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Assessment of Heavy Metal Concentration in Soil and Water from Mechanic Sites in Makurdi, Benue State, Nigeria

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Abstract

This study assessed heavy metal concentrations and physicochemical properties in soil and water samples from mechanic workshops in Apir and North Bank, Makurdi, Nigeria. sixteen soils, sixteen water samples were collected using a systematic random sampling design, along with control samples from uncontaminated sites. Soil samples were collected from depth of 15 cm using a hand auger and stored in labeled polyethylene bags, while water samples were collected in clean plastic bottles and taken to the laboratory. The physicochemical properties analyzed included pH, moisture content, cation exchange capacity (CEC), electrical conductivity (EC), and total dissolved solids (TDS), measured using standard laboratory procedures. Heavy metal concentrations of manganese (Mn), lead (Pb), iron (Fe), and chromium (Cr) were determined using atomic absorption spectrophotometry (AAS) after acid digestion. The results showed that North Bank soils had higher manganese levels (1.24 mg/kg) compared to Apir (0.28 mg/kg), while Apir exhibited elevated concentrations of lead (3.14 mg/kg) and chromium (1.04 mg/kg) compared to North Bank (Pb: 2.78 mg/kg, Cr: 0.57 mg/kg). However, all heavy metal concentrations were below the NESREA (National Environmental Standards and Regulations Enforcement Agency) permissible limits. Soil pH values were 7.2 for North Bank and 6.9 for Apir, both within the acceptable NESREA range (6.5–8.5). Moisture content and CEC were higher in North Bank and Apir, respectively. Water samples contained no detectable levels of manganese, lead, or chromium, and their physicochemical properties, including pH, EC, and TDS, were within safe limits. The findings suggest that soil contamination remains within regulatory thresholds, necessitating continuous monitoring and improved waste management practices.

Keywords: *Contamination, Electrical conductivity, Systematic, Thresholds*

Introduction

The improper disposal of spent motor oil at mechanic sites is a significant environmental issue, especially in urban areas like Makurdi, Nigeria, where mechanic workshops are prevalent. Spent motor oil contains harmful substances such as polycyclic aromatic hydrocarbons (PAHs) and heavy metals, including lead (Pb), iron (Fe), chromium (Cr), and other toxic elements. These substances, when disposed of improperly, can seep into the soil and water systems, leading to contamination that disrupts the natural balance of the environment (Okobia *et al*., 2024; Nwite & Alu, 2015). The infiltration of spent motor oil into soil alters its physicochemical properties, including an increase in soil acidity, which significantly reduces its fertility and makes it less suitable for agricultural or ecological purposes (Ogugbue *et al*., 2017; Nwite & Alu, 2015). Additionally, the contamination of soil with heavy metals can interfere with nutrient availability, further degrading soil quality and diminishing its ability to support plant growth (Kabata-Pendias & Pendias, 2011).

Heavy metals, such as Pb, Cr, and Fe, are of particular concern due to their toxicity and persistence in the environment. These metals can accumulate in the soil, leading to long-term contamination that can affect plant and microbial life (Alloway, 2013). The immobilization of essential nutrients by heavy metals, along with the reduction in microbial diversity and activity, impairs soil health and its natural processes, such as organic matter decomposition and nutrient cycling (Jung *et al*., 2016). Soil microbial populations, which are crucial for maintaining soil fertility, are also severely impacted by the presence of these toxic substances. Studies have shown that in areas contaminated with spent motor oil, the abundance and diversity of microorganisms decrease, with only a few resilient species surviving, while others, essential for bioremediation and soil regeneration, are eliminated (Okobia *et al*., 2024; Onwujekwe *et al*., 2022).

Moreover, the contamination of water sources with heavy metals and other pollutants from spent motor oil poses significant health risks to humans and wildlife. Contaminated water can affect communities that rely on local water sources for drinking, irrigation, and other domestic purposes (Mohanty *et al*., 2013; Onwujekwe *et al*., 2022). The accumulation of heavy metals in the food chain can lead to serious health conditions, including cancer, liver damage, and neurological disorders (Eze & Orjiakor, 2020). Given the widespread use of mechanic workshops in Makurdi and the improper disposal of spent motor oil in these areas, both soil and water quality are at risk. This highlights the urgent need for effective environmental management strategies, including proper waste disposal methods and the promotion of bioremediation techniques to restore affected sites. The contamination of both soil and water by spent motor oil remains a critical issue that requires further investigation and action to prevent long-term environmental damage and safeguard public health (Ogugbue *et al*., 2017; Onwujekwe *et al*., 2022). The aim of this study is to investigate the impact of spent motor oil on soil and water quality in mechanic sites located in Makurdi, Nigeria with the objectives of assessing the basic physical and chemical properties of soil and water and also carrying out heavy metals analysis on the soil and water samples from the mechanic sites while also comparing the level of pollution with NESREA standards.

Materials and Methods

The Study Area

Makurdi, the capital of Benue State in North Central Nigeria, is situated along the Benue River at latitude 7.44°N and longitude 8.32°E, within the Benue valley, and approximately 100 meters above sea level. In 2007, Makurdi had an estimated population of 500,791 and covered an area of about 820 km². The city is characterized by various human activities such as irrigational farming, sand extraction for construction, fishing, market operations, and auto-mechanic sites, which are significant sources of heavy metal pollution (Adamu *et al*., 2003).

For this study, two sampling sites were chosen within Makurdi: The Kanshio mechanic site at latitude 7.69°N and longitude 8.54°E, located along the Makurdi-Otukpo road opposite the National Open University, known for its extensive automobile repair and maintenance services; and the North Bank Mechanic site at latitude 7.73°N and longitude 8.53°E, recognized for motor body repairs and mechanical and electrical motor services.

Sample Collection

Random sampling techniques were employed to collect both soil and water samples from the 2 different mechanic sites located at Kanshio and North Bank. Soil sample was also collected from a farm land close to the mechanic sites and was used as a control while control for water was taken from well water away from the mechanic sites. A soil auger was used to collect the soil samples at a depth of 15 cm. A total of sixteen soil samples and sixteen water samples were collected to be analyzed. The collected soil samples were placed in a clean polythene bag before being transferred into a well-labelled zip bag and moved to the lab. Water samples were placed in clean labeled water bottles.

Soil Sample Collection and Preparation: Before heading out to the field, all sampling equipment, including soil augers, spades, gloves, and polyethylene bags, were cleaned and sterilized to prevent contamination. The polyethylene bags were labeled with relevant information such as site location, depth, and date of collection to maintain organization. At each site, soil samples were collected from the top 0-15 cm layer using a soil auger. This depth is critical as it is most likely affected by surface contaminants like spent motor oil. A random sampling method was employed to

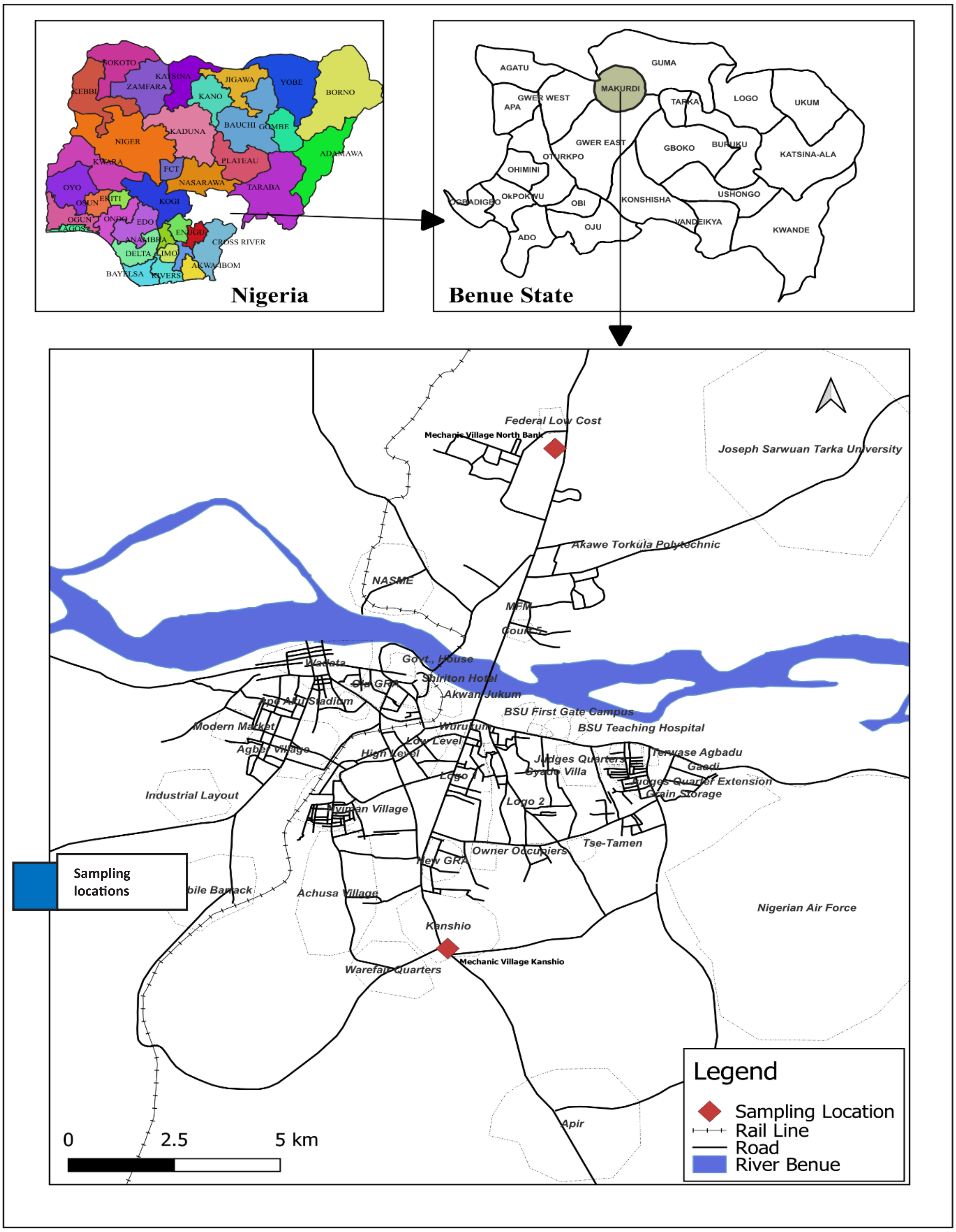

Fig 1: Map of Makurdi showing the Sampling Locations

select specific points within each site, ensuring that the samples were representative. Using the soil auger, it was carefully inserted into the soil to the desired depth, rotated to cut through the soil, and then lifted out to retrieve the sample. Each composite soil sample was placed into its labeled polyethylene bag, which was tightly sealed to maintain the sample's integrity. Upon arrival at the lab, the soil samples were spread on clean trays to air-dry at room temperature, reducing moisture content. After drying, the samples were passed through a 2-mm sieve to remove debris and homogenize them. Thorough mixing of the sieved soil ensured uniformity in the sample. The prepared samples were then stored in labeled containers for subsequent analyses. For physical and chemical analyses, measurements of soil pH, percentage moisture, Cation Exchange Capacity (CEC), particulate nature, Total dissolved solids, organic dissolved oxygen, turbidity, and heavy metals were conducted.

Water Sample Collection and Preparation: Sampling sites were carefully selected based on their proximity to mechanic sites and potential points of oil contamination from groundwater sources. Clean plastic bottles were used for collecting the water samples to avoid contamination. The sampling process involved collecting water from different points within each designated site to ensure a representative sample. Each sample bottle was labeled with the site location, date, and time of collection. Upon arrival at the laboratory, the water samples were subjected to a series of analyses to determine their physical, and chemical properties. Physical parameters such as pH, total dissolved solids, dissolved oxygen, and turbidity were measured using appropriate sensors and meters. The chemical analyses focused on detecting contaminants like heavy metals (manganese, Fe, Pb, Cr).

Laboratory Analysis

Determination of Soil Quality Parameters:

The physiochemical parameters were determined using standard laboratory methods as reported by Gupta and Sinha. (2006).

Determination of soil pH: Weigh 5g of the soil sample, suspend it in 50 mL of distilled water, then put the pH meter and take the pH reading.

Cation Exchange Capacity: A CEC meter is used to take the reading.

Percentage Moisture: Using the oven drying method, the soil sample is collected in a moisture can, and wet weight of the sample is recorded. The soil sample is dried in a hot air oven at 105 ^{0}C until constant weight is obtained and dry weight of the sample is recorded.

$$\text{Moisture content (on weight basis)} = \frac{Wet\ weight - Dry\ weight\ X\ 100}{Dry\ Weight}$$

Particulate Nature: Weigh 100g of the soil in a measuring cylinder, add 100mL of water and 5g of detergent. Shake the mixture rigorously. Allow the mixture to settle to allow the different particles to settle in the order of top to bottom with clay on top, then sand and silt. Measure the entire length of the soil in cm, then also measure the length of the individual clay, sand and silt. Inputting them into the following formulas below, the % particulate matter can be calculated,

$$\frac{Amount\ of\ each\ component}{Total\ volume\ of\ soil} \times 100 = \%\ Component$$

Determination of Water Quality Parameters:

The physicochemical parameters were determined using the methods outlined by Arafat *et al*., 2021 and Udo *et al.,* 2009

Dissolved Oxygen (DO): Dissolved oxygen was determined using HANNA dissolved oxygen (DO) meter Model HI 93246. This was done in situ by immersing the probe of the meter into the water and the reading on the LCD taken when it stabilized.

pH (Hydrogen ion concentration), Temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS): These parameters were determined using HANNA multiparameter water tester model HI 98129. This was done by inserting the probe of the meter into the water sample and setting the mode to read the respective parameter using the keypad MODE.

Evaluation of Heavy Metals: The elemental analysis of (Mn, Pb, Fe, and Cr) was carried out according to the method of the Association of Official Analytical Chemists (AOAC, 2016). 2 mL of sample was digested using an acid mixture of nitric acid, perchloric acid, and sulphuric acid (HNO_3:$HClO_4$, H_2SO_4). 2 mL of the acid mixture was dispensed in the tube containing 2 mL of the water samples. The tubes were then placed in the digester under the fume cupboard and heated until a clear and colorless fume was noted. The contents of the tubes were allowed to cool and then diluted with 250 mL of distilled water. From the diluent, an aliquot of the samples was taken for the analysis of minerals using an Atomic Absorption Spectrophotometer (AAS).

Statistical Analysis: Data was statistically analyzed using Statistical Package for Social Sciences (SPSS) for Windows (Version 21). Analysis of Variance one way (ANOVA) was used to determine the level of significance of variations between the samples. Results were considered statistically significant when ($P<0.05$). Results obtained from soil and water analysis were expressed as mean values, with their standard deviation using the Duncan Multiple Range Test (DMRT).

Results and Discussion

Physiochemical Characteristics of Soil and Water Samples

Table 1 and Table 2 are the results for the physicochemical properties of soil and water samples collected from the Kanshio and North Bank mechanic sites in Makurdi, along with their respective control samples. In the soil samples, North Bank exhibited a slightly more alkaline pH of 7.25 compared to Kanshio's 6.98. Both values fall within NESREA's acceptable range of 6.5–8.5, indicating no significant pH imbalance. Additionally, North Bank demonstrated a higher moisture content of 14.23% compared to Kanshio's 11.28%, suggesting that the soils at North Bank are better at retaining water. The Cation Exchange Capacity (CEC) was significantly higher in Kanshio at 4.19 meq/100g, while North Bank recorded 3.55 meq/100g, indicating that Kanshio's soil may be more effective at holding nutrients. Both locations had a high sand content of approximately 80%, although the control soils contained slightly more clay. In the water samples, all pH values were within NESREA's recommended range of 7.0–8.5. However, Kanshio water had the lowest pH at 6.80, while the Kanshio Control had the highest at 7.40, suggesting minor pH fluctuations due to mechanical activities. Electrical Conductivity (EC) levels were significantly below NESREA's limit of 400 µS/cm, indicating low salinity in all water samples. Total Dissolved Solids (TDS) remained under the permissible limit of 500 mg/L, although Kanshio water recorded a slightly higher TDS of 88.75 mg/L compared to the controls, which may indicate potential contamination. Dissolved Oxygen (DO)

Table 1: Physicochemical Composition of Soil Samples Across Locations in Makurdi

SAMPLES	pH	Percentage Moisture (%)	CEC (meq/100g)	Particulate Nature		
				Clay (%)	Sand (%)	Silt (%)
Kanshio	6.98 ± 0.15^{b}	11.28 ± 0.22^{c}	4.19 ± 0.18^{a}	12.41 ± 0.21^{ab}	80.64 ± 0.27^{b}	7.20 ± 0.25^{a}
North Bank	7.25 ± 0.06^{a}	14.23 ± 0.22^{b}	3.55 ± 0.29^{b}	12.89 ± 0.44^{a}	80.81 ± 0.53^{b}	6.31 ± 0.17^{b}
Kanshio Control	7.13 ± 0.05^{a}	21.05 ± 0.39^{a}	2.48 ± 0.27^{c}	11.83 ± 0.52^{b}	81.66 ± 0.49^{a}	6.52 ± 0.23^{b}
North Bank Control	6.90 ± 0.08^{b}	21.06 ± 1.59^{a}	2.31 ± 0.16^{c}	10.54 ± 0.48^{c}	82.27 ± 0.28^{a}	7.09 ± 0.23^{a}
P-Value	0.001	<0.001	<0.001	<0.001	<0.001	<0.001
NESREA	6.5 – 8.5	-	-	-	-	-

Note: Means on the same column with different superscripts differ significantly

pH = potential of hydrogen; CEC = Cation Exchange Capacity; NESREA = National Environmental Standards and Regulations Enforcement Agency

Table 2: Physicochemical Composition of Water Samples Across Locations in Makurdi

SAMPLES	pH	E.C (µS/cm)	TDS (mg/L)	DO (mg/L)	Turbidity (NTU)
Kanshio	6.80 ± 0.14^{d}	55.26 ± 0.91^{a}	88.75 ± 6.29^{bc}	4.05 ± 0.37^{a}	0.48 ± 0.05^{a}
North Bank	7.20 ± 0.08^{b}	61.05 ± 1.44a	85.50 ± 9.40^{bc}	4.25 ± 0.52^{a}	0.50 ± 0.05^{a}
Kanshio Control	7.40 ± 0.08^{a}	42.08 ± 0.18^{b}	98.25 ± 10.99^{ab}	4.38 ± 0.46^{a}	0.39 ± 0.06^{b}
Northbank Control	6.95 ± 0.13^{c}	56.00 ± 7.48^{a}	84.25 ± 6.85^{a}	4.33 ± 0.19^{a}	0.35 ± 0.20^{b}
P-Value	<0.001	0.145	0.002	0.692	0.002
NESREA	7.0-8.5	400	500	4.0-5.0	5.0

Note: Means on the same column with different superscripts differ significantly

E.C = Electrical Conductivity; TDS = Total Dissolved Solid; DO = Dissolved Oxygen;

levels were consistent across samples, averaging around 4.0 mg/L, which is within NESREA's range of 4.0–5.0 mg/L, suggesting adequate oxygen levels for aquatic life. Turbidity was marginally higher in the water from Kanshio and North Bank, ranging from 0.48 to 0.50 NTU, compared to the controls, yet still well below the NESREA limit of 5.0 NTU, indicating minimal particulate pollution.

Heavy metal distribution in soil and water

The results for heavy metal concentrations in soil and water samples from the Kanshio and North Bank mechanic sites are presented in Table 3 and Table 4. In the soil samples, North Bank exhibited a significantly higher concentration of Mn at 1.24 mg/kg, while Kanshio recorded only 0.28 mg/kg. Conversely, Fe levels were much higher in Kanshio at 19.48 mg/kg compared to North Bank's 11.41 mg/kg. Both sites showed elevated levels of Pb and Cr, with Kanshio having greater concentrations of Pb (3.14 mg/kg) and Cr (1.04 mg/kg) than North Bank, which had 2.78 mg/kg and 0.57 mg/kg, respectively. Control samples indicated much lower concentrations of all metals, suggesting possible contamination from mechanic activities at both locations. Nevertheless, the heavy metal concentrations in all samples were well below NESREA's regulatory limits, especially for Pb (164 mg/kg) and Cr (100 mg/kg). In the water samples, no Mn or Pb was detected in any of the water from both sites or the control. Fe concentrations were low, with Kanshio and the control showing similar values around 0.02 mg/L, slightly higher than North Bank's 0.01 mg/L. Cr levels were not detectable in the water samples from any location. All measured values in water remained within NESREA's guidelines, indicating minimal heavy metal contamination in the water sources near the mechanic sites.

The pH levels of soils from the North Bank and Kanshio mechanic sites were slightly alkaline, measuring 7.2 and 6.9, respectively, which falls within NESREA's acceptable range of 6.5 to 8.5. This finding is consistent with the work of Okoronkwo *et al*. (2006), who noted a similar slightly alkaline pH in mechanic site soils in Owerri, likely due to the presence of metallic contaminants like Pb and Fe. In contrast, Nwachukwu *et al*. (2010) reported more acidic soils in mechanic villages in Lagos, which may be attributed to greater degradation or fuel leakage.

The moisture content was higher at North Bank (14.23%) compared to Kanshio (11.28%), indicating better water retention. This observation aligns with

Table 3: Mean Heavy Metal Concentration of Soil Samples Across Locations in Makurdi

SAMPLES	Mn(mg/kg)	Fe(mg/kg)	Pb(mg/kg)	Cr(mg/kg)
Kanshio Soil	0.28 ± 0.04^{b}	19.48 ± 3.33^{a}	3.14 ± 0.15^{a}	1.04 ± 0.14^{a}
North Bank Soil	1.24 ± 0.10^{a}	11.41 ± 1.79^{b}	2.78 ± 0.28^{b}	0.57 ± 0.06^{b}
Kanshio Control	0.22 ± 0.01^{bc}	4.73 ± 0.73^{c}	0.12 ± 0.02^{c}	0.30 ± 0.02^{c}
North Bank control	0.14 ± 0.04^{c}	3.91 ± 0.49^{c}	0.12 ± 0.01^{c}	0.15 ± 0.07^{d}
P-Value	<0.001	<0.001	<0.001	<0.001
NESREA	–	–	164	100

Note: Means on the same column with different superscripts differ significantly

Mn = Manganese; Fe = Iron; Pb = Lead; Cr = Chromium

Table 4: Mean Heavy Metal Concentration for Water Samples Across Locations in Makurdi

SAMPLES	Mn (mg/l)	Fe (mg/l)	Pb (mg/l)	Cr (mg/l)
Kanshio	0.00 ± 0.00	0.02 ± 0.01^{a}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
North Bank	0.00 ± 0.00	0.01 ± 0.00^{b}	0.00 ± 0.00^{a}	0.00 ± 0.00^{a}
Kanshio Control	0.00 ± 0.00	0.02 ± 0.00^{a}	0.00 ± 0.00^{b}	0.00 ± 0.00^{a}
Northbank Control	0.00 ± 0.00	0.00 ± 0.00^{b}	0.00 ± 0.00^{b}	0.00 ± 0.00^{a}
P-Value	0.000	<0.001	0.024	0.756
NESREA	0.05	0.1	–	–

Note: Means on the same column with different superscripts differ significantly

Mn = Manganese; Fe = Iron; Pb = Lead; Cr = Chromium

Olayinka and Alo (2004), who found that mechanic site soils with increased clay and silt content tend to retain more moisture.

Additionally, Kanshio exhibited a higher Cation Exchange Capacity (CEC) of 4.19 meq/100g, compared to North Bank's 3.55 meq/100g, which is consistent with the findings of Odjegba and Atewolara-Odule (2016), who associated higher CEC values with soils rich in organic matter and clay. In the water samples, pH levels were within NESREA's acceptable range of 7.0 to 8.5, corroborating the results of Akan *et al*. (2012), who reported similar findings in water samples near mechanic sites in Kaduna. The electrical conductivity (EC) levels were below NESREA's threshold of 400 µS/cm, supporting the findings of Olaniran *et al*. (2013), who also noted low EC in water near mechanic sites in Port Harcourt. Although turbidity levels were elevated (0.48–0.50 NTU) compared to control samples, they remained below NESREA's limit of 5.0 NTU, similar to the results reported by Adie *et al*. (2009) in water near mechanic sites in Ibadan. However, the higher total dissolved solids (TDS) at Kanshio (88.75 mg/L) indicate potential contamination from site activities, as noted by Osibanjo and Ajayi (2017).

The levels of heavy metals in the soil, such as Pb and Cr, were found to be higher at Kanshio than at North Bank. This finding is consistent with Adekola *et al*. (2012), who reported increased levels near mechanic sites in Ilorin. Nevertheless, the concentrations of these heavy metals remained below the limits set by NESREA (164 mg/kg for Pb and 100 mg/kg for Cr), which aligns with the observations made by Eze and Agbo (2011). In contrast, the Manganese (Mn) levels were higher at North Bank, supporting the findings of Ibeto *et al*. (2013), who attributed similar results to residues from tires and brake pads. Water samples showed no detectable levels of Pb, Mn, or Cr, which is in agreement with Oyeku and Eludoyin (2010), who reported low heavy metal contamination in water sources in Ibadan. The Fe concentrations in the water samples (0.01–0.02 mg/L) were also within safe limits, consistent with the findings of Ikhane *et al*. (2015), who noted similarly low levels in water near mechanic sites.

Conclusion

This study has provided important insights into the contamination levels of soils and water surrounding mechanic sites in North Bank and Kanshio, particularly in relation to NESREA standards. The soils exhibit slight alkalinity that remains within acceptable limits; however, the detection of heavy metals like Pb and manganese, especially at the Kanshio site, points to significant contamination associated with mechanic activities. While the concentrations are below NESREA's permissible limits, their presence indicates ongoing pollution that could potentially worsen over time. The water samples generally fell within safe limits for most parameters, but the higher levels of total dissolved solids (TDS) at Kanshio suggest that runoff from site activities is impacting water quality. From a broader perspective, this study supports trends observed in previous research throughout Nigeria, where mechanic sites are known to contribute to localized environmental pollution. However, the relatively lower contamination levels compared to studies from larger cities like Lagos indicate that while the risk exists, there is a chance to implement preventive measures now, before the situation escalates.

This study therefore suggests that regular monitoring of soil and water in and around mechanic sites should be conducted by relevant environmental agencies to ensure compliance with NESREA standards. This will help in the early detection of pollution and enable timely interventions to prevent further ecological degradation. Mechanic sites should adopt environmentally friendly practices in waste disposal, such as proper handling and disposal of used oils, batteries, and other hazardous materials. This will reduce the leaching of harmful substances into the soil and water bodies, thereby minimizing contamination. Environmental awareness and training programs should be organized for operators of mechanic sites. These programs should focus on the importance of environmental protection, proper waste management practices, and the long-term benefits of maintaining clean surroundings. And also, bioremediation techniques, such as the use of microorganisms to degrade harmful pollutants, be introduced in contaminated areas. This could help in restoring the soil and water quality over time.

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