared to the untreated polluted soil (67.82%), while the application of increasing amounts of *A. africana* manure led to a gradual decrease in sand content from 67.41% to 67.23%. The silt content was significantly higher in the control (22.10%) compared to the polluted control (9.61%). The application of *A. africana* manure resulted in a gradual increase in silt content from 9.50% to 15.64% as the amendment rate increased from 0.5 kg to 2.0 kg. Similarly, the clay content decreased from 22.57% in the polluted soil to 10.35% in the unpolluted soil (control). The application of *A. africana* manure led to a gradual decrease in clay content from 23.09% to 17.13% as the amendment rate increased. The soil moisture content was significantly higher in the control (64.37%) compared to the polluted soil (42.47%). The application of *A. africana* manure resulted in an increase in moisture content from 51.32% to 53.25% as the amendment rate increased.

Table 1: Physical properties of used engine oil contaminated soil remediated with Aspilia africana manure

Parameters	**Polluted soil**	**Polluted soil + 0.5kg *A. africana***	**Polluted soil + 1.0kg *A. africana***	**Polluted soil + 1.5kg *A. africana***	**Polluted soil + 2.0kg *A. africana***	**Unpolluted soil (control)**
Sand (%)	67.82±2.07	67.41±1.90	67.32±1.22	67.29±1.10	67.23±1.98	67.55±1.64
Silt (%)	9.61±1.07	9.50±1.36	13.56±1.28	14.69±1.67	15.64±1.83	22.10±1.52
Clay (%)	22.57±1.06	23.09±1.14	19.12±1.64	18.02±1.40	17.13±1.20	10.35±1.53
Moisture (%)	42.47±1.28	51.32±1.44	52.71±1.72	52.79±1.18	53.25±1.75	64.37±1.60

Mean ± standard error from 3 replicates

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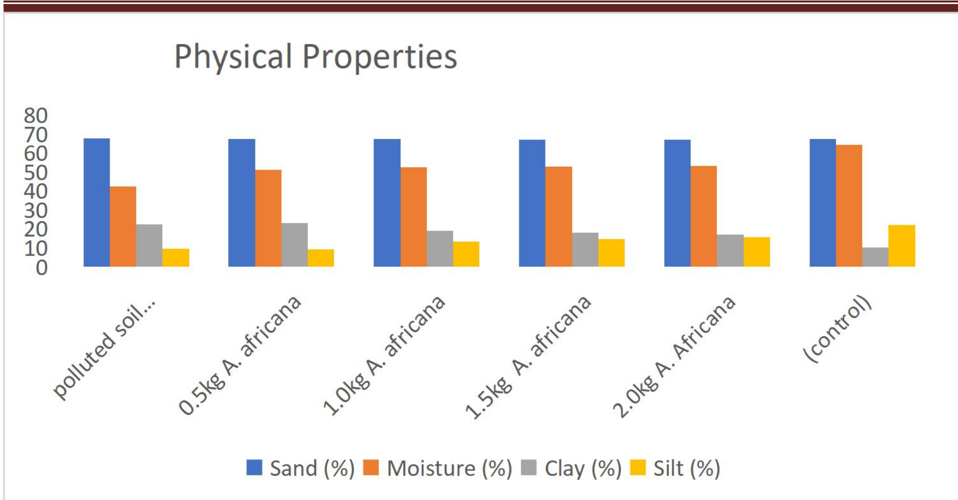


Fig 1: Physical properties (sand, moisture, clay and slit) of contaminated and remediated soils

The increase in soil moisture content observed with the application of *A. africana* manure can be attributed to the improved soil structure and porosity, which enhances water retention capacity. The organic matter content in the manure helps to bind soil particles together, improving soil aggregation and reducing compaction.

3.2 Chemical Properties of Used Engine Oil Contaminated Soil Remediated with *A. africana* Manure

The chemical properties of used engine oil contaminated soil remediated with *A. africana* manure are presented in Table 2. Soil pH (Figure 2) climbed from a strongly acidic 4.65 in the contaminated baseline to about 5.40 at 1.5 kg and 2.0 kg manure, approaching the value of unpolluted control soil (5.30). Such liming effects of organic residues have been reported by Sparks [25], who noted that decomposition of organic inputs releases basic cations that neutralize acidity. This gradual amelioration is critical, as low pH can immobilize nutrients and inhibit microbial degradation of hydrocarbons. The organic carbon content was significantly higher in the polluted soil (4.29%) compared to the control (1.34%). The application of *A. africana* manure resulted in a decrease in organic carbon content from 3.77% to 2.92% as the amendment rate increased. This trend can be attributed to the enhanced microbial activity stimulated by the *A. africana* manure, leading to increased decomposition of organic matter and utilization of carbon as an energy source by hydrocarbon-degrading microorganisms. This dynamic also seen in studies by Thamaraiselvi and Balasubramanian [26]), who linked organic amendment–driven microbial respiration to reductions in soil organic carbon during remediation.

Table 2: Chemical properties of used engine oil contaminated soil remediated with *A. africana* manure

Parameters	Polluted soil + 0kg *A.africana*	Polluted soil + 0.5kg *A. africana*	Polluted soil + 1.0kg *A. africana*	Polluted soil + 1.5kg *A. africana*	Polluted soil + 2.0kg *A. Africana*	Unpolluted soil (control)
pH	4.65±0.40	5.20±0.33	5.30±0.52	5.40±0.65	5.40±0.15	5.30±0.26
Organic carbon (%)	4.29±0.22	3.77±0.13	3.21±0.62	3.04±0.40	2.92±0.62	1.34±0.35
N (%)	0.07±0.05	0.08±0.02	0.09±0.07	0.12±0.04	0.13±0.02	0.25±0.04
P (mg/100g)	0.11±0.05	1.35±0.90	1.46±0.74	1.55±0.81	1.57±0.21	7.14±0.27
Ca (mg/100g)	2.63±0.73	2.37±0.83	2.39±0.32	2.47±0.21	2.48±0.13	1.39±0.34
Mg (mg/100g)	2.13±0.84	2.12±0.28	2.17±0.20	2.22±0.39	2.26±0.90	1.22±0.60
Na (mg/100g)	7.24±0.63	5.12±0.69	5.24±0.33	5.34±0.42	5.34±0.82	0.40±0.07
K (mg/100g)	3.19±0.65	3.10±0.28	3.08±0.16	3.05±0.39	2.94±0.28	2.19±0.32

Mean ± standard error from 3 replicates

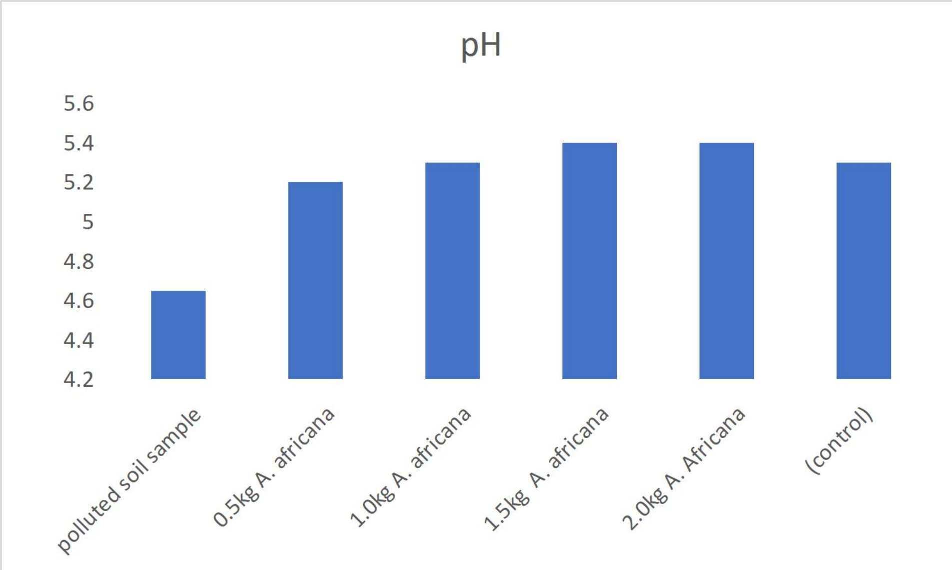


Figure 2: pH of contaminated soil with used engine oil and remediated soils with *A. africana* manure

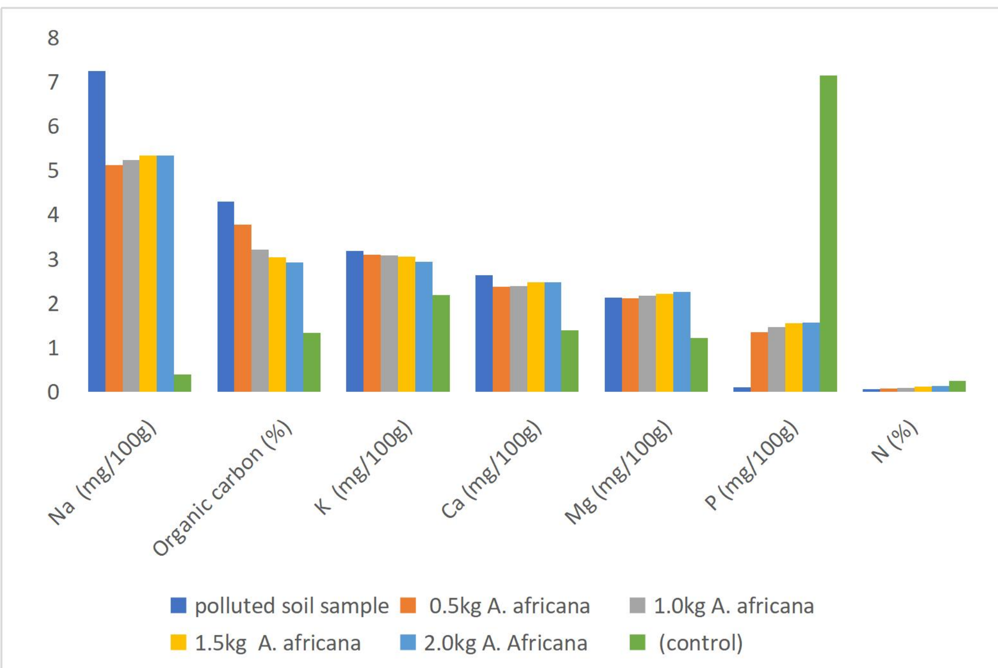
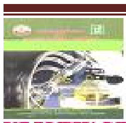


Fig 3: Chemical properties (Na, organic carbon, K, Ca, Mg, P and N) contaminated soil with used engine oil and remediated soil with *A. africana* manure

Conversely, the total nitrogen content was lower in the unamended polluted soil (0.07%) compared to the control (0.25%). The application of *A. africana* manure led to a gradual increase in total nitrogen content from 0.08% to 0.13% as the amendment rate increased. This increase in nitrogen content can be attributed to the nitrogen-rich composition of *A. africana* manure, which supplements the soil with essential nutrients. Available phosphorus was significantly lower in the polluted soil (0.11 mg/100g) compared to the control (7.14 mg/100g). The application of A. africana manure resulted in an increase in available phosphorus from 1.35 mg/100g to 1.57 mg/100g as the



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amendment rate increased. The increase in available phosphorus with the application of *A. africana* manure can be attributed to the release of phosphorus from the manure and the mineralization of organic phosphorus compounds.
Exchangeable cations (Ca, Mg, Na, K) displayed minor fluctuations. Calcium and magnesium decreased slightly from initial polluted levels (2.63 and 2.13 mg/100 g) to 2.48 and 2.26 mg/100 g at 2.0 kg, respectively, whereas potassium dipped marginally. Sodium, initially high due to oil-induced salinization (7.24 mg/100 g), dropped to 5.34 mg/100 g with amendment. The higher levels of exchangeable cations in the polluted soil can be attributed to the release of these elements from the used engine oil. The overall stability of base cations suggests that *Aspilia africana* manure can buffer cation exchange capacity without drastically altering essential nutrient pools. The application of organic amendments, such as *A. africana* manure, helps to restore soil chemical properties by providing essential nutrients and stimulating microbial activity.

3.3 Heavy Metal Contents of Used Engine Oil Contaminated Soil Remediated with *A. africana* Manure

The heavy metal contents of used engine oil contaminated soil remediated with *A. africana* manure are presented in Table 3. The results show that the concentrations of Fe, Pb, Zn, Cu, and Mn were significantly higher in the polluted soil compared to the control. This indicates that used engine oil contamination introduces heavy metals into the soil. The application of *A. africana* manure resulted in a decrease in Fe, Zn, Cu, and Mn concentrations as the amendment rate increased, while Pb concentration showed a slight increase. Unexpectedly, lead concentrations rose slightly from 1.92 to 2.07 mg/100 g at higher manure rates; this may reflect lead content within the manure itself or mobilization under shifting pH [27] of organic amendments occasionally introducing trace metal loads.
The decrease in heavy metal concentrations with the application of *A. africana* manure can be attributed to several mechanisms, including adsorption, complexation, precipitation, and plant uptake. The organic matter in *A. africana* manure contains functional groups such as carboxyl, hydroxyl, and phenolic groups, which can form complexes with heavy metals, reducing their bioavailability and mobility in the soil. Additionally, the increased pH observed with the application of *A. africana* manure may have contributed to the precipitation of heavy metals as insoluble hydroxides, carbonates, or phosphates.

Table 3: Heavy metal contents of used engine oil contaminated soil remediated with A. africana manure

Parameters	Polluted soil + 0 kg *A. africana*	Polluted soil +0.5kg *A. africana*	Polluted soil + 1.0kg *A. africana*	Polluted soil + 1.5kg *A. africana*	Polluted soil +2.0kg *A. africana*	Unpolluted soil (control)
Fe (mg/100g)	1.41±0.14	1.32±0.39	1.24±0.83	1.23±0.40	1.21±0.21	0.52±0.85
Pb (mg/100g)	1.92±0.48	1.97±0.92	2.03±0.74	2.05±0.21	2.07±0.82	0.32±0.06
Zn (mg/100g)	1.23±0.20	0.32±0.07	0.29±0.02	0.26±0.04	0.26±0.03	0.18±0.03
Cu (mg/100g)	1.26±0.63	1.36±0.83	1.26±0.70	1.22±0.23	1.20±0.28	0.53±0.300
Mn (mg/100g)	2.22±0.83	1.27±0.23	1.23±0.57	1.21±0.27	1.16±0.24	0.43±0.06

Mean ± standard error from 3 replicates

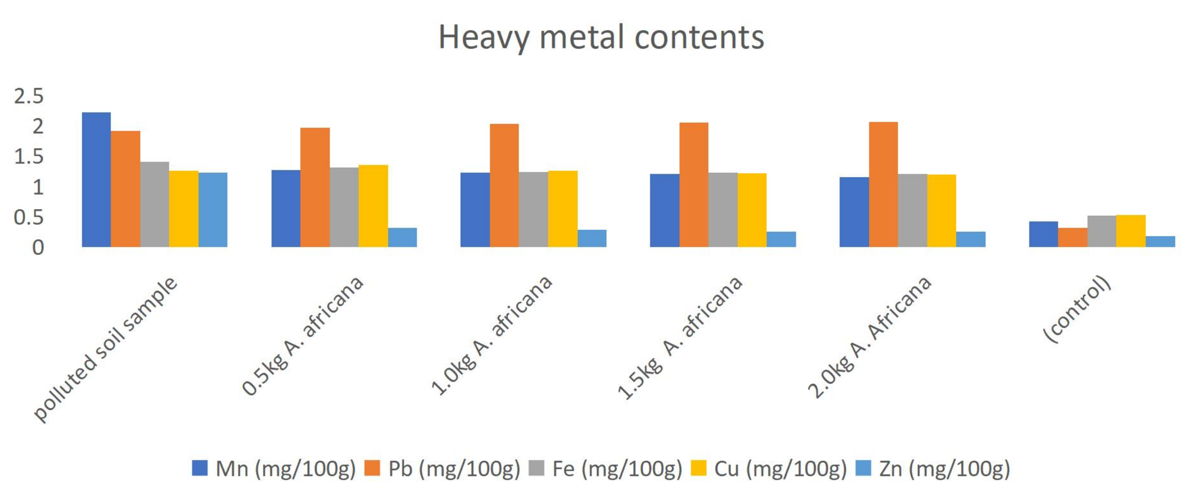

Fig 4: Heavy metal contents of contaminated soil with used engine oil and remediated soil with *A. africana* manure

The observed increase in Pb concentration following the application of *Aspilia africana* manure deviated from the general trend of reduction observed for other heavy metals. This exception may be attributed to the strong affinity of Pb for organic matter, which likely promoted the formation of stable organometallic complexes that were resistant to microbial degradation and chemical transformation. Additionally, Pb is known to exhibit a higher binding affinity for soil colloids and mineral surfaces compared to other trace metals, contributing to its reduced mobility and persistence in the soil matrix. These interactions may limit its bioavailability while simultaneously elevating its measurable concentration in amended soils [28].

4. CONCLUSION

The results of this study showed that contamination by used engine oil significantly degraded soil physical and chemical properties while introducing heavy metals into the soil. However, the application of *Aspilia africana* manure effectively mitigated these negative impacts by enhancing soil structure, increasing moisture retention, elevating soil pH, and reducing heavy metal concentrations — with the exception of lead (Pb). These findings indicate that *A. africana* manure offers a promising, low-cost, and environmentally sustainable solution for remediating used engine oil–contaminated soils, especially in developing regions where advanced remediation technologies are often financially out of reach. Future research could explore combining *A. africana* manure with other soil amendments, such as biochar, to further immobilize heavy metals and ensure safer, healthier soil conditions.

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Conflict of interest

The author has no relevant financial or non-financial interests to disclose

Contribution of the Author

The work was designed by Dr. Richard A. Ukpe. Both authors carried out the bench work and also in the writing of the manuscript.

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