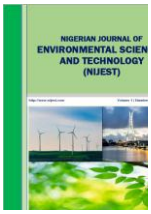
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Geotechnical and Chemical Characterisation of Soils from Automobile Mechanic Workshops across Different Contamination-Age Categories in Osun State, Nigeria

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ABSTRACT

Soils at automobile mechanic workshops may receive petroleum hydrocarbons and other automotive wastes, but their engineering behaviour also reflects natural soil variability and site conditions. This study evaluated the geotechnical parameters of soils from six mechanic-workshop locations in Osun State, Nigeria, grouped by reported period of workshop waste-disposal activity (< 1 year, 1–5 years and > 5 years), with one reference soil. Disturbed samples were collected from depths of 300–500 mm, subsequently analyzed for natural moisture content, specific gravity, particle-size distribution, Atterberg limits, compaction, unsoaked California Bearing Ratio (CBR), direct shear strength, permeability, one-dimensional consolidation, and X-ray fluorescence (XRF), adhering to the specified standards in the methodologies. Compared with the reference soil, the workshop samples generally had lower natural moisture contents (3.76–12.47%), specific gravity (1.43–2.21), maximum dry density (1.70–1.93 g/cm³) and unsoaked CBR (33–85%, compared with 93%). Two samples were classified as non-plastic. Direct-shear results varied between sites: MW2 recorded the highest reported cohesion (22.00 kPa), while MW3 had the highest friction angle (40.74°), exceeding the reference value of 36.65°. Permeability ranged from 1.92 × 10^{-5}cm/s (MW4) to 1.75 × 10^{-1} cm/s (MW3), compared with 6.39 × 10^{-4} cm/s for the reference. The reported mean compression index (Cc) was 0.0780 for the reference, 0.0855 for the <1-year group, 0.0840 for the 1–5-year group and 0.0630 for the >5-year group; corresponding mean coefficient of volume compressibility (Mv) values were 1.48 × 10^{-4}, 1.618 × 10^{-4}, 1.607 × 10^{-4} and 1.544 × 10^{-4} m²/kN, respectively. XRF results showed differences in oxide composition among sites, including ZnO values of 0.031% in the reference and up to 0.257% at MW5. These are site-level observations and do not establish that contamination duration caused the differences. Because only two workshop sites represented each duration category, direct hydrocarbon concentrations were not measured, and location and soil variability were not independently controlled, the findings were interpreted as an exploratory comparison rather than a causal or statistically generalisable estimate of ageing effects.

Keywords: Contaminant ageing; mechanic workshop soil; geotechnical properties; California Bearing Ratio; shear strength; X-ray fluorescence; Basement Complex; Nigeria

1.0. Introduction

Petroleum hydrocarbons can modify soil–water interactions and the measured consistency, compaction, hydraulic and strength properties of soils. Field soils at mechanic workshops, however, are exposed to mixtures of spent engine oil, fuels, grease, hydraulic fluids and other wastes, and their behaviour also depends on gradation, mineralogy, drainage, compaction history and weathering. Laboratory contamination studies commonly compare untreated soil with soil amended under controlled conditions, whereas field investigations capture the combined influence of contaminant exposure and natural site variability. The present study is a field comparison and does not isolate the effect of ageing experimentally. Therefore, differences between the reported duration groups are interpreted as associations rather than proof that ageing

caused a particular response. Previous work has described changes in geotechnical behaviour following oil contamination (Akinwumi et al., 2014; Oluremi et al., 2017), while research on weathering and ageing has shown that contaminant composition and soil response may evolve with time (Rajabi & Sharifipour, 2018; Ahmadi et al., 2024). These studies provide context, but laboratory findings should not be treated as direct evidence for the mechanisms operating at the field sites examined here.

Automobile-workshop soils may also contain metals and other elements associated with vehicle maintenance and waste handling (Duru et al., 2024). X-ray fluorescence (XRF) can describe differences in bulk elemental/oxide composition between samples, but oxide percentages alone cannot identify the source of an element or distinguish contamination effects from natural differences in parent material. The term "contaminant ageing" is used in this paper as a working description of the reported duration of workshop waste-disposal activity, not as a directly measured chemical-age parameter. Processes such as volatilization, oxidation, adsorption, biodegradation and leaching may occur in exposed soils, but they were not measured directly in this study.

This issue becomes relevant in Nigeria, where mechanic-workshop land may later be redeveloped for residential, commercial or institutional uses. The engineering concern is practical: differences in CBR, shear strength, permeability and compressibility may affect pavement and foundation assessment. In Osun State, the selected sites are located in Ikirun, Iragbiji, Ibokun, Ilesa, Ikire, Osogbo and Iwo. Although the region includes Precambrian Basement Complex rocks and associated residual soils (Rahaman, 1988), the samples were collected from different towns and were not independently characterised for site-specific mineralogy or parent material. They should therefore not be assumed to be geologically identical. The study addresses a local evidence gap by reporting geotechnical and XRF measurements from six workshop sites and one reference site, while recognizing that the small number of sites limits generalisation.

The study compared measured geotechnical and XRF properties across five mechanic-workshop sites assigned to three reported-duration categories and one reference site. The objectives were to: (i) describe the site-history basis for the reported duration categories; (ii) compare moisture content, specific gravity, particle-size distribution, Atterberg limits, compaction, unsoaked CBR, shear strength, permeability and consolidation properties; (iii) describe differences in XRF oxide composition; and (iv) discuss the implications of the observed values for site-specific geotechnical assessment. The design does not independently separate duration from location, soil type, drainage, workshop practice or contaminant loading.

2.0 Methodology

2.1 Materials

The materials used are the soil samples collected at different locations of the study areas. The study was carried out in Osun State, southwest Nigeria, which is situated between latitudes 6°30′N and 8°10′N and longitudes 4°00′E and 5°05′E. It covers an area of about 9,251 km² and has a humid tropical climate with mean annual rainfall of 1,200–1,500 mm and mean temperatures of 24–32 °C (NiMet, 2024).The state is underlain by Precambrian Basement Complex rocks: granite gneiss, migmatite gneiss, quartzite, schist and amphibolite whose in-situ weathering has produced the residual lateritic soils that form the principal foundation material used across the state (Rahaman, 1988; Adeniji, et al., 2020).

2. Supplies and Procedures

Following reconnaissance involving site inspection and discussions with workshop operators, six active mechanic-workshop sites and one reference site were selected. The duration categories (<1 year, 1–5 years and >5 years) represent reported duration of workshop activity and/or waste-disposal history, based on the site-history information available to the researchers; they are not direct measurements of the time. The available study records do not provide independent documentary verification of the duration at each site. Category labels are treated as approximate site-history classifications. Each category contains two sites, and each category is represented by different towns. Duration is therefore confounded with location, soil composition, drainage, workshop practice and contaminant loading.

Table 1. Sampling locations and Reported contamination-age classification.

City/Town	Sample code	Reported Age category	Approx. coordinates
Ikirun (control)	CS1	Reference	7.9125° N, 4.680° E
Iragbiji	MW2	< 1 year	7.8731° N, 4.8752° E
Ibokun	MW4	< 1 year	7.6196° N, 4.9922° E
Ilesa	MW3	1–5 years	7.6217° N, 4.7227° E
Ikire	MW6	1–5 years	7.2661° N, 4.5495° E
Osogbo	MW1	> 5 years	7.7649° N, 4.5586° E
Iwo	MW5	> 5 years	7.6246° N, 4.1837° E



Figure 1: Map of Osun State Showing the Selected Sampling Locations

Source: Authors GIS compilation, 2026

Disturbed samples were collected at a target depth interval of 300–500 mm below ground surface, selected to examine shallow subsurface soil potentially affected by workshop activities. The same nominal depth interval was used for the sites as reported in the study records. One field subsample was collected at each site;

Samples were sealed in labeled bags and transported for laboratory testing. The reference site was selected as an area without known mechanic-workshop activity; because direct total petroleum hydrocarbon (TPH) or other contaminant screening was not reported for the reference soil, it is described here as a reference soil rather than as chemically proven uncontaminated soil.

2.2 Methods

Laboratory testing followed the standards listed in Table 2. Particle-size distribution was determined using the dry sieving Method, with sieving carried out down to the 0.075mm sieve. Hydrometer analysis was not conducted. The percentage of fines was estimated by subtracting the combined percentages of gravel and sand from 100%. A representative sample of air-dried soil was weighed and passed through a nest of standard sieves of decreasing aperture size, the smallest of which was the 0.075mm sieve. The sieves were mechanically shaken and the amount of soil retained on each sieve was determined. The gravel and sand percentages were obtained from the corresponding sieve fractions while the fines percentage was obtained by subtracting the total percentage of gravel and sand from 100%. Hydrometer analysis was not conducted.Atterberg limits by the Casagrande liquid-limit and thread-rolling plastic-limit procedures, and compaction by standard Proctor effort. Laboratory compaction assessments were conducted following BS 1377-4: 1990 Clause 3.3, employing British Standard Light compaction effort (2.5Kg rammer, 305 mm drop, 3 layers, and 25 blows per layer in a 1000cm³ mold) to ascertain the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of both the reference (CS1) and contaminated soils. Unsoaked CBR was measured at a penetration rate of 1.25 mm/min and reported as the higher ratio at 2.5 or 5.0 mm penetration. Direct shear tests were conducted on specimens at their natural moisture content as obtained from the field, in a 60 mm × 60 mm apparatus under normal stresses of 50, 100 and 150 kN/m². Permeability was determined by the falling head method in which the water was allowed to pass through the sample under a dropping head. Initial head (h1) and final head (h2) were recorded at different time intervals (t). The first head (h1) and last head (h2) were measured at different time intervals (t). Oedometer tests employed incremental loading from 20 to 320 kPa. The oven-dried, pulverized material was sieved to pass 75 μm and prepared as pressed pellets for XRF analysis. The reference soil (CS1) and contaminated soils (MW1, MW3, MW4, MW5 and MW6) were analyzed for their elemental oxide composition by XRF

Table 2. Laboratory test standards adopted in this study.

Property	British Standard	ASTM Standard
Natural moisture content	BS 1377: Part 2 (1990)	ASTM D2216–19
Specific gravity	BS 1377: Part 2 (1990)	ASTM D854–23
Particle-size distribution	BS 1377: Part 2 (1990)	ASTM D6913/D6913M–17(2025)
Atterberg limits	BS 1377: Part 2 (1990)	ASTM D4318–26
Standard Proctor compaction	BS 1377: Part 4	ASTM D698–12(2021)
California Bearing Ratio	BS 1377: Part 4	ASTM D1883–21
Direct shear strength	BS 1377: Part 7	ASTM D3080/D3080M-23e1
Permeability (falling head)	BS 1377: Part 5	ASTM D2434-26
Site investigation / sampling	BS 5930:2015	ASTM D420–18

Quality assurance was described as including equipment calibration, duplicate analysis and laboratory blanks, with moisture content, specific gravity and Atterberg limits based on at least two laboratory trials. Because there are only two independent field sites in each workshop-duration category and site location is confounded with category, inferential comparisons cannot robustly isolate an age effect. Accordingly, results are presented descriptively; no claim of statistical significance is made. Laboratory repeats are not treated as independent field replicates.

3.0 Results and Discussion

Table 3 summarizes the reported index and engineering properties of six mechanic-workshop soils (MW1–MW6) and one reference soil (CS1). The observations are compared by site and reported-duration category. Since site history, location and natural soil characteristics were not independently controlled, the comparisons identify patterns in this dataset rather than causal effects of contamination age.

Table 3. Summary of geotechnical and index properties of Reference and contaminated soils.

Code	Town	Age	w (%)	Gs	LL (%)	PI (%)	MDD (g/cm³)	OMC (%)	CBR (%)	C (kPa)	φ (°)
CS1	Ikirun	Reference	13.14	2.22	36.36	9.79	1.95	13.09	93	9.45	36.65
MW2	Iragbiji	<1 yr	10.96	2.21	28.91	1.93	1.80	16.16	46	22.00	23.82
MW4	Ibokun	<1 yr	9.97	1.43	27.40	12.64	1.70	17.33	50	0.00	23.95
MW3	Ilesa	1–5 yr	12.47	1.72	21.00	8.31	1.83	14.14	47	4.71	40.74
MW6	Ikire	1–5 yr	6.01	1.88	NP	NP	1.92	3.96	33	0.00	33.29
MW1	Osogbo	>5 yr	9.48	2.15	27.50	7.20	1.93	13.92	85	12.34	22.50
MW5	Iwo	>5 yr	3.76	1.78	NP	NP	1.93	9.29	57	0.00	35.42

3.1. Natural Moisture Content

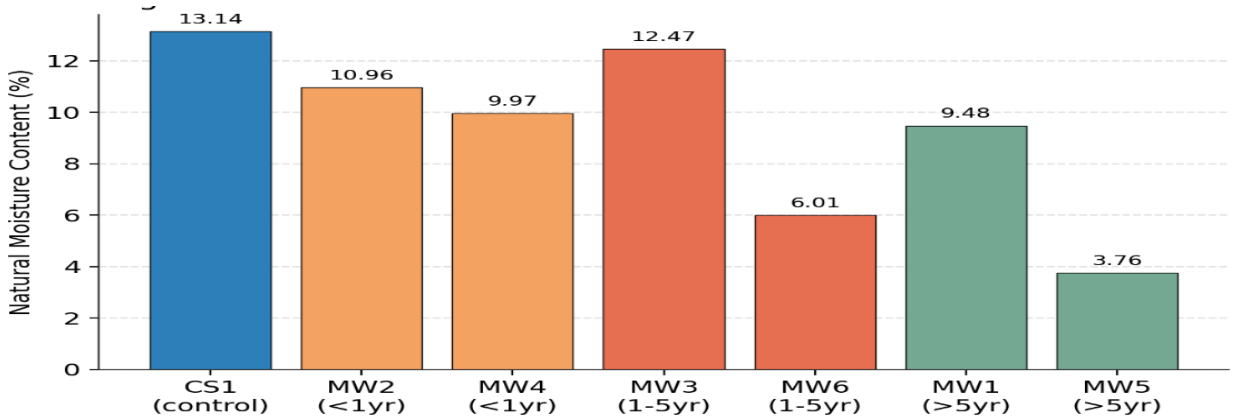


Figure 2: Natural moisture content of Reference and contaminated soils.

The reference soil (CS1) recorded a natural moisture content of 13.14%, whereas the workshop soils ranged from 3.76% (MW5, reported duration >5 years) to 12.47% (MW3, 1–5 years). All workshop samples were below the reference value. The group means calculated from the two sites in each category are 10.47% for <1 year (MW2 and MW4), 9.24% for 1–5 years (MW3 and MW6), and 6.62% for >5 years (MW1 and MW5). These descriptive means decrease across the reported-duration categories, but the small, site-confounded dataset does not establish a temporal trend. Differences in soil texture, drainage, recent rainfall, sampling conditions and contaminant loading could also influence moisture content; these factors were not quantified. Hydrophobic effects are a possible explanation, not a mechanism demonstrated by the present *measurements.*

3.2. Specific gravity

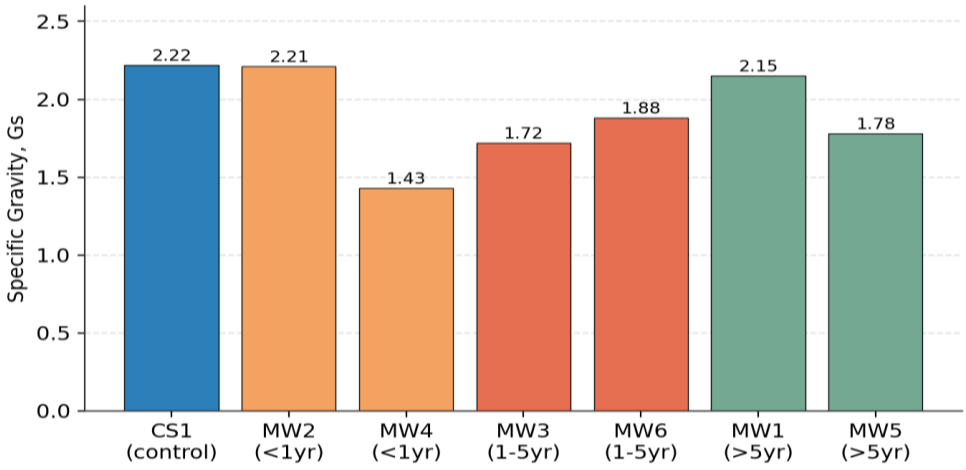


Figure 3: Specific gravity of Reference and contaminated soils.

The reference soil had a specific gravity (Gs) of 2.22. Workshop samples ranged from 1.43 at MW4 to 2.21 at MW2. Lower Gs values at several sites may reflect differences in mineral composition, organic or hydrocarbon content, or testing variability; this study did not measure mineralogy or hydrocarbon concentration sufficiently to distinguish among these possibilities. The values do not show a consistent relationship with reported duration.

3.3. Particle-size distribution

Table 4. Summary of particle-size distribution results.

Code	Gravel (%)	Sand (%)	Fines (%)	Cu	Cc
CS1	18.40	77.10	4.50	13.34	0.89
MW1	3.00	93.10	3.90	6.45	0.98
MW2	2.50	91.30	6.20	5.60	1.02
MW3	33.70	60.40	5.90	31.66	3.41
MW4	19.90	72.60	7.50	6.97	1.74
MW5	6.30	91.30	2.40	6.33	0.99
MW6	9.70	78.70	11.60	—	—

Sand was the dominant reported fraction in all samples (60.40–93.10%). MW1 had the highest sand content (93.10%), while MW3 had the highest gravel content (33.70%) and the lowest sand content (60.40%). Fines ranged from 2.40% at MW5 to 11.60% at MW6. The coefficient of uniformity (Cu) and coefficient of curvature (Cc) were not reported for MW6; the values were not calculable from particle-size distribution curve.

Gradation differences may reflect parent-material variability, weathering or local disturbance, but these factors were not separately measured. Although gradation can influence drainage and frictional behaviour, the present data alone do not prove that it caused MW3's high friction angle or the permeability differences.

3.5. Atterberg limits

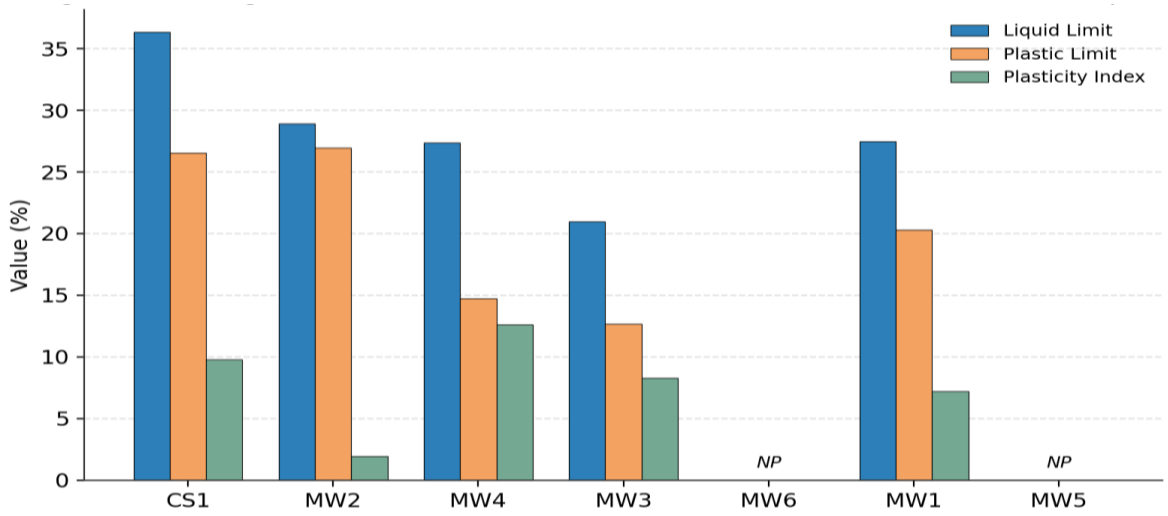


Figure 4: Atterberg limits of Reference and contaminated soils (MW5 and MW6 non-plastic**).**

The reference soil recorded LL = 36.36%, PL = 26.57% and PI = 9.79%. The contaminated-site samples with reported plasticity had lower LL values (21.00–28.91%); PI ranged from 1.93% at MW2 to 12.64% at MW4. MW3's PI (8.31%) is higher than MW1's PI (7.20%), and this comparison should not be described otherwise. MW5 and MW6 were reported as non-plastic.

These observations indicate differences in consistency between the reference and workshop samples, but clay mineralogy, hydrocarbon adsorption and the composition of the fines were not measured. Hydrocarbon films and changes in soil–water interaction are possible explanations, not confirmed mechanisms. The non-plastic classification of MW5 and MW6 is reported as a test outcome and cannot, by itself, establish why those soils were non-plastic.

3.6. Compaction characteristics MDD OMC

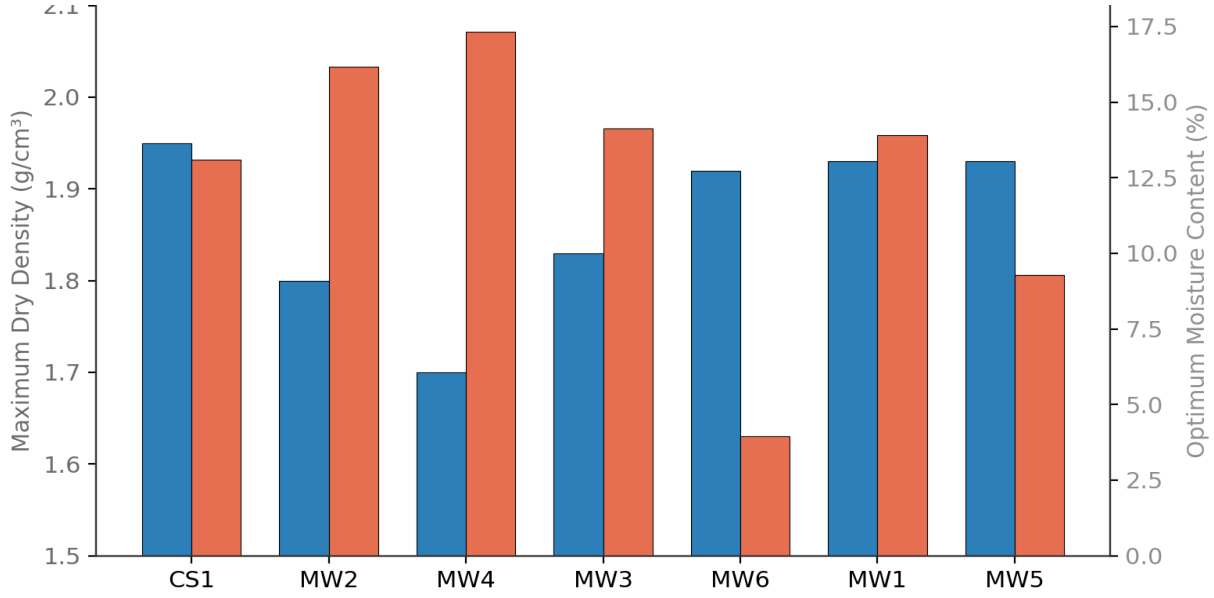


Figure 5: Maximum dry density (MDD) and optimum moisture content (OMC) of soil samples**.**

The reference soil had a reported maximum dry density (MDD) of 1.95 g/cm³ and optimum moisture content (OMC) of 13.09%. The table reports MDD values of 1.70–1.93 g/cm³ for the workshop samples. relative to the reference MDD, the reductions are approximately 7.69% for MW2, 12.82% for MW4, 6.15% for MW3, 1.54% for MW6, 1.03% for MW1 and 1.03% for MW5, using the values in Table 3. MW6's OMC of 3.96% is unusually low. Compaction response may depend on gradation, fines, specific gravity, specimen

preparation and contaminant content; these factors were not independently controlled. The comparatively high MDD values for MW1 and MW5 do not establish equivalence to the reference soil because other measured properties differ.

3.6. California Bearing Ratio

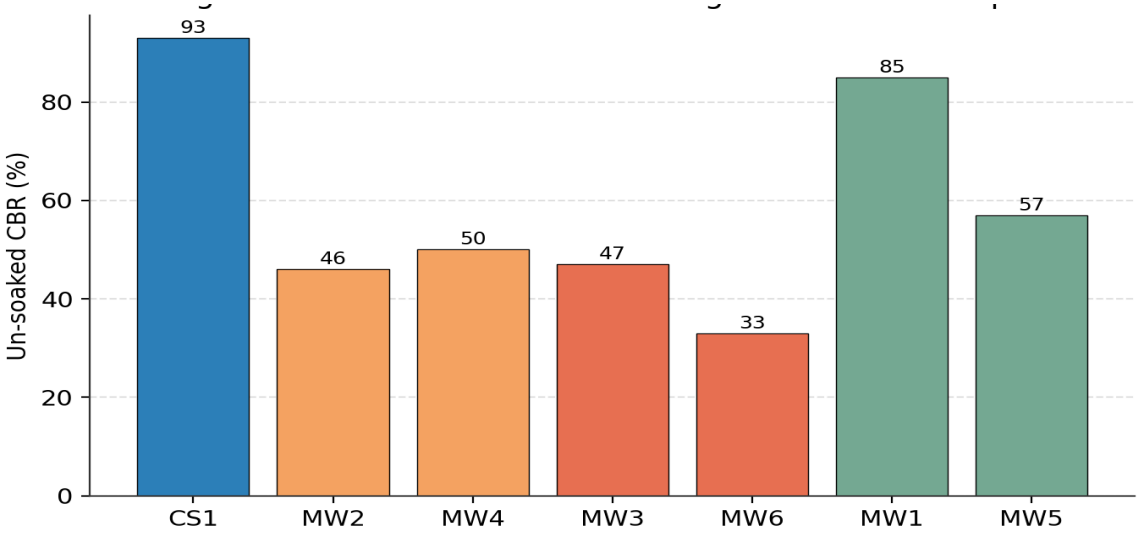


Figure 6: Un-soaked California Bearing Ratio (CBR) of Reference and contaminated soils.

The unsoaked CBR was 93% for the reference soil and 33–85% for the six workshop samples. Thus, every workshop-site value was lower than the reference value in this dataset. The largest relative reduction was at MW6 (approximately 64.5%), while the smallest was at MW1 (approximately 8.6%). These are descriptive differences; no statistical-significance claim is made. Only unsoaked CBR results are reported, so the findings should not be used to infer soaked or wet-season performance. Hydrocarbon-related changes in particle contact or compaction are possible explanations, but were not directly verified. Pavement-layer selection or thickness cannot be recommended from these values alone without the applicable design method, traffic category, drainage conditions and pavement design calculation.

3.7. Shear strength

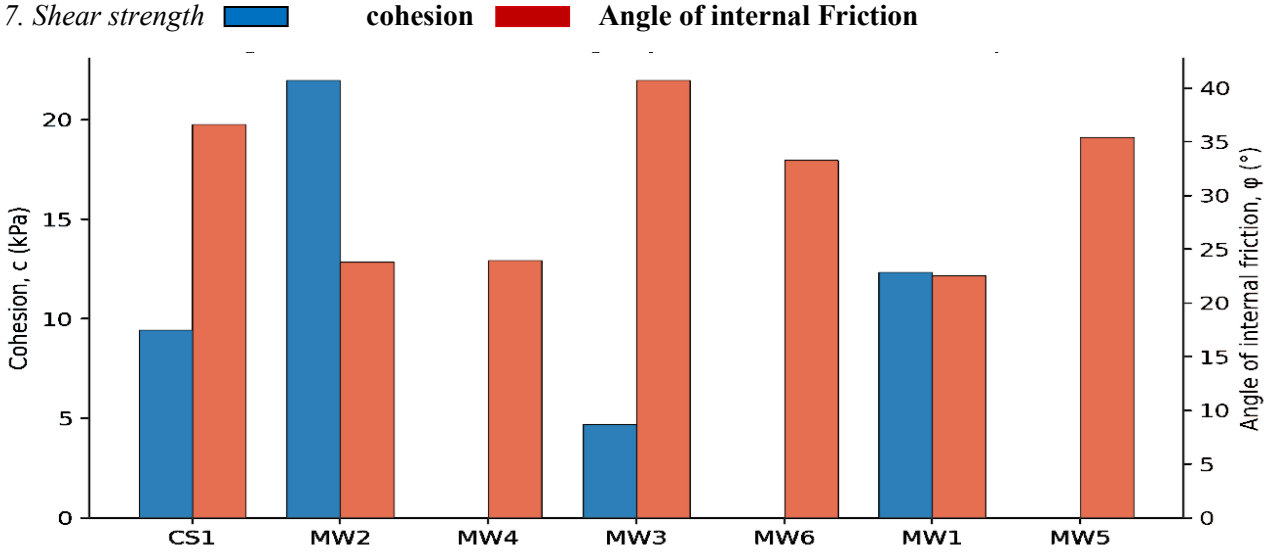


Figure 7: Direct shear strength parameters (cohesion and friction angle) of soil samples.

Direct-shear results varied across the sites. The reference soil had c = 9.45 kPa and φ = 36.65°. MW2 had the highest reported cohesion (22.00 kPa), while MW1 recorded 12.34 kPa. MW4, MW5 and MW6 had negative regression intercepts in the original calculations and are reported as approximately zero cohesion in Table 3;

MW3 recorded φ = 40.74°, higher than the reference value, whereas MW1 had the lowest friction angle (22.50°). The reasons for these differences cannot be assigned to hydrocarbon bonding, lubrication or gradation alone because contaminant concentration, mineralogy and test variability were not measured independently. Implications for bearing capacity and stability are therefore qualitative; no design or slope-stability calculation was undertaken.

3.8. Permeability

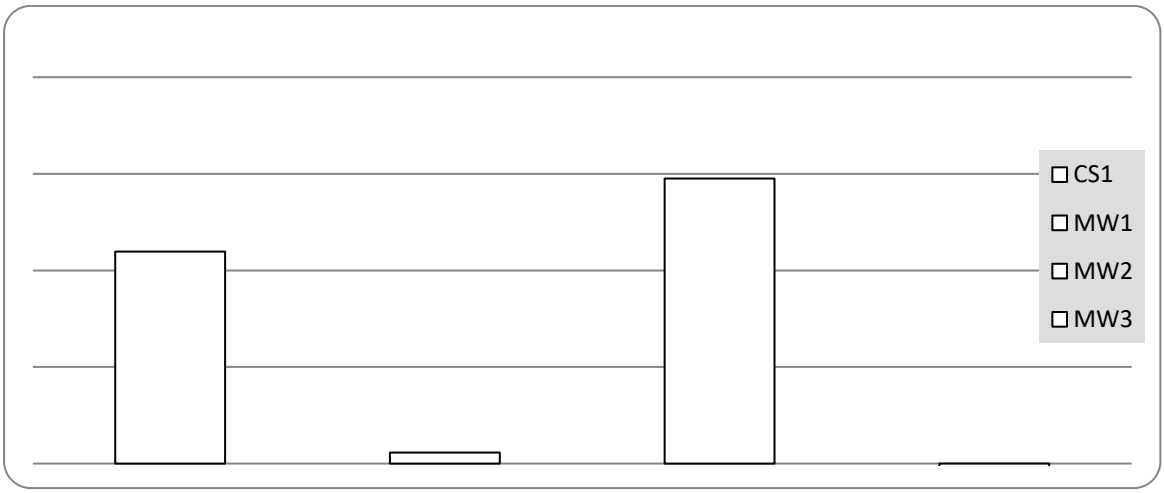


Figure 8: Coefficient of permeability of Reported Age Category of Reference and Contaminated soils (log scale)

The reference soil (CS1) recorded a mean permeability of 6.39 $\times 10^{-4}$ cm/s, compared with 6.56 $\times$ 10^{-5} cm/s for the < 1-year category. Permeability increased considerably to 8.95 $\times 10^{-2}$ cm/s in the 1-5year category before declining to 3.87 $\times$ 10^{-2} cm/s in the > 5-year category. This non-linear variation suggests that prolonged hydrocarbon contamination alters soil pore structure and hydraulic conductivity, although the effect is not directly proportional to exposure duration.

3.9.Chemical composition (XRF) and engineering implications

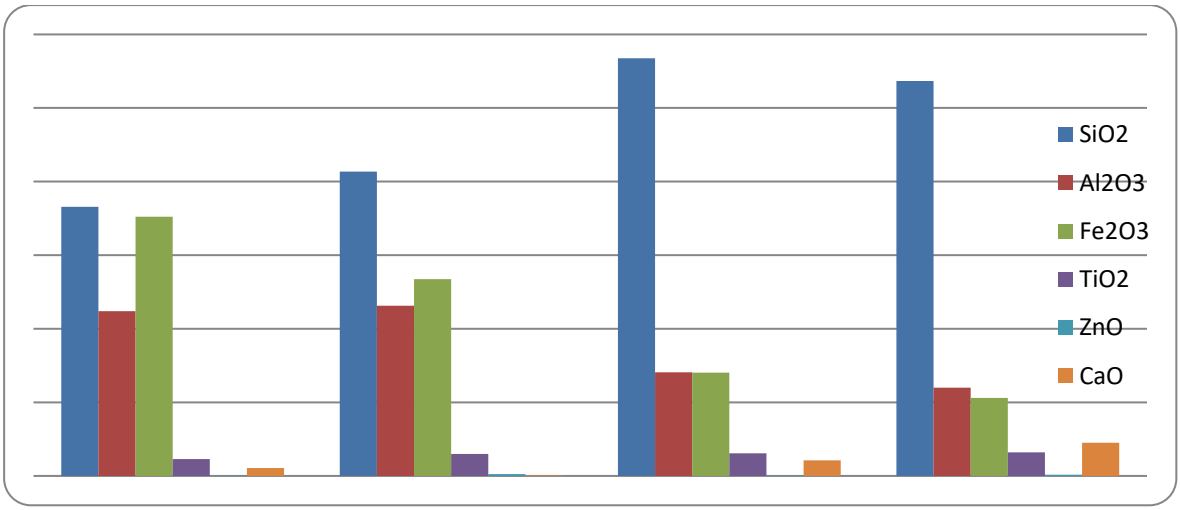


Figure 9: Dominant oxides concentration in reference and contaminated soils based on the Reported Age Category

The XRF results revealed variations in the major oxide composition of the soils across the different workshop-age categories. The reference soil (CS1) was dominated by SiO_2 (36.579%), Fe_2O_3 (35.210%) and Al_2O_3 (22.398%). In the less-than-one-year category, SiO_2 and Al_2O_3 increased to 41.369% and 23.139%, respectively, while Fe_2O_3 decreased to 26.735%. The 1–5-year category recorded the highest SiO_2 concentration (56.740%), alongside reductions in Al_2O_3 (14.087%) and Fe_2O_3 (14.053%). Similarly, the greater-than-five-year category recorded a high SiO_2 content (53.660%), while Al_2O_3 and Fe_2O_3 declined further to 11.972% and 10.592%, respectively. TiO_2 increased progressively from 2.307% in the reference soil to 3.221% in the oldest category. However, ZnO exhibited a non-uniform trend, recording its highest concentration (0.226%) in the less-than-one-year category, while CaO reached its highest value (4.530%) in the greater-than-five-year category.

3.10 Consolidation characteristics

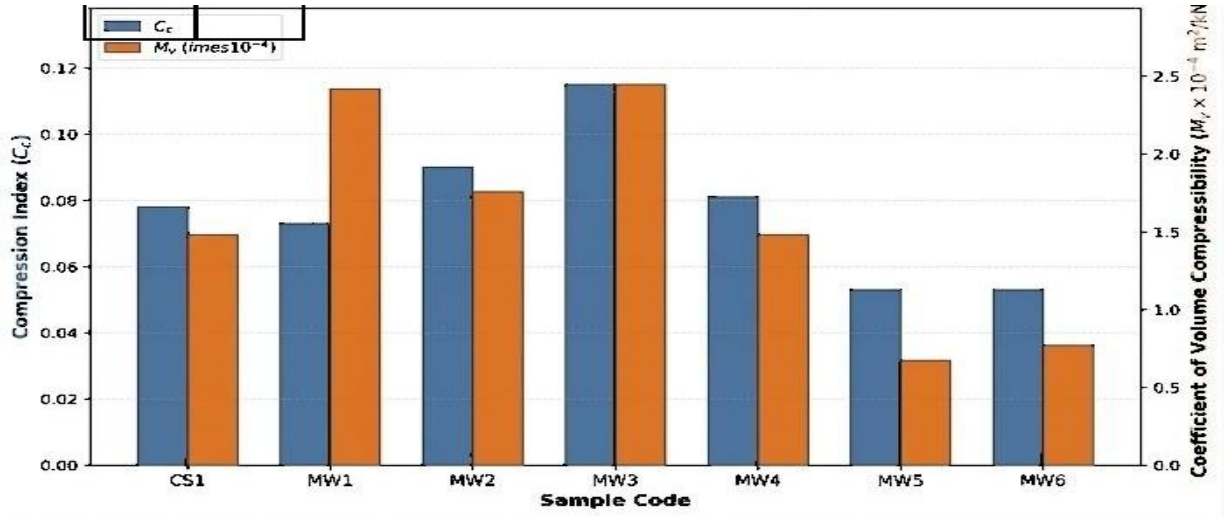


Figure 10: Consolidation characteristics of Reference and contaminated soil (Cc and Mv)

The mean compression index (Cc) was 0.0780 for CS1(reference), 0.0855 for the <1-year group, 0.0840 for the 1–5-year group and 0.0630 for the >5-year group. Relative to the reference, these correspond to approximately 9.6% and 7.7% higher Cc in the <1-year and 1–5-year groups, respectively, and 19.2% lower Cc in the >5-year group. Mean coefficient of volume compressibility (Mv) values was 1.48×10^{-4} m²/kN for CS1 (reference) ,1.618×10^{-4} m²/kN for <1 year, 1.607×10^{-4} m²/kN for 1–5 years and 1.544×10^{-4} m²/kN for >5 years. These group summaries indicate modestly higher Mv in the two younger reported-duration categories and a value slightly above the reference for the >5-year group, whereas Cc is lower in the >5-year group. The results support a cautious, site-specific engineering interpretation. First, the lower unsoaked CBR values at all six workshop sites indicate that the reference value should not be substituted for testing at a workshop site; soaked performance and pavement design were not evaluated. Second, the spread in direct-shear parameters means that strength values should be established for the particular site and design condition rather than inferred from duration category. Third, the permeability and consolidation results vary substantially between sites. Because duration categories are represented by different locations and only two sites per category, the age of workshop activity alone should not be used to predict engineering performance. Direct hydrocarbon testing, additional field sampling and verified laboratory records would be needed to distinguish contamination effects from natural site variability.

3.11. Study limitations and interpretation

The study is based on six workshop sites and one reference site, with only two sites in each reported-duration category. The categories are represented by different towns and therefore cannot be separated from location, natural soil variability, drainage, workshop practice or contaminant loading. Direct total petroleum hydrocarbon measurements, independent confirmation of the reference soil chemistry, site-specific mineralogical data, and direct measurements of ageing processes were not captured all between-site and between-category interpretations are descriptive; no causal or statistically significant age effect is claimed.

4.0. Conclusions

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The study revealed variations in the geotechnical and chemical characteristics of soils obtained from automobile mechanic workshops with different reported durations of operation in Osun State. The variations observed across the study sites indicate that workshop environments may influence soil properties, although the changes were not consistent across the operational-duration categories.

This study compared geotechnical and XRF results from five automobile mechanic-workshop sites in Osun State with one reference site. The categories were based on reported duration of workshop activity or waste-disposal history; they were not direct measurements of contaminant age. The findings are limited by the small number of sites, confounding of category with location, lack of direct hydrocarbon measurements and incomplete reporting of some quality-control and replicate data.

The findings showed variations in unsoaked CBR, compression index, permeability and coefficient of volume compressibility among the workshop soils and the reference soil. The study highlights the importance of assessing workshop soils before construction, particularly when considering their suitability for foundation.

Generally, the dataset does not show a consistent monotonic pattern across the reported-duration categories. Further work should include verified workshop histories, multiple independent field samples, direct TPH and metal analyses, seasonal sampling, documented replicate testing and, where appropriate, mineralogical or microstructural analysis.

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