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Research Article

Auto-Mechanic Workshops as Urban Soil Pollution Hotspots: Physicochemical Alteration and Metal Enrichment in Kano Metropolis, Nigeria

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ABSTRACT

Soil contamination from informal auto-mechanic workshop activities is an emerging urban environmental concern, as spent engine oil, lubricants, fuel residues, and metal-bearing wastes can alter soil physicochemical conditions and increase contaminant mobility, groundwater vulnerability, and human-exposure risks. This study assessed the physicochemical properties of hydrocarbon-impacted soils from selected auto-mechanic workshops in Kano Metropolis, Nigeria, and compared them with an uncontaminated control soil to evaluate workshop-related soil-quality alteration, nutrient imbalance, and metal enrichment. Soil samples were collected from three auto-mechanic workshops and one non-oil-contaminated control site. Particle-size distribution, pH, nitrogen, exchangeable cations, and exchangeable acidity were determined using conventional soil analytical procedures, while effective cation exchange capacity was calculated from exchangeable cations and exchangeable acidity. Electrical conductivity, organic carbon, and phosphorus were predicted from near-infrared spectra using the established CDA soil spectral library, whereas Zn, Mn, and Fe were quantified following microwave digestion using MP-AES. One-way analysis of variance was used to test significant differences among sampling locations at $p \leq 0.05$, while Tukey's pairwise comparison test was used for mean separation. The workshop soils differed clearly from the control soil. They were slightly more acidic, with pH values of 5.77–5.89 compared with 6.01 in the control. Electrical conductivity and organic carbon were higher in the workshop soils, ranging from 89.40 to 101.16 µS/cm and 1.21 to 1.23%, respectively, compared with 34.00 µS/cm and 0.38% in the control. In contrast, nitrogen, phosphorus, and potassium were lower in the workshop soils. The acid-digestible (pseudo-total) concentrations of Zn, Mn, and Fe were also substantially higher in the workshop soils than in the control. The findings indicate that the sampled auto-mechanic workshop soils were characterized by chemical alteration, nutrient depletion, and relative metal enrichment compared with the control soil. The study provides site-specific baseline evidence supporting routine soil monitoring, proper waste-oil management, and improved environmental control of automobile-workshop activities.

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1.0 INTRODUCTION

Soil contamination in rapidly expanding urban areas has become an important environmental and public-health concern, particularly where informal industrial and service activities operate without adequate waste-control systems (Adewumi & Ogundele, 2024; Çayır et al., 2025; Duru et al., 2024). Auto-mechanic workshops are among the common urban pollution hotspots in many Nigerian cities because their daily activities involve vehicle servicing, oil changing, engine repairs, battery handling, painting, welding, and disposal of worn-out vehicle parts. These activities often release spent engine oil, lubricants, fuel residues, grease, brake fluids, solvents, battery wastes, and metal-bearing particles directly into the surrounding soil environment (Duru et al., 2024; Owamah et al., 2023).

The environmental importance of these workshop-derived wastes lies not only in their visible accumulation on the soil surface, but also in their capacity to alter soil conditions and influence contaminant behaviour over time (Okebalama et al., 2024). Spent engine oil and related petroleum residues are complex mixtures of degraded hydrocarbons, polycyclic aromatic hydrocarbons, additives, and trace metals; once introduced into the soil, these contaminants can modify key physicochemical properties such as pH, electrical conductivity, organic carbon, nutrient status, exchangeable acidity, and effective cation exchange capacity (Bahar et al., 2024; Kamranifar et al., 2025). Such properties determine whether contaminants are retained in the soil, transported by runoff, leached toward groundwater, or made available for microbial and biological interaction; therefore, physicochemical assessment provides more than a basic description of soil quality; it offers early evidence of how auto-mechanic activities may affect contaminant persistence, mobility, soil fertility, and broader environmental vulnerability (Adeniran et al., 2023; Nyarko et al., 2019).

Beyond soil-quality alteration, workshop-derived contaminants also raise wider hydrological and human-exposure concerns. In permeable urban soils, rainfall, surface runoff, infiltration, and soil-water movement can redistribute petroleum residues and metal-bearing particles from workshop surfaces into nearby drainage channels, surface waters, and shallow groundwater systems, particularly where waste oil is discharged on bare ground without containment infrastructure (Adeniran et al., 2023; Wu et al., 2024). This pathway is important in densely used urban settings because mechanics, residents, traders, and passers-by may be exposed to contaminated soil and dust through dermal contact, incidental ingestion, and inhalation of contaminated particulates, while indirect exposure may occur through impacted water sources or food-chain transfer (Correia & Rasteiro, 2025; Kicińska & Wikar, 2024; Shetty et al., 2024). Thus, auto-mechanic workshop soils should not be viewed only as localized degraded soils, but as potential environmental-health interfaces requiring routine monitoring and proper waste-oil management (Petruzzelli et al., 2025).

The relevance of this problem is particularly evident in Kano Metropolis, where auto-mechanic workshops operate within active urban, commercial, and residential environments. Recent evidence from Kofar Ruwa Automobile Mechanic Village confirms that mechanic-related activities in Kano can introduce mixed hydrocarbon pollutants and heavy metals into soils, with implications for soil quality, groundwater safety, and public health (Iya et al., 2026). However, the environmental behaviour of these contaminants cannot be fully understood from hydrocarbon or metal concentrations alone, because soil physicochemical conditions strongly influence contaminant retention, mobility, nutrient availability, and exposure potential. This creates the need for site-specific assessment of physicochemical soil properties in auto-mechanic workshop environments across Kano Metropolis. Therefore, this study assessed the physicochemical properties of hydrocarbon-impacted soils from selected auto-mechanic workshops in Kano Metropolis and compared them with a control soil sample, with the aim of generating baseline evidence for the support of urban pollution monitoring, groundwater-vulnerability awareness, human-exposure prevention, and proper waste-oil management.

2.0 MATERIALS AND METHODS

2.1 Study area and sampling

The study was conducted in Kano Metropolis, northwestern Nigeria. Soil samples were collected from three long-term auto-mechanic workshops with visible hydrocarbon contamination and one control site. The workshop sites were designated as Workshop A (11°57′50″N, 8°25′55″E), Workshop B (11°58′17″N, 8°26′43″E), and Workshop C (11°59′21″N, 8°29′06″E). The control site (11°57′40.1″N, 8°22′01.8″E) was a farmland with no history of industrial or vehicular activity and was located approximately 7 km from the nearest workshop.

2.2 Sample collection and preparation

At each sampling site, two independent composite surface-soil samples were collected from a depth of 0–30 cm. Each composite sample was prepared independently from five spatially distributed subsamples collected using a grid/zig-zag sampling pattern to account for within-site spatial heterogeneity. Thus, a total of ten field subsampling points were sampled per site, arranged as two independent sets of five subsamples. The five subsamples constituting each composite were thoroughly mixed and homogenized, and the resulting composite sample was placed in a separate sterile polyethylene bag. Accordingly, two independently collected composite samples were obtained from each of the three auto-mechanic workshops and the control site, giving two independent field replicates per site (n = 2) and a total of eight composite samples. All samples were transported to the laboratory (Centre for Dryland Agriculture (CDA), Bayero University, Kano), air-dried at room temperature, gently crushed, homogenized, and passed through a 2-mm sieve to remove stones and other debris before analysis (Kok et al., 2024).

2.3 Soil Laboratory Analysis

Air-dried soil samples were gently crushed, homogenized and passed through a 2-mm sieve before analysis. Particle-size distribution was determined by the hydrometer sedimentation method, with sedimentation analysis of the fine-grained fraction consistent with the principles of ASTM D7928-17 (ASTM International, 2017). Soil pH was determined conventionally following the procedure described by Motsara and Roy, (2008), using a 1:1 soil-to-water ratio, while nitrogen was determined using the standard CDA procedure based on Motsara and Roy, (2008).

Electrical conductivity (EC), organic carbon (OC) and phosphorus (P) were predicted from near-infrared spectra using a NIRS D-2500 (Metrohm, Switzerland) and the established CDA soil spectral library. Instrument operation followed the manufacturer's instructions, while calibration and spectral prediction followed the CDA standard operating procedure using the machine spectral library. Each independent composite sample was scanned three times, and the replicate spectra were averaged to obtain a single analytical value before statistical analysis; therefore, the repeated scans were treated as technical rather than independent field replicates. Exchangeable Ca, Mg, K and Na were determined following Mehlich-3 extraction, whereas exchangeable acidity was determined by extraction with 1 N KCl followed by titration with 0.5 M NaOH. Effective cation exchange capacity (ECEC) was calculated as the sum of exchangeable Ca, Mg, K and Na and exchangeable acidity (EA), expressed as cmol(+)/kg. Zn, Mn and Fe were quantified as acid-digestible (pseudo-total) metal concentrations following microwave digestion and subsequent determination using an Agilent 4210 Microwave Plasma–Atomic Emission Spectrometer (MP-AES); these metals were therefore not NIRS-predicted measurements. The specific calibration equations and historical model-performance statistics associated with the CDA NIRS spectral library for the NIRS-predicted properties, including R^2, RMSEP and RPD, were not available to the authors and are therefore not reported.

2.4 Statistical Analysis

Data were analyzed using one-way analysis of variance (ANOVA) to test for significant differences among the workshop and control soils. Statistical significance was evaluated at $\alpha = 0.05$. Where significant differences were detected, Tukey's pairwise comparison test was used for mean separation. Results were reported using letter-based groupings, where means sharing the same superscript letter are not significantly different. Descriptive statistics were presented as mean ± standard deviation.

3.0 RESULTS AND DISCUSSION

3.1 Particle-size Distribution and Implications for Contaminant Behavior

The particle-size distribution differed markedly between the auto-mechanic workshop soils and the control soil (Table 1). The workshop soils contained 51.30–54.18% sand, 18.81–21.72% silt, and approximately 26.98–27.02% clay and were classified as sandy clay loam according to the USDA textural classification system. In contrast, the control soil contained 81.97% sand, 13.83% silt, and 4.21% clay and was classified as loamy sand**.** Thus, although sand constituted the largest particle-size fraction in all samples, the workshop soils contained substantially more clay and considerably less sand than the control soil.

The observed textural differences are environmentally relevant because soil particle-size composition influences infiltration, runoff, sorption, leaching, and contaminant retention (Angelaki et al., 2022). The relatively greater clay fraction of the workshop soils may provide more adsorption and exchange sites for the retention of cationic metals and other contaminants, whereas the much coarser, sandier control soil would generally provide fewer fine-particle sorption sites and may permit greater water movement through the soil profile. Clay-rich fractions can enhance contaminant retention through adsorption and ion-exchange processes, while coarser soil fractions may favour contaminant mobility under suitable hydrological conditions (Haghighizadeh et al., 2024). Accordingly, the higher clay content of the workshop soils may have contributed to the retention of some workshop-derived contaminants within the sampled soil matrix.

This textural distinction is also important when interpreting the broader environmental implications of the study. Auto-mechanic workshops are open or semi-open service environments in which waste oil, fuel residues, metal-bearing particles, and other automobile-derived wastes may be repeatedly deposited on exposed soil surfaces. Soil texture can therefore influence whether such contaminants remain near their point of deposition, become associated with fine soil particles, or are redistributed through runoff and subsurface water movement (Angelaki et al., 2022; Haghighizadeh et al., 2024). However, soil texture is an inherent site characteristic, and the present study does not establish that the observed differences in sand, silt, and clay contents were caused by workshop activities. The marked textural difference between the workshop and control soils should therefore be considered as an important site characteristic that may partly influence contaminant retention, mobility, and the observed physicochemical differences among the sampling locations.

Table 1: Particle-size distribution and textural class of workshop and control soils

Soil sample	Sand (%)	Silt (%)	Clay (%)	Soil texture
Workshop A	54.18 ± 0.02	18.81 ± 0.07	27.02 ± 0.05	Sandy clay loam
Workshop B	51.30 ± 0.07	21.72 ± 0.07	26.98 ± 0.14	Sandy clay loam
Workshop C	52.08 ± 0.07	20.92 ± 0.08	27.00 ± 0.01	Sandy clay loam
Control	81.97 ± 0.52	13.83 ± 0.47	4.21 ± 0.05	Loamy sand

Values are mean ± standard deviation of two independent composite samples per site (n = 2).

3.2 Soil Reaction, Electrical Conductivity, and Organic Carbon

The pH values of the workshop soils ranged from 5.77 to 5.89, while the control soil had a pH of 6.01 (Table 2). Although all samples were slightly acidic, the workshop soils were more acidic than the control soil. The differences among the workshop soils were not statistically significant, but the control soil differed significantly from the contaminated workshop soils. Soil pH is one of the most important regulators of contaminant behaviour because it affects metal solubility, nutrient availability, microbial activity, and the rate of organic pollutant transformation (Chakraborty et al., 2025). The slightly acidic condition observed in the workshop soils may be linked to the accumulation and degradation of petroleum-derived residues, oxidation of organic wastes, and long-term modification of soil chemical conditions by workshop activities. Acidic soil conditions can increase the mobility and bioavailability of some metals, thereby strengthening the need for routine monitoring of mechanic-workshop soils.

Electrical conductivity showed a clear difference between the workshop soils and the control. EC values ranged from 89.40 to 101.16 µS/cm in the workshop soils, compared with 34.00 µS/cm in the control soil. The higher EC values in the workshop soils indicate greater soluble-ion concentrations relative to the control and may reflect repeated inputs from automobile-service activities, including waste oil, lubricants, battery-related residues, corroded metal particles, and other automobile-derived wastes. Significant differences were also observed among the three workshop sites, indicating spatial variation in soil chemical conditions that may reflect differences in workshop activity intensity, waste-handling practices, and the duration or frequency of contaminant inputs.

Organic carbon was also higher in the workshop soils than in the control soil. The workshop soils recorded OC values of 1.21–1.23%, while the control soil had 0.38%. This enrichment may reflect the repeated accumulation of petroleum-derived organic residues, spent oil, lubricants, grease, and other carbon-containing wastes from vehicle servicing activities. However, the higher OC in the workshop soils should not be interpreted as evidence of improved soil quality, because it occurred alongside lower nitrogen, phosphorus, and potassium values compared with the control soil. This pattern suggests that the additional carbon was likely associated with hydrocarbon residues rather than stable, nutrient-supporting organic matter. Petroleum-derived residues can create hydrophobic soil conditions and restrict the availability of water, oxygen, and nutrients required for microbial activity and plant growth (Hoang et al., 2021; Koshlaf & S Ball, 2017).Therefore, the elevated OC observed in the workshop soils is better interpreted as an indicator of workshop-related organic contamination and altered nutrient cycling rather than improved soil fertility.

Table 2: Soil chemical properties and nutrient status of workshop and control soils

Soil sample	pH (1:1)	EC (µS/cm)	OC (%)	N (%)
Workshop A	5.81±0.00^{A}	95.32±0.08^{A}	1.23±0.04^{A}	0.09±0.00^{A}
Workshop B	5.77±0.07^{A}	101.16±0.02^{B}	1.21±0.02^{A}	0.09±0.00^{A}
Workshop C	5.89±0.09^{A}	89.40±0.02^{C}	1.23±0.02^{A}	0.09±0.00^{A}
Control	6.01±0.01^{B}	34.00±1.41^{D}	0.38±0.00^{B}	0.31±0.00^{B}

Means that do not share the same superscript letter are significantly different at p ≤ 0.05.

Table 2: (continued)

Soil sample	P (mg/kg)	K (cmol(+)/kg)	Ca (cmol(+)/kg)	Mg (cmol(+)/kg)
Workshop A	1.63±0.04^{A}	0.17±0.02^{A}	2.78±0.12^{A}	0.97±0.00^{A}
Workshop B	0.70±0.02^{B}	0.21±0.01^{A}	2.33±0.04^{BC}	0.97±0.00^{A}
Workshop C	1.64±0.03^{A}	0.19±0.00^{A}	2.69±0.00^{AB}	0.97±0.00^{A}
Control	14.05±0.00^{C}	0.47±0.02^{B}	2.20±0.13^{C}	1.07±0.10^{A}

Means that do not share the same superscript letter are significantly different at p ≤ 0.05.

3.3 Nutrient status and exchangeable cations

As shown in table 2, the nutrient results showed a clear contrast between the workshop soils and the control soil. Nitrogen was lower in all workshop soils, with a uniform value of 0.09%, compared with 0.31% in the control soil. Similarly, available phosphorus was much lower in the workshop soils, ranging from 0.70 to 1.64 mg/kg, compared with 14.05 mg/kg in the control soil. Potassium also followed the same pattern, with values of 0.17–0.21 cmol(+)/kg in the workshop soils compared with 0.47 cmol(+)/kg in the control soil. These differences suggest that workshop-related contamination may be associated with nutrient depletion or reduced nutrient availability.

The lower N, P, and K values in the workshop soils are environmentally important because these macronutrients are essential for soil productivity, microbial activity, and ecological functioning (Liu et al., 2024). Petroleum residues can create hydrophobic soil conditions, reduce aeration, alter microbial communities, and interfere with organic matter decomposition and nutrient cycling (Ambaye et al., 2022). In addition, contaminants may bind to soil particles or affect the biological processes that regulate nutrient release (Zhang et al., 2025; Zhao et al., 2022). Therefore, even though the workshop soils had higher organic carbon, their lower nutrient status indicates that the carbon enrichment was not necessarily agronomically beneficial.

Exchangeable calcium showed significant site-specific variation ($p = 0.008$). Workshop A recorded the highest Ca concentration (2.78 cmol(+)/kg), followed by Workshop C (2.69 cmol(+)/kg), Workshop B (2.33 cmol(+)/kg), and the control soil (2.20 cmol(+)/kg). Tukey's HSD test showed that Ca concentrations in Workshops A and C were significantly higher than in the control soil, whereas Workshop B did not differ significantly from the control. Magnesium, in contrast, did not differ significantly among the sampling locations ($p = 0.262$), with values ranging from 0.97 to 1.07 cmol(+)/kg. These results indicate that workshop-associated differences in exchangeable bases were parameter- and site-specific rather than uniform across all workshop soils.

As shown in Table 3, sodium remained relatively constant across the workshop and control soils, with no significant difference among the sampling locations. In contrast, exchangeable acidity was much higher in the control soil, with a value of 1.06 cmol(+)/kg, compared with 0.03–0.06 cmol(+)/kg in the workshop soils. Effective cation exchange capacity also varied significantly among the sampling locations. The control soil recorded the highest ECEC (4.88 cmol(+)/kg), followed by Workshops A and C with 4.06 and 3.98 cmol(+)/kg, respectively, while Workshop B had the lowest value (3.60 cmol(+)/kg). Tukey's test showed that the control differed significantly from all three workshop soils, while Workshop B also differed significantly from Workshops A and C; however, Workshops A and C did not differ significantly from each other. The higher ECEC in the control soil suggests greater overall cation-retention capacity compared with the workshop soils, despite the higher organic carbon recorded in the workshop soils.

Overall, the nutrient and exchangeable-cation results show that the workshop soils were chemically altered but not in a uniform direction. The most consistent pattern was depletion of key macronutrients, especially N, P, and K, alongside higher organic carbon and parameter-specific differences in exchangeable cations. This supports the interpretation that auto-mechanic workshop contamination affects soil quality through multiple interacting processes, including hydrocarbon accumulation, nutrient imbalance, altered cation retention, and changes in the chemical environment that may influence contaminant persistence and mobility (Mekonnen et al., 2024; Sarkar et al., 2021).

Table 3. Exchangeable cations and effective cation exchange capacity of workshop and control soils

Soil sample	Na(cmol(+)/kg)	EA (cmol(+)/kg)	ECEC (cmol(+)/kg)
Workshop A	0.06 ± 0.00^{A}	0.06 ± 0.00^{A}	4.06 ± 0.011^{B}
Workshop B	0.06 ± 0.00^{A}	0.03 ± 0.01^{A}	3.60 ± 0.01^{C}
Workshop C	0.06 ± 0.00^{A}	0.05 ± 0.00^{A}	3.98 ± 0.01^{B}
Control	0.06 ± 0.01^{A}	1.06 ± 0.08^{B}	4.88 ± 0.02^{A}

Means that do not share the same superscript letter are significantly different at $p \leq 0.05$.

Table 4. Acid-digestible (pseudo-total) Zn, Mn and Fe concentrations in workshop and control soils

Soil sample	Zn (mg/kg)	Mn (mg/kg)	Fe (mg/kg)
Workshop A	25.20 ± 0.01^{A}	24.73 ± 0.05^{A}	169.21 ± 0.03^{A}
Workshop B	23.89 ± 0.12^{B}	25.42 ± 0.13^{B}	168.51 ± 0.07^{B}
Workshop C	22.61 ± 0.02^{C}	24.73 ± 0.06^{A}	170.58 ± 0.02^{C}
Control	17.85 ± 0.38^{D}	1.20 ± 0.14^{C}	3.18 ± 0.02^{D}

Means that do not share the same superscript letter are significantly different at $p \leq 0.05$.

3.4 Micronutrient and metal enrichment in workshop soils

The acid-digestible (pseudo-total) concentrations of Zn, Mn and Fe were higher in the workshop soils than in the control soil (Table 4). Zinc ranged from 22.61 to 25.20 mg/kg in the workshop soils, compared with 17.85 mg/kg in the control soil. Manganese showed a stronger contrast, ranging from 24.73 to 25.42 mg/kg in the workshop soils compared with 1.20 mg/kg in the control soil. Iron showed the largest contrast, ranging from 168.51 to 170.58 mg/kg in the workshop soils, while the control soil contained 3.18 mg/kg. These differences were statistically significant and indicate substantial relative enrichment of the acid-digestible metal fraction in the workshop soils compared with the control.
The elevated concentrations of Zn, Mn, and Fe are consistent with the expected waste profile of auto-mechanic environments. Zinc may originate from lubricants, tyre wear, galvanized materials, paints, and metal components, while manganese and iron may be associated with corroded vehicle parts, welding residues, brake materials, scrap metals, and the mixing of soil with rusted automobile wastes (Mayer et al., 2024; McKenzie et al., 2009). Similar evidence has been reported in recent Nigerian studies, where automobile workshop activities and mechanic-workshop dusts were associated with physicochemical soil alteration and enrichment of metals such as Zn, Mn, Fe, Cu, Pb, and Cd (Augustine et al., 2024; Iwegbue et al., 2024).

4.0 CONCLUSION

The sampled auto-mechanic workshop soils in Kano Metropolis showed clear physicochemical alteration, nutrient imbalance, and relative enrichment of acid-digestible Zn, Mn, and Fe compared with the control soil. The workshop soils generally had lower pH, higher electrical conductivity and organic carbon, lower N, P, and K, and substantially higher acid-digestible metal concentrations than the control. These findings provide site-specific evidence that long-term automobile-servicing activities can be associated with altered soil chemical conditions and accumulation of metal-bearing residues. However, the study was based on three auto-mechanic workshop sites and one control location; therefore, the findings should be interpreted as baseline evidence from the sampled locations rather than as representative of all auto-mechanic workshops throughout Kano Metropolis**.** Differences in inherent site characteristics, particularly soil texture, should also be considered when interpreting workshop-control contrasts. Although groundwater quality and direct human-health outcomes were not assessed, the observed soil alterations indicate potential environmental vulnerability where automobile wastes are repeatedly discharged onto exposed soil surfaces.
The findings support improved waste-oil collection, workshop hygiene, and routine environmental monitoring at automobile-service locations. Future studies should include a larger and more spatially representative number of workshop and reference sites, together with total petroleum hydrocarbons, polycyclic aromatic hydrocarbons, broader metal profiles, groundwater assessment, and human-exposure risk analysis to determine the wider extent and environmental significance of workshop-associated soil contamination across Kano Metropolis.

ETHICAL CLEARANCE

This study did not involve human participants, human biological materials, clinical data, live animals, or animal experimental procedures. Therefore, formal ethical approval was not required. Soil samples were collected only for environmental physicochemical analysis.

CONFLICT OF INTEREST

The authors declare that they have no financial or non-financial conflict of interest related to this manuscript.

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