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ORIGINAL ARTICLE

Spatial Dispersion of Spent Engine Oil in Soil and Gradient-Dependent Effects on Growth and Physiological Responses of Spinach (*Spinacia oleracea* L.)

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ABSTRACT

Spent engine oil (SEO) is a persistent soil contaminant in many developing regions, yet its long-term spatial dispersion and indirect effects on surrounding vegetation remain poorly understood. This study investigated the spatial dispersion of SEO from a generator maintenance facility at Admiralty University of Nigeria and evaluated gradient-dependent effects on soil properties and the growth and physiological responses of spinach (*Spinacia oleracea* L.). Soil sampling followed a directional composite approach to capture spatial variability. At the disposal point (Site A), soil subsamples were collected from composite sample. The same procedure was applied at 50 m (Site B), 100 m (Site C), and 150 m (Site D) from the disposal point, while an uncontaminated composite soil (Site E) served as the control. Soil physicochemical properties and heavy metal concentrations were analyzed prior to transplanting and plant growth responses were monitored for 15 days after transplanting (DAT). Result showed that soil pH was strongly acidic (5.93) at the disposal point (Site A) and gradually increased with distance, while electrical conductivity was significantly ($p = 0.02$) higher at site A (80.8 µS/cm) and gradually reduced with distance. Concentrations of Zn, Pb, Cu, and Ca were highest at site A and declined progressively along the gradient (A > B > C > D > E). Spinach growth exhibited clear gradient-dependent inhibition, with 100% plant mortality at Site A within 7 DAT and reduction in leaf number (67%) and stem length (79.3%) between the (A-D) soils and the control. The findings demonstrate that chronic SEO disposal promotes spatial dispersion in soil, broadening phytotoxicity effects beyond the point of discharge and posing significant risks to soil fertility and crop productivity.

Keywords: Spent engine oil; Chronic contamination; Soil dispersion; Heavy metals; Plant physiological stress; Spinach.

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1.0 INTRODUCTION

Spent engine oil (SEO) is a ubiquitous petroleum-derived waste generated during routine servicing of automobiles, generators, and industrial machinery. In many developing regions, including Nigeria, SEO is frequently discharged indiscriminately onto open ground, drainage systems, and unused land without adequate containment or remediation measures (Onwusiri et al., 2017, Musa & Ikhajiagbe, 2024). This practice creates chronic soil contamination hotspots that persist for years, particularly around mechanic workshops and generator houses. SEO is chemically complex, it contains degraded hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), and heavy metals such as zinc, lead, copper, nickel, and vanadium originating from engine wear and additive breakdown (Helmenstine, 2013). Once introduced into soil, these contaminants can persist due to low biodegradability, altering soil physicochemical properties, impairing microbial processes, and disrupting nutrient cycling (Udom et al., 2012; Musa et al., 2019). These changes directly influence plant physiological processes, including water uptake, nutrient assimilation, photosynthesis, and root development (Musa & Ikhajiagbe, 2019). Most existing studies on SEO contamination have focused on direct exposure scenarios, where oil is artificially mixed into soil at known concentrations (Osawuru & Abioye, 2012; Ramanlal et al., 2020; Musa et al., 2025). While informative, such approaches fail to capture real-world contamination dynamics, where oil is deposited repeatedly over long periods and allowed to disperse spatially through soil matrices. Oil dispersion in soil can occur both vertically and laterally via capillary forces, soil macropores, surface runoff, and rainfall infiltration, particularly in tropical environments with high precipitation (Kingsley et al., 2026; Ikhajiagbe & Musa, 2019). Chronic contamination may be seen as extremely concerning where oil disposal sites are located near farmlands. A layman believe may be that since there is repeated SEO discharge for a long time, contaminants and constituents of the SEO may migrate outward from the source, exposing soils and crops that are not directly planted on contaminated soil. However, empirical data demonstrating such gradient-dependent plant responses under field-realistic conditions remain scarce (Njoku et al., 2012; Francis et al., 2024), especially as it relates to effects on crops and leafy vegetables. Spinach (*Spinacia oleracea* L.) is a fast-growing leafy vegetable widely consumed in Nigeria and globally (Musa et al., 2025). Due to its shallow root system, rapid biomass accumulation, and sensitivity to soil contaminants, spinach is frequently used as a bioindicator species in ecotoxicological and plant physiology studies (Roychowdhury et al., 2020). Physiological stress in spinach manifests rapidly as reduced leaf expansion, chlorosis, necrosis, and impaired root development, making it a suitable model for assessing sub-lethal soil toxicity. At Admiralty University of Nigeria (ADUN), the generator maintenance facility, where SEO has been continuously discharged for over five years is located approximately 1000 m from the university farm. This prolonged contamination history provides a unique opportunity to evaluate whether chronic SEO disposal has resulted in spatial dispersion of contaminants and measurable impacts on plant growth beyond the disposal point. This study therefore aimed to (i) characterize the spatial dispersion of SEO in soil using physicochemical and heavy metal indicators and (ii) assess gradient-dependent effects on the growth and physiological responses of spinach.

2.0 MATERIALS and METHODS

2.1 Study area and history of contamination

This study was conducted at Admiralty University of Nigeria (ADUN), Delta State, Nigeria (6.16457°N, 6.57543°E). The study area lies within the tropical rainforest zone and is characterized by a bimodal rainfall pattern with an annual rainfall of approximately 1700–2000 mm and mean ambient temperatures ranging from 27 to 31°C. The primary SEO contamination site is located at the university generator maintenance facility, where waste engine oil from routine generator servicing has been indiscriminately discharged onto bare soil for over five years without containment or remediation. This prolonged and continuous discharge history provided a realistic field scenario for evaluating chronic oil contamination and spatial dispersion in soil. The generator house is situated approximately 1000 m from the university farm, raising concerns about potential lateral migration of oil-derived contaminants into agricultural soils.

2.2 Experimental design and soil sampling strategy

A gradient-based sampling approach was adopted to assess the spatial dispersion of SEO in soil. Soil samples were collected along a linear transect radiating from the main oil disposal point. Five sampling sites were established:

Site A: Primary spent engine oil disposal point
Site B: 50 m from Site A
Site C: 100 m from Site A
Site D: 150 m from Site A
Site E (Control): Uncontaminated soil collected from the university biological garden outside the influence of oil contamination.

At each site, soil samples were collected from the topsoil layer (0–5 cm). Using a stainless-steel soil auger at the primary disposal point (Site A), soil subsamples were collected from the north, south, east and west directions and pooled to form composite sample. The same procedure was applied at 50 m (Site B), 100 m (Site C), and 150 m (Site D) from the disposal point, while an uncontaminated composite soil (Site E) served as the control (Figure 1).

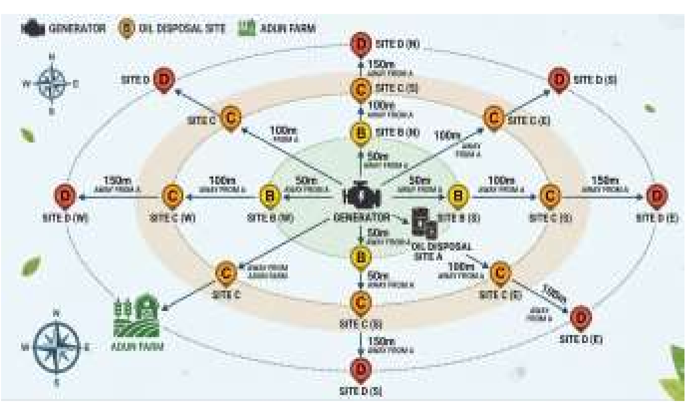

Figure 1. Oil disposal site mapping and distance

2.3 Soil preparation and pot experiment setup

Collected soil samples were air-dried at room temperature, gently crushed, and passed through a 2 mm mesh sieve to remove debris and stones. Polyethylene planting bags (30 × 35 cm) were perforated at the base to allow drainage and filled with 20 kg of processed soil from each sampling site. The experiment was arranged in a completely randomized design (CRD) consisting of five soil treatments (Sites A–E) with three replicates per treatment, giving a total of 15 experimental units. All pots were placed in the university biological garden under uniform environmental conditions.

2.4 Collection of spinach seeds and transplanting

Spinach seeds used in this research were collected from Songai-Delta at Amukpe village. Songai is an agricultural hub renowned for its cultivation, breeding and packaging of seeds of various crops. The seeds were carefully chosen to ensure no physical damage or disease. About 100 seeds of the green amaranth were purchased for the experiment. The seeds were transported to the biological garden of the Admiralty University of Nigeria, for further analysis. The seeds at the biological garden were germinated in uncontaminated nursery soil. Uniform seedlings (14 days old) with similar height and leaf number were selected for transplanting to minimize initial variability. Five seedlings were transplanted into each planting bag. Plants were watered daily with equal volumes (200 mL) of distilled water to maintain soil moisture near field capacity throughout the experimental period.

2.5 Soil physicochemical analysis

Soil physicochemical properties were analyzed prior to transplanting spinach seedlings to characterize the contamination gradient. Soil pH was determined using a digital pH meter in a 1:2.5 soil-to-distilled water suspension (Helmenstine, 2013). Electrical Conductivity (EC) was measured in the same soil suspension using a conductivity meter and expressed in µS cm^{-1}. Available Nitrogen (N) was determined using the Kjeldahl digestion method (Osawuru & Abioye, 2012). Available Phosphorus (P) was determined using the Olsen method. Exchangeable Potassium (K) was determined using flame photometry following ammonium acetate extraction. Water Holding Capacity (WHC) was determined using the gravimetric method, while soil temperature was recorded in situ at the time of sampling using a soil thermometer. Concentrations of zinc (Zn), lead (Pb), copper (Cu), and calcium (Ca) were quantified using flame atomic absorption spectrophotometry (AAS) following standard procedures described by Udom et al., (2012).

2.6 Assessment of growth and physiological parameters

Plant growth and physiological responses were monitored for 15 days after transplanting (DAT). The following parameters were assessed: Leaf number (counted manually), stem length (cm) measured from the soil surface to the apical meristem, leaf length (cm) measured using transparent ruler, root length (cm) measured after harvest, number of secondary roots, fresh biomass (g) measured immediately after harvest, visual stress indicators, including leaf chlorosis, necrosis, wilting, and plant mortality. Plant mortality was recorded when complete wilting and tissue necrosis were observed.

2.7 Statistical analysis

All data were subjected to one-way analysis of variance (ANOVA) using IBM SPSS Statistics version 26. Differences among treatment means were separated using Duncan's Multiple Range Test (DMRT) at a significance level of $p < 0.05$. Data are presented as mean ± standard error (SE).

3.0 RESULTS

Marked spatial variation in soil physicochemical properties was observed across the spent engine oil (SEO) contamination gradient (Table 1). Soil pH values showed a clear distance-dependent pattern, with strongly acidic conditions recorded at the primary disposal point (Site A: pH = 5.93) and at (Site B: pH = 5.99) which is 50 m away from A. In contrast, soils collected at 100 m (Site C) and 150 m (Site D) exhibited moderately acidic pH values (6.14 and 6.26, respectively), while the uncontaminated control soil (Site E) recorded the highest pH (6.44). Statistical analysis revealed distance-dependent significant differences when compared to the control ($p < 0.05$). Soil nutrient status varied markedly across the sampling sites. Soil available nitrogen (N) was lowest at site A (49.5 kg/ac) and increased progressively through sites B and C, reaching the highest concentration in the control soil (225.5 kg/ac). Similar spatial trends were observed for available phosphorus and potassium. Phosphorus concentrations were severely reduced at Site A (2.0 kg/ac) compared with the control (10.8 kg/ac), while potassium content increased from 55.6 kg/ac at Site A to 125.6 kg/ac at Site E. These differences were statistically significant ($p < 0.05$), demonstrating substantial nutrient depletion is SEO-impacted soils. Electrical conductivity (EC), an indicator of ionic contamination, was highest at Site A (80.8 µS/cm^{-1}) and declined progressively with distance from the contamination source, reaching the lowest value at the control site (28.5 µS/cm^{-1}). Water holding capacity (WHC) also differed significantly among sites, with the lowest WHC recorded at Site A (18.06%), with increasing WHC as the distance progresses, resulting to the highest WHC at Site E (31.96%). Heavy metals analysis revealed marked spatial variation consistent with lateral dispersion of SEO-derived contaminants (Figure 2).

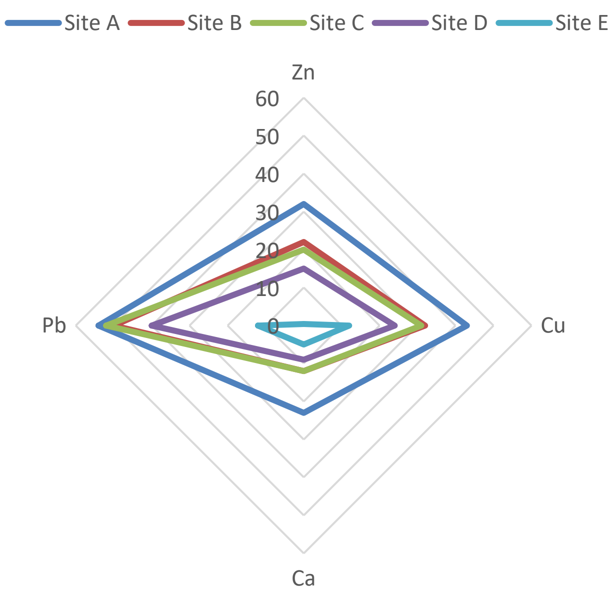

Figure **2.** Heavy metal concentration of the assayed soil

Zinc was the predominant metal with the highest concentration observed at Site A (32 mg kg^{-1}). Zinc concentrations declined consistently with increasing distance from the oil disposal point, following the trend Site A > Site B > Site C > Site D, while no detectable heavy metals were recorded in the control soil. Lead and copper exhibited similar spatial patterns, with elevated concentrations detected in soils proximal to the disposal point and progressively lower concentrations at increasing distances. The absence of detectable heavy metals in the control soil confirms that contamination was localized around the generator facility and supports the hypothesis of spatial dispersion rather than background geochemical influence.

The gradient-dependent effects of spent engine oil dispersion on growth and physiology of spinach were evaluated (Table 2). Result showed that the control soil (E) was observed to show the highest leaf number at all the assayed days compared to the other soil sites. Leaf number at Site A showed minimal development over the observation period. At day 3, the seedlings have one leaf and no increase in leaf number was recorded by 6DAT. By 9DAT, seedlings began to exhibit signs of wilting. This wilting condition persisted through 12DAT and 15DAT. At Site B (50 m from the pollution source), the mean leaf number was 1.0 at 3DAT, increasing slightly to 1.1 at 6DAT and 1.3 at 9DAT and 12DAT. However, by 15DAT, the seedlings exhibited wilting. At Site C (100 m from the source), leaf number increased progressively from 1.9 at 3DAT to 2.2 at 6DAT, 2.9 at 9DAT, 3.1 at 12DAT and 3.2 at 15DAT, showing improved performance compared to Site B. Similarly, Site D (150 m from the source) showed better growth than Site B and C. The control Site E exhibited the highest leaf number increase. There was no significant difference ($p > 0.05$) between Sites A and B at early stages (3 and 6DAT), as both exhibited similarly low leaf numbers. The control site consistently recorded the highest leaf numbers, which were significantly different ($p < 0.05$) from Sites A, B, C and D throughout the study period. Overall, a clear gradient-dependent was observed in terms of leaf number as increases was observed as distance from the spent engine oil disposal site increased.

The effect of spent engine oil dispersion on stem length of spinach seedlings showed a clear gradient-dependent pattern over the 15-day observation period (Table 3). At Site A (point of disposal), stem length remained 0.6 cm at 3DAT and 6DAT, after which no measurable growth was recorded (ND) from 9 to 15DAT, consistent with earlier observations of seedling wilting and failure. At Site B (50 m from the source), slight growth was observed initially, with stem length increasing from 0.6 cm (3DAT) to 0.7 cm (6DAT) and 0.8 cm (9 – 12DAT). However, by 15DAT, stem length was not calculated due to wilting. At Site C (100 m from the source), it was observed that stem length increases from 0.6 cm at 3DAT and 6DAT to 0.8 cm from 9DAT – 15DAT. At Site D (150 m from the source), a steady increase was observed from 0.8 cm at 3DAT to 1.4 cm at 15DAT. The control site showed stem length increased markedly from 1.2 cm at 3DAT up to 4.9 cm at 15DAT. Seedlings at Sites C, D and the control had significantly higher stem lengths compared to Sites A and B, especially from 9DAT onward. There was no significant difference ($p > 0.05$) between Sites A and B at the early stages (3 and 6DAT), as both showed similarly low stem lengths. Generally, stem elongation was observed to increased progressively with increasing distance from the disposal point, while site closer to the source exhibited severe growth inhibition and eventual plant failure.

Table **1.** Soil physico-chemical parameters

Soil parameters	Soil pH	Soil N (kg/ac)	Soil P (kg/ac)	Soil K (kg/ac)	EC (µS/cm)	ST (°C)	WHC (%)
Site A	5.93 ± 0.02^{a}	49.5 ± 0.01^{a}	02.0 ± 0.02^{a}	55.6 ± 0.22^{a}	80.8 ± 0.02^{a}	29.9 ± 0.06^{a}	18.06 ± 0.06^{a}
Site B	5.99 ± 0.12^{a}	84.8 ± 0.12^{b}	11.6 ± 0.02^{b}	79.3 ± 0.04^{b}	52.5 ± 0.08^{b}	29.7 ± 0.01^{a}	20.46 ± 0.01^{b}
Site C	6.14 ± 0.06^{b}	89.6 ± 1.05^{c}	12.8 ± 0.07^{c}	55.6 ± 0.02^{c}	35.1 ± 0.32^{c}	30.0 ± 0.02^{b}	26.23 ± 0.07^{c}
Site D	6.23 ± 0.10^{b}	93.3 ± 0.04^{d}	15.3 ± 0.03^{d}	79.3 ± 0.11^{b}	37.9 ± 0.02^{c}	30.1 ± 0.12^{b}	28.83 ± 0.11^{d}
Site E	6.44 ± 0.21^{b}	225.5 ± 0.02^{e}	16 ± 0.12^{e}	123.8 ± 0.02^{d}	28.5 ± 0.02^{d}	30.0 ± 0.09^{b}	31.96 ± 0.03^{d}

Results with similar alphabetic superscripts on same column did not differ from each other (p>0.05). Results were in mean and standard error of three replicates. Soil N= Soil available nitrogen, Soil P = Soil available phosphorus, Soil K= Soil available potassium, EC= Electrical conductivity, ST= Soil temperature, WHC = Water holding capacity.

Table 2. Leaf number of spinach seedlings at varying distances from spent engine oil disposal site

Samples	Leaf Number				
	3DAT	6DAT	9DAT	12DAT	15DAT
Site A	1.0 ± 0.23a	1.0 ± 0.23a	ND	ND	ND
Site B	1.0 ± 0.12a	1.1 ± 0.12a	1.3 ± 0.12a	1.3 ± 0.12a	ND
Site C	1.9 ± 0.11b	2.2 ± 0.11b	2.9 ± 0.11b	3.1 ± 0.11b	3.2 ± 0.11a
Site D	2.2 ± 0.01b	2.7 ± 0.01b	3.2 ± 0.01c	3.3 ± 0.01b	3.5 ± 0.01a
Site E (Control)	3.9 ± 0.22c	4.6 ± 0.22c	5.9 ± 0.22d	6.7 ± 0.22c	7.9 ± 0.22b

Results with similar alphabetic superscripts on same column did not differ from each other (p > 0.05). Results were in mean and standard error of three replicates. DAT=Days after transplant. ND= Not detected.

Table 3. Stem length of spinach seedlings at varying distances from spent engine oil disposal site

Samples	Stem length (cm)				
	3DAT	6DAT	9DAT	12DAT	15DAT
Site A	0.6 ± 0.11a	0.6 ± 0.01a	ND	ND	ND
Site B	0.6 ± 0.01a	0.7 ± 0.02a	0.8 ± 0.10a	0.8 ± 0.11a	ND
Site C	0.6 ± 0.03a	0.6 ± 0.11a	0.8 ± 0.20a	0.8 ± 0.10a	0.8 ± 0.61a
Site D	0.8 ± 0.11b	1.0 ± 0.01b	1.2 ± 0.03c	1.3 ± 0.04b	1.4 ± 0.21b
Site E (Control)	1.2 ± 0.32c	2.1 ± 0.23c	3.9 ± 0.23d	4.5 ± 0.22c	4.9 ± 0.25c

Results with similar alphabetic superscripts on same column did not differ from each other ($p > 0.05$). Results were in mean and standard error of three replicates. DAT=Days after transplant. ND= Not detected.

Table 4 shows variation in leaf length (cm) of spinach seedling across the spent engine oil dispersion gradient. At Site A (disposal point), leaf length increased slightly from 0.4 cm at 3DAT to 0.5 cm at 6DAT, after which no measurements were recorded from 9 to 15DAT due to seedling wilting and failure. At Site B (50 m from A), leaf length increased gradually from 0.6 cm at 3DAT to 0.8 cm at 6DAT and 0.9 cm at 9DAT. However, no data were recorded at 12 and 15DAT due to seedling death. At Site C (100 m from A), steady growth was observed, with leaf length increasing from 1.0 cm at 3DAT to 1.1 cm at 6DAT, 1.3 cm at 9DAT, 1.4 cm at 12DAT and 1.5 cm at 15DAT. At Site D (150 m from A), higher growth performance was recorded, with leaf length increasing from 2.2 cm at 3DAT to 2.6 cm at 6DAT, 2.7 cm at 9DAT, 2.8 cm at 12DAT and 2.9 cm at 15DAT. The control site exhibited the highest leaf length values throughout the study, increasing from 2.2 cm at 3DAT, to 2.9 cm at 6DAT, 3.2 cm at 9DAT, 3.4 cm at 12DAT and 3.6 cm at 15DAT. Seedlings at Sites C, D and E recorded significantly higher leaf lengths compared to Sites A and B, especially from 9DAT onward. The control site consistently showed the highest leaf length values, which were significantly different ($p < 0.05$) from Sites A, B, C and D. Generally, leaf length increased progressively with distance from the point of disposal. Severe inhibition and plant failure was observed at sites closer to the point of disposal, while optimal growth was observed at the control site. Results from Table 5 and Figure 3 shows the response of spinach seedlings in terms of root length and number of secondary roots. At site A, root length was 2 cm at 10DAT, after which no measurement was recorded at 15DAT, which may be due to the wilting observed earlier. A similar result was observed at Site B. Site C showed improvement in terms of root length as it increases from 4 cm at 10DAT to 5 cm at 15DAT. At Site D, further enhancement in root growth occurred, with root length increasing from 5 cm at 10DAT to 7 cm at 15DAT. Site E (control) recorded the highest values with root length increasing substantially from 10cm at 10DAT to 16 cm at 15DAT. A similar pattern was observed for the number of secondary roots. At Site A, seedlings had 5 secondary roots at 10DAT, but no data determined at 15DAT, indicating poor sustainability. At Site D, a higher number was recorded, increasing from12 at 10DAT to 16 at 15DAT. Control site E, showed the highest proliferation, with secondary roots increasing from 18 at 10DAT to 24 at 15DAT. The control site recorded the highest root length, which was significantly different ($p < 0.05$) from all other sites, followed by Site D and C, showing a clear gradient-dependent increase in root development. Generally, root length and secondary root development improved progressively with increasing distance from the pollution source. Sites closer to the spent engine oil disposal exhibited severe inhibition of root growth and eventual plant failure, while sites farther away, particularly the control, supported robust root systems development

Table 4. Leaf length of spinach seedlings at varying distances from spent engine oil disposal site

Samples	Leaf length (cm)				
	3DAT	6DAT	9DAT	12DAT	15DAT
Site A	0.4 ± 0.11a	0.5 ± 0.23a	ND	ND	ND
Site B	0.6 ± 0.02b	0.8 ± 0.12b	0.9 ± 0.12a	1.0 ± 0.12a	ND
Site C	1.0 ± 0.02c	1.1 ± 0.11c	1.3 ± 0.11b	1.4 ± 0.05b	1.5 ± 0.21a
Site D	2.2 ± 0.22d	2.6 ± 0.01d	2.7 ± 0.01c	2.8 ± 0.09c	2.9 ± 0.31b
Site E (Control)	2.2 ± 0.32d	2.9 ± 0.22e	3.2 ± 0.22d	3.4 ± 0.01d	3.6 ± 0.21c

Results with similar alphabetic superscripts on same column did not differ from each other ($p > 0.05$). Results were in mean and standard error of three replicates. DAT=Days after transplant. ND= Not detected.

Table 6 shows the occurrence of leaf tip necrosis and chlorosis in spinach seedlings. At Site A (point of disposal), a high level of damage was observed early, with 20% leaf tip necrosis and chlorosis at 5DAT. No data were recorded at 10 and 15DAT due to complete seedling failure. At Site B (50 m from A), 15% leaf tip necrosis and chlorosis were recorded at 5DAT, which increased to 20% at 10DAT. However, no data were recorded at 15DAT due to plant death. At Site C (100 m from A), no signs of leaf tip necrosis and chlorosis were observed throughout the study period (5, 10 and 15DAT), indicating minimal or no stress impact. Similarly, Site D (150 m from A) showed no observable symptoms of necrosis or chlorosis at all sampling periods. The control Site E exhibited very low levels of leaf tip chlorosis and necrosis, with 5% at 5DAT and 2% at 10DAT. No signs of necrosis or chlorosis were observed at 15DAT. Generally, the incidence of leaf tip necrosis and chlorosis was observed to decrease progressively with increasing distance from the spent engine oil disposal point. Severe symptoms and plant failure were observed at sites closest to the disposal point, while distant and control sites showed little to no physiological damage.

Table 5. Root length and number of secondary roots in spent engine oil polluted soil at varying distances from spent engine oil disposal site

Samples	Root length (cm)		Number of secondary roots	
	10DAT	15DAT	10DAT	15DAT
Site A	02 ± 0.02a	ND	05 ± 0.12a	ND
Site B	02 ± 0.03a	ND	07 ± 0.23b	ND
Site C	04 ± 0.04b	05 ± 0.21a	09 ± 0.10c	11 ± 0.06a
Site D	05 ± 0.21c	07 ± 0.06b	12 ± 0.01d	16 ± 0.19b
Site E	10 ± 0.02d	16 ± 0.20c	18 ± 0.26e	24 ± 0.21c

Results with similar alphabetic superscripts on same column did not differ from each other ($p > 0.05$). Results were in mean and standard error of three replicates. DAT=Days after transplant. ND= Not detected.

Table 6. Leaf tip necrosis and chlorosis percentage of seedlings at varying distances from spent engine oil disposal site

Samples	LTNC (%)		
	5DAT	10DAT	15DAT
Site A	20	ND	ND
Site B	15	20	ND
Site C	No sign	No sign	No sign
Site D	No sign	No sign	No sign
Site E (Control)	No sign	No sign	No sign

DAT=Days after transplant. ND= Not detected. LTNC = Leaf Tip Necrosis and Chlorosis

Variation in weight of spinach seedlings (g) across the spent engine oil dispersion gradient was observed (Figure 4). At Site A (point of disposal), seedling wight was 1.3 g at 5DAT, after which no measurements were recorded because the seedling had died before 10DAT. At Site B (50 m from A), seedling weight increased from 2.0 g at 5DAT to 2.4 g at 10DAT. However, no data were recorded at 15DAT because the seedling had wilted and died off. At Site C (100 m from A), steady growth was observed with seedling weight increasing from 3.0 g at 5DAT, to 3.8 g at 10DAT and 4.0 g at 15DAT. At Site D (150 m from A), slightly higher values were recorded, increasing from 3.4 g at 5DAT to 4.2 g at 10DAT and 4.4 g at 15DAT. The control site showed the highest growth performance, with seedling weight increasing from 4.2 g at 5DAT to 5.2 g at 10DAT and 5.9 g at 15DAT. Generally, seedling biomass was observed to increase progressively with distance from the disposal point. Sites closest to the disposal point exhibited reduced biomass weight, while sites farther away, particularly the control, supported higher weight.

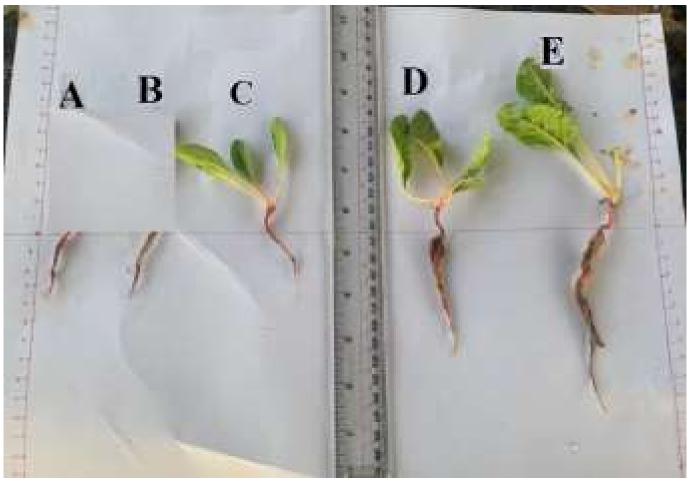

Figure **3.** Root length parameters

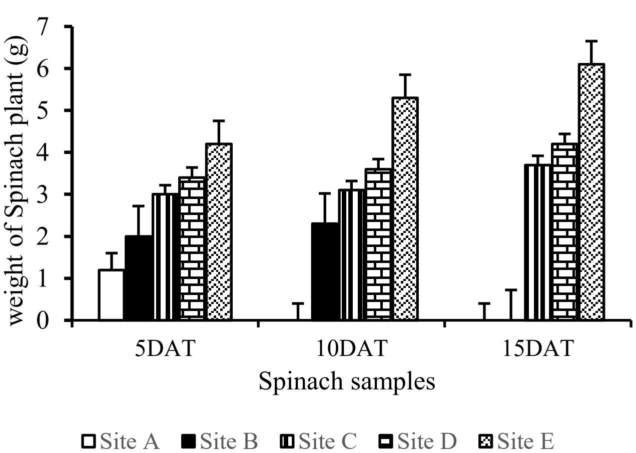

Figure **4.** Response of Spinach grown on spent engine oil polluted region ADUN generator house on plant weight

4.0 DISCUSSION

The present study provides compelling evidence that prolonged disposal of spent engine oil facilitates its spatial dispersion in soil, leading to gradient-dependent deterioration of soil quality and plant growth. The five-year history of continuous SEO discharge at the ADUN generator house likely played a critical role in enabling contaminant migration beyond the immediate disposal zone. Chronic input of oil over extended periods allows repeated wetting-drying cycles, rainfall infiltration, and soil structural changes to enhance lateral movement of oil-associated contaminants.

The strongly acidic pH observed at the primary disposal point and its gradual increase with distance reflect the localized accumulation of petroleum degradation products and metal ions, which can acidify soils through oxidation reactions (Dong et al., 2014). Elevated electrical conductivity near the disposal site further indicates increased ionic strength resulting from dissolved metal species and petroleum residues. Similar spatial trends in EC and pH have been reported in long-term oil-contaminated soils (Nwoko et al., 2017).

Heavy metal concentrations followed a clear contamination gradient (A > B > C > D > E), confirming lateral dispersion of SEO-derived metals. Zinc dominance among detected metals is consistent with its widespread use in engine oil additives and its persistence in soil (Helmenstine, 2013). The depletion of soil macronutrients (N, P, and K) in contaminated soils highlights the indirect consequences of SEO contamination on soil fertility. Reduced aeration, impaired microbial activity, and metal-nutrient antagonism likely contributed to diminished nutrient availability (Nwoko et al., 2017). These soil-level constraints translated directly into severe inhibition of spinach growth, particularly at Sites A and B. The poor performance of spinach seedlings at sites A and B, such as reduced growth and eventual plant failure indicates high levels of residual toxicity in soils near the disposal point. Spent engine oil contains complex mixtures of aliphatic and aromatic hydrocarbons, as well as heavy metals such as lead, cadmium and zinc (Musa et al., 2020; Uchenna et al., 2026). These chemicals are known to persist in soils and exert toxic effects on plants (Moses et al., 2023). In this study, with the physiological behavior of spinach seedlings from the disposal point (A) and at 50m (B) and 100 m (C) away from the disposal point, it can be safe to say that the contaminants from the spent engine oil has interfered with key physiological processes in spinach seedling such as cell division, nutrient uptake and photosynthesis, leading to stunted growth and reduced biomass. Similar inhibitory effects have been widely reported in plants exposed to petroleum-contaminated soils (Enerijiofi et al., 2023; Saheed et al., 2026). The gradual improvement in plant performance observed at sites C and D indicates that contaminant concentration decreases with distance, which may be because the contaminant movement has not reached the site D (150 m away from A). Previous studies have it that processes such as leaching, diffusion, surface runoff can cause contaminants to be transferred across soil gradients. This aligns with previous findings that hydrocarbons can migrate through soil profiles depending on soil texture, rainfall patterns and topography, thereby extending their environmental impact beyond the original contamination site (Ikhajiagbe & Musa, 2019; Roychowdhury et al., 2020).

Furthermore, the reduced root length and number of secondary roots that were observed in the spent engine oil disposal site as well as 50 m away suggests limited water and nutrient uptake due to hydrocarbon-induced hydrophobicity and poor soil aeration (Ikhajiagbe & Musa, 2020). In contrast, improved root architecture at farther distances indicates low toxicity at those sites. Occurrence of leaf tip necrosis and chlorosis at sites closer to the spent engine oil disposal point further confirms the presence of physiological stress. These symptoms are typically associated with chlorophyll degradation, oxidative stress and nutrient imbalance, all of which are common responses to hydrocarbon toxicity. The absence of such symptoms at site C, D and the control suggests that contaminant levels at these distances fall below phytotoxic thresholds and that the contaminants has not reach such father distances.

Conclusion

The present study demonstrates that long-term disposal of spent engine oil can disperse through the soil environment and result in measurable phytotoxic effects on crops located at varying distances from the disposal point. The five-year history of SEO discharge at the ADUN generator house likely facilitated lateral migration of contaminants, extending ecological impacts well beyond the point of release. Using spinach seedlings as sensitive bioindicators, a clear gradient-dependent response was observed with severe growth inhibition, reduced biomass, impaired root development and increased physiological stress (leaf tip necrosis and chlorosis) at sites closest to the spent engine oil disposal point. Conversely, seedlings at sites farther from the disposal point and at the control site exhibited significant growth properties with little stress symptoms, indicating a reduction in contamination concentration with distance. These highlight the utility of plant physiological parameters as effective early indicators of soil contamination, offering a cost-effective and practical tool for environmental monitoring. Given the observed dispersion and phytotoxic effects, it is recommended that spent engine oil be properly contained, managed and remediated and that regular monitoring of nearby farmlands be implemented to prevent long-term ecological and agronomic consequences. Generally, this research provides critical insight into the environmental behavior of spent engine oil and its implications for crop safety and land management, offering both scientific and practical guidance for mitigating pollution in semi-urban agricultural settings.

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Conflict of interest
The authors declare that there are no conflicts of interest that could have influenced the design, conduct, analysis, interpretation, or reporting of the findings presented in this study.

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Authors contributions
Musa conceived and designed the study and performed the data analysis. Onyeka Elfreda conducted the initial study. Musa and Thelma performed analysis. Thelma generated data, wrote first draft of the manuscript. Isitua provided intellectual input and suggestions. All authors read and approved the final manuscript.

REFERENCES

Dong, J., Akbar, C., and Suit, C. (2014). Electrical conductivity as an indicator of soil heavy metal pollution. *Chemosphere*. 95, 123–130. https://doi.org/10.4103/2277-9183.94395

Enerijiofi, K. E., Musa, S.I., Okolafor, F.I., Okolafor, Francis Aibuedefe Igiebor, Efota Bright Odozi and Beckley Ikhajiagbe (2023). Sustainable approaches for the remediation of agrochemicals in the environment. In: Ogwu, M.C., Chibueze Izah, S. (eds) *One Health Implications of Agrochemicals and their Sustainable Alternatives, Sustainable Development and Biodiversity*. Vol 34. Springer Nature, Singapore Pte Ltd. https://doi.org/10.1007/978-981-99-3439-3_19

Francis Aibuedefe Igiebor, Edokpolor Osazee Ohanmu, Gloria Omorowa Omoregie, Ojo Otokiti Jennifer, S.I. Musa, Denzel Ejale, Nathaniel Okojie, Richard Afe, Stanley Ivbobie, Beckley Ikhajiagbe (2024). Nanobioherbicides and plant growth hormones synthesis and stress-mediated hormones. 6. https://doi.org/10.1002/9781394234769.ch20

Helmenstine, A. M. (2013). Chemical composition and environmental behavior of petroleum products. *Environmental Chemistry Reviews*. 7, 45–58. https://doi.org/10.19080/IJESNR.2018.11.555811

Ikhajiagbe, B. and Musa, S. I. (2019). Effect of changes in cation exchange capacity on the reclamation of lead by *Eleusine indica* (L.) Gaertn. *FUDMA Journal of Sciences.* 3(4): 2645-2944. https://fjs.fudutsinma.edu.ng/index.php/fjs/article/view/1636

Ikhajiagbe, B. and Musa, S.I. (2020). The effects of salicylic acid on the germination and early seedling growth of pigeon pea (*Cajanus cajan*). Notulae Scientia Biologicae, 12(3), 683 – 692. https://doi.org/10.15385/nsb12310777.

Ibrahim, M. S., Konyeme, T. E., & Ikhajiagbe, B. (2026). Screening of rice genotypes for adaptability to ferruginous ultisol using morphological, physiological and molecular makers. Bio-Research, 24(1), 445–453. https://doi.org/10.4314/br.v24i1.18

Kingsley Erhons Enerijiofi, Saheed Ibrahim Musa, Deepshikha Bhowmik, Soumitra Nath (2026). Detrimental influence of diverse pollutants on water environment and human life. *Environmental Health and Toxicology*. https://doi.org/10.1201/9781003500452-5

Moses, N., Ezenwata, I.S. and Musa, S.I. (2023). Some physicochemical properties and heavy metals in water from Oboshi River, Ibusa in Delta State, Nigeria. Journal of Applied Environmnetal Management. 27(6): 1291-1294. https://dx.doi.org/10.4314/jasem.v27i6.33

Musa S. I. and B, Ikhajiagbe (2019). Bioaccumulation of heavy metals by *Vigna unguiculata* (cowpea) grown o Olusosun dump site soil. Lagos, Nigeria. 1(1): 91-98. https://sulegumes.org/

Musa, S., Awayewaserere, K., and Njoku, K. (2019). Effects of dumpsite soil on the leaf structures of *Luffa cylindrical* (sponge gourd) and *Amaranthus viridis* (green amaranth). Journal of Applied Sciences and Environmental Management, 23(2), 309-313. https://doi.org/10.4314/jasem.v23i2.

Musa, S., Enerijiofi, K.E., Okoji, C. and Ikhajiagbe, B. (2025). Evaluation of bioremediation of diesel-contaminated soil amended with poultry droppings and pig dung. *Scientia Africana*. 24(1): 113-124. https://doi.org/10.4314/sa.v24i1.11

Musa, S.I. and Beckley Ikhajiagbe (2024). Effects of plant growth promoting bacteria (PGPB) rhizo inoculation on soil physico-chemical, bacterial community structure and root colonization of rice (*Oryza sativa* L. var. FARO 44) grown in ferruginous ultisol conditions. *Science World Journal.* 19(3): 894-899. https://doi.org/10.4314/swj.v19i3.38

Musa, S.I., Oke, F.M. and Ndiribe, C.C. (2020). Bioremediation of diesel polluted soils with *Eichhornia crassipes* (water hyacinth). *Notulae Scientia Biologicae* 12(4): 920-928. https://doi.org/10.15835/nsb12410814.

Njoku, C., Ngenne, P. N. Nwogbaga, A. C. (2012). Assessment of selected heavy metals in sewage sludge disposal soils in Abakaliki, Southeastern Nigeria. *Greener Journal of Physical Sciences*. 2(4): 117-119. https://doi.org/10.33003/fjs-2024-0806-3079

Nwoko, C., Mike, J. and Kingsley, C. (2017). Soil–plant interactions in petroleum-polluted environments. *Journal of Environmental Management*. 196, 683–692. https://doi.org/10.70728/jopen.be.0126.006

Onwusiri, K. C., Aguoru, C. U., Akomolafe, G. F. (2017). Effect of spent engine oil on germination and growth parameters of fluted pumpkin (*Telfairia occidentalis* Hook F.) in Makurdi, Benue State, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*. 9(4): 1-8. https://doi.org/10.90394181

Osawaru, M. E. and Abioye, O. (2012). Growth performance of Okra (*Abelmoschus esculentus* (L.) Moench) cultivar in soil polluted at different concentrations of spent engine oil. *Environmental Science, Agriculture and Food Sciences*. 12(2): 12-31. https://doi.org/10.138998778

Uchenna, O., Ughamba, K. T., Ezeh, C. C., Animashaun, R. O., Ogbonna, N. K., Nebo, B. N., Eze, S. C., & Eke, E. U. (2026). Evaluation of plant growth-promoting properties of nitrogen-fixing Enterobacter mori strain P5 (Mw242734.1) isolated from spent mushroom substrates. Bio-Research, 23(3), 162–170. https://doi.org/10.4314/br.v23i3.5

Ramanlal, D. B., Kumar, R. N., Kumar, N. (2020). Assessing potential of weeds (Acalypha indica and Amaranthus viridis) in phytoremediating soil contaminated with heavy metals-rich effluent. *Discover Applied Sciences*. 2(10): 63-69. https://doi.org/10.1007/s42452-020-2859-0?utm_source=chatgpt.com

Roychowdhury, T., Chile, C. and Victor, J. (2020). Heavy metal stress and vegetable crop responses. *Ecotoxicology and Environmental Safety*. 192, 110278. https://doi.org/10.1007/s13762-019-02215-8

Udom, G. J., Nwankwoala, H. O., Jepthah, H.A. (2012). Seasonal variation of groundwater chemistry in parts of Yenegoa, Bayelsa State. *International Journal of Innovation Environmental Studies Research.* 1: 40-54. https://doi.org/10.189444863