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Assessment of public health risk of heavy metals from contaminated water, soil and edible vegetables in selected areas of nasarawa state, Nigeria

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Abstract

This study assessed the public health risk of heavy metals from contaminated water, soil and edible vegetables in selected industrialized area of Lafia, Nasarawa State, North Central Nigeria. A total of ten (10) contaminated water, edible vegetables and soil samples were collected within different proximate locations of human anthropogenic activities in Lafia Local Government and analysed for the presence of heavy metals using standard methods. Four (4) varieties of edible vegetables namely: *Telfairia occidentalis, Amaranthus hybridus, Talinun Triangulare* and *Corchorus* sp. were investigated for the presence of heavy metals and soil-vegetable transfer coefficients. One hundred and twelve (112) human inhabitants living within the sampling locations were selected using simple random sampling technique and assessed for health risk employing the Inductively Coupled Plasma-Atomic Emission Spectrometry Instrument (ICP–AES) with axial viewing configuration. Seven (7) heavy metals were detected in all samples analysed. Among such includes Cd, Cu, Zn, Mn, Pb, Fe and Ni. The mean contamination degree was highest for Fe (106.02) and lowest for Pb (0.05). The Pollution Load Index of soil was >1 while those of water and edible vegetables were less than 1. The mean risk index of heavy metals on the environment was in the order: soil (77.11)> edible vegetables (69.67)> water (66.39). Exposure concentration of the heavy metals on the study population for soil (mg/kg) is in the range of 0.73–98.90 ppm while that of water (mg/ml) is between 1.00–233.31ppm. Conversely, estimated daily intake showed varying results for the vegetables between the ranges of 0.001–0.034mg/kg. The hazard index was highest for Fe (4.298) and lowest for Pb (0.418) and this followed the order: Fe> Zn> Cu> Ni> Mn> Cd> Pb. The soil-vegetable transfer coefficients showed an efficacy of 1.99 for *T. occidentalis*, 1.52 for *A. hybridus*, 1.25 for *Corchorus* sp. and 1.01 for *T. triangulare*. From the data obtained from this study, it was observed that no matter how low levels of heavy metals are present in environmental samples particularly in vegetables, their presence pose health risk and is thus not desirable. The presence of cadmium, copper and lead in the edible vegetables analysed is a cause for alarm and denote serious public health risk to consumers of this food. Therefore, there is need for regular scrutiny soil, irrigating water, and foodstuff for heavy metals so as to avoid extreme accrual in the food chain which may eventually elude human health risks. Consequently, this study encourages environmentalists, administrators, and public health workers to create public awareness to avoid the consumption of vegetables grown in contaminated soils, hence reducing health risks.

Keywords: public health, heavy metals, water, soil, edible vegetables, Nasarawa State, Nigeria

Introduction

Heavy metals refer to metals with a specific gravity greater than five (5). They are toxic and accumulate within organisms in the natural environment (Enuneku *et al.*, 2018) [12]. They are ubiquitous in the environment and due to rapid urbanization and industrialization worldwide, it is anticipated that heavy metals are being continuously introduced into the environment from a variety of sources such as discharge of domestic sewage, industrial wastewater, discharge of urban and industrial solid wastes, exhaust pipes of motor cars, generators and chimneys, usage of agrochemicals and atmospheric deposition (Fosu-Mensah *et al.*, 2018) [15]. In the aquatic environment for instance, heavy metals can be discharged via several routes including effluent/waste discharge, run-offs, leachates, shipping activities, and atmospheric depositions, especially from industrial and urban areas (Maanan, 2008; Enuneku *et al.*, 2018) [35, 12]. Environmental pollution due to heavy metals has harmful effects on both plants and animals (Förstner and Wittmann, 2012) [14]. Heavy metals pollution in soil and water has a lot of adverse effects and thus is of great concern to public health and agricultural production. The soil pollution is mainly due to disposal of industrial and urban wastes as well as usage of agrochemicals, while water pollution is primarily caused by industrial wastes, sewage disposal, petroleum contamination, and agricultural drainage water (Singh *et al.*, 2010) [45]. Many growing developing countries are vulnerable to air pollution due to the fact that heavy metals containing aerosols are normally deposited on soil surface and get absorbed by vegetables or sometimes get deposited on plant leaves (Sharma *et al.*, 2006) [44]. The uptake of heavy metals by the plants from the soil depends on different factors, including application of agrochemicals, solubility of heavy metals, soil pH, soil type, and plant species (Gupta *et al.*, 2013; Kacholi and Sahu, 2018) [16, 27].

In addition to causing environmental damage, heavy metals in soil, air, and other media in mining-affected areas enter plants by absorption through the vegetable roots and dust on leaves (Li *et al.*, 2017). Meanwhile, ingestion of heavy metals can upset the body chemistry, especially because these metals do not undergo decomposition within the body and have a high affinity for many body systems (Duruibe *et al.*, 2007) [10]. Increasing evidence indicates that oral exposure is the most important way for heavy metals in the environment to enter the body; contaminated soil can result in heavy metal translocation into the food chain, and high consumption of contaminated vegetables can pose a serious risk to the human body (Hough *et al.*, 2004; Yeganeh *et al.*, 2012) [20, 56]. Interestingly, several studies such as those of Li *et al.* (2013), Ha *et al.* (2014) and Huang *et al.* (2016) [21] of the accumulation and origin of heavy metals in soil and the potential ecological hazards associated with this process have revealed an increasing trend. Recently, some intensive research has attracted attention to the effects of heavy metals on human health, especially in infants and children (Krishna and Mohan, 2016; Izhar *et al.*, 2016) [32, 24]. Humans generally are exposed to toxic heavy metals in the environment through different routes including ingestion, inhalation, and dermal absorption. People are more exposed to toxic metals in developing countries (Kpan *et al.*, 2014) [31]. Generally, people have poor awareness and knowledge about exposure to heavy metals and its consequences for human health, especially in the developing countries. People may be exposed to heavy metals in the work place and in the environment (Noli and Tsamos, 2016) [40]. Human exposure to toxic chemicals in the work place is called occupational exposure while exposure to such chemicals in the general environment is called non-occupational or environmental exposure. Workers are exposed to heavy metals in mining and industrial operations where they may inhale dust and particulate matter-containing metal particles. People extracting gold through the amalgamation process are exposed to mercury (Hg) vapours (Ali *et al.,* 2019).

Also, it has been reported that welders with occupational prolonged exposure to welding fumes had significantly higher levels of the heavy metals chromium (Cr), nickel (Ni), cadmium (Cd), and lead (Pb) in blood than the control and showed increased oxidative stress (Mahmood *et al.*, 2015) [36]. Cigarette smoking is also a principal source of human exposure to Cd and other toxic heavy metals present in the tobacco leaves (Järup, 2003) [25]. On the other hand, heavy metals may enter the body of an organism directly from the abiotic environment, i.e., water, sediments, and soil or may enter the organism body from its food/prey. Ali *et al.* (2019) reports further that heavy metals are strong neurotoxins in fish species. The interaction of heavy metals with chemical stimuli in fish may interrupt the communication of fish with their environment. Among many toxic elements, lead, arsenic, and cadmium are considered to be potential carcinogens and are associated with the development of several diseases, especially cardiovascular, kidney, nervous system, blood, and bone diseases (Järup, 2003) [25]. Although copper is an essential element for humans, a high concentration in soil and vegetables leads to human toxicity (Yang *et al.*, 2018) [55]. Acute exposure to heavy metals in the environment is a real threat to living organisms (Wieczorek-Dabrowska *et al.*, 2013) [54]. For instance, high zinc content may cause growth and reproduction impairment; while lead toxicity causes dysfunction of kidney, reproductive, cardiovascular systems, joints problems, lessening in haemoglobin formation, and enduring impairment to the central and peripheral nervous systems (Tasrina *et al.*, 2015) [49].

The study area (Nasarawa State) is nicknamed “The Home of Solid Minerals”, and mining activities at both local and industrial scale is pervasive. Yang and colleagues (2018) [55] in their research on heavy metal contamination of soils and vegetables in China noted that the smelting process in metal mines can produce large amounts of waste, resulting in high accumulation of heavy metals in the soil and in the river and underground water surrounding the mining area. This connotes public health risk considering the role of the environment in the transmission of diseases within a population and the fact that most of these heavy metals are carcinogenic. Consequently, this present study sought to assess the public health risk of heavy metals in contaminated water, soil and edible vegetables in some selected industrialized areas of Nasarawa State, North-Central Nigeria. It is plausible to add that monitoring and analysis of heavy metal concentrations in the physical environment are imperative for pollution assessment and control. Hence, data obtained from this present research will assist government and other relevant agencies to take appropriate remediation approach that will protect the health of the inhabitants of the study areas in particular and the wellbeing of the environment in general.

Research Methodology

Research Settings

Nasarawa state comprises of different categories of solid minerals and the state had 13 Local Government Areas which are subdivided into three senatorial districts: southern senatorial, northern senatorial and western senatorial districts. The southern zone consists of five LGA which are Awe, Doma, Lafia, Keana, and Obi while the Northern senatorial zone consist of only three; they are Akwanga, Nassarawa Eggon, and Wamba while the western zone complete the remaining five, viz Karu, Keffi, Kokona, Nassarawa, and Toto respectively. The most dominant tribes include Hausa/Fulani, Eggon, Alago, Afo and Gwandara (Akwa *et al.,* 2007) [4]. This study was conducted in Lafia Local Government Area of Nasarawa State. Lafia is 27.137.8^2 km in size, it is the capital of Nasarawa State. Nasarawa state is bounded in the North by Kaduna State, in the West by Abuja, the capital city of Nigeria, in the South by Kogi and Benue States and in the East by Taraba and Plateau States (NAGIS. 2015) [38]. Located in the savannah region, the lands in Lafia is characterized by a low swampy plain, rugged hill of granite and sandstone, volcanic plugs and plateaus developed on sedimentary and volcanic rock.

Sample Size Determination and Sampling Techniques

Four (4) political wards, two (2) each from urban and rural areas of Lafia were assessed. Twenty eight (28) people were recruited at random per ward making a total of one hundred and twelve (112). Thus 112 questionnaires were distributed to the study candidates in order to identify the probable route of exposure and the impact of heavy metal contamination of the environment on their health and general wellbeing. Due to large size of the target population, the researcher used the Taro Yamani formula to arrive at the sample population of the study.

$$n = \frac{N}{1+N\,(e)^2}$$

Where:

N is the approximate population of inhabitants in proximity to the sampling sites.
1 is the constant (in this case, the constant was represented by the number of wards assessed which is 4)
e is the degree of error expected
n is the sample size

$$n = \frac{120}{4+120(0.05)^2}$$
$$\frac{120}{4+120(0.0025)}$$
$$\frac{120}{4+0.36}$$
$$\frac{120}{4.36}$$
$$n = 27.5$$
$$n = 28$$

Sampling Sites

The sampling sites were selected based on their proximity to areas of anthropogenic activities and human settlement. Such activities include mining, agro-allied, pharmaceutical, small scale farming, animal rearing, fishing activities, rock breaking, clothes washing and swimming.

Fig 1: Map of Nasarawa State Showing the Study Area

Sample Collection and Processing

Soil Sample

A total of ten (10) topsoil sites were sampled. The method of Huang *et al.* (2019) [22] was used for collection of soil sample. At each sample site, four subsamples were collected from an approximately 16m^2 grid and thoroughly mixed to achieve a total composite soil sample weight of about one-kilogram. The soil samples were then sealed in plastic bags and air-dried at room temperature (20–25°C) for further analysis. After which the samples were filtered through a 2mm and a 2µm polyethylene sieve in sequence, plant roots and shredded rocks were removed from the soil sample to prepare for chemical analysis.

Water Sample

The technique of Vongdala *et al.* (2019) [52] was adopted for collection of water samples. A total of ten (10) samples from surface water in landfill wetlands, from an average water depth of 1–1.5m were collected each from four different areas within the two wards in Lafia from upstream to downstream. Good quality samples were randomly taken from each of the sampling site, and another two subsamples were obtained accordingly. The samples were later stored in 1-L polyethylene bottles and subsequently adjusted by HNO_3 to obtain pH<2. The values of pH, temperature (◦C), electrical conductivity (EC), and dissolved oxygen (DO) were measured using a U-50 Multiparameter Water Quality Meter within the sampling sites. Furthermore, two groundwater samples were collected from wells inside and in the vicinity of mining area, farm land which agrochemicals had been used on, and wetlands where animals are reared.

Edible Vegetables

A total of 4 (four) different edible vegetable samples were collected in two ponds within the sampling sites at Lafia. The samples were collected in both wet and dry seasons. The roots, stems, and leaves of the plants obtained were separated and stored in zipped polyethylene bags. Thereafter, the samples were washed thoroughly with tap water and rinsed with distilled water for 1 minute to clear them of periphyton and detritus as recommended by Gworek *et al.* (2016). The vegetation samples were then dried at 40°C for 2 days in an oven until a consistent weight is maintained, after which the samples were grounded into a fine powder by a mortar and stored in the dark at 5°C for further analysis as described by Vongdala *et al*. (2019) [52].

Chemical Analyses of Heavy Metals

Analysis of Water Samples

The surface and groundwater samples were filtered by filter papers to obtain a 100-mL solution, to which 1 mL of HNO_3 (65%) was added and then heated for 2 hours without boiling at 80–90°C. The samples were then cooled to room temperature and then filtered again with 0.2-µm syringe filters as demonstrated by (Kar *et al.*, 2008) [29]. The water samples were then analyzed using a multitype Inductively Coupled Plasma Emission Spectrometer (ICP-ES) and ICPE-9000.

Analysis of Soil Samples

The method of Vongdala *et al.* (2019) [52] was used for heavy metals determination in the soil samples. Briefly, five (5) grams of soil was added to 20mL of HNO_3 (7 mol/L), stirred for 1 hour, and then placed in an autoclave at 120°C for 30 min. The mixtures were then cooled to room temperature, filtered by filter papers, and diluted by deionized water. The samples were then filtered again by a 0.2-µm syringe filter and transferred to tubes for analyses by ICPE-9000.

Analysis of Edible Vegetable Samples

Heavy metal determination of roots, stems, and leaves of edible plant samples was conducted by initially drying and grounding these plants parts into powder form. Thereafter, 0.5g of each sample was added to 6mL of concentrated HNO_3 (65%) and 2mL of concentrated HCl (30%) and allowed to stand until the reaction is completed. The mixture was then moved to an autoclave for 66 minutes at 132°C for digestion as described by Andersen and Kisser (2004) [6]. The plant samples were further analyzed by ICPE-900.

Ecological Risk Assessment of Heavy Metals

Pollution Load Index (PLI)

Pollution load index (PLI) represents the number of times by which the metal content in the sample exceeds the background concentration. It provides comprehensive information about the metal toxicity in a particular sample (Yang *et al*., 2011) [55]. The pollution load index (PLI) is defined as the nth root of the multiplications of the concentrations; i.e., the square roots of the calculated pollution index. The PLI value of >1 indicates polluted, whereas <1 indicates no pollution (Barakat *et al*., 2012) [8]. PLI was evaluated using the following formula proposed by Tomilson *et al*. (1980) [50].

$$\mathbf{PLI = (CF_1 \times CF_2 \times CF_3 \cdots \times CF_n)^{1/n}}$$

Where n is the number of metals identified and CF is the contamination factor. The contamination factor can be calculated from the following relation:

$$\mathbf{CF = \frac{Metal\ concentration\ in\ sample}{Background\ value\ of\ metal}}$$

According to Håkanson (1980) [19], CF <1 indicates low degree of contamination, 1< CF <3 indicates moderate degree of contamination, 3< CF < 6 indicates considerable degree of contamination, and CF > 6 indicates very high degree of contamination.

Contamination Degree (CD)

This parameter refers to the sum of all contamination factors. It gives an indication of the degree of overall contamination in sediments from a sampling site. It expressed as:

$$\mathbf{CD = \sum_{i=1}^{n} CF.}$$

Håkanson (1980) [19] proposed the classification Cd <6 is low degree of contamination, 6 ≤ Cd < 12 is indicative of moderate degree of contamination, 12 ≤ Cd < 24 indicates considerable degree of contamination, and Cd ≥ 24 represents very high degree of contamination.

Potential Ecological Risk Index (RI)

The potential ecological risk could be used to evaluate the ecological risk of heavy metals in sediments by considering the toxicity of the metal and a comparison between the concentration of the metal and the background value. RI was used in this study to quantify the potential ecological hazard of contaminated samples. Håkanson (1980) [19] provides a formula to estimate RI.
Firstly,

$$\mathbf{E^i_r = T^i_r \times CF,}$$

Where T^i_r *is the toxic response factor for a given substance and CF is the contamination factor.*
The toxic response factor assigned to the following heavy metals Co, Cd, Cu, Zn, Mn, Pb, and Ni to be used in the calculation of potential ecological risk index (RI) are 5, 30, 5, 1, 1, 5, and 5, respectively as previously adopted by Jiao *et al*. (2015) [29] and Soliman *et al*. (2015) [48].

Soil-Plant Transfer Coefficient (%)

The soil-transfer coefficient was calculated as ratio of a heavy metal in a plant (dry weight) to a total heavy metal concentration in the soil as shown in the following equation as demonstrated by Kacholi and Sahu (2018) [27]:

$$\mathbf{TC} = \frac{C\mathrm{plant}}{C\mathrm{soil}} \times 100$$

TC is transfer coefficient (%), Cplant is heavy metal concentration in vegetable tissue (mg/100g), and Csoil is metal concentration in soil (mg/100g dry soil).

Human Health Risk Assessment of Heavy Metals

Exposure Assessment

Exposure to toxic heavy metals could also be of significant concern to humans living close to contaminated environment. In this present study, three primary pathways of exposure to heavy metals when dealing with human health risk assessment were considered. They are ingestion, dermal contact, and inhalation. The exposures through ingestion, inhalation, and dermal contact were calculated respectively using equations proposed by Enuneku *et al*. (2018) [12]:

1. $$\mathbf{EXP\ (ingestion) = \frac{C \times IRs \times ED \times EF}{BW \times AT}}$$
2. $$\mathbf{EXP\ (dermal) = \frac{C \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}}$$
3. $$\mathbf{EXP\ (inhalation) = \frac{C \times IR(inh) \times EF \times ED}{PEF \times BW \times AT}}$$

Where C is the concentration of heavy metals in the samples, IRs is the ingestion rate (114mg/day); CF is the unit conversion factor (10−6kg/mg); EF is the exposure frequency (350days/year); ED is the exposure duration (30years); BW is the body weight (70kg); SA is the exposed skin surface area (5700 cm^2); AF is the adherence factor from sediment to skin (0.07mg/cm2); and ABS is the dermal absorption from sediment (0.001) (unitless); SL is the skin adherence factor (0.2 mg cm^{-2} h^{-1}) for children and (0.2 mg cm^{-2} h^{-1})for adults; PEF is the particle emission factor (1.316 × 10−9m^3 kg^{-1}); AT is the average time. For non-carcinogens, it is ED × 365days. For carcinogens, it is 70 × 365 = 25,550days.
Similarly, dietary intake of contaminated food has been implicated as a primary source of human exposure to toxic chemicals including heavy metals. The exposure through ingestion of contaminated edible plants (vegetables) was calculated using equation below:

$$\mathbf{EXP\ (diet) = \frac{C \times IR\ (biota) \times ED \times EF}{BW \times AT}}$$

Where C is the concentration per mass of the medium (ppm), IR is the ingestion rate of the medium (g/day), ED is the exposure duration (years), EF is the exposure frequency (days/year), BW is the body weight (kg) and AT is the average time (years).

Public Health Risk Characterization

Assessment of Hazards to Human Health

The potential non-cancer risk of heavy metal concentrations in the sampling sites was characterized using a hazard quotient (HQ). Hazard quotient (HQ) assumes that there is a level of exposure known as the reference dose (RfD). It is estimated that a daily oral intake of the heavy metal at the reference dose will pose no reasonable risk even to sensitive populations, over a 70-year lifetime (Afrifa *et al.*, 2013) [1]. USEPA (2010), defines hazard quotient (HQ) as the ratio of the average daily intake or dose (ADD) (mg/ (kg/day)) to the reference dose (RfD, mg/ (kg/day)). It was estimated using the formula:

$$\mathbf{HQ} = \frac{\mathbf{EXP}}{\mathbf{RfD}}$$

Where HQ = hazard quotient (unitless), ADD = average daily dose (mg/kg−day), RfD = Reference dose (mg/kg−day). For n number of heavy metals, the non-carcinogenic effect to the population is as a result of the summation of all the HQs due to individual heavy metals.

$HI = HQ_1 + HQ_2 \cdots + HQ_n$

If the HI is less than 1.0, it is highly unlikely that significant additive or toxic interactions would occur, so no further evaluation is necessary. When the HI exceeds 1.0, there may be a concern for potential non-cancer health effect.

Statistical Analysis

Data obtained from this study were analysed using the Statistical Package for Social Sciences (SPSS) IBM version 22 software. Both descriptive and inferential statistical analysis were carried out and used thereafter to describe the data obtained in the study. One-way Analysis of Variance (ANOVA) was conducted to test differences among measured parameters with respect to sampling locations. Statistical significance was set at $P \leq 0.05$.

Ethical Issues

Ethical clearance and authorization for the study was sought from the Lafia Local Government Health Department, while permission to assess sampling sites was obtained from the owners of the mining sites, the farmers in case of farmlands and other people undertaking any anthropogenic activities within any of the sampling sites. Likewise an informed consent was obtained from the participants that volunteered to participate in the study and the screening was done at no cost whatsoever to them. All information obtained from this study was handled confidently.

Results

Assessment of heavy metals from the different soil types showed that Cd is present in the soil of Shabu, Agyaragu, Adogi and Tudun Adabu. Cu was also detected from the soil types of the four locations sampled. Zn on the other hand is present in the soil samples of Agyaragu and Tudun Adabu, but absent in the soils of Shabu and Adogi accordingly. Mn, Fe and Ni were also detected from the soil samples of the four locations within Lafia Local Government Area of Nasarawa State. Nonetheless, Pb was detected in the soils of Agyaragu and Adogi, but absent in the soils of Shabu and Tudun Adabu (Table 1). The detection of heavy metals from water samples within Lafia Metropolis and environs was reported in Table 2. Cd was found to be present in all the four locations sampled viz: Shabu, Agyaragu, Adogi and Tudun Adabu. In the same vein, Zn, Mn and Fe was also detected in all the water samples from the four sampling locations assessed; while Pb was detected in the water samples of all areas sampled with the Shabu. Similarly, Ni was observed to contaminate water samples from Shabu, Agyaragu and Tudun Adabu, but was obviously absent in the water samples of Adogi.

Heavy metals contamination of the edible vegetables assessed was presented in Table 3. Cd, Cu, Zn, Mn, Fe and Ni were found to be present in *T. occidentalis, A. hybridus, T. trangulare* and *Corchorus* spp. However, Pb was detected in three of the four edible vegetables screened except from fluted pumpkin leaves. Nonetheless, all heavy metals with the exception of Zn were completely not detected from the control vegetable samples collected from the Nasarawa State College of Agriculture Lafia. Contamination degree and pollution load index of the soil, water and edible vegetables showed that the soil samples were more contaminated with heavy metals followed by vegetables and lastly water. The contamination degree of the soil samples was highest for Fe at 174.93mg/kg, followed by Zn (2.86mg/kg) and Pb has the lowest contamination degree of 0.08mg/kg. Meanwhile, the contamination degree of water samples was within the ranges of 0.02–45.95mg/kg, while that of the edible vegetable samples ranged between 0.04–97.17mg/kg. However, the mean contamination degree of the three environmental samples against all the heavy metals detected was highest for Fe (106.02) and Zn (2.11), but lowest degree was observed for Pb (0.05). The pollution load index was highest for soil (1.19kg/ml), followed by vegetable (0.67mg/kg) and lastly water (0.47mg/ml) (Table 4).

Individual potential risks and potential ecological risks index of soil, water and edible vegetable samples in Lafia and environs was presented in Table 5. Potential risk in soil, water and edible vegetable was highest in Cd: 55.11, 55.78 and 56.44, but lowest in Mn: 0.64, 0.20 and 0.29 respectively. However, the Risk Index of 77.11 for soil samples was the highest, followed by 69.67 for edible vegetable samples and lastly 66.39 for water samples accordingly. The concentration of exposure of the heavy metals for both the soil and water samples showed that Fe with a concentration (ppm) of 98.90 ± 12.29 was the most occurring contaminant in the soil followed by Zn (79.47 ± 12.54) and Mn (22.50 ± 3.69); while for water samples, Fe, Zn and Cu with an exposure concentration (ppm) of 233.31 ± 25.01, 132.67 ± 23.55 and 62.42 ± 10.21 were the most encountered (Table 6). However, Cd is the lowest concentration in terms of exposure for soil samples (0.73± 0.46ppm) and also for water samples (1.00± 0.64ppm).

Estimated Daily Intake (EDI) of heavy metals from ingestion of edible vegetables in Lafia Local Government Area of Nasarawa State was presented in Table 7. Accordingly, *T. occidentalis* has Fe (0.023) and Zn (0.021) as the most ingested heavy metals by the inhabitants of the study areas. Similarly, Zn and Fe had an EDI (mg/kg) of 0.018 and 0.017 respectively for *A. hybridus*. On the other hand, *T. trangulare* had an EDI of 0.034 ppm and 0.022 ppm for Cu and Zn respectively. The highest estimated daily intake of heavy metals for jute leaves (*Corchorus* sp.) showed highest concentration for Fe (0.021ppm) and Zn (0.015ppm). Hazard Index (HI) for the inhabitants exposed to the heavy metal contaminants from environmental samples of Lafia was presented in Table 8. The specific hazard posed by the heavy metals within the soil environment ranged between 0.04–3.487, while those of the water samples ranged from 0.296–1.364, while the vegetable samples was within the range of 0.005–0.01. The actual hazard index however was highest for Fe (4.298) and Zn (4.293), while the lowest HI was recorded for Pb (0.418). The soil-vegetable transfer coefficients of the heavy metals indicates that Cu with values of 5.82%, 5.48% and 3.84% has the highest transfer coefficients in *T. occidentalis*, *A. hybridus* and *T.*

triangulare respectively. However, for *Corchorus* sp., Zn (3.35%) showed the highest transfer coefficient. The average transfer coefficient of the heavy metals on the edible vegetables screened was 4.55% for Cu, 2.24% for Zn, 1.31% for Ni, 1.09% for Mn, 0.49% for Pb, 0.31% for Fe and O.13% for Cd. More so, the efficacy of transfer of the heavy metals on the vegetables was highest in *T. occidentalis* (1.99%), *A. hybridus* (1.52%), *Corchorus* sp. (1.25%) and *T. triangulare* (1.01%); while the average efficacy of transfer of the heavy metals was 1.44% as presented in Table 9.

Table 1: Heavy Metals Detected from Soil Samples within Lafia and Environs, Nasarawa State

Heavy Metals			Sampling Location	
	Shabu	**Agyaragu**	**Adogi**	**Tudun Adabu**
Cd	+	+	+	+
Cu	+	+	+	+
Zn	–	+	–	+
Mn	+	+	+	+
Pb	–	+	+	–
Fe	+	+	+	+
Ni	+	+	+	+

Key: + = Present, – = Absent

Table 2: Heavy Metals Detected from Water Samples within Lafia and Environs, Nasarawa State

Heavy Metals	Shabu	Sampling Location Agyaragu	Adogi	Tudun Adabu
Cd	+	+	+	+
Cu	+	+	+	+
Zn	+	+	+	+
Mn	+	+	+	+
Pb	–	+	+	+
Fe	+	+	+	+
Ni	+	+	–	+

Key: + = Present, – = Absent

Table 3: Heavy Metals Detected from Edible Vegetable Samples within Lafia and Environs, Nasarawa State

Edible Vegetables	Heavy Metals						
	Cd	**Cu**	**Zn**	**Mn**	**Pb**	**Fe**	**Ni**
Fluted pumpkin leaves (*Telfairia occidentalis*)	+	+	+	+	–	+	+
Green African spinach (*Amaranthus hybridus*)	+	+	+	+	+	+	+
Water Leaf (*Talinum triangulare*)	+	+	+	+	+	+	+
Jute Leaves (*Corchorus* sp)	+	+	+	+	+	+	+
Control sample	–	–	+	–	–	–	–

Key: + = Present, – = Absent

* Control Sample = uncontaminated vegetable samples collected from the demonstration farms of the Nasarawa State College of Agriculture Lafia

Table 4: Calculated Contamination Degree and Pollution Load Index (PLI) of Soil, Water and Edible Vegetable Samples from Lafia and Environs, Nasarawa State

Heavy Metals	Soil	Water	Vegetable	Total Samples
Cd	1.84	1.86	1.88	1.86
Cu	0.46	0.15	0.20	0.27
Zn	2.86	1.57	1.91	2.11
Mn	0.62	0.26	0.28	0.38
Pb	0.08	0.02	0.04	0.05
Fe	174.93	45.95	97.17	106.02
Ni	0.32	0.09	0.19	0.20
PLI	1.19	0.47	0.67	0.78

Table 5: Individual Potential Risks and Potential Ecological Risks Index of Soil, Water and Edible Vegetable Samples from Lafia and Environs, Nasarawa State

Heavy Metals	Soil	Water	Vegetable	Total Samples
Cd	55.11	55.78	56.44	55.78
Cu	2.32	0.76	1.01	1.36
Zn	14.30	7.87	9.54	10.57
Mn	0.64	0.20	0.29	0.38
Pb	3.08	1.28	1.39	1.92
Fe	14.30	7.87	9.54	10.57
Ni	1.60	0.47	0.96	1.01
RI	77.11	66.39	69.67	71.06

Table 6: Exposure Concentration of Heavy Metals (ppm) in Soil and Water Samples within Lafia Metropolis and Environs, Nasarawa State

Heavy Metals		Environmental Samples
	Soil (mg/kg) ± S.D	**Water (mg/ml) ± S.D**
Cd	0.73 ± 0.46	1.00 ± 0.64
Cu	5.46 ± 1.38	62.42 ± 10.21
Zn	79.47 ± 12.54	132.67 ± 23.55
Mn	22.50 ± 3.69	51.41 ± 7.32
Pb	2.85 ± 0.63	5.62 ± 0.87
Fe	98.90 ± 12.29	233.31 ± 25.01
Ni	3.08 ± 1.48	8.49 ± 2.54

Key: S.D. = Standard Deviation

Table 7: Estimated Daily Intake (EDI) of Heavy Metals (mg/kg) amongst the Study Population from Consumption of Vegetables

Edible Vegetables	Heavy Metals						
	Cd	**Cu**	**Zn**	**Mn**	**Pb**	**Fe**	**Ni**
Fluted pumpkin leaves (*Telfairia occidetalis*)	0.001	0.01	0.021	0.007	0.001	0.023	0.014
Green African spinach (*Amaranthus hybridus*)	0.002	0.009	0.018	0.008	0.001	0.017	0.012
Water Leaf (*Talinum triangulare*)	0.004	0.034	0.022	0.006	0.002	0.015	0.009
Jute Leaves (*Corchorus* sp)	0.002	0.007	0.015	0.0011	0.004	0.021	0.008

Table 8: Specific Hazard Index (HI) for Inhabitants Exposed to Contaminated Environmental Samples from Lafia and Environs, Nasarawa State

Heavy Metals	Soil	Water	Vegetable	Hazard Index
Cd	0.353	0.296	0.006	0.655
Cu	1.661	0.775	0.006	2.442
Zn	3.487	0.801	0.005	4.293
Mn	1.353	0.384	0.006	1.743
Pb	0.04	0.37	0.008	0.418
Fe	2.924	1.364	0.01	4.298
Ni	1.204	0.693	0.015	1.912

Table 9: Soil-Vegetable Transfer Coefficients (%) of Heavy Metals from Different Parts of Lafia and Environs, Nasarawa State

Edible Vegetables	Cd	Cu	Zn	Mn	Pb	Fe	Ni	Efficacy
T. occidentalis	0.15	5.82	2.88	1.42	1.08	0.49	2.14	1.99
A. hybridus	0.11	5.48	1.87	0.89	0.61	0.38	1.32	1.52
T. triangulare	0.04	3.84	0.86	1.12	0.15	0.17	0.92	1.01
Corchorus sp.	0.20	3.07	3.35	0.96	0.14	0.20	0.85	1.25
Average	0.13	4.55	2.24	1.09	0.49	0.31	1.31	1.44
USEPA Guideline (μgL^{-1})	5.0	1300	500	50	15	300	–	

Discussion and Conclusion

Discussion

In this present study, Cd, Cu, Mn, Fe and Ni was detected in the soils of all the locations sampled. Zn and Pb were observed to be present in 2 and 3 of the 4 areas assessed. The same trend was also observed for both water and vegetable samples within Lafia Local Government. This scenario is expected since the locations were samples were collected are in proximity to mining locations and other areas of human anthropogenic activities. The presence of heavy metals in the environmental samples particularly in water is quite worrisome because it was observed from literatures that heavy metals are extremely toxic to aquatic organisms even at very low concentrations (Ahmed *et al.*, 2014) [3]. These elements can cause significant histopathological alterations in tissues of aquatic organisms (Afrin *et al.*, 2015) [2]. The concentrations of copper recorded in soils were below the WHO/FAO (2007) permissible limit of 100 mg/kg. The values recorded were within the normal range of copper concentration required by plants for growth and development. More so, the concentration of copper recorded in this study was lower than earlier reported values of 47.0mg/kg reported by Fisseha *et al.* (2008) [13] and 22.14 mg/kg around an oil depot at Jos in Nigeria (Babatunde *et al*., 2014) [7]. Additionally, the concentrations of lead in soils were below the WHO/FAO (2007) permissible limit of 50mg/kg. However, substantial amount of lead concentration was recorded at the study area indicating some anthropogenic source of lead pollution in the environment. The values recorded in this study were higher than of 14.13mg/kg and 13.53mg/kg recorded in a previous study by Babatunde *et al.* (2014) [7]. Similarly, the zinc content of soils analyzed was below the WHO/FAO (2007) permissible limit of 300mg/kg. However, the values of zinc recorded in this study were within the normal range of zinc required by plants. The concentration of zinc observed in this study was lower than 237.96mg/kg reported in an earlier study (Okunola *et al*., 2007) [41].

The aquatic habitat on the other hand are contaminated by heavy metals from different sources, however, Zhuang *et al.* (2013) [57] confirmed that one major source of heavy metals in the aquatic ecosystem is effluents from mining operations. Nasarawa State in general in known for large-scale mining activities, this perhaps explains the presence of 7 heavy metals in soil, water and edible vegetables of Lafia. On the basis of mean contamination degree of the heavy metals on the environmental samples analysed, Fe (106.02) had the highest contamination degree, while Ni (0.20) had the least contamination degree. The Pollution Load Index exceeded 1.00mg/kg for soil samples (1.19). The results depicted soil samples in Lafia to be heavily contaminated with heavy metals suggesting possible anthropogenic impacts. This corresponds with an earlier report by Fosu-Mensah *et al.* (2018) [15] and Enuneku *et al.* (2018) [12]. More so, the individual potential ecological risks of the heavy metals depicted the highest mean potential risk for Cd, Zn and Fe, while the Risk Index was higher in soil samples (77.11) compared to edible vegetables (69.67) and water (66.39). The potential risk index for the heavy metals is significantly high. In fact, they were higher than those observed by DeForest *et al.* (2007) [9], Enuneku *et al.* (2014) [12] and Enuneku *et al.* (2018) [12]. It is important to note however that Pb has a comparably low individual potential risk index compared to the other heavy metal. This perhaps could be due to the category of solid minerals mined within the vicinity of the sampling locations. Lead is not mined per say in Lafia but could be introduced into the environment through other human anthropogenic activities other than mining. Several workers such as Duruibe *et al.* (2007) [10], Dzoma *et al.* (2010) [11], Khan *et al.* (2011) and Kamunda *et al.* (2016) [28] reiterate this particular assertion, which conform to the findings of this present study.

Accordingly, exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. Various effects occur over a broad range of doses, with the developing young and infants being more sensitive than adults (Rusyniak *et al.*, 2010) [43]. Lead poisoning, which is so severe as to cause evident illness, is now very rare. Lead performs no known essential function in the human body; it can merely do harm after uptake from food, air, or water (Singh and Kalambhad, 2011; Singh *et al.*, 2011) [46, 47]. Despite the complexity, the toxicity of heavy metals in plants and in animals and humans that eat contaminated plants is primarily associated with previous environmental contamination (Tasrina *et al.*, 2015) [49]. Therefore, the presence of lead in the environmental components of Lafia even though minimal is a threat to public health. Interestingly, the soil-vegetable transfer coefficients observed for this particular study were greater than 1 for Cu, Zn, Mn and Ni. The standard of the United States Environmental Protection Agency (USEPA) stipulates that transfer factor of >1 transfer factor of heavy metals for foods including cereals and vegetables is deleterious. Ibhadon *et al.* (2014) opined that a transfer factor of 1 and above indicates that the metal is biomagnified. Except for Pb and Cd, all other transfer factors in *T. occidentalis, A. hybridus, T. triangulare* and *Corchorus* sp. were above 1 indicating that there was bio-magnification of the rest heavy metals in the edible vegetables of Lafia. The soil-to-plant transfer of heavy metals is a very important step in the trophic transfer of such metals in food chains. These metals are taken up by plants from polluted soil and subsequently transferred to herbivorous animals along the food chain as demonstrated by Nica *et al.* (2012) [39].

In fact, those workers pointed out regarding the contamination of the human food chain, that contamination of crops such as cereals and vegetables is a very serious issue. In this present study, almost all the heavy metals detected had significant soil-to-plant transfer coefficient. Orisakwe and colleagues (2012) in their work on the risk of consuming heavy metal contaminated food in Owerri Nigeria deduced that the consumption of foods contaminated with toxic heavy metals may cause risk to human health. On the same note, heavy metals in higher concentration ranges have been reported in vegetables grown with wastewaters compared to those grown with groundwater. Furthermore, higher concentrations of these metals have been found in leafy vegetables compared to those in other types of vegetables such as bulbs and tubers as reported by Mahmood and Malik (2014) [37]. This reinforced the findings of this present study.

Conclusion

In this study, seven heavy metals namely: cadmium, copper, zinc, manganese, lead, iron and nickel were found at varying concentrations in soil, water and edible vegetables within Lafia metropolis and environs. The mean concentrations of most of the heavy metals in the soil samples were found to be within their natural corresponding background values, while the pollution load index of the soil is high, but those of water and edible vegetables were not too high. The PLI reported in this research can provide a valuable information and advice for policy and decision makers to evaluate the pollution status of Lafia in Particular and Nasarawa State in general. Hence, subsequent investigation should be conducted intermittently to monitor environmental pollution due to the on-going mining activities and evaluate the public health risks associated with metal pollution on miners and inhabitants of such areas.

From the findings of this study, the following recommendations became necessary

a. The industries operating in this community should adopt more sustainable and eco-innovative management options in order to attenuate potential ecological and human health risk of metal pollution.
b. Remediation methods should be adopted by the Nasarawa State Waste Management Board and other local authorities to safeguard the general health of communities living close to areas of human anthropogenic activities.
c. It is vital that the bioaccumulation values rather than the total contents of heavy metals should be taken into consideration during risk assessment henceforth for proper evaluation of human health risk of the contaminants.
d. It is vital to monitor extensively and occasionally heavy metals in vegetables especially those grown in areas with close proximity to mining locations or those irrigated with water of poor chemical and biological quality in order to safeguard the health of the population.

References

1. Afrifa CG, Ofosu FG, Bamford SA, Wordson DA, Atiemo SM, Aboh IJ, *et al*. Heavy metal contamination in surface soil dust at selected fuel filling stations in Accra, Ghana. American J Sci Ind Res. 2013; 4:404-413.
2. Afrin R, Mia MY, Ahsan MA, Akbor A. “Concentration of heavy metals in available fish species (bain, Mastacembelus armatus; taki, Channa punctatus and bele, Glossogobius giuris) in the Turag river, Bangladesh,” Pakistan Journal of Scientific and Industrial Research Series B: Biological Sciences. 2015; 58(2):104-110.
3. Ahmed MK, Parvin E, Islam MM, Akter MS, Khan S, Al-Mamun MH, *et al*. “Lead- and cadmium-induced histopathological changes in gill, kidney and liver tissue of freshwater climbing perch Anabas testudineus (Bloch, 1792),” Chemistry and Ecology. 2014; 30(6):532-540.
4. Akwa VL, Bimbol Samarita KL, Marcus ND. Geography perspective of Nasarawa State. Onaivi Printing and Publishing Company Ltd, Keffi, Nasarawa State, Nigeria, 2007.
5. Ali H, Khan E, Ilahi I. Environmental Chemistry and Ecotoxicology of Hazardous Heavy Metals: Environmental Persistence, Toxicity, and Bioaccumulation. Journal of Chemistry. Article ID 6730305, 14 pages, 2019. https://doi.org/10.1155/2019/6730305
6. Andersen KJ, Kisser MI. Digestion of Solid Matrices–Desk Study Horizontal; Eurofins A/A: Kwai Chung, Denmark. 2004; 59:25-33.
7. Babatunde O, Oyewale A, Steve P. Bioavailable Trace Elements in Soils around NNPC Oil Depot Jos, Nigeria. Journal of Environmental Science, Toxicology and Food Technology. 2014; 8(1):47-56.
8. Barakat A, El Baghdadi M, Rais J, Nadem S. Assessment of heavy metal in surface sediments of Day River at Beni-Mellal- Region, Morocco. Res. J Environ. Earth Sci. 2012; 4(8):797-806.
9. De Forest DK, Brix KV, Adams WJ. Assessing metal bioaccumulation in aquatic environments: the inverse relationship between bioaccumulation factors, trophic transfer factors and exposure concentration, Aquatic Toxicology. 2007; 84(2):236-246.
10. Duruibe JO, Ogwuegbu MOC, Egwurugwu JN. Heavy metal pollution and human biotoxic effects. Int. J Phys. Sci. 2007; 2:112-118.
11. Dzoma BM, Moralo RA, Motsei LE, Ndou RV, Bakunzi FR. Preliminary findings on the levels of five heavy metals in water, sediments, grass and various specimens from cattle grazing and watering in potentially heavy metal polluted areas of the north West Province of South Africa. J Anim. Vet. Adv. 2010; 9:3026-3033.
12. Enuneku A, Omoruyi O, Tongo I, Ogbomida E, Ogbeide O, Ezemonye L, *et al.* evaluating the potential health risks of heavy metal pollution in sediment and selected benthic fauna of Benin River, Southern Nigeria. Applied Water Science. 2018; 8:224-

231.

13. Fisseha I, Jorn B, Mats O. The fate and bioavailability of some trace elements applied to two vegetable farms in Addis Ababa. African Journal of Agricultural Research. 2008; 3(11):797-807.
14. Förstner U, Wittmann GTW. Metal Pollution in the Aquatic Environment. Springer Science & Business Media, 2012.
15. Fosu-Mensah BY, Ofori A, Ofosuhene M, Ofori-Attah E, Nunoo FKE, Darko G, *et al*. Assessment of Heavy Metal Contamination and Distribution in Surface Soils and Plants along the West Coast of Ghana. West African Journal of Applied Ecology. 2018; 26(SI):167-178.
16. Gupta S, Jena V, Jena S. "Assessment of heavy metal contents of green leafy vegetables". Croatian Journal of Food Science and Technology. 2013; 5(2):53-60.
17. Gworek B, Dmuchowski W, Koda E, Marecka M, Baczewska AH, Bragoszewska P, *et al*. Impact of the municipal solid waste Łubna landfill on environmental pollution by heavy metals. Water, 2016, 8:470.
18. Ha H, Olson JR, Bian L. Analysis of heavy metal sources in soil using kriging interpolation on principal components. Environ. Sci & Technol. 2014; 48:4999-5007.
19. Håkanson L. An ecological risk index for aquatic pollution control—a sedimentological approach. Water Research. 1980; 14:975-1001.
20. Hough RL, Breward N, Young SD. Assessing potential risk of heavy metal exposure from consumption of home-produced vegetables by urban populations. Environmental Health Perspective. 2004; 112:215-221.
21. Huang JH, Li F, Zeng GM. Integrating hierarchical bioavailability and population distribution into potential eco- risk assessment of heavy metals in road dust: A case study in Xiandao District, Changsha city, China. Science of the Total Environment. 2016; 541:969-976.
22. Huang S, Shao G, Wang L, Wang L, Tang L. Distribution and Health Risk Assessment of Trace Metals in Soils in the Golden Triangle of Southern Fujian Province, China. Int. J Environ. Res. Public Health. 2019; 16:97-113.
23. Ibhadon S, Emere MC, Abdulsalami MS, Yilwa V. Bioaccumulation of some trace metals in wild and farm-raised African Catfish Clarias gariepinus in Kaduna, Nigeria. Pakistan Journal of Nutrition. 2014; 13(12):686-691.
24. Izhar S, Goel A, Chakraborty A. Annual trends in occurrence of submicron particles in ambient air and health risk posed by particle bound metals. Chemosphere. 2016; 146:582-590.
25. Järup L. Hazards of heavy metal contamination. Britain Medical Bulletin, 2003, 68:167. DOI:10.1093/bmb/ldg032
26. Jiao X, Teng Y, Zhan Y, Wu J, Lin X. Soil heavy metal pollution and risk assessment in Shenyang industrial district, North-east China. PLoS One. 2015; 10(5):e0127736.
27. Kacholi DS, Sahu M. Levels and Health Risk Assessment of Heavy Metals in Soil, Water, and Vegetables of Dar es Salaam, Tanzania. Journal of Chemistry, 2018. Article ID: 1402674, 9 pages https://doi.org/10.1155/2018/1402674
28. Kamunda C, Mathuthu M, Madhuku M. Health Risk Assessment of Heavy Metals in Soils from Witwatersrand Gold Mining Basin, South Africa. Int. J Environ. Res. Publ. Health. 2016; 13:663-674.
29. Kar D, Sur P, Mandai SK, Saha T, Kole RK. Assessment of heavy metal pollution in surface water. Int. J Environ. Sci. Tech. 2008; 5:119-124.
30. Khan T, Muhammad S, Khan B, Khan H. "Investigating the levels of selected heavy metals in surface water of Shah Alam River (a tributary of River Kabul, Khyber Pakhtunkhwa)" Journal of Himalayan Earth Sciences. 2011; 44(2):71-79.
31. Kpan JDA, Opoku BK, Gloria A. Heavy Metal Pollution in Soil and Water in Some Selected Towns in Dunkwa-on-Offin District in the Central Region of Ghana as a Result of Small Scale Gold Mining. Journal of Agricultural Chemistry and Environment. 2014; 3(2):40-47.
32. Krishna AK, Mohan KR. Distribution, correlation, ecological and health risk assessment of heavy metal contamination in surface soils around an industrial area, Hyderabad, India. Environmental Earth Science, 2016, 75.
33. Li F, Huang JH, Zeng GM. Spatial risk assessment and sources identification of heavy metals in surface sediments from the Dongting Lake, Middle China. Journal of Geochemical Exploration. 2013; 132:75-83.
34. Li F, Zhang JD, Jiang W. Spatial health risk assessment and hierarchical risk management for mercury in soils from a typical contaminated site, China. Environ. Geochem Health. 2017; 39:923-934.
35. Maanan M. Trace metal contamination of marine organisms from the Morrocan North Atlantic coastal environments. Environmental Pollution. 2008; 153(1):176-183.
36. Mahmood A, Malik RN. "Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan," Arabian Journal of Chemistry. 2014; 7(1):91-99.
37. Mahmood Q, Wang J, Pervez A, Meryem SS, Waseem M, Ullah Z, *et al*. "Health risk assessment and oxidative stress in workers exposed to welding fumes" Toxicological & Environmental Chemistry. 2015; 97(5):634-639.
38. Nasarawa Geographical Information Services (NAGIS). GPS Map of Nasarawa State showing all the Local Government Areas. www.nagis.gov.ng, 2015.
39. Nica DV, Bura M, Gergen I, Harmanescu M, Bordean DM. "Bioaccumulative and conchological assessment of heavy metal transfer in a soil-plant-snail food chain," Chemistry Central Journal. 2012; 6(1):55.
40. Noli F, Tsamos P. Concentration of heavy metals and trace elements in soils, waters and vegetables and assessment of health risk in the vicinity of a lignite-fired power plant. Science of the Total Environment. 2016; 563:377-385.
41. Okunola OJ, Uzairu A, Ndukwe G. Levels of trace metals in soil and vegetation along major and minor roads in metropolitan city of Kaduna, Nigeria. African. Journal of Biotechnology. 2007; 6(14):1703-1709.
42. Orisakwe OE, Nduka JK, Amadi CN, Dike DO, Bede O. "Heavy metals health risk assessment for population via consumption of food crops and fruits in Owerri, South Eastern, Nigeria" Chemistry Central Journal.

2012; 6(1):77.

43. Rusyniak DE, Arroyo A, Acciani J, Froberg B, Kao L. Heavy metal poisoning: management of intoxication and antidotes. EXS. 2010; 100:365-396.
44. Sharma RK, Agrawal M, Marshall F. “Heavy metal contamination in vegetables grown in wastewater irrigated areas of Varanasi, India” Bulletin of Environmental Contamination and Toxicology. 2006; 77(2):312-318.
45. Singh A, Sharma RK, Agrawal M, Marshall FM. “Risk assessment of heavy metal toxicity through contaminated vegetables from waste water irrigated area of Varanasi, India” Tropical Ecology. 2010; 51(2):375-387.
46. Singh J, Kalambhad AS. Effects of Heavy Metals on Soil, Plants, Human Health and Aquatic Life. Int. J Res. Chem. Environ. 2011; 1(2):15-21.
47. Singh R, Gautam N, Mishra A, Gupta R. Heavy metals and living systems: An overview. Indian Journal of Pharmacology. 2011; 43:246-253.
48. Soliman NF, Nasr SM, Okbah MA. Potential ecological risk of heavy metals in sediments from the Mediterranean coast, Egypt. J Environ Health Sci Eng. 2015; 13:70-81.
49. Tasrina RC, Rowshon A, Mustafizur AMR, Rafiqul I, Ali MP. “Heavy metals contamination in vegetables and its growing soil,” Journal of Environmental and Analytical Chemistry. 2015; 2(3):142.
50. Tomilson DC, Wilson JG, Harris CR, Jeffrey DW. Problems in assessment of heavy metals in estuaries and the formation of pollution index. Helgol Meeresunlters. 1980; 33:566-575.
51. United Stated Environmental Protection Agency (USEPA). Risk assessment guidance for superfund. In: Human health evaluation manual part a, interim final, vol. I. United States Environmental Protection Agency, Washington (DC). EPA/540/1-89/002, 2010.
52. Vongdala N, Tran H, Xuan TD, Teschke R, Khanh TD. Heavy Metal Accumulation in Water, Soil, and Plants of Municipal Solid Waste Landfill in Vientiane, Laos. Int. J. Environ. Res. Public Health. 2019; 16:22-34.
53. WHO/FAO. Joint FAO/WHO Food Standard Programme Codex Alimentarius Commission 13th Session. Report of the Thirty Eight Session of the Codex Committee on Food Hygiene. Houston, United States of America, ALINORM 07/30/13, 2007.
54. Wieczorek-Dabrowska M, Tomza-Marciniak A, Pilarczyk B, Balicka-Ramisz A. “Roe and red deer as bioindicators of heavy metals contamination in North-western Poland” Chemistry and Ecology. 2013; 29(2):100-110.
55. Yang J, Ma S, Zhou J, Song Y, Li F. Heavy metal contamination in soils and vegetables and health risk assessment of inhabitants in Daye, China. Journal of International Medical Research. 2018; 46(8):3374-3387.
56. Yeganeh M, Afyuni M, Khoshgoftarmanesh AH. Health risks of metals in soil, water, and major food crops in Hamedan Province, Iran. Human Ecological Risk Assessment. 2012; 18:547-568.
57. Zhuang P, Li ZA, McBride MB, Zou B, Wang G. “Health risk assessment for consumption of fish originating from ponds near Dabaoshan mine, South China” Environmental Science and Pollution Research. 2013; 20(8):5844-5854.