Jewel Journal of Scientific Research (JJSR), 4(1&2): 122–130, 2019
©Federal University of Kashere-Nigeria (ISSN: 2384 - 6267)
jjsr.fukashere.edu.ng

Health Risk Assessment of Heavy Metals in Soil Samples around Maiganga Coal Mine site and Kumo Town in Akko Local Government, Area of Gombe State

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Abstract
The presence of heavy metals in soils are of great concern to humans and the environment, owing to their toxicity, bio-accumulative potentiality, biodegradability, and intractable nature. Heavy metals are significant environmental pollutants and their toxicity is a problem of increasing significance for ecological, nutritional and environmental reasons. A total of 10 soil samples was obtained in which five samples (m1, m2, m3, m4 and m5) was taken from the Maiganga mining site, and another five (K1, K2, k3, k4 and k5) was taken from Kumo. Samples were collected on a clean plastic and transported to FUK chemistry laboratory to be analyzed for Chromium, Cadmium, Copper, Iron and Zinc (Cr, Cd, Cu, Fe, and Zn). Cd recorded the lowest value of 0.010 ppm amongst all other heavy metals tested in this study, of which four of the five samples (K2, K3, K4 and K5) were below the detectable level and a low value of 0.010 ppm was detected in sample K1. Likewise, samples (M1, M3 and M5) from around the coal mine was below the detectable level of the instrument for Cd. Meanwhile Cd recorded the maximum value of 0.320 ppm. Fe had the highest value among all the heavy metals tested, with a maximum value of 101.265 ppm which was obtained from the mining Areas, and a minimum value of 66.960 ppm obtained from the residential area (Kumo). In conclusion, it was observed that higher values were recorded from samples obtained from the mining area, although all of which were below the permissible limit by WHO/FAO. Therefore, from the soil from Maiganga and Kumo is below the permissible limit and it not risky human health for use.

Keywords: Soil, Heavy Metals, Coal mining, Maiganga, Kumo

Received: 15th Sept, 2019 *Accepted:* 20th Dec., 2019 *Published Online:* 30th Dec. 2019

Introduction

The presence of heavy metals in soils are of great concern to humans and the environment, due to their harmfulness, bio-accumulative potentiality, biodegradability, and intractable nature. Some metals are essential for life, playing an irreplaceable role as sources of vitamins and minerals for human organs to function. All living organisms require varying amounts of metals, but at higher concentrations they become toxic (Adesuyi *et al*., 2015). More so, some metals do not play any useful role in human physiology and might be toxic even at low rates of exposure. They might continuously get accumulated in vital organs such as the brain, the liver, bones, and kidneys, for years or decades, in turn causing serious health problems (Kabata-Pendias and Pendias, 2011).

Severe ingestion of Cadmium (Cd) is also known to be toxic, even in low amounts, being regarded as a probable carcinogen as well. Severe exposure to Cd may result in pulmonary effects such as alveolitis, bronchiolitis, and emphysema (Adedokun *et al*., 2016). It can also result in bone fracture, kidney dysfunction, hypertension, and even cancer (Kamunda *et al*., 2016). More so, some of its odd long-term effects include arthritis, diabetes, anaemia, cardiovascular disease, cirrhosis, reduced fertility, headaches, and strokes.

Zinc (Zn) and Copper (Cu) are essential for human life, yet too much intake of these metals may have non-carcinogenic impacts on human health. Higher concentrations of Zn have been associated with growth and reproduction impairment, whereas higher amounts of Cu are associated with liver damages (Adesuyi *et al*., 2015; Kamunda *et al*., 2016). While Chromium (III) is an essential element, chromium (VI) compounds are known to be mutagenic and carcinogenic. Inhaling high levels of chromium (VI) may cause asthma and shortness of breath. Also, long-term exposure to it might damage the liver and the kidneys (Podsiki, 2008).

Iron (Fe) is the most abundant and an essential constituent for all plants and animals. On the other hand, at high concentration, it causes tissues damage and some other diseases in humans. Exposure to iron dust may cause respiratory diseases such as chronic bronchitis and ventilation difficulties It is also responsible for anemia and neurodegenerative conditions in human being (Fuortes and Schenck, 2000).

Materials and Methods

Study area

The study area, Maiganga village is located in Akko Local Government Area (LGA) of Gombe state. It is located 8 km off Gombe – Yola road. Maiganga village is located West of Kumo town between Latitude 09°18' and 11°59'E (Fig. 1). According to Oruonye *et al*., 2016**,** Maiganga community covers an area of about 20,129.47 Acres (48.16 Km). Maiganga coal mine is where coal is being extracted, coal is a fossil fuel formed from the decomposition of organic materials that have been subjected to geologic heat and pressure over millions of years. It is considered a non-renewable resource because it cannot be replenished on the human time frame (United State Environmental Protection Agency USEPA, 2000). The economic activity of the study area is farming which includes the cultivation of different crops such as maize, millet, guinea corn, groundnut, sorghum and groundnut.

This study is restricted to soil samples from Maiganga coal mine and soil used for agricultural purposes in Kumo areas which is few kilometers from the coal mine in Akko local government Area of Gombe State. Gombe State is an agricultural producing state of Nigeria, situated in the northern-eastern part of Nigeria, with a population of over 2.3 million, the capital city is Gombe located at the central part of the state with an estimated area of 18,768Km^2 (7,246 sq. mi). The state has a coordinates of $10^0 15^l$ N and $11^0 10^l$ E. The area is predominantly covered with land and Hills. The study area, Maiganga village is located in Akko Local Government Area (LGA) of Gombe state. It is located 8 km off Gombe – Yola road. Maiganga village is located West of Kumo town between Latitude 09°18' and 11°59'E. Therefore, the current study intends to determine concentration levels of heavy metals in soils from the study areas.

Collection of Samples

Sampling of soils was performed in August, 2019, in which a sum of ten soil samples was obtained from two different locations. Control samples were obtained 8 km off the mining sites. All collected samples were properly tagged and identified by their sampling locations. Furthermore, the coordinates were obtained, using a Global Positioning System (GPS) receiver. The collected soil samples were taken to the Federal University of Kashere, Chemistry Research Laboratory for further preparations. The soil samples were air-dried and sieved to <0.25mm, then stored in desiccators prior to heavy-metal content analysis. To determine total heavy metal content, one gram of sample was placed in a 250 ml digestion tube and 10 ml of concentrated HNO_3 was added. The mixture was boiled gently for 30–45 min to oxidize all easily oxidizable matter. After cooling, 5 ml of 70 % $HClO_4$ was added and the mixture was boiled gently until dense white fumes appeared. After cooling, 20 ml of distilled water was added and the mixture was boiled further to release any fumes. The solution was cooled, further filtered through Whatman No. 42 filter paper and <0.45 lm Millipore filter paper and transferred quantitatively to a 25 ml volumetric flask by adding distilled water, the samples made from reagents were analyzed. Zinc (Zn), Iron (Fe), Chromium (Cr), Copper (Cu), and Cadmium (Cd) levels were determined using Atomic absorption spectrometry (Hseu *et al.,* 2002).

The readings were taken from the equipment and the results were converted to actual concentration of the metal in the sample, using this equation (Aderinola *et al.,* 2009):

$$\text{Concentration of metal} = \frac{\text{Calibration Reading} \times \text{Volume of Digest}}{\text{Weight of Sample}} \quad \text{...1}$$

Where calibration reading was the reading from the instrument, volume of digest was 25 ml, and weight of sample, 1 g.

Human health risk assessment is a process used to estimate the health effects that might result from exposure to carcinogenic and non-carcinogenic chemicals. The risk assessment process is made up of four basic steps: hazard identification, exposure assessment, toxicity (dose-response) assessment, and risk characterization (USEPA, 2004). Hazard Identification basically aims to investigate chemicals that are present at any given location, their concentrations, and spatial distribution. In the study area, Fe, Cd, Cr, Cu and Zn were identified as possible hazards for the community. The purpose of exposure assessment is to measure or estimate the intensity, frequency, and duration of human exposures to an environmental contaminant. In the study, exposure assessment was carried out by measuring the average daily intake (*ADI*) of heavy metals earlier identified through ingestion, inhalation and dermal contact by adults and children from the study area. Adults and children are separated because of their behavioral and physiological differences.

Dose-response assessment estimates the toxicity due to exposure levels of chemicals. The cancer slope factor (*CSF*, a carcinogen potency factor) and the reference dose (*RfD*, a non-carcinogenic threshold) are two important toxicity indices used. *RfD* values are derived from animal studies using the "No observable effect level" principle. For humans, *RfD* values are multiplied 10-fold to account for uncertainties (USEPA, 1989). Risk characterization predicts the potential cancerous and non-cancerous health risk of children and adults in the study area by integrating all the information gathered to arrive at quantitative estimates of cancer risk and hazard indices (USEPA, 2004).

The potential exposure pathways for heavy metals in contaminated soils are calculated based on recommendations by several American publications. *ADI* (mg/kg-day) for the different pathways were calculated using the following exposure Equations (1-3) as prescribed by (USEPA, 2004).

Ingestion of Heavy Metals through Soil

$$ADI_{ing} = \frac{C \times IR \times EF \times ED \times CF}{BW \times AT} \quad \text{............2}$$

where ADI_{ing} is the average daily intake of heavy metals ingested from soil in mg/kg-day, *C* = concentration of heavy metal in mg/kg for soil. *IR* in mg/day is the ingestion rate, *EF* in days/year is the exposure frequency, *ED* is the exposure duration in years, *BW* is the body weight of the exposed individual in kg, *AT* is the time period over which the dose is averaged in days. *CF* is the conversion factor in kg/mg.

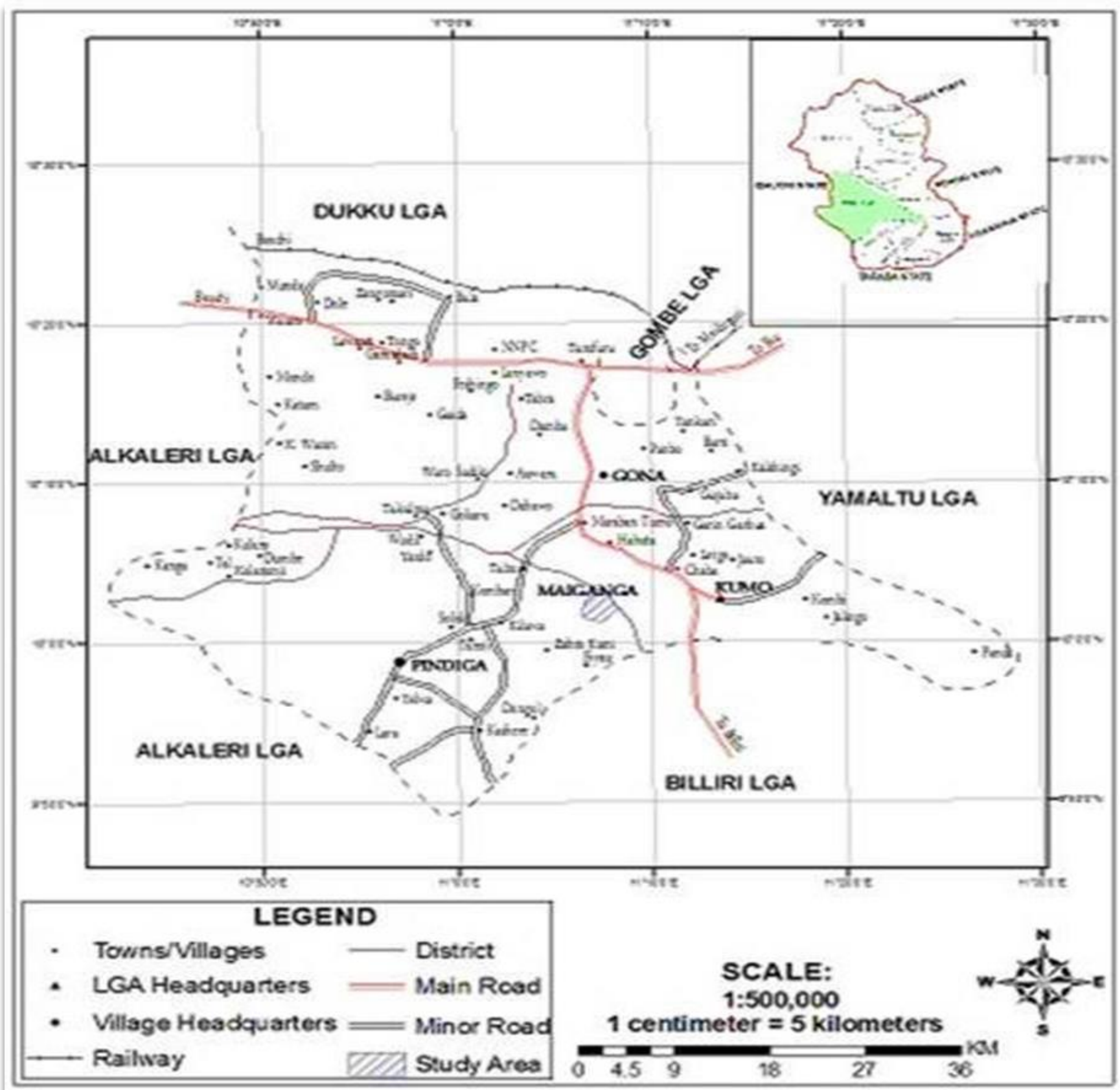

Figure 1. Map of Akko showing Study Area Maiganga Coal mine and Kumo (Oruonye *et al*., 2016)

Inhalation of Heavy Metals via Soil Particulates

$$ADI_{ing} = \frac{C \times IR \times EF \times ED \times CF}{BW \times AT} \qquad 3$$

where ADI_{inh} is the average daily intake of heavy metals inhaled from soil in mg/kg-day, C_S is the concentration of heav

Dermal Contact with Soil

$$ADI_{ing} = \frac{CS \times IR_{air} \times EF \times ED}{BW \times AT \times PEF} \qquad 4$$

where ADI_{dems} is the exposure dose via dermal contact in mg/kg/day. C_S is the concentration of heavy metal in soil in mg/kg, *SA* is exposed skin area in cm^2, *FE* is the fraction of the dermal exposure ratio to soil, *AF* is the soil adherence factor in mg/cm^2, *ABS* is the fraction of the applied dose absorbed across the skin. *EF*, *ED*, *BW*, *CF* and *AT* are as defined earlier in equation 4

Non-Carcinogenic Risk Assessment

Non-carcinogenic hazards are characterized by a term called hazard quotient (*HQ*). *HQ* is a unit less number that is expressed as the probability of an individual suffering an adverse effect. It is defined as the quotient of *ADI* or dose divided by the toxicity threshold value, which is referred to as the chronic reference dose (*RfD*) in mg/kg-day of a specific heavy metal as shown in Equation (5) (USEPA, 1989):

$$HQ \frac{ADI}{R_f D} \quad 5$$

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. This is considered to be another term called the Hazard Index (*HI*) as described by USEPA document. Equation (6) shows the mathematical representation of this parameter:

$$HI = \sum_{k=1}^{n} HQK = \sum_{k=1}^{n} \frac{ADI_k}{R_f D_k} \quad 6$$

Where HQ_k, ADI_k and RfD_k are values of heavy metal *k*. If the *HI* value is less than one, the exposed population is unlikely to experience adverse health effects. If the *HI* value exceeds one, then there may be concern for potential non-carcinogenic effect. (USEPA, 1989).

Yuswir *et al*. (2015), cited the gastro-intestinal absorption factor of several HMs. The reference doses as well as the cancer slope factors are given in Table 1.

Carcinogenic risk characterization

The carcinogenic risk is estimated as the incremental probability of the occurrence of cancer over a lifetime as a result of exposure to a potential carcinogenic contaminant. Incremental excess lifetime cancer risk (IELCR) is the terminology for characterizing carcinogenic risk and it can be calculated using equation 7

IELCR = LADD X CSF 7

To sum the carcinogenic effect resulting from exposure to two or more carcinogens, the cumulative target risk (CTR) can be calculated from the equation 8

$$CTR = \sum_i IELCR \quad 8$$

if CTR exceeds 1×10^{-4} – 1×10^{-6} further chemical-specific assessment is required and when CTR fall below 1×10^{-4} – 1×10^{-6} no action is required from a human health perspective GHDQRAD(2017). These thresholds have been adopted because they represent the risk at the exposed population that is likely going to have an adverse health effect or not. The values 1×10^{-4} and 1×10^{-6} represent the upper and lower limits of human health risk, beyond which there is a statistical significant evidence of adverse health effect GHDQRAD (2017). The upper limit value (1×10^{-4}) has been used in this investigation as a reference CTR. Table 2 shows the exposure parameters, used for health risk assessment of standard residential exposure scenario through different exposure pathways.

Table 1. Reference Dose and Cancer Slope Factor of Some Heavy Metals

Metals	Oral Reference dose	Inhalation Reference dose	Dermal Reference dose	CSF Oral	CSF Inhalation	CSF Dermal absorption
Pb	4.00 E-03	3.50 E-03	5.25 E-04	8.50 E-03	4.20 E-02	8.50 E-06
Hg	3.00 E-04	8.60 E-05	2.10 E-05			
As	3.00 E-04	4.29 E-06	3.00 E-04	1.5	1.50 E + 01	3.66 E + 00
Cd	1.00 E-03	2.86 E-06	2.50 E-05	-	6.30 E + 00	-

Table 2. Exposure parameters, used for health risk assessment through different exposure pathways for soil (USEPA, 2011)

Parameter (Unit)	Child	Adult
Body weight (BW) kg	15 kg	70 kg
Exposure frequency (EF) (days/year)	350	350
Exposure duration (ED) (years)	6	30
Ingestion rate (IR) (mg/day)	200	100
Inhalation rate (IR_{air}) (m^3/day)	10	20
Skin surface area (SA) (cm^2)	2100 cm^2	5800 cm^2
Soil adherence factor (AF) (mg/cm^2)	0.2	0.07
Dermal Absorption factor (ABS)	0.1	0.1
Dermal exposure ratio (FE)	0.61	0.61
Particulate emission factor (PEF) (m^3/kg)	1.3×10^9	1.3×10^9
Conversion factor (CF) (kg/mg)	10-6	10-6
Average time (AT) (days) *For carcinogens*	365×70	365×70
For non-carcinogens	365×ED	365×ED

Results and Discussion

The concentrations (ppm) of Chromium (Cr), Zinc (Zn), Iron, Cadmium (Cd) and Copper (Cu) in soil samples from Maiganga coal mine and Kumo in Akko Local Government Areas are depicted in Table 3 and 4 respectively.

The results show that Iron (Fe) is the most abundant nutritionally essential metal in soil samples, ranging from 79.702 to 101.295 ppm in the soil samples from Maiganga coal mine and 66.960 to 92.062 ppm in soil samples from Kumo. The permissible limit according to FAO/WHO (2001) is 425.00 ppm which is above values obtained from samples from both sample sites, hence, it can be said to be safe for use for human use either for agriculture or other use.

Cadmium concentration in soil samples range from Not Detected (ND) to 0.032 ppm in Maiganga coal mine and range from Not Detected (ND) to 0.010 ppm in Kumo. Cd concentrations in soil samples from both sites were below the standard limit of 0.2 mg/kg set by FAO/WHO (2001). Hence it can be safe for use by human for different purposes.

Chromium (Cr) is more available in the soils samples obtained from Maiganga coal mine than ones taken from Kumo while these differences may be attributed to the mining activities in Maiganga coal mine. The Cr concentrations varies from 0.447 to 0.928 ppm among the soil samples from Maiganga and vary from 0.086 to 0.567 ppm from Kumo. The (FAO/WHO) Standards for Cr in the soils is 100 mg/kg. Soil samples (M1, M2, M4 and M5) from Maiganga coal mine and soil samples (K1, K2, K3) investigated in this study exceeded the EU permissible limits for Chromium which makes it safe for use for agricultural purposes or exposure

Zinc concentrations in this study ranges from 0.088 to 5.455 ppm for soil samples from Maiganga coal mine and from 0.945 to 10 ppm for soil samples from Kumo. Although some soils samples obtained from Maiganga did not detect Zn. The Zn concentrations in this study did not exceed the permissible limits of 60 mg/kg (WHO/FAO, 2007). Hence it is said to be safe.

The values of Cu in soil range from 0.217 to 1.120 ppm in soil samples from Maiganga and range from 0.174 to 0.819 ppm in soil samples from Kumo. Comparing both values it can be seen that high concentration of Cu was obtained from the coal mine site.

Table. 3 Heavy metal levels in the soil samples from Maiganga coal mine and International threshold values for heavy metal concentration in soils (ppm)

Sample	Site	Fe	Cd	Cr	Zn	Cu	GPS COORDINATES
M1	Maiganga	80.465	ND	0.687	ND	0.346	Lat. 10^{0} 2^{1} $50.64^{''N}$ Long. 11^{0} 12^{1} $23.54^{''E}$ Alt.: 399m
M2	Maiganga	101.265	0.032	0.928	0.088	1.120	Lat. 10^{0} 2^{1} $52.93^{''N}$ Long. 11^{0} 12^{1} $24.85^{''E}$ Alt.: 399m
M3	Maiganga	81.380	ND	0.206	1.137	0.303	Lat. 10^{0} 2^{1} $46.90^{''N}$ Long. 11^{0} 12^{1} $26.11^{''E}$ Alt.: 399m
M4	Maiganga	94.962	0.010	0.928	5.455	0.819	Lat. 10^{0} 2^{1} $53.62^{''N}$ Long. 11^{0} 12^{1} $31.99^{''E}$ Alt.: 413m
M5	Maiganga	79.702	ND	0.447	ND	0.217	Lat. 10^{0} 2^{1} $57.49^{''N}$ Long. 11^{0} 12^{1} $35.22^{''E}$ Alt.: 399m
6	Control	425.00	0.20	100	60.00	10.00	

***ND= Not Detected**

Table 4. Heavy metal levels in the soil samples from Kumo and International threshold values for heavy metal concentration in soils (ppm)

Sample	Site	Fe	Cd	Cr	Zn	Cu	GPS COORDINTES
K1	Kumo	92.062	0.010	0.567	10.083	0.819	Lat. 9^{0} 59^{1} $26.60^{''N}$ Long. 11^{0} 9^{1} $20.54^{''E}$ Alt.: 426m
K2	Kumo	85.195	ND	0.326	6.445	3.100	Lat. 9^{0} 59^{1} $25.48^{''N}$ Long. 11^{0} 9^{1} $18.64^{''E}$ Alt.: 425m
K3	Kumo	78.634	ND	0.326	2.690	0.174	Lat. 9^{0} 59^{1} $18.81^{''N}$ Long. 11^{0} 9^{1} $18.91^{''E}$ Alt.: 426m
K4	Kumo	75.734	ND	0.206	0.945	0.217	Lat. 9^{0} 59^{1} $31.25^{''N}$ Long. 11^{0} 9^{1} $19.13^{''E}$ Alt.: 422m
K5	Kumo	66.960	ND	0.086	2.867	0.303	Lat. 9^{0} 59^{1} $39.94^{''N}$ Long. 11^{0} 9^{1} $19.54^{''E}$ Alt.: 421m
6	Control	425.00	0.20	100	60.00	10.00	

***ND= Not Detected**

Human Health Risk Assessment

It is clearly shown from table 5 that the adult population in Maiganga coal mine community and Kumo town, calculated HQ values for all metals were below 1, also HI values of all the pathways were less than one , which shows that the population of adult in these communities were not at risk of non-carcinogenic effects. While HQ values for children population from tables 5 clearly shown that only two sites (M4 and K4) out of ten sites have HQ above one. Also HI values from three different sites were found to be more than one. This may pose a very high non cancer heath risk to the children living around the two mining communities.

Table 5. Carcinogenic and Non-carcinogenic Risk of HM for Child and Adult

Samples	HI Adult	HI Children	HQ Adult	HQ Children
M 1	0.564	1.098	0.754	0.456
M 2	0.902	0.987	0.654	0.978
M 3	0.965	0.954	0.897	0.876
M 4	0.661	0.876	0.909	1.098
M 5	0.129	0.892	0.919	0.912
K 1	0.867	0.678	0.689	0.891
K 2	0.923	1.876	0.231	0.798
K 3	0.789	0.912	0.897	0.945
K 4	0.450	1.943	0.901	1.187
K 5	1.089	0.896	0.675	0.967

Conclusion

Based on the results from the present study, it can be concluded that mining activities contribute to elevate level of heavy metals in surrounding soils of the mining areas. Considering the health hazards from the accumulation of heavy metals, especially the high level of copper in this study, it is necessary to monitor the consumables grown around mining sites and environs. The present study provides a good basis for further research on the impact of mining and its various processes to the environment. There is a great need for educationist, environmentalist, and other interested stakeholders to have a keen interest in the operations of artisanal as well as small and large scale mining so as to address the problems caused by their operations. Based on the WHO and USEPA acceptable standards of heavy metals in soil and the findings of this research, it can be concluded that the soils of Maiganga have higher levels of Cd and the levels of Cr, Cu, Fe and Zn compared to that of Maiganga although they are all within the recommended standards.

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