Impact of Heavy Metals on the Environment and Human Health: A Comparative Analysis of Two Mining Communities in Niger State, Nigeria.

Aliyu Haruna Sani*, Amanabo Musa, Achimugu Dickson Musa

Department of Biochemistry, Ibrahim Badamasi Babangida University Lapai, Nigeria.

***Corresponding Author**

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ABSTRACT

Unregulated mining of precious metals has led to pollution in the environment and food chain, as well as outbreaks of poisoning in affected communities. However, there is limited evidence on the effect of heavy metals on the environment and health of communities in north-central Nigeria. This study investigated the comparative presence and concentration of some heavy metals, namely, arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn) in various samples collected from water sources, soils, staple food cultivars, and blood samples of inhabitants around Kataeregi and Kurebe mining communities in Niger State, Nigeria. The samples were collected using standard methods and digested using a tri-acid mixture and concentration of heavy metals was determined using Atomic Absorption Spectrometry (AAS). The analysis revealed the water and soil samples only showed exceeding levels in As, 0.017 mg/L; Hg, 0.014 mg/L; Pb, 0.004 mg/L; and As, 37.2 mg/kg, Cd, 6.7 mg/kg, and Hg, 1.1 mg/kg, respectively, in Kataeregi; and Cd, 0.023 mg/L; Hg, 0.012; and Hg, 0.315 mg/kg, respectively, in Kurebe. Heavy metal concentrations in staple food cultivars consumed at both mining sites were found to be within the permissible levels set by the WHO/FAO, except for As (1.72:1.82 mg/kg), Cd (0.41:0.09 mg/kg), Ni (0.41 mg/kg) and Hg (0.71 mg/kg) in cereals and vegetables from Kataeregi, and As (1.56 mg/kg), Hg (2.09 mg/kg), in legumes and Cd (0.43 mg/kg) in tubers from Kurebe. Also, significant elevations in the blood Pb, 11.2 µg/L; Hg, 11.1 µg/L; urea, 8.43 mmol/L and creatinine, 1.61 mg/dL and a decreased mean hemoglobin (Hb) concentration (67.1%, 9.8±2.3 g/dL, $P<0.05$) was observed in samples from Kataeregi. Attributing the compromised renal functioning and hematologic impairment to the accumulation of toxic heavy metals, as evident in the clinical manifestation of inhabitants in both mining sites. Alternative safe drinking water sources, continuously monitoring, sensitization and assessment on the potential health risks and profiles are highly advocated for in this community; additionally, nanobioremediation approaches are needed to clean up polluted farmlands and waters to reduce heavy metal contamination in the food chain and the associated health risks.

Keywords: heavy metals; mining; outbreak; poisoning; staple food cultivars; nanobioremediation

INTRODUCTION

Background

Central Nigeria is home to Niger State, which happens to be the largest state by landmass, endowed with abundant mineral deposits which has led to the proliferation of artisanal mining activities in the area (Obaje et al., 2018). Artisanal and small-scale mining (ASM) is conducted by individual miners or small enterprises with limited capital investment and production (O'Neill & Telmer, 2017). In Nigeria, ASM has become a persistent phenomenon due to the rising price of precious metals, coupled with the ever increasing poverty and unemployment rates (Liman et al., 2021). ASM exposes our water bodies, soils, food chain to deliterious heavy

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metals which subsequently affects human metabolomics and the entire ecological function; these which has remained an issue of public health concern.

Heavy metals are ubiquitous elements with atomic density greater than 5 g/cm^3, atomic number greater than 20, and atomic weight greater than 40 amu (Kaur et al., 2019). The presence of heavy metals in water can be detrimental to human health and the aquatic ecosystem, a clear instance is seen in the "Mina Mata Disease" which occurred in Japan, caused by mercury poisoning of consumers of fish, from the industrially polluted Mina Mata Bay (World Health Organisation [WHO], 2017). Most recently, the lead poisoning outbreaks in Zamfara, and Rafi, in Niger states as a result of unregulated arisanal mining of precious metals.

Scholarly articles have been well documented on the effects of heavy metals as it pertains to artisanal mining on the environment and human health across the globe. Despite the tendency of outbreaks, notably in northeastern and central Nigeria, from Zamfara to Niger, only a paucity of data on the many repercussions of small-scale artisanal mining has been reported, ranging from environmental and food crop pollution to health concerns and mitigation (Abdulkareem et al., 2015; Liman et al., 2021; Mallo, 2012). This study therefore aimed to assess the comparative presence and health impacts of some heavy metals, namely, As, Cd, Co, Cr, Cu, Fe, Hg, Ni, Pb and Zn in various samples collected from drinking water sources, soils, staple food cultivars, and blood samples of inhabitants around Kataeregi and Kurebe mining communities in Niger State, Nigeria. This study is necessary and timely, as the findings may likely constitute a vital planning tool that could be streamlined into the green economy blueprint of the State government.

METHODOLOGY

The study was conducted in two mining communities located in eastern and southern districts of Niger State. Kataeregi, situated in Katcha Local Government Area of Niger State is located approximately 39km south of Minna town at an elevation of 152 meters above sea level, between Latitudes 09º21′N to 09º25′N and Longitudes 006º17′E to 006º 22′E on the scale of 1:25,000 covering a total area of about 68 km^2. with a population of 122,176 (National Population Commission [NPC], 2006). Kurebe is a remote community located in Shiroro Local Government Area of Niger State, Nigeria, at longitude 6°57′59.0"E and latitude 10°27′46.3"N. Shiroro has a population of 235,404 and a land area of 5,558.0 sq km (NPC, 2006). The community is split into neighbouring villages of Rafin Kanya, Gidan Zarmai and Dagwachi, with a large proportion of Hausa and Gbagyi tribes engaged in artisanal small-scale mining operations and local farming of crops such as sorghum, millet, soybeans, groundnut, cowpeas, yam, and maize (Fashae et al., 2017). The temperature is highest with an average value of 28.7°C in April and lowest with an average value of 23.9°C around August annually (Nigerian Meteorological Agency [NMA], 2014).

Sample Collection

Water samples

In both communities, a total of 30 water samples were collected using Grab method from the available drinking water sources (river, stream, well and borehole) from the mining communities within the period of three months, into appropriately-labeled plastic bottles thoroughly washed and rinsed with deionized water and fixed with few drops of conc. HNO_3 to prevent precipitation, adsorption and microbial degradation (Lønborg et al., 2009). The samples were then kept in ice-chests with ice packs to maintain transportation temperature (4 °C), and were later transferred into a refrigerator at 4 °C until the analyses were completed.

Food crops samples

Quintuplet samples of each staple crops, classified as tubers: yam (*Discorea rotundata*) and cassava (*Manihot esculenta*); legumes: beans (*Phaseolus vulgaris*) and soybean (*Glycine max*), and leafy vegetables; okra (*Abelmoschus esculentus*), Roselle (*Hibiscus sabdariffa*) and amaranth (*Amaranthus retrofleus*); cereals: maize (*Zea mays*), guinea corn (*Sorghum bicolor*) and millet (*Pennisetum glaucum*) were randomly collected at study

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sites. Staple crop cultivars were thoroughly washed with deionised water to prevent airborne contaminants and oven dried at 80 °C until stable weight was obtained (Chiroma et al., 2019). The dried cutivars were then ground in a mortar, sieved, and kept for heavy metal analysis.

Soil samples

A total of 40 surface and sub-surface (20-30 cm below the surface) soil samples each, were collected randomly around the mining sites (Kataeregi and Kurebe) at a distance of not less than 1 km apart, using a plastic spoon and put in a labeled polyethylene bag. The samples were air dried in the laboratory, ground with mortar and pestle, and then sieved with a 2mm mesh. The sieved samples were stored in labeled polyethene bags prior to analysis (Nimyel et al., 2020).

Blood samples

A total of 100 blood samples was collected from the inhabitants of Kataeregi and Kurebe mining communities using standard methods, and dispensed into labeled potassium ethylene diamine tetra-acetic acid (K-EDTA) tubes and sealed plain tubes certified for determination of metals in blood and hematological assays and serum electrolytes analysis (Aliyu and Amanabo, 2021). Samples were immediately placed in ice packs at the site of blood collection and transferred into a refrigerator at 4 °C (Cornelis et al., 2005). Site of the venipuncture were thoroughly swabbed to avoid external contamination of the blood sample. Renal function parameters were determined using Rayto RT-9200 Semi-auto Chemistry Analyser. Hematologic parameters of Mean corpuscular volume (MCV), Hemoglobin (Hb) were analyzed by DIATRON Abacus 380 Hematology Analyzer (Diatron-A380, Hungary).

Ethical clearance and informed consent

All participants were given written copies and verbal explanations of the informed consent to participate in the study, and ethical approvals were obtained from the Research, Ethics and Publication Committee of General Hospital Minna (HMB/126/VOL.II/792) and Niger State Ministry of Health Ethical Review Committee (ERC/PAN/2022/03/21).

Sample preparation and Digestion

One gram (1.0 g) of the soil and food cultivar samples were digested with 25 ml of aqua regia (HCl + HNO3, 3:1 v/v) at °C on a water bath in a fume cupboard. The digested samples were filtered through Whatman No. 40 filter paper into 100 ml volumetric flask each and made up to the 25 cm^3 mark with distilled water (Enyoh and Isiuku, 2020). Similarly, 100 mL of the filtered water sample was mixed with 5 mL concentrated nitric acid (HNO_3) and 5 mL concentrated sulphuric acid (H_2SO_4). It was then filtered through Whatman's 0.45 µm filter paper to 100 mL. The concentrations of the metals in blood and the digested solutions were determined using Shimadzu AA 500 Atomic Absorption Spectrophotometer (WINPRO-AAS500VGP. Spectrum, USA), at wavelengths and slits specific to each metal.

Statistical Analysis

Results were expressed as the mean ± standard deviation and values of mean were calculated and two-factor without replication ANOVA was used to ascertain the relationships between the heavy metals in media analysed. Microsoft Excel was adopted to compare the graphical distribution of the contaminants in the study area. The results were discussed and compared with the reference standards with respect to the associated health risk.

RESULTS AND DISCUSSION

The mean concentration of heavy metals (mg/L, mg/kg, µg/L) in water, soil, blood samples and food crops at Kataeregi and Kurebe, are illustrated in Tables 1-4 and Figures 1-3.

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Table 1: Mean concentration (mg/L) of heavy metals in water samples from Kataeregi and Kurebe (WHO, 2011 & NSDWQ, 2015).

Study Area	**Metal**	**Minimum**	**Maximum**	**Mean**	**SD**	**WHO**	**NSDWQ**
Kataeregi	As	0.014	0.022	0.044	0.001	0.010	0.010
	Cd	0.005	0.010	0.007	0.005	0.009	0.019
	Cu	0.050	1.010	0.383	0.004	2.000	2.000
	Cr	0.010	0.030	0.043	0.008	0.050	0.050
	Fe	0.230	0.890	0.530	0.001	3.000	3.000
	Hg	0.011	0.017	0.015	0.002	0.006	0.001
	Pb	0.030	0.050	0.043	0.005	0.010	0.010
	Ni	0.001	0.002	0.001	0.003	0.020	0.020
	Zn	0.10	1.56	0.867	0.003	5.000	3.000
Kurebe	As	0.002	0.009	0.005	0.090	0.010	0.010
	Cd	0.010	0.036	0.023	0.008	0.009	0.019
	Cu	0.070	0.160	0.117	0.001	2.000	2.000
	Cr	0.003	0.008	0.006	0.002	0.050	0.050
	Fe	0.900	1.020	0.950	0.005	3.000	3.000
	Hg	0.003	0.023	0.013	0.003	0.006	0.001
	Pb	0.006	0.008	0.010	0.022	0.010	0.010
	Ni	0.006	0.012	0.009	0.017	0.020	0.020
	Zn	0.720	1.230	0.947	0.012	5.000	3.000

*nd: not detectable, WHO: World Health Organisation, NSDWQ: Nigerian Standard for Drinking Water Quality.

The results revealed that the mean concentrations of heavy metals in 65% of the water samples analysed from both study areas were within WHO/NSDWQ permissible limits; except for As, 0.044:0.005 mg/L and Hg, 0.015:0.013 mg/L; and Pb, 0.043mg/L and Cd 0.023 in Kataeregi and Kurebe, respectively (Table 1). The mean concentration of the heavy metals in water sources at both mining sites decreased in the order Zn>Fe>Cu>Pb>Hg>As>Cd>Cr>Ni with higher concentrations of As, Hg and Pb recorded in Kataeregi. This could be due to the local geology (Omanayin et al., 2016), and higher artisanal gold-ore processing activities at the Kateregi mines. This was in good agreement with results reported by Musa et al. (2021) and Singh et al. (2018). Lusilao-Makiese et al. (2014) agreed with the finding of this study that artisanal small-scale mining may affect the Hg level in groundwater near the sites. However, the concentrations recorded were lower, but higher than the values reported in a recent study by Omondi et al. (2023). The results of this study are also consistent with research of Akpanowo et al. (2021), and in contrast with the findings of Prasad et al. (2020) and Liang et at. (2017).

The mean concentrations of As (37.2 mg/kg), Cd (6.7 mg/kg) and Hg (0.75 mg/kg) in soils from Kataeregi sites are above the WHO/USEPA maximum permissible level. With the exception of Hg (0.35mg/kg) in soil, all metals analysed at the vicinity of Kurebe mining site were within the maximum recommended limits as seen in Table 2. This implied that there could be a slight level of contamination due to the artisanal mining, geologic formation and other anthropogenic process. This finding concurs with research conducted by Nimyel and Chundusu (2021), on farmlands around mining site in Plateau and Kabir *et al*. (2017), around abandoned Pb–Zn mines in Yelu, Alkaleri Local Government Area of Bauchi State. However, the mean concentration of As, Cd, Cu, Pb and Zn in this study disagrees with the values reported by Omanayin at the same site in 2016, and by Mafuyai *et al*. 2019 at Barkin Ladi.

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Table 2: Mean concentration (mg/kg) of heavy metals in surface and sub-surface soil samples from Kataeregi and Kurebe.

Study Area	Metal	Surface soil	Sub-surface soil	SD	WHO/USEPA (mg/kg)
Kataeregi	As	38.0	36.4	0.021	20.0
	Cd	7.1	6.3	0.015	3.0
	Cu	44.7	33.4	0.012	100
	Cr	33.3	26.7	0.008	100
	Fe	127.6	78.4	0.001	400
	Hg	0.8	0.7	0.022	0.3
	Pb	124.6	87.7	0.005	400
	Ni	nd	nd	0.013	0.3
	Zn	143.2	170.9	0.017	300
Kurebe	As	12.1	11.7	0.018	20.0
	Cd	2.3	1.7	0.022	3.0
	Cu	45.1	22.2	0.012	100
	Cr	33.3	12.6	0.032	100
	Fe	78.7	84.2	0.021	400
	Hg	0.4	0.3	0.062	0.3
	Pb	77.3	54.8	0.015	400
	Ni	0.04	0.07	0.009	0.3
	Zn	97.7	121.0	0.017	300

*nd: not detectable, WHO: World Health Organisation. USEPA: United State Environmental Protection Agency

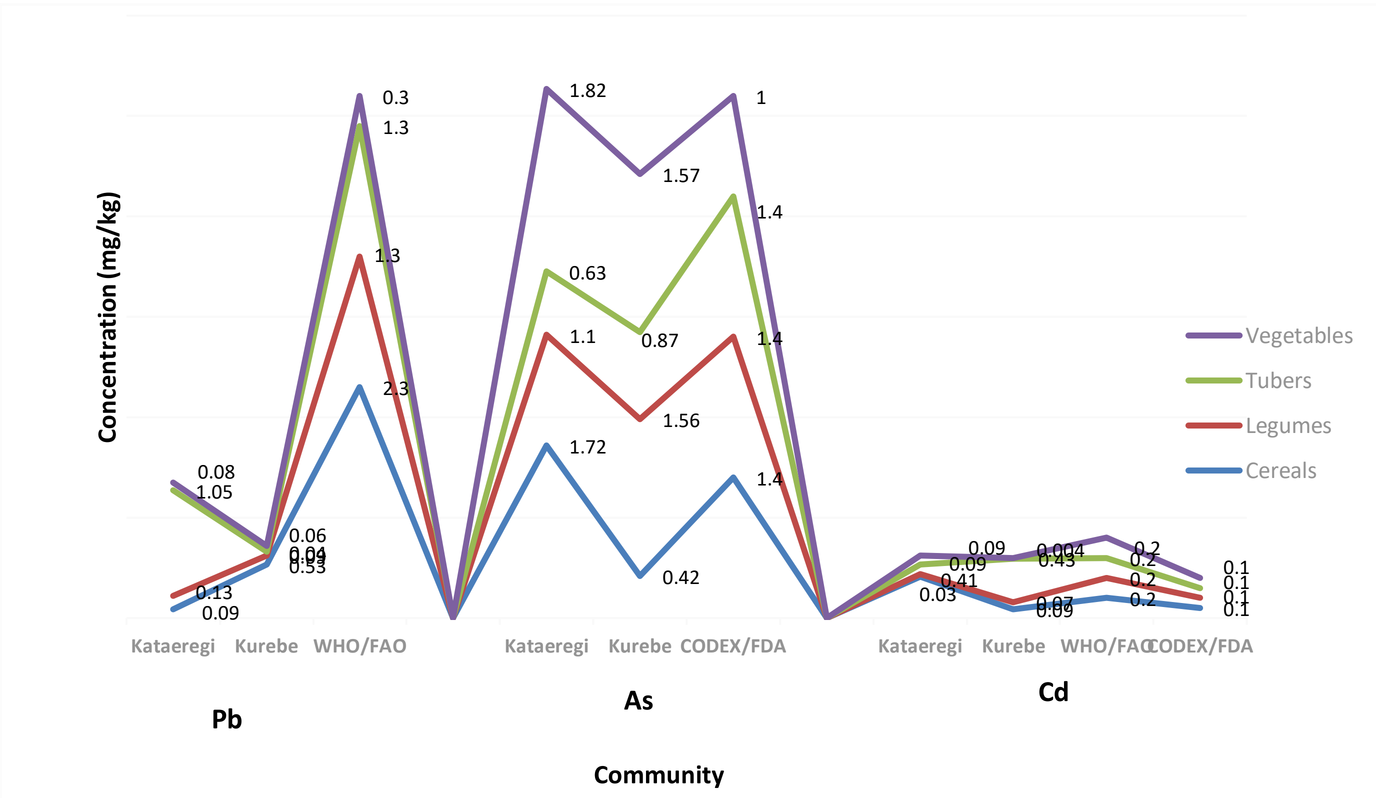

Fig. 1: Mean concentration of Pb, As & Cd in staple food crops consumed at Kataeregi and Kurebe mining communites.

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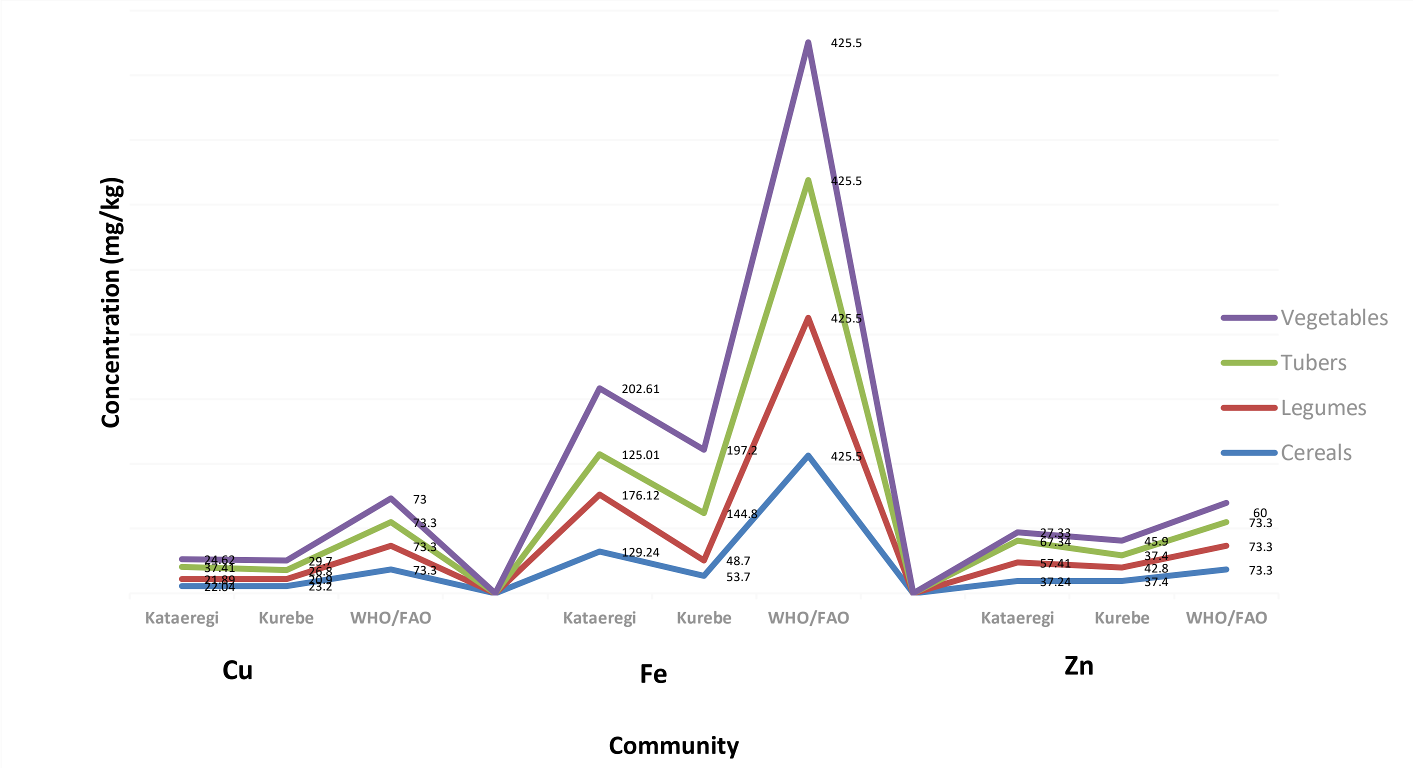

Fig. 2: Mean concentration of Cu, Fe & Zn in staple food crops consumed at Kataeregi and Kurebe mining communites.

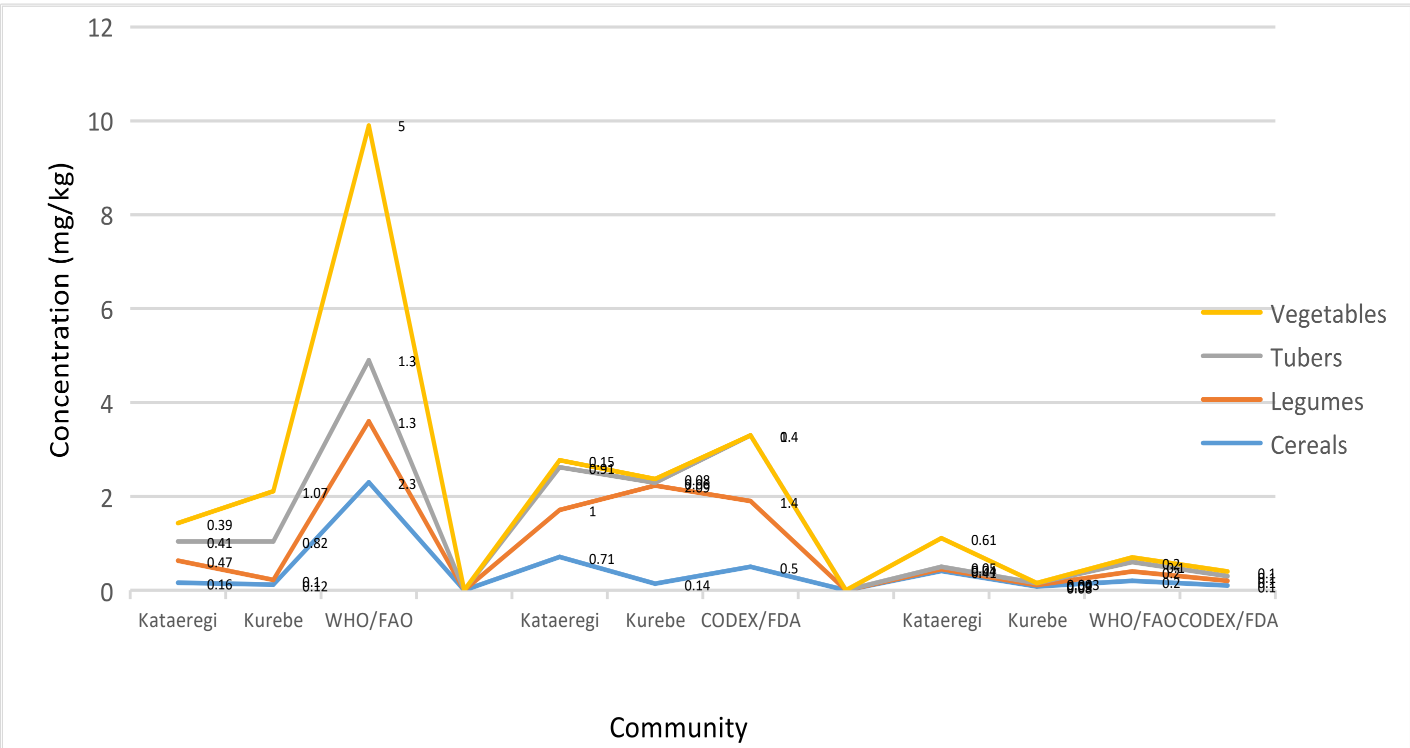

Fig. 3: Mean concentration of Cr, Hg & Ni in staple food crops consumed at Kataeregi and Kurebe mining communites.

To better reflect the heavy metal concentration in staple crops across the two study areas, variety of staple crops collected were classified into four groups (cereals, legumes, vegetables and tubers). The mean concentrations of heavy metals in staple crops from Kataeregi and Kurebe were calculated and presented in Figures 1-3. The mean concentrations of As, Cd, Hg, Ni from staple crops in Kataeregi were 1.72, 0.41, 0.71, 0.41 mg/kg in cereals; 1.10, 0.03, 1.00, 0.04 mg/kg in legumes; 1.82, 0.09, 0.15, 0.61 mg/kg in vegetables, 0.63, 0.09, 0.91, 0.05 mg/kg in tubers, respectively. The results also reveals that the bioaccumulation pattern of heavy metals in this study indicates the trend Fe>Zn>Cu>As>Hg>Ni>Cd>Cr>Pb in cereals just as revealed in the findings of Tegegne (2015), and a slightly different order occurred in the case of vegetables: Fe>Zn>Cu>As>Ni>Cr>Hg>Cd>Pb, irrespective of the study areas; Kataeregi and Kurebe mining sites. The concentration of Cd in the vegetables varied significantly with the leafy vegetables having higher values. Leafy vegetables have been linked with high absorption rates because of their large surface area (Latif et al., 2018). Similarly, staple crops grouping also showed a striking decreasing order: cereals>vegetables>legumes>tubers. The results indicated that all the metal concentrations except for As, Cd, Hg and Ni in cereals and vegetables, were below the recommended safe limit of FAO/ WHO. As (1.56 mg/kg) and Hg (2.09 mg/kg) in legumes at Kurebe were higher than the WHO/FAO stipulated limits. Hence showing that the cereals and vegetables in Kataeregi, and legumes in Kurebe mining sites would be dangerous for human consumption. The finding of this study which is in agreement with the report of Adam et al. (2022), Malik et al. (2017) and Hussain and Dubey, (2019), but much higher than the values reported by other researchers (Abiya et al., 2019; Orisakwe et al., 2017; Ratul et al., 2018).

Table 3. Characteristics of the population

Category	Kataeregi mining site	Kurebe mining site
Total number of respondents	50	50
Gender		
Male	32 (66%)	41 (82%)
Female	18 (36%)	09 (18%)
Age		
16-30 yrs	16 (32%)	18 (36%)
31-45 yrs	22 (44%)	27 (54%)
46-60 yrs	12 (24%)	05 (10%)
Years of activity		
1-3 yrs	18 (36%)	23 (46%)
4-6 yrs	11 (22%)	12 (24%)
7-10 yrs	13 (26%)	10 (20%)
>10 yrs	08 (16%)	05 (10%)
Smoking habit		
Yes	21 (42%)	32 (64%)
No	29 (58%)	18 (36%)
Education level		
Formal	30 (60%)	27 (54%)
Informal	18 (36%)	19 (38%)
No information	02 (4%)	04 (8%)

A total of 100 subjects from Kataeregi and Kurebe mining communities were recruited in this study, with their demographic characteristics depicted as seen in table 3 above. 100 blood samples were collected from local miners and inhabitants of both mining areas after completing consent forms and questionnaires consisting of personal information, employment status, lifestyle and education level.

Table 4. Mean concentrations of heavy metals, urea, creatinine and hematological parameters among human participants in Kataeregi and Kurebe.

	As (µg/L)	Cd (ng/mL)	Cu (µg/L)	Fe (µg/L)	Hg (µg/L)	Pb (µg/dL)	Zn (µg/L)	Urea (mmol/L)	Creatinine (mg/dL)	Hb (g/dL)	MCV (fL)
Kataeregi	0.41	5.17	68.24	73.75	11.12	11.20	125.54	8.42	1.61	9.81	70.13
Kurebe	0.32	2.92	74.41	66.55	5.91	4.22	123.89	8.16	1.00	11.60	77.32
Reference	(1.0)	(<5)	(62-140)	(50-175)	(<10)	(<10)	(60-130)	(2.5-8.3)	(0.8-1.5)	(12-18)	(80-100)

This environmental epidemiologic study on the mining areas, evaluated heavy metals levels and their correlations with hematologic and renal function indicators for miners and inhabitants of Kataeregi and Kurebe mining communities.

The mean blood heavy metal levels analysed among Kurebe inhabitants were well within the stipulated reference values, with a slightly below the hematologic reference for blood hemoglobin (Hb) and mean corposcular volume (MCV) values. On the other hand, biochemical assays of blood samples from inhabitants in Kataeregi mining area revealed elevated levels of urea and creatinine, with correspondingly decreased blood Hb and MCV, indicating heavy metal toxicity and oxidative stress. As backed by the report of Adewumi et al. (2020). Mean blood Cd (5.17 ng/mL), Hg (11.12 µg/L) and Pb (11.2 µg/dL) inhabitants from Kataeregi mines were comparatively higher than in Kurebe. Out of 50 samples collected from Kataeregi, 19 blood samples (38%) exceeded the CDC recommended level (5 µg/dL) of Pb in blood and 37 samples exceeded 2 µg/dL, recommended by Gilbert and Weiss (2006). The blood Cd and Hg concentrations conforms with the findings in the studies by Wahl et al. (2021) and Hokuto et al. (2021), but disagrees with the finding of Noor et al. (2019). Mean blood Pb concentrations detected among inhabitants in Kataeregi mining vicinity were much higher than in samples analysed from Anka-Zamfara by Yahaya et al. (2022). However, the finding is consistent with reports by Bello et al. (2016) on blood lead concentration on the population of Adudu community living near a lead–zinc mine in Nasawara, Nigeria, and that by Tilako et al. (2019) on blood-lead levels among Inhabitants of Enyigba Lead-Zinc Mining Community of Ebonyi State, Nigeria.

CONCLUSION

It is evident from the present study that the concentrations of some heavy metals in drinking water, soils and staple crops from Kataeregi mining area showed higher levels of pollution than those from Kurebe. Generally, levels of As, Hg and Pb in water from Kataeregi exceeded WHO stipulated limits, while that of Cd and Hg, were higher in drinking water sampled at Kurebe. The extent of heavy metal in soils and staple crops from Kataeregi and Kurebe ranged from excessive pollution and severe pollutions to slight contaminations respectively. As such, can be deleterious to consumers as levels of these heavy metals were above the WHO/FAO stipulated limits. These which were implicated in the elevated urea-creatinine levels and corresponding significant decrease in the Hb, MCV levels of inhabitants around the mines; suggesting compromised renal functioning and anemia among inhabitants, particularly in Kataeregi mining community. Serious public health problems could set in after prolonged exposure to these metals, which may lead to the damage of several organs in the body such as the brain, lungs, liver and kidney causing diseases in the body. It therefore recommends the need for the provision of safe alternative water sources, proper sensitization and monitoring of the mining activities to curb further contamination and health risks in these two communities.

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