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Disposal of spent oil into soils around auto parts markets impacts heavy metal concentrations and poses a potential ecological risk

Chinyere Blessing Okebalama¹, Chioma Lucy Onwurah¹, Chika Mike Jidere¹ and Chukwuebuka Christopher Okolo^{2*}

Abstract

Nigeria is facing the problem of soil degradation as a result of continuous deposition of spent oil in the soil. The physiochemical properties, including heavy metals concentrations, of spent oil contaminated soils and adjacent control soils were investigated at 0–15 and 15–30 cm depths at Ladipo and Berger auto-mobile Markets in Lagos, southwest Nigeria. The soils were collected in triplicate and analyzed in a 2 (location) * 2 (study site) * 2 (soil depth) factorial experiment. The results showed a uniform soil texture in both study sites and at both soil depths, with loamy sand at Ladipo and sandy loam at Berger. Bulk density was significantly decreased, while the total porosity (46.44%), organic C (21.79 g kg⁻¹), available P (16.48 mg kg⁻¹), Na⁺ (0.72 cmol_c kg⁻¹) and K⁺ (0.81 cmol_c kg⁻¹) increased in the contaminated site compared to the control site. Soil pH was higher at Ladipo (8.4) than at Berger (7.4). However, the soil pH and available P concentration decreased in the contaminated soil compared to the control at both locations, resulting in a decrease in available P concentration of more than 300% and 100% at Ladipo and Berger, respectively. At the Ladipo location, the concentration of Ca²⁺ was higher in the control than in the contaminated counterpart, while the opposite was true at the Berger location. The concentrations of the heavy metals Pb and Zn in the contaminated soils were low, while the Cu concentration was high. Although the concentrations of these heavy metals were below the standards for potential environmental risks, the high Cu concentration at both locations poses a potential ecological risk and may affect soil and human health as Cu accumulates in critical levels in the soil due to the continued irresponsible disposal of spent oil on the ground.

Keywords Heavy metals, Soil properties, Used engine oil, Soil contamination, Ladipo, Berger, Mechanic workshop, Spent oil disposal

*Correspondence:

Chukwuebuka Christopher Okolo
okolochukwuebuka@gmail.com

¹Department of Soil Science, Faculty of Agriculture, University of Nigeria,
Nsukka 410001, Nigeria

²Department of Natural Resources Management, Jimma University, P. O.
Box 307, Jimma, Ethiopia



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Introduction

Due to its non-recyclable nature and lack of meaningful secondary use, the disposal of spent engine oil in the soil poses a threat to the environment (Onwuka et al. 2012; Bala et al. 2019; Eze et al. 2019). Spent oil or waste lubricating oil or similar petroleum substances from refined crude oil are usually recovered after servicing and subsequent draining from the engine of automobile, generators and industrial machines (Patrick-Iwuanyanwu et al. 2010). This oil has been used for its intended purpose and is contaminated by physical or chemical contaminants such as iron, steel, copper, zinc, lead, barium, cadmium, sulfur, dirt particles and ash that enter the oil as the engine wears (Irwin 1997; Nwite and Alu 2015). Due to these additives and contaminants, the disposal of used motor oil can be more environmentally damaging than crude oil pollution (Abioye et al. 2012) and can have both short- and long-term effect when it enters the environment via waterways or through the soil (Anoliefo and Vwioko 1995; Okolo et al. 2013a; Nwite et al. 2016a, b).

The increasing number of vehicles in Nigeria has necessitated greater production and use of automobile engine oil. This has led to the generation of large quantities of spent engine oil during vehicle servicing and maintenance. Spent engine oil is considered by most auto mechanics in Nigeria as common waste and the oil is constantly dumped on the ground, gutters, and drains unless the oil is collected by unregistered and unregulated dealers (Okonokhua et al. 2007). Oil pollution is a major contributor to the higher concentrations of heavy metals in the environment (Onwuka et al. 2012). Spent oils contain a higher proportion of aromatic and aliphatic hydrocarbons, N and S compounds, Mg, Ca and heavy metals (Va, Al, Ni, Fe, Zn, Pb) than fresh/unused oils (Whisman et al. 1974; Wang et al. 2000). While small amounts of these metals in the environment and also in food are necessary for ecosystem sustainability and good health, large amounts can lead to severe and chronic toxicity (Voroney 2006). Some of the heavy metals are essential micronutrients for plants in low concentrations, but high concentrations can cause metabolic disorders and growth inhibition in most plant species (Fernandes and Henriques 1991; Batjargal et al. 2010).

Spent engine oil causes great damage to soils and soil microflora (Adedokun and Ataga 2007), thereby affecting water resources and agricultural land (Rashid et al. 2023). Okonokhua et al. (2007) showed significant changes in soil properties due to hydrocarbon contamination, affecting the physical, chemical and microbiological properties of the soil. An increase in bulk density and heavy metal content as well as a decrease in water holding capacity, aeration propensity, N, P, K, Mg, Ca, and Na were found in spent oil contaminated soil (Kayode et al. 2009). Soil pollution by spent oil generally leads to reduced seed

germination, plant growth, and crop yield (Osubor and Anoliefo 2003; Okonokhua et al. 2007; Nwite and Alu 2015; Nwachukwu et al., 2020). Spent engine oil contamination leads to unsatisfactory soil health due to poor aeration, immobilization of soil nutrients and lowering of soil pH (Ugoh and Moneke 2011). Furthermore, humans can be exposed to soil contaminants through the food chain, with consumption of crops grown on contaminated soils leading to tissue accumulation, toxicity and diseases when critical levels are reached (Martin and Griswold 2009; Singh et al. 2011; Okolo et al. 2013b, 2015). However, little is known about the composition and concentrations of heavy metals in soils around automobile repair shops in most metropolitan cities in Nigeria. Contaminated soils represent an environment of direct exposure to toxic heavy metals (Anant et al. 2018). As they subsequently enter groundwater (Okolo et al. 2018) and the food chain (Singh et al. 2011), the impact of spent oil contaminant on soil quality is of critical importance.

This research work focuses on the characterization of soils, including the determination of heavy metals in and around spent oil contaminated sites in Lagos State, Nigeria. Lagos is the most populous and important economic center of the country as well as a major transportation hub for Nigeria and sub-Saharan Africa. The increasing use of petroleum products in Lagos results in huge liters of spent oil being generated and improperly disposed of in the soil. A more comprehensive analysis of the impacts of spent oil disposal on soil will provide a better understanding of the mechanisms of retention, exposure and toxicity of heavy metals. The study is expected to provide reliable and useful ground truth information needed to establish procedures for regulating, controlling and monitoring the environmental impact of spent oil pollution from automobile mechanics. The information would also be useful to the government in establishing policies to ensure sustainable land use planning and combating unhealthy disposal practices in Nigeria. The objective of the study was to assess soil physiochemical properties, including concentration of heavy metals in spent oil contaminated site and an adjacent uncontaminated site at Ladipo and Berger Auto Parts Markets in Lagos State, Nigeria. The assessment of the pattern of heavy metal contamination, including risks to the environment and human health, is beyond the scope of this study.

Materials and methods

Description of the study area

Lagos State is located in southwestern Nigeria, approximately between longitude 2°42' and 3°42' E and between latitude 6°23' and 6°41' N (Iwugo et al. 2003). Lagos has a total area of 3577 km², of which about 787 km² is water area. There are two distinct seasons in the region; dry

(August and September; December to March) and wet (April to July, October and November). The climate is tropical with an average temperature of 26.70 °C and an annual rainfall of approximately 1,783 mm (Climate Data 2024). In general, the relief of Lagos reflects the coastal location of the state. More than 40% of the total area of the state is covered by water and wetlands, with a further 12% at risk of seasonal flooding (Iwugo et al. 2003). The geology is mainly sedimentary and consists of tertiary and quaternary sediments, and the major soil groups are juvenile, organic- hydromorphic and ferrallitic soils.

The study was conducted at Ladipo Automobile Spare Parts Market (latitude 6°54' N and longitude 3°35' E), and Berger Automobile Market (latitude 6°45' N and longitude 3°32' E), in Lagos State, Nigeria (Fig. 1). A field reconnaissance survey was carried out before the two locations were selected. Ladipo Auto Spare Parts Market is located around Akinwunmi Lane, off Ladipo Street, Papa Ajao Mushin, Mushin Local Government Area of Lagos State. It is from this area (Ladipo Street) that the acclaimed name in automotive circles originated more than twenty years ago. Berger Auto Market is located along the Mile 2-Apapa Expressway in Apapa Local Government, Lagos, and has only been in operation for about nine years.

Field study

Core and loose soil samples were taken in triplicate at a depth of 0–15 cm (surface) and 15–30 cm (subsurface) from the spent oil contaminated site and the adjacent

uncontaminated site, which are approximately 800 m and 1600 m apart, at the Ladipo and Berger locations, respectively. At both locations, the spent oil contaminated sites were officially designated locations for the sale of spare parts and the repair/servicing of automobile vehicles. The soils were black, rich in spent oil and contained tiny remnants of spare parts and broken glass. The uncontaminated site at the Ladipo location was a weed-covered area located near a canal, while that at the Berger location was bare soil near a residential area.

At each study location, three experimental plots (replicates) were selected along an established transect for the contaminated and uncontaminated (control) sites and sampled for this study, with the replicate plots approximately 300 m apart. At each depth within each replicated plot along an established transect for both contaminated and uncontaminated sites, three auger samples were collected resulting in three sampling points per soil depth and nine samples per experimental plot. The three auger samples were pooled to obtain a composite sample for each depth and replicated plot in each site (contaminated and uncontaminated) at each location. A total of twenty-four (24) bulk and twenty-four (24) core samples (two locations, two sites, two sampling depths, and three replicates) were collected for this study. The collected soil samples were labelled and transported in black polyethylene bags to the Soil Science Undergraduate Laboratory, Department of Soil Science, University of Nigeria, Nsukka for analysis.

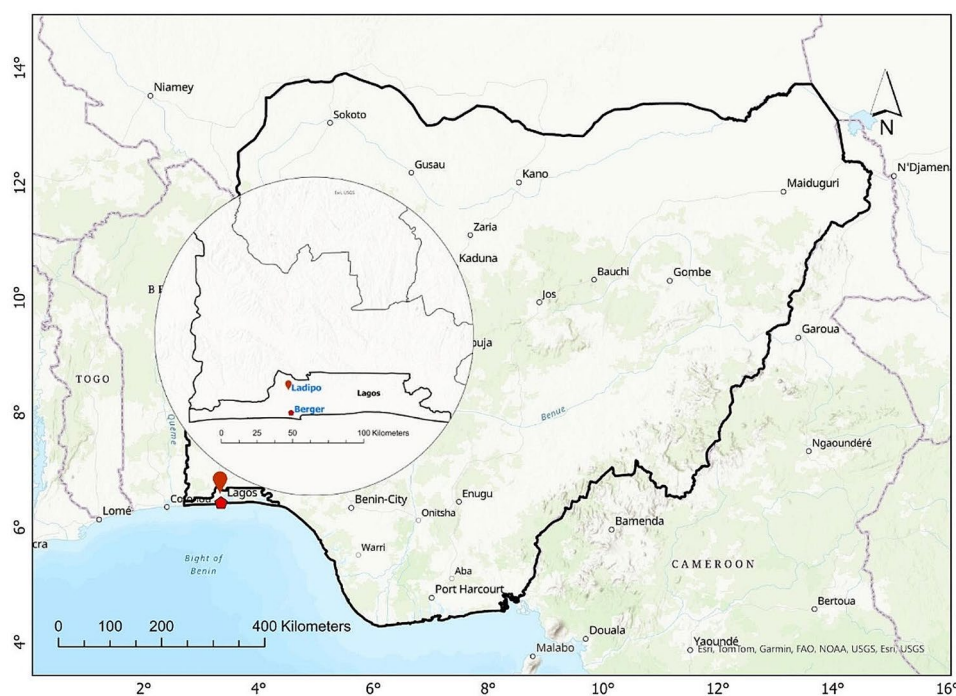


Fig. 1 Map of the study area indicating the study locations

Soil physical properties

The particle size distribution was determined using the hydrometer method (Gee and Bauder 1986 and sodium hexametaphosphate as the chemical dispersant. Soil core samples were used to determine saturated hydraulic conductivity (Ksat) using the constant pressure head method (Klute and Dirksen 1986) and also to determine soil bulk density (BD) as described by Blake and Hartage (1986). Total porosity (TP) was calculated as a function of the total volume not occupied by soil solids assuming a particle density of 2.65 Mg m^{-3} according to Danielson and Sutherland (1986).

Soil chemical properties

The soil pH was determined using a pH meter at a ratio of 1:2.5 soil/distilled water and soil/0.1 N KCl solution. Soil organic carbon (OC) was determined using the Walkley and Black wet oxidation method described by Nelson and Sommers (1983). Total nitrogen was determined using the micro-Kjeldhal distillation method (Bremner 1996), while available P was determined using the Bray-II method. The titration method with 1KCl extract was used to determine exchangeable H^+ and Al^{3+} (McLean 1982), while exchangeable Ca^{2+} , Mg^{2+} , Na^+ and K^+ were measured in 1 N NH_4OAc pH 7 (Thomas 1983). The concentrations of heavy metals Zn, Pb and Cu were determined by a selective extraction procedure in 1 N NH_4OAc pH 4.8 (Minkina et al. 2018. Briefly, 5.0 g of finely ground soil sample was leached with 1 N NH_4OAc pH 4.8 to 100 ml volume. Then, 10 ml of the aliquot was pipetted into a conical flask and 10 ml of ammonium hydroxide buffer, 25 ml of deionized water and 2 ml of 12% hydroxylamine hydrochloride were added and shaken continuously for 3 min. The concentrations of the heavy metals in the extracted solution were measured

using a UV/VIS spectrophotometer Single Beam VT-LI-295 model (wavelength range, 190–1000 nm).

Statistical analysis

The $2 \times 2 \times 2$ factorial experiment consists of Factor A, which are the two locations (Ladipo and Berger); Factor B consists of the spent oil contaminated site and the uncontaminated (control) site, and factor C comprises the two soil depths (0–15 and 15–30 cm). The heavy metal data were considered as a 2×2 factorial comprising the location and soil depth factors. The collected data on soil parameters were analyzed using Analysis of Variance (ANOVA) in GenStat (11th edition) for PC/Windows. Separation of means was carried out using the least significant differences (LSD) of means with 5% probability. Principal component analysis (PCA) was used to assess potential sources of variations in the study and was performed using R software (Version 4.0.5).

Result and discussion

Physical properties of the soils in the study locations

The particle size distribution of the soils at the study locations, study sites and soil depths did not vary appreciably except for the silt content (Table 1). At the Ladipo and Berger locations, the sand content dominated with mean values of 83.21 and 76.96%, respectively, while the silt (6.36) and clay (10.59%) contents were the lowest. The high sand content could be related to the parent material (sedimentary rock) of the soils. Accordingly, the Ladipo and Berger soils have a coarse and moderately coarse texture, respectively. The slight difference could be due to the different silt content ($\text{CV}=51.74\%$). As such, the textural class of the soils was loamy sand at Ladipo and sandy loam at Berger, and these remained consistent in the contaminated and uncontaminated sites and across

Table 1 Particle size distribution and textural classification of the topsoil layers at Ladipo and Berger locations

Location/Study site	Soil depth cm	Sand		Silt	Clay	Textural class
			%			
Ladipo						
Control soil	0–15	81.28	7.61	11.02		Loamy sand
	15–30	80.98	7.94	11.06		Loamy sand
Contaminated soil	0–15	84.98	5.28	9.76		Loamy sand
	15–30	85.68	4.61	9.76		Loamy sand
	Mean	83.21	6.36	10.43		
Berger						
Control soil	0–15	78.28	11.98	9.76		Sandy loam
	15–30	78.96	11.28	9.76		Sandy loam
Contaminated soil	0–15	77.68	11.28	11.02		Sandy loam
	15–30	72.98	15.28	11.76		Sandy loam
	Mean	76.96	12.45	10.59		
CV (%)		6.94	51.74	12.31		

CV - Coefficient of variation

soil depths. Obi (2000) stated that texture is a ‘permanent property’ of the soil.

Table 2 shows some physical properties of the studied sites at different soil depths of the two locations. The bulk density, hydraulic conductivity and total porosity of the soils at Ladipo and Berger locations ranged from 1.38 to 1.70 g cm⁻³, 20.40 to 34.43 cm hr⁻¹, and 35.97 to 47.92%, respectively. These ideal bulk density values are typical for loamy sand and sandy loam soils (NRCS 2001). The bulk density was significantly higher in the control site (1.57 g cm⁻³) than in the spent oil contaminated site (1.42 g cm⁻³), while the opposite was found for the total porosity of the soils (control, 40.72%; contaminated site, 46.44%). Kayode et al. (2009), Udebuani et al. (2011) and Nwite and Alu (2015) reported significant changes in bulk density, total porosity, and hydraulic conductivity of soils polluted with spent oil. Soil texture is closely related to nutrient storage, water retention and infiltration, porosity, etc. The lower bulk density and moderately porous condition of the soils are an indication of good drainage and rapid permeability of liquids from the topsoil to the subsoil.

Table 2 Some physical properties of the topsoil layers at Ladipo and Berger locations

Location	Study site	Soil depth cm	Bulk density g cm ⁻³	Ksat cm hr ⁻¹	Total porosity %
Ladipo	Control	0–15	1.61	30.57	39.24
		15–30	1.48	22.87	44.27
		Mean	1.54	26.72	41.76
	Contaminated	0–15	1.43	27.93	46.16
		15–30	1.47	26.50	44.65
		Mean	1.45	27.22	45.40
Grand mean	1.50	26.97	43.58		
Berger	Control	0–15	1.70	34.43	35.97
		15–30	1.50	29.00	43.39
		Mean	1.60	31.72	39.68
	Contaminated	0–15	1.40	20.40	47.04
		15–30	1.38	28.40	47.92
		Mean	1.39	24.40	47.48
Grand mean	1.50	28.06	43.58		
LSD _{0.05} Location		NS	NS	NS	
LSD _{0.05} Study site		0.12	NS	4.41	
LSD _{0.05} Soil depth		NS	NS	NS	
LSD _{0.05} Location x Study site		NS	NS	NS	
LSD _{0.05} Location x Soil depth		NS	NS	NS	
LSD _{0.05} Site x Soil depth		NS	NS	NS	
LSD _{0.05} Location x Study site x Soil depth		NS	NS	NS	

K_{sat} - Saturated hydraulic conductivity, LSD_{0.05} - least significant difference at 5% probability level, NS - not significant

Chemical properties of the soils in the study locations

In general, most of the chemical properties considered in the study showed differences between the study sites, while location-related differences and the interaction between study site × soil depth only affected soil pH and total N, respectively (Table 3). However, there was no statistical differences in soil chemical properties between the two soil depths, between location × soil depth, and the location × study site × soil depth interaction. The pH values of the study sites ranged from 7.33 to 9.10 in water and from 6.13 to 8.10 in KCl (Table 3) and were significantly higher at Ladipo than at the Berger location. The pH_{KCl} was also higher in the control sites than in the contaminated sites at both locations. Accordingly, the pH of the study sites at the Ladipo location was moderately to strongly alkaline (8.40, 9.05) while the study sites at the Berger location were slightly to moderately alkaline (7.43, 8.07). The lower pH of the contaminated soils, as also reported by Vwioko et al. (2006); Kayode et al. (2009) and Ugoh and Moneke (2011) could be due to the deposition of spent oil containing larger amounts of aromatic and aliphatic hydrocarbons. While the control soil (pH 8.56) can support the growth of alkali-tolerant crops, the contaminated soil (pH 7.92) can influence the availability of soil nutrients for plant uptake (Marschner 1995). The satisfactory pH range of 5.50 -7.00 is considered optimal for most crops (Rodrighero et al. 2015).

The OC content in the contaminated soil (21.79%) was significantly higher than in the control (1.08%). The high OC content in the spent oil contaminated soils, as also reported by Okonokhua et al. (2007), Kayode et al. (2009) and Udebuani et al. (2011), could be related to the hydrocarbon content of the crude oil from which lubricating oil was produced (Selley 1998). Wang et al. (2000) showed that spent lubricating oil is the main source of one hundred and eighty aromatic compounds, and ninety-nine polycyclic aromatic hydrocarbons (PAHs), including the comparatively toxic 5-ring PAHs. The total N content of the studied soils was low (between 0.03 and 0.08%) and differed statistically between the study sites. The lower N value in the contaminated site (0.04) compared to the control site (0.06) agrees with the findings of Gbaruko and Uhegbu (2005) and Kayode et al. (2009), but contradicts the reported increase in soil N due to the application of spent oil (Okonokhua et al. 2007). Accordingly, the 147.38% increase in the C: N of the contaminated soil (552.97) compared to the control (19.37) indicates impaired organic matter decomposition by incapacitated soil microorganisms due to the oxidative stress and the inhibitory potential of petroleum hydrocarbon at high concentrations (Abioye et al. 2012).

The average available P content in the spent oil contaminated soils and control soils was 14.15 and 53.78 mg kg⁻¹ at the Ladipo location and 18.81 and 39.17 mg kg⁻¹

Table 3 Effect of spent oil disposal on the chemical properties of topsoil layers at Ladipo and Berger locations

Location	Study site	Soil depth cm	pH (H ₂ O)	pH (KCl)	OC g kg ⁻¹	TN %	Avail. P mg kg ⁻¹	Ca ²⁺ cmol kg ⁻¹	Mg ²⁺ cmol kg ⁻¹	Na ⁺	K ⁺	H ⁺
Ladipo	Control	0–15	9.10	7.93	1.08	0.05	49.43	6.53	0.80	0.04	0.08	8.00
		15–30	9.00	8.10	1.21	0.05	58.14	6.33	1.47	0.05	0.10	7.00
		Mean	9.05	8.02	1.15	0.05	53.78	6.43	1.13	0.05	0.09	7.50
	Contaminated	0–15	8.43	7.00	22.23	0.04	8.39	3.20	0.87	0.74	0.87	10.00
		15–30	8.37	7.53	27.03	0.05	19.90	4.33	1.13	0.91	0.99	10.00
		Mean	8.40	7.27	24.63	0.05	14.15	3.77	1.00	0.82	0.93	10.00
	Grand mean	8.56	7.64	12.89	0.05	33.96	5.10	1.07	0.43	0.51	8.75	
Berger	Control	0–15	8.13	6.83	1.26	0.08	40.41	1.60	0.33	0.04	0.09	9.00
		15–30	8.00	6.13	0.76	0.05	37.93	1.93	1.00	0.03	0.08	11.67
		Mean	8.07	6.48	1.01	0.07	39.17	1.77	0.67	0.04	0.09	10.33
	Contaminated	0–15	7.53	6.93	17.68	0.03	18.03	4.60	0.73	0.59	0.66	8.33
		15–30	7.33	6.77	20.21	0.05	19.58	4.13	1.07	0.65	0.73	12.67
		Mean	7.43	6.85	18.95	0.04	18.81	4.37	0.90	0.62	0.69	10.50
	Grand mean	7.92	6.67	9.98	0.05	28.99	3.07	0.78	0.33	0.39	10.42	
LSD _{0.05}	Location		0.26	0.52	NS	NS	NS	NS	NS	NS	NS	NS
LSD _{0.05}	Study site		0.26	NS	5.40	0.01	9.31	NS	NS	0.18	NS	NS
LSD _{0.05}	Soil depth		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD _{0.05}	Location x Study site		NS	0.73	NS	NS	13.17	1.59	NS	NS	NS	NS
LSD _{0.05}	Location x Soil depth		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
LSD _{0.05}	Study site x Soil depth		NS	NS	NS	0.02	NS	NS	NS	NS	NS	NS
LSD _{0.05}	Location x Study site x Soil depth		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

OC - Organic carbon, TN - Total nitrogen, Avail. P - Available phosphorus, Ca²⁺, Mg²⁺, Na⁺, K⁺ and H⁺ - exchangeable calcium, magnesium, sodium, potassium, and hydrogen, LSD_{0.05} - Least significant difference at 5% probability level, NS - not significant

at the Berger location, respectively. These P values were moderately high in the control soils but low in the contaminated soils. Statistically, the available P content in the control soils was significantly higher than in the spent oil contaminated soils and reduced by more than 300% and 100% in the spent oil contaminated soils at the Ladipo and Berger locations, respectively. This indicates a negative impact of spent oil disposal on available P in the soil and confirms the reports of Okonokhua et al. (2007), Kayode et al. (2009) and Udebuani et al. (2011). The low range of available P in the contaminated soils may be due to conversion to fixed P either by P-sorption and/or P precipitation, suggesting that spent oil contaminants have a large P-fixation capacity in the soils studied.

The concentrations of exchangeable cations were very low at both locations, study sites and soil depths. The differences in the concentrations of exchangeable Mg and H were not significant, but statistical variations were found in the concentrations of exchangeable Na and K between the study sites. The contaminated site had higher concentrations of Na⁺ and K⁺ than the control site. The Ca²⁺ content was significantly higher in the control than in the contaminated counterpart at the Ladipo location, while the opposite was true at the Berger location. These differences in Ca²⁺ content in the two study sites and at the two locations could be due to the different composition of the disposed spent oil. Okonokhua et al. (2007) found an increase in Mg content, while Kayode et al. (2009) and Nwite and Alu (2015) reported a decrease in exchangeable bases (Ca, Mg, Na and K) in soils contaminated with spent oil. Overall, the similarity in exchangeable cation content between the two soil depths of the control soils suggests that the 30 cm depth, which corresponds to the depth of the tillage layer for most arable crops, contains little nutrient reserves to support food production.

Table 4 Effect of spent oil disposal on heavy metal concentrations in the topsoil layers at Ladipo and Berger locations

Location	Soil depth cm	Lead	Copper	Zinc
		mg kg ⁻¹		
Ladipo	0–15	0.11	6.55	0.23
	15–30	0.06	6.70	0.21
	Mean	0.09	6.62	0.22
Berger	0–15	0.05	3.88	0.32
	15–30	0.03	4.63	0.34
	Mean	0.04	4.25	0.33
LSD _{0.05} Location		NS	NS	NS
LSD _{0.05} Soil depth		NS	NS	NS
LSD _{0.05} Location x Soil depth		NS	NS	NS

LSD_{0.05} - Least significant difference at 5% probability level, NS - not significant

Heavy metal concentration in the study soils

The individual and interactive effect of location and soil depth on heavy metals showed that the concentrations of Zn, Pb and Cu were statistically similar (Table 4). The concentrations of Zn and Pb are low, ranging from 0.21 to 0.34 mg kg⁻¹ and 0.03 to 0.16 mg kg⁻¹, respectively, across all locations and soil depths. A higher value of 4.11 mg kg⁻¹ Zn concentration in spent crude oil polluted soil was reported by Ikhajiagbe and Ogwu (2020). The level of Zn in soil is influenced by soil texture, with sandy soils containing less Zn than clay soils (FAO 2022). According to the permissible limits for heavy metals in soils (MEF 2007; UNEP 2013), the Zn and Pb concentrations in the studied soils do not pose any ecological or health risks, indicating that the spent oil contamination does not contribute to the accumulation of these heavy metals in the soil. The Pb concentration, which is below the reported Geo-accumulation index of 0.98 mg kg⁻¹ (Ahmad et al. 2021), confirms this assertion. Nonetheless, Pb is an extremely toxic heavy metal that, even at low concentrations, affects various plant physiological processes such as photosynthetic rate, germination rate, yield, nutrient uptake, C metabolism and enzymes activities (Rani et al. 2024).

Copper concentrations varied between 6.55 and 6.70 mg kg⁻¹ at the Ladipo and between 3.88 and 4.63 mg kg⁻¹ at the Berger, indicating a high Cu concentration (Lindsay and Norvell 1978; FAO 1979). Okonokhua et al. (2007) reported Cu values between 4.80 and 12.10 ppm in sandy soils contaminated by spent engine oil with a concentration of 1.3 mg l⁻¹ Cu. Given the Geo-accumulation index of 1.00 and a contamination factor of 3.02 mg kg⁻¹ for Cu (Ahmad et al. 2021), our results show that spent oil contributes significantly to Cu retention in the top 30 cm soil depth. The high Cu concentration could be related to the Cu composition of the dumped spent oil (not determined), the long deposition time and the lower mobility of Cu in the soils. The positively charged Cu ions are electrostatically attracted and firmly bound to the soil surfaces and colloidal particles by sorption forces or chelation mechanism (Yong 2000; Okonokhua et al. 2007). This implies that continued dumping of spent oil into the soil carries a higher risk of accumulating to harmful concentrations as Cu is less mobile (FAO 2022). Given the low water table and poor surface drainage systems in the coastal lowlands in Lagos, an increased risk of groundwater contamination is also to be expected.

Although Cu is an essential micro-element, it becomes toxic at high concentrations, and exposure to excess Cu increases the risk of Cu toxicity (Copperiedus). Some exposure media for Cu toxicity in humans are commonly through inhalation, consumption of food and drinking water, and dermal contact with air, water, and soil (Anant et al. 2018). According to Royer and Sharman (2020),

ingestion of >1 g of copper sulfate results in symptoms of Cu toxicity. This suggests that auto-repair workers, patronizing customers and visitors, including surrounding residential areas and farms, are predisposed to the adverse effects of excess Cu through direct exposure to contaminated soil and indirectly through entry into water and the food chain due to leaching, flooding erosion, runoff and uptake by plants. An overview of the potential toxic role of Cu in soil-plant-human systems has been documented (Shabbir et al. 2020).

It is necessary to highlight the health risk associated with exposure to excess Cu. Excess Cu leads to DNA damage and decreased cell proliferation (Royer and Sharma 2020), and simultaneous ingestion of large amounts of Cu at once has been associated with severe vomiting, abdominal pain, and purging, followed by headache and, in fatal cases, convulsions or paralysis before death (Ashish et al. 2013). Other health risks associated with Cu toxicity that are of public health concern include acne, alopecia, anemia, anxiety, arthritis, autism, *Candida albicans* infections, cystic fibrosis, depression, diabetes,

dental decay, fractures, headaches and migraines, heart attacks, hypothyroidism, urinary tract infections, decreased libido, kidney disorders, and increased risk of cancer (Ananat et al., 2018). It is important that responsible spent oil disposal management and practices are enforced to avoid negative impacts on ecosystems and human health.

Principal component analysis

Principal component analysis was used to explain the relationship between the measured heavy metals and the soil physico-chemical properties at both locations (Fig. 2) and soil depths (Fig. 3). The PCA explained the variability of the measured parameters using two main factors (Figs. 2 and 3). Across both locations, the factors explained 50.50% of the total variance. It is noteworthy that factor 1 (30.10% explained variance) was dominated by high values of bulk density, sand fraction, OM, Ksat and pH, which correlated positively with Pb and Cu at the Ladipo location. The Berger location was characterized by high factor loadings of Ca, TP, and clay and silt

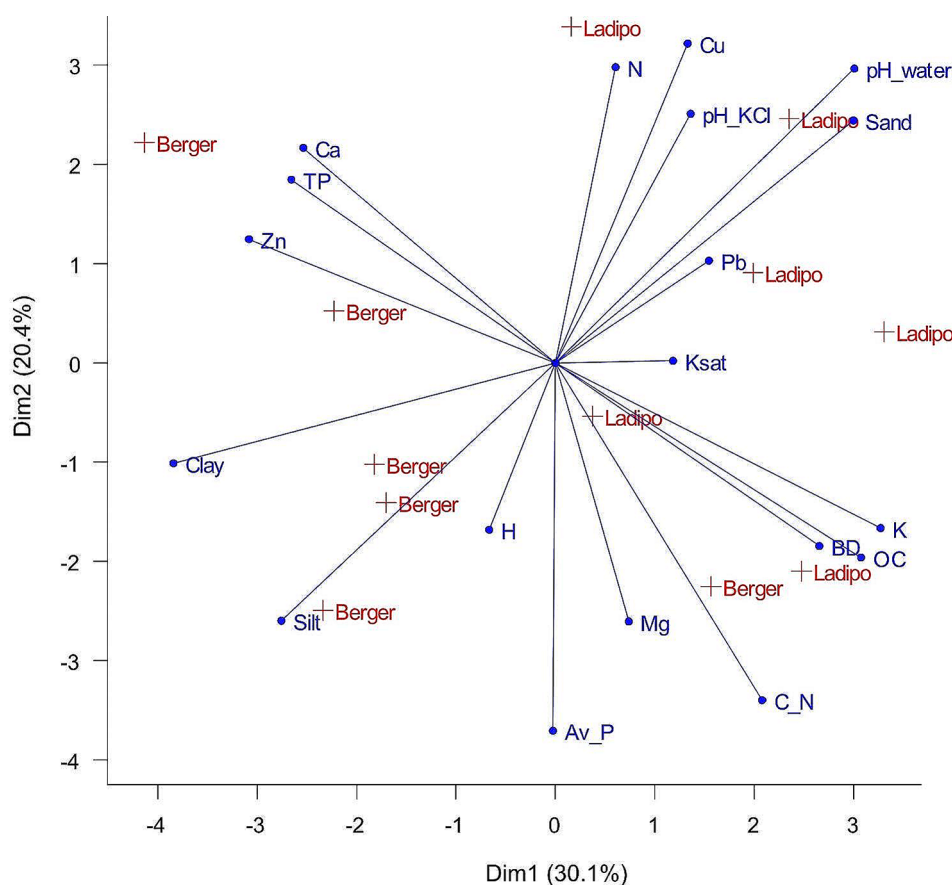


Fig. 2 Principal component analysis biplot of the intercorrelation between the physiochemical properties of the soils and heavy metal concentrations at the study locations (Berger and Ladipo). Where BD=bulk density; TP=total porosity; Ksat=saturated hydraulic conductivity; pH_KCl=pH (KCl); pH_water=pH (H₂O); OC=organic carbon; N=nitrogen; C_N=carbon-nitrogen ratio; Av_P=available phosphorus; Ca, Mg, K and H=exchangeable calcium, magnesium, potassium and hydrogen, respectively; Z=zinc; Pb=lead; Cu=copper

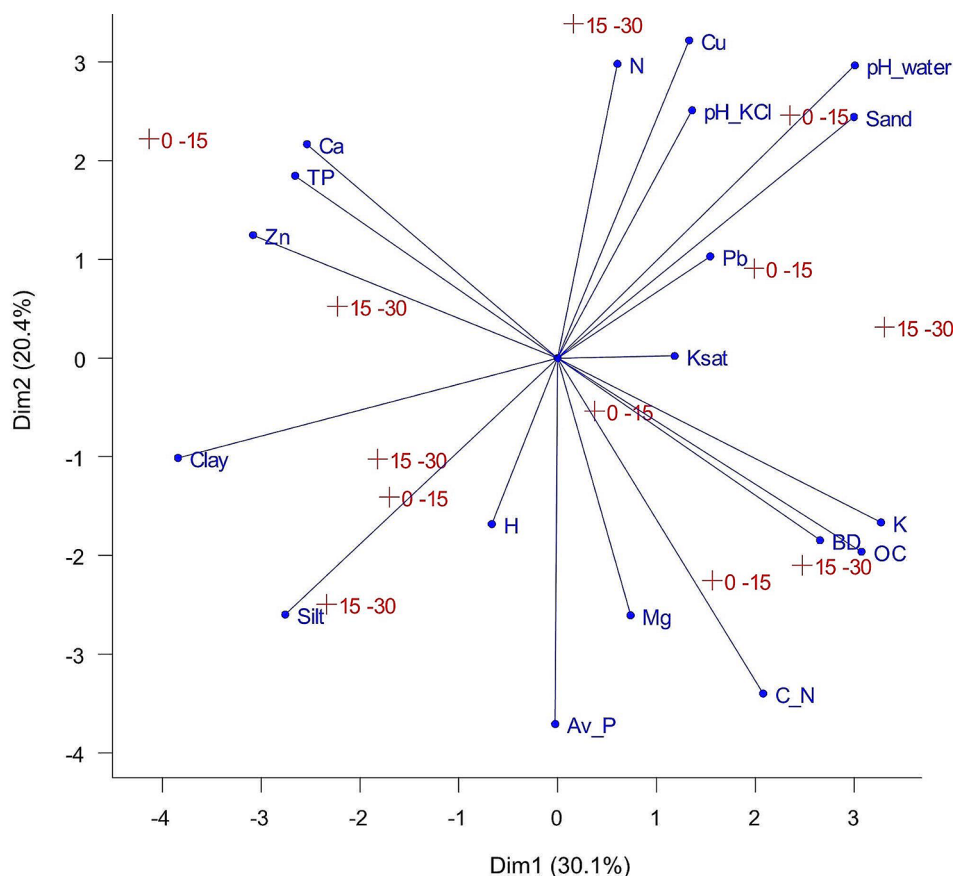


Fig. 3 Principal component analysis biplot of the intercorrelation between the physiochemical properties of the soils and heavy metal concentrations at 0–15 and 15–30 cm soil depths. Where BD=bulk density; TP=total porosity; Ksat=saturated hydraulic conductivity; pH_KCl=pH (KCl); pH_water=pH (H₂O); OC=organic carbon; N=nitrogen; C_N=carbon-nitrogen ratio; Av_P=available phosphorus; Ca, Mg, K and H=exchangeable calcium, magnesium, potassium and hydrogen, respectively; Z=zinc; Pb=lead; Cu=copper

contents, which correlated positively with Zn concentration, as shown in factor 2 (with 20.40% explained variance) (Fig. 2). Organic matter is an important factor that decreases or increases the mobility of metals through the formation of organic–metallic complexes (Batjargal et al. 2010) and could be responsible for the high Cu concentration. Soil pH and sand content were strongly correlated with Pb and Cu at the Ladipo location, while clay and silt contents were strongly correlated with Zn at the Berger location. Zinc concentration in the soil is influenced by soil texture, with sandy soils containing less Zn than clay soils (FAO 2022). Plausible reason for the differences among locations could be attributed to the different geographical locations of the automobile spare parts markets.

Across soil depths, pH (KCl), pH (H₂O) and sand content modulated the high values of Pb and Cu in the top-soil (0–15 cm) in factor 1 with 30.10% explained variance (Fig. 3). In Factor 2 (with 20.40% explained variance), a similar distribution of silt and clay contents could not account for any significant variation in the distribution of Zn concentration in both surface (0–15 cm) and

subsurface (15–30 cm) soil (Fig. 3). High OC, BD, Na⁺ and K⁺ values were found in the surface soils, while high C: N, TP and K⁺ values dominated the subsurface soils. The results showed that the concentrations of the studied heavy metals and the physico-chemical properties of the soils varied with locations and soil depths. The high concentrations of heavy metals Pb and Cu in the surface soils can be attributed to the type of waste deposited. This is consistent with the findings of Okolo et al. (2015) and Aja et al. (2021) at Abakiliki mechanic village and municipal dumpsites respectively, and Zhao et al. (2022) in anthropogenic-related activities in China.

Implication of spent oil contamination on food safety and environmental management

Heavy metal contamination, even at trace amount, poses a serious environmental and health concern as these metals find their way into the surrounding agricultural soil and accumulate in the ecosystem over a long period of time. In view of this, food safety issues and potential health risks arising from public exposure through the consumption of potentially contaminated vegetables are

a major concern (Gebeyehu and Bayissa 2020; Zhao et al. 2022). The soils around the vicinity of the auto parts market could be used for agricultural purposes, provided that the necessary ecotoxicological risk assessments are carried out. In addition, sustainable land reclamation measures can be employed before the commencement of any agricultural activity in such and similar areas. Although the concentration of heavy metals found at these sites does not currently pose an immediate threat to the environment, continuous and regular monitoring of the contaminated sites can be adopted to prevent rapid and unexpected mobilization that could lead to serious environmental and health problems. Considering the current global population growth and high production and use of motor vehicles, the results of our study suggest that accumulation of heavy metal in the soil and heavy metal environmental pollution may occur in different regions of the world where similar spent oil disposal is practised. This study emphasises the need for other regions to assess heavy metal concentrations in soils around spent oil disposal sites and urgently implement a responsible disposal plan to take proactive measures to protect the ecosystem from the harmful effects of irresponsible spent oil disposal.

Conclusion

The soil texture at the Ladipo and Berger locations was loamy sand and sandy loam, respectively. The control site exhibited favorable soil properties at both locations with lower bulk density, moderate porosity, moderate to strong alkalinity, moderate available P, but low OC and exchangeable cations. Spent oil contamination altered the soil physiochemical properties, including bulk density, total porosity, soil pH, OC, total N, C:N, available P, Ca^{2+} , Na^+ and K^+ concentrations. However, the negative effects of spent oil contamination on soil pH, C:N, available P and Ca^{2+} reduce the fertility and health of the soils studied. The concentrations of the heavy metals Pb, Zn and Cu in the contaminated topsoil (0–30 cm) of both locations were within the safe range. Nevertheless, high Cu accumulation due to spent oil contamination can affect soil quality and lead to health problems in humans when exposed to excess Cu in the environment. The assessment of the potential risk of Cu to the environment and human health is outside the structured scope of our quantitative research, which focused specifically on heavy metal concentrations in spent oil contaminated soils. This limitation would therefore need to be considered in future studies. Despite limitations, the disposal of spent oil in the soil poses a potential ecological risk and therefore requires responsible disposal given the low groundwater table and poor surface drainage systems of the coastal lowlands in Lagos State, Nigeria. This study highlights the need for proactive measures to protect the

urban environment and the population through periodic monitoring of contaminated sites. Therefore, the Environmental Protection Agency of Lagos State Government should ensure strict enforcement of regulations on the discharge and disposal of spent oil in auto parts markets to prevent indiscriminate pollution of the ecosystem.

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Author contributions

CBO conceptualized, analyzed and interpreted the data, including writing the article for intellectual content. CLO conducted the research (investigation, data acquisition and interpretation). CMJ administered the research. CCO performed the final review of the manuscript, contributed in data interpretation and was a major contributor in writing the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethic approval and consent to participate

Not applicable.

Consent for publication

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Competing interests

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