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ASSESSMENT OF SPATIAL DISTRIBUTION OF HEAVY METALS IN ROADSIDE SOILS AND SOME VEGETALES ALONG NNAMDI AZIKIWE EXPRESS WAY, KADUNA.

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ABSTRACT
The research aimed to assess the spatial distribution of heavy metals in some vegetables and roadside soils along the Nnamdi Azikiwe Expressway in Kaduna. The soil samples were collected at random from nine locations down to a depth of 20 cm in replicates. In the same area where the soil samples were collected, the vegetable samples were likewise chosen at random. The Nariya farm provided the control samples. The samples were allowed to air dry, mixed, and sieved. Nine soils and twenty-seven vegetables were used to prepare the samples. The samples were then digested using the wet technique. Using a pH meter and the conventional Walkley-Black method, the following physiochemical parameters were measured: pH, electrical conductivity, organic carbon, and soil organic matter. Atomic Absorption Spectroscopy was used to assess the concentrations of Pb, Cd, Zn, Cu, and Ni in soil and vegetable samples that were gathered from the roadside at Kawo, Panteka, Kurmin Mashi, Badikko, Tudun Wada, Kabala West, Kudenda, Nassarawa, and Trikania. The findings showed that the soil's pH was generally basic (7.8) and somewhat acidic (6.9). At Kawo and Nassarawa, the EC value was 0.278 ds/cm and the OC value was 12.0g/kg. Zn had the greatest mean concentration in mg/kg of Pb, Cd, Zn, Cu, and Ni, measuring 166.40. The same was true for vegetables, with Zn values of 278.28, 230.90, and 274.90 for spinach, lettuce, and cabbage, respectively. The contamination factor indicates that Ni is marginally enhanced in vegetables at Badikko and Tudun Wada and below the detection limit in all soil samples. For every metal, the translocation factor was less than 1, however at Kawo, Panteka, Badikko, Tudun Wada, and Nassarawa. With the exception of one location that exhibits heavy pollution with PLI >1, the area was not significantly polluted. Nonetheless, the assessment's findings show that there was an increased concentration of Zn and Pb at all nine locations, which was consistent with findings from other researchers. As a result, the toxicants were below the NESREA-established permissible limit. However, because of the metals present from various operations that took place at the site, the concentration of these metals does not follow a regular pattern; instead, fluctuation was seen in the sample. To reduce the spread of harmful contaminants into the environment, government organizations should, however, provide for legislation, awareness, education, waste management, a modern transportation system, and regular analysis.
***Key words*: Soil, Pollution, concentration, contamination factor, Total organic carbon**

1. INTRODUCTION

Heavy metals are defined as dense, toxic elements, that pose a significant threat to the environment and human health even at low levels. While, they occur naturally, human activities like industry, agriculture, and transportation have drastically increased their presence in the environment. Along the Nnamdi Azikiwe Expressway in Kaduna, growing traffic volumes have led to considerable heavy metal contamination in adjacent soils and farm produce. Vehicles release metals such as lead, cadmium, zinc, copper, and nickel through exhaust, tire, and brake wear, and fluid leaks. These pollutants settle in the roadside soils and are subsequently absorbed by leafy vegetables like spinach, lettuce and cabbage, introducing them into the food chain and creating health risks for consumers. The extent of contamination is influenced by factors like traffic density, distance from the road, and weather conditions

2. MATERIALS AND METHODS

2.1.Reagents

Every reagent used was analytical grade and didn't require any additional purification. These included concentrated nitric acid (HNO_3) (Assay: 65%, v/v; M_r = 63 g/mol), hydrochloric acid (HCl) (SG: 1.18; 36% v/v; M_r = 36.46 g/mol), perchloric acid ($HClO_4$), lead nitrate ($Pb(NO_3)_2$) (Assay: 99%; M_r = 331.23 g/mol), cadmium nitrate tetrahydrate ($Cd(NO_3)_2 \cdot 4H_2O$) (Assay: 98%; M_r = 236.42 g/mol), copper(II) sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$) (Assay: 99.99%; M_r = 249.64 g/mol), nickel nitrate ($Ni(NO_3)_2$) (Assay: 98.5%; M_r = 290.7 g/mol), Walkley–Black chromic acid, potassium dichromate ($K_2Cr_2O_7$), calcium chloride ($CaCl_2$), buffer-7 solution, sulfuric acid (H_2SO_4) (SG: 1.83; 98% v/v; M_r = 98.0 g/mol), phenanthroline ferrous sulfate indicator, ferrous

sulfate ($FeSO_4$) (SG: 1.68; M_r = 227.86 g/mol), and deionized water, which was used in preparing all sample solutions.

2.2. Study Area

This research was conducted along Nnamdi Azikiwe Expressway in Kaduna North and South, which runs close to the equator between latitudes 7°20′03″ to 7°31′04″ E and longitudes 9°55′00″ to 10°37′10″ N. Table 1 list the main urban centers in the research region.

Table 1 Showing the sampling points and respective coordinates

Name of Locations	Coordinates: N	E
Kawo	(10^0 34' 56.18" N ;	7^0 27' 08.74" E)
Panteka	(10^{0}34' 5.58"N ;	7^{0}25'04.42"E)
Kurmin Mashi	(10^{0}33' 05.31"N ;	7^{0}25' 00.66"E)
Badiko	(10^{0}32' 13.77"N ;	7^{0}24' 35.59"E)
Tudunwada,	(10^{0}30' 34.46"N ;	7^{0}24' 04.35"E)
KabalaWest,	(10^{0}29' 3.13"N ;	7^{0}23' 42.76"E)
Kudenda,	(10^{0}28' 52.65"N ;	7^{0}22' 50.30"E)
Nassarawa,	(10^{0}28' 28.86"N ;	7^{0}23' 41.33"E)
Trikaniya	(10^{0}27' 28.31"N ;	7^{0}23' 38.20"E)

The area is characterized by intense commercial and industrial activity, including Mechanic workshops, markets, factories. abattoirs, welding and metal fabrication, car wash services, cement production, energy-related services, paint manufacturing, transportation, farming, residential settlements, trailer parks, and the movement of heavy-duty trucks into and out of Kaduna.

2.3. Sample collection

A total of nine samples and three vegetable samples were obtained from each sampling point. Samples were randomly collected at varying distances from the roadside to the depth of 20cm, using acid- washed, clean polythene bags that were properly labeled according to their locations. Samples collection was carried out between December 2023 and January 2024 using the method of Okonkwo *et al.* (2012), to minimize the effects of rainfall washing away heavy metals. Control samples for both soil and vegetables were collected from Nariya Farm, which is located behind Kabala West. At each site, the samples were thoroughly mixed after removing debris and foreign materials to form composite samples.

Altogether, nine soil and twenty-seven vegetable composites were obtained, totaling thirty-six composite samples for the study. The vegetable specimens were taken to the Herbarium Unit for identification and authentication by botanist Mr. Gadafi, who assigned the following voucher numbers: lettuce: NDA/BIOH/2024/40, spinach: NDA/BIOH/2024/41, and cabbage: NDA/BIOH/2024/42 (Department of Biological Sciences, Nigerian Defence Academy, Kaduna).

2.3.1. Sample preservation

All samples were placed in acid-washed, labeled polythene bags and stored in clean plastic containers at room temperature until they were taken to the laboratory for analysis (Matuku, 2010).

2.3.2. **Sample pre-treatment**

Soil samples were air – dried at room temperature to remove moisture, pulverized using a clean mortar and pestle, sieved through a 2 mm mesh to obtained fine particles. Similarly, vegetable sample were washed thoroughly with tap water to remove attached soil or dust, air – dried for one week, and ground into fine powder using an electric blender and then sieved through a 2 mm mesh for easy digestion.

2.3.3. **Sample preparation and digestion**

Soil Digestion: A 2 g aliquot of each composite, was weighed into a clean beaker and digested with 30 cm^3 of a 3:1 mixture of HCl and HNO_3 (aqua regia). The mixture was heated on a hot plate until near dryness. The cooled residue was then diluted with to 100 cm^3 deionized water, filtered through Whatman filter paper into a 250 cm^3 volumetric flask. The filtrate was then stored in labeled bottles for Atomic Absorption Spectrophotometric (AAS) analysis. A reagent blank (HCl–HNO_3 solution without soil) was also prepared to validate the analytical accuracy of the procedure.

Plant Digestion: A 1 g portion of each ground vegetable sample was digested using 30 cm^3 of a 4:1 mixture of HNO_3 and $HClO_4$. The mixture was heated to near dryness, cooled, diluted to 100 cm^3 with deionized water, centrifuged, filtered, and final filtrate was transferred into sample bottles with labels for AAS analysis using a SEARCH-TECH AA 20 model spectrophotometer.

2.4. Methods of Analysis

The physicochemical properties of the soil samples, such as pH, electrical conductivity (EC), organic carbon (OC), and organic matter (OM) were determined using digital instruments. pH and EC were measured in soil-water extracts, with EC representing the concentration of soluble ions and the soil resistance to electrical current. Organic carbon was determined using the walkley-Black method (wet oxidation with potassium dichromate), While soil organic matter was calculated by multiplying organic carbon values by 1.742, assuming that organic matter contains approximately 58% carbon.

2.4.1.Preparation of 1000 ppm standard solutions

The preparation was stand solutions of the metals were carried out using a multivariant method. This method allowed the calculated amount of the metal salt to be dissolve in deionized water in a 250cm^3 beaker and transferred to a 1000cm3 volumetric flask and dilute to mark. The salt used in the study were 1.6 g of $Pb(NO_3)$, 2.8 g of $Cd(NO_3)_2{\cdot}4H_2O$, 2.9 g of $Zn(NO_3)_2$, 3.9 g of $CuSO_4{\cdot}5H_2O$ and 4.9 g of $Ni(NO_3)_2{\cdot}6H_2O$ were used. Working standards of 10,8,6, 4 and 2 ppm were prepared using the dilution formula (Adeola *et al.*, 2015).

2.4.2. Assessment of Metal Concentrations

The concentration of heavy metals in soils and vegetables was evaluated using various contamination indices, including Bioaccumulation Factor (BAF), Translocation Factor (TF), Contamination Factor (CF), and Pollution Load Index (PLI). Bioaccumulation Factor (BAF): measures the degree to which metals accumulate in plants from soil while Translocation Factor (TF) indicate the movement of metals within plant tissues (e.g., from roots to leaves). i.e.

$$BAF = \frac{\text{Concentration of metal in plant}}{\text{Concentraton of metal in soil}} \quad (2.1)$$

$$TF = \frac{\text{Metal concentration in leaves or Stem}}{\text{Metal concentration of Root.}} \quad (2.2)$$

where Cs is the background value of heavy metal in uncontaminated soil, Cp is the measured concentration of the estimated metal in the plant, CL is the measured concentration of the estimated metal in the leaves or stem, and Cr is the metal concentration of the root. (Khairy, 2011). As indicated below, four CF classifications were proposed and utilized to assess the levels of metal pollution.

Contamination Factor (CF):which measures the degree of metal contamination of the soil and plants, is computed as follows: CF = (Cm Background)/(Cm Sample) (3.3)

When the contamination factor is less than 1, it indicates low contamination; when it is greater than 3, it indicates moderate contamination; when it is greater than 6, it indicates significant contamination; and when it is greater than 6, it indicates very high contamination..

The level of heavy metal contamination at each research location was evaluated. The Pollution Load Index (PLI), created by Tomlinson et al. (1980), was used to assess the overall pollution level and offer a straightforward yet comparable indicator of site quality. The following formula was used to calculate it:

PLI = (Cf1 x Cf2 x Cf3…Cf n)1/n or alternatively represented as the geometric mean of the contamination factors (CF), where: n= number of metals examined, and CF = contamination factor (as specified in Equation 2.3). PLI values can be interpreted as follows: PLI < 1 denotes a perfect state, meaning there is no pollution; PLI = 1 denotes baseline or natural levels of pollutants; and PLI > 1 denotes contamination-induced site deterioration.To reduce the impact of outlier data that could skew the results, the geometric mean approach was used in this study to calculate the PLI.

2.4.3. **Pollution Load Index (PLI):** This index is defined as the geometric mean of individual contamination factors (CF), that provide a single value for site quality. PLI < 1 denote no pollution, PLI = 1 indicates baseline levels, and PLI > 1 confirms contamination and environmental deterioration. The geometric mean calculated was specifically selected to minimize potential distortion from outlier values.

2.5. Statistical Analysis

For statistical comparison, Analysis of Variance (ANOVA) was conducted using Microsoft Excel to test for significant differences in mean heavy metal concentrations across the various sites, with a significance threshold of $p < 0.05$.

3.0. Results

This chapter outlines the research findings, which encompass an analysis of the soil's physiochemical parameters, the baseline concentrations of heavy metals in environmental samples (soils and vegetables) gathered from multiple locations, and the subsequent computation of bioaccumulation and pollution index values.

Table 2: Analysis of Soil Physiochemical Properties.

S/ No	SID/ Code	Sample Locations	pH (H_2O)	($CaCL_2$)	EC ds/cm	OC g/kg	SOM mg/kg
1	SS1	Kawo	7.7	7.4	0.278	5.4	0.9
2	SS2	Panteka	7.3	6.8	0.177	8.2	1.4
3	SS3	K/Mashi	6.5	6.0	0.078	8.0	1.4
4	SS4	Badikko	7.8	7.4	0.164	9.6	1.7
5	SS5	T/Wada	7.5	7.0	0.170	7.4	1.3
6	SS6	K/West	6.3	5.3	0.050	7.0	1.2
7	SS7	Kudenda	6.9	6.0	0.074	6.8	1.2
8	SS8	Nassarawa	6.9	6.0	0.274	12.0	1.1
9	SS9	Trikaniya	6.6	6.0	0.132	7.6	1.3

Standard Limits: pH (4.98–7.45); EC (14–172 µS/cm); OC (0.27–5.44%); SOM (0.33–3.19%)
Source: Akan et al., 2013

Table 3: Concentration of Heavy Metal in Soil Sample from Different Location

S/ No	SID/ Code	Sample Location	Pb mg/kg	Cd mg/kg	Zn mg/kg	Cu mg/kg	Ni mg/kg
1	SS1	Kawo	12.70	1.00	69.15	1.00	2.70
2	SS2	Panteka	15.80	0.45	107.75	0.45	4.45
3	SS3	K/Mashi	7.70	22.75	38.20	22.75	0.80
4	SS4	Badikko	15.75	22.20	148.10	22.20	DBL
5	SS5	T/Wada	22.00	9.50	74.05	9.50	7.85
6	SS6	K/West	9.25	4.55	45.05	4.55	8.60
7	SS7	Kudenda	8.50	3.35	64.75	3.35	11.00
8	SS8	Nassarawa	38.35	9.05	166.40	9.05	11.50
9	SS9	Trikaniya	9.65	4.50	35.45	4.50	3.10
10	Cn	Naria	3.60	0.05	7.85	0.07	BDL

Sample Identifications–**Soil** Sample (1, 2, 3, …); Cn – Control Sample; BDL–Below Detection Limit.

Table 4: Concentration of heavy metals in vegetable from Different Location

S/N	SID	Vegetables Sample /locations	Pb (mg/kg)	Cd (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Ni (mg/kg)
		Spinach					
1	PS1	Kawo	4.60±0.17	4.90±0.11	97.10±1.74	16.30 ±0.00	**1.40±2.72**
2	**PS2**	**Panteka**	**10.0±0.00**	**4.25±0.00**	**13.20±2. 17**	**11.35±0. 00**	**5.00± 0.00**
3	**PS3**	**K/Mashi**	**2.50±0. 00**	**0.60±0. 00**	**260.70±0. 00**	**11.00±0. 00**	**4.90± 0.00**

4	PS4	Badikko	8.80±0.00	6.70±0.00	99.00±0.00	7.60±1.08	13.80±2.18
5	PS5	T/Wada	13.20±2.18	18.00±0.00	140.20±0.00	7.60±1.08	13.80±2.18
6	PS6	K/West	18.70±0.00	12.20±2.18	87.70±0.00	9.00±0.00	16.20±0.00
7	PS7	Kudenda	16.80±0.06	17.10±0.01	207.30±0.01	14.40±0.06	5.20±0.10
8	PS8	Nassarawa	21.40±0.01	26.30±2.23	278.28±1.64	8.80±0.54	1.80±0.00
9	PS9	Trikania	20.50± 0.76	12.10±0.01	213.80±0.78	6.30±0.78	0.40±0.02
10	Cn	Lettuce	7.70±1.78	8.00±0.23	7.00±2.72	3.40±0.23	0.90± 0.03
1	PS10	Kawo	4.10±0.45	11.10±0.33	124.40±0.54	6.10± 0.03	2.20±0.72
2	PS11	Panteka	5.95±0.02	3.78±0.03	159.55±0.10	16.15±0.06	3.85±2.33
3	PS12	K/Mashi	12.20±0.02	2.60±0.01	179.85±	8.40±0.31	6.40± 0.03
4	PS13	Badikko	11.10±0.32	11.60±0.32	121.40±22.1	8.00±1.66	15.80± 0.05
5	PS14	T/Wada	13.20±0.84	18.00±0.25	140.20±1.73	7.60±0.28	13.80±0.93
6	PS15	K/West	17.40±0.01	12.00±0.01	87.65±0.33	9.00±0.33	16.20±0.02
7	PS16	Kudenda	16.60±0.00	17.20±0.01	195.20±0.06	14.20±0.54	5.00±0.00
8	PS17	Nassarawa	20.80±0.03	15.10±0.03	117.50±0.06	7.20±0.24	0.80±0.87
9	PS18	Trikania	13.20±0.02	16.00±0.01	230.90±0.49	0.40±0.01	7.70±0.08
10	Cn	Nariya Cabbage	7.50±0.01	6.90±0.03	26.50±0.15	0.30±0.228	0.60±0.03
1	PS19	Kawo	4.35±0.33	8.00±0.02	110.75±0.11	11.20±0.03	1.80±0.41
2	PS20	Panteka	1.20±0.02	3.30±1.19	187.90±11.2	4.80±0.03	2.70±0.01
3	PS21	K/Mashi	9.70± 0.28	4.60±0.01	99.00±0.41	5.80±0.02	7.90±0.27
4	PS22	Badikko	13.40±0.02	16.80±0.01	143.80±3.03	7.70±0.03	24.60±0.06
5	PS23	T/Wada	12.00±0.03	23.90±2.28	274.90±0.06	4.60±0.02	24.90±0.02
6	PS24	K/West	18.05±0.34	12.10±0.01	87.65±0.24	8.98±0.28	17.03±0.01
7	PS25	Kudenda	16.70±0.06	17.15±0.01	201.25±0.07	14.30±0.03	5.10± 0.06
8	PS26	Nassarawa	21.10±0.03	20.70±0.02	197.85±0.02	8.00±0.01	1.30± 0.54
9	PS27	Trikania	16.85±0.02	14.10±0.02	222.35±0.02	2.00±0.08	4.05±0.91
10 C		Nariya	0.80±0.03	1.00±0.01	10.00±4.93	1.40±0.06	2.20±0.09

SID: Sample Identity; PS: Plant Sample 1, 2, 3……. Etc

Table 5: presents the **BAF** of heavy metals in the vegetable samples.

SID/Code	Vegetable/Location	Pb	Cd	Zn	Cu	Ni
	Spinach					
PS1	Kawo	0.36	4.90	1.40	1.41	0.52
PS2	Panteka	0.68	9.44	1.22	0.65	1.12
PS3	K/Mashi	0.32	0.03	6.82	1.24	6.13
PS4	Badikko	0.56	0.03	0.67	0.92	BDL
PS5	T/Wada	0.60	1.89	1.89	0.84	1.76
PS6	K/West	2.02	2.68	1.95	1.20	1.88
PS7	Kudenda	1.98	5.10	3.20	1.68	0.47
PS8	Nassarawa	0.50	2.90	1.67	0.12	0.16
PS9	Trikania	2.12	2.69	6.03	0.18	0.13
	Lettuce					
PS1	Kawo	0.32	11.10	1.80	0.53	0.81

PS2	Panteka	0.38	8.40	1.48	0.93	0.87
PS3	K/Mashi	1.58	0.11	4.71	0.95	8.00
PS4	Badikko	0.70	0.52	0.84	0.88	BDL
PS5	T/Wada	0.50	1.10	3.0	0.92	1.80
PS6	K/West	1.88	2.64	1.94	1.20	1.87
PS7	Kudenda	1.95	5.13	3.01	1.66	0.45
PS8	Nassarawa	0.54	1.67	0.71	0.09	0.07
PS9	Trikania	1.37	3.56	6.51	0.01	2.48
	Cabbage					
PS1	Kawo	0.34	8.00	1.60	0.97	0.67
PS2	Panteka	0.08	7.33	1.74	0.28	0.61
PS3	K/Mashi	1.26	0.20	2.59	0.66	9.88
PS4	Badikko	0.85	0.74	0.97	0.85	BDL
PS5	T/Wada	0.55	2.52	3.71	0.51	3.20
PS6	K/West	1.96	2.66	1.95	1.20	1.98
PS7	Kudenda	1.96	3.63	3.11	1.67	0.46
PS8	Nassarawa	0.55	2.29	1.19	0.10	0.03
PS9	Trikania	1.75	3.13	6.27	0.06	1.31

Table 6: presents **Translocation Factors (TF)** of heavy metals in the vegetable samples studied.

SID	Vegetables/Location	Pb	Cd	Zn	Cu	Ni
	Kawo					
PS1	Spinach	0.50	0.5045	0.500	0.5	0.5054
PS2	Lettuce	0.50	0.5	0.5724	0.5	0.4966
PS3	Cabbage	0.50	0.50	0.5001	0.4993	O.5
	Panteka					
PS4	Spinach	0.4993	0.502	0.4991	0.4993	0.502
PS5	Lettuce	0.5116	0.5	0.4991	0.4995	0.4981
PS6	Cabbage	0.5	0.5	0.4991	0.5	0.5
	Kurmin Mashi					
PS7	Spinach	0.4970	0.5	0.5	0.5007	0.718
PS8	Lettuce	0.5006	0.5029	0.5	0.5	0.4988
PS9	Cabbage	0.4997	0.4984	0.5	0.4987	0.4991
	Badikko					
PS10	Spinach	0.4991	0.4984	0.5	0.5009	0.4989
PS11	Lettuce	0.5	0.5006	0.5000	0.5OIO	0.500
PS12	Cabbage	0.5006	0.4495	0.4995	0.4990	0.5
	Tudun Wada					

PS13	Spinach	0.5	0.5	0.4995	0.4990	0.5
PS14	Lettuce	0.4993	0.4996	0.5001	0.5009	0.5
PS15	Cabbage	0.50	0.5003	0.4992	0.4984	0.5
	Kabala West					
PS16	Spinach	0.4996	0.5006	0.4991	0.4991	0.5
PS17	Lettuce	0.5	0.5	0.5	0.5008	0.5005
PS18	Cabbage	0.4983	0.49930	0.5001	0.50	0.5004
	Kudenda					
PS19	Spinach	0.5	0.4995	0.5	0.5	0.1451
PS20	Lettuce	0.4995	0.4995	0.5000	0.4995	0.5015
PS21	Cabbage	0.5004	0.4978	0.4991	0.4983	0.1508
	Nassarawa					
PS22	Spinach	0.4996	0.5003	0.4991	0.5	0.5
PS23	Lettuce	0.4996	0.4995	0.5000	0.4995	0.5094
PS24	Cabbage	0.4118	0.5	0.5	0.4983	0.4943
	Trikania					
PS25	Spinach	0.4996	0.4995	0.5000	0.5	0.4815
PS26	Lettuce	0.5	0.4995	0.5000	0.4894	0.5010
PS27	Cabbage	0.5004	0.5	0.5000	0.5038	0.5

SID: Sample Identity; **PS**: Plant Sample 1, 2, 3……. Etc

Table 7: Shows Contamination Factor of Soil samples

SAMPLE ID/CODE	SAMPLE LOCATIONS	Pb	Cd	Zn	Cu	Ni
SS1	Kawo	1.20	0.18	0.52	0.38	BDL
SS2	Panteka	1.49	0.08	0.52	0.57	BDL
SS3	Kurmin mashi	0.73	4.1	0.29	0.29	BDL
SS4	Badikko	1.49	4.04	1.13	0.30	BDL
SS5	Tudun wada	2.08	1.72	0.56	0.30	BDL
SS6	Kabala west	0.87	0.82	0.34	0.25	BDL
SS7	Kudenda	0.80	0.61	0.49	0.28	BDL
SS8	Nassarawa	3.62	1.64	1.26	2.69	BDL
SS9	Trikania	0.91	0.82	0.27	0.26	BDL

Table 8: Shows Contamination Factor of Some Vegetables

SID/Code	Vegetables./Location	Pb (mg/kg)	Cd (mg/kg)	Zn (mg/kg)	Cu (mg/kg)	Ni (mg/kg)

	Kawo					
PS1	Spinach	0.10	0.07	0.33	1.06	0.10
PS2	Lettuce	0.09	0.16	0.42	0.40	0.16
PS3	Cabbage	0.09	0.12	0.37	0.72	0.13
	Panteka					
PS4	Spinach	0.22	0.06	0.44	0.74	0.36
PS5	Lettuce	0.12	0.06	0.54	1.05	0.28
PS6	Cabbage	0.03	0.05	0.63	0.31	0.35
	Kurmin Mashi					
PS7	Spinach	0.05	0.01	0.87	0.71	0.35
PS8	Lettuce	0.26	0.04	0.61	0.55	0.46
PS9	Cabbage	0.20	0.07	0.33	0.38	0.57
	Badikko					
PS10	Spinach	0.17	0.10	0.33	0.54	0.50
PS11	Lettuce	0.23	0.17	0.41	0.52	1.14
PS12	Cabbage	0.28	0.24	0.48	0.50	1.77
	Tudun Wada					
PS13	Spinach	0.28	0.26	0.47	0.49	0.99
PS14	Lettuce	0.29	0.28	0.43	0.54	0.07
PS15	Cabbage	0.25	0.35	0.93	0.30	1.79
	Kabala West					
PS 16	Spinach	0.39	0.18	0.30	0.02	1.17
PS17	Lettuce	0.36	0.18	0.29	0.58	1.16
PS18	Cabbage	0.18	0.38	0.30	0.58	1.23
	Kudenda					
PS19	Spinach	0.35	0.25	0.70	0.94	0.37
PS20	Lettuce	0.35	0.25	0.66	0.92	0.36
PS21	Cabbage	0.35	0.18	0.68	0.93	0.37
	Nassarawa					
PS22	Spinach	0.45	0.39	0.94	0.57	0.13
PS23	Lettuce	0.44	0.22	0.40	0.47	0.06
PS24	Cabbage	0.44	0.30	0.67	0.52	0.09
	Trikania					
PS25	Spinach	0.43	0.18	0.72	0.41	0.03
PS26	Lettuce	0.28	0.24	0.78	0.03	0.55

PS27	Cabbage	0.35	0.21	0.75	0.13	0.29

Table 9: Shows Pollution Load Index of Soil at Different Location

S/N	SID	LOCATION	Value	PLI
1	SS1	Kawo	0	**< 1**
2	SS2	Panteka	0	**< 1**
3	SS3	K/mashi	0	**< 1**
4	**SS4**	**Badikko**	0	**< 1**
5	SS5	T/Wada	0	**< 1**
6	SS6	K/West	0	**< 1**
7	SS7	Kudenda	0	**< 1**
8	SS8	Nassarawa	0	**< 1**
9	SS9	Trikaniya	0	**< 1**

SID: Sample Identity; **SS:** Soil Sample 1,2,3…… etc.

Table 10: Shows Pollution Load Index of Vegetable at Different Location

S ID	Vege/Location	Value	PLI
	Kawo		
PS1	Spinach	0.14	**< 1**
PS2	Lettuce	0.16	**< 1**
PS3	Cabbage	0.10	**< 1**
	Panteka		
PS4	Spinach	0.20	**< 1**
PS5	Lettuce	0.17	**< 1**
PS6	Cabbage	0.04	**< 1**
	Kurmi mashi		
PS7	Spinach	0.05	**< 1**
PS8	Lettuce	0.04	**< 1**
PS9	Cabbage	0.20	**< 1**
	Badikko		
PS10	Spinach	0.20	**< 1**
PS11	Lettuce	0.49	**< 1**
PS12	Cabbage	0.84	**< 1**
	Tudun wada		
PS13	Spinach	0.64	**< 1**
PS14	Lettuce	0.18	**< 1**
PS15	Cabbage	1.05	**> 1**
	Kabala west		
PS16	Spinach	0.11	**< 1**
PS17	Lettuce	0.56	**< 1**
PS18	Cabbage	0.60	**< 1**
	Kudenda		
PS19	Spinach	0.73	**< 1**
PS20	Lettuce	0.40	**< 1**
PS 21	Cabbage	0.60	**< 1**
	Nassarawa		
PS22	Spinach	0.55	**< 1**
PS23	Lettuce	0.17	**< 1**
PS24	Cabbage	0.32	**< 1**

	Trikania		
PS25	Spinach	0.13	**< 1**
PS26	Lettuce	0.15	**< 1**
PS27	**Cabbage**	**0.23**	**< 1**

SID: Sample Identity;.**PS**: Plant Sample 1, 2, 3……. etc.

4.0. Discussion

Soil physicochemical properties

Table **2** presents the summary of the physicochemical characteristics of the soil samples collected from the study area.

The soil pH values ranged from 6.3 to 6.9 in some location, indicating moderately acidic conditions, while other samples showed slightly basic characteristics with values between 7.0 and 7.9 for both H_2O and $CaCl_2$ measurements.

These findings are comparable to the pH range of 4.1–8.8 reported by Chang *et al.,* (2014) , that of 6.0–7.4 observed by Nigam *et a.,* (2016). The observed variations in pH could be attributed to differences in climatic conditions and parent material composition of the soils. According to Stone (2016), most crops perform optimally in slightly acidic soils, typically within a pH range of 6.2–6.8.

The Electrical Conductivity (EC) of the soil samples ranged from 0.050 to 0.278 ds/cm with a mean standard deviation of 0.08. All values were below permissible limits indicating low soluble salt content recommended by NSEREA (2011) and WHO (2004). This means the soils are not saline and are suitable for agriculture from a salinity perspective. Regarding Organic Carbon (OC), the highest concentrations were recorded at Nassarawa (12.0%) and Badikko (9.6%) followed by Kabala West (7.0%), Tudun Wada (7.4%), and Trikaniya (7.6%). Kurmin Mashi and Pantaka had values of 8.0% and 8.22%, respectively. While Kawo had the lowest OC value at 5.4%. The relatively high organic carbon levels may be attributed to the presence of biosolids and organic residues in the soil. These results align with findings from previous studies, including Chang *et al.,* (2014), who reported 7.4%, Wuana *et al.,* (2010), who reported 8.8%, and Nigam *et al.,* (2016), who found a relatively lower value of 0.14%, According to Nigam *et al*., (2016), soil organic matter (SOM) content varies by soil type ranging from 20-98 % in Histosols and 1.5 – 3.0 % in vertisols. Based on this classification, the SOM values from this study do not correspond directly to either of these soil types. However, the present results agree with Chang *et al.,* (2014), who noted that lower SOM values can be influenced by soil texture. Furthermore, the current finding indicates that SOM increases with rising pH, suggesting a pH-dependent relationship (Table 2). Statistical analysis using one-way ANOVA showed a significant difference in the physiochemical properties of soils across different sampling locations, with p-value= $0.001 < \alpha = 0.05$. This implies a strong relationship between soil characteristics and sampling locations, further support by the overall p-value of 9.2×10^{-17}, confirming that location has a statistically significant effect on soil physiochemical properties

Concentration of Heavy Metal in Soil Sample from Different Location

Table 3 summarizes the levels of five specific heavy metals in soil samples taken from different locations: lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), and nickel (Ni). The following were the total concentration ranges noted: Zn: 45.05–166.40 mg/kg; Cu: 0.45–22.75 mg/kg; Ni: 0.80–11.50 mg/kg; Pb: 7.70–38.35 mg/kg; Cd:0.45–22.75mg/kg.All of these concentrations fell below the upper limits allowed by FEPA/NAFDAC and other international regulatory bodies, suggesting that the soils are free of heavy metal contamination and can be used for farming. There were differences in the levels of heavy metals at each sampling site. With zinc (Zn) levels of 166.40 mg/kg, Nassarawa had the highest contamination level, followed by Badiko with 148.10 mg/kg. In Nassarawa, lead (Pb) also accumulated at a comparatively high rate (38.35 mg/kg). Despite the raised Pb levels, they were still below international guidelines, such as the critical concentration range (100–400 mg/kg), Europe's (300 mg/kg), and India's (250–500 mg/kg) restrictions. The findings, according to Hindarwati *et al.* (2018), are within the typical soil range of 2–300 mg/kg. Vehicle emissions, industrial operations, and the use of pesticides in adjacent farmlands may all contribute to the presence of lead and other metals. On the other hand, as flora prefers to absorb and accumulate these metals from the soil, the decrease in heavy metal content may be the result of plant uptake.The concentrations of heavy metals in the soils generally went as follows: Zn (166.40) > Pb (38.35) > Cu (30.50) > Cd (22.75) > Ni (11.50) mg/kg.

The contamination pattern across sites declined in the following sequence of spatial variation: Ka > Pa > K/M > Ba > T/W > K/W > Ku > Na > Tri > Nariya. According to statistical analysis, there were significant differences ($p < 0.05$) in metal concentrations between the several sampling sites. According to Luo *et al.,* (2011b), emissions from lead-containing trash are probably to blame for the comparatively high Pb levels found. Nonetheless, the total amounts found were still more than those Xu *et al.*, (2016) reported. The results of possibly hazardous metal concentrations in vegetable samples taken from the same study region are shown in the following section (Table 4) present the results of potentially toxic metal concentrations in vegetable samples collected from the same study area.

Concentrations of heavy metals detected in the analyzed vegetable samples.

Table 4 presents the concentrations of heavy metals detected in the analyzed vegetable samples. The highest zinc (Zn) levels were recorded in spinach (278.28 mg/kg)**,** followed by cabbage (274.90 mg/kg) and lettuce (230.90 mg/kg**)**. Overall, the pattern Zn > Cu > Cd > Pb > Ni was followed by the order of metal accumulation in spinach in Kawo. According to Zuang *et al.,* (2009), the usage of wastewater or effluent that contains trace levels of these metals, which are absorbed and translocated by plants, may be connected to the enhanced metal concentration. In samples from Pantaka, Kabala West, and Kawo, the maximum zinc accumulation was 298.00 mg/kg, which is almost eight, five, and four times greater than the WHO/FAO recommended limits for spinach, lettuce, and cabbage, respectively.

The heavy metal concentration trend in spinach at Kurmin Mashi was Zn > Cu > Ni > Pb > Cd, whereas at Badiko, the order was Zn > Ni > Pb > Cu > Cd. The order for Tudun Wada was Zn > Cd > Ni > Pb > Cu. These results contrast with those of Mohammed *et al.,* (2012), who found that Tudun Wada has greater levels of lead (Pb), cadmium (Cd), and chromium (Cr) because of its close vicinity to slaughterhouses and other man-made pollution sources. The maximum zinc accumulation was 298.00 mg/kg, which is almost eight, five, and four times greater than the WHO/FAO recommended limits for spinach, lettuce, and cabbage, respectively.

The heavy metal concentration trend in spinach at Kurmin Mashi was Zn > Cu > Ni > Pb > Cd, whereas at Badiko, the order was Zn > Ni > Pb > Cu > Cd. The order for Tudun Wada was Zn > Cd > Ni > Pb > Cu. These results contrast with those of Mohammed *et al.,* (2012), who found that Tudun Wada has greater levels of lead (Pb), cadmium (Cd), and chromium (Cr) because of its close vicinity to slaughterhouses and other man-made pollution sources.

Table 5 present the Bioaccumulation Factor of few chosen Metals

The Bioaccumulation Factors (BAF) of a few chosen heavy metals (Pb, Cd, Zn, Cu, and Ni) in three vegetable species—spinach, lettuce, and cabbage—that were gathered from different sites are shown in Table 5. The study found that soils from industrial, mining, wastewater-irrigated, and dumpsite locations, including Kawo, Pantaka, Kurmin Mashi, Badikko, Tudun Wada, Kabala West, Kudenda, Nassarawa, and Trikania, had varying levels of heavy metal buildup. Across all research locations, the observed BAF levels for the heavy metals varied as follows:

Zn: 0.67 – 6.82, Cu: 0.12 – 1.68, Ni: 0.00 – 6.13, Pb: 0.32 – 2.12, Cd: 0.03 – 9.44

Lead (Pb)

Spinach's Pb bioaccumulation did not deviate substantially from the 0.2 mg/kg WHO permitted limit for food. Reported values in literature include 0.0096–0.0105 (Afolayan and Hassan, 2017), 0.06–0.32 (Oladejo et al., 2017), 0.00075–0.0086 (Nwite and Alu, 2015), 0.0008–0.001 (Yu *et al.,* 2017), 0.007–0.009 (Jin et al., 2014), and 0.24–1.20 (Awokunmi et al., 2014)—all consistent with the range obtained in this study.

Cadmium (Cd)

Additionally, there was no discernible difference between the Cd amounts in the three plant species and the FAO/WHO (2011) food standard of 0.1 mg/kg. Nonetheless, compared to other investigations, the detected Cd levels were often higher. Afolayan and Hassan (2017), Oladejo et al. (2017), Nwite and Alu (2015), Yu et al. (2017), and Awokunmi *et al.,* (2014), for example, reported 0.176–0.197 mg/kg, 0.15–0.44 mg/kg, 0.0028–0.003 mg/kg, and 0.081–0.135 mg/kg, respectively. Cd exhibited the greatest bioaccumulation of any of the metals examined, especially in spinach.

Fitzgerald et al. (2019) state that when plants absorb significant levels of metals from the soil, they are deemed hyperaccumulators. According to Chaney *et al.,* (2019), hyperaccumulators may have levels of Cd above 1 mg/kg, whereas ordinary plants only accumulate 0.001–0.05 mg/kg. Metal chemical form, soil pH, organic matter content, plant species, and climate all affect the uptake of Cd (Gall and Rajakaruna, 2013).

Nickel (Ni)

Although nickel is a necessary trace metal for plant growth, greater doses make it hazardous. The BAF for Ni in spinach, lettuce, and cabbage varied from 0.13 to 6.13 mg/kg, 0.07 to 8.00 mg/kg, and 0.03 to 9.88 mg/kg, respectively, in this investigation. The absorbed amounts are below acceptable limits for consumption, as all values were below the WHO tolerable limit of 10 mg/kg. The comparatively low Ni concentrations found indicate that the majority of it is bonded in immobile soil components, which lowers plant absorption.

Zinc (Zn)

Zinc bioaccumulation in spinach, lettuce, and cabbage ranged from 0.67 to 6.82 mg/kg, 0.72 to 6.51 mg/kg, and 0.97 to 6.27 mg/kg, respectively. These values are below the WHO allowed limit of 50 mg/kg, although they are greater than those reported by Ibrahim et al. (2015) (0.23–0.99), Awokunmi et al. (2014) (0.07–0.44), and Oladejo et al. (2017) (0.047–0.4). Low zinc concentrations in the soil could be the cause of the comparatively low zinc uptake seen in some areas. This result is in contrast to Raymond and Felix's (2011) analysis, which found that vegetable crops accumulated more zinc. According to the study, bioaccumulation levels range by metal type, plant species, and location, which reflects variations in the environmental factors and sources of soil pollution.

Table 6 present Translocation values for Metals:

Translocation Factor (TF) values for all heavy metals were less than one (TF < 1) for all vegetable samples grown in the different locations, as shown in Table 6. A TF value less than one indicates that the metals were not well translocated inside the plants, primarily remaining in the roots instead of moving to the aerial sections. In other words, metals collected in the root system at a higher concentration, with little transport to the stems and leaves.

The bioaccumulation and translocation variables differed somewhat but not significantly, according to statistical analysis using ANOVA. The observed alterations were not statistically significant at the 95% confidence level, according to the p-value of 0.533, which is just above the 0.05 significance threshold.

Table 7 and 8:

All nickel samples were below the detectable limit, indicating that there was no nickel contamination of the soil, according to the results in table (5). The F critical value is 2.641465 and the p-value is 0.003276, according to the Anova result in Appendix 5, which suggests that there is no statistically significant difference in the contamination factor. The second table 6 displays the contamination factors for the different heavy metals examined in each vegetable sample collected from different locations. It reveals that for some plants collected from different locations, the contamination factor CF for the metal found in lettuce grown in Panteka is greater than one (CF>1), while for others, it is less than one (CF<1). A contamination factor larger than one indicates that the plant was successfully contaminated with metals. For Cd, 0.10 to 0.45 mg/kg Pb, 0.29 to 0.94 mg/kg Zn, and 0.03 to 0.94 mg/kg Cu, the lowest rate of contamination was 0.01 mg/kg, while the highest rate was 0.39. However, the one-way Anova result shows that the p-value is much lower than the 0.5% acceptable, meaning that the contamination values are the same without any statistically significant difference. Ni in Kabala West, Badiko, and Tudun Wada were above the contamination factor of one (1), indicating that the metal concentration at these locations was contaminated.

Table 9 and 10: Pollution Load Index for Soil and Vegetables

Additionally, the Pollution Load Index (PLI) for vegetables (Table 9) and soils (Table 10) was computed. A pristine environment is denoted by a PLI value of 0, baseline pollution is represented by a value of 1, and contamination is indicated by values more than 1 (Rashed, 2010; Islam et al., 2015a). All of the soil samples in this investigation had PLI values less than 1, indicating that there was no discernible pollution. In line with research by Bhuiyan et al. (2010) and Islam et al. (2014), this points to low levels of pollution from industrial processes such the manufacture of lead-acid batteries, tanneries, and dyeing businesses. Similarly, all nine research locations' vegetable PLI readings were less than 1, with the exception of Tudun Wada's cabbage, which had a slightly higher PLI of 1.05, indicating mild pollution. Pollutant buildup in the atmosphere and long-distance transportation may be to blame for this. Vegetables in the research region were not polluted, nevertheless, as the mean PLI values for all plants were below 1 (PLI < 1.0)

Conclusion

Analysis of heavy metals in roadside soils and leafy vegetables along Nnamdi Azikiwe Expressway in Kaduna yielded the following conclusions: The soil chemistry ranged from moderately acidic to slightly basic. Key parameters like electrical conductivity were within safe limit set by regulatory bodies, and organic carbon content was consistent across the study area. Among the heavy metals tested, zinc was the most prevalent in soil, though its level remained below the international safety threshold. However, zinc concentrations in the vegetables themselves exceeded international (WHO/FAO) standards. Calculated indices provided a detailed picture of contamination:

Bioaccumulation Factor (BAF): All metals were within permissible limits for transfer from soil to plants. Contamination Factor (CF): Most samples showed no significant contamination, with only a few instances of slight contamination in specific vegetables from one location.

Enrichment Factor (EF) and Geo-Accumulation Index (Igeo): These revealed localized hotspots, indicating high levels of lead in Kawo and Panteka, and elevated zinc in Trikania.

Pollution Load Index (PLI): Crucially, the overall PLI for both soil and vegetables was below 1, confirming that the area is not significantly polluted. A single elevated PLI value for cabbage from Tudun Wada was noted, potentially due to atmospheric deposition from long-range pollution.

Generally, the soils are suitable for agriculture, and the vegetables are safe for consumption. Variation in metal levels across different sites points to localized pollution sources, with zinc and lead being the metals of primary concern, necessitating continued environmental monitoring.

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