

## CASE STUDY

# Evaluation of Selected Heavy Metal Concentration of Soil Along Some Highways in Imo State, Nigeria

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## ABSTRACT

This study evaluated the concentration of selected heavy metals (Pb, As, Zn, Cu, Hg) in soils along two major highways, Owerri–Aba and Owerri–Okigwe, and a non-highway control site at Egbeada in Imo State, Nigeria. Soil samples were collected at depths of 0–15 cm and 15–30 cm, and at distances of 0–50 m and 50–100 m from the road. Laboratory analyses were conducted at the Soil Science Department Laboratory of the Federal College of Land Resources Technology, Owerri, to determine both physical (particle size distribution, bulk density, porosity, moisture content) and chemical (pH, organic carbon, total nitrogen, available phosphorus, exchangeable bases, cation exchange capacity) properties, alongside heavy metal concentrations using Atomic Absorption Spectrophotometry. Results indicated higher concentrations of heavy metals along highways compared to the control site, with Zn showing the highest levels and Hg the lowest. Concentrations decreased with increasing distance from the road and with soil depth. Positive correlations were observed between heavy metal content and parameters such as moisture content, bulk density, and cation exchange capacity, while negative correlations were found with organic carbon, available phosphorus, total nitrogen, sand, and clay content. The concentrations of certain metals along highways exceeded WHO permissible limits, indicating potential environmental and public health risks.

**Keywords:** Heavy Metals; Soil Contamination; Highways; Zn; Pb; As; Cu; Hg

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## 1. Introduction

Soil is a fundamental natural resource that underpins agricultural production, environmental sustainability, and supports an increasing population of the world<sup>[1,2]</sup>. Soil is a dynamic resource that supports plant life. It is made of different-sized mineral particles, organic matter, and numerous species of living organisms. Thus, the soil has biological, chemical, and physical properties, some of which are dynamic and can change in response to how the soil is managed. Soils are classified as natural bodies on the basis of their profile characteristics<sup>[3]</sup>. Celik et al.<sup>[4]</sup> posit that soil quality is generally defined as the capacity of soil to function within ecosystem boundaries to support biological productivity, maintain environmental quality, plus promote plant, animal, and human health. However, this ability is increasingly threatened by environmental pollution rising from industrialization, urbanization, and transportation activities. In the midst of the various sources of soil contamination, road networks and vehicular traffic have been identified as significant contributors to the accumulation of potentially toxic elements in roadside soils. Brady and Weil<sup>[3]</sup> found that soil has biological, chemical, and physical properties, some of which are dynamic and can change in response to how the soil is managed. Consequently, Celik et al. and Obineche and Oriaku<sup>[4,5]</sup> posited that roads are essential infrastructure that play a vital role in stimulating social and economic activities of any nation. However, road construction has also resulted in heavy environmental pollution. Environmental pollution is any discharge of substances into water, soil, and air that cause acute or chronic effects that are detrimental to the earth's ecological balance, in addition to reducing the quality of life. Highways are essential in modern industrialized society. In addition to their tangible economic profits, highways are the source of most environmental problems encountered<sup>[6-10]</sup>. Plešnicar and Supanic<sup>[11]</sup> observed that automobiles release metals into the environment mainly through car wear, leaking oil, and corrosion. These metals include lead, cadmium, copper, and zinc<sup>[12]</sup>. Some emitted particles with heavymetal precipitate on highway side soil, whereas others, direct deposits on the roadway surface,

are washed onto adjacent soils by rainfall runoff<sup>[13-16]</sup>. Additionally, Begum et al.<sup>[17]</sup> found that the concentration of heavy metals increases with the number of vehicles, traffic flow, and traffic density. Fakayode and Olu-Owolabi<sup>[18]</sup> found that high metal concentrations at low vehicular speed, which can be attributed to increased exhaust fume emissions over a longer time, occur. Hence, Akinola and Adedji<sup>[19]</sup> observed that due to increased wear and tear from tyre abrasion and attrition, rough roads often aggravate metal concentration. Heavy metal is any metallic material that has a comparatively high density and a low concentration and is toxic in nature<sup>[20]</sup>. To avert this limitation, the need for a systematic appraisal of the soil resource with respect to its extent, distribution characteristics, behavior, and nutrient status is crucial for developing a productive and sustainable agricultural system. This study was conducted to evaluate the concentration and spatial distribution of selected heavy metals (Pb, As, Zn, Cu, and Hg) in soils along Owerri-Aba and Owerri-Okigwe highways, using a non-highway location at Egbeada as a control. The study also examines the effect of soil depth plus distance from the road on heavy metal accumulation, as well as the relation between heavy metals and selected soil physical and chemical properties. The outcomes are intended to contribute to environmental monitoring efforts and provide baseline information for soil management and pollution control in the region.

## 2. Materials and Methods

The study was carried out along two major transportation routes in Imo State, South-Eastern Nigeria, namely the Owerri-Okigwe as well as Owerri-Aba highways respectively (**Figure 1**). A non-highway site located at Egbeada in the Owerri East Senatorial district was selected as a control. Imo State lies within the humid tropical zone and is geographically located between latitudes approximately 50°45' N–60°00' N, and longitudes 70°15' E–70°30' E, with an average elevation of about 300 m above sea level. The geology of the study area is dominated by false-bedded sandstones of the Ajali Formation, with contributions from the Nsukka Formation and Imo Clay Shale. The soils are largely derived from

coastal plain sands (Benin Formation), which typically produce light-textured soils with high sand content. The district experiences a bimodal precipitation pattern with an annual precipitation range of approximately 2000–2500 mm. It has six major entrances and exit routes,

which are Okigwe, Orlu, Umuahia, Aba, Onitsha, and Port Harcourt roads<sup>[21]</sup>. It was characterized by a main annual precipitation ranging from 2000–2500 mm, a mean temperature ranging from 260 °C–280 °C, and humidity ranging from 70–80%<sup>[22]</sup>.

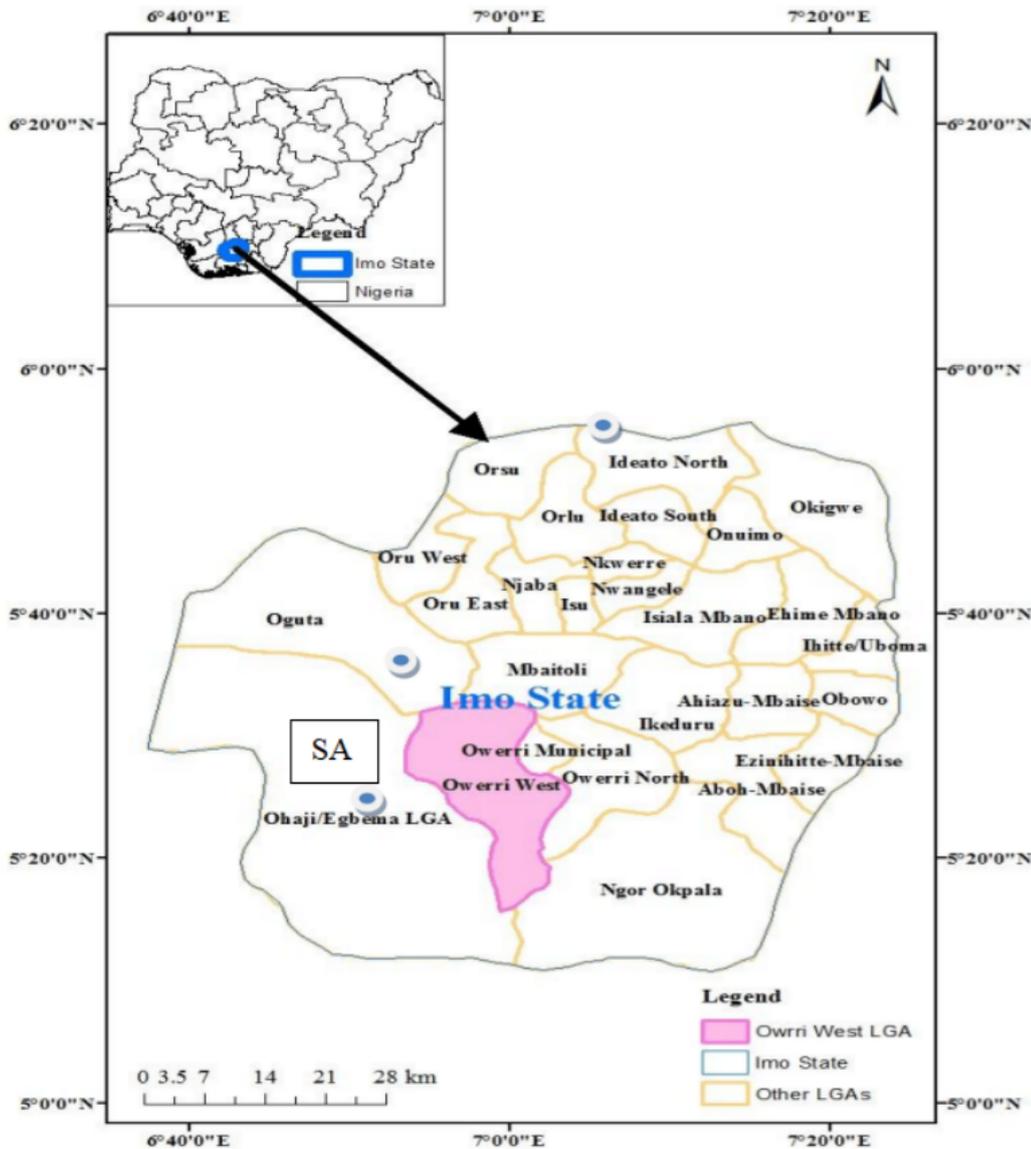


Figure 1. A map of Imo State showing the study area.

## 2.1. Climatic Condition of the Study Location

The climate conditions at the study area are characterized by two distinct seasons, namely the rainy season, which extends from April to September, and the dry season from October to March. These climatic conditions strongly influence soil formation, nutrient dynam-

ics, and the mobility of contaminants within the soil profile. The annual mean temperature is approximately 30 °C, whereas 37 °C was the temperature recorded at the Municipality. In the same vein, the relative humidity annually is 87%, while the mean relative humidity is measured to be 73%, respectively<sup>[23]</sup>. In addition, the soils of the region under investigation are derived from coastal plain sand known as Benin Formation<sup>[24–26]</sup>.

## 2.2. Laboratory Analysis

Samples of the soil for the experiment were collected along the Owerri-Aba and Owerri-Okigwe highways at two horizontal distances from the road edge, 0–5 m and 50–100 m. At each distance, samples were obtained from two soil depths of 0–15 cm (topsoil) and 15–30 cm (subsoil). The equivalent sampling strategy was adopted at the control site (Egbeada), which is located away from major vehicular activities. At each sampling point, composite soil samples were collected using a soil auger, while undisturbed core samples were taken for bulk density determination. A total of four (4) representative samples were obtained per site based on depth and distance combinations. The collected samples were air-dried, gently crushed, and passed through a 2 mm sieve prior to laboratory analysis. The soil samples obtained at the site were analyzed in the laboratory using standard methods, while an atomic absorption spectrophotometer (AAS) was used to determine the heavy metal content of the soil samples. These include physical properties such as particle size distribution, moisture content, bulk density, and porosity. The modified hydrometer method was utilized in the determination of the particle size distribution as posited by Gee and Or<sup>[27]</sup>. Silt clay ratio was obtained by calculation, soil moisture content was determined gravimetrically by weighing an oven-drying soil sample collected from the field at 105 °C until a constant weight was obtained<sup>[28]</sup>. In the same vein, the soil bulk density was determined using the core samples as noted by Grossman and Reinsch<sup>[29]</sup>. Soil pH was measured in both distilled water and 1 M potassium chloride (KCL) solutions using a glass electrode pH meter at a soil-to-solution ratio of 1:2:5<sup>[30]</sup>. Organic carbon content was determined using standard wet oxidation procedures, and organic matter was calculated from organic carbon values. Total nitrogen was analyzed using established digestion methods, while available phosphorus was extracted and quantified using appropriate colorimetric techniques. Total exchangeable bases ( $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$ ,  $\text{K}^+$ , and  $\text{Na}^+$ ) were extracted using 1 M ammonium acetate solution, while exchangeable acidity ( $\text{Al}^{3+}$  and  $\text{H}^+$ ) was determined using unbuffered potassium chloride extraction<sup>[31]</sup>. Effective cation exchangeable capac-

ity (ECEC) was calculated as the sum of exchangeable bases and exchangeable acidity, and base saturation was expressed as a percentage of ECEC. The heavy metal concentration (Pb, Zn, Cd, and As) in the soil samples was determined using Atomic Absorption Spectrophotometry (AAS). Soil samples were subjected to appropriate digestion procedures prior to analysis, and metal concentrations were expressed in ( $\text{mg kg}^{-1}$ ) of dry soil.

## 2.3. Statistical Analysis

The analysis of variance (ANOVA) was utilized in the data determination, as the treatment means were separated and the standard deviation was obtained through calculations. Additionally, simple linear correlation was used to study the interaction between heavy metal content and selected physical and chemical properties of the soil<sup>[32]</sup>.

## 3. Results

Moisture content will be determined gravimetrically; soil samples were collected with a core sampler. Differences in soil weight after drying were taken for the moisture content as follows.

In Owerri-Aba, the mean sand fraction values are 82.50% and 79.00% for 50 m and 100 m away from the highway. Mean silt values ranged from 13.35% to 12.75% from 50 m to 100 m away from the highway, while mean clay values ranged to 4.40% to 8.25%.

In Owerri-Okigwe, the mean sand fraction values ranged from 83.10% and 72.75%, the mean silt values ranged from 9.50% to 11.80%, and the mean clay values ranged from 5.35% to 8.25% for 50 m and 100 m away from the highway, respectively.

Egbeada (control), the mean sand fraction values ranged from 83.80% to 72.75%, the mean silt values ranged from 11.20% and 11.50% for 50 m and 100 m, respectively. It was revealed in **Table 1** that the outcome from Owerri-Aba has the lowest value of 82.50%. Whereas **Table 2** shows that Egbeada has the lowest value of sand fraction of 2.75%. This indicates that Egbeada has more organic matter content than other sites studied.

**Table 1.** Soil physical properties 0–50 m away from the road.

Location	Soil Depth (cm)	MC (%)	Bulk Density (g cm <sup>-3</sup> )	Sand (%)	Silt (%)	Clay (%)	TC	Porosity (%)
Owerri-Aba	0–15	13.00	1.55	80.50	14.70	5.30	S	41.60
	15–30	13.70	1.59	84.50	12.00	3.50	S	40.00
	Mean	13.35	1.57	82.50	13.35	4.40	S	40.80
Owerri-Okigwe	0–15	15.20	1.72	82.50	12.10	5.40	S	35.10
	15–30	16.50	1.80	83.70	11.50	5.30	S	32.10
	Mean	15.85	1.76	83.10	11.80	5.35	S	33.60
Egbeada (control)	0–15	19.50	1.20	79.60	6.00	14.40	SL	54.80
	15–30	20.00	1.23	88.00	4.00	8.00	S	53.60
	Mean	19.75	1.22	83.80	5.00	11.20	SL	54.20
LSD <sub>0.05</sub>		0.17	0.12	2.12	1.08	0.27		1.58

Note: MC = Moisture Content, TC = Textural Class, BD= Bulk Density.

**Table 2.** Soil physical properties of 50–100 m away from the road.

Location	Soil Depth (cm)	MC(%)	Bulk Density (g cm <sup>-3</sup> )	Sand (%)	Silt (%)	Clay (%)	TC	Porosity (%)
Owerri-Aba	0–15	75.00	15.00	10.00	SL	8.50	1.50	43
	15–30	83.00	10.50	6.50	S	6.50	1.48	44
	Mean	79.00	12.75	8.25	SL	7.50	1.49	44
Owerri-Okigwe	0–15	84.00	8.50	7.50	S	11.50	1.52	43
	15–30	80.50	10.50	9.00	S	8.2	1.55	42
	Mean	82.25	9.50	8.25	S	9.85	1.54	42
Egbeada (control)	0–15	70.50	16.50	13.00	SCL	16.50	1.21	54
	15–30	75.00	15.00	10.00	SL	14.20	1.24	53
	Mean	72.75	15.75	11.50	SL	15.35	1.23	54
LSD <sub>0.05</sub>		3.25	1.72	0.62		3.05	0.05	3.00

Note: MC = Moisture Content, TC = Textural Class, BD = Bulk Density.

The results presented in **Table 1** reveal that the mean silt value on the Owerri-Aba road is 13.35%, while Egbeada has the lowest value with 5.00%. The presentation in **Table 2** indicates that Egbeada has the highest silt value of 15.75%, while Owerri-Okigwe has the lowest value with 9.50%. The high sand fractions in all the sites studied will be attributed to the nature of the parent material (coastal plain sand) of the area. The textures of the soil were generally sandy.

Owerri-Aba highway has the mean values of 13.35%, 1.57 g cm<sup>-3</sup>, 40.80% for moisture content, bulk density, and porosity, respectively. Similarly, Owerri-Okigwe highway has the mean values of 15.83%, 1.76 g cm<sup>-3</sup>, and 33.60% for moisture content, bulk density, and porosity, respectively. Egbeada non-highway has a mean value of 19.75%, 1.22 g cm<sup>-3</sup> and 54.20% for moisture content, bulk density, and porosity, respectively (**Table 1**).

The Owerri-Aba highway has the mean values of 7.50%, 1.49 g cm<sup>-3</sup> and 44% for moisture content, bulk density, and porosity, respectively. Similarly, Owerri-

Okigwe has the mean value of 9.85%, 1.54 g cm<sup>-3</sup> and 42% for moisture content, bulk density, and porosity, respectively. Egbeada, non-highway, has the mean values of 15.35%, 1.22 g cm<sup>-3</sup> and 54% for moisture content, bulk density, and porosity, respectively. Soil textures were generally sandy loam (**Table 2**).

The results of physical properties of the soil were significantly different at a probability level of 5%, the greatest improvement in soil physical properties was observed in the control, followed by 50 m and 100 m away from the highways studied.

## 4. Discussion

Available P has a mean value that ranges from 2.45 to 3.24 (mg kg<sup>-1</sup>) for 0–50 m and 50–100 m away from the highway. ECEC ranged from 3.45% to 4.09%. Base saturation values ranged from 37.68% to 44.24%.

Owerri-Okigwe highway has a mean pH in H<sub>2</sub>O value of 4.67 and 4.74 for 0–50 m and 50–100 m away from the highway. Organic matter and organic carbon

range from 1.10% to 1.30% and 0.64% to 0.70%, respectively. Available P has mean values of 2.32 to 2.88 (mg kg<sup>-1</sup>) for 0–50 m and 50–100 m away from the highway. ECEC and base saturated ranged from 3.64% to 4.13% and 36.87% to 46.00%, respectively.

Egbeada has a mean value of pH in H<sub>2</sub>O that ranges from 5.00 to 5.64. Organic matter and Organic Carbon have values of 1.56% to 1.91 % and 0.91% to 1.11% for 0–50 m and 50–100 m (Tables 3 and 4).

In Owerri-Aba highway for 0–50 m and 50–100 m

away from the highway, Lead (Pb) mean value ranges from 0.33 to 1.74 (mg kg<sup>-1</sup>), Arsenic (As) has a mean value ranging from 0.45 to 2.05 (mg kg<sup>-1</sup>), Zinc (Zn) has a mean value ranged from 0.37 to 0.58 (mg kg<sup>-1</sup>). While, Owerri-Okigwe highway for 0–50 m and 50–100 m, Lead (Pb) has mean values ranged from 0.39 to 1.24 (mg kg<sup>-1</sup>), Arsenic (As) range from 0.29 to 1.89 (mg kg<sup>-1</sup>), Zinc (Zn) ranged from 1.25 to 2.17 (mg kg<sup>-1</sup>), copper (Cu) ranged from 0.40 to 1.14 (mg kg<sup>-1</sup>), while mercury (Hg) ranged from 0.34 to 0.35 (mg kg<sup>-1</sup>).

**Table 3.** Soil chemical properties from 0–50 m.

Location	Soil Depth (cm)	pH H <sub>2</sub> O	pH KCL	OC (%)	OM (%)	TN (%)	AVP Mg kg <sup>-1</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Al <sup>3+</sup>	H <sup>+</sup>	ECEC	BS
Owerri-Aba	0–15	4.82	4.20	1.01	1.84	0.09	3.82	44.01	0.73	0.43	0.02	0.62	1.44	0.85	4.09
	15–30	4.85	4.40	0.82	1.41	0.06	2.65	43.77	0.70	0.44	0.02	0.63	1.58	0.72	4.09
	Mean	4.84	4.30	0.95	1.63	0.08	3.24	44.25	0.72	0.44	0.02	0.63	1.51	0.79	4.09
Owerri-Okigwe	0–15	4.62	4.12	0.89	1.53	0.08	3.42	47.73	0.82	0.66	0.03	0.59	1.50	0.80	4.40
	15–30	4.86	4.20	0.62	1.07	0.06	2.33	44.04	0.62	0.52	0.01	0.55	1.46	0.70	3086
	Mean	4.74	4.16	0.76	1.30	0.07	2.88	46.00	0.72	0.59	0.02	0.57	1.48	0.75	4.13
Egbeada (control)	0–15	5.20	4.80	0.95	1.64	0.19	6.70	77.45	1.72	1.85	0.29	0.58	0.72	0.59	5.73
	15–30	4.80	4.30	0.86	1.48	0.13	5.50	77.69	1.52	1.62	0.26	0.50	0.60	0.552	5.02
	Mean	5.60	4.55	0.91	1.56	0.16	6.10	77.26	1.62	1.74	0.28	0.54	0.66	0.56	5.41
LSD <sub>0.05</sub>		0.75	0.55	0.42	0.33	0.03	0.85	15.25	0.20	0.65	0.02	0.07	0.05	0.15	0.50

Note: OC = Organic carbon, KCL = potassium chloride, OM= organic matter, TN= total nitrogen, AVP= Available phosphorus, Ca = Calcium, Mg= Magnesium, Na= sodium, K= potassium, Al= Aluminum, H= hydrogen, ECEC=electrical cation exchange capacity, BS= base saturation.

**Table 4.** Soil physical properties from 50–100m.

Location	Soil Depth (cm)	pH H <sub>2</sub> O	pH KCL	OC (%)	OM (%)	TN (%)	AVP Mg kg <sup>-1</sup>	Ca <sup>2+</sup>	Mg <sup>2+</sup>	Na <sup>+</sup>	K <sup>+</sup>	Al <sup>3+</sup>	H <sup>+</sup>	ECEC	BS
Owerri-Aba	0–15	4.90	4.48	0.58	0.99	0.16	2.85	0.42	0.55	0.47	0.12	1.28	1.07	3.91	39.901
	15–30	4.42	4.18	0.52	0.89	0.10	2.05	0.26	0.35	0.37	0.06	1.10	1.03	5.17	32.88
	Mean	4.66	4.33	0.55	0.95	0.13	2.45	0.34	0.45	0.42	0.09	1.19	1.05	3.45	37.68
Owerri-Okigwe	0–15	4.72	4.36	0.67	1.16	0.21	2.75	0.38	0.48	0.55	0.16	1.32	1.16	4.05	38.77
	15–30	4.62	4.12	0.60	1.03	0.14	1.85	0.27	0.32	0.42	0.07	1.07	1.02	3.17	34.07
	Mean	4.67	4.24	0.64	1.10	0.18	2.32	0.33	0.40	0.49	0.12	1.20	1.09	3.65	36.81
Egbeada (control)	0–15	5.86	5.20	1.20	2.07	0.32	5.72	0.82	0.92	0.65	0.32	1.47	1.20	5.28	51.33
	15–30	5.42	5.02	1.01	1.74	0.21	6.20	0.72	0.52	0.50	0.22	1.22	1.07	4.25	46.12
	Mean	5.64	5.11	1.11	1.91	0.27	5.96	0.77	0.72	0.58	0.27	1.35	1.14	4.83	48.45
LSD <sub>0.05</sub>		0.15	0.21	0.10	0.32	0.05	1.05	0.21	0.02	0.06	0.09	0.03	0.03	0.95	0.88

Note: OC = Organic carbon, KCL = potassium chloride, OM = organic matter, TN = total nitrogen, AVP = Available phosphorus, Ca = Calcium, Mg = Magnesium, Na = sodium, K = potassium, Al = Aluminum, H = hydrogen, ECEC = electrical cation exchange capacity, BS = base saturation.

Similarly, in Egbeada, the non-highway is for 0–50 m and 50–100 m. Lead (PL) has a mean value ranged from 0.04 to 0.12 (mg kg<sup>-1</sup>), Arsenic (As) ranged from 0.03 to 0.46 (mg kg<sup>-1</sup>), Zinc (Zn) ranged from 0.85 to 2.11 (mg kg<sup>-1</sup>), Copper (Cu) ranged from 0.28 to 1.67 (mg kg<sup>-1</sup>) and Mercury (Hg) has the mean value ranged from 0.07 to 0.20 (mg kg<sup>-1</sup>). Soil heavy metal contents decreased with depth for each site, both for 0–50 m and 50–100 m (Tables 5 and 6).

It was observed that in Table 7, all the sites studied from 0–50 m have increased concentration of heavy metals (Pb, As, Zn, Cu, Hg) except Egbeada, which has the smallest mean values. An increase in heavy metal content on the highways may be attributed to the movement of vehicles, coupled with domestic materials scattered on the road. Zinc (Zn) has the highest concentration, unlike other heavy metals, in all the sites, while mercury (Hg) has the lowest concentration.

**Table 5.** Selected heavy metals content of the study area for 0–50 m (mg kg<sup>-1</sup>).

Location	Soil Depth (cm)	Pb	As	Zn	Cu	Hg
Owerri-Aba	0–15	1.63	2.00	2.42	1.32	1.04
	15–30	1.85	2.16	2.50	0.09	0.12
	Mean	1.74	2.08	2.46	1.11	0.58

**Table 5. Cont.**

Location	Soil Depth (cm)	Pb	As	Zn	Cu	Hg
Owerri-Okigwe	0-15	1.50	1.86	2.01	0.75	0.50
	15-30	1.58	1.92	2.33	0.05	0.20
	Mean	1.54	1.89	2.17	0.40	0.35
Egbeada (control)	0-15	0.10	0.43	0.82	0.45	0.25
	15-30	0.13	0.49	0.88	0.10	0.15
	Mean	0.12	0.46	0.85	0.28	0.20
LSD <sub>0.05</sub>		0.41	0.52	0.72	0.08	0.25

Note: Pb = Lead, As = Arsenic, Zn = Zinc, Cu = Copper, Hg = Mercury.

**Table 6.** Selected heavy metals content of the study area for 50-100 m (mg kg<sup>-1</sup>).

Location	Soil Depth (cm)	Pb	As	Zn	Cu	Hg
Owerri-Aba	0-15	0.55	0.74	1.35	1.37	0.62
	15-30	0.10	0.16	1.22	1.20	0.12
	Mean	0.33	0.45	1.29	1.29	0.37
Owerri-Okigwe	0-15	0.62	0.51	1.42	1.25	0.58
	15-30	0.15	0.07	1.07	1.02	0.10
	Mean	0.39	0.29	1.25	1.14	0.34
Egbeada (control)	0-15	0.07	0.05	2.50	2.30	0.10
	15-30	0.01	0.02	1.72	1.04	0.03
	Mean	0.04	0.04	2.11	1.67	0.07
LSD <sub>0.05</sub>		0.10	0.18	0.06	0.10	0.03

**Table 7.** The relationship between heavy metal contents and selected soil properties.

Content	Pb	As	Zn	Cu	Hg
Sand	-0.32	-0.52	-0.42	-0.15	-0.16
Clay	-0.72	-0.62	-0.16	-0.25	-0.17
MC	0.62	0.60	0.52	0.72	0.32
BD	0.51	0.42	0.78	0.17	0.05
OC	-0.72	-0.70	-0.52	-0.16	-0.67
Ar. P	-0.50	-0.65	-0.42	-0.72	0.55
TN	-0.32	-0.44	0.92	-0.77	-0.45
ECEC	0.65	0.55	0.72	0.25	0.15

The heavy metal contents decrease with distance in all the highways studied. The heavy metal decreases with depth, which agrees with Celik et al. and Mbila et al. [4,33] that the concentration of heavy metal is higher in the topsoil than in the subsoil. The heavy metals studied exceeded the permissible limits<sup>[34]</sup> in all the highways except the non-highway Egbeada.

**The Relationship between Heavy Metal Content and Some Selected Soil Properties**

Heavy metals (Pb, As, Zn, Cu, Hg) studied correlated positively with moisture content, bulk density, effective cation exchange capacity, and exchangeable acidity. This implies that an increase in heavy metal contents increases the moisture content, bulk density, and effective cation exchange capacity, vice versa. Some correlated negatively with heavy metal content, such as or-

ganic carbon, available phosphorus, total nitrogen, sand content, and clay. This means that an increase in heavy metal content decreased the soil properties.

**5. Conclusions**

The findings reveal that soils along the Owerri-Aba and Owerri-Okigwe highways contain elevated concentrations of Pb, As, Zn, Cu, and Hg compared to the control site, Egbeada, with zinc being the most abundant and mercury the least. The spatial distribution patterns show that heavy metal concentrations decrease with both distance from the road and soil depth, highlighting the influence of vehicular emissions, road dust, and other roadside activities on soil contamination. Correlation analysis demonstrated that heavy metal accumula-

tion is associated with increased moisture content, bulk density, and cation exchange capacity, while it inversely affects soil organic matter, available phosphorus, and nitrogen content. The concentrations of certain metals exceeded WHO limits, suggesting the need for regular monitoring and the implementation of mitigation measures to reduce environmental and health hazards. This study underscores the importance of pollution control strategies along major transportation routes to preserve soil quality and protect the ecosystem and human health.

## Author Contributions

Conceptualization, O.C.A.; methodology and formal analysis, C.I.O.; editing and investigation, R.U.O. All authors have read and agreed to the published version of the manuscript.

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Not applicable.

## Conflicts of Interest

The authors declare no conflict of interest.

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