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Health risk of heavy metal exposure in vegetable around owukpa coal mine field, north central Nigeria

G.G Yebpella, R.O.A Adelagun, Michael A. Abakpa * and Johnson Gani

Department of Chemical Science, Federal University Wukari, P.M.B 1020 Wukari Katsina- Ala Road Wukari, Taraba Stata.

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Abstract

The evaluation of trace metals in the environmental around Owukpa coal mine field, Ogbadibo Local Government Area, Benue State Nigeria was carried out to evaluate the degree of contamination due to mining activity in the area. The mean concentration of selected heavy metals (Ni, Fe, Cd, Cr, Pb and Mn) in Vegetables (*Vernonia amygdalina*) around coal mines were investigated. Results of the atomic absorption spectrophotometric (AAS) were as follows Ni (4.47), Fe (29.18), Cd (1.27), Cr (3.76), Pb (4.64), and Mn (12.84) with a variation pattern in the order: Fe>Mn>Pb>Ni>Cr>Cd. It was observed that the trend of EDIs for heavy metals in the samples were in the order of Fe > Mn > Pb > Ni > Cr > Cd. The HRIs of Ni, Cd, Cr and Pb were higher than 1 (HRI > 1), with Carcinogenic Risk values of Cd (0.0668), Cr (0.0157), Fe (0.2432), Mn (0.1070), Ni (0.0340), and Pb (0.0003), respectively.

Keywords: Heavy metals; Carcinogenic; Pollution; Concentration and Vegetables

1. Introduction

The Pollution of the environment has over the years gained increase at alarming rate due to different natural and anthropogenic (industrial) activities (Dontala *et al*., 2015). Several of these pollutants are persistent and accumulate beyond the permissible limits. They are very toxic to biological system and may be accumulated to higher trophic levels through food chain contamination (Iftikhar*et al*., 2017).

Heavy metals have the potential to accumulate and migrate in the soil environment. Metal pollutants in soil are absorbed by the plants through their roots and vascular system. Accumulation of metals in soil could pose a threat to animals, plants, and human and affect the ecosystem safety (Codex, 2015). High content of metals in the plant could inhibit the ability of the plant to produce chlorophyll, increase the plant oxidative stress and weaken stomata resistance (Ashraf *et al*., 2011). Unnaturally occurring heavy metals such as cadmium (Cd) and chromium (Cr) may suppress the growth of a plant, whether the pollution comes from soil or air (Enetimi and syvester, 2019). Perchance heavy metals can enter human bodies via the food chain, leading to increment of chronic diseases such as cancer and affecting the central nervous system, particularly in children (Zhao *et al*., 2009).

Plants growing at the roadside might be exposed to high levels of metal contamination, especially through vehicle emissions and trace content in the air (Al-Ashkar, 2007). Heavy metal from traffic emission might accumulate in roadside plants from the soil (Feng *et al*., 2011). Heavy metals from activities involving traffic could accumulate in the soil before being absorbed by plant roots. Because heavy metals are resistant and stay in the plant for a long time (Boularbah*et al*., 2006), they may be transferred to humans via the food chain (Zhang *et al*., 2018). The bioavailability of heavy metals is primarily affected by the soil's plant species (Koz and Cevik 2014; Keshavarzi *et al*., 2015; Zhao and Duo 2015) and physical-chemical properties (Liu *et al*., 2007). Some species of roadside plants are edible while others can be used for medicinal purposes (Chandrashekara and Thasini 2016). Certain species such as Chromolaenaodorata (CO) is known to be used for medicinal purposes and Athyriumesculentum (AE) are edible (Roslan *et al*., 2016).

* Corresponding author: Michael A Abakpa

2. Material and methods

2.1. Map of the Study Area

The study area is located within latitudes 6° 30' and 7° 26'N and longitudes 7° 10' and 7° 30'E. Owukpa is a district situated in Ogbadibo Local Government Area, Benue State Nigeria. It shares boundary with Obollo Eke in Udenu Local Government Area, Enugu State while Orokam borders Owukpa in the West and covers an area of about 1286 km^2. The study area has a tropical sub-humid climate, with two distinct seasons, namely wet and dry season. The wet season lasts for seven months, starting from April to October. The annual rainfall total ranges from (1,200 to 1500) mm.

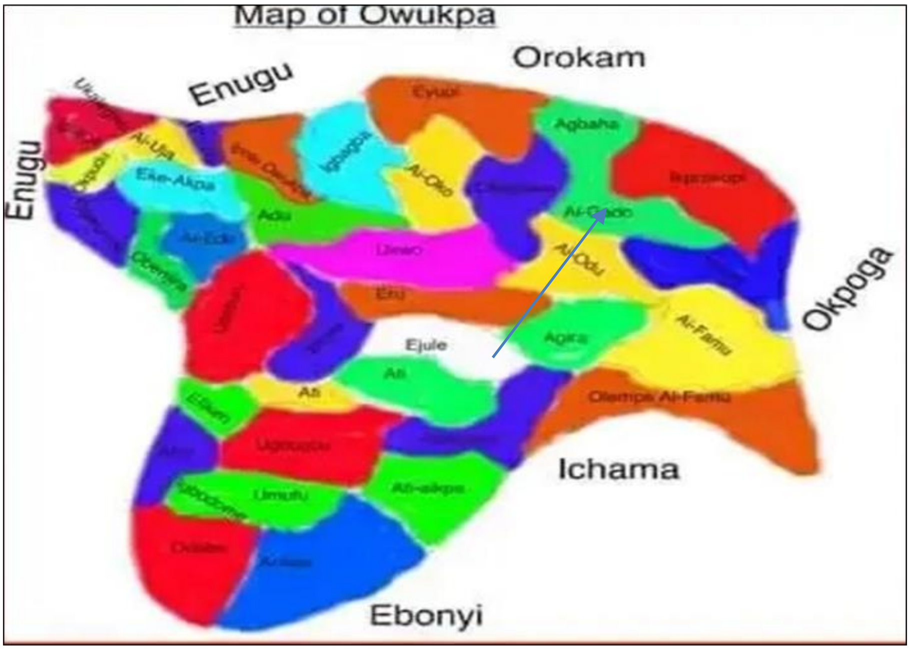

Figure 1 Map of Owukapa Showing neighbouring Communities and States

Temperatures are generally very high during the day, particularly in March and April. The region records average maximum and minimum daily temperatures of 35 °C and 21 °C in summer and 37 °C and 16 °C in winter, respectively. The meta-sediments are dominantly sand stone, but also contain shale, siltstone, limestone and quartzite. The residents of the study area depend solely on water from the nearby rivers, streams and well for domestic uses such as drinking, bathing, washing etc. and for irrigation purpose in the dry season and rain water in the rainy season. (Sesugh *et al.,* 2021).

2.2. Sample Collection and Pretreatment

A total of ten (10) representative vegetable (*Vernonia amygdalina*) samples were collected from 10 (ten) different farms in Owukpa coal mine area at a distance of 50 m from each other. Samples were labelled VSA – VSJ while the control sample was collected from Orokam at a distance of 2 km from the coal mine area, the sample was labelled VCS. The samples were wrapped in a big brown labeled envelope before taking them to the laboratory. Each sample was washed with distilled water and then dried in an oven at 80°C for 72 hrs to ensured proper drying. The oven was allowed to cooled, and each sample was grounded into a fine powder with the aid of mortar and pestle. The grounded samples were sieved with 2 mm mesh size and the samples were finally stored in a 250 cm^3 screw capped plastic jar appropriately labeled (Sharma *et al*., 2015).

2.3. Sample Preparation and Digestion

The method used was adopted from Ji *et al*., (2017) in which 0.5 g of the powdered sample was weighed into a 100 cm^3 kjeldahls flask and 20 cm^3 of Nitric Acid (HNO_3), 2 cm^3 of $HClO_4$ and 1 cm^3 H_2SO_4 were added. The solution was heated at 90 °C slowly in a fume cupboard for 1 hr to ensure complete escape of the brown fumes, the remaining solution was allowed to cool. It was then filtered into a 100 cm^3 storage container and the filtrate was made up to mark with deionized water and analyzed with AAS (Bohr's model). Similar procedure was repeated for other samples.

3. Results

The results of heavy metals concentration in this study areas were represented in table 1 below. The results are expressed in mean ± standard deviation of triplet determination as mg/kg. Results with same alphabet superscript show no significant difference while results with different alphabet superscript within the row show significant difference at $p < 0.05$. Where VCS represent Vegetable sample from control area while VSA to VSJ represent Vegetable samples A to J from coal mine areas. The trend of heavy metals occurrence in the vegetable were in the order Fe > Mn > Pb > Ni > Cr >Cd as presented in table 1. Similar trend in the following metals Mn > Ni > Cd was reported by Moyo et al., (2020) in vegetable obtained from Thohoyandou town area, South Africa.

Table 1 Concentration (mg/kg) of heavy metals in vegetables around Owukpa Coal Mine field

SAMPLE	Cd	Cr	Fe	Mn	Ni	Pb
VCS	$1.82{\pm}0.03^{b}$	ND	$25.20{\pm}0.00^{d}$	$25.86{\pm}0.09^{e}$	$4.33{\pm}0.03^{c}$	ND
VS1	$1.21{\pm}0.04^{b}$	ND	$18.95{\pm}0.01^{f}$	$12.15{\pm}0.06^{e}$	$3.48{\pm}0.00^{d}$	$2.90{\pm}0.10^{c}$
VS2	$1.29{\pm}0.04^{b}$	$30.49{\pm}0.01^{e}$	$62.10{\pm}0.02^{f}$	$9.00{\pm}0.07^{d}$	$4.62{\pm}0.00^{c}$	ND
VS3	$1.53{\pm}0.00^{b}$	$5.65{\pm}0.00^{d}$	$12.58{\pm}0.02^{f}$	$11.98{\pm}0.02^{e}$	$4.68{\pm}0.02^{c}$	ND
VS4	$1.46{\pm}0.01^{a}$	$6.05{\pm}0.00^{c}$	$26.31{\pm}0.00^{f}$	$15.83{\pm}0.06^{e}$	$4.51{\pm}0.00^{b}$	$6.73{\pm}0.00^{d}$
VS5	$1.27{\pm}0.00^{b}$	$4.05{\pm}0.01^{c}$	$38.61{\pm}0.00^{f}$	$12.92{\pm}0.01^{e}$	$4.66{\pm}0.01^{d}$	ND
VS6	$1.25{\pm}0.00^{b}$	ND	$15.50{\pm}0.01^{f}$	$10.15{\pm}0.03^{e}$	$4.90{\pm}0.00^{c}$	$5.22{\pm}0.14^{d}$
VS7	$1.10{\pm}0.02^{a}$	$2.08{\pm}0.00^{b}$	$38.60{\pm}0.00^{f}$	$30.94{\pm}0.01^{e}$	$4.53{\pm}0.00^{c}$	$5.85{\pm}0.06^{d}$
VS8	$1.18{\pm}0.00^{b}$	$5.98{\pm}0.00^{e}$	$40.99{\pm}0.00^{f}$	$3.48{\pm}0.00^{c}$	$3.90{\pm}0.00^{d}$	ND
VS9	$1.25{\pm}0.00^{a}$	$2.04{\pm}0.00^{b}$	$25.54{\pm}0.01^{f}$	$13.52{\pm}0.04^{d}$	$4.65{\pm}0.01^{c}$	$19.78{\pm}0.00^{e}$
VS10	$1.11{\pm}0.03^{a}$	$1.30{\pm}0.00^{b}$	$12.64{\pm}0.00^{f}$	$8.43{\pm}0.00^{e}$	$4.80{\pm}0.01^{c}$	$5.94{\pm}0.00^{d}$
Mean±SD	1.27±0.01	3.76±0.00	29.18±0.01	12.84±0.03	4.47±0.00	4.64±0.03
Range	1.10 - 1.53	1.30- 30.49	12.58-62.10	3.48 - 30.94	3.48 - 4.90	2.90 - 19.78

VCS = Vegetable control sample, VS = Vegetable sample, ND = not detected

Table 2 Estimated Daily Intake / Carcinogenic risk of Heavy Metals in, Vegetable samples

Experimental Plot	Estimated Daily Intake	Carcinogenic risk	Health Risk index (HRI)
Cd	0.0106	0.0668	10.6000
Cr	0.0313	0.0157	10.4330
Fe	0.2432	0.2432	0.3470
Mn	0.1070	0.1070	0.7640
Ni	0.0373	0.0340	1.8650
Pb	0.0387	0.0003	11.0570

4. Discussion

4.1. Cadmium concentrations (mg/kg) in vegetable sample

The concentrations of Cd in vegetables were found to be highest in the control area VCS (1.53 mg/kg) and lowest in VSJ (1.09 mg/kg) with mean content of 1.31±0.01 (mg/kg). The values were above 0.82 mg/kg in tomatoes obtained in Edo State (Idowu, 2020). The mean concentration of Cd in this work was found to be above the permissible limit of 0.20 FAO/WHO 2018). This could be as result of leaking sewage sludge from the mining site. Similar investigation was carried out on vegetables and fruits in Maharashtra, India with mean concentration of Cd (0.02±0.1 mg/kg) which was within the permissible limit (Govind *et al*., 2022). Cadmium is a non-essential element and has no advantageous role and no nutritious ability in plants and animals including humans. According to Kabata-Pendias (2000), Cd can alter the uptake of minerals by plant, Cd concentration in soil between 5 to 30 mg/kg could cause injury to most plant species. Stomata opening, transpiration and photosynthesis have been reported to be affected by Cd.

4.2. Chromium concentrations (mg/kg) in vegetable sample

Chromium concentrations (mg/kg) in each of the samples analyzed were all detected except in samples VCS, VSA and VSF which were below the detectable limit of 0.001 mg/kg (Yebpella *et al*., 2014). Cr is a toxic metal that can cause severe health challenge to plants and animals whether at low or high concentration. Cr content vary from 1.30 to 30.50 (mg/kg) among the vegetable samples analyzed (table 1) with mean concentration of 5.24±0.01 mg/kg. The mean value reported in this work was also found to be lower than 1.01, 1.34 and 2.14 (mg/kg) as reported for artisanal mining site of Dilimi, Bukuru and Barkin Ladi North Central Nigeria respectively (Orisakwe *et al*., 2018). The mean concentration of Cr in the present work is higher than the FAO/WHO (2006) acceptable limit of 0.2 mg/kg in vegetables (Bett *et al*., 2019). At low concentration, Cr is known to cause hyperglycemia, elevated body fat, and decreased sperm count (Girigisu *et al*., 2020). Although chromium is known to be toxic and detrimental to plant growth and development, some plants species (hyper-accumulators) could accumulate a reasonable amount of Cr without showing any morphological symptoms (Adamu *et al*., 2015).

4.3. Iron concentrations (mg/kg) in vegetable sample

The concentration of Fe was found to be highest in sample VSB (62.10 mg/kg) and lowest in VSC (12.58 mg/kg) with mean value of 29.18±0.01 (mg/kg). From previous literature, Koleleni, and Tafisa (2019) reported Fe concentration of 620 mg/kg which is 21.5 times higher than Fe content obtained in this work. The mean concentration of Fe from this study was lower than the permissible limit of 425.50 (FAO/WHO 2008), this could be an indication that the level of Fe in vegetables grown near the vicinity of coal mine may not be toxic to plants, animals and humans inclusive. Iron is the most crucial element for growth and survival of almost all living organisms (Valko *et al.*, 2005).

4.4. Manganese concentrations (mg/kg) in vegetable sample

Mn was found to be present in all the samples in the study area, with the highest concentration (mg/kg) in VSG (30.94 mg/kg), the lowest concentration in VSH (3.48 mg/kg) and the mean value of 12.84±0.03 (mg/kg) (Table 1). Yebpella *et al.,* (2011) reported a mean concentration of 17 mg/kg in vegetable grown in irrigated farm along River Kubani, which was higher than 14.02 obtained in the present work. The level of Mn in the control area was higher than those obtained near the mine fields, this show that the source of Mn contamination of vegetable may not be attributed to the mining activities rather the geology of the area or other anthropogenic sources. The average daily consumption of Mn ranged from 2.0 to 8.8 mg/kg/day (WHO, 2018). The mean concentration of Mn found in the vegetable samples was above the permissible daily intake, this implies that the vegetables could satisfy the health effects suggested for the accumulation of Mn. According to Jarup (2003), high concentration of manganese (Mn) causes hazardous effects on lungs and brains of humans.

4.5. Nickel concentrations (mg/kg) in vegetable sample

The concentration (mg/kg) of Ni was found to be highest in VSF (4.90±0.00) mg/kg and lowest in VSA (3.48±0.00) mg/kg, with the mean concentration of 4.47±0.01 mg/kg as shown in table 1. From literature, Girigisu *et al.,* (2020) reported a mean concentration of 13.11 mg/kg which is relatively higher compare to each concentration of Ni in Vegetable sample obtained in this study. The mean concentration of Ni in this study is lower than the permissible limit of 67.9 (WHO/FAO, 2008). This may imply that Ni content of the vegetable in the study area may not be toxic nor have possible health effect when consumed by humans. Plants are known to accumulate nickel and as a result the nickel update from vegetable may be notable (Adamu *et al*., 2015).

4.6. Lead concentrations (mg/kg) in vegetable sample

Pb was not detected in sample VCS, VSB, VSC, VSE and sample VSH (Table 1). The highest concentration of Pb (mg/kg) was recorded in VSI (19.78 mg/kg) and the lowest in VSA (2.90 mg/kg) with the mean value of 4.64±0.03 (mg/kg) (Table 1). Yebpella *et al.,* (2014) reported a mean concentration of 31.26 mg/kg on Irrigated Vegetable Food Crops Consumed in Zaria which was 7 times higher than the mean value (4.64 mg/kg) reported in this present work this might be due to the fact that some phosphate and micronutrient fertilizers contain elevated levels of arsenic, cadmium and lead. The samples analyzed contain relatively high level of Pb than the FAO/WHO acceptable limit of 0.3 mg/kg (WHO, 2008; Castro-González., *et al*., 2017). The level of Pb in the control area was lower than those obtained near the mine fields, this suggest that the source of Pb contamination of vegetable may be attributed to the mining activities in the area. The consumption of vegetables grown near coal mines may cause disruption of the biosynthesis of hemoglobin and anemia, rise in blood pressure, kidney damage, miscarriages and subtle abortions, disruption of nervous systems and brain damage due to the high concentration of Pb in the environment (Tasrina *et al.,* 2015).

4.7. Carcinogenic Risk

The cancer risk (CR) was calculated by multiplying the average daily intake (in mg/(kg¨ day) over a lifetime) with a cancer slope factor (SF) presented in table 2. Cancer Risk is estimated as the incremental probability of an individual developing cancer over a lifetime (Bianchini *et al*., 2002; Kamińska *et al*., 2015). Acceptable risk levels for carcinogens range from 10^{-4} (risk of developing cancer over a human lifetime is 1 in 10000) to 10^{-6} (risk of developing cancer over a human lifetime is 1 in 1000000) (USEPA, 2010). For example, a CR of 10^{-4} indicates a probability of 1 in 10,000 individuals developing cancer. Table 2 shows Carcinogenic Risk values of Cd (0.0668), Cr (0.0157), Fe (0.2432), Mn (0.1070), Ni (0.0340), and Pb (0.0003), respectively, all greater than 10^{-4}, samples indicating a high potential carcinogenic risk in vegetables. Among the six investigated metals, Mn, Cd, Cr, and Ni were of greatest concern for their carcinogenicity (Stevens *et al*., 2011, Wang *et al*., 2015). According to the USEPA, a one to one hundred in a million chance of additional human cancer over a 70-year lifetime (10^{-6} – 10^{-4}) is regarded as an acceptable or inconsequential risk (USEPA, 2010).

4.8. The Health Risk Index (HRI)

The Health Risk Index (HRI) has been recognized as a useful indicator for evaluation of risk associated with the consumption of metals in contaminated food (Sridhara *et al*., 2008, Oluwole *et al*., 2013; Ihedioha *et al*., 2016). The health risk assessment in this study was done for some metals (Ni, Fe, Cr, Cd, Pb and Mn) as shown in table 2. The HRIs of Ni, Cd, Cr and Pb (for Vegetable Samples) were higher than 1 (HRI > 1), indicating high risk of heavy metal contamination. According to Khan *et al*., (2009), if the value of HRI is less than 1 (HRI < 1), the health risk to the population is considered acceptable. On the other hand, if the HRI is equal or greater than 1 (HRI ≥ 1) the population is exposed to unacceptable health risk (Okunola *et al*., 2011).

5. Conclusion and Recommendation

The concentrations of iron (Fe) and nickel (Ni) in the vegetable test samples were comparatively lower than the permissible limits of FAO/WHO (2008) for plants. Fe was found to have a significant correlation with Cr, this suggest that their contamination could be influenced by the coal mining activities or geology of the study area. This call for frequent research to determine the level of these metals on other components such as soil, water, air etc. around the study area.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that there is no conflict of interest.

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