

## RESEARCH ARTICLE

## A COMPREHENSIVE ANALYSIS OF SOIL AND WATER CONTAMINATION NEAR AUTO-MECHANIC WORKSHOPS IN WARRI AND ENVIRON SOUTH-SOUTH, NIGERIA

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## ARTICLE DETAILS

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## ABSTRACT

The pH values of soil samples collected from the topsoil to a depth of 50cm range from 5.78 to 6.64, with an average of 6.284, indicating slightly acidic soil. Water samples near auto-mechanic workshops fall below NSDWQ and WHO standards. Soil heavy metal levels mostly meet ACV and Dutch guidelines, except for Iron (Fe), Copper (Cu), Zinc (Zn), Cadmium (Cd), and Chromium (Cr). Soil contamination analysis shows a high to extreme degree of contamination, likely from the auto-mechanic workshop. Positive correlations between metal pairs suggest a common source and transport to the soil. Principal Component Analysis (PCA) of soil samples reveals Cu, Zn, Fe, Ni, and Pb as dominant metals, while Ni-Cr shows negative correlations with others. In water samples, Cu, Cd, and Co dominate, indicating a different contamination source. Soil and water samples generally meet NSDWQ and WHO standards, but Total Dissolved Solids (TDS), Electrical Conductivity (EC), and Salinity exceed these standards. Understanding these findings is crucial for managing and mitigating contamination risks near auto-mechanic workshops.

## KEYWORDS

Contamination, Principal load index, Principal Component Analysis, Dendrogram, ANOVA

## 1. INTRODUCTION

Automotive services and repair shops constitute the primary contributors to the production of hazardous waste. These establishments generate various types of waste during their daily operations, including used oils and fluids, discarded metal parts, asbestos brake pads, and waste resulting from the use of cleaning solvents to clean parts. Disposing of these wastes is both expensive and risky due to their hazardous nature. Among the hazardous waste produced in auto repair shops, the solvents used for cleaning parts are particularly dangerous. Many of the chemicals present in these solvents pose significant risks to human health and the environment (Imevbore and Adeyemi, 1981). Improper handling of these chemicals can lead to their contamination of the soil, surface water, groundwater, and even the atmosphere (Adeniyi and Afolabi, 2002). Numerous parts cleaners and solvents pose health hazards, and used oil may contain toxic components such as lead, cadmium, barium, and other potentially harmful metals (Edebiri and Nwanokwale, 1981; USEPA, 2001).

While heavy metals are essential for living organisms at appropriate levels, excessive concentrations of these metals are associated with pollution and toxicity problems. Auto-mechanic workshops have emerged as a major source of increased heavy metal levels in the Nigerian ecosystem (Adewale and Uchegbu, 2010). These workshops are predominantly situated in open plots of land or building structures within rural and urban towns and cities. Various specialized activities, such as welding, body fabrication, electrical works, panel beating, and spray painting, take place around these workshops, each generating waste materials like gasoline, paints, and diesel engine oil, which can negatively impact the surrounding soil and plants. Despite the harmfulness of the

waste these workshops in Nigeria produce, it has not received enough attention. It is imperative to continuously monitor and manage the nature, volume, harmful effects, disposal methods, and environmental impacts of these waste materials. In a study in Abraka, Delta State, the researcher looked at the physicochemical characteristics of soils in automobile workshops and discovered that the activities in these workshops contributed to soil contamination. However, the contamination levels are not currently high (Osakwe, 2014).

Another study focused on two mechanic villages in Benin City, Nigeria. The research revealed the presence of elevated concentrations of metals such as Fe, Zn, Mn, Pb, Cu, Cd, Cr, and Ni in the soil, exceeding the limits set by the World Health Organization (WHO) and the National Environmental Standards and Regulations Enforcement Agency (NESREA) (Idugboe et al., 2014). This indicated pollution in the soil of the auto-mechanic villages, primarily due to the waste generated in the auto-mechanic market. Furthermore, a group of researchers investigated the impacts of informal automobile mechanic workshop activities in Akinyele L.G.A., Oyo State, on groundwater quality (Oloruntuba, and Ogunbunmi, 2020). The results showed high concentrations of heavy metals such as Pb, Cd, Cr, and Cu, as well as oil and grease content, in the groundwater of the study area. This contamination of the water supply poses a significant threat to consumers, compromising water quality.

This research aims to identify and understand the effects of heavy metals on soil and groundwater resulting from effluent waste discharges from automobile mechanic workshops. The study also aims to provide potential mitigation strategies and methods for controlling contamination and treating the affected soil. This study is crucial for scientific inquiry and practical application, aiming to reveal the environmental consequences of auto-mechanic activities. It serves as a foundation for

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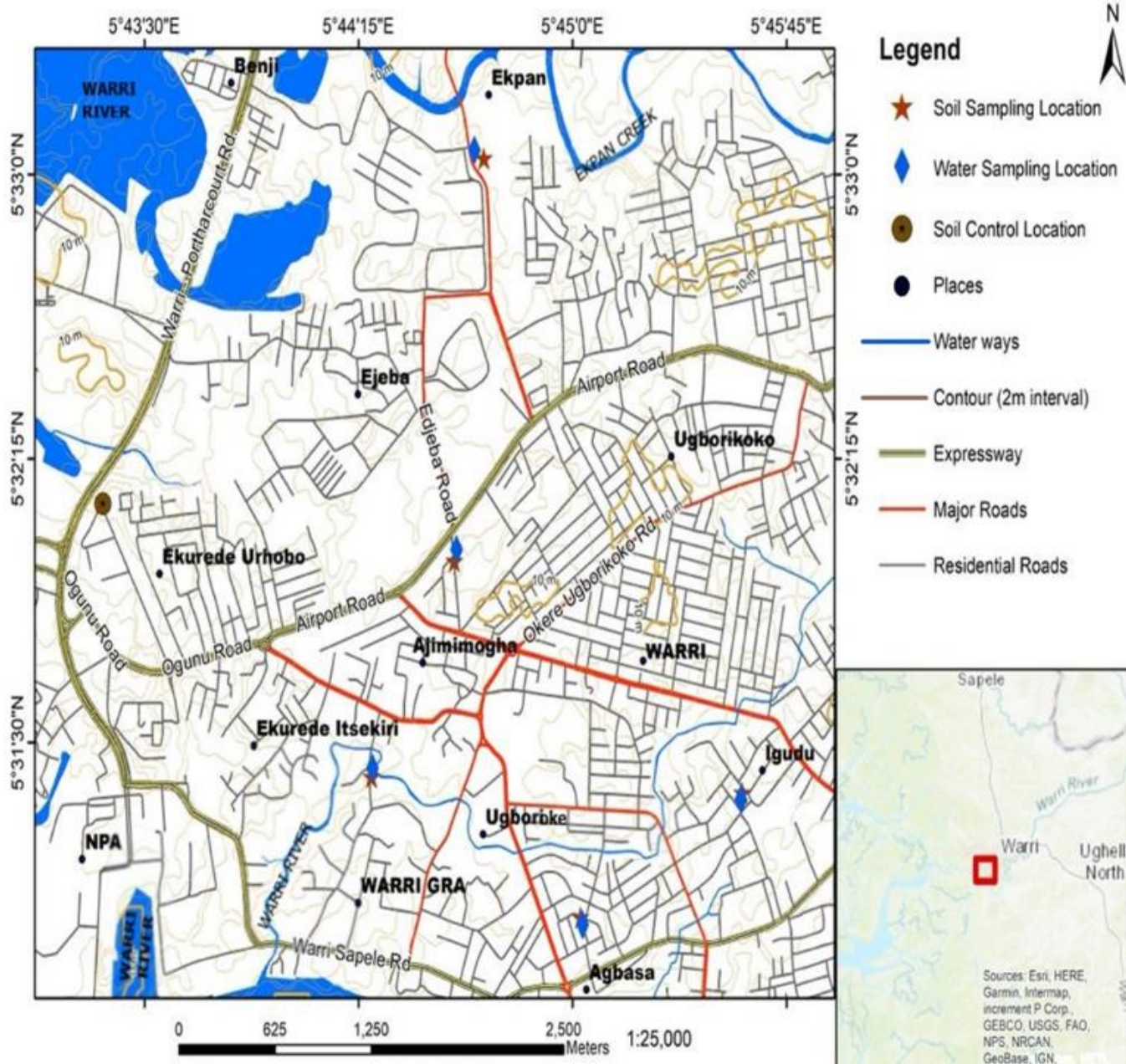
informed regulatory decisions and strategies to mitigate adverse impacts on the environment and public health. The research identifies heavy metals and contaminants in soil and water, emphasizing risks to public health. Compliance with environmental standards is assessed against national and international benchmarks. The study delves into correlations between heavy metals, aiding in pollution control measures. The data guides land-use planning, informs policymakers, and advocates for targeted remediation strategies to minimize environmental impact from auto-mechanic activities. In essence, it provides valuable insights for diverse regions, promoting effective environmental management.

**1.1 Review of the Study Area**

Warri, a coastal town located strategically in the Niger Delta region of Nigeria, serves as an operational hub for numerous oil-producing and servicing companies. Its population is estimated to exceed half a million people based on the 2006 population census, (Demographic and Social Statistics, 2020). Warri is located between latitudes 5° 30'N to 5° 33'N and longitudes 5° 29' to 5° 48'E. It is located approximately 50 kilometers away from the Atlantic Ocean within the oil-rich provinces of Nigeria. The town is situated in a low-lying area with an average elevation of 6 meters above sea level. It features a flat landscape that gently slopes towards the Warri River and its tributaries, which ultimately discharge into the Atlantic Ocean. Warri has two main entry points, one from Benin in Edo State and the other from Port-Harcourt in River State.

Additionally, the city has a wide variety of road networks, such as the one that connects the Effurun neighborhood to the Warri-Sapele Road via the NPA/NNPC expressway and Refinery Road, among others (Figure 1). These well-connected roads make it convenient to access various sampling locations within the city. The study area in Warri is characterized by a low-lying topography with an average height of 6 meters above sea level. The Warri River and its intricate network of tributaries and creeks, which ultimately flow into the sea, drain it (Figure 2). The Warri River exhibits extensive flood plains and a dendritic drainage pattern, with tributaries branching without a distinct orientation. Due to the mixture of fresh and saltwater, the riverbanks and associated creeks create a brackish environment, leading to the presence of different species of mangrove plants along the riverbanks (Olabaniji and Owoyemi, 2006).

The climate in Warri belongs to the tropical equatorial type and is characterized by two main seasons: a long, wet season from April to October and a short, dry season from November to March. The interaction of the south-west and north-east trade winds that traverse Nigeria affects these seasons. Annual rainfall typically exceeds 3000mm, as no month of the year is devoid of rainfall. The temperature remains above 28°C, and humidity levels hover around 80% (Iloeje, 1981). The natural vegetation in the area is predominantly mangrove swamp forest, transitioning to rainforest further inland. However, human activities like farming and logging have extensively altered the original vegetation, often leading to its replacement by grassland.



**Figure 1:** Location Map of Warri City Showing Sampling Points

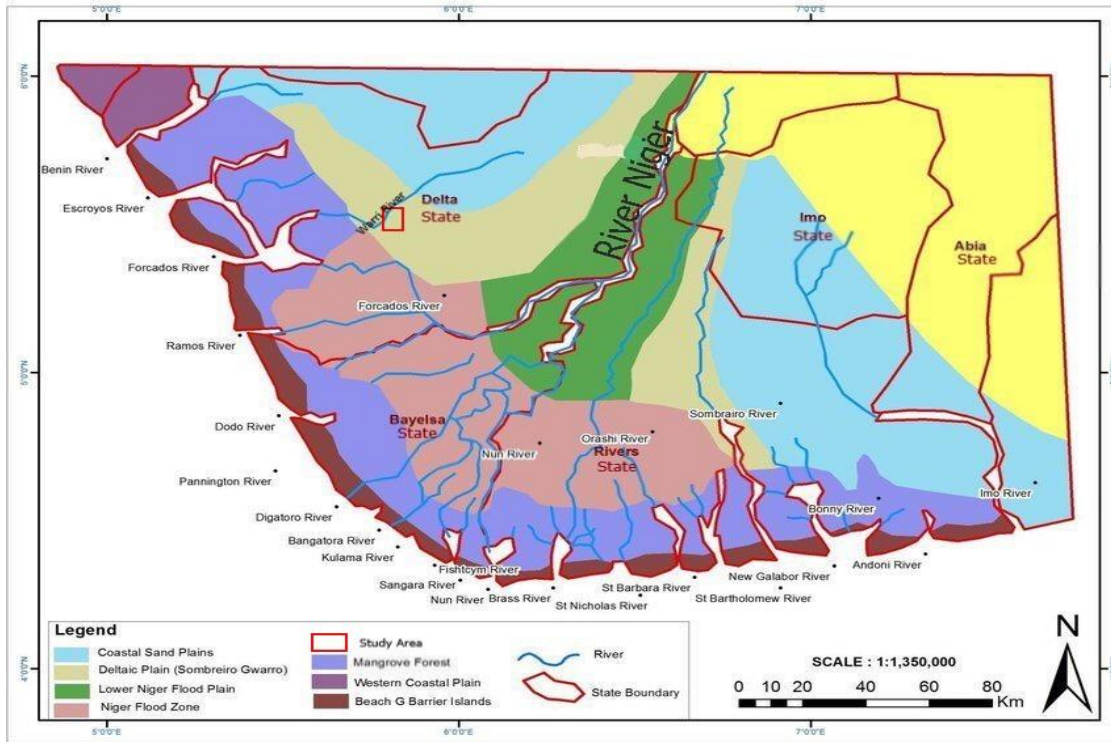


Figure 2: Map of the Niger Delta Showing the Drainage System, Rivers and Vegetation Zones (Chidumeje et al., 2015)

1.2 Geology of the study area

The Niger Delta basin covers most areas of the Rivers, Bayelsa, Edo, and Delta states of Nigeria. It covers an area of approximately 75000 km<sup>2</sup> and consists predominantly of cretaceous to recent, regressive clastic sediment piles of about 8000–12,000 m thick (Orife and Avbovbo, 1982). The Niger Delta is located in the Gulf of Guinea, central West Africa, at the culmination of the Benue trough and is considered one of the most prolific hydrocarbon provinces in the world (Corredor et al., 2005). The delta consists of a broad riverine area through which the river Niger enters the Atlantic Ocean, dividing into numerous rivulets that fan out into the sea. It also includes a number of tidal creeks separating small islands less than 10 meters above sea level (Offodile, 2002).

The Anambra basin and the Abakaliki high to the north, the Cameroun volcanic line to the east, the Dahomey embayment to the west, and the

Gulf of Guinea to the south define the boundaries off the Niger Delta. Burke and Dewey remarked that the siliciclastic system of the Niger Delta began to prograde across the pre-existing continental slope into the deep sea during the late Eocene and is still active today (Burke and Dewey, 1972). The town of Warri is underlain by a sequence of sedimentary formations with a thickness of up to 8000m, which includes, from bottom to top, the Akata formation, the Agbada formation, the Benin formation, and largely the Sombreiro-Warri Atlantic plain sands (Allen, 1965; Reyment, 1965; Short and Stauble, 1967). The Sombreiro-Warri deltaic plain sand is quaternary to recent in age and directly underlies the study area, as shown in Figure 3. consists of fine to medium unconsolidated sands that are often feldspathic (30–40% with feldspars) and occasionally gravelly (Wigwe, 1975). The sequence is locally stratified with peat and lenses of soft and plastic clay that could be sandy and shaly, predominantly unconfined, and generally do not exceed 120m in thickness.

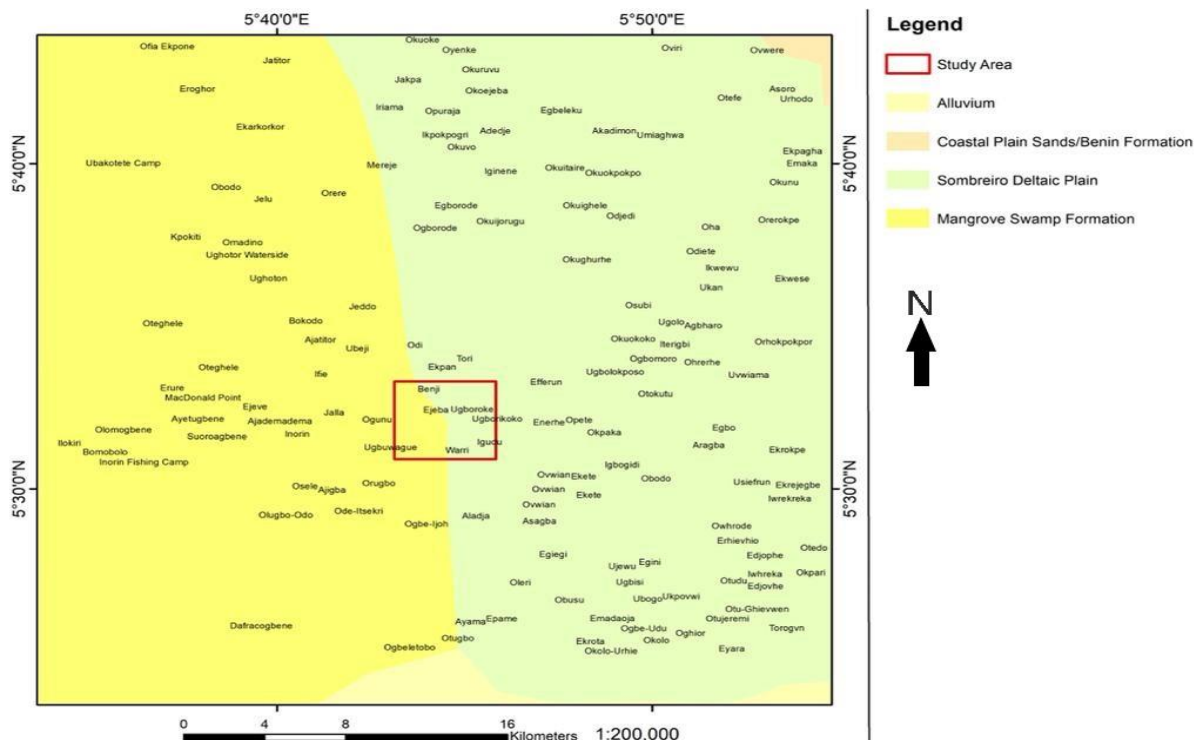


Figure 3: Geological Map of the Study Area

## 2. MATERIALS AND ANALYTICAL METHODS

This study was carried out in different auto repair workshops situated/located in Warri City. Warri is located at latitudes 5°31'N to 5°33'N and longitudes 5°43'E to 5°45'E. Soil samples were collected at five (5) auto repair workshops and two control soil samples at locations away from the auto-mechanic workshops, and four (4) samples were collected at each site at depths ranging from 0–10 cm, 10–25 cm, 25–40 cm, and 40–50 cm. Two other sand samples were also collected with the same depth specifications at locations away from the mechanic workshops for control purposes. A hand trowel was used in digging to the required depth and was washed at each site with water before further

sampling. The sampled soils were stored in clear plastic polythene bags labeled, then transported to the laboratory for analysis. Five water samples and one control sample were collected in clear plastic one-liter bottles; they were first washed with water before the collection of water samples. These water samples were collected at or close to the auto-mechanic workshops. From there, they were stored and transported for analysis. The soil and groundwater samples were analyzed for heavy metals (copper, zinc, cadmium, iron, cobalt, nickel, chromium, and lead) using a Buck Scientific 210 VGP Atomic Absorption Spectrometer (AAS). The coordinates of each sample location are shown in Table 1.

**Table 1:** Location of Sampling Points and their Co-ordinates.

Location, Name of Workshop and Type of Workshop	Longitude And Latitude (GPS Co-Ordinates)	Samples Collected	Age of Auto-Mechanic Workshop
SS1, HDW1, Akin Mechanic Workshop, Cars and Jeep/Suvs, Igbudu	05031.361'N-005045.586'E	Water and Soil Samples	21 Years
SS2, HDW2, Akpos Mechanic Workshop, Cars, Trucks, Agbassa	05031.039'N-005045.029'E	Water and Soil Samples	13 Years
SS3, HDW3, Lukes Auto Mechanic Shop, Cars and Trucks, NNPC Housing Estate, Ugboroke / Ekpan	05033.043'N-005044.690'E	Water and Soil Samples	8 Years
SS4, HDW4, Alfreds Mechanic workshop, Cars /SUV/ Trucks, Ajamimogha By Pass	05°31.397'N -005°44.322'E 05°31.417'N-005°44.330E	Soil Water	5 Years
SS5, HDW5, Cars, Trailers, Truck, Jeep, Fani-Kayode Street off Airport Road	05031.958'N-005044.586'E	Soil and Water	18 Years

### 2.1 Contamination Factor (CF)

Contamination factor CF determines the level of contamination of soils in terms of anthropogenic input. The calculated results are listed in the table with their nomenclature.

Contamination Factor (CF) =  $\frac{\text{Concentration of metals in sample of area of study}}{\text{Concentration of background metal}}$

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$$C_f = C_o / C_n \quad (1)$$

The  $C_i$  is the single element index.  $C_o$  is the mean content of metals from at least five sampling sites and  $C_n$  is the metal concentration of the control samples.

### 2.2 Degree of Contamination

A significant number of indicators have been designed to approximate the quality of soils (Caeiro et al., 2005). The Contamination Degree (Cd) (Håkanson, 1980) is calculated by:

$$Cd = \sum C_f \quad (2)$$

**Table 2:** Contamination factor (CF) and degree of contamination (Cd values) (Håkanson, 1980)

S/N	CF Value	Level of Contamination	Cd Value	Degree of Contamination
1	CF < 1	Low contamination factor	Cd < 7	Low degree of contamination
2	1 < CF < 3	Moderate contamination factor	7 ≤ Cd < 14	Moderate degree of contamination
3	3 < CF < 6	high degree of contamination	14 ≤ Cd < 21	High degree of contamination
4	Cd ≥ 21	very high degree of contamination	Cd ≥ 21	Very high degree of contamination

### 2.3 Pollution Load Index (PLI)

The pollution load index represents the number of times the metal content in the soil exceeds the average natural background concentration and gives a summative indication of the overall level of heavy metal toxicity in a particular sample. Control samples were taken to give a natural background (Angulo, 1996). The pollution load index (PLI) can give an estimate of the heavy metal contamination status and the necessary action that should be taken. The PLI is obtained as a contamination factor CF of each metal concerning the natural background value in the soil using equations (Angulo, 1996).

$$PLI = (CF_1 \times CF_2 \times CF_3 \times CF_n)^{1/n} \quad (3)$$

Where, CF= contamination factor

n = number of metals

### 2.4 Geoaccumulation Index (I-geo)

The geo-accumulation index was calculated from the equation

$$\text{Geo-accumulation index (i-geo)} = \log_2 \frac{C_{\text{metal}}}{1.5 C_{\text{ref}}} \quad (4)$$

Where,  $C_{\text{metal}}$  = concentration of heavy metal in soil sample

$C_{\text{ref}}$  = concentration of heavy metal in control or reference sample

1.5= constant to minimize the possible variation in control value which may be attributed to lithogenic factors.

## 3. RESULTS AND DISCUSSION

### 3.1 Data Analysis of Physiochemical Parameters and Heavy Metals of Soil Samples Collected at selected Auto-Mechanic Workshop.

Physiochemical parameters and heavy metals for soil samples from selected auto-mechanic workshops in Warri are shown in Tables 3 and 4. pH is among several properties that affect the availability, retention, and mobility of nutrients and heavy metals in soils. The pH values of soil samples collected from topsoil to 50cm in depth range from 5.78 to 6.64, with an average value of 6.284. This indicates that the soil is slightly acidic. The acidic nature of the soil is due to the presence of carbonic acid from the decay of organic matter that produces  $H^+$ , which is responsible for acidity (Wikipedia). The mean concentration value of soil electrical conductivity (EC) ranges from 973.5 to 1153.25  $\mu S/cm$ . It measures the amount of salt in the soil. It is an important indicator of soil health. If the values of EC are very high, it will affect soil health and hinder plant growth in that soil by affecting the soil-water balance. The mean concentration of

EC is below the permissible limit of 100  $\mu\text{S}/\text{cm}$  for soil.

The TOM values range from 1.475 to 1.91 percent, with a mean of 1.663%. Organic matter is the reservoir of essential and non-essential elements for plant growth and development; here, increased organic matter may lead to increased soil productivity (Anikwe and Nwobodo, 2001). With an increase in organic matter, the soil recovers its natural buffer capacity; this means an increase in pH in acid soils (Mielniczuk, 1996). The soil organic carbon mean concentration ranges from 0.85 to 1.1 (%). Higher soil organic carbon promotes soil structure or tilth. This improves soil aeration (oxygen in the soil), water drainage, and retention, and reduces the risk of erosion and nutrient leaching. Soil organic carbon is a measurable component of soil organic matter that contributes to nutrient retention, soil structure, moisture retention, degradation of pollutants, and carbon sequestration.

Soil organic carbon influences nutrient availability in the soil and also improves soil physical structure by promoting aggregation. The mean concentration values of ECEC and EA range from 1.94 to 5.49  $\text{cmol}/\text{kg}$  and 0.76 to 1.62  $\text{cmol}/\text{kg}$ , respectively. Soils with a higher clay fraction tend to have a higher ECEC. Organic matter has a very high ECEC. Pure sand has a very low ECEC, less than 2  $\text{cmol}/\text{kg}$ . The low mean concentration value of ECEC indicates that the organic matter present is low, which will not allow the root plant to grow effectively and maintain its health. Soil acidity is a crop production problem. When the acidity of the soil is high, the roots of plants will not effectively grow. The causes for soils to become acidic are acid rainfall and leaching, acidic parent material, organic matter decay, and nitrification of ammonium. The mean concentration values of calcium, magnesium, potassium, and sodium range from 0.278 to 0.58 ( $\text{cmol}/\text{kg}$ ), 0.82 to 1.14 ( $\text{cmol}/\text{kg}$ ), 0.18 to 3 ( $\text{cmol}/\text{kg}$ ), and 0.007 to 0.05 ( $\text{cmol}/\text{kg}$ ).

Calcium is important for continuous cell division and formation as it regulates hormonal activity and increases both fruit set and quality. Magnesium is the center molecule of chlorophyll, improves the utilization and mobility of phosphorus, and helps the plant form and transport sugar

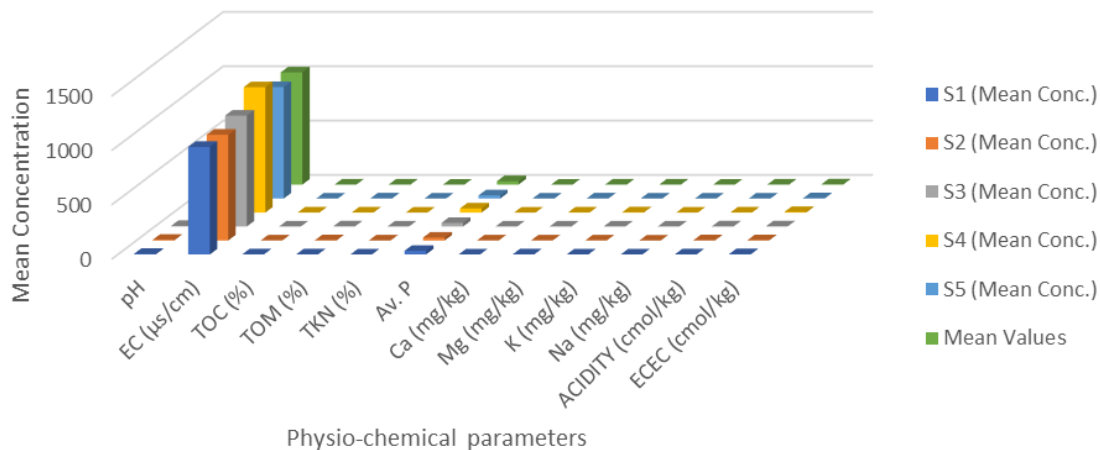
and starches. When the potassium ion concentration is too high, it affects the way the soil absorbs other critical nutrients (Ishfaq et al., 2022). The low mean concentration of potassium ions will lower the concentration of phosphorus ions in the soil and also help to improve drought resistance (Ishfaq et al., 2022). The concentration of magnesium ions is dominant compared to other positive cation ion concentrations in the soil samples collected from the study area. The low mean concentration values of sodium and magnesium confirm that the electrical conductivity mean concentration value is also low in soil samples collected from the study area, as shown in Table 3 and Figure 4.

The mean concentration values of the following heavy metals in the soil samples (lead (Pb), cobalt (Co), and nickel) range from 3.17–5.5  $\text{mg}/\text{l}$ , 4.37–5.7  $\text{mg}/\text{l}$ , and 6.82–7.2  $\text{mg}/\text{l}$ , respectively, below the ACV and Dutch guidelines. The mean concentration values of chromium (Cr) range from 69.09 to 107.5  $\text{mg}/\text{l}$ , which is below ACV and higher than the Dutch guideline, except for S5, which is below the Dutch guideline permissible value of 100  $\text{mg}/\text{l}$ . The average amount of iron (Fe) in the samples is between 817.5–2827.5  $\text{mg}/\text{l}$ , which is higher than the 40  $\text{mg}/\text{l}$  limit set by ACV and the Dutch government. The higher iron (Fe) levels may be because of auto mechanics throwing away iron (Fe) scrap, unused car body parts, tin cans, solvents, hydraulic fluid, used lubricants, and other things (Abidemi, 2011). and Cadmium (Cd) ranges from 2.5 to 6  $\text{mg}/\text{l}$ , which is higher than the Dutch guideline permissible value of  $1\text{mg}/\text{l}$  but less than the ACV permissible value of 10  $\text{mg}/\text{l}$ .

Most of the zinc (Zn) concentrations and levels that are high are likely caused by auto mechanic work, since zinc is an element that is added to many lubricating oils (Abenchi et al., 2010). As you can see in Table 4 and Figure 5, the copper (Cu) levels are higher than the ACV and Dutch guideline levels of 70–200  $\text{mg}/\text{l}$  and 20–50  $\text{mg}/\text{l}$ , respectively. This is because the copper levels in S3 are below the Dutch guideline. According to automobile waste containing electrical and electronic parts, such as copper wires, electrodes, and copper pipes and alloys, from corroding vehicle scraps is a major source of copper, which gradually leached into the soil (Nwachukwu et al., 2011).

**Table 3:** Physicochemical parameter of Soil Samples from selected Auto-Mechanic Workshops in Warri

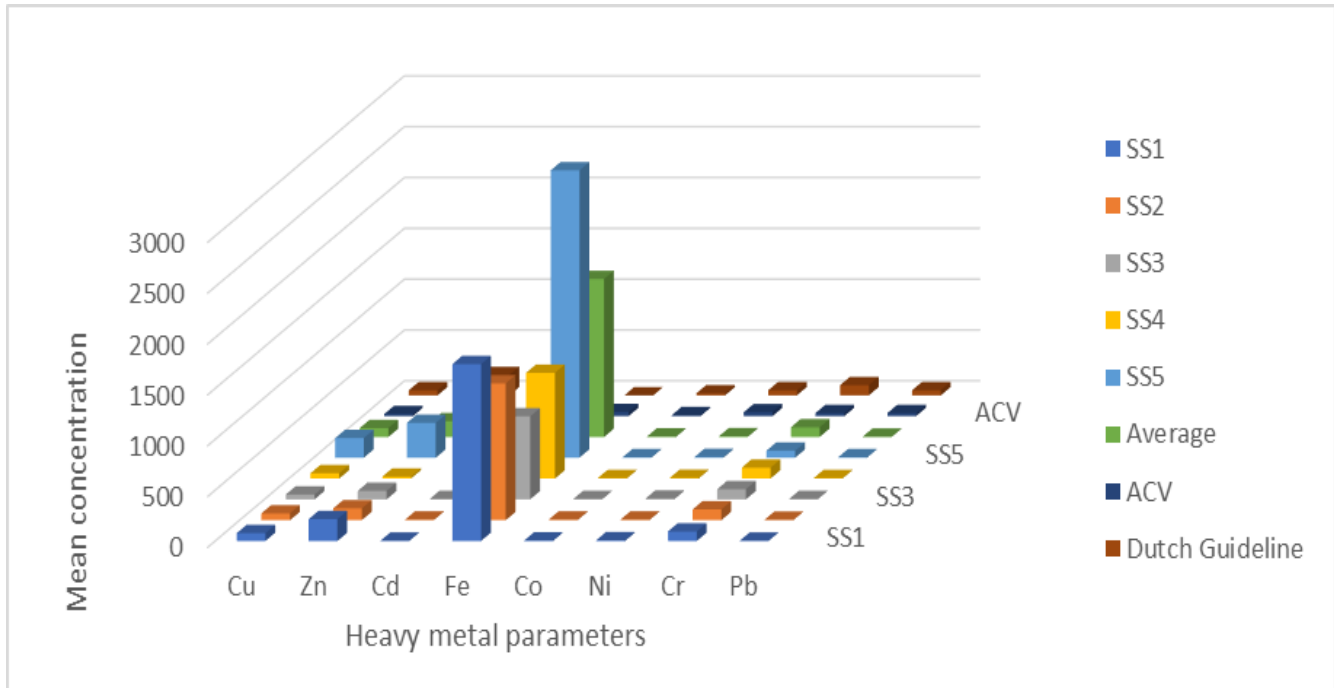
Soil Sampling Points/Parameters	S1 (Mean Conc.)	S2 (Mean Conc.)	S3 (Mean Conc.)	S4 (Mean Conc.)	S5 (Mean Conc.)	Mean Values
pH	6.16	6.22	5.78	6.62	6.64	6.284
EC ( $\mu\text{S}/\text{cm}$ )	989.75	973.5	1020.75	1153.25	1026.25	1032.7
TOC (%)	1.1	1.07	0.85	0.92	0.86	0.96
TOM (%)	1.91	1.85	1.475	1.59	1.49	1.663
TKN (%)	0.16	0.14	0.16	0.15	0.15	0.152
Av. P	32.6	26.75	33.05	37.65	29.8	31.97
Ca ( $\text{mg}/\text{kg}$ )	0.14	0.58	0.13	0.15	0.39	0.278
Mg ( $\text{mg}/\text{kg}$ )	1.14	0.95	0.82	1.21	1.2	1.064
K ( $\text{mg}/\text{kg}$ )	0.47	0.43	0.18	3.00	0.54	0.924
Na ( $\text{mg}/\text{kg}$ )	0.05	0.02	0.04	0.007	0.03	0.0294
ACIDITY ( $\text{cmol}/\text{kg}$ )	0.76	1.62	0.97	1.13	1.04	1.104
ECEC ( $\text{cmol}/\text{kg}$ )	2.56	2.335	1.94	5.49	3.2	3.105



**Figure 4:** Mean concentration against physicochemical parameters of soil samples

**Table 4: Mean Concentrations of Heavy Metals of Soil (Mg/Kg) from Auto-Mechanic Workshops.**

Soil Sampling Points	SS1	SS2	SS3	SS4	SS5	Mean Conc.	ACV (Puyate et.al 2007)	Dutch Guideline
<b>Cu (mg/kg)</b>	76.5	66.75	48	52.25	193.5	87.4	20	50
<b>Zn (mg/kg)</b>	215	116.75	83.5	18.75	343.5	155.5	70	200
<b>Cd (mg/kg)</b>	3.25	6	4	4.5	2.5	4.05	10	1
<b>Fe (mg/kg)</b>	1740	1345	817.5	1040	2827.5	1554	40	-
<b>Co (mg/kg)</b>	5.7	5.65	4.37	5.57	5.35	5.328	10	20
<b>Ni (mg/kg)</b>	7	6.93	6.82	7.05	7.2	7	38	50
<b>Cr (mg/kg)</b>	93.75	106.25	100.25	107.5	69.09	95.368	30	100
<b>Pb (mg/kg)</b>	3.55	3.87	3.17	3.95	5.5	4.008	30	50



**Figure 5: Mean concentration against Heavy metal parameters of soil samples**

**3.2 Assessment of Source of Contamination**

**3.2.1 Classification of Contamination Factor (CF) (Hakanson, 1980) and Igeo values (Muller, 1969)**

From Table 5, lead (Pb) has a mean contamination factor value of 0.1002, copper (Cu) has a mean contamination factor value of 4.37, and iron (Fe) has a mean contamination factor value of 38.85. The soil contamination factor values range from 0.1002 to 38.85, and their contamination level ranges from low to extreme contamination, while the Igeo values range from 3.296 to 10.632, and their contamination level ranges from strong to extreme contamination. This indicates that the soil samples collected from the auto-mechanic workshop area are highly contaminated with heavy metals. These heavy metals may affect the soil (inability of plants to grow and non-existence of living organisms), and this may also reduce the soil nutrient and organic matter content in the study area. The organic matter contents of the soil play an important role in absorption reactions,

water retention, and improving water holding capacity in the soil, as they prevent pollutants from reaching the groundwater source (Alloway and Aryes, 1997). The contamination factor decreases in this order, Fe<Cu<Cr<Zn<Co<Cd<Ni<Pb, while I-geo increases in this order, Cd>Co>Pb>Ni>Cu>Cr>Zn>Fe, as shown in Table 5.

**3.2.2 Degree of Contamination (Cd) (Håkanson, 1980) and Pollution Load Index classification (PLI) (Lacatusu, 2000)**

The mean degree of contamination ranges from 0.668 to 194.25. The degree of contamination classified the soil samples analyzed as low to very high, as shown in Table 6. However, the pollution index load classification values range from 22.9310 to 40.2417, which is classified as an extremely high degree of pollution. This indicates that the soil samples collected from the selected auto-mechanic workshop are extremely polluted with heavy metals, which will affect plants, living organisms, and water in the study area, as shown in Table 7.

**Table 5: Classification of Contamination Factor (CF) (Hakanson, 1980) and Igeo values (Muller, 1969)**

S/ N	Soil Sampling Points	Mean Concentration of Heavy metals	Contamination factor values (CF)	Contamination level	I <sub>geo</sub> values	Contamination level
1	<b>Cu (Mg/Kg)</b>	87.4	4.37 >3	Considerable	7.061 >5	Extremely
2	<b>Zn (Mg/Kg)</b>	155.5	2.22 <3	Moderate	8.89 >5	Extremely
3	<b>Cd (Mg/Kg)</b>	4.05	0.405 <1	low	3.296 <5	Strongly
4	<b>Fe (Mg/Kg)</b>	1554	38.85 >6	Extreme	10.632 >5	Extremely
5	<b>Co (Mg/Kg)</b>	5.328	0.5328 <1	low	3.57 <5	Strongly
6	<b>Ni (Mg/Kg)</b>	7.00	0.184211 <1	low	5.178 >5	Strongly
7	<b>Cr (Mg/Kg)</b>	95.368	3.178933 >3	Slight	7.553 >5	Extremely
8	<b>Pb (Mg/Kg)</b>	4.008	0.1002 <1	low	4.672 <5	Strongly

**Table 6:** Classification of Degree of Contamination (Cd) of soil samples (Håkanson, 1980)

DEGREE OF CONTAMINATION OF SOIL SAMPLES						
Heavy Metals	SS1	SS2	SS3	SS4	SS5	ΣCF
Cu (mg/kg)	3.825	3.337	2.4	2.612	9.675	21.85>21
Zn (mg/kg)	3.071	1.668	1.193	0.268	4.907	11.107<14
Cd (mg/kg)	0.325	0.60	0.40	0.45	0.25	2.025<7
Fe (mg/kg)	43.5	33.625	20.437	26.00	70.687	194.25>21
Co (mg/kg)	0.57	0.565	0.437	0.557	0.535	2.664<7
Ni (mg/kg)	0.184	0.182	0.179	0.185	0.189	0.921<7
Cr (mg/kg)	3.125	3.542	3.342	3.583	2.303	15.895>14
Pb (mg/kg)	0.118	0.129	0.106	0.132	0.183	0.668<7

Cd<7 Low degree of contamination, 7≤Cd<14 Moderate degree of contamination, 14≤Cd<21 High degree of contamination, Cd≥21 Very high degree of contamination

**Table 7:** Pollution Load Index classification (PLI) (Lacatusu 2000) of the Selected Auto-Mechanic Workshops

S/N	Auto-Mechanic Workshop Location	PLI Range Value	Contamination level
1	SS1	32.4685 > 16	Extremely high degree of pollution
2	SS2	31.6720 >16	Extremely high degree of pollution
3	SS3	24.3633 >16	Extremely high degree of pollution
4	SS4	22.9310 >16	Extremely high degree of pollution
5	SS5	40.2417 >16	Extremely high degree of pollution

**3.2.3 Assessment of source of contamination relationship of Heavy metals in soil samples using Correlation, Hierarchical Cluster Analysis and Principal Component Analysis**

The significance of the observed correlation coefficient results is presented in Table 8. Out of the 36 correlation values found between two parameters, five (5) were found to have a very strong positive correlation at the 1% level (P < 0.01), and seven (7) were found to have a strong positive correlation at the 50% level (P<0.05). Twelve (12) were found to be between Zn and Cu (0.905941), Fe and Cu (0.964702), Fe and Zn (0.951467), Ni and Cu (0.820585), Ni and Zn (0.648393), Ni and Fe (0.841135), Ni and Co (0.533545), Cr and Cd (0.822545), Pb and Cu (0.936951), Pb and Zn (0.725237), Pb and Fe (0.884903), and Pb and Ni (0.98002). The ten (10) heavy metals that show strong negative correlations were found to be between Cr and Cu (-0.95448), Cr and Zn (-0.93985), Cr and Fe (-0.92429), Cr and Ni (-0.71028), Cd and Cu (-0.65431), Cd and Zn (-0.70194), Fe and Cd (-0.64816), Ni and Cd (-0.55329), Pb and Cr (-0.80325), and Pb and Cd (-0.46596) (P>0.05). Six (6) were found to have a weak positive correlation that was less than 50% (P<0.05). The high degree of positive correlations between various pairs of metals reflects their simultaneous release, identical source from the auto-mechanic workshop, transport, and accumulation in soil. The significance of the correlations indicates that they may have originated from a common source of contamination. The heavy metals that show a strong negative correlation indicate that they are from different sources of contamination, as shown in Table 8.

The dendrogram divides the source of contamination of the sampling location and heavy metals into 3 clusters and 2 clusters based on their similarity in contamination sources, as shown in Figures 6 and 7. For

sampling location, Cluster 1 (SS3 and SS4) has the same source of contamination, Cluster 2 (SS1 and SS2) has the same source of contamination, and Cluster 3 (SS5) has the same source of contamination, as shown in Figure 6. Similarly, for heavy metals, Cluster 1 (Co, Pb, Cd, Ni, Cu, Cr, and Zn) has the same source of contamination as Cluster 2 (Fe), which has its own source of contamination that is similar to another cluster, as shown in Figure 7.

The heavy metal values obtained from the water samples were analyzed using the PCA (factor analysis) extraction method (Kaiser 1960), which revealed three groups of related elements and their communalities from the PCA, as shown in Table 13. Factor1: (Cu-Cd-Co). This accounted for about 51.171% of the total variance in the data matrix, with an Eigen value of 3.582, which is the most significant, and the source of contamination may likely be an auto-mechanic workshop. but Fe (-0.923) and Ni (-0.715) of factor 1 show a strong negative correlation, which indicates that they are from different sources of contamination, as shown in Figure 8. Factor 2: (Zn-Cd). This accounted for about 31.689% of the total variance of the variables, with an Eigenvalue of 2.218.

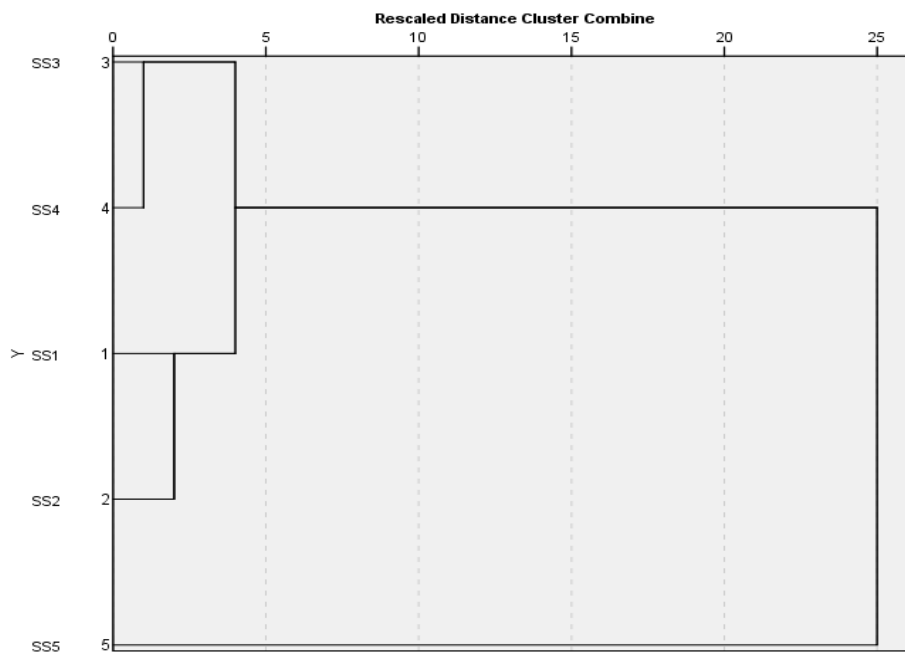
The elements also showed a positive correlation and were mostly likely to be from the same source as those in group 1, but Cr (-0.673) of factor 2 showed a strong negative correlation, which indicates that its source of contamination is different. Factor 3. (Ni-Cr). This is the least significant of all the factors. It accounted for 15.929% with an Eigenvalue of 1.115. From the PCA, the result revealed that Cu, Zn, Fe, Ni, and Pb are dominant metals with the highest variance and eigenvalues, as shown in Table 9. From Table 12, Ni-Cr shows a negative correlation with other metals, which indicates that their source may be different from other sources of contamination.

**Table 8:** Correlation Heavy metals of soil samples

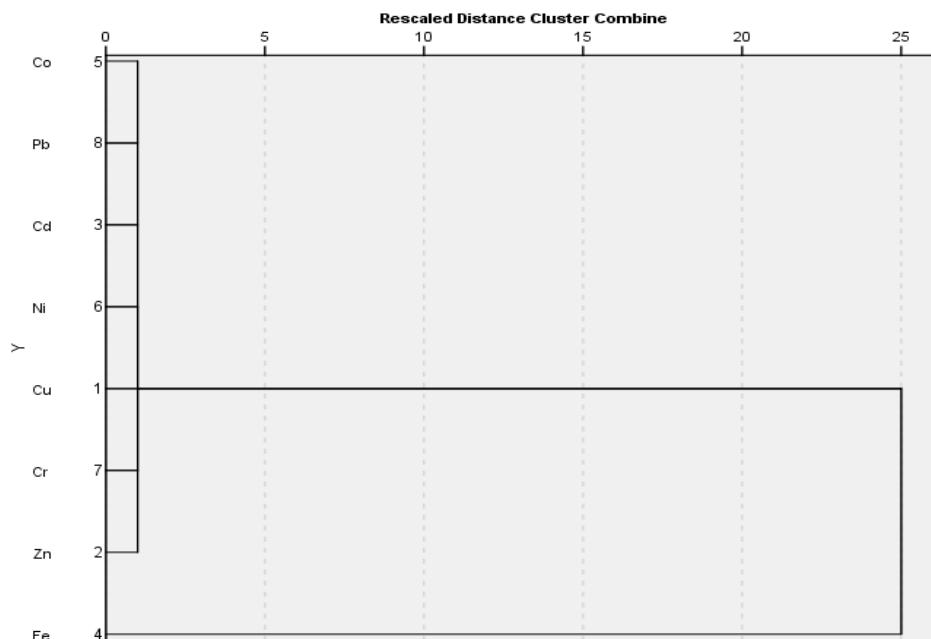
	Cu	Zn	Cd	Fe	Co	Ni	Cr	Pb
Cu	1							
Zn	0.905941	1						
Cd	-0.65431	-0.70194	1					
Fe	0.964702	0.951467	-0.64816	1				
Co	0.156491	0.177481	0.154534	0.349601	1			
Ni	0.820586	0.648393	-0.55329	0.841135	0.533545	1		
Cr	-0.95448	-0.93985	0.822545	-0.92429	0.016846	-0.71028	1	
Pb	0.936951	0.725237	-0.46596	0.884903	0.309154	0.908002	-0.80325	1

**Table 9:** Principal component analysis: Factor analysis of soil samples

Extraction Method: Principal Component Analysis (PCA)			
	Factor 1	Factor 2	Communalities
Cu	0.979	-0.054	0.962
Zn	0.922	-0.137	0.87
Cd	-0.732	0.483	0.769
Fe	0.985	0.082	0.976
Co	0.262	0.918	0.911
Ni	0.875	0.358	0.895
Cr	-0.954	0.294	0.996
Pb	0.909	0.197	0.865
Eigen values	5.887	1.357	
% of Variance	73.583	16.959	
Cumulative %	73.583	90.542	
Factor 1	Cu-Zn-Fe-Ni-Pb		
Factor 2	Co		



**Figure 6:** Dendrogram using average linkage between groups of soil showing contamination relationship between sampling points.



**Figure 7:** Dendrogram using average linkage between groups of soil showing relationship between Heavy metals.



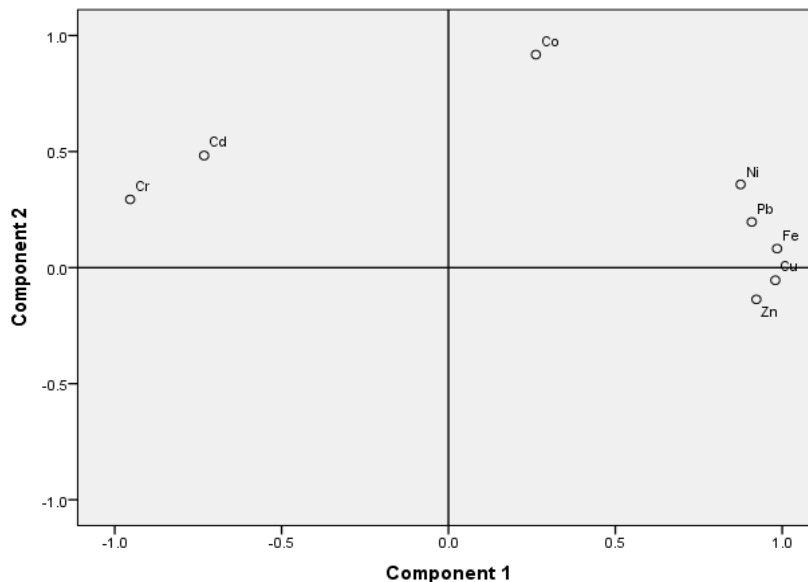


Figure 8: Component plot of Heavy metals of soil samples showing their source relationship from Factor Analysis.

3.3 Data Analysis of Physicochemical Parameters and Heavy metals of water Samples Collected at selected Auto-Mechanic Workshop.

All the physicochemical parameters of the water samples analyzed conformed to the NSDWQ and WHO standard values except TDS (1025), EC (1734.75), and salinity (756.75), which are above the NSDWQ (2007) and WHO (2011) standard values (NSDWQ, 2007; WHO, 2011). The pH values of the surface water (hand-dug wells) from within and around the vicinity of the auto-mechanic workshops range from 5.58 to 6.12, which is below the NSDWQ and WHO standard values. This indicates that the water in the study area is acidic and could be a result of discharge from battery electrolytes and other chemicals that reduce or acidify the water, as shown in Table 10.

The major cations analyzed are Mg, Ca, Na, and K. The mean concentrations of the major cations are Mg (3.604 cmol/kg), Ca (0.88 cmol/kg), Na (0.416 cmol/kg), and K (6.36 cmol/kg). The mean concentration of Ca and Na conforms with NSDWQ and WHO permissible standard values, except for Mg (3.604) and K (6.38), which are above NSDWQ and WHO permissible standard values, as shown in Table 11 (NSDWQ, 2007; WHO, 2011). This high mean concentration of Mg and K will impact the taste of the water samples collected in the study.

However, the mean concentration value of copper (Cu) ranges from 0.12-0.26 mg/l with an average value of 0.196 mg/l, which conforms with the NSDWQ and WHO permissible values of 1 mg/l and 2 mg/l (NSDWQ, 2007; WHO, 2011). The mean concentration value of zinc (Zn) ranges from 0.081 to 0.1 mg/l, with an average value of 0.1008 mg/l, which conforms with the NSDWQ and WHO permissible values of 3 mg/l and 5 mg/l (NSDWQ, 2007; WHO, 2011). The mean concentration value of cobalt (Co) ranges from 0.015 to 0.023 mg/l, with an average value of 0.0194 mg/l,

which conforms with the NSDWQ and WHO permissible values of 0.05 mg/l and 1 mg/l (NSDWQ, 2007; WHO, 2011). The mean concentration value of nickel (Ni) ranges from 0.01 to 0.014 mg/l, with an average value of 0.0118 mg/l, which conforms with the NSDWQ and WHO permissible values of 0.02 mg/l, as shown in Table 12 (NSDWQ, 2007; WHO, 2011).

The mean concentration value of cadmium ranges from 0.017 to 0.12 mg/l, with an average value of 0.0636 mg/l, which is above the NSDWQ permissible value of 0.01 mg/l but below the WHO permissible value of 1 mg/l (NSDWQ, 2007). A high concentration of cadmium in the human body can cause psychological disorders, diarrhea, and damage to the immune system. The high concentration of cadmium in the study area could be attributed to lubricating oils, vehicle wheels, dumping of PVC plastic, cadmium batteries, and metal alloys used for hardening metal parts. The mean concentration values of chromium and iron range from 0.55-0.72 mg/l with an average value of 0.632 mg/l and 0.64-1.45 mg/l with an average value of 1.796 mg/l, which is above the NSDWQ and WHO permissible values of 0.05 mg/l and 0.03 mg/l (NSDWQ, 2007; WHO, 2011).

The high concentration of chromium in water can cause skin rashes, stomach ulcers, respiratory problems, and kidney and liver damage. Sources could be from discarded paint containers, lubricant waste, general discharge from automobiles, plating, or welding. The high concentrations of iron in HDW water samples collected are due to auto-mechanic workshop activities around the study area. When iron concentration is high in water, it can cause hemochromatosis (iron overload), damage to the heart, liver, and pancreas (diabetes), liver cirrhosis, heart attack, and depression, as shown in Tables 12, 9, and 10 (WHO, 2011).

**Table 10: Physicochemical parameters of Surface Water (HDW) from the selected Auto-Mechanic Workshops in Warri**

SAMPLES	HDW 1	HDW 2	HDW 3	HDW 4	HDW 5	MEAN	NSDWQ (2007)	WHO (2011)
pH	5.8725	5.58	5.84	5.95	6.12	5.8725	6.5-8.5	6.5-8.5
EC µs/cm	1734.75	1679	1745	1692	1823	1734.75	1000	900
Turbidity	2.25	2	3	2	2	2.25	5	5
TSS	3.5	5	3	3	3	3.5	-	-
TDS	1025	988	995	990	1127	1025	500	1000
TS	1028.5	993	998	993	1130	1028.5	-	-
Salinity	756.75	735	741	738	813	756.75	500	500
Hardness	6.5	8	6	5	7	6.5	150	
Alkalinity	4.25	5	3	4	5	4.25	-	
PO4 (mg/l)	0.1575	0.18	0.17	0.12	0.16	0.1575	-	
NO3 (mg/l)	2.25	1.9	2	2.4	2.7	2.25	50	5
SO3 (mg/l)	0.2075	0.24	0.16	0.28	0.15	0.2075	100	400
Cl (mg/l)	1.3675	1.33	1.34	1.33	1.47	1.3675	100	250

**Table 11: Major Cation Concentration in Water Samples from selected Auto-Mechanic Workshops in Warri**

SAMPLES	HDW 1	HDW 2	HDW 3	HDW 4	HDW 5	MEAN	NSDWQ (2007)	WHO (2011)
Mg (cmol/kg)	3.62	3.62	3.58	3.58	3.62	3.604	2.06	2.06
Ca (cmol/kg)	1.6	1.4	0.1	0	1.3	0.88	2.49	1.87
Na (cmol/kg)	0.65	0.21	0.27	0.54	0.41	0.416	8.70	8.70
K (cmol/kg)	8.6	9.2	4.4	3.8	5.9	6.38	1.41	1.41

**Table 12: Heavy Metal Concentration in Water Samples from selected Auto-Mechanic Workshops in Warri**

SAMPLES	HDW 1	HDW 2	HDW 3	HDW 4	HDW 5	MEAN	NSDWQ (2007)	WHO (2011)
Cu (mg/l)	0.17	0.2	0.12	0.23	0.26	0.196	1	2
Zn (mg/l)	0.1	0.087	0.082	0.085	0.081	0.087	3	5
Cd (mg/l)	0.12	0.043	0.017	0.064	0.074	0.0636	0.01	1
Fe (mg/l)	0.97	0.75	1.45	0.67	0.64	0.896	0.3	0.3
Co (mg/l)	0.023	0.017	0.015	0.02	0.022	0.0194	0.05	1
Ni (mg/l)	0.012	0.01	0.014	0.012	0.011	0.0118	0.02	0.02
Cr (mg/l)	0.57	0.55	0.61	0.72	0.71	0.632	0.05	0.05

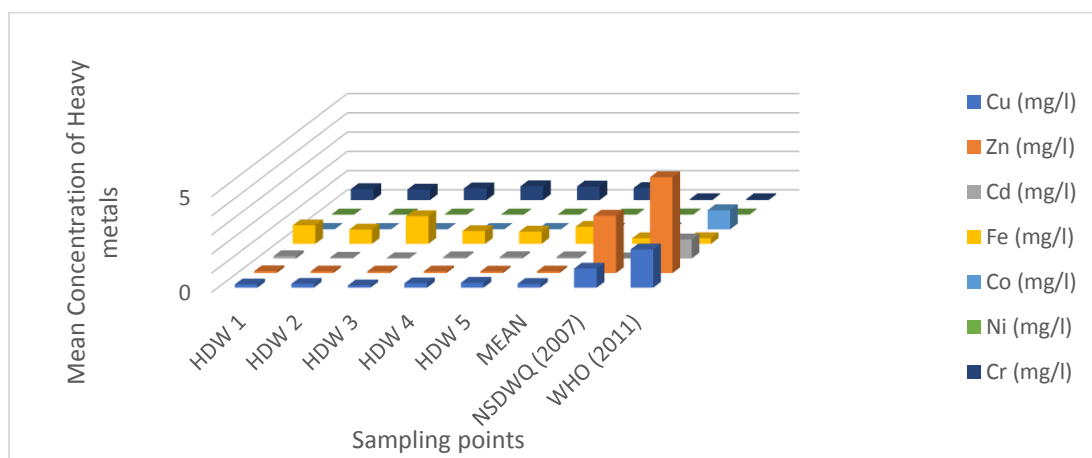


Figure 9: Mean concentration of heavy metals and sampling points of water samples

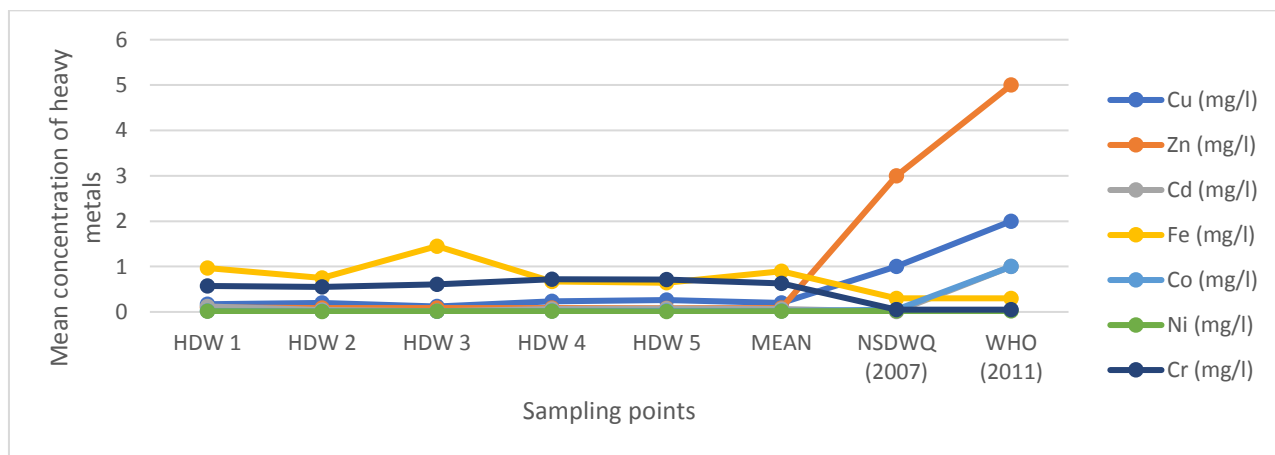


Figure 10: Scatter diagram of Heavy metals of water samples

**3.4 Assessment of source of contamination relationship of Heavy metals in water samples using Correlation, Hierarchical Cluster Analysis and Principal Component Analysis**

The significance of the observed correlation coefficient results is presented in Table 13. Out of the twenty-eight (28) correlation values found between two parameters, one (1) was found to have a very strong positive correlation at the 1% level ( $P < 0.01$ ), and five (5) were found to have a strong positive correlation at the 50% level ( $P < 0.05$ ). The six (6) very strong positive correlations are found to be between Cd and Zn (0.769483), Co and Cu (0.574306), Co and Zn (0.505622), Co and Cd (0.939967), Ni and Fe (0.831876), and Cr and Cu (0.640661). The four (4) heavy metals that show strong negative correlations were found to be between Fe and Cu (-0.94538), Co and Fe (-0.58117), Ni and Cu (-0.6975), and Cr and Cu (-0.55536), while six (6) show negative correlations, which

were found between Fe and Cd (-0.41546), Ni and Zn (-0.08815), Ni and Zn (-0.08815), Zn and Cu (-0.24758), Ni and Cd (-0.2742), and Cr and Fe (-0.42192) ( $P < 0.05$ ). Five (5) were found to have a weak positive correlation that is less than 50% ( $P < 0.05$ ). The high degree of positive correlations between various pairs of metals reflects their simultaneous release, identical source from the auto-mechanic workshop, transport, and accumulation in water. The significance of the correlations indicates that they may have originated from a common source of contamination. The heavy metals with a strong negative correlation indicate that they are from different sources of contamination, as shown in Table 13.

The dendrogram divides the source of contamination of the sampling location and heavy metals into 2 clusters and 2 clusters based on their similarity in contamination sources, as shown in Figures 11 and 12. For sampling location, Cluster 1 (HDW4 and HDW5) has the same source of

contamination, and HWD2 and HDW1 have similar sources as HDW4 and HDW2. Cluster 2 (HDW3) has the same source of contamination as shown in Figure 10. Similarly, for heavy metals, Cluster 1 (Co, Cd, Ni, Cu, and Zn) has the same source of contamination as Cluster 2 (Fe and Cr), which has its own source of contamination as shown in Figure 11.

The heavy metal values obtained from the water samples were analyzed using the PCA (factor analysis) extraction method, which revealed three groups of related elements and their communalities from the PCA, as shown in Table 13 (Kaiser 1960). Factor1: (Cu-Cd-Co). This accounted for about 51.171% of the total variance in the data matrix, with an Eigen value of 3.582, which is the most significant, and the source of contamination may likely be an auto-mechanic workshop. but Fe (-0.923) and Ni (-0.715) of factor 1 show a strong negative correlation, which

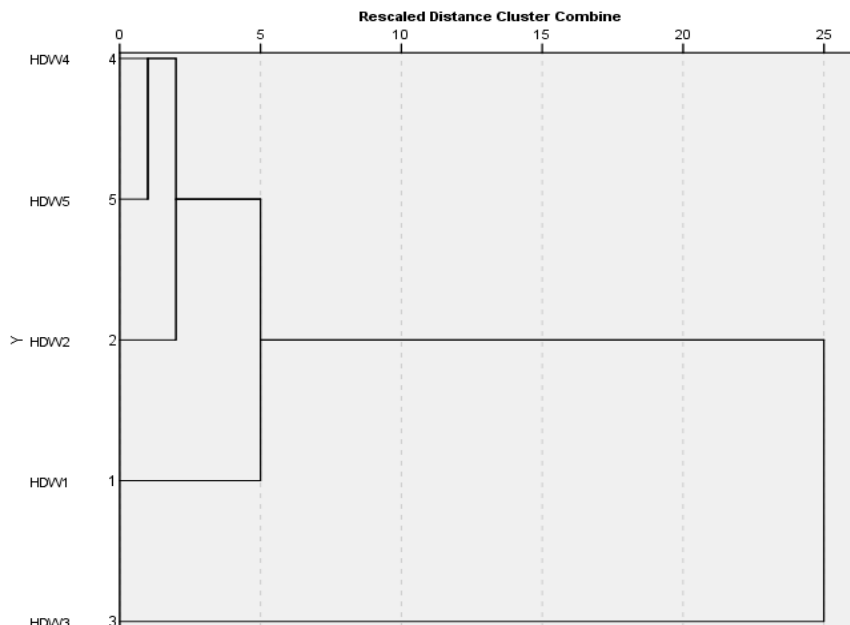
indicates that they are from different sources of contamination. Factor 2: (Zn-Cd). This accounted for about 31.689% of the total variance of the variables, with an Eigenvalue of 2.218. The elements also showed a positive correlation and were mostly likely to be from the same source as those in group 1, but Cr (-0.673) of factor 2 showed a strong negative correlation, which indicates that its source of contamination is different. Factor 3. (Ni-Cr). This is the least significant of all the factors. It accounted for 15.929% with an Eigenvalue of 1.115. From Table 13, Ni (-0.715) and Fe (-0.923) show a strong negative correlation with other metals, which indicates that their sources of contamination are different, as shown in Figure 13. From the PCA, the result revealed that Cu, Cd, and Co are dominant metals with the highest variance and eigenvalues, as shown in Table 14.

**Table 13:** Correlation Heavy metals of water samples

	<i>Cu</i>	<i>Zn</i>	<i>Cd</i>	<i>Fe</i>	<i>Co</i>	<i>Ni</i>	<i>Cr</i>
<i>Cu</i>	1						
<i>Zn</i>	-0.24758	1					
<i>Cd</i>	0.32173	0.769483	1				
<i>Fe</i>	-0.94538	0.017535	-0.41546	1			
<i>Co</i>	0.574306	0.505622	0.939967	-0.58117	1		
<i>Ni</i>	-0.6975	-0.08815	-0.2742	0.831876	-0.33093	1	
<i>Cr</i>	0.640661	-0.55536	0.005289	-0.42192	0.307414	0.08976	1

**Table 14:** Principal component analysis: Factor analysis

Extraction Method: Principal Component Analysis (PCA)				
Heavy Metals	Factor 1	Factor 2	Factor 3	Communality
<i>Cu</i>	0.886	-0.462	-0.035	0.999
<i>Zn</i>	0.225	0.959	-0.026	0.971
<i>Cd</i>	0.711	0.650	0.264	0.998
<i>Fe</i>	-0.923	0.268	0.229	0.977
<i>Co</i>	0.847	0.362	0.365	0.982
<i>Ni</i>	-0.715	0.084	0.692	0.996
<i>Cr</i>	0.400	-0.673	0.616	0.991
Eigen values	3.582	2.218	1.115	
% of Variance	51.171	31.689	15.929	
Cumulative %	51.171	82.86	98.789	
Factor 1	Cu-Cd-Co			
Factor 2	Zn-Cd			
Factor 3	Ni-Cr			



**Figure 10:** Dendrogram using average linkage between groups of water samples showing relationship between sampling points

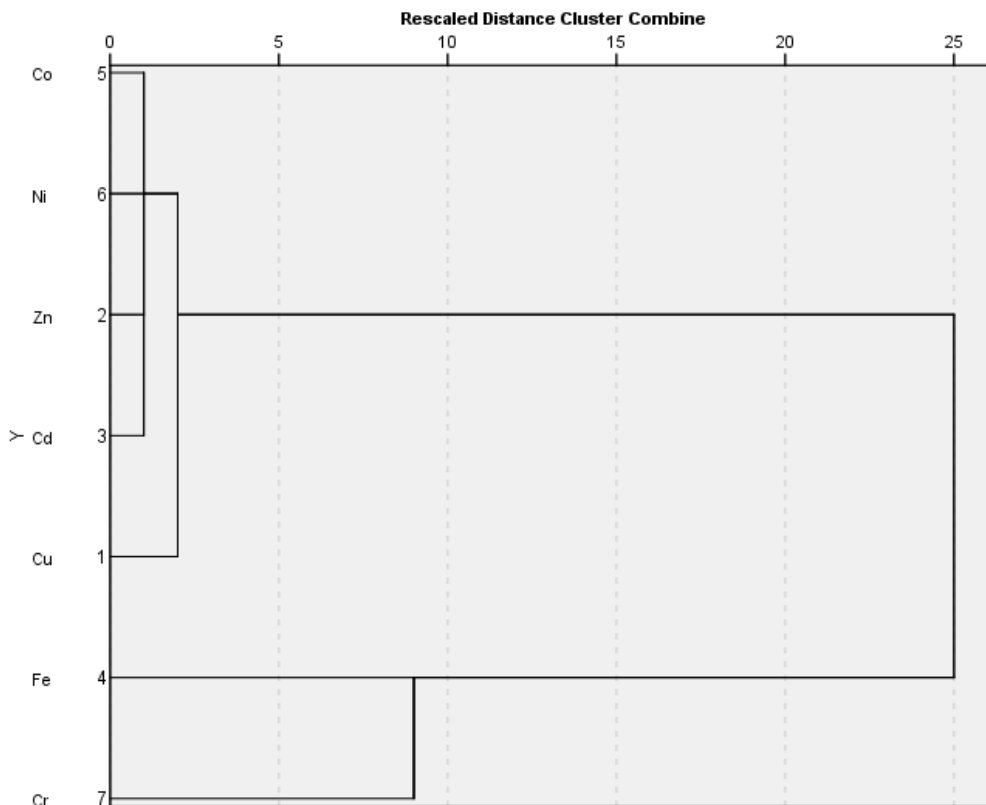


Figure 12: Dendrogram using average linkage between groups of water samples showing relationship between Heavy metals.

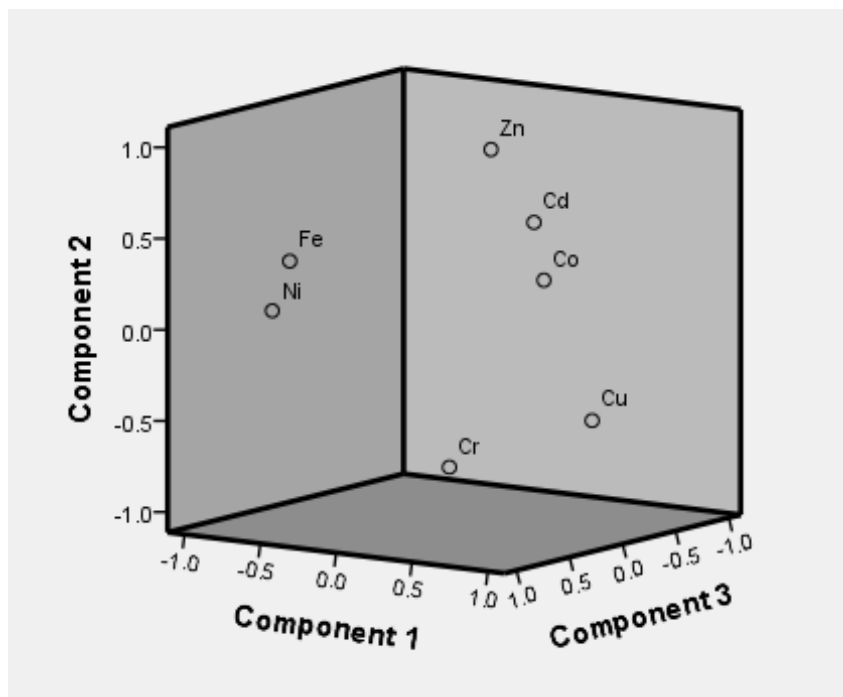


Figure 13: Component plot of Heavy metals of water samples showing their source relationship from Factor Analysis.

**3.5 Comparative of Soil and Water samples mean concentration of Heavy metals**

From the ANOVA result in Table 15, the mean concentration of soil samples is 322584.2, while the mean concentration of water samples is 0.12232. This indicates that the concentrations of the two sample types are significantly different. The MS (mean square) for the row (auto-mechanic activities) is 259689.9, and for the column (sample type), it is 161452.9. The F-value for the row is 1.611664, and for the column, it is 1.001994. The p-value for the row is 0.251274, and for the column, it is 0.499066. The critical F-value (F crit) for the row is 5.987378, and for the column, it is 4.283866.

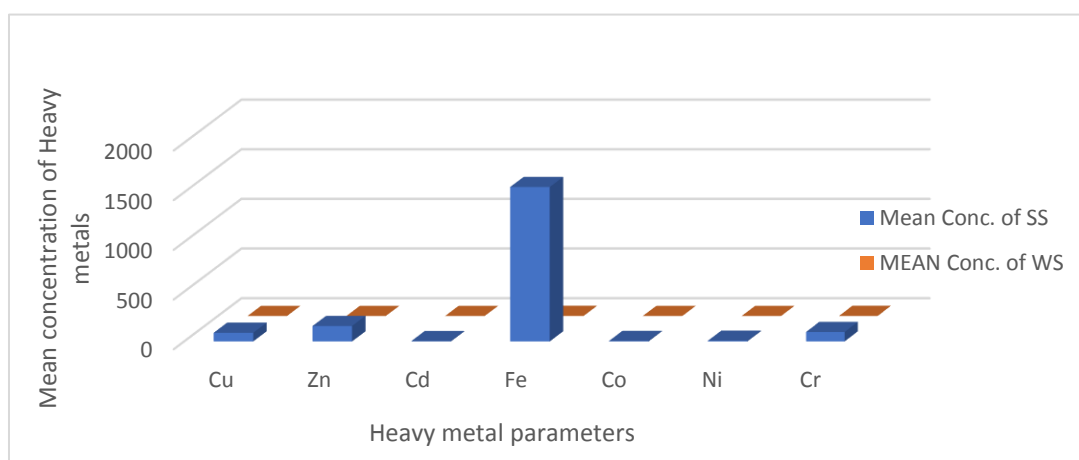
The fact that both the p-values for the row and the column are less than 0.05 suggests that there is a statistically significant impact of auto-

mechanic activities on the soil samples compared to the water samples. In other words, there is evidence to conclude that auto-mechanic activities have a direct and significant impact on soil concentrations when compared to water concentrations, as shown in Table 15.

Figure 14 visually represents the statistical difference between the mean concentration of soil samples and the mean concentration of water samples. Iron has the highest mean concentration value, followed by chromium (Cr), and nickel (Ni) in the mean concentration of soil samples compared to the mean concentration of water samples. The higher mean concentration of iron (Fe) in soil samples compared to water samples suggests that there is a direct and significant impact on the soil compared to the water concentration, which could potentially have environmental implications as it might indicate contamination or pollution due to the auto-mechanic activities in the study area.

**Table 15: ANOVA of Soil and Water samples mean concentration of Heavy metals**

<i>SUMMARY</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>		
Mean conc. Soil	7	1908.646	272.6637	322584.2		
Mean conc. water	7	1.9058	0.272257	0.12232		
Cu	2	87.596	43.798	3802.269		
Zn	2	155.587	77.7935	12076.6		
Cd	2	4.1136	2.0568	7.945692		
Fe	2	1554.896	777.448	1206066		
Co	2	5.3474	2.6737	14.09062		
Ni	2	7.0118	3.5059	24.41747		
Cr	2	96	48	4487.455		
<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Rows	259689.9	1	259689.9	1.611664	0.251274	5.987378
Columns	968717.2	6	161452.9	1.001994	0.499066	4.283866
Error	966788.9	6	161131.5			
Total	2195196	13				

**Figure 14:** Comparative of mean concentration of Heavy metals

#### 4. CONCLUSION

Auto-mechanic workshops employ various chemicals, substances, and processes that have the potential to be harmful to both the environment and human and animal health. Analytical studies of physicochemical parameters and heavy metals in soil and groundwater indicate a significant level of contamination and pollution. Pollutants, including heavy metals, batteries, paint, petrol, panel beating, and car body scraping residues, as well as lubricants and grease, accumulate in high concentrations in the soil. These contaminants subsequently seep or percolate into the groundwater, creating hazards for people who consume the water and posing risks to soil health. Contaminated water poses a direct threat to the health of individuals who rely on it for drinking and other domestic uses.

The presence of pollutants in water sources can lead to various health issues for the population, ranging from acute effects to long-term illnesses. Soil organisms play a crucial role in maintaining soil health and fertility. Heavy metal contamination from auto-mechanic activities can negatively affect soil organisms, leading to a reduction in their population and diversity. The disruption of soil ecosystems can have cascading effects on nutrient cycling, soil structure, and plant growth. The presence of heavy metals such as Cd, Cr, Cu, Zn, Ni, Co, and Fe in concentrations above recommended standards is a clear indicator of contamination.

These heavy metals are known to have toxic effects on various organisms, including plants, animals, and microorganisms. The soil contamination factor and Igeo values suggest varying degrees of contamination, from low to extremely high. The degree of contamination classified the soil samples analyzed as low to very high, while PLI classified the soil as having an extremely high degree of pollution. The contamination factor decreases in this order, Fe<Cu<Cr<Zn<Co<Cd<Ni<Pb, while I-geo increases in this order, Cd>Co>Pb>Ni>Cu>Cr>Zn>Fe. It's evident from research that there is a critical need to address these issues to safeguard both the

environment and the well-being of local communities.

#### RECOMMENDATION

- Propose the establishment of designated areas ("mechanic villages") for new auto repair shops, away from residential zones.
- This zoning can help prevent contamination from affecting populated areas.
- Advocate for the adoption of safe practices within auto-mechanic workshops, emphasizing proper disposal of hazardous waste.
- Encourage the use of septic tanks and adequate flooring to prevent pollutants from leaching into the soil and groundwater.
- Promote education and awareness among stakeholders, including workshop owners, workers, and residents.
- Raise awareness about the risks of improper waste disposal and the potential consequences for the environment and health.

Recommend soil excavation in the case of older workshops to halt ongoing contamination of the soil, where feasible.

Recommendations for future research are as follows:

- For a more comprehensive environmental assessment, 1D and 2D geophysical investigations could be carried in the study area so as to determine the depth and lateral extent of contamination.
- Time lapse study implementation:** Continue monitoring heavy metal concentrations in soil, groundwater, and surface water in and around auto-mechanic workshops. This should be done over an extended period to track changes and trends, especially in areas

where workshop activities are prevalent.

- **Health Impact Studies:** Undertake epidemiological studies to assess the health impacts on individuals living near auto-mechanic workshops. Investigate the correlation between exposure to contaminants and health issues, both short-term and long-term.

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