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Using Geo-Accumulation Index and Enrichment Factor to Assess Spatial Distribution of Heavy Metals in Roadside Soils and Vegetables Along Nnamdi Azikiwe Expressway, Kaduna

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Abstract
Heavy Metals (HMs) pollution is currently of major environmental concern. An investigative study was carried out along Nnamdi Azikiwe Expressway to determine the spatial distribution of heavy metal in roadside soils and vegetables samples with nine selected areas. The samples were digested and analyzed for toxic metals: Pb, Cd, Zn, Cu, and Ni using Atomic Absorption Spectroscopy (AAS) technique. The assessment of the heavy metals was derived using the geo-accumulation index and enrichment factor. This study revealed that the soil and vegetable contain metals hi which is predominantly Ni < Cu < Zn< Pb < Cd. The data were subjected to analysis of variance (ANOVA) to explain the factors interaction between the soil and vegetable obtained from the sample sites, geo accumulation and enrichment factor revealed that the enrichment factor was greater than 1. 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 across the nine locations, which was consistent with findings from other researchers. As a result, the toxicants were below the NESREA-established permissible limit .It shows that the area is not heavily impacted due to human activity and is safe.

Keywords: Heavy Metals, Geo-Accumulation Index, Enrichment Factor, Vegetables, Soil, Pollution

Introduction

Heavy metals are 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. Thus, it becomes necessary to study the composition of soil and vegetable to know the potential pollution sources. A geo - accumulation indexing and enrichment factor approach, Igeo is used to quantify the degree of anthropogenic contamination and compare different metals that appear in different ranges of concentration in the soil and vegetable (Muller 1969).

$$Igeo = \ln (Cn/1.5 \times Bn) \quad (1)$$

Where Cn= measured concentration, mg kg-1and Bn = geochemical background value, mg kg-1.

In equation 1, average values were used and 1.5 is the factor used for lithologic variations of trace elements. The geo-accumulation index compares the measured concentration of the element in the fine-grained sludge fraction Cn with the geochemical background value Bn. Average values of soil samples of the study region (which is taken as reference point) are considered as Bn values. The index of geo-accumulation consists of seven grades, whereby the highest grade reflects 100-fold enrichment above background values (Praveena et al. 2008). Förstner et al. 1993 listed geo-accumulation classes and the corresponding contamination intensity for different indices.

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Table 1. Geo-accumulation index classification

Sediment Igeo Contamination	Geoaccumulation class intensity	Index, Igeo
> 5	6	Very strong
> 4 - 5	5	Strong to very strong
> 3 - 4	4	Strong
> 2 - 3	3	Moderate to strong
> 1 - 2	2	Moderate
> 0 - 1	1	Uncontaminated to moderate
> 0	0	Practically uncontaminated

Aim and Objectives of the study

The primary aim of this research is to assess the spatial distribution of selected heavy metals in roadside soils and some leafy vegetables along the Nnamdi Azikiwe Expressway. The specific objectives are to:

1. analyze key soil properties, including pH, electrical conductivity, organic carbon, and organic matter.
2. quantify the concentration of lead(Pb), cadmium (Cd), zinc (Zn), copper(Cu), and nickel (Ni) in roadside soils and some vegetables samples using Atomic Absorption Spectroscopy (AAS).
3. calculate various pollution indices - Bioaccumulation Factor (BAF), Translocation Factor(TF), contamination Factor(CF), Enrichment Factor (EF) to - understand metal movement and soil enrichment.
4. determined the Geo-accumulation index (Igeo) and Pollution Load Index (PLI) to assess the overall contamination level of the study area

Materials and Methods

Geographical locations of the 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 2 lists the main urban centers in the research region. 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.

Table 2 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)

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Fig 1 Location of the study area

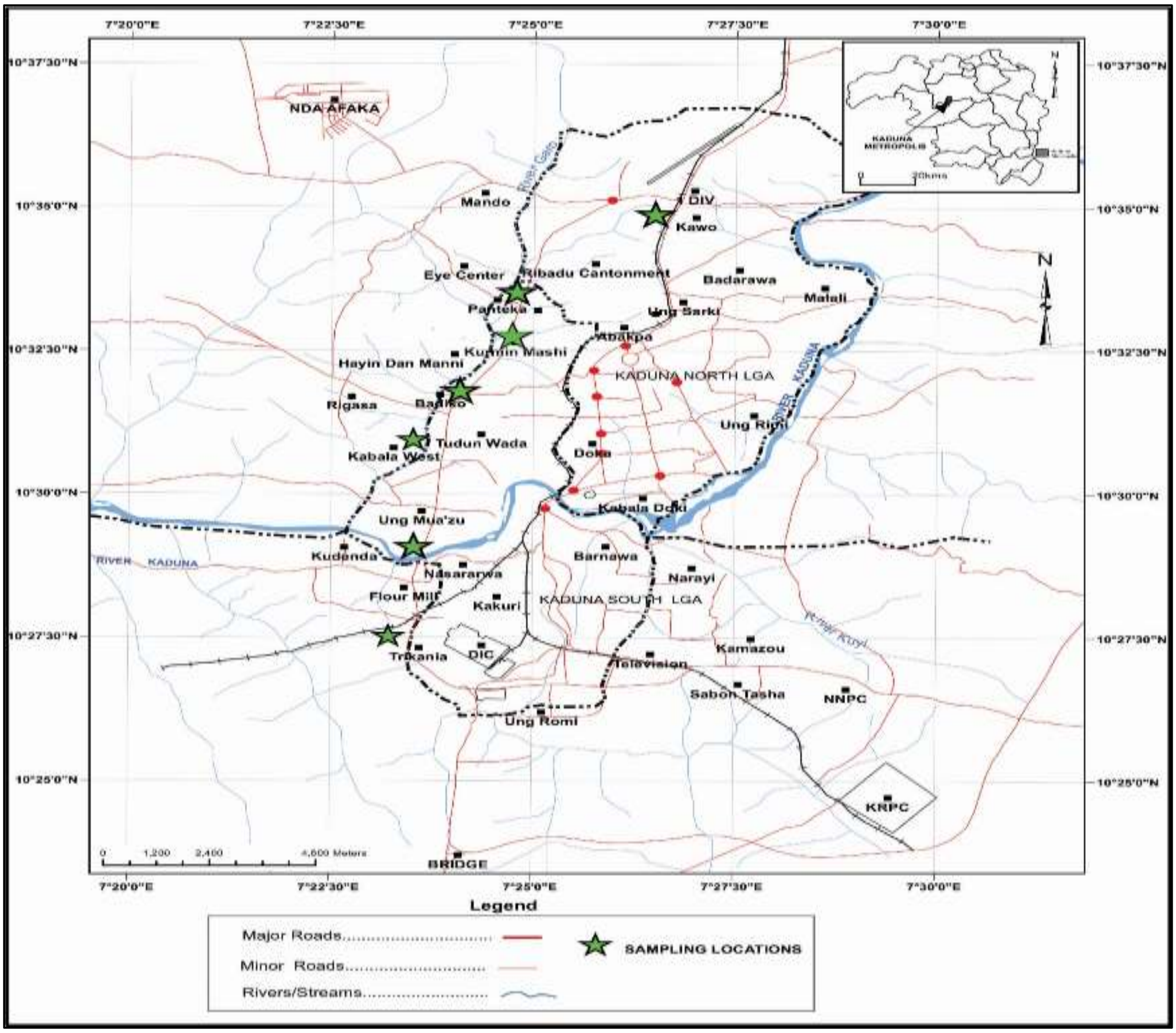

Figure 1: Map Showing Sampling Locations along Nnamdi Azikiwe Expressway, Kaduna. **Source:** Author's Fieldwork (2022), certified by the Department of Geography, Nigerian Defence Academy

Apparatus and instruments

Properly cleaned and sterilized polyethylene bags have been employed for soil and vegetable samples collection. A Milestone Microwave (Model: STRAT D 134348, EVISA) was used for digestion of vegetable and soil samples, while Drying Oven (Model: DHG-9123A) was employed to dry the soil and vegetable samples. Analytical balance (Model E11140, Switzerland) was employed to weigh the processed samples, and measuring cylinders, pipette, and micropipette (Merck KGaA, Darmstadt, Germany) were used to measure different volumes of sample solutions, acid reagents and metal standard solutions. The digested samples were filtered with Whatman No. 42 filter paper and the digestion process were performed in a laboratory fume hood. The AAS Spectrophotometer (Model:ARCOS FHS12, USA) was used for the determination of target metals in vegetable and soil samples considered in this study.

Chemicals and reagents

All reagents and chemicals used in this study were analytical grade, unless otherwise stated.

Distilled water was used for all preparation and dilution purposes of solutions throughout the experimental procedures. Chemicals such as HNO3 (69%), H2SO4 (98%) and H2O2 (30%) and HCl (37%) ($Pb(NO_3)_2$) (A99%), cadmium nitrate tetrahydrate ($Cd(NO_3)_2 \cdot 4H_2O$) (98%), copper(II) sulfate pentahydrate ($CuSO_4 \cdot 5H_2O$)

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(99.99%), nickel nitrate ($Ni(NO_3)_2$) (98.5%), Walkley–Black chromic acid, potassium dichromate ($K_2Cr_2O_7$), calcium chloride ($CaCl_2$), buffer-7 solution), (all from Sigma Aldrich, USA) were used during sample digestion procedures. Stock standard solutions of 1000 ppm were prepared from their corresponding salts for the selected heavy metals (Cu, Zn,Ni, Pb, ACd). Standard buffer solutions of pH = 7 was used for pH meter calibration and KCl (from Sigma Aldrich, USA) was used for conductivity meter calibration.

Soil sample collection and preparation

Soil samples (about 1 Kg) were collected into a clean polyethylene bag from the same sites where the vegetable samples were collected (for each vegetable type separately) with the consent of the farmers at 0–20 cm depth using a steeliness steel auger and pooled together to form composite sample. The collected samples were carefully packed and labeled. Soil samples were then transported to the Agricultural and Nutritional Research Laboratory for pretreatment and analysis.

In laboratory, the soil samples were air dried in a dry and dust free place at room temperature (25˚C) for 5 days, followed by an oven dry until constant weights were attained. The samples were then ground with a mortar and pestle to pass through a 2 mm sieve and homogenized. The dried, sieved, and homogenized soil samples were finally stored in polyethylene bags and kept in desiccators until digestion and analysis

Digestion procedures for vegetable samples.

A 1 g portion of each homogeneous grinded vegetable sample was digested using 30 cm³ of a 4:1 mixture of HNO_3 and $HClO_4$. The mixture was heated to near dryness, using hot plate in a fume cupboard at 180˚C for 45 mins, cooled and diluted to 100 cm³ with deionized water, centrifuged, filtered using Whatman No. 42 filter paper into 50 mL volumetric flask and was made to mark with distilled water. Finally, the filtrate was transferred into sample bottles with labels for AAS analysis using a SEARCH-TECH AA 20 model spectrophotometer.

Each vegetable sample was digested and analyzed in duplicate and the data reported is as mean ±SD. The blank solutions were prepared by following similar procedure as per the optimum conditions established and consequently analyzed.

Digestion procedures for soil samples. Soil Digestion: A 2 g of dried and homogenized composite soil samples, was weighed into a clean beaker and digested with 30 cm³ 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 cm³ deionized water, filtered through Whatman filter paper into a 250 cm³ 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.

Heavy metals analysis of the samples. The concentrations of Cd, Zn, Pb, Cu, and Ni in the soil and vegetable samples were determined by using AAS after properly calibrating the instrument using calibration blank and five working calibration standard solutions of each metal to analyzed. All the calibration procedures were evaluated based on their corresponding correlation coefficients (r^2) of the calibration curves which were found to be 0.998. In addition, the instrument's parameters such as plasma power, pump speed, coolant flow, Nebulizer flow and etc.

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 3: Analysis of Soil Physiochemical Properties.

S/ No	SID/ Code	Sample Locations	pH (H_2O)	pH ($CaCL_2$))	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

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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 4: 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 5: 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	7.50±0.01	6.90±0.03	26.50±0.15	0.30±0.228	**0.60±0.03**
	Cabbage						
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 Cn		**Nariya**	**0.80±0.03**	**1.00**±0.01	**10.00±4.93**	**1.40±0.06**	**2.20±0.09**

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

Table 6. presents the **Bioaccumulation Factors (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 7: Present Enrichment Factors for 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	0.82	0.57	BDL
SS3	Kurmin mashi	0.73	4.04	0.29	0.29	BDL
SS4	Badikko	1.99	4.0	1.12	0.30	BDL
SS5	Tudun wada	2.08	1.73	0.56	0.30	BDL
SS6	Kabala west	0.80	0.83	0.34	2.14	BDL
SS7	Kudenda	0.80	0.61	0.49	0.28	BDL
SS8	Nassarawa	3.62	1.65	4.26	2.69	BDL
SS9	Trikania	0.91	0.82	4.27	0.26	BDL

Table 8: Present Enrichment Factors for Vegetable Samples

SID	Vegetables./Location	Pb	Cd	Zn	Cu	Ni
	Kawo					
PS1	Spinach	0.10	0.07	0.33	1.06	**0.10**
PS2	Lettuce	0.90	0.16	0.42	0.40	**0.16**
PS3	Cabbage	0.09	0.12	0.37	0.72	**0.13**
	Panteka					

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PS4	Spinach	0.22	0.06	0.44	0.74	**0.36**
PS5	Lettuce	0.12	0.06	0.54	1.05	**0.08**
PS6	Cabbage	0.03	0.05	0.63	0.31	**0.19**
	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**
PS13	Cabbage	0.28	0.24	0.48	0.50	**1.77**
	Tudun Wada					
PS14	Spinach	0.28	0.26	0.47	0.49	**0.99**
PS15	Lettuce	0.29	0.28	0.43	0.54	**0.07**
PS17	Cabbage	0.25	0.35	0.93	0.30	**1.79**
	Kabala West					
	Spinach	0.39	0.18	0.30	0.02	**1.17**
PS18	Lettuce	0.36	0.18	0.29	0.58	**1.16**
PS19	Cabbage					
	Kudenda	0.38	0.18	0.30	0.58	1.23
	Spinach	0.35	0.25	0.66	0.92	**0.36**
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: Present Igeo of each Metal in Soil Samples at Different Location

S/N	SID	Location	Pb	Cd	Zn	Cu	Ni	Limit values	Grade II
1	SS1	Kawo	4.50	1.30	8.71	5.46	BDL	Pb 70-600	300
2	SS2	Panteka	0.47	0.50	9.16	5.87	BDL	Cd 1.4-22	0.3
3	SS3	K/Mashi	3.10	4.42	8.12	5.19	BDL	Cu 53-91	100
4	SS4	Badikko	4.71	4.40	9.47	5.22	BDL	Zn 200-360	250
5	SS5	T/Wada	5.05	3.55	8.78	5.22	BDL	Ni	
6	SS6	K/West	4.18	2.81	6.41	5.03	BDL		
7	SS7	Kudenda	4.095	2.51	8.65	5.16	BDL		
8	SS8	Nassarawa	5.60	3.50	9.59	7.42	BDL		
9	**SS9**	**Trikania**	**4.22**	**2.80**	**8.04**	**5.08**	**BDL**		

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

Table 10: Present Igeo of each Metal in Vegetable Samples at Different Location

SID	Vegetables./Location	Pb	Cd	Zn	Cu	Ni
	Kawo					
PS1	Spinach	4.99	5.40	9.39	5.12	**2.56**
PS2	Lettuce	4.87	6.22	8.63	4.14	**3.01**
PS3	Cabbage	4.93	5.89	8.52	4.74	**2.81**
	Panteka					
PS4	Spinach	5.83	5.67	10.16	4.76	**3.84**
PS5	Lettuce	5.24	4.56	10.36	5.11	**3.57**
PS6	Cabbage	3.64	5.01	10.52	3.90	**3.22**
	Kurmin Mashi					
PS7	Spinach	4.38	3.30	10.85	4.73	**3.82**
PS8	Lettuce	5.96	5.18	10.48	4.46	**4.08**
PS9	Cabbage	5.73	5.34	9.88	4.08	**4.29**
	Badikko					

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PS10	Spinach	5.63	5.72	9.88	4.45	**4.17**
PS11	Lettuce	5.87	6.27	10.09	4.41	**4.99**
PS12	Cabbage	6.05	6.62	10.26	4.37	**5.43**
	Tudun Wada					
PS13	Spinach	6.40	6.70	10.23	4.36	**4.85**
PS14	Lettuce	5.85	6.74	10.13	4.45	**4.87**
PS15	Cabbage	5.94	6.99	10.90	3.85	**5.44**
	Kabala West					
PS16	Spinach	6.39	6.32	9.76	4.53	**5.01**
PS17	Lettuce	6.32	6.30	9.76	4.52	**5.00**
PS18	Cabbage	6.35	6.31	9.76	4.52	**5.06**
	Kudenda					
PS19	Spinach	6.28	6.65	10.62	4.100	**3.88**
PS20	Lettuce	6.27	6.66	10.56	4.98	**3.84**
PS21	Cabbage	6.27	6.66	10.59	4.99	**3.86**
	Nassarawa					
PS22	Spinach	6.52	7.08	10.92	4.50	**2.81**
PS23	Lettuce	6.50	6.53	10.05	4.30	**2.00**
PS24	Cabbage	6.51	6.84	10.58	4.40	**2.49**
	Trikania					
PS25	Spinach	6.48	6.31	10.65	4.17	**1.31**
PS26	Lettuce	6.04	6.59	10.73	1.41	**4.27**
PS27	**Cabbage**	**6.28**	**6.46**	**10.69**	**3.02**	**3.63**

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

Discussion

Soil Physiochemical Properties

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 H2O and $CaCl_2$ measurements. These findings are comparable to the pH range of 4.1–8.8 reported by Chang et al., 2014) then 6.0–7.4 observed by Nigam et al., 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 bio solids 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 3). 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< α =0.05. This implies a strong relationship between soil characteristics and sampling locations, further support by the overall p-value of $9.2x10^{-17}$, confirming that location has a statistically significant effect on soil physiochemical properties.

Concentration of Heavy Metal in Soil Sample from Different Location

Table 4 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: 0.45–22.75 mg/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.

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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

Concentration of heavy metals in vegetable from Different Location

Table 5, 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. 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 distribution of heavy metals in different places did not follow a consistent pattern, according to the current study; rather, the discrepancies are a result of local pollution sources such effluent discharges, municipal garbage, and industrial waste dumps. The fluctuation in concentration is probably caused by site-specific activities that impact plant uptake and metal deposition. According to Aliyu et al. (2015), Kaduna State is one of Nigeria's most industrialized and quickly developing regions. Large amounts of garbage and sludge containing heavy metals have been produced as a result of industrial growth, and these materials frequently enter the Kaduna River through tributaries and drainage channels. Therefore, the riverbanks, which are frequently utilized for both wet and dry season agricultural, are vulnerable to contamination. Although the measured metal concentrations in vegetables were higher than the limits for lead (Pb: 0.3 mg/kg) and cadmium (Cd: 0.2 mg/kg), they were below the FAO/WHO (2001) limits for copper (Cu: 73.3 mg/kg), suggesting possible health hazards if ingested over time. Although there are variations, they are not statistically significant, according to statistical analysis using ANOVA, which revealed no significant differences ($p < 0.05$) between the vegetable samples from various places.

Bioaccumulation Factors (BAF) of heavy metals in the vegetable samples.

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 6. 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.

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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 & Rajakaruna (2013)

Ni(nickel)
Although nickel is a necessary trace metal for plant growth, greater concentrations 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 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.

Enrichment Factor (EF) Assessment
Lead (Pb) was the sole metal in Kawo and Pantaka with an enrichment factor (EF) value higher than 1, according to the examination of soil samples. All metals in Nasarawa have EF values greater than 1, with the exception of nickel (Ni). The results (shown in the table) showed that only a small number of metals seemed to be impacted by factors other than human activity when the enrichment factors from the nine sampling locations were compared. The statistical analysis yielded a p-value of 0.039631, indicating that the nine research locations' EF values did not differ significantly. With the exception of the cabbage samples from Badikko, which had an EF of 1.77, the metals' EF values were generally less than 1.5.

The obtained values were not significantly correlated with environmental contamination, according to spatial changes in EF throughout the research area. When comparing the findings from the soil and plant samples utilized in the investigation, there was no discernible difference in the EF patterns. However, plants from Tudun Wada and Badikko exhibited a minor enrichment of nickel (Ni), indicating a possible danger of contamination in those places. Conversely, copper (Cu) values were very low in spinach from Kabala West and lettuce from Trikania. In general, nickel showed the greatest EF values at all study sites, especially in Badikko cabbage. However, these high EF values do not necessarily indicate pollution; rather, they indicate a relatively clean environment due to low dust levels and little anthropogenic effect. The results of Tripathee et al. (2014), who similarly found no significant EF differences between the reference soils (UCC and Tibetan topsoil) utilized in their enrichment factor studies, are consistent with the lack of substantial variance in EF patterns across all soil samples from the Kaduna study region.

Table 9, lists the heavy metals' geo-accumulation index (Igeo) values in soil along with the relevant pollution ratings. For every metal and sampling location, the Igeo was established. The findings showed that, with the exception of Tudun Wada and Nasarawa, where the values marginally above 5 (Igeo > 5), suggesting significant contamination, the majority of sites reported Igeo ≤ 5 for lead (Pb). The Igeo values for copper (Cu) and cadmium (Cd) were both greater than 5, indicating that the soils in these regions were of low quality and extremely polluted. Tripathee et al. (2016a) reported unpolluted soils with Igeo values close to zero, which is in contrast to these

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findings. The findings imply that heavy metal buildup in the study area is significantly influenced by anthropogenic (human-induced) activities. Nickel (Ni) was not found in any of the soil samples at Panteka, although Pb and Cd pollution was low, with Igeo values of 0.47 and 0.5, respectively. This suggests that while some locations are polluted, others are comparatively unpolluted. According to Müller (1969), pollution grading is classified as follows:

- Igeo < 0: unpolluted
- 0 < Igeo ≤ 1: unpolluted to moderately polluted
- 1 < Igeo ≤ 2: moderately polluted
- 2 < Igeo ≤ 3: moderately to heavily polluted
- 3 < Igeo ≤ 4: heavily polluted
- 4 < Igeo ≤ 5: heavily to extremely polluted
- Igeo > 5: extremely polluted

All sampling locations in this investigation had high levels of Cu and Zn pollution, according to the Igeo data. Zn pollution ranged from uncontaminated (Igeo < 0) to highly contaminated (Igeo = 9.59), while Pb contamination ranged from uncontaminated to highly contaminated (Igeo = 5.60). Ni was not detected, Cd recorded Igeo = 4.42, and Cu readings varied from uncontaminated to highly contaminated (Igeo = 7.42). While Cd in Kabala West, Kudenda, and Trikania exhibited low to high contamination (Igeo < 3), Pb and Cd in Pantaka and Kawo showed low contamination (Igeo < 2). Given that the p-value (4.92E-16) was significantly below 0.05 at a 95% confidence level, statistical analysis (Table 9) showed no discernible variation in Igeo values across the study sites. A highly contaminated soil environment was indicated by the greatest Igeo values (0.50–7.08) for Cd, which followed the trend of contamination order: Cd > Pb > Zn > Cu > Ni.

Conclusion

The result of our study revealed that the levels of Pb, Cd, Cu, and Ni were found to not exceeding the recommended values in soil. Similarly, Pb, Cd, Ni and Cd were found in an acceptable concentration in lettuce, spinach and cabbage samples analyzed. The geo accumulation factor was found to be within the limit except for Tudun Wada and Nasarawa, where the values marginally above 5 (Igeo > 5), suggesting significant contamination, the majority of sites reported Igeo ≤ 5 for lead (Pb). The Igeo values for copper (Cu) and cadmium (Cd) were both greater than 5, indicating that the soils in these regions were of low quality and extremely polluted. An enrichment factor (EF) value higher than 1 in Lead (Pb) obtained from Kawo and Pantaka revealed according to the examination of soil samples. All metals in Nasarawa have EF values greater than 1, with the exception of nickel (Ni). The results showed that only a small number of metals seemed to be impacted by factors other than human activity when the enrichment factors from the nine sampling locations were compared

Recommendations

To safe guard environmental and public health, the following measures are recommended:

1. Mitigate Vehicle Emissions: Enforce strict vehicle emission standards through regular inspections and promote mass transit system to reduce traffic volume and idling–related pollution.
2. Improve Infrastructure: Develop alterative road networks and modern roundabouts to enhance traffic flow and minimize congestion.
3. Enhance Agricultural Practices: Educate farmers and industrial operators on proper waste disposal, responsible pesticide use, and the principles of Extended Producer Responsibility (EPR) to curb pollution at the source.
4. Strengthen Waste Management: Implement and enforce strict waste management laws to prevent the dumping of industrial and automotive waste (used oil) on farmlands, while promoting recycling and reuse initiatives.
5. Targeted Awareness: Conduct specific awareness campaigns for auto mechanics and industrial operators on the proper handling and disposal of hazardous materials

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