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Geochemical assessments and human health risk evaluations of selected farm soils within the Abuja metropolis, North-central, Nigeria

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Abstract

Toxin accumulations in agricultural soils decreases the crop quality and productivity, and threatens the safety of foods, which could cause adverse human health effects. This study assessed the risks associated with potential toxins in the agricultural soils obtained from Lugbe and Jikwoyi in Abuja, Nigeria. An analytical technique for absorption spectrophotometry was adopted, and human health risks were evaluated. Twenty soil samples were collected from two farmlands, and two control samples were taken on unpolluted sites at depths 5-20 cm from the surface at the average suspension of plant roots where the soil holds most plant nutrients and water at a space interval of 5 m. The soils generally had low mean concentrations of Ca, Cu, Zn, Mn, Fe, and Co and moderately high mean concentrations of F, Ni, Pb, Cr, and Mo. The pattern of the pollutants reflected that the pollutants were majorly from anthropogenic activities, such as long-term fertilizer applications and other agrochemicals. The contamination indices revealed reassuringly low to moderate pollution risks to humans. The overall pollution loads suggested that the samples were largely unpolluted. The non-carcinogenic and carcinogenic health risks were within the safety limits for inhalation, dermal, and ingestion, which pose no significant risk to children and adults living in the vicinities of the farmlands. The cancer risks for inhalation were higher than dermal and ingestion, with Cr showing the highest values. The samples were slightly contaminated with potentially toxic metals, which could lead to increased phyto-accumulations, soil pollution, and groundwater contamination.

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1. Introduction

Soils are loose organic and inorganic particles that cover the subsurface, provide plants with structural supports, and serve as the source of nutrients and water to plants [1, 2]. Soils also filter and retain potential pollutants and regulate water flow. Good soil structure promotes plant health by allowing air and water movements in the soil profile, thereby promoting food production [3]. Soil biological, chemical, and physical processes and properties vary due to the differences in soil composition, microbial loads, weathering, and leaching. The chemical structure of the soil is majorly determined by the soil's chemical makeup from natural

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sources and anthropogenic activities [2]. The elements contaminate the soil in high concentrations, become toxic to humans when inhaled, ingested, and adsorbed, and could lead to biotoxicity. About ninety-two natural elements are found in agricultural soils, but only eighty-two could be actively or passively absorbed by plants [4], which could lead to adverse health conditions in man if available in high concentrations.

The accumulations of heavy metals in soil have increased because of industrialization, agricultural activities, and urbanization over the years [5]. The degree of exposure and concentrations of essential elements, such as iodine, molybdenum, copper, selenium, iron, zinc, cobalt, and chromium in agricultural soils could be toxic, adequate, and deficient, and both the toxicity and deficiency in soils can result into human health issues, such as electrolyte abnormalities, nutritional disorders, and obesity [6]. The essential elements at an adequate level in soils could stabilize cellular structure. Some elements, such as lead (Pb) and cadmium (Cd), do not have a significant benefit to human health and could cause high risks, even at deficient concentrations [2]. The primary exposure pathways of most toxins are through skin (contact), inhalation (respiratory system), and consumption (food), as the components of biomaterials are transported to the bloodstream and deposited in the body tissues and cells. Hence, there is a need for frequent assessments of human health risks.

The study of soil qualities in human health is ancient and crucial to environmental scientists and concerned individuals, as soil degradation enormously affects human civilization [2]. Healthy farmland ecosystems result in food chain safety, a primary requisite for human health safety [7]. The increased concentrations of heavy metals in farmlands due to anthropogenic sources and the excess applications of agricultural chemicals seriously threaten soil health, drawing notable research attention globally [1, 8]. Fertilizers do not necessarily contain only the elements required for a plant's healthy growth but also include elements capable of polluting the soil [5]. Food quality and its nutritional benefits largely depend on the soil's health. The plants pick up the high presence of elements in the soils and also seep into the groundwater through the soil spaces, thereby affecting the water quality [3, 9]. In recent times, soil quality has been extensively affected by increased mechanized farming systems through the use of machines, fertilizers, and poultry manure and organic livestock traditional agricultural fertilizers [7], industrial and domestic disposal systems [9], climate change [10], and other environmental conditions [6]. Most elements in soils that are available at very minute concentrations are essential for plant and animal growth, and if available in high amounts, they will contaminate the soil, plants, and animals.

The total elemental concentrations in soils and their mobility, availability and high presence in the food chain give insight into the range of challenges in the healthy conditions of crops, livestock, and human beings. Soil has been known to harbour heavy metals and other elements in which soil-water-human and soil-plant-human relationships are built [5]. High availability of toxins in the soil is transferred to groundwater and plants, which could lead to serious human health problems when consumed [9]. Thus, soil elemental concentrations determine the plant's quality and element stabilities in the human body system. Over the years, soil qualities have been assessed using several techniques because heavy metal contaminations in soils are mostly integrated pollutions and not by a single element [7, 11]. Therefore, heavy metal concentrations in farmland within Lugbe and Jikwoyi communities of the Federal Capital Territory, Abuja, were assessed using the Atomic Absorption Spectroscopy technique, and the contamination indices which provide more comprehensive pollution indications and accurate health assessments of the soils were estimated. Human health risks were assessed to have an apparent effect on humans, considering the World Health Organization (WHO) indicators.

2. The study area

The study was conducted on two farmlands in the Federal Capital Territory, Abuja. The Dozie's farmland, with an average area of 120,000 m^2, is located within the Lugbe community and bounded by latitudes N8°59′53.57′′ and N8°59′54.48′′, and longitude E7°22′16.30′′ and E7°22′15.08′′. The Marcus's farmland, situated within the Jikwoyi community, has an average size of 160,000 m^2 and within latitudes N8°59′15.74′′ and N8°59′14.89′′, and longitude E7°34′48.15′′ and E7°34′49.36′′. The geology of Abuja is mainly basement complex, and Dozie's and Marcus's farmlands have Magnetite and Porphyroblastic Gnesis formations, respectively (Figure 1). Lugbe and Jikwoyi's proximity to the center of Abuja and their affordable living standards make the communities the favorable hub for most low-income and average-income earners.

The two farmlands have been cultivated for the past fifteen years and have different sections, such as cassava, cocoyam, soya beans, potatoes, vegetables, and lots more. The farmlands are cultivated throughout the year by employing an irrigational system during the dry seasons and regularly depositing significant amounts of domestic and organic manures to improve crop yields. The climatic condition of Abuja is transitional between the north single rainfall maximum and south double rainfall maximum of Nigeria, and Abuja has humid and hot tropical conditions [12]. Rainfalls usually occur between March and November on the southern boundary and April and October in the northern region. Extreme rainfalls are experienced from July to September every year, accounting for approximately 60% of the total annual rainfall in Abuja, especially in the northern region [13]. Generally, total rainfall within Abuja metropolis differs yearly from north to south. Rainfall is a crucial environmental condition to agricultural practices, and rainfall characteristics such as temperature and diurnal and seasonal distribution, frequency, duration, and intensity of rain periods are different in time and place within Abuja [14].

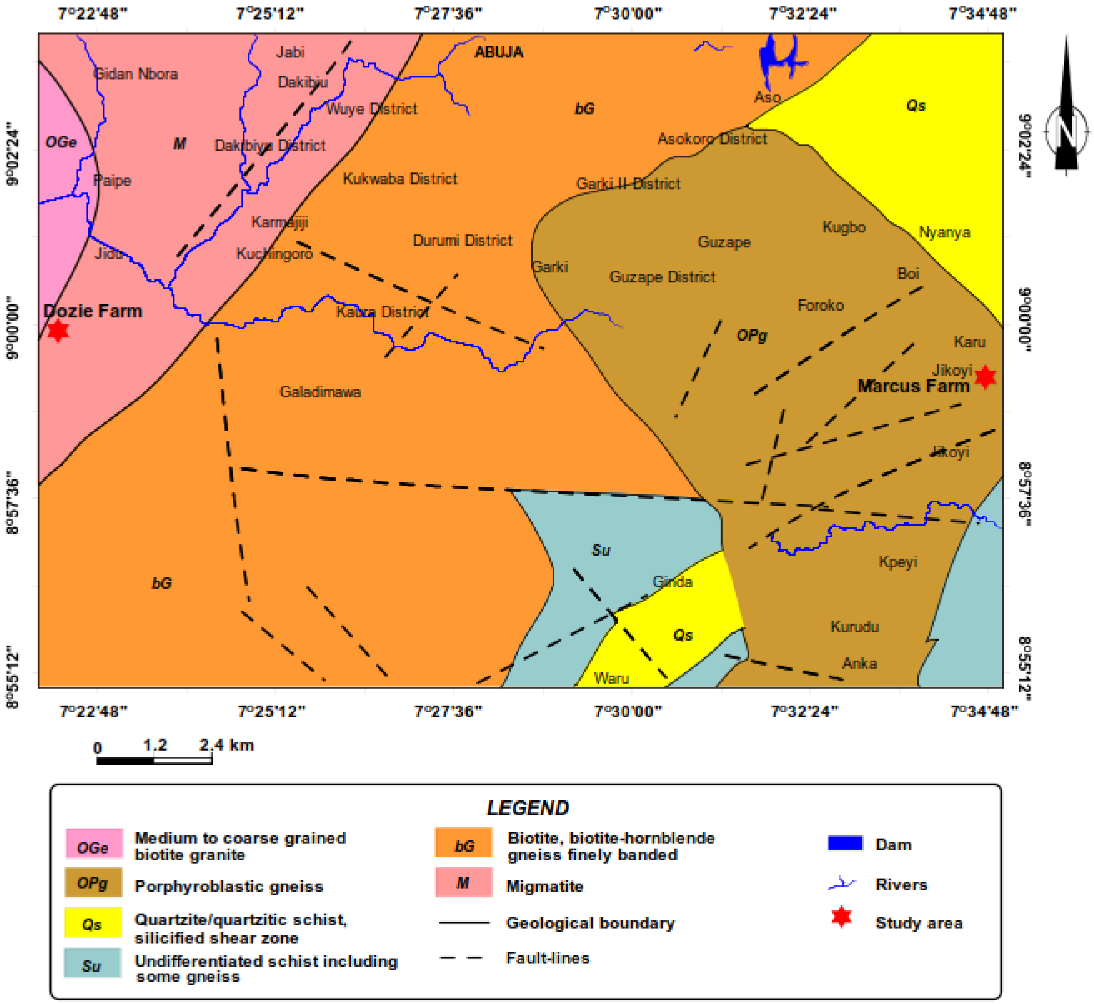

Figure 1: The geological map of Abuja metropolis showing the study areas.

3. Methodology

3.1. Sample collection, preparation and analysis

Soil samples were collected using soil huger and hand gloves into non-reacting polythene bags at depths 5-20 cm (the level of average suspension of plant roots where the soil holds most plant nutrients) at a space interval of 5 m on Dozie and Marcus farmlands. After each sample collection, the soil huger and gloves are cleaned to avoid contamination and reading alterations. The two farmlands had different sections for cultivating crops, such as cassava, cocoyam, soya beans, potatoes, and vegetables. Ten soil samples were obtained from each farmland, and twenty study samples were collected in addition to two control samples taken about 1 km from each farmland on unpolluted sites. The samples were appropriately labeled to avoid mixing up. After that, the soils were air-dried in an uncontaminated space to remove water, debris, and other extraneous matter, crushed in the mortar using a pestle, and ground using grinding stones to have refined powdered grains. An approximate 2 g of the post-sieved samples were prepared and transported to Ahmadu Bello University, Zaria, Nigeria's multi-user laboratory, using the flame atomic absorption spectrophotometry (model AA24oFS) analysis.

Before the analysis, the samples were digested using the procedures adopted by Ojo *et al.* [9] and Yahaya *et al.* [15] to increase the toxic metals matrices. The process prepares 1 g of the soil samples into a conical flask and mixed with $HClO_4$:HNO_3:HF in the ratio 1:3:3. The solution was heated to 90°C for 2.5 hours, and then filtered and deionized water was added to the digests to fill up to 100 ml in the measuring cylinder. The digests were fed into the atomic absorption spectrophotometer, and the concentrations of fluoride (F), manganese (Mn), lead (Pb), zinc (Zn), cobalt (Co), molybdenum (Mo), iron (Fe), copper (Cu), chromium (Cr), calcium (Ca), and nickel (Ni) in the samples were measured. The quality assurance and control tests were conducted on the digested samples to ensure the data reliability and evaluate the scientific procedures and efficiencies of the spectrophotometer by World Health Organization [16] and as stated by Ojo *et al.* [9]. The analysis was done in triplicate, after which a standard solution and field blank samples were analysed to ensure data accuracy.

3.2. Contamination indexes

The contamination indexes showed the contaminants distributions in the soils [17], and contamination factor (Cf), potential ecological risk factor (Erf), pollution load (Pl), enrichment factor (Ef), and geo-accumulation index (Gi). The Cf showed individual toxic metal contaminations in the samples using Eq. (1).

$$Cf = \frac{\text{Conc}}{C_{\text{Ref}}}, \tag{1}$$

where Conc. is the toxins concentration, and C_{Ref} is the reference soil concentration for the metals in Nigeria soils [18]. The Cf values are classified as; $Cf > 6$: high, $3 < Cf < 6$: considerable, $1 \leq Cf < 3$: moderate, and $Cf < 1$: low.

The Pl index gives the gross assessments of the toxins in the soil samples by estimating the products of all the Cf of the considered toxic metals, as indicated in Eq. (2).

$$Pl = (Cf_{\text{Ni}} \times Cf_{\text{Pb}} \times Cf_{\text{Cd}} \times Cf_{\text{Mn}} \times Cf_{\text{Cu}} \times Cf_{\text{Fe}} \times \text{Cf}_{\text{Zn}})^{\frac{1}{9}}. \tag{2}$$

According to Shaheen *et al.* [17], Pl values are classified as: Pl≤1 (uncontaminated), Pl≤ 2 (slight), $1 < Pl \leq 2$ (moderate), and $Pl > 3$ (severely).

The Gi of the toxins were obtained using Eq. (3), according to Wang *et al.* [19].

$$Gi = \log_2 \frac{\text{Conc}}{1.5 \times C_{\text{std}}}. \tag{3}$$

The Gi are classified according to Mukhopadhyay *et al.* [20] as: extreme (>5), heavy to extreme (4-5), heavy (3-4), moderate to heavy (2-3), moderate (1-2), uncontaminated to moderate (0-1), and uncontaminated (0).

The Erf values are estimated using Eq. (4). The potential Erf revealed the individual toxins in the soil samples through their toxic responses (Tr) (Cd = Fe = 30; Cu = Ni = Pb = 5; and Zn = Mn = 1) according to Bali & Sidhu [21] :

$$Erf = Cf \times Tr. \tag{4}$$

The Erf values are classified according to Mukhopadhyay *et al.* [20] as: very high ($Erf \geq 320$); high ($160 \leq Erf < 320$); considerable ($80 \leq Erf < 160$), moderate ($40 \leq Erf < 80$), and low ($Erf < 40$).

The Ef determine the concentrations of metal in the soil compared to the amount of the metal in the Earth's crust [15], and was estimated using Eq. (5):

$$Ef = \frac{\left(\frac{\text{Conc.}}{\text{Conc.}_{\text{Mn}}}\right)}{\left(\frac{\text{Conc.Ref}}{\text{Conc.Ref}_{\text{Mn}}}\right)}. \tag{5}$$

Soils are enriched with Mn and it normalizes high toxic metals in soil to obtain more accurate values for Ef [19]. As indicated in the equation, Mn is used as the reference metal due to its abundance in the Earth crust (nature). Where Conc._{Mn} is the concentration of Mn in the samples, Conc.Ref is the referenced concentration of the considered element, and $\text{Conc.Ref}_{\text{Mn}}$ is the concentration of the the reference metal. According to Sutherland [22], metals enrichment due to anthropogenicity in soil are classified as: <1 (crustal origin), <2 (minimal), 2-5 (moderate), 5-20 (significant), 20-40 (very high), and >40 (extremely high).

3.3. Health risks assessments

Human health risk assessments could be carcinogenic and non-carcinogenic [2]. Toxic metals bioaccumulate in the soil system over time and could seep into the groundwater through the soil pores, escape into the atmosphere in the form of dust, or be picked up by plants alongside other soil nutrients. Hence, it is necessary to frequently assess potential health hazards due to human exposure to various toxic metals through body contact with dust or water, consumption of food or drinking of water, and inhalation of contaminated dust [23]. The risk assessments involve dose exposures by estimating the average daily dose (AD) of the toxins and toxicity evaluation through hazard quotients (HQ), hazard indices (HI), and cancer risks (CR) [24]. The estimations of AD (mg/kg/day) through body (dermal) contacts (AD_{der}), consumption (ingestion) (AD_{ing}), and inhalation (AD_{inh}) are shown in Eqs. (6), (7) and (8), respectively [23].

$$\text{AD}_{\text{der}} = Conc. \times \frac{EF \times AF \times ED \times SA \times ABF}{AT \times ABW} \times 10^{-6}. \tag{6}$$

$$\text{AD}_{\text{ing}} = Conc. \times \frac{IR_{\text{ing}} \times EF \times ED}{PEF \times AT \times ABW}. \tag{7}$$

$$\text{AD}_{\text{inh}} = Conc. \times \frac{IR_{\text{inh}} \times EF \times ED}{AT \times ABW} \times 10^{-6}. \tag{8}$$

The concentration of metals (Conc.) is in mg/kg; exposure frequency, EF = 350 days/yr; adherence factor, AF = 0.07 (children) and 0.2 mg/cm^2 (adults); exposure duration, ED = 6 (children) and 30 years (adults); skin's surface area, SA = 1150 (children)

Table 1: Reference dose (RfD) and cancer slope factor (CSF) for the metals [23, 29].

Parameters	Ni	Cu	Co	Mn	Zn	Cr	Fe	Pb	Mo
RfD_{ing}	0.020	0.04	0.020	0.140	0.30	0.003	0.700	0.0035	0.005
RfD_{inh}	0.0206	0	0.016	0.000014	0	0.000028	0.0002	0.0352	0
RfD_{der}	0.0054	0.04	0.0000057	3	0.30	6	2	0.00052	0.001
CSF_{ing}	0	2	1	0.0233	0	0.00006	0.002	5	9
CSF_{inh}	1.700	0.01	-	-	0.06	0.501	-	0.00850	0.002
CSF_{der}	0.840	2	-	-	0	42.000	-	0.0420	0

and 2145 cm^2 (adults); dermal absorption factor, ABF = 0.001; average time, AT = 25,550 days; average body weight, ABW = 70 (adults) and 15 kg (children); ingestion rate, IR_{ing} = 100 (children) and 200 mg/day (adults); particle emission factor, PEF = 1.36×10^9 m^3/kg; and inhalation rate, IR_{inh} = 7.5 (children) and 15 m^3/day (adult) [7, 25].

The toxicities were evaluated by the non-carcinogenic reference dose (Rfd) using the HQ (individual potential hazards), HI (total potential hazards), and carcinogenic slope factor (Csf) for toxins exposures for both adult and children through contact, inhalation, and ingestion [26]. The recommended values of RfD and Csf for the considered metals to estimate their toxicities in soils are shown in Table 1. The HQ and HI values were calculated using Eqs. (9) and (10), respectively [27]. When $HQ\ or\ HI \geq 1$, the heavy metals are significant and non-carcinogenic health risks are severe, they should be of primary concern [24].

$$HQ_{\text{der}} = \frac{\text{AD}_{\text{der}}}{\text{Rdf}_{\text{der}}}, HQ_{\text{ing}} = \frac{\text{AD}_{\text{ing}}}{\text{Rdf}_{\text{ing}}},\ HQ_{\text{inh}} = \frac{\text{AD}_{\text{inh}}}{\text{Rdf}_{\text{inh}}}. \quad (9)$$

$$HI = \sum \left(HQ_{\text{der}} + HQ_{\text{ing}} + HQ_{\text{inh}}\right). \quad (10)$$

Unlike the RfD, the CSF values are not available for all metals but only considered for the carcinogenic elements such as Ni, Cr, and Pb [28]. Rarely, elements such as Zn, Mn, Cu and Co were described as carcinogenic [30]. The estimated CR for Pb, Cr and Ni were obtained using Eq. (11).

$$\text{CR}_{\text{der}} = (\text{AD}_{\text{der}} \times \text{Csf}_{\text{der}}), \text{CR}_{\text{ing}} = \left(\text{AD}_{\text{ing}} \times \text{Csf}_{\text{ing}}\right),\ \text{CR}_{\text{inh}} = (\text{AD}_{\text{inh}} \times \text{Csf}_{\text{inh}}).$$

$$CR = \sum \left(\text{CR}_{\text{der}} + \text{CR}_{\text{ing}} + \text{CR}_{\text{inh}}\right). \quad (11)$$

According to the framework for metals risk assessment by the United States Environmental Protection Agency [31], $CR<10^{-6}$ shows no carcinogenic risks, while $CR>10^{-4}$ indicate high carcinogenic risks, and the International Commission on Radiological Protection (ICRP) recommended a safety threshold of 10^{-5} [7].

4. Results and discussion

4.1. Soil elemental background characterization

The geochemical patterns on a typical basement complex formation in Nigeria are controlled mainly by the degree of pollution, rate of mineral occurrences and weathering, and lithology [2]. The descriptive analyses for the potential toxic elements in the study and control samples were presented in Table 2.

The Ni concentrations in the soil samples ranged from 0.88-10.69 ppm with a mean value of 4.72 ppm for Dozie's farm and 0.22-1.06 ppm with a mean value of 0.80 ppm for Marcus's farm. The mean control concentrations were close to Marcus's sample concentrations. The permissible value in agricultural soils is 0.05 ppm [32], which indicates that the farm soils were polluted. Ni promotes iron absorption, treats osteoporosis, and prevents moderate anaemia in soils and drinking water [17]. Excess Ni in soils is toxic and threatens water and food security, adversely affecting the United Nations' global sustainable development goals [2, 27]. Spike in the concentrations of Ni in soils leads to high Ni in the food chain through plants, causing severe human health concerns such as reduced lung function, cancer, and allergy [33]. Nickel is deposited in soils from different natural and anthropogenic activities, and the elevated concentrations in some of the study samples could be due to excess applications of fertilizers on the farmlands. According to El-Naggar *et al.* [33] and Poznanović Spahić *et al.* [34], increasing pollution of Ni in soils has become a concern, specifically in developing nations such as Nigeria, because of its threats to global ecological sustainability and non-degradability in the environment.

The concentrations of Cu in the soil samples were relatively low and ranged between 1.07 and 4.28 ppm, with an average value of 2.94 ppm in Dozie's samples and between 0.31 and 0.71 ppm with a mean value of 0.46 ppm in Marcus's samples. The mean concentrations were low compared to the permissible value of 36 ppm, as recommended by the World Health Organization guidelines

Table 2: Descriptive analyses of the elemental concentrations in the soil samples.

Parameters	Dozie's Farmland				Marcus's Farmland				MCS
	Min.	Max.	Mean	Median	Min.	Max.	Mean	Median	
F (ppm)	18.46	535.99	151.88	90.15	28.7	790.45	263.5	115.23	21.03
Ni (ppm)	0.88	10.69	4.72	3.34	0	1.06	0.8	0.71	0.71
Cu (ppm)	1.07	4.28	2.94	3.09	0.22	0.71	0.46	0.42	0.65
Co (ppm)	0.35	5.65	2.89	2.97	0.31	0.8	0.49	0.43	0.39
Mn (ppm)	2.09	34.1	25.07	29.19	0.25	111.21	78.72	89.75	3.84
Zn (ppm)	2.99	21.1	10.37	8.74	3.46	0.98	0.74	0.73	0.87
Cr (ppm)	0.1	9	2	1.28	0.56	0.9	0.33	0.16	0.29
Fe (ppm)	204.8	264.4	231.53	229.92	0.07	200.07	164.49	181.95	120.09
Mo (ppm)	4	15.65	5.47	4.12	99.7	14.67	5.53	3.69	1.95
Pb (ppm)	2.28	3	1.71	1.92	6	1.56	0.56	0.46	0.45
Ca (ppm)	0.45	20.45	7.93	6.85	2.01	20.67	9.38	8.73	2.74

Min: Minimum, Max.: Maximum, MCS: Mean Control Sample

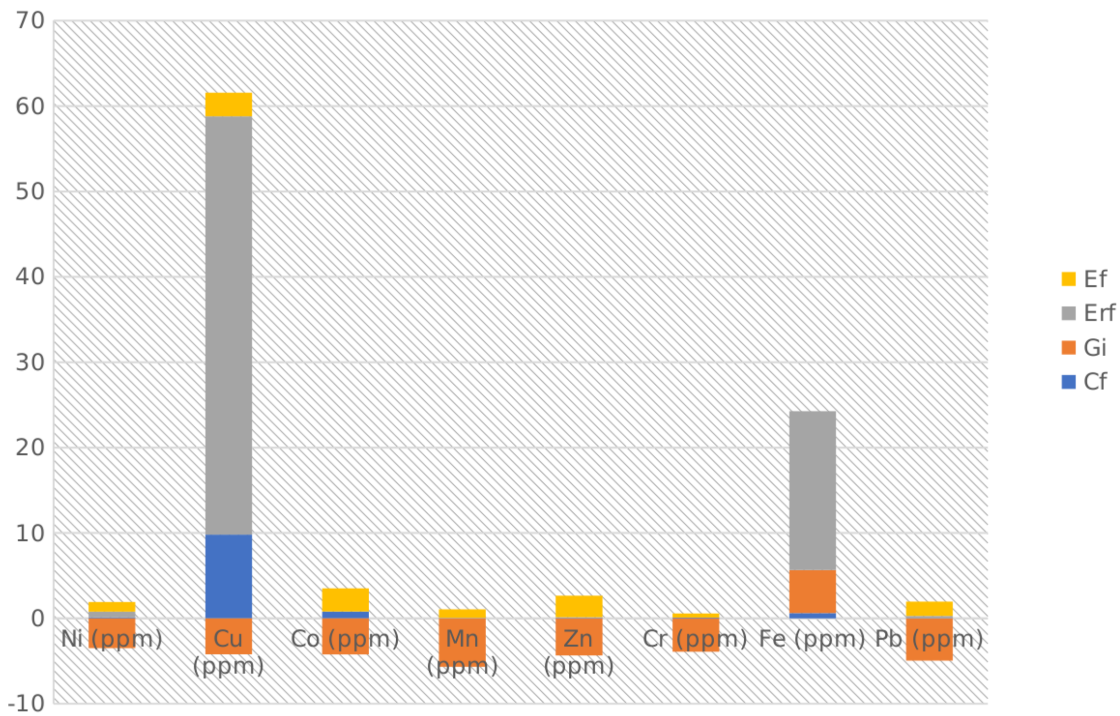

Figure 2: Contamination indices for Dozie's farm samples.

for trace elements in human nutrition and health [35]. The study of Ojo *et al.* [9] showed the same range of Cu concentrations (2.3923-4.9361 mg/kg) as this present study. Generally, Cu accumulates in agricultural soils quickly due to the massive use of Cu-containing agrochemicals such as fertilizers, miticides, nematicides, herbicides, insecticides and fungicides [36]. Also, sewage sludge or manure applications to the soil and plant disease control using Cu-containing compounds increase soil content [37]. Phosphate fertilizers contribute to high Cu concentrations in soil, and excess Cu in soil decreases the amount of phosphate available to plants [38]. High copper concentrations in soils are not chemically degraded or biologically decomposed and could lead to severe threats to human health, food security, and the environment [37]. Copper plays essential roles in human health development and metabolism, and its deficiencies in soils and eventually in the food chain and human body could lead to anaemia, low immunity, and other health effects [3]. Copper could also lead to dental caries or tooth decay when excess vegetables, fruits, soils, and water are available.

Cobalt concentrations in the study samples ranged from 0.35-5.65 ppm with a mean value of 2.89 ppm in Dozie's samples and 0.25-0.80 ppm with an average value of 0.49 ppm in Marcus's soils. The control samples had an average value of 0.39 ppm, within the same range as the study samples. The permissible values ranged from 1-10 mg/kg [39], indicating low concentrations of Co in the study soil samples. Cobalt is beneficial for the growth of plants and human beings but highly toxic in relatively high concentrations,

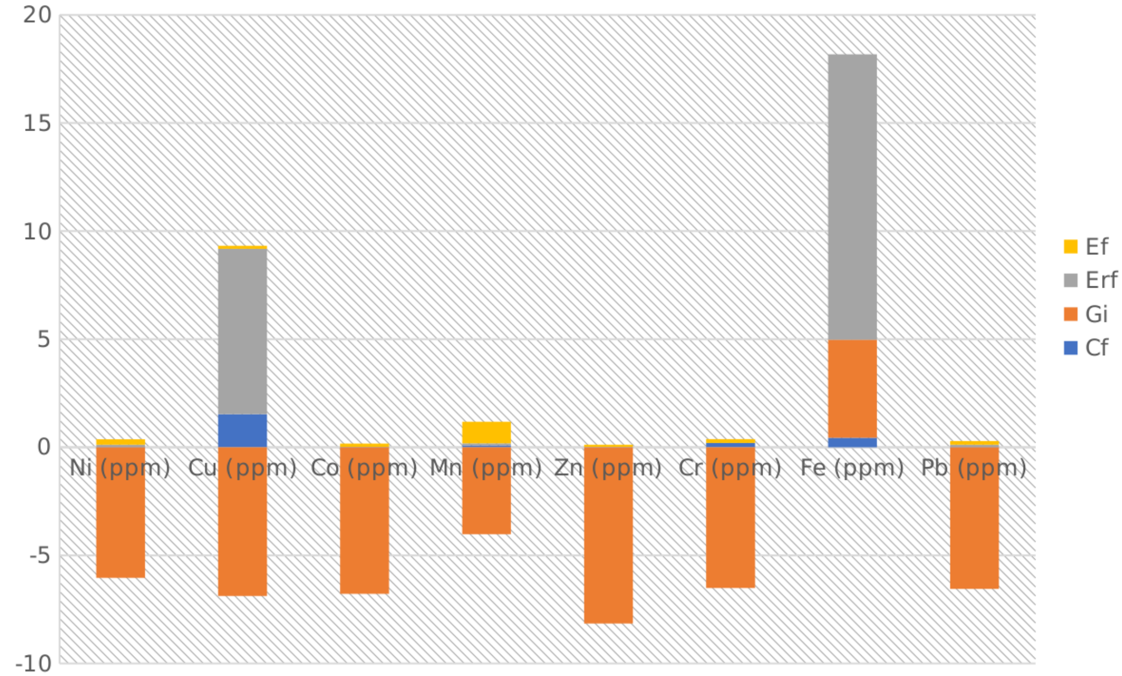

Figure 3: Contamination indices for Marcus's farm samples.

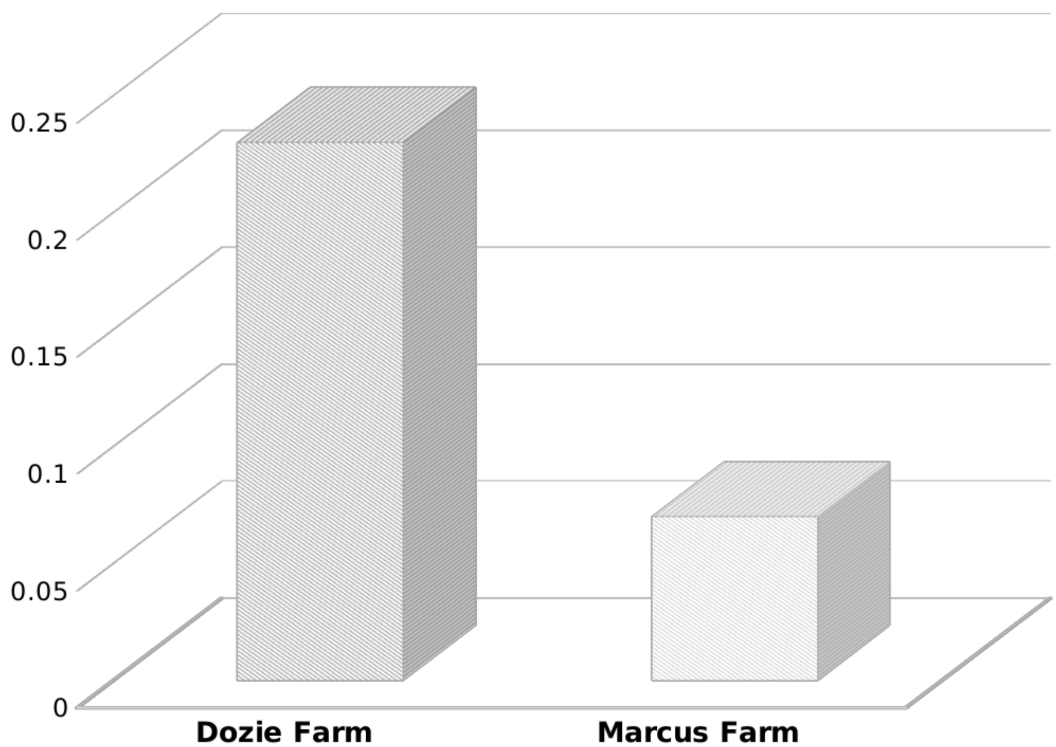

Figure 4: Pollution loads of the study samples.

leading to detrimental physiological behaviours in all plants and animals, including humans [40, 41]. A deficiency of Co could cause retarded growth in plants and illnesses such as pernicious anaemia in humans [42]. Co is not available in soil as a base element but as a component of over seventy naturally occurring metals. Co is usually associated with Ni and Cu and accumulates in soils through natural and anthropogenic sources, such as phosphate fertilizers, solid wastes, and the burning of fossils [43]. The Co impacts on food depend on the concentrations drawn from the soils, which are eventually consumed as part of human nutrition. Cobalt constitutes between 80 and 300 mg of vitamin B_{12} in animal body contents, including human beings [41].

Manganese in the samples ranged between 2.09 and 34.10 ppm, with an average value of 25.07 ppm in Dozie's soils, while the mean concentrations were between 3.46 and 111.21 ppm, with a mean value of 78.72 ppm in Marcus's samples. The mean control concentration is lower than the average values in the study samples, and Dozie's samples indicated values lower than the standard value of 100 ppm by World Health Organization [35], while some of Marcus's samples were above the allowable value. The toxicity of Mn in soils is highly dynamic. It could cause dental caries incidences, especially in male adults [6], and other human ailments such as liver problem, cardiovascular toxicity, and neurodegenerative disorder [44, 45]. Manganese is available in soils through the crustal and solid and liquid wastes such as refuse, sludges, and waste waters used in micronutrient fertilizers production [46]. Mahmud *et al.* [47] reported high concentrations of Mn in the soils of Mechaghona, Bangladesh. Also, Mn was found in higher concentrations ranging from 50.05-195.52 ppm in some agricultural soils within the Abuja metropolis, Nigeria [48].

The zinc concentrations in the samples ranged from 2.99-21.10 ppm with a mean value of 25.07 ppm for Dozie's samples and 0.56-098 ppm with a mean value of 0.74 ppm for Marcus's samples. The mean of the control samples' concentrations was low, and the study samples' concentrations were within the permissible limit of 50 ppm. Zinc is a micronutrient, and its deficiency determines the diet quality, while its availability in excess is toxic, leading to adverse effects on fauna, higher plants, and micro-organisms and, by extension causes human health challenges such as immunologic and gastrointestinal problems [49]. Zinc deficiency in humans could lead to defective immune systems, cancer, damaged DNA, infective risks, retarded growth, anaemia, and loss of appetite. Most of the time, soil polluted with Zn has high concentrations of non-essential trace metals such as Pb and Cd [50].

Leads are highly toxic in soil even at low concentrations and have no significant benefits to living beings because of their persistent toxic ability in soils and other environmental samples [2, 51] . Pb could cause biochemical, physiological, and morphological problems [52], and it is a possible human carcinogenic element. The concentration of Pb in the samples was between 0.45-3.00 ppm with an average concentration of 1.71 ppm in Dozie's samples and ranged from 0.22-1.56 ppm with a mean value of 0.56 ppm in Marcus's samples. The effects of Pb, most especially in young individuals, have led to various public health concerns and challenges [3]. Massive Pb poisoning has been over the years reported in Nigeria and Senegal's agricultural soils, which is a significant challenge being faced by many developing countries as regards soil contamination by toxic metals and adverse effects on human health [51]. According to Chiroma *et al.* [32], Pb is naturally found in soils between 50 and 400 ppm, and the recommended safe limit for agricultural soils is 0.1 ppm. The study samples were polluted, and could lead to human health challenges such as problems related to the nervous system, skeleton, brain, heart, liver, and kidney [52]. Early symptoms of Pb poisoning through contacts (dermal) or inhalation are anaemia, memory loss, dullness, and headache [53].

Chromium concentrations in Dozie's farm samples ranged from 1.10-9.00 ppm with an average value of 2.00 ppm, while Marcus's soil samples Cr concentrations ranged from 0.07-0.90 ppm with a mean concentration of 0.33 ppm. The Cr values on the soils were high and mainly above the permissible limit of 0.1 ppm for agricultural soils. Chromium harms all living organisms' health [24], and gets released into the soil and groundwater through various anthropic activities. Human beings get exposed to Cr through dermal contact, ingestion, and inhalation, and its effect on human health can be harmful and positive depending on Cr oxidation state, exposure time, and dose [54]. Ingested and inhaled Cr polluted farm produce and dust leads to pathological changes in human systems' gastrointestinal tract, skin, and respiratory tract [55]. High concentrations of Cr in soils affect plants' physiological processes [56]. Its high concentrations in soil and water potentially have developmental and neuropsychological effects on children [57]. The most common compounds of Cr in soils are CrO_4^{2-} and $HCrO_4$, and they can quickly get deposited in the soil and picked up by plants [55], which could have adverse effects on plant tissues and eventually on man health and safety. Chromium is grouped as a class A carcinogen and its high concentrations in soil could cause long-term toxicity and carcinogenicity [58]. Therefore, farmland polluted with Cr poses serious health risks to humans because of unsafe crop production.

The concentrations of Fe ranged from 204.84-264.40 ppm, with an average value of 231.53 ppm for Dozie's farmland, and for Marcus's samples, the concentrations ranged between 99.76 and 200.07 ppm with a mean value of 164.49 ppm. The control samples had a mean concentration lower than the study samples. According to Khan *et al.* [59], Fe concentrations in farmland soils within the Sargodha District, Pakistan, ranged between 10.635 and 48.638 mg/kg, lower than the values obtained in this study. Iron concentrations are the fourth most prevalent on earth, and they play essential roles in the functional and structural development of all living organisms [60]. Iron is crucial for human biological oxidation, blood, and physiological functions [61], but if available in high concentrations, it could cause diabetes, nausea, abdominal problems, hemochromatosis, and severe damage to the heart, pancreas, and liver.

Molybdenum concentrations ranged from 2.28-15.65 ppm, with an average value of 5.47 ppm for Dozie's farm samples and concentrations between 2.01 and 14.67 ppm with a mean value of 5.53 ppm for Marcus's samples. The mean control concentration was 1.95 and lower than the sample's mean concentrations. Yalçın and Çimrin [62] reported Mo contents ranging from 0.001-0.064 ppm, which were lower than the present study concentrations. Mo toxicity in agricultural soils is relatively low because Mo is not very toxic except added with sulfur to form thiomolybdate that causes physiological copper deficiency in ruminant animals if available between 10 and 20 ppm [63, 64]. Molybdenum occurs in soils and is present in various forms, such as in organic matter, in the mineral's crystal lattice, absorbed by soil colloids, and available in soil solutions [65]. Excess Mo concentration in soils is from parent rocks and anthropogenic activities.

The calcium contents in the samples were relatively high and ranged from 3.21-20.45 ppm with a mean value of 7.93 ppm for

Table 3: AD for Dozie's farm samples.

Parameter	AD_{der} (Children)	AD_{der} (Adult)	AD_{ing} (Children)	AD_{ing} (Adult)	AD_{inh} (Children)	AD_{inh} (Adult)
F	6.70×10^{-7}	3.83×10^{-7}	$6.12\times10^{-}8$	1.31×10^{-7}	6.24×10^{-6}	1.34×10^{-5}
Ni	2.08×10^{-8}	1.20×10^{-7}	1.90×10^{-9}	4.08×10^{-9}	1.94×10^{-7}	4.16×10^{-7}
Cu	1.30×10^{-9}	7.40×10^{-9}	1.17×10^{-9}	2.54×10^{-9}	1.21×10^{-7}	2.60×10^{-7}
Co	1.27×10^{-9}	7.28×10^{-9}	$1.16\times10^{9-}$	2.50×10^{-9}	1.19×10^{-7}	2.55×10^{-7}
Mn	1.11×10^{-8}	6.31×10^{-8}	1.01×10^{-8}	2.16×10^{-8}	1.03×10^{-6}	2.21×10^{-6}
Zn	5.57×10^{-9}	2.61×10^{-8}	4.18×10^{-9}	8.95×10^{-9}	4.26×10^{-7}	9.13×10^{-7}
Cr	8.82×10^{-10}	5.04×10^{-9}	8.06×10^{-10}	1.73×10^{-9}	8.22×10^{-8}	1.76×10^{-7}
Fe	1.02×10^{-7}	5.83×10^{-7}	9.32×10^{-8}	2.00×10^{-7}	9.51×10^{-6}	2.04×10^{-5}
Mo	2.41×10^{-9}	1.38×10^{-8}	2.20×10^{-9}	4.72×10^{-9}	2.24×10^{-7}	4.82×10^{-7}
Pb	7.54×10^{-10}	4.31×10^{-8}	6.89×10^{-10}	1.48×10^{-9}	7.03×10^{-8}	1.51×10^{-7}
Ca	3.50×10^{-9}	2.00×10^{-8}	3.20×10^{-9}	6.85×10^{-9}	3.26×10^{-7}	6.98×10^{-7}

Table 4: AD for Marcus's farm samples.

Parameter	AD_{der} (Children)	AD_{der} (Adult)	AD_{ing} (Children)	AD_{ing} (Adult)	AD_{inh} (Children)	AD_{inh} (Adult)
F	1.16×10^{-7}	6.64×10^{-7}	1.06×10^{-7}	2.28×10^{-7}	1.08×10^{-5}	2.32×10^{-5}
Ni	3.53×10^{-10}	2.01×10^{-9}	3.22×10^{-10}	6.91×10^{-10}	3.29×10^{-8}	7.05×10^{-8}
Cu	2.03×10^{-10}	1.16×10^{-9}	1.85×10^{-10}	3.97×10^{-10}	1.89×10^{-8}	4.05×10^{-8}
Co	2.16×10^{-10}	1.23×10^{-9}	1.97×10^{-10}	4.23×10^{-10}	2.02×10^{-8}	4.32×10^{-8}
Mn	3.47×10^{-8}	1.98×10^{-7}	3.17×10^{-8}	6.80×10^{-8}	3.24×10^{-6}	6.93×10^{-6}
Zn	3.26×10^{-10}	1.86×10^{-9}	2.98×10^{-10}	6.39×10^{-10}	3.04×10^{-8}	6.52×10^{-8}
Cr	1.46×10^{-10}	8.31×10^{-10}	1.33×10^{-10}	2.85×10^{-10}	1.36×10^{-8}	2.91×10^{-8}
Fe	7.26×10^{-8}	4.14×10^{-7}	6.63×10^{-8}	1.42×10^{-7}	6.76×10^{-6}	1.45×10^{-5}
Mo	2.44×10^{-9}	1.39×10^{-8}	2.23×10^{-9}	4.77×10^{-9}	2.27×10^{-7}	4.87×10^{-7}
Pb	2.47×10^{-10}	1.41×10^{-9}	2.26×10^{-10}	4.83×10^{-10}	2.30×10^{-8}	4.93×10^{-8}
Ca	4.14×10^{-9}	2.36×10^{-8}	3.78×10^{-9}	8.10×10^{-9}	3.85×10^{-7}	8.26×10^{-7}

Dozie's farm and 3.12-20.67 ppm with a mean concentration of 9.38 for Marcus's farm. The mean concentration of the control samples was low, indicating sample contamination. Calcium in soils depends on the weathering activities, soil pH, and nature of the parent rocks [66]. It can sometimes be deposited mainly through anthropogenicity, but its primary origin is found naturally in minerals such as antibiotics, feldspars, calcite, and dolomite, and excess availability of Ca in agricultural soils could induce K and Mg deficiencies [67]. Calcium is the fourth most abundant element in soil, and its availability in soils enhances several biological and developmental processes in plants [29].

4.2. Environmental contamination indices assessment

The contamination indices showing the individual contaminant distributions in the soil samples for Dozie's and Marcus's farmlands were presented in Figures 2 and 3, respectively. Figure 4 also shows the overall pollution indices in the samples. The Cf were low in the samples except for Cu, which had highly contaminated the soils in Dozie's farm samples and moderately contaminated the samples in Marcus's farm. Similarly, the study of Ahmad *et al.* [26] showed low to moderate contamination factors in the representative agricultural soils. The Gi is very low in all the samples except Fe, with extreme contamination in Dozie's samples and heavy to extreme contamination in Marcus's farm samples. The study samples indicated low Erf except for Cu, which moderately polluted the samples from Dozie's farm. In Dozie's samples, the Ef showed crustal origin for Cr, anthropogenic sources for Ni, Mn, Pb (minimal), and Cu, Co, and Zn (moderate).

Similarly, Marcus's farm samples indicated that Pb, Cr, Zn, Ni, Cu, and Co were from the crust, while Mn was from minimal anthropogenic sources. According to Antoniadis *et al.* [68], soil contamination indices Ef and Cf had values indicating majorly human-induced soil contamination. The overall pollution loads for Dozie and Marcus farmland were below unity, and the study samples were generally uncontaminated while considering all the metals in aggregates. The study samples were slightly contaminated with potentially toxic elements, especially Dozie's farm samples, and over time, the accumulation of the toxins in the soils could cause an increase in phyto-accumulations [2].

Table 5: HQ for Dozie's farm soil samples.

Pm	HQ_{ing} (Children)	HQ_{inh} (Children)	HQ_{der} (Children)	HI (Children)	HQ_{ing} (Adult)	HQ_{inh} (Adult)	HQ_{der} (Adult)	HI (Adult)
Ni	9.50×10^{-8}	9.42×10^{-6}	3.85×10^{-6}	1.34×10^{-5}	2.04×10^{-7}	2.02×10^{-5}	2.22×10^{-5}	4.26×10^{-5}
Cu	2.93×10^{-8}	2.88×10^{-6}	1.08×10^{-7}	3.02×10^{-6}	6.35×10^{-8}	6.19×10^{-6}	6.17×10^{-7}	6.87×10^{-6}
Co	5.80×10^{-8}	7.44×10^{-6}	2.22×10^{-4}	2.29×10^{-4}	1.25×10^{-7}	1.59×10^{-5}	1.27×10^{-3}	1.29×10^{-3}
Mn	7.21×10^{-8}	7.20×10^{-2}	4.76×10^{-7}	7.20×10^{-2}	1.54×10^{-7}	1.50×10^{-1}	2.71×10^{-6}	1.50×10^{-1}
Zn	1.39×10^{-8}	1.42×10^{-6}	9.28×10^{-8}	1.53×10^{-6}	2.98×10^{-8}	3.04×10^{-6}	4.35×10^{-7}	3.50×10^{-6}
Cr	2.69×10^{-7}	2.87×10^{-2}	1.47×10^{-5}	2.87×10^{-2}	5.77×10^{-7}	6.15×10^{-3}	8.40×10^{-5}	6.23×10^{-3}
Fe	1.33×10^{-7}	4.76×10^{-2}	5.10×10^{-5}	4.77×10^{-2}	2.86×10^{-7}	1.00×10^{-1}	2.92×10^{-4}	1.00×10^{-1}
Mo	4.40×10^{-7}	1.18×10^{-4}	1.21×10^{-6}	1.20×10^{-4}	9.44×10^{-7}	2.54×10^{-4}	6.90×10^{-6}	2.62×10^{-4}
Pb	1.97×10^{-7}	2.00×10^{-6}	1.44×10^{-6}	3.64×10^{-6}	2.98×10^{-8}	3.04×10^{-6}	4.35×10^{-7}	8.68×10^{-5}

Pm=Parameter

Table 6: HQ for Marcus's farm soil samples.

Pm	HQ_{ing} (Children)	HQ_{inh} (Children)	HQ_{der} (Children)	HI (Children)	HQ_{ing} (Adult)	HQ_{inh} (Adult)	HQ_{der} (Adult)	HI (Adult)
Ni	1.61×10^{-8}	1.60×10^{-6}	6.54×10^{-8}	1.68×10^{-6}	3.46×10^{-8}	3.42×10^{-6}	3.72×10^{-7}	3.83×10^{-6}
Cu	4.62×10^{-9}	4.50×10^{-7}	1.69×10^{-8}	4.71×10^{-7}	9.92×10^{-9}	9.64×10^{-7}	9.67×10^{-8}	1.07×10^{-6}
Co	9.85×10^{-9}	1.26×10^{-6}	3.78×10^{-5}	3.91×10^{-5}	2.12×10^{-8}	2.70×10^{-6}	2.15×10^{-4}	2.18×10^{-4}
Mn	2.26×10^{-7}	2.30×10^{-1}	1.49×10^{-6}	2.30×10^{-1}	4.86×10^{-7}	4.80×10^{-1}	8.50×10^{-6}	4.80×10^{-1}
Zn	0.99×10^{-9}	1.01×10^{-7}	5.43×10^{-9}	1.07×10^{-7}	2.13×10^{-9}	2.17×10^{-7}	3.10×10^{-8}	2.50×10^{-7}
Cr	4.43×10^{-8}	4.76×10^{-4}	2.43×10^{-5}	5.00×10^{-4}	9.50×10^{-8}	1.02×10^{-3}	1.39×10^{-5}	1.03×10^{-3}
Fe	9.47×10^{-8}	3.07×10^{-2}	3.63×10^{-5}	3.07×10^{-2}	2.03×10^{-7}	6.59×10^{-2}	2.07×10^{-4}	6.61×10^{-2}
Mo	4.46×10^{-7}	1.19×10^{-4}	1.22×10^{-6}	1.21×10^{-4}	9.54×10^{-7}	2.56×10^{-4}	6.95×10^{-6}	2.63×10^{-4}
Pb	6.46×10^{-8}	6.53×10^{-7}	4.70×10^{-7}	1.19×10^{-6}	1.38×10^{-7}	1.40×10^{-6}	2.69×10^{-6}	4.23×10^{-6}

Pm=Parameter

Table 7: CR for Dozie's farm samples.

Pm	CR_{der} (Children)	CR_{ing} (Children)	CR_{inh} (Children)	CR (Children)	CR_{der} (Adult)	CR_{ing} (Adult)	CR_{inh} (Adult)	CR (Adult)
Ni	8.84×10^{-7}	3.23×10^{-9}	1.63×10^{-7}	1.05×10^{-6}	5.10×10^{-6}	6.94×10^{-9}	3.49×10^{-7}	5.46×10^{-6}
Cr	1.76×10^{-8}	4.04×10^{-10}	3.45×10^{-6}	3.47×10^{-6}	1.01×10^{-7}	8.67×10^{-10}	7.39×10^{-6}	7.49×10^{-6}
Pb	6.41×10^{-12}	5.86×10^{-12}	2.95×10^{-9}	2.96×10^{-9}	3.66×10^{-10}	1.26×10^{-11}	6.34×10^{-9}	6.72×10^{-9}

Pm=Parameter

Table 8: CR for Marcus's farm samples.

Pm	CR_{der} (Children)	CR_{ing} (Children)	CR_{inh} (Children)	CR (Children)	CR_{der} (Adult)	CR_{ing} (Adult)	CR_{inh} (Adult)	CR (Adult)
Ni	1.50×10^{-8}	5.47×10^{-10}	2.76×10^{-8}	4.32×10^{-8}	8.54×10^{-8}	1.17×10^{-9}	5.92×10^{-8}	8.60×10^{-6}
Cr	2.92×10^{-9}	6.66×10^{-11}	5.71×10^{-7}	5.74×10^{-7}	1.66×10^{-8}	1.43×10^{-10}	1.22×10^{-6}	1.23×10^{-6}
Pb	2.10×10^{-12}	1.92×10^{-12}	9.66×10^{-10}	9.70×10^{-10}	1.20×10^{-11}	4.11×10^{-12}	2.07×10^{-9}	2.09×10^{-9}

Pm=Parameter

4.3. Potential human health risk assessments

The AD for children and adults in Dozie and Marcus farmlands based on their behavior, body metabolism and physiology, and immune systems were presented in Tables 3 and 4.

The hazard assessments in Tables 5 and 6 showed low values, less than 1 for HQ and HI. Dozie samples had relatively high HI values for Mn and Fe, and in Marcus samples, HI had a reasonably high value for Mn. These values indicated no significant non-carcinogenic health risks associated with the agricultural soil samples. In a similar study on farmland soil pollution by Zeng *et* *al.* [7], the total non-carcinogenic hazard indices were within the permissible threshold for adults and a slight risk for children.

The assessment of carcinogenic health risks for children and adults due to the presence of Ni, Cr, and Pb in the soil samples was shown in Tables 7 and 8. Rarely, Co and Cu were considered to be carcinogens [23–27, 29]. The total CR was generally low for the representative soil samples and within the acceptable range [2], indicating safety thresholds for children and adults living near the study areas. The CR for inhalation is the highest, followed by dermal, and the least was through ingestion. According to Miletic *et al.* [23], inhalation and dermal contact exposure routes for toxic metals into the human body are more dangerous compared to the direct ingestion route. Also, high values for CR_{inh} may be due to high values of Csf for the inhalation exposure route of Cr, which is about 80 times higher than Csf for ingestion. The Cr has the highest values for both children and adults, and Cr is known to be highly toxic and carcinogenic [58], and could still cause long-term adverse effects to men at low CR values.

5. Conclusion

Toxins in soils depend on the soils' characteristics and the degree of contaminants' availability. The accumulation of toxins in agricultural soils decreases the quality and productivity of crops and threatens the safety of foods, which could cause adverse human health effects. The soil samples generally had low pollution rates of Fe, Mn, Co, Zn, Ca, and Cu and moderately high concentrations of F, Ni, Pb, Cr, and Mo. The pattern of the pollutants reflected that the contaminants were majorly from anthropogenic sources, such as long-term application of fertilizers and other agrochemicals and sewage irrigation, which had polluted the study area soils. The contamination indices revealed low to moderate pollution risks to plants, animals, and humans. The non-carcinogenic and carcinogenic human health risks were within the safety limits for inhalation, dermal, and ingestion, which pose no significant risk to children and adults living in the vicinities of the study areas.

Data availability

The data are available and can be requested from the corresponding author.

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