



Environmental Risk Assessment of Metal Contamination of Agricultural Soils along Major Roads of Two Peri – Urban Areas in Nasarawa State, North Central, Nigeria

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Abstract

This research focused on the level, pollution, and ecological risk assessment of selected heavy metals from agricultural soils at major roadsides in Nasarawa Eggon and Doma areas. Composite soil samples were collected at 0–20 cm depth, homogenised, and assayed for metal (As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, U and Zn) levels using the X–ray fluorescence technique. Pollution and toxicity of the studied metals were determined by evaluating enrichment factor (E_f), geo–accumulation index (I_{geo}), contamination factor (C_f), degree of contamination (C_d), pollution load index (PLI), and ecological risk assessment (ERA). The result showed that concentrations of As, Cd, Cr, Cu, Fe and Ni were lower than the average shale values, except for As of site N2 in the Nasarawa Eggon area and Fe of site D4 in the Doma area. The E_f suggests a significant anthropogenic contribution to the presence of As, Co, Hg, Mn, Pb and Zn in some of the sampled sites. The I_{geo} indicated that Nasarawa Eggon sampled soils were polluted by Hg and Pb while Hg and Co polluted those of Doma. The C_f values revealed that most of the soils were contaminated with Hg in addition to As, Co, Fe, Mn, and Zn in some sites. All sites have low C_d except N2 and N4 (Nasarawa Eggon) and D2 and D4 (Doma). However, PLI showed that only sites N2 and D4 were polluted. ERA revealed that As, Co, and Hg posed potential ecological risks ranging from low to a significant level in different sites. Sites N2, D2 and D4 showed a moderate ecological risk index. Therefore, this study showed significant anthropogenic inputs from automobile emissions and human activities to the pollution of agricultural soils along major roads and the pollution could pose negative health implications to human and animal health.

Keywords: Ecological risk, soil contamination, agricultural soil, heavy metals, pollution assessment

1. INTRODUCTION

Soil pollution by metals (especially heavy metals) is a global phenomenon which results from natural or anthropogenic sources. However, the authorities in Nigeria give little attention to the associated health and physiological risks to humans and animals. Metals are unique environmental pollutants given their ubiquity and distribution in various environmental matrices [1]. Natural sources of metals depend on the geological substrates and the processes that form the soils [2]. Metals are concentrated and transformed into various products via anthropogenic processes. These processes often lead to much higher concentrations of different chemicals than those naturally present in the

environment. According to De-Miguel *et al.* [3], the categories of anthropogenic sources of heavy metals can be generally classified as; urban elements, natural elements and elements of a mixed origin, implying that some metallic pollutants undergo geochemical reactions which alter their significant features. Heavy metals act antagonistically disrupting trace elements in the body, inhibiting, and competing with protein and enzyme for binding sites and impairing the immune system. Unachukwu and Agomuo [4] reported that non-communicable diseases (NCDs) such as cardiovascular disease, diabetes mellitus, cancer, renal diseases, liver failure etc., may be associated with heavy metal toxicity and are probably more pronounced through occupational exposures [5].

Nasarawa Eggon and Doma towns can be described as peri–urban or semi–urban areas which are the administrative headquarters of their respective Local Government Areas in Nasarawa State, north-central Nigeria. These towns are surrounded by rural areas and are predominantly agricultural areas with majority of the inhabitants known to be farmers and traders. Nasarawa Eggon town is located along the ever-busy Lafia–Abuja road. This major road is characterized by high automobile/vehicular and human traffic due to its

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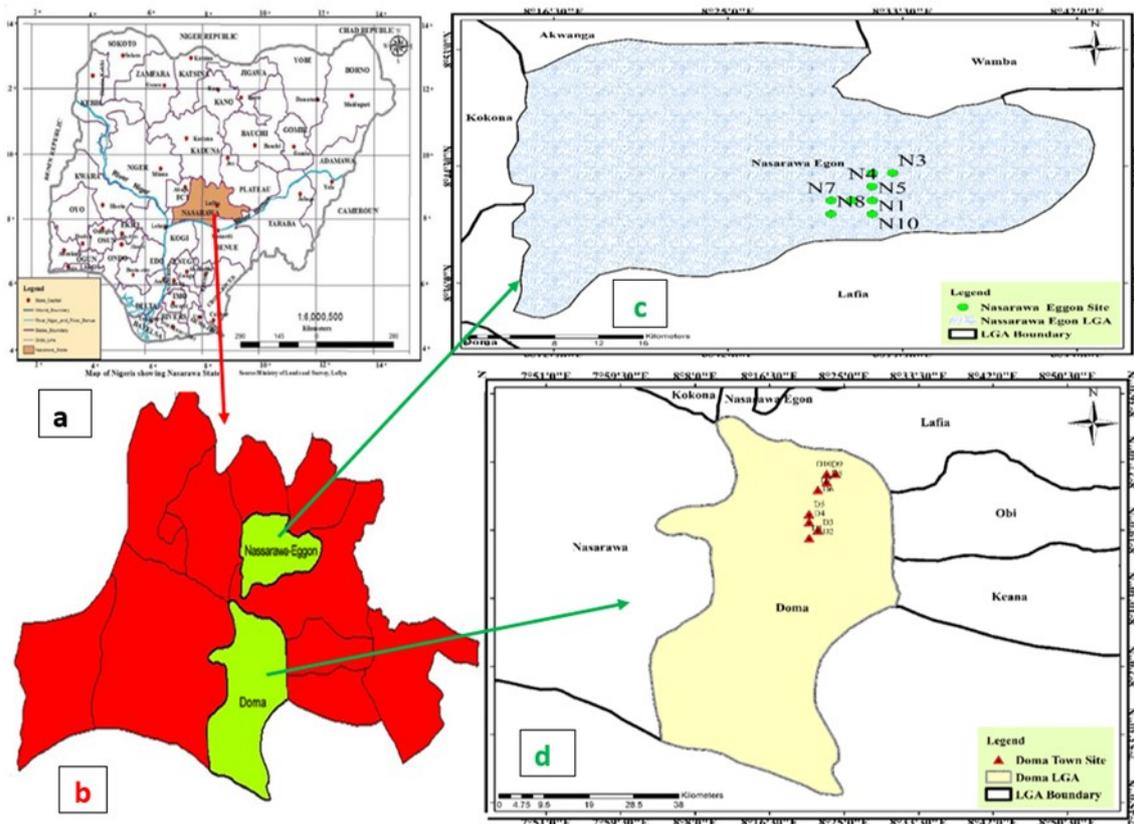


Figure 1. Map of Nigeria (a), Nasarawa State (b), Nasarawa Eggon (c) and Doma (d) Local Government Areas showing sample collection points.

proximity to Nigeria's Federal Capital Territory, Abuja as well as the Nasarawa State capital, Lafia. Commuters (public and private) stopover at this town to buy agricultural produce (tubers such as yam and potatoes, fruits etc.) and food, while inhabitants of surrounding rural areas visit the town to carry out minor business transactions and also board vehicles to Abuja and other destinations. Drivers equally stopover in the town to repair and refuel their vehicles as well as pick passengers. Doma town is along busy Lafia–Rukubi road. It is a major road characterized by a high volume of automobile traffic arising from its linkage to Rukubi where Africa's largest rice mill is located and also, a major route to rural agricultural farms in Doma where large-scale irrigation farming is practised all year round, using water from Doma dam. Thus, the focal towns are located on the highway characterized by heavy vehicular and human traffic which results in high human activities [6].

The busy nature of Nasarawa Eggon and Doma major roads make them attractive to sundry human activities, ranging from indiscriminate citing of automobile parks and workshops (which are centres of sundry activities ranging from automobile

servicing, panel beating, spraying, etc.), markets, business centers (typing, photocopying, printing, cybercafé, Nijabet stations, movie or football viewing center etc.), food vending spots, gas stations, primary health care centres, etc. Most of the businesses on these major roads (Nasarawa Eggon and Doma) are powered by generators due to a lack of power supply from the National grid. Their activities generate different kinds of wastes (gaseous, liquid and solid) which comprise automobile/vehicular and generator emissions, medical wastes, electronic waste (such as computers and their accessories, TV sets, fax machines, cell phones, telephones, photocopy machines and printers, dryers, wireless devices, video cameras, chips, motherboards, cathode ray tubes and peripheral items, kitchen equipment, electronic toys, washing machines, refrigerators etc.), automobile workshop wastes (damaged vehicle parts, car paint dust, engine oil, grease etc.) faeces, urine, garbage, sludge from sewage etc [6].

The unregulated disposal of waste in these towns results in indiscriminate and open dumping of these generated wastes (which are the surrounding agricultural soils) which wind up in landfills and

informal dumps where they decompose and release toxic metals into the environment. Long-term dumping of municipal wastes can influence soil properties and productivity at municipal waste dump sites but still may be used for farming provided that ecotoxicological risks associated with its usage are continuously assessed and controlled [7].

The concentration of these toxic metals in the environment has significantly increased due to increased human activities through emissions from industrial plants, thermal power stations, waste disposal, soil amendments and fertilization, vehicular traffic and road infrastructure [8], mining, smelting and refining of ores. Heavy metals such as cadmium (Cd), copper (Cu), chromium (Cr), lead (Pb), manganese (Mn), nickel (Ni) and zinc (Zn) are often contained as additives in some lubricants and gasoline are non-degradable in the soil. Some of them have been classified as priority pollutants by United State Environmental Protection Agency (USEPA). At the moment, very few technologies, such as soil washing and bioremediation, are available to treat these mixed wastes [9]. Edori and Kpee [10] reported that heavy metals can be generated from faeces and urines of mammals which are either deposited in the agricultural soil or washed into the nearby agricultural soil.

High levels of heavy metals in soils do not necessarily reflect anthropogenic influence but instead may be of a diagenetic origin or grain size effects [11]. Since metals from both natural and anthropogenic sources accumulate in soils, it is often difficult to determine what fraction of soil's metal load comes from which source. A crucial step for pollution assessment of soil is to establish the expected natural background concentrations [12], from which various approaches can be used to quantify anthropogenic inputs. Thus, this study is aimed at quantifying the level of selected metals in agricultural soils along major roads of Nasarawa Eggon and Doma and evaluating their origins (natural and anthropogenic), contamination level and toxicity.

2. MATERIALS AND METHODS

2.1. Description of Study Areas

Nasarawa Eggon (NE) town is in the Local

Government Area (LGA) of Nasarawa State, Nigeria and lies between latitudes 8°33" and 8°52" N and between longitudes 8°14" and 8°39" E. The climate of NE falls within the tropical savannah climate with two clearly marked seasons; wet and dry. It has a mean temperature of 15.6 °C and 26.7 °C with annual rainfall between 1317 mm and 1450 mm [13].

Doma town is in Doma LGA of Nasarawa State, Nigeria and located at latitude 8°24'N and 8°5'N and longitude 6°E and 6°30'E of the Greenwich meridian. The entire LGA is generally characterized by a low land area about 100-200 m above sea level although there is a kind of spatial variation in the surface area [14].

The ground positions of the sampling points in both Nasarawa Eggon and Doma study areas were referenced with a handheld global positioning system (GPS) unit (Garmin GPSMAP 76) and are shown in Figure 1.

2.2. Sample Collection and Preparation

A total of 20 (twenty) composite soil samples were collected from 20 (twenty) agricultural farms at both study areas (Nasarawa Eggon and Doma). The investigated agricultural farms are within 50 m from the major road but more than 1 km apart from each other. At each agricultural farm, six quadrats were marked. In each quadrat, four core soil samples were collected randomly at 0–20 cm depth using a soil auger and mixed together properly to form a composite of that agricultural farm. Thus, 10 (ten) composite soil samples were collected from each study area. Foreign materials such as rocks, pebbles, metal scraps, plant debris, waste polythenes and plastics were removed from the soil samples. They were air-dried for a week, ground and sieved through a 2 mm sieve. The samples were then stored in a dried plastic container for analysis.

2.3. Elemental Analysis

The concentration of elements (metals) in the soil samples was determined using x-supreme8000 model of Energy Dispersive X-ray fluorescent Analyzer [Detection limit: 0.0001 % (1 ppm)–99.9999 %]. A recovery test was carried out on the XRF machine by spiking analyses so as to ensure the reliability of the result.

Table 1. Classes of E_f , Igeo, C_f , C_d , Er and RI in relation to enrichment, pollution, contamination, degree of contamination, potential ecological risk and ecological risk levels, respectively

E_f Classes	Enrichment Level	I-geo value Classes	Pollution Level
$E_f < 1$	No enrichment	0; I-geo ≤ 0	Practically unpolluted
$E_f = 1-3$	Minor enrichment	1; I-geo = 0-1	Unpolluted to moderately polluted
$E_f = 3-5$	Moderate enrichment	2; I-geo = 1-2	Moderately polluted
$E_f = 5-10$	Moderate severe enrichment	3; I-geo = 2-3	Moderately to strongly polluted
$E_f = 10-25$	Severe enrichment	4; I-geo = 3-4	Strongly polluted
$E_f = 25-50$	Very severe enrichment	5; I-geo = 3-5	Strongly to extremely polluted
$E_f > 50$	Extremely severe enrichment	6; I-geo > 5	Extremely polluted
Cf Classes	Contamination Level	Cd Classes	Degree
$C_f < 1$	Low contamination	$C_d < 8$	Low degree of contamination
$C_f = 1-3$	Moderate contamination	$C_d = 8-24$	Moderate degree of contamination
$C_f = 3-6$	Considerable contamination	$C_d = 24-48$	Considerable degree of contamination
$C_f > 6$	High contamination	$C_d > 48$	Very high degree of contamination
Er Classes	Er Level	RI Classes	Risk Levels
$Er < 40$	Low potential ecological risk	$RI < 150$	Low ecological risk
$Er = 40-80$	Moderate potential ecological risk	$RI = 150-300$	Moderate ecological risk
$Er = 80-160$	Significant potential ecological risk	$RI = 300-600$	Significant ecological risk
$Er = 160-320$	High potential ecological risk	$RI > 600$	High ecological risk
$Er > 320$	Very high potential ecological risk		

2.4. Soil Pollution Assessment

The metal contamination, as well as ecological risk of the soil samples in the study areas, were assessed using enrichment factor (E_f), geo-accumulation index (Igeo), contamination factor (C_f), degree of contamination (C_d), pollution load index (PLI), ecological risk (Er) and potential ecological risk index (RI) models.

2.4.1. Enrichment Factor

The enrichment factor (E_f) was evaluated by normalizing the metal concentration in the sample with respect to a reference metal [15]. The most common reference elements are Sc, Mn, Ti, Al and Fe [16]. The E_f of the metals/metalloids in the soil samples at both studied areas were calculated using Eq.1.

$$E_f = \left(\frac{C_n(\text{sample}) / C_{\text{ref}}(\text{sample})}{B_n(\text{Background}) / B_{\text{ref}}(\text{Background})} \right) \quad (1)$$

Where $C_n(\text{sample})$ is the concentration of the investigated metal “n” in the study site, $C_{\text{ref}}(\text{sample})$ is

the concentration of the reference metal in the study site; $B_n(\text{background})$ is the background concentration of the investigated metal (usually the average shale value of the investigated heavy metal) and $B_{\text{ref}}(\text{background})$ is the background concentration of the reference metal (usually the average shale value of the reference metal). In this study, Fe is the most naturally abundant element in all the studied soils and thus, was used as the reference metal while the average shale value described by Turekian and Wedepohl [17] was used as the reference value.

2.4.2. Geo-accumulation Index

The geo-accumulation index (Igeo) values for the determined heavy metals were evaluated using the formula proposed by Muller [18] as shown in Eq. 2.

$$I_{\text{geo}} = \log_2 \left[\frac{C_n}{1.5B_n} \right] \quad (2)$$

Where C_n is the concentration of the heavy metal “n” in the soil sample; B_n is the geochemical

background value for heavy metal “*n*” which is either directly measured in fossil argillaceous sediments of the area or adopted from literature (world average shale value); 1.5 is the correction factor for the variations in background value which could be due to lithogenic effects. The world average shale values of the studied heavy metals as described by Turekian and Wedepohl [17] and shown in Table 2; were used in this study. Geo-accumulation classes proposed by Muller [18] as reported in Table 1, was used for the interpretations of geo-accumulation index.

2.4.3. Contamination Factor (C_f), Degree of Contamination (C_d) and Pollution Load Index (PLI)

The extent of soil contamination by a certain metal was determined using the contamination factor (C_f). C_f is the ratio of the concentration of metal to the background value of the metal, as given by Eq. 3.

$$C_f = \frac{C_n}{C_b} \tag{3}$$

Where C_n is the concentration of the metal “*n*” in the sample, C_b is the background concentration of the metal “*n*”. Nigerian Directorate of Petroleum Resources target values for metals in soils (Table 2) were adopted as the background values “ C_b ” [19]. The sum of all contaminant factors of the various metals is referred to as the degree of contamination (C_d) [20]. It was calculated using Eq.4.

$$C_d = \sum_{i=1}^{n=12} (C_{fi}) \tag{4}$$

Where n is the number of metals studied and C_{fi} is the contamination factor for metal “*i*” in the soil sample. The standard employed in the interpretation of contamination factor and degree of contamination values was adopted from the different classes proposed by Hakanson [21] as reported in Table 1.

Pollution Load Index (PLI) was calculated so as to obtain a proper assessment of the degree of contamination. The procedure (Eq. 5) by Tomlinson *et al.* [22] was used to calculate PLI in order to measure the overall level of metal toxicity at a particular sampling site.

$$PLI = (C_{f1} \times C_{f2} \times C_{f3} \times C_{f4} \times \dots \dots C_{fn})^{1/n} \tag{5}$$

Where n is the number of metals and C_f is the contamination factor. A PLI value under one indicates unpolluted soils or sediments; zero indicates perfection; a value of one indicates the presence of only baseline levels of pollutants and values above one would indicate progressive deterioration of the soil quality (i.e., polluted) [22]. The pollution load index was interpreted as reported in Table 1.

2.4.4. Ecological Risk (Er) and Potential ecological Risk Index (RI)

Hakanson [21] proposed ecological risk factor (Er) as a quantitative expression of the potential ecological risk of a given contaminant (metal). It was calculated using Eq. 6.

$$Er = Tr \times C_f \tag{6}$$

Er is the single index of ecological risk factor and Tr is the toxic response factor suggested by Hakanson [21] which is presented in Table 2. The potential ecological risk index (RI) index reflects the general situation of pollution caused by the simultaneous presence of the twelve (12) metals and was calculated using the expression in Eq. 7.

$$RI = \sum_i^n Er \tag{7}$$

n is the number of the metals considered; Er and RI are the potential ecological risk factors of individual and multiple metals, respectively. The ranges of values used for the interpretation of the potential ecological risk factor [21] are reported in Table 1.

3. RESULTS AND DISCUSSIONS

3.1. Metals

Table 2 presents the concentrations of metals (As, Cd, Co, Cr, Cu, Fe, Hg, Mn, Ni, Pb, U and Zn) analysed in the soil samples at the various sampled sites of Nasarawa Eggon and Doma study areas. Based on the mean value, the metal concentrations follow a decreasing order of Fe> Mn> Zn> Pb> Ni> Hg> As> U and Fe> Mn> Co> Zn> Pb> Hg> Cr> As> U, in the Nasarawa Eggon and Doma study areas respectively. It was observed that the mean concentration of Fe in each study area was higher

Table 2: Heavy Metal Concentrations (mg/kg) of the Studied Soil Samples.

Sample Code	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	U	Zn
Nasarawa Eggon												
N1	BDL	BDL	BDL	BDL	BDL	4403.79	9.22	220.43	BDL	21.29	BDL	28.67
N2	19.29	BDL	BDL	BDL	BDL	30662.08	7.02	838.78	BDL	33.06	BDL	55.09
N3	BDL	BDL	BDL	BDL	BDL	25894.28	5.93	513.95	BDL	27.25	8.68	32.84
N4	6.90	BDL	BDL	BDL	BDL	15335.66	BDL	334.15	BDL	37.81	BDL	96.11
N5	BDL	BDL	BDL	BDL	BDL	22065.54	7.92	834.16	BDL	62.34	BDL	35.19
N6	BDL	BDL	BDL	BDL	BDL	5255.97	7.12	480.78	BDL	26.53	BDL	14.76
N7	BDL	BDL	BDL	BDL	BDL	12455.85	BDL	444.98	64.59	46.44	BDL	23.41
N8	BDL	BDL	BDL	BDL	BDL	12790.33	5.43	452.24	BDL	52.08	BDL	23.96
N9	BDL	BDL	BDL	BDL	BDL	24990.22	10.73	761.82	BDL	39.66	BDL	16.30
N10	BDL	BDL	BDL	BDL	BDL	16634.97	BDL	971.81	BDL	82.64	BDL	142.35
Mean	2.62	BDL	BDL	BDL	BDL	17048.87	5.34	585.31	6.46	42.91	0.87	46.87
Doma												
D1	BDL	BDL	BDL	BDL	BDL	8431.96	7.86	197.21	BDL	7.10	BDL	19.58
D2	6.60	BDL	203.76	35.96	BDL	35423.02	6.12	609.75	BDL	13.40	5.30	41.71
D3	BDL	BDL	BDL	BDL	BDL	14948.09	BDL	330.26	BDL	7.30	4.79	17.35
D4	7.09	BDL	203.42	BDL	BDL	81069.80	8.67	1261.60	BDL	22.85	4.22	64.27
D5	3.55	BDL	BDL	BDL	BDL	21401.33	5.59	204.95	BDL	4.73	BDL	26.94
D6	BDL	BDL	BDL	BDL	BDL	4016.14	5.87	375.85	BDL	BDL	BDL	5.32
D7	BDL	BDL	BDL	BDL	BDL	4476.67	5.49	174.73	BDL	BDL	BDL	5.68
D8	BDL	BDL	BDL	BDL	BDL	4262.81	6.26	153.88	BDL	BDL	BDL	BDL
D9	BDL	BDL	BDL	BDL	BDL	2385.52	4.90	166.94	BDL	BDL	BDL	BDL
D10	BDL	BDL	BDL	BDL	BDL	5205.55	BDL	194.21	BDL	BDL	BDL	BDL
Mean	1.72	BDL	40.72	3.56	BDL	18162.09	5.08	366.94	BDL	5.54	1.43	18.09
Average Shale Values [17]	13.00	0.30	19.00	90.00	45.00	47200.00	0.40	850.00	68.00	20.00	3.70	96.00
DPR Target Values [19]	1.00	0.80	20.00	100.00	36.00	38000.00	4.00	850.00	35.00	85.00	23.00	140.00
Tr [21]	10.00	30.00	5.00	2.00	5.00	NA	40.00	1.00	5.00	5.00	NA	1.00

NA = Not Available; **BDL** = Below Detectable Limit; **DPR** = Department of Petroleum Resources (Nigeria); Tr = Toxic Response Factor

than that of other metals but was below DPR and average shale reference values [19]. Also, the mean concentration of Fe is higher in Doma (18162.09 mg/kg) than in Nasarawa Eggon (17048.87 mg/kg) area. The mean concentrations of Cd, Cr, Cu, Fe, Mn, Ni, U and Zn for both study areas are lower than the reference values of DPR [19] and average shale [17] while the mean concentration of Hg is higher than the reference values. However, the mean concentrations of As in Nasarawa Eggon and Doma areas, are below the average shale [17] value but above the DPR [19] value. Contrarily, the mean Co concentration in Nasarawa Eggon is below the aforementioned reference values but above them (reference values) in the Doma area.

Arsenic (As) is naturally found in water, soil, and sediments [23]. The nature of the soil parent material appears to be the main factor that determines the As concentration in soils, although due to its low supergene mobility, the soils are slightly enriched in As compared with their soil parent rocks [24]. As is not only toxic but rated to be carcinogenic which causes skin lesions such as hyperpigmentation (especially on the trunk), keratosis on the palms and soles, chronic cough, crepitation in the lungs, diabetes mellitus, hypertension, and weakness [23]. In this study, As levels recorded in the sampled sites in Nasarawa Eggon (except N2 and N4) and Doma (except D2, D4 & D5) study areas are below the instrumentation limit of detection. However, in Nasarawa Eggon, the level of As in sampled site N2 is above DPR [19] and average shale [17] reference values while in sampled site N4 (Nasarawa Eggon) as well as sampled sites D2, D4 and D5 (3.55–6.60 mg/kg) of Doma study area, As levels are above the DPR [19] value but below average shale [17] value. This indicates possible anthropogenic contribution to As level in sampled site N2 while lithogenic origin with little or no anthropogenic contribution could be the source of As in other sampled sites including N4, D2, D4 and D5. The range of As in this study is higher than those recorded by Edori and Kpee [9] and Fosu–Mensah *et al.* [25] for soils within selected abattoirs in Portharcourt, Nigeria and soils at Korle Lagoon area in Accra, Ghana; respectively. However, Li *et al.* [26] and Santos-Francés *et al.* [27] reported As concentrations higher than the findings of this study, for surface

soils in electronic waste dismantling area and soils of the Andes mountain range, respectively.

The concentrations of copper (Cu) and cadmium (Cd) in the various investigated soil samples from the study areas are below the instrumentation detectable limit and the reference values of DPR [19] and average shale [17]. This suggests little or no possible anthropogenic contribution (such as fertilizer, pesticides, plastics, plumbing, welding etc.) to the presence of Cu and Cd in the sampled soils of both study areas. Thus, their presence is of lithogenic or natural origin. Cu is an essential micronutrient required for plant growth. Although a human can handle a proportionally high concentration of Cu, human exposure to it causes a variety of health problems. At lower concentrations, it causes headache, nausea, vomiting and diarrhea while at significant concentrations, it causes to anaemia, gastrointestinal disorder, flu-like condition known as metal fever, liver, and kidney malfunctioning in extreme cases [28][29]. On the other hand, Cd is a toxic metal that occurs naturally at a low level in the environment [30] and can disrupt biological systems more than most toxic metals, at acute and chronic exposures through inhalation and ingestion [31]. Chronic exposure leads to ulcerations and perforations of the nasal septum, chronic bronchitis, decreased pulmonary function, pneumonia, bone disease, coughing, emphysema, headache, hypertension, kidney diseases, lung and prostate cancer, lymphocytosis, microcytic hypochromic anaemia, testicular atrophy and vomiting [32][33]. Studies by Iwegbue *et al.* [34], Amos- Tautua *et al.* [35], Asawalam and Eke [36] and Njoku and Ayoka [37] reported similar low concentration range of Cd for urban agricultural and waste dump soils. However, higher Cu concentrations were recorded by Fosu–Mensah *et al.* [25], Esen *et al.* [38], Tang *et al.* [39] for soils at Korle Lagoon area in Accra, Ghana; surface sediments of Nemrut Bay, Aegean Sea and soils from Wenling city, respectively.

Cobalt (Co) is a natural occurring essential element to plants (though still under consideration) and has some biological functions in humans. Soil pollution problems from Co are generally less significant than those associated with some other heavy metals [40]. In this study, Co concentrations in sampled sites from Nasarawa Eggon and Doma

Table 3. Enrichment Factor (E_f) for Heavy Metals in Nasarawa Eggon and Doma Soil Samples

Sample Code	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	U	Zn
Nasarawa Eggon												
N1	0.00	0.00	0.00	0.00	0.00	1.00	247.05	2.78	0.00	11.41	0.00	3.20
N2	2.28	0.00	0.00	0.00	0.00	1.00	27.02	1.52	0.00	2.54	0.00	0.88
N3	0.00	0.00	0.00	0.00	0.00	1.00	27.02	1.10	0.00	2.48	4.28	0.62
N4	1.63	0.00	0.00	0.00	0.00	1.00	0.00	1.21	0.00	5.82	0.00	3.08
N5	0.00	0.00	0.00	0.00	0.00	1.00	42.35	2.10	0.00	6.67	0.00	0.78
N6	0.00	0.00	0.00	0.00	0.00	1.00	159.85	5.08	0.00	11.91	0.00	1.38
N7	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.98	3.60	8.79	0.00	0.92
N8	0.00	0.00	0.00	0.00	0.00	1.00	50.10	1.96	0.00	9.61	0.00	0.92
N9	0.00	0.00	0.00	0.00	0.00	1.00	50.67	1.69	0.00	3.75	0.00	0.32
N10	0.00	0.00	0.00	0.00	0.00	1.00	0.00	3.24	0.00	11.72	0.00	4.21
Mean	0.39	0.00	0.00	0.00	0.00	1.00	60.41	2.27	0.04	7.47	0.04	1.63
Doma												
D1	0.00	0.00	0.00	0.00	0.00	1.00	109.99	1.30	0.00	1.99	0.00	1.14
D2	0.68	0.00	14.29	0.53	0.00	1.00	20.39	0.96	0.00	0.89	1.91	0.58
D3	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.23	0.00	1.15	4.09	0.57
D4	0.31	0.00	6.23	0.00	0.00	1.00	12.62	0.86	0.00	0.67	0.66	0.39
D5	0.60	0.00	0.00	0.00	0.00	1.00	30.82	0.53	0.00	0.52	0.00	0.62
D6	0.00	0.00	0.00	0.00	0.00	1.00	172.47	5.20	0.00	0.00	0.00	0.65
D7	0.00	0.00	0.00	0.00	0.00	1.00	144.71	2.17	0.00	0.00	0.00	0.62
D8	0.00	0.00	0.00	0.00	0.00	1.00	173.28	2.00	0.00	0.00	0.00	0.00
D9	0.00	0.00	0.00	0.00	0.00	1.00	242.38	3.89	0.00	0.00	0.00	0.00
D10	0.00	0.00	0.00	0.00	0.00	1.00	0.00	2.07	0.00	0.00	0.00	0.00
Mean	0.16	0.00	2.05	0.05	0.00	1.00	90.67	2.02	0.00	0.52	0.67	0.46

(except D2 and D4) are below the instrumentation detectable limit (BDL), DPR [19] and average shale [17] reference values. This implies that the presence of Co in these sampled sites could be due to natural (lithogenic) processes such as fragmentation or weathering of rock. However, Co levels in D2 and D4 of the Doma study area are significantly higher than the reference values. This indicates anthropogenic contribution (such as automobile workshop waste, burning of municipal waste, cola combustion, fertilizer, leachate from Pb mining and processing etc.) to the level of Co in these two sampled sites in Doma. A high level of Co intake could depress Fe and Cu levels in the body which can lead anaemia [41]. Human exposure to Co can be through occupational, dietary, environmental and medical pathways or sources and chronic exposure can cause skin rashes, asthma, neurological (e.g., hearing and visual impairments), cardiovascular, and endocrine deficits [42].

The concentrations of Cr in sampled soils from Nasarawa Eggon and Doma are below the DPR [19] and average shale [17] values, indicating lithogenic or natural or crustal origin (such as rock weathering/fragmentation) of Cr in all sampled sites of the study areas. This is in agreement with findings by Amos-Tautua *et al.* [35] for soils of municipal open waste dumpsite in Yenagoa, Nigeria but contradicts higher Cr concentrations reported by Dawaki *et al.* [43] and Agbaji *et al.* [44] for Kano urban agricultural soils and soils in Kakuri Industrial Area of Kaduna, Nigeria; respectively. Thus, the highest Cr level of 35.96 mg/kg was recorded in sampled site D2 which suggests a possible little anthropogenic contribution to crustal origin (such as rock weathering/fragmentation) of Cr in sampled site D2. Anthropogenic sources of Cr in the soils could be due to waste consisting of lead-chromium batteries, coloured polythene bags, discarded plastic materials and empty paint containers [45]. Cr (III) is not toxic but Cr (VI) is a carcinogen [46] whose acute toxicity is due to oxidation properties, hemolysis and organ failures [47]. Occupational exposure to Cr is mostly by inhalation, but gastrointestinal tract and skin can occur [48]. Cr (VI) corrodes skin and causes denaturation and precipitation of tissue proteins [49].

Iron (Fe) is one of the most abundant naturally

occurring elements in the earth's crust. In this study, it is the most abundant metal present in all the soil samples analysed. The concentration varied from 4403.79–30662.08 mg/kg and 2385.52–81069.80 mg/kg for Nasarawa Eggon and Doma soils respectively (Table 2). Thus, Fe levels in the various sampled soils of both study areas are below the DPR target [19] and average shale [17] values except for sample D4 (81069.80 mg/kg) in the Doma area. The findings of this study are significantly higher than those reported by Iwegbue *et al.* [34] and Osakwe [50] for soils around cassava processing mills in sub-urban areas of Delta State, Nigeria and soils from automobile workshops in Abraka, Delta State, Nigeria; respectively. High Fe levels obtained in this study could be a combined effect of lithological or crustal and anthropogenic origins based on the fact that natural soils contain significant amounts of Fe [51]. Thus, the presence of Fe in the soil could be attributed to weathering of rock types, geothermal activities, indiscriminate disposal and discharge from automobile waste (metal scraps from vehicle repairs, crankshafts wear), sewage discharge etc. Acute exposure to Fe in humans leads to vomiting, cardiac depression and metabolic acidosis [52].

Mercury (Hg) is one of the most toxic metals generated naturally in the environment from degassing of the earth's crust during volcanic emissions. Result (Table 2) shows that Hg level was significantly found in most of the analysed soils from Nasarawa Eggon and Doma areas ranging from BDL – 10.73 mg/kg and BDL – 8.67 mg/kg respectively. Thus, Hg levels in a few of the Nasarawa Eggon (N4, N7 and N10) and Doma (D3 and D10) soils, are below the instrumental detectable limit and reference values of DPR [19] and average shale [17]. However, Hg concentrations of the other soils which varied from 5.43–10.73 mg/kg and 4.90–8.67 mg/kg for Nasarawa Eggon and Doma areas respectively; are above the reference values. Higher Hg concentrations were reported for simple household e-waste recycling workshops [39] and soils in the Kakuri Industrial Area of Kaduna, Nigeria [44]. However, Hg levels lower than the findings of this study were reported in other literature [25][39][53] for e-waste dumpsites. Hg levels in the sampled sites could be attributed to lithogenic (such as rock

Table 4. Geo-accumulation Index (Igeo) of Heavy Metals in Selected Soils of Nasarawa Eggon and Doma

Sample Code	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	U	Zn
Nasarawa Eggon												
N1	0.00	0.00	0.00	0.00	0.00	-4.01	3.94	-2.53	0.00	-0.49	0.00	-2.33
N2	-0.02	0.00	0.00	0.00	0.00	-1.21	3.55	-0.60	0.00	0.14	0.00	-1.39
N3	0.00	0.00	0.00	0.00	0.00	-1.45	3.30	-1.31	0.00	-0.14	0.65	-2.13
N4	-1.50	0.00	0.00	0.00	0.00	-2.21	0.00	-1.93	0.00	0.33	0.00	-0.58
N5	0.00	0.00	0.00	0.00	0.00	-1.68	3.72	-0.61	0.00	1.06	0.00	-2.03
N6	0.00	0.00	0.00	0.00	0.00	-3.75	3.57	-1.41	0.00	-0.18	0.00	-3.29
N7	0.00	0.00	0.00	0.00	0.00	-2.51	0.00	-1.52	-0.66	0.63	0.00	-2.62
N8	0.00	0.00	0.00	0.00	0.00	-2.47	3.18	-1.50	0.00	0.80	0.00	-2.59
N9	0.00	0.00	0.00	0.00	0.00	-1.50	4.16	-0.74	0.00	0.40	0.00	-3.14
N10	0.00	0.00	0.00	0.00	0.00	-2.09	0.00	-0.39	0.00	1.46	0.00	-0.02
Mean	-0.15	0.00	0.00	0.00	0.00	-2.29	2.54	-1.25	-0.07	0.40	0.07	-2.01
Doma												
D1	0.00	0.00	0.00	0.00	0.00	-3.07	3.71	-2.69	0.00	-2.08	0.00	-2.88
D2	-1.56	0.00	2.84	-1.91	0.00	-0.10	3.35	-1.06	0.00	-1.16	-0.07	-1.79
D3	0.00	0.00	0.00	0.00	0.00	-2.24	0.00	-1.95	0.00	-2.04	-0.21	-3.05
D4	-1.46	0.00	2.84	0.00	0.00	0.20	3.85	0.72	0.00	-0.39	-0.40	-1.16
D5	-2.46	0.00	0.00	0.00	0.00	-1.73	3.22	-2.64	0.00	-2.67	0.00	-2.42
D6	0.00	0.00	0.00	0.00	0.00	-4.14	3.29	-1.76	0.00	0.00	0.00	-4.76
D7	0.00	0.00	0.00	0.00	0.00	-3.98	3.19	-2.87	0.00	0.00	0.00	-4.66
D8	0.00	0.00	0.00	0.00	0.00	-4.05	3.38	-3.05	0.00	0.00	0.00	0.00
D9	0.00	0.00	0.00	0.00	0.00	-4.89	3.03	-2.93	0.00	0.00	0.00	0.00
D10	0.00	0.00	0.00	0.00	0.00	-3.77	0.00	-2.71	0.00	0.00	0.00	0.00
Mean	-0.55	0.00	0.57	-0.19	0.00	-2.78	2.64	-2.09	0.00	-0.83	-0.07	-2.07

fragmentation, volcanic eruptions, geothermal activities etc.) and anthropogenic (such as discharges from used batteries, household e-waste, paint wastes, coal combustion, manometer at pressure measuring sites and hydraulic lifts attached to heavy-duty trucks on the ever-busy roads) sources. Exposure to Hg can have some adverse effects on humans such as ataxia, attention deficit, blindness, deafness, decreased rate of fertility, dementia, dizziness, dysphasia, gastrointestinal irritation, gingivitis, kidney problem, loss of memory, pulmonary edema, reduced immunity and sclerosis [33][54].

Manganese (Mn) is the second most abundant metal found in all the sampled sites of the study areas and the concentration varied from 220.43–971.81 mg/kg and 153.88–1261.60 mg/kg for Nasarawa Eggon and Doma sampled sites respectively. Mn concentrations in samples N10 (971.81 mg/kg) and D4 (1261.60 mg/kg) from Nasarawa Eggon and Doma respectively, are above the DPR target [19] and average shale [17] values while the concentrations of Mn in the other analysed soils from both study areas are below the aforementioned reference values. In comparison to the findings of this study, Osakwe [50] found lower concentrations of Mn in soils from automobile workshops. High Mn levels could be attributed to lithogenic origin based on the fact that in the form of oxide, Mn is a component of subsoil material [55]. However, high levels of Mn in sampled sites N10 and D4 indicates possible contributions from anthropogenic sources such as used batteries, discarded metal scraps, machinery parts, automobile exhaust fume and wastes from welding works and spray paintings of the vehicles [50][56] [57]. Mn is an essential microelement for both plants and animals. However, exposure to a high dose of Mn results in kidney failure, liver and pancreas malfunctioning low fetal birth weight and increased infant mortality [58].

Nickel (Ni) is absorbed through the lungs [59], gastrointestinal tract [60] and skin [61], but excreted in the urine [62]. Human exposure to nickel causes a variety of pathologic effects but its adverse health effects are dependent on exposure route (inhalation, oral or dermal) and classification based on systemic, immunologic, neurologic, reproductive, distorted developmental or

carcinogenic effects, following acute (1 day), sub-chronic (10–100 days) and chronic (100 days or more) exposure periods [63]. In this study, Ni concentrations in the sampled sites of Nasarawa Eggon (except N7) and Doma study areas are below the instrumentation detectable limit and the reference values. Ni was significantly found only in site N7 (64.59 mg/kg) of the Nasarawa Eggon area which is above the reference value by DPR [19] but below that of the average shale [17] value. This implies that the presence of Ni in sampled site N7 is possibly due to anthropogenic origin such as leaching from metal scraps, runoff of paints/pigment waste, discharge from sewage and indiscriminate waste dumps etc.

Lead (Pb) is the most immobile element present in the soil [64]. A literature survey showed that Pb has several negative health implications on various organs and systems in all living species under experimental conditions, including the blood, reproductive, immune system and kidneys [65]. Pb is a highly neurotoxic agent that particularly affects the development of the central nervous system (CNS) and consequently can be the cause of many negative effects on humans such as anorexia, chronic nephropathy, damage to neurons, high blood pressure, hyperactivity, insomnia, learning deficits, reduced fertility (by reducing testosterone production *in vitro* and *in vivo*), renal system damage, a risk factor for Alzheimer's disease and shortened attention span [15][66]. In this study, the Pb concentrations in the investigated soils from Nasarawa Eggon varied from 21.29–82.64 mg/kg and thus, are above the average shale [17] value but below the DPR [19] value. However, only Pb concentration in sample D4 of the Doma study area was above the average shale [17] value but below the DPR [19] value. Hence, the Pb concentrations in the remaining analysed Doma soils are below both aforementioned reference values. Pb concentrations in the sampled soils of both study areas could be a contribution from anthropogenic sources mainly from atmospheric depositions from automobile exhaust and generator emissions/fumes and others such as used dry cell batteries, sewage effluents, runoff of paint/pigment wastes and leachate from municipal waste, owing to the close proximity of the sites to high vehicular traffic [35] [54]. The low concentration range of Pb in most sampled sites in

Table 5. Contamination factor (Cf), degree of contamination (Cd) and pollution load index (PLI) of the soil samples

Sample Code	Cf										Cd			PLI
	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	U	Zn		
Nasarawa Eggon														
N1	0.00	0.00	0.00	0.00	0.00	0.12	2.31	0.26	0.00	0.25	0.00	0.20	3.14	0.63
N2	19.29	0.00	0.00	0.00	0.00	0.81	1.76	0.99	0.00	0.39	0.00	0.39	23.63	1.13
N3	0.00	0.00	0.00	0.00	0.00	0.68	1.48	0.60	0.00	0.32	0.38	0.23	3.69	0.71
N4	6.90	0.00	0.00	0.00	0.00	0.40	0.00	0.39	0.00	0.44	0.00	0.69	8.82	0.91
N5	0.00	0.00	0.00	0.00	0.00	0.58	1.98	0.98	0.00	0.73	0.00	0.25	4.52	0.88
N6	0.00	0.00	0.00	0.00	0.00	0.14	1.78	0.57	0.00	0.31	0.00	0.11	2.91	0.64
N7	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.52	1.85	0.55	0.00	0.17	3.42	0.75
N8	0.00	0.00	0.00	0.00	0.00	0.34	1.35	0.53	0.00	0.61	0.00	0.17	3.00	0.74
N9	0.00	0.00	0.00	0.00	0.00	0.66	2.68	0.90	0.00	0.47	0.00	0.12	4.83	0.82
N10	0.00	0.00	0.00	0.00	0.00	0.44	0.00	1.14	0.00	0.97	0.00	1.02	3.57	0.94
Mean	2.62	0.00	0.00	0.00	0.00	0.45	1.33	0.69	0.19	0.50	0.04	0.34	6.15	0.82
Doma														
D1	0.00	0.00	0.00	0.00	0.00	0.22	1.97	0.23	0.00	0.08	0.00	0.14	2.64	0.57
D2	6.60	0.00	10.19	0.36	0.00	0.93	1.53	0.72	0.00	0.16	0.23	0.30	21.02	0.90
D3	0.00	0.00	0.00	0.00	0.00	0.39	0.00	0.39	0.00	0.09	0.21	0.12	1.20	0.52
D4	7.09	0.00	10.17	0.00	0.00	2.13	2.17	1.48	0.00	0.27	0.18	0.46	23.95	1.22
D5	3.55	0.00	0.00	0.00	0.00	0.56	1.40	0.24	0.00	0.06	0.00	0.19	6.00	0.67
D6	0.00	0.00	0.00	0.00	0.00	0.11	1.47	0.44	0.00	0.00	0.00	0.04	2.06	0.61
D7	0.00	0.00	0.00	0.00	0.00	0.12	1.37	0.21	0.00	0.00	0.00	0.04	1.74	0.58
D8	0.00	0.00	0.00	0.00	0.00	0.11	1.57	0.18	0.00	0.00	0.00	0.00	1.86	0.75
D9	0.00	0.00	0.00	0.00	0.00	0.06	1.23	0.20	0.00	0.00	0.00	0.00	1.49	0.70
D10	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.23	0.00	0.00	0.00	0.00	0.37	0.75
Mean	1.72	0.00	2.04	0.04	0.00	0.48	1.27	0.43	0.00	0.07	0.06	0.13	6.24	0.73

Doma could be due to natural processes such as fragmentation of source rocks. It was observed that the concentrations of Pb are higher in Nasarawa Eggon sampled sites than in Doma. This suggests higher vehicular/automobile traffic in the Nasarawa Eggon area than in Doma which is not surprising because Nasarawa Eggon has accessibility to many economic locations than Doma. Nduka *et al.* [29] who investigated Pb in scrap paint dust reported lower Pb concentrations while the results of Ololade [67] investigation on soils within auto–mechanic workshops, agree with those of this study.

Uranium (U) is a naturally occurring radioactive and chemical metal with a global background concentration in the earth's crust of approximately 2–4 mg/kg. Natural U is approximately 10 times more abundant than other toxic heavy metals such as cadmium (0.3 mg/kg) or mercury (0.4 mg/kg) [15][17]. Table 2 showed that U concentrations in most sampled sites of Nasarawa Eggon and Doma study areas were below the instrumentation limit of detection. Therefore, significant amounts of U were only determined in sampled sites N3 (8.68 mg/kg) of Nasarawa Eggon and D2 (5.30 mg/kg), D3 (4.79 mg/kg) and D4 (4.22 mg/kg) of Doma. This implies they are above the average shale [17] reference value but below the DPR [19] value and hence suggests a contribution of anthropogenic sources (such as coal and fuel combustion) to the presence of U in these soils (N3, D2, D3 and D4). U has biologically dynamic toxicity, metabolic toxicity and chemical toxicity, leading to potential long-term harm to mammalian reproduction and development with reduced biological fertility, abnormal and slow embryonic development [68]. A similar low U concentration was recorded in southeastern Brazil mine [69] and sediments of watersheds in Abiete-Toko gold district, Southern Cameroon [15].

Zinc (Zn) is a micronutrient essential for normal plant growth which is involved in various metabolic activities of many organisms [70]. Human exposure to a high dose of Zn can cause many health disorders such as ataxia, depression, gastrointestinal irritation, haematuria, icterus, impotence, kidney and liver failure, lethargy, macular degeneration, metal fume fever, prostate cancer, seizures, and vomiting for Zn [71]. Result (Table 2) shows that Zn concentrations in the sampled sites in Nasarawa

Eggon (except N4 and N10) and Doma are lower than the reference values of average shale [17] and DPR [19]. The level of Zn in N10 soil of Nasarawa Eggon is above the reference values while in sample N4, the Zn level was above the average shale [17] value but below the DPR [19] value. Similar to the trend of Pb concentration, higher Zn concentrations were also observed in Nasarawa Eggon sampled sites than in Doma. This supports the earlier suggestion of higher automobile/vehicular traffic as well as generator usage in the studied Nasarawa Eggon area than in the Doma area. Zn and Pb are products of gasoline combustion from automobiles and generators exhaust [72]. Other anthropogenic sources such as runoff of paint/pigment wastes, smelting activities, indiscriminate disposal and dumping of Zn containing wastes, crude oil tyre etc. [72] could be responsible for the high concentrations of Zn observed while lithogenic processes were indicated by low Zn concentration especially in Doma study area. According to Jaradat and Momani [73], the major sources of Zn in soils are probably the attrition of motor vehicle tyre rubber and the lubricating oils in which Zn is found as part of many additives as zinc dithiophosphates. Result obtained in this study is within the Zn concentrations reported by Dawaki *et al* [43] and Iwegbue *et al.* [34] for Kano urban agricultural soils and soils around Cassava Processing Mills in Sub-Urban Areas of Delta State, Southern Nigeria respectively. However, higher Zn concentrations were found in automobile workshop soils as reported by Osakwe [50].

3.2. Soil Pollution Indices or Assessment

In order to understand the quality of agricultural soils along major roads with high vehicular and human traffic, levels of metal pollution were evaluated using different techniques for environmental assessment.

3.2.1. Enrichment Factor

The enrichment factor (E_f) is generally used as an appropriate method to discriminate between natural and anthropogenic sources of metals [74] and to reflect the status of environmental contamination, based on the use of a normalization element in order to improve the variations produced

Table 6. Ecological risk (Er) and potential ecological risk index (RI) in the soil samples

Sample Code	Er										RI		
	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb		U	Zn
Nasarawa Eggon													
N1	0.00	0.00	0.00	0.00	0.00	NC	92.40	0.26	0.00	1.25	NC	0.20	94.11
N2	192.90	0.00	0.00	0.00	0.00	NC	70.40	0.99	0.00	1.95	NC	0.39	266.63
N3	0.00	0.00	0.00	0.00	0.00	NC	59.20	0.60	0.00	1.60	NC	0.23	61.63
N4	69.00	0.00	0.00	0.00	0.00	NC	0.00	0.39	0.00	2.20	NC	0.69	72.28
N5	0.00	0.00	0.00	0.00	0.00	NC	79.20	0.98	0.00	3.65	NC	0.25	84.08
N6	0.00	0.00	0.00	0.00	0.00	NC	71.20	0.57	0.00	1.55	NC	0.11	73.43
N7	0.00	0.00	0.00	0.00	0.00	NC	0.00	0.52	9.25	2.75	NC	0.17	12.69
N8	0.00	0.00	0.00	0.00	0.00	NC	54.00	0.53	0.00	3.05	NC	0.17	57.75
N9	0.00	0.00	0.00	0.00	0.00	NC	107.20	0.90	0.00	2.35	NC	0.12	110.57
N10	0.00	0.00	0.00	0.00	0.00	NC	0.00	1.14	0.00	4.85	NC	1.02	7.01
Mean	26.19	0.00	0.00	0.00	0.00	NC	53.36	0.69	0.93	2.52	NC	0.34	84.02
Doma													
D1	0.00	0.00	0.00	0.00	0.00	NC	78.80	0.23	0.00	0.40	NC	0.14	79.57
D2	66.00	0.00	50.95	0.72	0.00	NC	61.20	0.72	0.00	0.80	NC	0.30	180.69
D3	0.00	0.00	0.00	0.00	0.00	NC	0.00	0.39	0.00	0.45	NC	0.12	0.96
D4	70.90	0.00	50.85	0.00	0.00	NC	86.80	1.48	0.00	1.35	NC	0.46	211.84
D5	35.50	0.00	0.00	0.00	0.00	NC	56.00	0.24	0.00	0.30	NC	0.19	92.23
D6	0.00	0.00	0.00	0.00	0.00	NC	58.80	0.44	0.00	0.00	NC	0.04	59.28
D7	0.00	0.00	0.00	0.00	0.00	NC	54.80	0.21	0.00	0.00	NC	0.04	55.05
D8	0.00	0.00	0.00	0.00	0.00	NC	62.80	0.18	0.00	0.00	NC	0.00	62.98
D9	0.00	0.00	0.00	0.00	0.00	NC	49.20	0.20	0.00	0.00	NC	0.00	49.40
D10	0.00	0.00	0.00	0.00	0.00	NC	0.00	0.23	0.00	0.00	NC	0.00	0.23
Mean	17.24	0.00	10.18	0.07	0.00	NC	50.84	0.43	0.00	0.33	NC	0.13	79.22

NC: Not Calculated

by heterogeneous sediments [75]. The E_f values close to unity indicate crusted origin, those less than 1.0 suggest a possible mobilization or depletion of metals, whereas $E_f > 1.0$ indicates that the element is of anthropogenic origin [76].

The E_f values obtained in this study for the soil samples from the study areas are presented in Table 3 and Birth [77] categorization of E_f values (Table 1) was used for the interpretation. Based on the average, both Nasarawa Eggon and Doma sampled soils are enriched minimally and extremely severe with Mn and Hg respectively. Pb and Zn are enriched at significant and minimal levels, respectively, in Nasarawa Eggon while Co is minimally enriched in Doma soils. As, Cd, Cr, Cu, Ni and U are not enriched in the sampled soils of both study areas.

A comparison among different sampling sites of the study areas based on E_f values of metals showed no enrichment of Cd, Cr, and Cu in all the investigated soils of both study areas. In most of the sampled soils of both study areas, Hg has the highest enrichment level ranging from severe to extremely severe enrichment. Hg is not enriched in sampled sites N4, N7 and N10 of Nasarawa Eggon soils and D3 and D10 of Doma soils. The E_f values indicate minimal to a severe enrichment level of Pb in Nasarawa Eggon soils and no enrichment to minimal enrichment levels in Doma soils. Mn is enriched at a minimal to moderate level in Nasarawa Eggon and no enrichment to a moderate level in Doma soil. The U enrichment levels range from no enrichment to moderate at both Nasarawa Eggon and Doma soils. Enrichment levels of As and Ni in Nasarawa Eggon soils range from no enrichment to moderate enrichment while there was no enrichment of either of the metals in Doma soils. Sampled sites N2 and N4 are minimally enriched with As while N7 and N3 are moderately enriched with Ni and U respectively. Co is not enriched in all the investigated soils from Nasarawa Eggon but ranged from no enrichment to severely enrich in Doma soils. Zn enrichment varied from no enrichment to moderate enrichment level in Nasarawa Eggon soils but in Doma soils, it varied from no enrichment to minimal enrichment.

Zn is not enriched in most of the Nasarawa Eggon soils except in N1, N4 and N10 which have moderate enrichment and N6 with minimal

enrichment. Only sampled site D1 in Doma soils is enriched minimally with Zn, with no enrichment in other sampled sites.

It is obvious from the results (Table 3) that the investigated soils of Nasarawa Eggon and Doma are highly enriched with Hg and Mn, as well as Pb and Zn in Nasarawa Eggon only and Co in Doma only. This is an indication that in addition to natural sources of these heavy metals, there is a significant contribution from anthropogenic sources to the presence of these heavy metals in the soils [78]. Studies by Gibson and Farmer [79] and Sezgin *et al.* [80] established that vehicular emission, industrial production and weathered materials are the three main sources of heavy metals in urban areas. Consequently, the high E_f of Pb, Mn and Zn in the soils could be attributed to automobile/vehicular traffic because Sutherland [16] had reported that automobile/vehicular exhaust emissions significantly accentuate Pb accumulations in the air and soils. Automobile emission accounts for about 80 % of heavy metal pollution in Nigeria [81] and has been shown to contain Pb and Mn from gasoline as well as Zn from tyres [72]. Weathering of rocks, burning of fossil fuels (petroleum and coals) and municipal waste (containing e-wastes, automobile and automobile workshop wastes, and medical wastes) [39] in these study areas are the probable sources (lithogenic and anthropogenic) of Hg, Pb, Mn, and Zn, in the investigated soils. The literature revealed that anthropogenic sources contribute more to heavy metal pollution than natural sources [9][25]. The E_f values of As, Cd, Co, Cr, Cu, Ni and U, as well as Pb and Zn in Doma; suggest they were majorly derived from crustal material, or natural weathering process [82].

3.2.2. Geo-accumulation Index (Igeo)

The level of pollution of the investigated soils was assessed using Igeo indices proposed by Muller [18] as shown in Table 1. The Igeo values of the different metals at different sampled sites in the study areas are presented in Table 4. The average Igeo values of the metals suggest that the soils from the study areas (Nasarawa Eggon and Doma) are moderate to strongly polluted by Hg and practically unpolluted to moderately polluted by the rest of the metals. Thus, Hg is the only toxic metal that has

accumulated in the investigated soils as a result of indiscriminate disposal of municipal waste and high automobile traffic.

A comparison of Igeo values among different sampled sites of the study areas showed that sampled sites in Nasarawa Eggon are strong to extremely polluted by Hg except N4, N7 and N10 which are practically unpolluted by Hg. However, sampled site N10 is moderately polluted by Pb and so is N5 which is also strongly polluted by Hg. Thus, Hg and Pb are two toxic metals that accumulate in studied agricultural soils of Nasarawa Eggon. The Igeo values of Doma investigated soils showed that except for D3 and D10, all sampled sites are strongly polluted by Hg. Sampled sites D2 and D4 are moderate to strongly polluted by Co. Hence, Hg and Co are the accumulating toxic metals in Doma studied agricultural soils which can be attributed to the combustion of household e-waste, fertiliser, automobile workshop waste etc.

3.2.3. Contamination Factor (C_f), Degree of Contamination (C_d) and Pollution Load Index (PLI)

The values of C_f , C_d and PLI at the sampled sites of both study areas are summarized in Table 5. Applying Hakanson [21] classification (Table 1), the sampled sites in the Nasarawa Eggon area showed low contamination by Cd, Co, Cr, Cu, Fe, Pb, U and Zn (Table 5).

However, sampled sites N2 and N4 are highly contaminated by As while N7 and N10 are moderately contaminated by Ni and Mn respectively. Except for N4, N7 and N10, all sampled sites in Nasarawa Eggon are moderately contaminated by Hg. The sampled sites in Doma showed low contamination by Cd, Cr, Cu, Mn, Ni, Pb, U and Zn based on their C_f values. D2 and D4 showed high contamination by As and Co. D4 is moderately contaminated by Fe while D5 is considerably contaminated by As. All sampled sites are moderately contaminated with Hg except for D3 and D10. High As contamination of some sampled sites showed that a metal that highly contaminated soil may not necessarily accumulate to cause pollution. This is because Igeo did not indicate that As is one of the toxic metals that accumulates in either Nasarawa Eggon or Doma area. Similarly, low Pb contamination of the sampled sites in the

Nasarawa Eggon area showed that even at the low contamination, a metal can still accumulate and pollute the site.

C_d measures the degree of overall contamination at a particular site [83]. C_d showed that sampled sites in Nasarawa Eggon had a low degree of contamination except for N2 and N4 which had a moderate degree of contamination. Sampled sites D2 and D4 in the Doma area, had a moderate degree of contamination while other sample sites had a low degree of contamination.

The PLI represents the number of times by which the metal content in the soil exceeds the average natural background concentration [67]. The PLI value greater than one (1) is considered polluted, less than one (1) indicates no pollution whereas a value equal to one (1) indicates contaminant loads close to the reference concentration [84]. Results (Table 5) show that only sampled sites N2 and D4 of Nasarawa Eggon and Doma, respectively, were polluted (PLI >1). Thus, this study has shown that a sampled site can be contaminated by metals but not polluted.

3.2.4. Ecological Risk (Er) and Potential Ecological Risk Index (RI)

The quality of the investigated soils in Nasarawa Eggon and Doma which are contaminated by metals, were assessed using this risk factor. Table 6 shows the Er and RI of metals in the investigated sites of the two study areas (Nasarawa Eggon and Doma). Er of Fe and U were not calculated as their toxic response factor are yet to be determined. By Hakanson classification (Table 1), the average Er of the metals showed that the levels of As, Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn do not pose any ecological risk to the study areas (Nasarawa Eggon and Doma). Nevertheless, the Hg level poses a moderate ecological risk ($40 \leq \text{Average } Er < 80$) to the environment of the study areas. This supports our earlier finding in the Igeo studies.

However, comparing the Er of metals in the investigated sites of the study areas showed that Cd, Co, Cr, Cu, Mn, Ni, Pb and Zn have low potential ecological risk ($Er < 40$) and thus, do not pose any risk of serious diseases (cancer, kidney, liver damage, etc.), as well as impact in the ecosystems. At Nasarawa Eggon, As has significant and moderate potential risk in sampled sites N2 and N4

respectively. The Hg has significant (N1 and N9), moderate (N2, N3, N5, N6 and N8) and low (N4, N7 and N10) potential ecological risks in the Nasarawa Eggon area. The low potential risk of As at sampled site D5 as well as the moderate potential risk of As and Co at D2 and D4 sites of Doma area was observed. However, Hg exhibits moderate potential ecological risk in sampled sites in Doma except in D4 where it shows significant potential ecological risk in D3 and D10 where it poses no ecological risk. RI sums the Er of all the studied metals in a sampled site. Results (Table 6) showed that except for sampled site N2, all sampled sites in Nasarawa Eggon presented a low ecological risk index ($RI < 150$).

Sample site N2 had a moderate ecological risk index which implies that the pollution of this soil can cause serious ecological risks. Sampled sites D2 and D4 in the Doma area also showed a moderate ecological risk index ($150 \leq RI < 300$) while the other sampled sites presented a low ecological risk index. This shows that soil may not be polluted ($PLI < 1$) but its usage could still pose an ecological risk to the inhabitants.

4. CONCLUSIONS

This study successfully quantified selected metals in sampled soils of study areas (Nasarawa Eggon and Doma) and evaluated their origin (natural and anthropogenic), contamination level and toxicity. The result showed non-uniform distribution of the analysed metals in the sampled sites of the study areas. Cd, Cr, Cu and Ni concentrations were all below average shale referenced value. Fe was the most abundant of the metals analyzed in all the sampled sites of the study areas. Significant concentrations of As, Co, Hg, Mn, Pb, U and Zn were recorded at the different sampled sites of both study areas. In pollution assessment, enrichment factor (E_f) analysis showed that some sampled sites in the Nasarawa Eggon area are enriched with As, Fe, Hg, Mn, Ni, Pb, U and Zn while Co, Fe, Hg, Mn, Pb, U and Zn are enriched in sampled sites (some) in Doma area. The enrichment levels of Mn, Pb and Zn are higher in Nasarawa Eggon soils than in Doma soils. However, geo-accumulation index (Igeo) suggested that only Hg and Pb could pollute the sampled soils and

similarly, Hg and Co could pollute Doma sampled soils despite being enriched with Co, Fe, Hg, Mn, Pb, U and Zn. Among the analysed metals, contamination factor (C_f) showed that sampled sites N2 and N4 in the Nasarawa Eggon area and D2 and D4 in the Doma area, recorded a moderate degree of contamination by all the studied metals. PLI values showed that only sampled sites N2 and D4 of Nasarawa Eggon and Doma area, respectively, were polluted. Ecological risk (Er) assessment revealed that As and Hg pose moderate to significant potential negative implications to human and animal health in some of the sampled sites in Nasarawa Eggon while As, Co and Hg showed similar ecological risk in some of the sampled sites in Doma. The potential ecological risk index (RI) showed that metal pollution in sampled site N2 of Nasarawa Eggon and D2 and D4 of Doma can cause serious negative health implications for humans and animals in such an environment. Thus, the study suggests higher vehicular/human activities in Nasarawa Eggon than the Doma study area and they had a remarkable contribution to the presence of the investigated metals in the nearby agricultural soils.

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Conflicts of Interest

The author(s) declared no conflict of interest

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