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Levels and Health Risks of Heavy Metals in Vegetables Cultivated near Dumpsites in Gombe State, Nigeria

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ABSTRACT

The contamination of vegetables by heavy metals in Kwadon and Dadinkowa, Gombe State, Nigeria, poses significant health risks. This study quantified cadmium (Cd), nickel (Ni), arsenic (As), cobalt (Co), lead (Pb), and chromium (Cr) in the leaves, stems, and roots of *Spinacia oleracea* and corresponding soils. A microwave plasma atomic emission spectrometer was used for metal analysis, while the Bioconcentration Factor (BCF) and Translocation Factor (TF) were calculated to assess metal transfer from soil to plants. Health risks were evaluated using Estimated Daily Intake (EDI), Hazard Quotient (HQ), Hazard Index (HI), and Lifetime Cancer Risk (LCR). Results showed that As had the highest concentrations across both locations, exceeding FAO/WHO permissible limits (e.g., Kwadon roots: 1.782 mg/kg; Dadinkowa roots: 0.992 mg/kg), while other metals remained within acceptable limits. Significant differences in metal concentrations between locations were observed ($P > 0.05$). Non-carcinogenic risks (HQ and HI) for adults and children were below critical thresholds (<1), suggesting no significant health effects. Carcinogenic risks (LCR) remained within acceptable limits ($<1\times10^{-6}$).These findings underscore the need for regular monitoring and remediation strategies to ensure the safety of *Spinacia oleracea* consumed from these regions. Arsenic contamination remains a critical concern for public health.

Key Words: Bioconcentration Factor, Estimated Daily Intake, Hazard Quotient, Heavy metals, Lifetime Cancer Risk, Vegetables.

INTRODUCTION

Environmental pollution caused by heavy metals has become an urgent ecological crisis due to their persistence and non-biodegradability. Consequently, toxic metal pollution has become the focus of most researchers particularly because of its potential impact on the environment and human health [1]. Heavy metals reach the soil through a variety of pathways, such as urban, industrial effluents, and aerosols produced by the burning of fossil fuel, smelting of metals, and other anthropogenic processes. Recently, researchers have attributed soil contamination to excessive doses of manure, micro-nutrients (inorganic) fertilizers, herbicides, insecticides, tannery, mining activities, and other sources of heavy metal poisoning [1, 2].

Heavy metal contamination of soil can impact negatively on crop physiological development and agricultural yield quality and represent a significant health risk to humans through the food chain [3, 4]. According to Emurotu, and Onianwa [2], human exposure to toxic metals may be primarily linked to chain transfer from soil to crops. Applications of fertilizers, pesticides, compost manures, and polluted water used for irrigation purposes all contribute to a large extent to the rise in soil heavy metal content. Plants cultivated on toxic metal polluted soil subsequently absorb and bio-accumulate the toxic metals in large quantities and eventually compromise food quality and safety [2].

Vegetables are major part of human platter as they have high amounts of fibers, minerals, vitamins, and antioxidants. Therefore, contamination of vegetables with heavy metals cannot be ignored because of their importance in ensuring food quality. The food chain pyramid is the track by which biologically toxic trace metals accumulated in humans and other animals [5].

This study aimed to generate comprehensive data to educate the public about the ecological and health risks associated with using dumpsite soils for agriculture.

MATERIALS AND METHODS

Study Area

This study was conducted within Dadinkowa and Kwandon area of Yamaltu/Deba local Government area of Gombe state, Nigeria. Dadinkowa area is located about 37 km away from the state capital, Gombe, along Gombe-Biu road. It lies between Latitude 10^0 19' 19" N and Longitude 11^0 28' 54'' E as shown in Figure 1. Kwadon area is located about 7 km away from the state capital, along Gombe-Biu road. It lies between Latitude 10^0 16' 15'' N and Longitude 11^0 17' 2" E as shown in Figure 1.

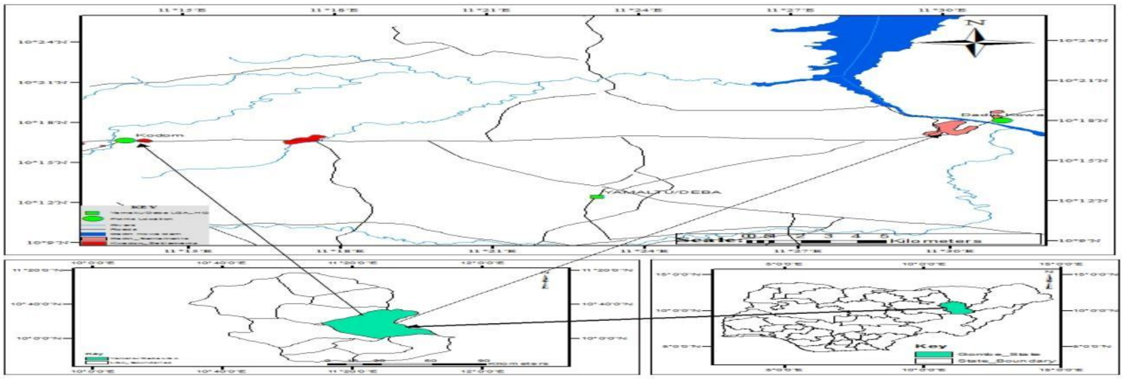

Figure 1: Map of the study area

Sample Collection and Preparation

The vegetable samples of spinach (*Spinacia oleracea*) were randomly collected 100 m away from the dumpsites during the month of June, stored in labelled ziploc polythene bags and transported to the laboratory from areas of known dumpsites in Kwadon and Dadinkowa. The *Spinacia oleracea* samples were washed thoroughly under clean tap water followed by distilled water to remove soil and air-born pollutants. Samples (leaves, stems and roots) were cut into small pieces, air dried at room temperature. The dried samples were ground and passed through a sieve of 2 mm size, stored in labelled ziploc bags and kept at room temperature for further analysis.

Soil samples were also collected simultaneously from the same sampling points as the *Spinacia oleracea* samples from the same dumpsites. Soil samples of about 1 kg were collected from topsoil at a depth of 0-15 cm and 15-20 cm, using soil auger and stored in labelled ziploc polythene bags. These bags were then transported to the laboratory. Approximately 20 g was taken from each sample, air dried at room temperature, crushed and sieved using 2 mm mesh and finally stored in clean polythene bags which were used for the analysis.

Digestion of Vegetable and Soil samples for Heavy Metals Analysis

The samples were prepared as programmed by the equipment; briefly: 200 mg of solid samples and 50 mL for liquid samples were weighed and transferred into 90 ml microwave digestion vessels. Approximately 10 mL mixture of 15.9 N trace metal grade Nitric acid, hydrogen peroxide and perchloric acid (7:2:1) were added to each vessel. After standing for one hour, the samples were processed by microwave digestion system as follows: ramp temperature from ambient to 200 °C over 20 min, then hold at 200 °C for 20 min, after digesting. They were cooled to approximately 50 °C or lower before handling. The digest was transferred to 50 ml volumetric flask. The solution volume was adjusted to 50 ml with deionized water and filtered for instrumental analysis.

Heavy Metals Analysis

A microwave plasma-atomic emission spectrometer (Agilent 4210 MP-AES), was used for the analysis of cadmium, nickel, arsenic, cobalt, lead and chromium concentrations in both the *Spinacia oleracea* and soil samples. Results were reported in mg/kg dry weight of sample.

Statistical Analysis

The concentration of heavy metals in the *Spinacia oleracea* and soil samples were analyzed using descriptive statistics such as mean, standard deviation using Microsoft Excel 2013 version. The mean concentration of the heavy metals in *Spinacia oleracea* and soil samples were compared to the standard criteria for heavy metal contamination in vegetables and soil established by FAO/WHO standards. Two-way analysis of variance (ANOVA) was used in this study to determine the significant variation of the heavy metals concentration in the *Spinacia oleracea* (leaves, stems and roots) between the two locations at ($P<0.05$).

Bioconcentration Factor of the Heavy Metals

BCF of heavy metals from soils to vegetables was assessed by computing the ratio of the concentration of each heavy metal in vegetable's edible parts and the concentration of corresponding heavy metals in the respective soil. If BCF is less than 1, it suggests less movement of heavy metals from soil to vegetables. Conversely, BCF of more than one indicate the higher uptake of heavy metals by tested vegetable from soil [6].

It was assessed by following Equation 1.

$$BCF = C_{vegetable}/C_{soil} \quad (1)$$

$C_{vegetable}$ is the concentration of heavy metals contained in the vegetable (roots, stems or leaves) (mg/kg), and C_{soil} is the concentration of heavy metals in the soil (mg/kg) [7]. If the BCF value less than one or equal to one, it shows the plant can only absorb but not accumulate heavy metals. If BCF is more than one, it indicates that the plant can absorb and accumulate metals [8].

Translocation factor

The transfer of metals between the roots and the leaves of vegetable can be estimated by the translocation factor (TF) [9] Translocation factor from the roots to the leaves was assessed using Equation 2.

$$TF = C_{vegetable}/C_{root} \quad (2)$$

C_{leaves} is the concentration of heavy metals contained in the leaves of the vegetable (mg/kg), and C_{root} is the concentration of heavy metals in the roots (mg/kg) [10]. High TF value indicates high mobilization of metal elements from roots to the leaves.

Health Risk Assessment

Human health risk assessment involves the estimation of the probability of adverse health effects in humans who are exposed to metals in contaminated environments. Generally, the health risk assessment process comprises four main components: identification, exposure assessment, toxicity assessment (dose-response) and risk calculation [11]. Based on the assessment of risk level, it can be categorized into carcinogenic and non-carcinogenic risks [12]. Carcinogenic risk assessment is a method of estimating the incremental probability of developing cancer over an individual's lifetime due to exposure to a potential carcinogenic metal [13].

Exposure Assessment

Estimated daily intake (EDI) was used to estimate human exposure to heavy metals through direct ingestion according to equation 3 adopted from USEPA methods [14]. Estimations were made for two groups: children (as a sensitive group) and adults (as the general population).

$$EDI = C \times IR \times EF \times ED / BW \times AT \quad (3)$$

Where EDI (mg/kg/day) is the estimated daily dose intake through ingestion, C is the concentration of metal (mg/kg) in the food, IR is the ingestion rate (kg/day), EF is the Exposure frequency, ED is the exposure duration, BW (kg) is the Standard body weight and AT is the time duration of human exposure. The parameters for calculating the estimated daily intake are presented in Table 1 adopted from USEPA [14].

Table 1: Parameters for assessment of Estimated Daily Intake (EDI).

PARAMETERS	VALUES
Ingestion Rate (IR)	0.0002 kg/day for children and 0.0001 kg/day for adults
Exposure Frequency (EF)	365 days/year
Exposure Duration (ED)	6years for children and 24 years for adults
Body Weight (BW)	70 kg for adults and 15 kg for children
Average Time (AT)	365 ×ED

Source: USEPA [14]

Non-carcinogenic Risk

Non-carcinogenic health risk involves estimating the likelihood that a given amount of a substance will have adverse health effects over a specified time period. Non-carcinogenic health risk was conducted using Hazard quotient and Hazard index.

Hazard Quotient

The HQ was calculated according to Equation 4. A hazard quotient is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected USEPA [14]. The individual reference dose (RD) for the various heavy metals are presented in table 2 adopted from USEPA [15].

$$HQ = EDI/RfD \quad (4).$$

Table 2: Reference dose and Cancer slope factor (CSF) of the heavy metals

HEAVY METALS	REF DOSE (RD) (mg/kg/day)	CANCER SLOPE FACTOR (CSF) (mg/kg/day)
Cd	0.001	0.0061
Ni	0.02	0.00084
As	0.0003	3.66
Co	0.02	0.01
Pb	0.04	0.0085
Cr	1.5	0.041

Source: USEPA Reference dose and CSF values [15]

Hazard Index

Hazard Index technique was used to evaluate the overall potential for non-carcinogenic health risk posed by many contaminants USEPA [14]. The hazard index for a mixture of pollutants is determined using equation 5 USEPA, [14]:

$$HI = \Sigma HQ \tag{5}$$

If the HI value is less than one, the exposed population is unlikely to experience obvious adverse health effects. If the HI value exceeds one, then adverse health effects may occur USEPA [14].

Carcinogenic Risk Assessment

Carcinogenic risks are estimated by calculating the probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. The carcinogenic health risk is calculated using a cancer slope factor as shown in equation 6. The cancer slope factor is an estimate of the probability that an individual will develop cancer if exposed to a chemical substance for a lifetime of 70 years.

$$LCR = EDI \times CSF \tag{6}$$

Where, LCR is the lifetime cancer risk and CSF is the cancer slope factor (mg/kg/day). LCR above 1×10^{-4} is viewed as unacceptable, risks below 1×10^{-6} are not considered to have significant health effects, and risk lying between 1×10^{-4} and 1×10^{-6} is considered an acceptable range [15]. The individual cancer slope factors as adopted from the USEPA [15] are presented in Table 2.

RESULTS AND DISCUSSION

Heavy Metals Concentration in the Vegetable

The concentrations of heavy metals in *Spinacia oleracea* (leaves, stems and roots) cultivated at the Kwadon and Dadinkowa study areas are presented in Figure 2 and 3 respectively. The analysis showed significant variations in heavy metal concentrations across the *Spinacia oleracea* samples from both locations. In Kwadon, the mean concentrations of heavy metals in the leaves followed the order: As (0.888 mg/kg) > Cr (0.170 mg/kg) > Ni (0.055 mg/kg) > Pb (0.034 mg/kg) > Co (0.028 mg/kg) > Cd (0.004 mg/kg). Similarly, in Dadinkowa, the order was: As (0.928 mg/kg) > Cr (0.166 mg/kg) > Ni (0.027 mg/kg) > Pb (0.022 mg/kg) > Co (0.018 mg/kg) > Cd (0.003 mg/kg). Notably, Arsenic recorded the highest concentrations in both locations, with values of 0.888 mg/kg in Kwadon and 0.928 mg/kg in Dadinkowa.

The mean concentrations of heavy metals in the stems followed the order: As (1.232 mg/kg) > Cr (0.098 mg/kg) > Ni (0.059 mg/kg) > Co (0.034 mg/kg) > Pb (0.032 mg/kg) > Cd (0.005 mg/kg) in Kwadon, and As (0.718 mg/kg) > Cr (0.18 mg/kg) > Ni (0.066 mg/kg) > Pb (0.020 mg/kg) > Co (0.010 mg/kg) > Cd (0.005 mg/kg) in Dadinkowa. Arsenic (As) exhibited the highest concentration, with levels of 1.232 mg/kg in Kwadon and 0.718 mg/kg in Dadinkowa.

The mean concentrations of heavy metals in the roots followed the order: As (1.782 mg/kg) > Ni (0.582 mg/kg) > Pb (0.314 mg/kg) > Cr (0.190 mg/kg) > Co (0.126 mg/kg) > Cd (0.014 mg/kg) in Kwadon and As (0.992 mg/kg) > Cr (0.178 mg/kg) > Pb (0.110 mg/kg) > Ni (0.099 mg/kg) > Co (0.050 mg/kg) > Cd (0.003 mg/kg) in Dadinkowa. Arsenic recorded the highest concentrations in both locations, with 1.782 mg/kg in Kwadon and 0.992 mg/kg in Dadinkowa, Additionally, cobalt and in Kwadon (0.126 mg/kg) slightly exceeded the FAO/WHO permissible limit of 0.1 mg/kg.

Arsenic levels significantly exceed the FAO/WHO permissible limit of 0.2 mg/kg [16] in all the *Spinacia oleracea* parts in both locations but arsenic values in this study align with the values reported by Sulaiman et al [17], who observed As concentrations ranging from 0.94 to 1.67 mg/kg in the roots of some vegetables grown from Jengka area in Malaysia. These high arsenic levels is raising serious concerns about the potential health risks posed by consuming *Spinacia oleracea* grown in these areas. The concentrations of chromium, nickel, lead, cobalt, and cadmium observed in this study were all within permissible limits, indicating relatively low contamination for these metals in both locations.

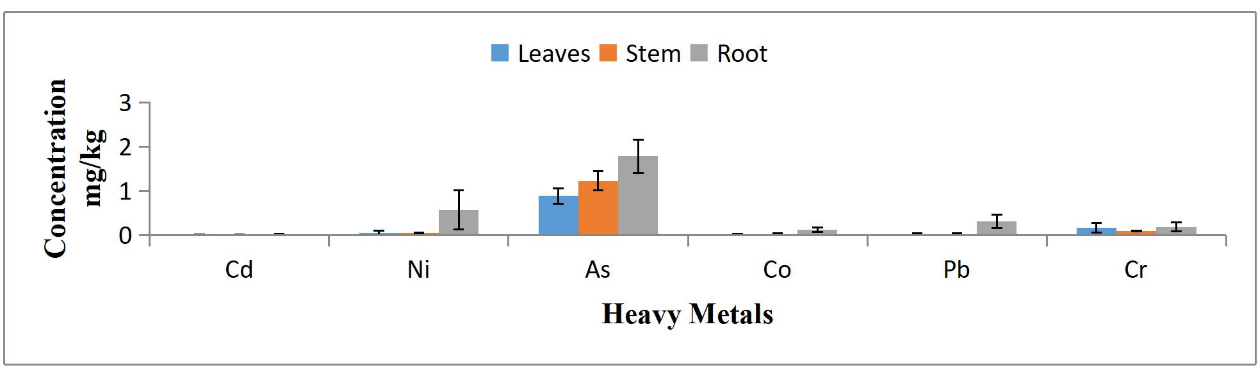

Figure 1: Heavy metals concentrations of *Spinacia oleracea* samples in Kwadon

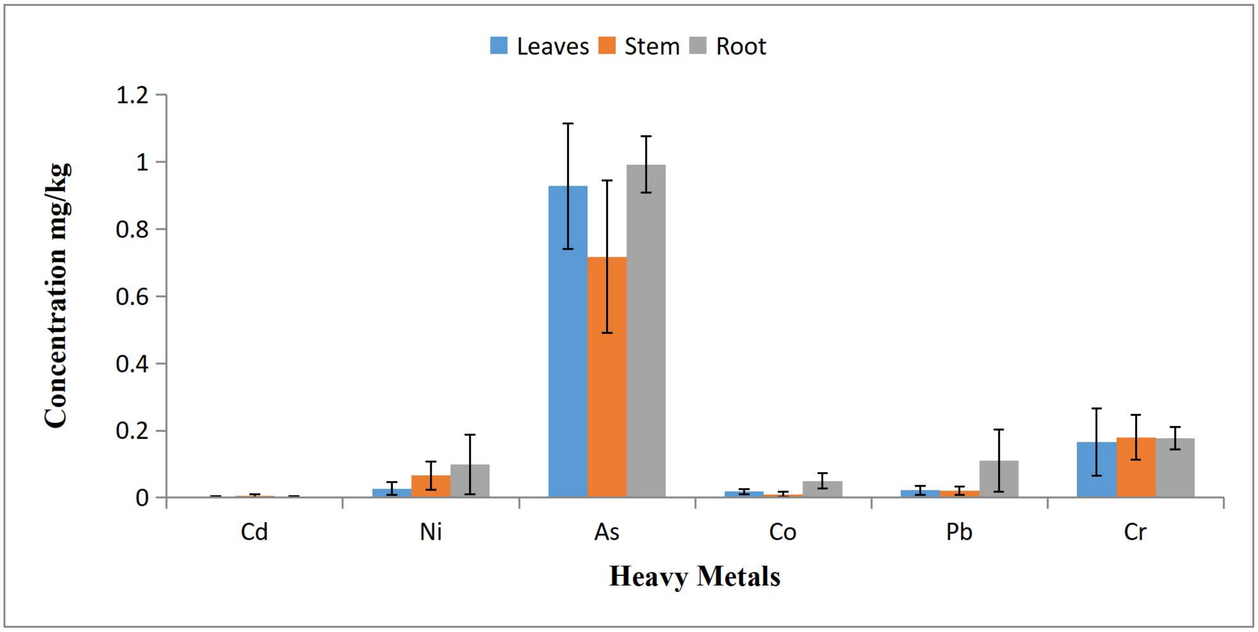

Figure 2: Heavy metals concentrations of *Spinacia oleracea* samples in Dadinkowa

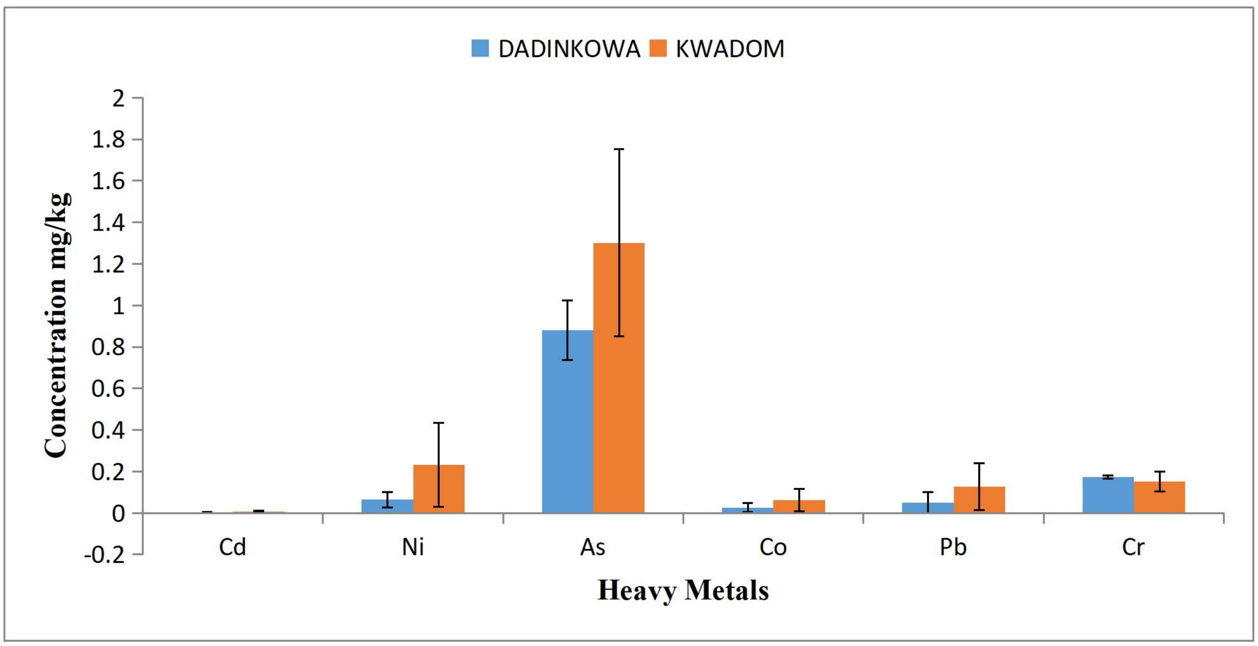

Figure 3: Heavy metals concentrations of *Spinacia oleracea* samples between both locations

The analysis of heavy metal concentrations in soil samples from the Kwadon site is presented in Figure 5, revealed significant variability. The mean concentrations were as follows: As at 1.548 mg/kg, Ni at 0.467 mg/kg, Cr at 0.208 mg/kg, Pb at 0.155 mg/kg, Co at 0.118 mg/kg, and Cd at 0.007 mg/kg. Similarly, the Dadinkowa site results, shown in Figure 6, demonstrated noticeable variation as well. The mean concentrations were: As at 1.339 mg/kg, Ni at 0.469 mg/kg, Cr at 0.224 mg/kg, Pb at 0.155 mg/kg, Co at 0.130 mg/kg, and Cd at 0.006 mg/kg. Importantly, all the heavy metal concentrations in both sites fall within the FAO/WHO permissible limits. At the Kwadon dumpsite, the mean concentrations at a depth of 0-15 cm were: Cd at 0.0086 mg/kg, Ni at 0.5398 mg/kg, As at 1.534 mg/kg, Co at 0.142 mg/kg, Pb at 0.184 mg/kg, and Cr at 0.21 mg/kg. At a depth of 15-20 cm, these values were slightly lower for most metals. In the Dadinkowa site, the mean concentrations at 0-15 cm were: Cd at 0.0068 mg/kg, Ni at 0.501 mg/kg, As at 1.556 mg/kg, Co at 0.148 mg/kg, Pb at 0.126 mg/kg, and Cr at 0.262 mg/kg, with similar trends observed at 15-20 cm. Nickel concentrations ranged from 0.03932 to 0.5398 mg/kg, which aligns with previous studies but remains below critical thresholds. Cobalt levels were consistent with other research, while lead concentrations were comparable to findings from prior studies. Cadmium levels were notably low, ranging from 0.0056 to 0.0086 mg/kg, which is below the concentrations reported by Zakari et al [17]. Chromium values also remained within safe limits, yet were significantly lower than higher values reported in other studies. Overall, while the concentrations of cadmium, nickel, arsenic, cobalt, lead, and chromium in the soil samples from both study areas fell within the stipulated permissible limits.

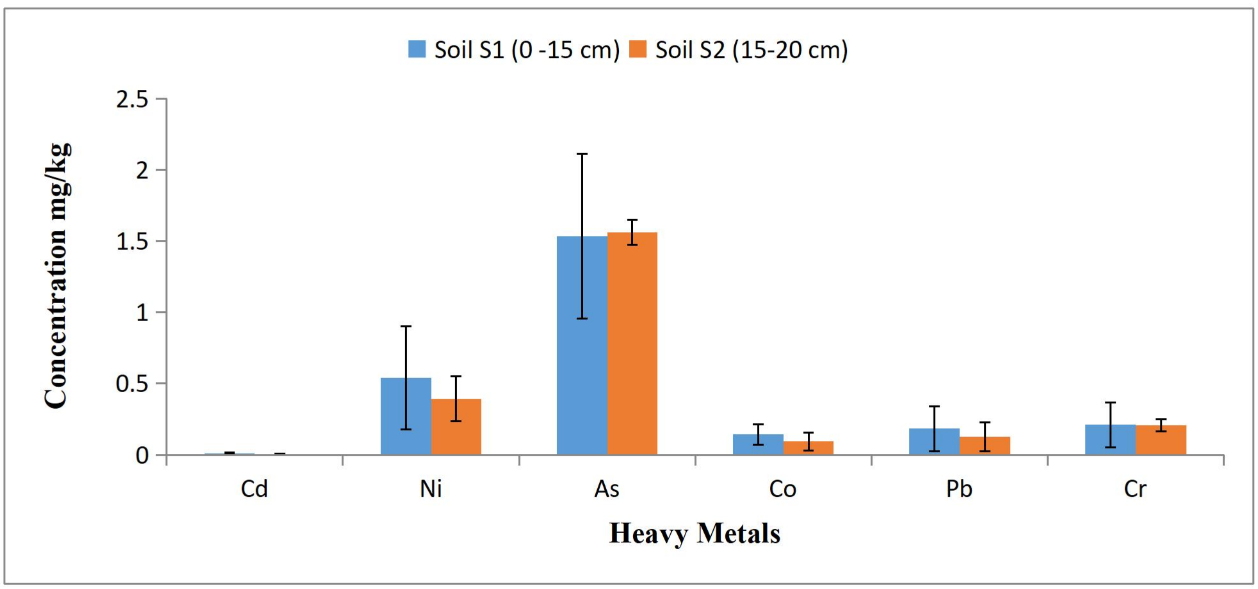

Figure 4: Heavy metals concentration of soil samples in Kwadon

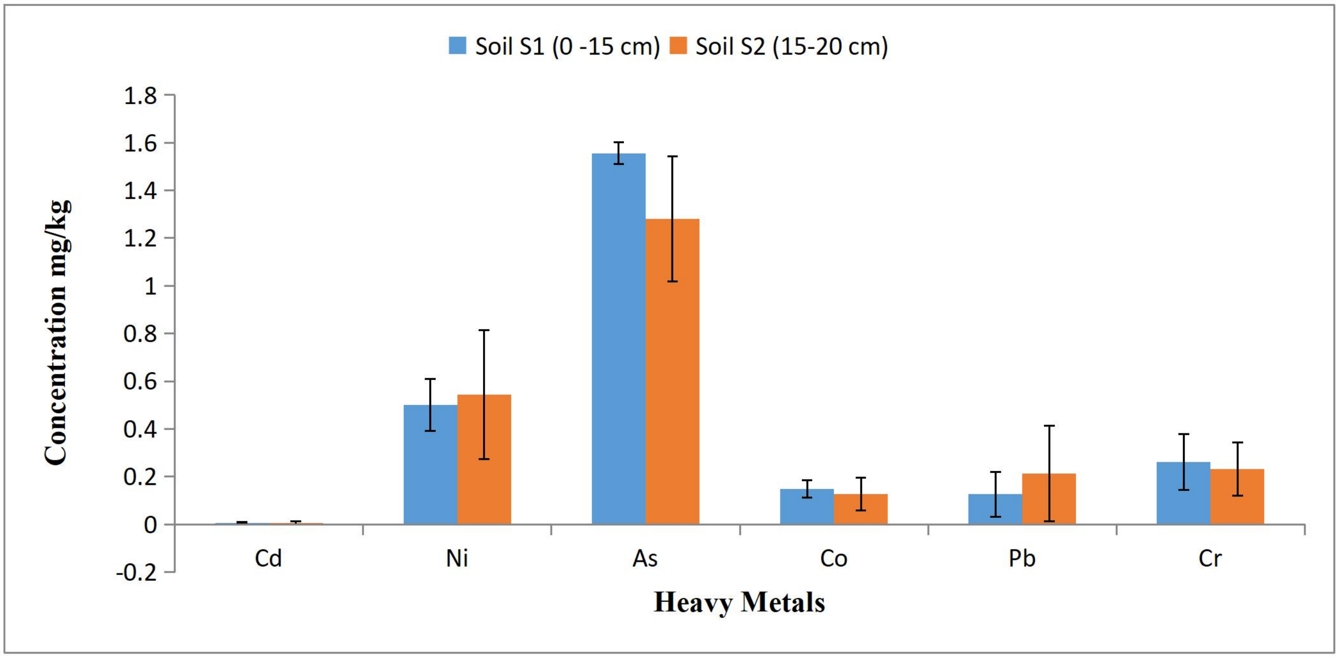

Figure 5: Heavy metals concentration of soil samples in Dadinkowa

Statistical Analysis

Two-way ANOVA was conducted to determine significant difference of the heavy metals concentration in the *Spinacia oleracea* (leaves, stems and roots) in the two locations separately and as well compared between the two locations at ($P<0.05$). The results of the analysis indicated there is a significant difference in the concentration of heavy metals in the *Spinacia oleracea* (leaves, stems and roots) in both locations with P-value=0.0001 < 0.05 for Kwadon and P-value=0.0155 < 0.05 for Dadinkowa. Comparing the two locations, the result showed that there is also significant difference in the concentration of the heavy metals in the *Spinacia oleracea* (leaves, stems and roots) at P-value = 0.000000257 < 0.05.

Bioconcentration Factor in Kwadon and Dadinkowa

The Bioconcentration Factor in the leaves of *Spinacia oleracea* from the Kwadon study area showed the following order: Cr (0.817), As (0.574), Cd (0.535), Co (0.237), Pb (0.219) and Ni (0.118) (Table 3). All BCF values were less than 1, indicating that while heavy metals are absorbed by the leaves, they are not accumulated [8]. In the stems from Kwadon, the BCF values were in the order: As (0.796), Cd (0.676), Cr (0.471), Co (0.288), Pb (0.206) and Ni (0.128) (Table 3). Similarly, all metals had BCF < 1, suggesting absorption without accumulation. The roots of the *Spinacia oleracea* in Kwadon displayed higher BCF values compared to the stems and leaves, with the order as follows: Pb (2.026), Cd (1.944), Ni (1.247), As (1.151), Co (1.068) and Cr (0.913) (Table 3). Here, all heavy metals except for Cr had BCF > 1, indicating both absorption and accumulation, with Pb showing the highest accumulation. In the Dadinkowa study area, the BCF in the leaves was ranked as: Cr (0.741), As (0.693), Cd (0.484), Pb (0.142), Co (0.138) and Ni (0.058) (Table 4). Also, all values were below 1, signifying absorption without accumulation. For the stems in Dadinkowa, the BCF order was: Cd (34.839), Cr (4.018), As (2.681), Ni (0.702), Pb (0.645) and Co (0.385) (Table 4). Here, Cd, Cr and As exhibited BCF > 1, indicating they were both absorbed and accumulated, while Ni, Pb and Co were only absorbed. The BCF in the roots of *Spinacia oleracea* from Dadinkowa was found in the order: Cr (0.795), As (0.741), Pb (0.709), Cd (0.452), Co (0.385), and Ni (0.212) (Table 4). All heavy metals in the roots had BCF < 1, indicating that they were absorbed but not accumulated.

Consequently, the study shows that in Kwadon, heavy metals in the leaves and stems of *Spinacia oleracea* are absorbed without accumulation, while in the roots, most metals accumulate, particularly lead and cadmium. In Dadinkowa, the leaves also exhibit absorption without accumulation, while the stems show significant accumulation of cadmium, chromium, and arsenic. However, the roots in Dadinkowa do not accumulate heavy metals. This pattern highlights the varying capacities of different plant parts to absorb and accumulate heavy metals, which is critical for understanding potential health risks associated with consuming these vegetable.

Translocation Factor in Kwadon and Dadinkowa

The Translocation Factor indicates the mobility of heavy metals from the roots to the leaves of *Spinacia oleracea*. In the Kwadon study area, the TF values were as follows: Cr (0.895), As (0.498), Cd (0.275), Co (0.222), Pb (0.108) and Ni (0.095) (see Table 3). This suggests that chromium is the most mobile heavy metal, as it has the highest BCF in the leaves (Table 3). In the Dadinkowa study area, the TF values from roots to leaves were ranked as follows: Cd (1.071), As (0.935), Cr (0.933), Co (0.360), Ni (0.276) and Pb (0.200) (see Table 4). This indicates that cadmium is easily transported from the roots to the stems, as reflected by its highest BCF in the stems. Notably, while chromium shows high mobility, it recorded the highest BCF in the leaves. However, these results highlight the varying mobility of heavy metals within different parts of *Spinacia oleracea* in both study areas.

Table 3: Bioconcentration Factor and the Translocation Factor of *Spinacia oleracea* in Kwadon Study Area

VEGETABLE PARTS	MEAN CONCENTRATION (mg/kg) OF HEAVY METALS					
	Cd	Ni	As	Co	Pb	Cr
KWD_L	0.0038	0.0552	0.888	0.028	0.034	0.17
KWD_M	0.0048	0.0598	1.232	0.034	0.032	0.098
KWD_R	0.0138	0.5818	1.782	0.126	0.314	0.19
KWD_S	0.0071	0.4665	1.548	0.118	0.155	0.208
BCF_L	0.535211	0.118328	0.573643	0.237288	0.219355	0.817308
BCF_M	0.676056	0.128189	0.795866	0.288136	0.206452	0.471154
BCF_R	1.943662	1.24716	1.151163	1.067797	2.025806	0.913462
TF	0.275362	0.094878	0.498316	0.222222	0.10828	0.894737

Table 4: Bioconcentration Factor and the Translocation Factor of *Spinacia oleracea* in Dadinkowa Study Area

VEGETABLE PART	MEAN CONCENTRATION (mg/kg) OF HEAVY METALS					
	Cd	Ni	As	Co	Pb	Cr
DAD_L	0.003	0.0274	0.928	0.018	0.022	0.166
DAD_M	0.216	0.329	3.59	0.05	0.1	0.9
DAD_R	0.0028	0.0992	0.992	0.05	0.11	0.178
DAD_S	0.0062	0.4685	1.339	0.13	0.155	0.224
BCF_L	0.483871	0.058485	0.693055	0.138462	0.141935	0.741071
BCF_M	34.83871	0.702241	2.681105	0.384615	0.645161	4.017857
BCF_R	0.451613	0.21174	0.740851	0.384615	0.709677	0.794643
TF	1.071429	0.27621	0.935484	0.36	0.2	0.932584

Health Risks Assessment

Estimated Daily Intake

The Estimated Daily Intake is an essential metric for evaluating health risks associated with heavy metals in vegetables. It assesses the non-carcinogenic risks related to these metals and represents the calculated daily intake of a specific heavy metal over an extended period, expressed in mg/kg/day for the Kwadon and Dadinkowa locations (Tables 5 and 6).

Table 5 shows health risks assessment from consumption of *Spinacia oleracea* in Kwadon, while Table 6 shows health risks assessment from consumption of *Spinacia oleracea* in Dadinkowa.

Table 5:Health risks assessment from consumption of *Spinacia oleracea* in Kwadon,

VEGETABLE PART	PARAMETERS	HEAVY METALS					
LEAVES		Cd	Ni	As	Co	Pb	Cr
		ADULT					
	EDI	1.50794E-11	2.1905E-10	3.52381E-09	1.1111E-10	1.34921E-10	6.74603E-10
	HQ	1.50794E-08	1.0952E-08	1.1746E-05	5.5556E-09	3.37302E-09	4.49735E-10
	HI	1.17814E-05	1.17814E-05	1.17814E-05	1.17814E-05	1.17814E-05	1.17814E-05
	LCR	9.19841E-14	1.84E-13	1.28971E-08	1.1111E-12	1.14683E-12	2.76587E-11
		CHILDREN					
	EDI	1.38813E-10	2.01644E-09	3.244E-08	1.02283E-09	1.24201E-09	6.21005E-09
	HQ	1.38813E-07	1.00822E-07	0.0001081	5.11416E-08	3.10502E-08	4.14003E-09
	HI	0.0001085	0.0001085	0.0001085	0.0001085	0.0001085	0.0001085
	LCR	8.46758E-13	1.69381E-12	1.187E-07	1.02283E-11	1.05571E-11	2.54612E-10
STEM		ADULT					
	EDI	1.90476E-11	2.37302E-10	4.88889E-09	1.34921E-10	1.26984E-10	3.88889E-10
	HQ	1.90476E-08	1.18651E-08	1.62963E-05	6.74603E-09	3.1746E-09	2.59259E-10
	HI	1.63374E-05	1.63374E-05	1.63374E-05	1.63374E-05	1.63374E-05	1.63374E-05
	LCR	1.1619E-13	1.99333E-13	1.78933E-08	1.34921E-12	1.07937E-12	1.59444E-11
		CHILDREN					
	EDI	1.75342E-10	2.18447E-09	4.5E-08	1.242E-09	1.16895E-09	3.57991E-09
	HQ	1.75342E-07	1.09224E-07	0.00015	6.21E-08	2.92237E-08	2.38661E-09
	HI	0.0001504	0.0001504	0.0001504	0.0001504	0.0001504	0.0001504
	LCR	1.06959E-12	1.83496E-12	1.647E-07	1.242E-11	9.93607E-12	1.46776E-10
ROOT		ADULT					
	EDI	5.47619E-11	2.30873E-09	7.07143E-09	5E-10	1.24603E-09	7.53968E-10
	HQ	5.47619E-08	1.15437E-07	2.35714E-05	0.000000025	3.11508E-08	5.02646E-10
	HI	2.37983E-05	2.37983E-05	2.37983E-05	2.37983E-05	2.37983E-05	2.37983E-05
	LCR	3.34048E-13	1.93933E-12	2.58814E-08	5E-12	1.05913E-11	3.09127E-11
		CHILDREN					

EDI	5.0411E-10	2.1253E-08	6.51E-08	4.60274E-09	1.14703E-08	6.94064E-09
HQ	5.0411E-07	1.06265E-06	0.000217	2.30137E-07	2.86758E-07	4.62709E-09
HI	0.0002191	0.0002191	0.0002191	0.0002191	0.0002191	0.0002191
LCR	3.07507E-12	1.78525E-11	2.383E-07	4.60274E-11	9.74977E-11	2.84566E-10

Table 6: Health risks assessment from consumption of *Spinacia oleracea* in Dadinkowa.

VEGETABLE PART	PARAMETERS	HEAVY METALS					
LEAVES		Cd	Ni	As	Co	Pb	Cr
				ADULT			
	EDI	1.19048E-11	1.0873E-10	3.68254E-09	7.14286E-11	8.73016E-11	6.5873E-10
	HQ	1.19048E-08	5.43651E-09	1.22751E-05	3.57143E-09	2.18254E-09	4.39153E-10
	HI	1.22987E-05	1.22987E-05	1.22987E-05	1.22987E-05	1.22987E-05	1.22987E-05
	LCR	7.2619E-14	9.13333E-14	1.34781E-08	7.14286E-13	7.42063E-13	2.70079E-11
				CHILDREN			
	EDI	1.09589E-10	1.00091E-09	3.39E-08	6.57534E-10	8.03653E-10	6.06393E-09
	HQ	1.09589E-07	5.00457E-08	0.000113	3.28767E-08	2.00913E-08	4.04262E-09
	HI	0.0001132	0.0001132	0.0001132	0.0001132	0.0001132	0.0001132
	LCR	6.68493E-13	8.40767E-13	1.241E-07	6.57534E-12	6.83105E-12	2.48621E-10
STEM				ADULT			
	EDI	2.06349E-11	2.61111E-10	2.84921E-09	3.96825E-11	7.93651E-11	7.14286E-10
	HQ	2.06349E-08	1.30556E-08	9.49735E-06	1.98413E-09	1.98413E-09	4.7619E-10
	HI	9.53549E-06	9.53549E-06	9.53549E-06	9.53549E-06	9.53549E-06	9.53549E-06
	LCR	1.25873E-13	2.19333E-13	1.04281E-08	3.96825E-13	6.74603E-13	2.92857E-11
				CHILDREN			
	EDI	1.89954E-10	2.40365E-09	2.6228E-08	3.65297E-10	7.30594E-10	6.57534E-09
	HQ	1.89954E-07	1.20183E-07	8.7428E-05	1.82648E-08	1.82648E-08	4.38356E-09
	HI	8.77788E-05	8.77788E-05	8.77788E-05	8.77788E-05	8.77788E-05	8.77788E-05
	LCR	1.15872E-12	2.01907E-12	9.5996E-08	3.65297E-12	6.21005E-12	2.69589E-10
ROOT				ADULT			
	EDI	1.11111E-11	3.93651E-10	3.93651E-09	1.98413E-10	4.36508E-10	7.06349E-10
	HQ	1.11111E-08	1.96825E-08	1.31217E-05	9.92063E-09	1.09127E-08	4.70899E-10
	HI	1.31738E-05	1.31738E-05	1.31738E-05	1.31738E-05	1.31738E-05	1.31738E-05
	LCR	6.77778E-14	3.30667E-13	1.44076E-08	1.98413E-12	3.71032E-12	2.89603E-11
				CHILDREN			
	EDI	1.02283E-10	3.62374E-09	3.624E-08	1.82648E-09	4.01826E-09	6.50228E-09
	HQ	1.02283E-07	1.81187E-07	0.0001208	9.13242E-08	1.00457E-07	4.33486E-09
	HI	0.0001213	0.0001213	0.0001213	0.0001213	0.0001213	0.0001213
	LCR	6.23927E-13	3.04395E-12	1.326E-07	1.82648E-11	3.41553E-11	2.66594E-10

In Kwadon, the EDI for heavy metals from leaf consumption for both adults and children ranked as follows: As > Cr > Ni > Pb > Co > Cd. For stem consumption, the order remained the same: As > Cr > Ni > Co > Pb > Cd. From root consumption, the rankings were: As > Cr > Ni > Pb > Co > Cd for adults, and As > Ni > Pb > Cr > Co > Cd for children. In Dadinkowa, the EDI for leaf consumption also followed the same order for both adults and children: As > Cr > Ni > Pb > Co > Cd. For stem consumption, the order remained consistent: As > Cr > Ni > Pb > Co > Cd. However, for root consumption, the order was: As > Cr > Pb > Ni > Co > Cd for both adults and children. Consequently, the EDI values for both adults and children in both locations were below the recommended daily intake limits for all analyzed heavy metals, indicating a low risk of adverse health effects from *Spinacia oleracea* consumption.

Non-carcinogenic Health Risks

To assess non-carcinogenic health risks associated with *Spinacia oleracea* consumption in the Kwadon and Dadinkowa study areas, Hazard Quotient and Hazard Index values were calculated, as presented in Tables 5 and 6. In the Kwadon study area, the HQ values for *Spinacia oleracea* leaves ranged from 4.49735E-10 to 1.1746E-05 for adults and from 4.14003E-09 to 0.0001081 for children. For the stems, HQ values ranged from 2.59259E-10 to 1.62963E-05 for adults and from 2.38661E-09 to 0.00015 for children. In the roots, HQ values ranged from 5.02646E-10 to 2.35714E-05 for adults and from 4.62709E-09 to 0.000217 for children. The HI values for leaves, stems, and roots were 1.17814E-05, 1.63374E-05 and 2.37983E-05 for adults, respectively, and 0.0001085, 0.0001504, and 0.0002191 for children. All HQ and HI values were below one, indicating no health risks associated with consuming *Spinacia oleracea* from the Kwadon area. In the Dadinkowa study area, HQ values for *Spinacia oleracea* leaves ranged from 1.19048E-11 to 3.68254E-09 for adults and from 4.04262E-09 to 0.000113 for children. For stems, HQ values ranged from 4.7619E-10 to 9.49735E-06 for adults and from 4.38356E-09 to 8.7428E-05 for children. In the roots, HQ values ranged from 4.70899E-10 to 1.31217E-05 for adults and from 4.33486E-09 to 0.0001208 for children. The HI values for leaves, stems, and roots were 1.22987E-05, 9.53549E-06 and 1.31738E-05 for adults, respectively, and 0.0001132, 8.77788E-05 and 0.0001213 for children. Also, all HQ and HI values were less than one, indicating no adverse health effects associated with consuming *Spinacia oleracea* grown in the Dadinkowa area [14].

Lifetime Cancer Risk

The Lifetime Cancer Risk associated with heavy metals from *Spinacia oleracea* consumption in the Kwadon and Dadinkowa study areas is presented in Tables 5 and 6. For both adults and children in these locations, the LCR values for all analyzed metals were below the acceptable limit of one, indicating that the risk of cancer from *Spinacia oleracea* consumption does not exceed safe threshold.

CONCLUSION

The study demonstrated that heavy metal such as arsenic was present in higher concentrations in *Spinacia oleracea*, the EDI values for both adults and children were below recommended limits. The HQ and HI calculations indicated no significant non-carcinogenic health risks from *Spinacia oleracea* consumption in both study areas. Furthermore, the LCR assessments showed that the risk levels for heavy metals remained within acceptable limits. However, the findings suggest that continuous monitoring is essential due to the potential for long-term exposure and the cumulative effects of heavy metals. The assessment of heavy metal concentrations in the *Spinacia oleracea* and soil samples from the Kwadon and Dadinkowa study areas reveals critical insights into potential health risks associated with agricultural practices in these regions. Elevated levels of certain heavy metals, particularly arsenic, were identified in both the soil and the *Spinacia oleracea* samples, raising concerns about their implications for human health, especially for vulnerable populations such as children. The BCF analysis indicated varying levels of absorption and accumulation of metals across different *Spinacia oleracea* parts, highlighting the potential for dietary exposure to toxic elements.

Recommendations

Regular Monitoring: Implement a routine monitoring program for soil and vegetables heavy metal concentrations to ensure ongoing safety and compliance with health standards.

Public Awareness: Educate local communities about the risks associated with heavy metal consumption and safe agricultural practices to minimize exposure.

Soil Remediation: Encourage the use of soil remediation techniques to reduce heavy metal concentrations in contaminated areas, including phytoremediation and soil amendments.

Alternative Irrigation Sources: Promote the use of safe irrigation sources to avoid contamination from polluted water, particularly for crops grown near industrial or urban areas.

Research and Policy: Support further research into the long-term effects of heavy metal exposure and develop policies that enforce stricter regulations on agricultural practices to protect public health.

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