Oncological Effects Accumulation of Heavy Metals in Bassa, Plateau State, Nigeria

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Abstract

Carcinogenic substances induce tumors, increase incidence or malignancy or shorten the time of tumor occurrence when they get into the body through inhalation, injection, dermal application or ingestion. This work unveils the accumulation of heavy metals in Bassa using XRF. The results of this study showed that the Geo-Accumulation Index (I_{geo}) of water for different heavy metals decreased in the order of Cr and Cd0.2)>As(0.085) >Pb(-0.11)>Ni(-0.7) Which is within the World Health Organization (WHO) recommended limit. Soil for all heavy metals has the total value of 0.3. The edible plants for different heavy metals decreased in the order of Cd(0.52)>Pb(0.28)>Cr(0.10)>Ni(0.06)>As(-0.16). 72% of these points are uncontaminated, except few points which are found within the uncontaminated to moderately contaminated level. It is concluded that the area falls within uncontaminated-moderately contamination which calls for regulation. Hence this study can be used as a reference for regulatory bodies like NNRA and the rest.

Keywords: *Heavy Metals; Soil; Plant; Water; Contamination Factor.*

Introduction

Carcinogenic substances are those that induce tumours (benign or malignant), increase their incidence or malignancy or shorten the time of tumour occurrence when they get into the body through inhalation, injection, dermal application or ingestion (Balabanova *et al.*, 2014; Bi *et al.*, 2006). Carcinogens are classified as either genotoxic or nongenotoxic depending on their modes of action (Filipović-Trajković *et al.*, 2012). Genotoxic carcinogens are those which initiate carcinogenesis by direct interaction with DNA, resulting in DNA damage or chromosomal aberrations that can be detected by genotoxicity tests (Freitas *et al.*, 2004; Guala *et al.*, 2001). On the other hand, nongenotoxic carcinogens are agents that indirectly interact with the DNA, causing indirect modification to DNA structure, amount, or function that may result in altered gene expression or signal transduction (Ibrahim *et al.*, 2014; Waida *et al.*, 2022a). Substances that induce tumours in animals are also considered human carcinogens until proven otherwise (Waida *et al.*, 2022b). All known human carcinogens that have been evaluated adequately in animal bioassays have been found to be also carcinogenic

in animal bioassay studies. In fact, it has been reported that of the nearly 100 known genotoxic and non-genotoxic human carcinogens, one-third were shown first to be carcinogenic in animals (Waida *et al.*, 2022c). Other studies have demonstrated a strong correlation between carcinogenic potencies estimated from epidemiological data and those from animal carcinogenesis bioassays (Rilwan *et al.*, 2020; Waida *et al.*, 2022d). These observations have been used as guidelines to avoid human exposure to such chemicals found to be carcinogenic in laboratory animals (Jolly *et al.*, 2013). According to evaluations done by the International Agency for Research on Cancer (IARC), carcinogenicity data reviewed of various trace elements are classified as reported by Kouamé *et al.* (2013) as: (i) sufficient, when a casual association is established between exposure to an agent and human cancer; (ii) limited, when an association has been observed but chance, bias, and confounding cannot be ruled out and (iii) inadequate, when the data are of insufficient quality, consistency or statistical power to allow a conclusion (Krstic *et al.*, 2007). The degree of solubility of chemical exposure, which influences biological effects as well as the long- or short-term experimental studies must be considered while deciding carcinogenicity classifications (Mmolawa *et al.*, 2011). Certain trace elements like zinc and selenium have been found to have anti-carcinogenic effect where as others tend to be carcinogenic in specific organs while showing no such effect in certain organs (Moore *et al.*, 2013; Naser *et al.*, 2011). No formal evaluation of anti-carcinogenic effects of these trace elements has been made by IARC. The carcinogenic capability of trace elements depends mainly on factors such as oxidation states and chemical structures. The oxidative concept in element carcinogenesis signifies that complexes formed by these elements, in vivo, in the vicinity of DNA, catalyze redox reactions, which in turn oxidize DNA (Ogunkunle *et al.*, 2013). The most significant effect of reactive oxygen species (ROS) in the carcinogenesis progression is DNA damage, which results in DNA lesions like strand breaks and the sister-chromatid exchange (Panuccio *et al.*, 2009). It has been estimated that approximately 29104 DNA damaging events occur in every cell per day (Rangnekar *et al.*, 2013); a major portion of these occur via ROS. Similarly, ROS damage results in lipid peroxidation and depletion of protein sulfhydryls. Even though the increase in oxidative DNA lesions has been frequently attributed to metal exposures, it is important to note that the molecular mechanism leading to tumor formation after such exposures is still not well understood (Rilwan *et al.*, 2021). The trace elements carcinogenesis is mediated either by the increased generation of ROS on the basis of ESR spin trapping studies or by interference with the repair process of DNA (Shamuyarira and Gumbo, 2014). Some oxygen species are worst carcinogenic molecules. There is a very fine balance between enzymatic [such as superoxide dismutase (SOD), glutathione peroxidase and catalase] and non-enzymatic (such as ascorbic acid, a-tocopherol, b-carotene and isoflavons) antioxidants and free radicals in each cell. When ROS production is higher than the cell reduction capabilities, they can induce lipid peroxidation, depletion of the sulfhydryl groups, change signal transduction pathways, calcium homeostasis and DNA damage (Tarradellas *et al.*, 1996). This may result in occurrence of aging effect and cancer infection.

Geo-accumulation Index (I_{geo})

This method assesses the trace elements accumulation in terms of seven (0 to 6) enrichment classes, ranging from background concentration to very heavily polluted according to Waida *et al.* (2022e) and Usman *et al*., (2020a) as follows:

$$I_{geo} = \log_2\left[\frac{C_s}{1.5xC_m}\right] = \frac{\log_{10}\left(\frac{CF}{1.5}\right)}{\log_{10} 2} = \frac{\log_{10}\left(\frac{CF}{1.5}\right)}{0.3} \quad 1$$

The factor 1.5 is introduced in the equation to minimize the effects of possible variations in the background values, CF equals contamination factor, C_s equals sample concentration and C_m equals background concentration (Usman *et al*., 2020b). The recommended World Average Values and Ranges of Geo-Accumulation Index are presented in Table 1.

Table 1. World Average Values and Ranges of Geo-Accumulation Index

I_{geo} Values	I_{geo} Class	Description of Soil Quality
>5	6	Extremely contaminated
4-5	5	Strongly to extremely contaminated
3-4	4	Strongly contaminated
2-3	3	Moderately to strongly contaminated
1-2	2	Moderately contaminated
0-1	1	Uncontaminated to moderately contaminated
0	0	Uncontaminated

The purpose of this work is to unveil the extent to which heavy metals (Ni, Cr, As, Cd and Pb) accumulates in soil, water and edible plants and assess their carcinogenic role to biological tissue that might result in cancer. This work will compare its results with the world standard limits and unveil whether the inhabitants of the study are liable to be affected by cancer in the long round or not.

Materials and Method

Materials

The materials that were used in carrying out this research includes Geo-positioning System meter (GPS meter) and X-Ray Fluorescence Spectrometry System (XRF).

Method

Study Area

Plateau is the twelfth-largest state in Nigeria. Approximately in the centre of the country, it is geographically unique in Nigeria due to its boundaries of elevated hills surrounding the Jos Plateau which is its capital, and the entire plateau itself (Waida *et al.*, 2022f).

Plateau State is celebrated as "The Home of Peace and Tourism". With natural formations of rocks, hills and waterfalls, it derives its name from the Jos Plateau and has a population of around 3.5 million people. Plateau State is located at North Central Zone out of the six geopolitical zones of Nigeria. With an area of 26,899 square kilometers, the State has an estimated population of about three million people. It is located between latitude 08°24'N and longitude 008°32' and 010°38' east. The state is named after the picturesque Jos Plateau, a mountainous area in the north of the state with captivating rock formations. Bare rocks are scattered across the grasslands, which cover the plateau. The altitude ranges from around 1,200 metres (3,900 ft) to a peak of 1,829 metres (6,001 ft) above sea level in the Shere Hills range near Jos. Years of tin and columbite mining have also left the area strewn with deep gorges and lakes (Waida *et al.*, 2022g).

Though situated in the tropical zone, a higher altitude means that Plateau State has a near temperate climate with an average temperature of between 13 and 22 °C. Harmattan winds cause the coldest weather between December and February. The warmest temperatures usually occur in the dry season months of March and April. The mean annual rainfall varies between 131.75 cm (52 in) in the southern part to 146 cm (57 in) on the Plateau. The highest

rainfall is recorded during the wet season months of July and August. The average lower temperatures in Plateau State have led to a reduced incidence of some tropical diseases such as malaria. The Jos Plateau makes it the source of many rivers in northern Nigeria including the Kaduna, Gongola, Hadeja and Damaturu rivers. The Jos Plateau is thought to be an area of younger granite which was intruded through an area of older granite rock, making up the surrounding states. These "younger" granites are thought to be about 160 million years old. This creates the unusual scenery of the Jos Plateau. There are numerous hillocks with gentle slopes emerging from the ground like mushrooms scattered with huge boulders. Also, volcanic activity 50 million years ago created numerous volcanoes and vast basaltic plateaus formed from lava flows. This also produces regions of mainly narrow and deep valleys and pediments (surfaces made smooth by erosion) from the middle of rounded hills with sheer rock faces. The phases of volcanic activities involved in the formation of Plateau State have made it one of the mineral rich states in the country. Tin is still mined and processed on the plateau (Waida *et al.*, 2022g).

Population Sample

The population of the study include all the notable towns where mining activities takes place within Bassa, Plateau State include 12 villages.

Sample Collection

Soil, water and vegetable samples were pair collected. A simple systematic random sampling technique was used to select twelve (12) soil sample, twelve (12) edible plant sample, and twelve (12) water samples from Bassa Local Government of Plateau State. Sixty (36) samples in all were analyzed in this study. Vegetables' rooted soil samples were taken at 0-20 cm depth. A composite sample composed of three (3) subsamples at each sampling site for water, vegetables and soils.

Soil Sample Collection

Twelve sample of soil from the Bassa Local Government of Plateau State was collected. The sample was collected by coring tool to a depth of 5 cm or to the depth of the plough line. The collected samples each of approximately 4 kg in wet weight was immediately transferred into a high-density polyethylene zip lock plastic bag to prevent cross contamination. Each sample was marked with a unique identification number (sample ID) for traceability and its position coordinates were recorded for reference purposes using GPS meter.

Edible Plant Sample Collection

Twelve edible plant samples were collected from the Bassa Local Government of Plateau State. The collected samples were immediately transferred into a high-density polyethylene zip lock plastic bag to prevent cross contamination. Each sample was marked with a unique identification number (sample ID) for traceability.

Water Sample Collection

Twelve water samples were collected from streams from the Bassa Local Government of Plateau State. The collected samples were immediately transferred into plastic containers and was well covered to avoid cross contamination. Each sample was marked with a unique identification number (sample ID) for traceability.

Edible Plant Sample Preparation

Only the edible part of each plant sample was used for analysis. The plant samples were washed with ultrapure water three times. After the water had evaporated, the plant samples

were weighed, oven-dried at 65 °C for 48 h, weighed again and then crushed into powder. The heavy metal concentrations in edible portions of plant was determined on a wet weight basis. The edible plant sample was taken for XRF analysis.

Soil Sample Preparation

All soil samples were naturally air-dried until constant weight is reached. The dried soil samples were homogenized with pestle in a mortar, and then passed through standard sieves 0.9 mm, 0.3 mm, and 0.15 mm for analysis of pH, organic matter (OM) and heavy metal contents, respectively. Soil pH were measured using a pH electrode and the ratio of solid: water was 1:2.5. OM contents of soil samples were determined using the loss on ignition method. The soil sample was taken for XRF analysis.

Water Sample Preparation

Water samples for heavy metals determination was acidified with two (2) drops of concentrated HNO_3; Samples for Dissolved oxygen determination was fixed with 2ml each of Manganese (II) sulphate solution (winkler A) and Alkali-iodide Azide reagent (Winkler B) per sample. These operations were carried out on the field. All samples were then placed in an ice-chest and taken to the laboratory on the same day. The digested water sample was taken XRF analysis.

Method of Results Analysis

Heavy Metals analysis was done using XRF analysis available at Centre for Solid Minerals Research and Development (CSMRD), Kaduna State Polytechnic, Kaduna State, Nigeria. The results obtained was used to assess the extent of the accumulation of these heavy metals in water, soil and plants through an index called the geo-accumulation index and can be with the aid of equation (1) as reported by Waida *et al.* (2022e) and Usman *et al*., (2020a).

Results and DiscussionResults

Table 2: Geo-Accumulation Index of Heavy Metals in Water of Bassa

H/M	Ni	Cr	As	Cd	Pb	Total
S/P			Bassa			
P01	-0.8	0.3	0.046	0.3	-0.65	**-0.69**
P02	-1.3	0.3	0.125	-0.1	0.046	**-0.87**
P03	-0.6	0.3	0.648	0.2	0.125	**0.734**
P04	-1.0	-0.1	0.347	0.6	0.046	**-0.04**
P05	-0.6	0.4	0.046	-0.1	0.347	**0.132**
P06	-0.8	-0.1	-0.35	0.2	-0.35	**-1.36**
P07	-0.2	0.2	-0.65	0.3	-0.18	**-0.41**
P08	-0.5	-0.4	0.347	0.6	0.125	**0.211**
P09	-0.8	0.3	0.046	0.3	-0.65	**-0.69**
P10	-0.6	0.3	0.648	0.2	0.125	**0.734**
P11	-0.8	-0.1	-0.35	0.2	-0.35	**-1.36**
P12	-1.3	0.3	0.125	-0.1	0.046	**-0.87**
Mean	**-0.7**	**0.2**	**0.085**	**0.2**	**-0.11**	**-0.37**

P = Points; Ni = Nickel; Cr = Chromium; As = Arsenic; Cd = Cadmium; Pb = Lead.

It was observed from Table 2 that the accumulation of heavy metals in water for Ni, Cr, As, Cd and Pb has the total of -0.7, 0.2, 0.085, 0.2 and -0.11 respectively.

It was observed from Table 2 that the total Geo Accumulation Index from Water Samples of Bassa Local Government Area is in descending order trend with P03 and P10 (0.734) > P08 (0.211) > P05 (0.132) > P04 (-0.04) > P07 (-0.41) > P01 and P09 (-0.69) > P02 and P12 (-0.87) > P06 and P11 (-1.36).

Table 3: Geo-Accumulation Index of Heavy Metals in Soil of Bassa

H/M	**Ni**	**Cr**	**As**	**Cd**	**Pb**	**Total**
S/P				**Bassa**		
P01	0.3	0.2	0.4	0.4	0.1	**1.4**
P02	0.2	0.3	0.1	0.3	0.3	**1.2**
P03	0.3	0.3	0.3	0.2	0.3	**1.4**
P04	0.1	0.2	0.1	0.3	0.3	**1.0**
P05	0.3	0.3	0.3	0.3	0.3	**1.5**
P06	0.3	0.3	0.2	0.1	0.3	**1.2**
P07	0.4	0.2	0.6	0.3	0.2	**1.7**
P08	0.4	0.3	0.3	0.2	0.2	**1.5**
P09	0.2	0.3	0.1	0.3	0.3	**1.2**
P10	0.1	0.2	0.1	0.3	0.3	**1.0**
P11	0.4	0.2	0.6	0.3	0.2	**1.7**
P12	0.3	0.3	0.3	0.2	0.3	**1.4**
Mean	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**1.3**

P = Points; Ni = Nickel; Cr = Chromium; As = Arsenic; Cd = Cadmium; Pb = Lead.

It was observed from Table 3 that the accumulation of heavy metals in water for Ni, Cr, As, Cd and Pb has the total of 0.3, 0.3, 0.3, 0.3 and 0.3 respectively.

It was observed from Table 3 that the total Geo Accumulation Index from Soil Samples of Bassa Local Government Area is in descending order trend with P04 and P10 (1.0) > P02, P06 and P09 (1.2) > P01, P03 and P12 (1.4) > P05 and P08 (1.5) > P07 and P11 (1.7).

Table 2: Geo-Accumulation Index of Heavy Metals in Edible Plants of Bassa

H/M	**Ni**	**Cr**	**As**	**Cd**	**Pb**	**Total**
Edible Plant				**Bassa**		
Zogale	0.06	0.15	-0.18	0.52	0.34	**0.889**
Kuka	-0.01	-0.10	-0.35	0.35	0.30	**0.176**
Rama	0.143	0.03	-0.18	0.52	0.20	**0.723**
Yateya	-0.04	0.19	-0.35	0.65	0.28	**0.733**
Alayyahu	0.17	0.17	-0.22	0.41	0.37	**0.896**
Shuwaka	0.27	0.09	-0.27	0.56	0.24	**0.885**
Yakuwa	-0.10	0.06	0.010	0.51	0.32	**0.798**
Karkashi	0.19	0.23	-0.18	0.56	0.27	**1.076**
Ugu	0.17	0.05	-0.09	0.58	0.33	**1.044**
Rogo	0.04	0.19	-0.12	0.44	0.21	**0.761**
Water Leaf	-0.17	0.11	-0.02	0.51	0.16	**0.583**
Kabeji	0.06	0.06	0.07	0.67	0.30	**1.162**
Mean	**0.06**	**0.10**	**-0.16**	**0.52**	**0.28**	**0.810**

It was observed from Table 4 that the accumulation of heavy metals in water for Ni, Cr, As, Cd and Pb has the total of 0.06, 0.10, -0.16, 0.52 and 0.28 respectively.
It was observed from Table 4 that the total Geo Accumulation Index from Edible Plant Samples of Bassa Local Government Area is in descending order trend with Kabeji (1.162) > Karkashi (1.076) > Ugu (1.044) > Alayyahu (0.896) > Zogale (0.889) > Shuwaka (0.885) > Yakuwa (0.798) > Rogo (0.761) > Yateye (0.733) > Rama (0.723) > Water Leaf (0.583) > Kuka (1.176).

1.1.1. Comparison of Results with World Health Organization (WHO)

The results presented on Table 2, Table 3 and Table 4 were used to plot charts in order to compare the results of the present study with World Health Organization (WHO) as seen in Figure 1, Figure 2 and Figure 3.

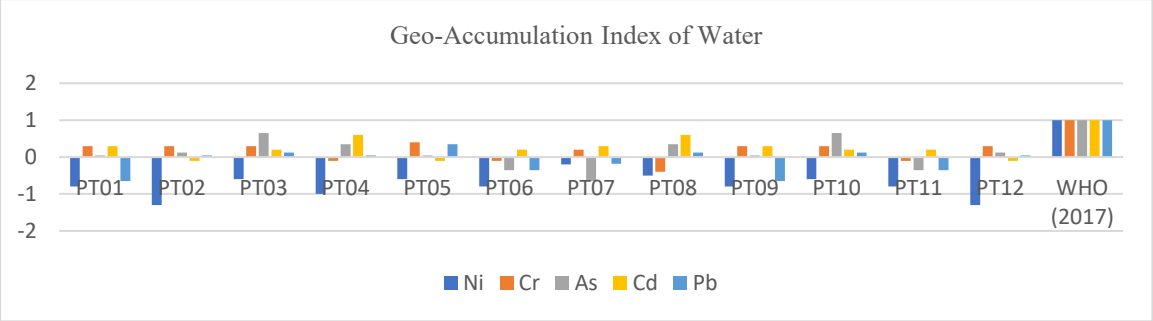

Figure 1: Comparison of Geo-Accumulation Index of Water with World Health Organization

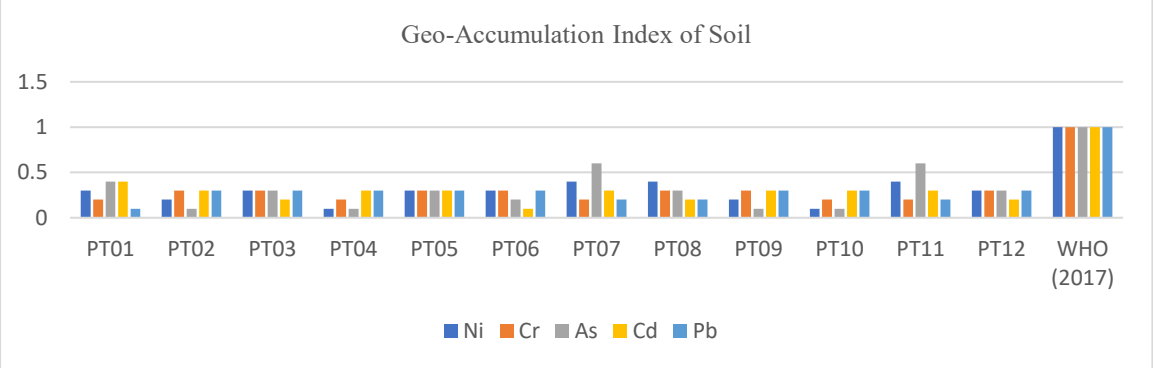

Figure 2: Comparison of Geo-Accumulation Index of Soil with World Health Organization

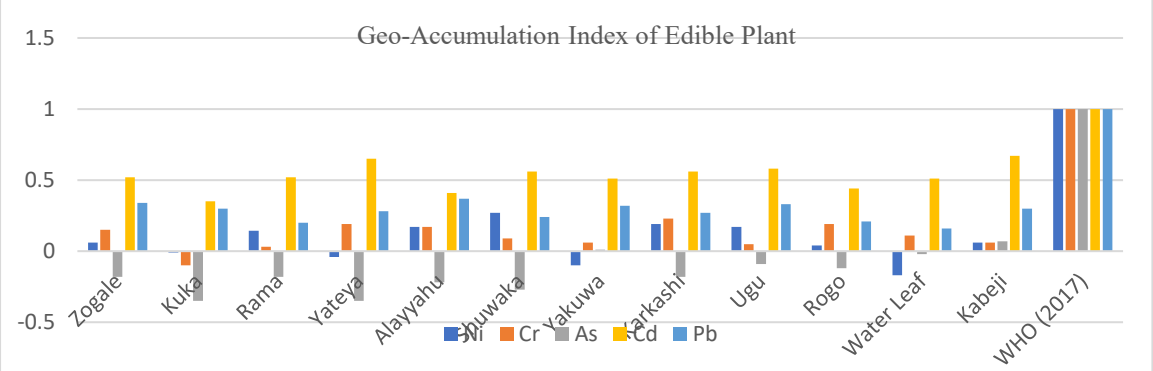

Figure 3: Comparison of Geo-Accumulation Index of Edible Plant with World Health Organization

Discussion

The results of this study showed that the Geo-Accumulation Index (I_{geo}) of water for different heavy metals (Ni, Cr, As, Cd and Pb) in all the sample points decreased in the order of P03 and P10 (0.734) > P08 (0.211) > P05 (0.132) > P04 (-0.04) > P07 (-0.41) > P01 and P09 (-0.69) > P02 and P12 (-0.87) > P06 and P11 (-1.36) with heavy metals decreasing in the order of Cr and Cd (0.2) > As (0.085) > Pb (-0.11) > Ni (-0.7).

Based on the chart presented in Figure 1, water has not been contaminated by Nickel (Ni) in all the points. The water is also not contaminated by Cadmium (Cd) in P02, P05 and P12, while other points are within uncontaminated to contaminated level. Figure 1 also showed that Chromium (Cr) in P04, P06, P08 and P11 has their values at uncontaminated level, whereas in other points, Chromium (Cr) are within uncontaminated to contaminated level. The same figure also showed that Arsenic (As) in P06, P07 and P11 has their values at uncontaminated level, whereas in other points, Arsenic (As) are within uncontaminated to contaminated level. Lastly, Figure 1 showed that Lead (Pb) in P01, P06, P07, P09 and P11 has their values at uncontaminated level, whereas in other points, Lead (Pb) are within uncontaminated to contaminated level considering the World Health Organization recommended value of $I_{geo} \leq 0$ as uncontaminated, $0 < I_{geo} \leq 1$ as uncontaminated to moderately contaminated, $1 < I_{geo} \leq 2$ as moderately contaminated, $2 < I_{geo} \leq 3$ as moderately to strongly contaminated, $3 < I_{geo} \leq 4$ as strongly contaminated, $4 < I_{geo} \leq 5$ as strongly to extremely contaminated and $I_{geo} > 5$ as extremely contaminated.

On the Geo-Accumulation Index (I_{geo}) of soil for different heavy metals (Ni, Cr, As, Cd and Pb) in all the sample points decreased in the order of P04 and P10 (1.0) > P02, P06 and P09 (1.2) > P01, P03 and P12 (1.4) > P05 and P08 (1.5) > P07 and P11 (1.7) with heavy metals decreasing in the order of Ni, Cr, As, Cd and Pb (0.3).

The chart presented in Figure 2 showed that, soil has not been contaminated by all heavy metals in all the points considering the World Health Organization recommended value of $I_{geo} \leq 0$ as uncontaminated, $0 < I_{geo} \leq 1$ as uncontaminated to moderately contaminated, $1 < I_{geo} \leq 2$ as moderately contaminated, $2 < I_{geo} \leq 3$ as moderately to strongly contaminated, $3 < I_{geo} \leq 4$ as strongly contaminated, $4 < I_{geo} \leq 5$ as strongly to extremely contaminated and $I_{geo} > 5$ as extremely contaminated.

On the Geo-Accumulation Index (I_{geo}) of edible plants for different heavy metals (Ni, Cr, As, Cd and Pb) in all the sample points decreased in the order of Kabeji (1.162) > Karkashi (1.076) > Ugu (1.044) > Alayyahu (0.896) > Zogale (0.889) > Shuwaka (0.885) > Yakuwa (0.798) > Rogo (0.761) > Yateye (0.733) > Rama (0.723) > Water Leaf (0.583) > Kuka (1.176) with heavy metals decreasing in the order of Cd (0.52) > Pb (0.28) > Cr (0.10) > Ni (0.06) > As (-0.16).

Lastly, the chart presented in Figure 3, edible plants has not been contaminated by Nickel (Ni) in Yateya, Yakuwa and Water Leaf, while other edible plants are within uncontaminated to contaminated level. Figure 3 also showed that Chromium (Cr) in Kuka has its value at uncontaminated level, whereas in other edible plants, Chromium (Cr) are within uncontaminated to contaminated level. Lastly, Figure 3 showed that Arsenic (As) in Yakuwa and Kabeji has their values at uncontaminated level, whereas in other edible plants, Arsenic (As) are within uncontaminated to contaminated level considering the World Health Organization recommended value of $I_{geo} \leq 0$ as uncontaminated, $0 < I_{geo} \leq 1$ as uncontaminated to moderately contaminated, $1 < I_{geo} \leq 2$ as moderately contaminated, $2 < I_{geo} \leq 3$ as moderately to strongly contaminated, $3 < I_{geo} \leq 4$ as strongly contaminated, $4 < I_{geo} \leq 5$ as strongly to extremely contaminated and $I_{geo} > 5$ as extremely contaminated.

Conclusion

Based on the results presented, 72 % of the area under investigation has their soil, water and edible plants at uncontaminated level considering the World Health Organization recommended value of $I_{geo} \leq 0$ as uncontaminated, $0 < I_{geo} \leq 1$ as uncontaminated to moderately contaminated, $1 < I_{geo} \leq 2$ as moderately contaminated, $2 < I_{geo} \leq 3$ as moderately to strongly contaminated, $3 < I_{geo} \leq 4$ as strongly contaminated, $4 < I_{geo} \leq 5$ as strongly to extremely contaminated and $I_{geo} > 5$ as extremely contaminated.

It can therefore be concluded that the soil, water and plants in the study area falls within the uncontaminated to moderately contaminated values which calls for serious concern and regulatory control especially for those points within moderate contamination level. Hence this study can be used as a reference data for regulatory bodies like NNRA and the rest.

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Reference

Balabanova, B., Stafilov, T., Šajn, R. & Bačeva, K. (2014). Comparison of response of moss, lichens and attic dust to geology and atmospheric pollution from copper mine. *International Journal of Environmental Science and Technology*. 11: 517-528.

Bi, X., Feng, X., Yang, Y., Qiu, G., Li, G., Li, F., Liu, T., Fu, Z. & Jin, Z. (2006). Environmental contamination of heavy metals from zinc smelting areas in Hezhang County, western Guizhou, China. *Environment International*. 32: 883- 890.

Filipović-Trajković, R., Ilić, S. Z. & Šunić, L. (2012). The potential of different plant species for heavy metals accumulation and distribution. *The Journal of Food, Agriculture and Environment*. 10: 959-964.

Freitas, H., Prasad, M.N.V. & Pratas, J. (2004). Plant community tolerant to trace elements growing on the degraded soils of São Domingos mine in the south east of Portugal: environmental implications. *Environment International*. 30: 65- 72.

Guala, S.D., Vegaa, F.A. & Covelo, E.F. (2001). The dynamics of heavy metals in plant-soil interactions. *Ecological Modelling*. 221: 1148-1152.

Ibrahim, A.K., Yakubu, H. & Askira, M.S. (2014). Assessment of heavy metals accumulated in wastewater irrigated soils and lettuce (Lactuca sativa) in Kwadon, Gombe State Nigeria. *American-Eurasian Journal of Agricultural & Environmental Sciences*. 14: 502-508.

Jolly, Y.N., Islam, A. & Akbar, S. (2013). Transfer of metals from soil to vegetables and possible health risk assessment. *Springer Plus*. 2: 385.

Kouamé, I.K., Kouassi, L.K., Dibi, B., Adou, K.M., Rascanu, I.D., Romanescu, G., Savané, I. & Sandu, I. (2013). Potential groundwater pollution risks by heavy metals from agricultural soil in Songon area (Abidjan, Côte d'Ivoire). *The Journal of Environmental Protection*. 4: 1441-1448.

Krstic, B., Stankovic, D., Igic, R. & Nikolic, N. (2007). The potential of different plant species for nickel accumulation. *Biotechnology & Biotechnological Equipment*. 21: 431-436.

Mmolawa, K.B., Likuku, A.S. & Gaboutloeloe, G.K. (2011). Assessment of heavy metal pollution in soils major roadside areas in Botswana. *African Journal of Environmental Science and Technology*. 5: 186-196.

Moore, F., Kargar, S. & Rastmanesh, F. (2013). Heavy metal concentration of soils affected by Zn-smelter activities in the Qeshm Island, Iran. *Journal of Sciences, Islamic Republic of Iran*. 24: 339-346.

Naser, H.M, Sultana, S., Mahmud, N.U., Gomes, R. & Noor, S. (2011). Heavy metal levels in vegetables with growth stage and plant species variations. *Bangladesh Journal of Agricultural Research*. 36: 563-574.

Ogunkunle, C.O., Fatoba, P.O., Awotoye, O.O. & Olorunmaiye, K.S. (2013). Root-shoot partitioning of copper, chromium and zinc in Lycopersicon esculentum and Amaranthus

hybridus grown in cement-polluted soil. *Environmental and Experimental Biology*. 11: 131-136.

Panuccio, M.R., Sorgonà, A., Rizzo, M. & Cacco, G. (2009). Cadmium adsorption on vermiculite, zeolite and pumice: batch experimental studies. *Journal of Environmental Manage*. 90: 364-374.

Rangnekar, S.S., Sahu, S.K., Pandit, G.G. & Gaikwad, V.B. (2013). Study of uptake of Pb and Cd by three nutritionally important Indian vegetables grown in artificially contaminated soils of Mumbai, India. *International Research Journal of Environmental Sciences*. 2: 1-5.

Rilwan U., Kamal, A.M., Mamman, A., Idris, M.M., Ubaidullah, A., Okara, O.G. & Ugwu, E.I. (2021). Health Implication of the Accumulation of Heavy Metals Concentration in Ara and Laminga Water Sources of Nasararawa Local Government Area in Nasarawa State, Nigeria. *NAUB Journal of Science and Technology (NAUBJOST)*. 1: 101-106.

Rilwan, U., Abbas, A.A. & Muhammad, S. (2020). Heavy Metal Contamination and Its Risk for Swampy Agricultural Soils of Keffi, Nasarawa West, Nigeria. *Asian Journal of Applied Chemistry Research*. 5: 1-11.

Shamuyarira, K.K. & Gumbo, J.R. (2014). Assessment of heavy metals in municipal sewage sludge: A case study of Limpopo Province, South Africa. *International Journal of Environmental Research and Public Health*. 11: 2569-2579.

Tarradellas, J., Bitton, G. & Russel, D. (1996). *Soil Ecotoxicology*. (ed) CRC Lewis Publisher, New York.

Usman, R., Abbas, A.A. & Hudu, A. (2020a). Heavy Metal Contamination in Swampy Agricultural Soils of Kokona, Nasarawa, Nigeria. *Asian Journal of Applied Chemistry Research*. 5: 28-33.

Usman, R., Kamal, A.M., Ugwu, E.I., Mustapha, I.M., Mamman, A. & Hudu, A. (2020b). "Assessment and Analysis of the Presence of Heavy Metals in Water in Ara and Laminga of Nasarawa State, Nigeria: Health Implication on the Populace". *The Pacific Journal of Science and Technology*. 21: 240-246.

Waida, J., Ibrahim, U., Goki, N.G., Yusuf, S.D. & Rilwan, U. (2022a). Transfer Factor of Heavy Metals due to Mining Activities in Some Parts of Plateau State, Nigeria (Health Implications on the Inhabitants). *Journal of Oncology Research*, 4(2), 13-26.

Waida, J., Ibrahim, U., Goki, N.G., Yusuf, S.D. & Rilwan, U. (2022b). Health Effects of Radiation Exposure to Human Sensitive Organs across Some Selected Mining Sites of Plateau State, Nigeria. *Journal of Oncology Research*, 4(2), 27-37.

Waida, J., Rilwan, U. & Ikpughul, S.I. (2022g). Geo-Accumulation Index of Radioactive Trace Elements (^{40}K, ^{226}Ra and ^{232}Th) Across Mining Sites of Barkin Ladi and Mangu, Plateau State, Nigeria. *Wat. Ener. Food. Env.*, 3(2), 13-25.

Waida, J., Rilwan, U., Galadima, O.O., Efe, O., Sawuta, J.M., Peter, E.O. & Rebecca, R. (2022c). Transfer of K^{40}, Ra^{226} and Th^{232} from Soil to Plants and Water Resulting from Mining Activities in Bassa, Plateau State, Nigeria (Health Implications on the Inhabitants). *J. Eco. Heal. Env.*, 10(2), 5-11.

Waida, J., Rilwan, U., Ismail, W.O., Yusuff, I.M. & Sunday, B.I. (2022e). Pollution Load Index of Heavy Metals Resulting from Mining Activities in Plateau State. Nigeria. *J. Rad. Nucl. Appl.*, 7(3), 57- 18.

Waida, J., Rilwan, U., Jafar, M., Alkasim, A. & Yuguda, H. (2022f). Contamination Factor of Radioactive Trace Elements (^{40}K, ^{226}Ra and ^{232}Th) due to Mining Activities in Barkin Ladi and Mangu, Plateau State, Nigeria. *Wat. Ener. Food. Env.*, 3(2), 1-12.

Waida, J., Rilwan, U., Rebecca, R., Peter E.O., Efe, O., Sawuta, J.M. & Galadima, O.O. (2022d). Contamination Factor of Radioactive Trace Elements (^{40}K, ^{226}Ra and ^{232}Th) due to Mining Activities in Bassa, Plateau State, Nigeria. *J. Eco. Heal. Env.*, 10(3), 13-20.

WHO (2017). *Trace elements in human nutrition: Manganese. Report of a WHO expert committee*. Geneva, World Health Organization, pp. 34–36 (Technical Report Series No. 532).

Yan, X., Zhang, F., Zeng, C., Zhang, M., Devkota, L.P. & Yao, T. (2012). Relationship between heavy metal concentrations in soils and grasses of roadside farmland in Nepal. *International Journal of Environmental Research and Public Health*. 9: 3209-3226.