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Assessment of heavy metal pollution of drinking water sources and staple food cultivars around artisanal mining site in Igade-Mashegu, Niger State, Nigeria

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Abstract

Ecotoxicological studies have been carried out on the precarious effects of heavy metal pollution and exposure attributed to anthropogenic practices such as mining, industrial and agricultural activities, which poses serious health challenges. This study investigated ten (10) heavy metals namely As, Cd, Co, Cr, Cu, Fe, Hg, Ni, Pb and Zn in one hundred and fifteen samples from water sources and staple food cultivars around Igade mining site in Mashegu Local Government Area of Niger State, North-Central Nigeria, using Atomic Absorption Spectrophotometer (AAS). The result revealed the concentrations of heavy metals in staple food cultivars consumed at Igade to be within the recommended maximum levels as stipulated by WHO/FAO, but As^{2+} and Cd^{2+} were higher in legumes (1.510 ± 0.169 mg/kg) and vegetables (1.666 ± 0.154 mg/kg); and cereals (0.328 ± 0.012 mg/kg) and tubers (0.421 ± 0.176 mg/kg) respectively. This implies that the artisanal mining contributed to the exogenous bioaccumulation of these metals in staple food cultivars following the pattern: Fe > Zn > Cu > As > Pb > Cr > Cd > Hg which could accumulate and destroy vital organs thereby affecting human health upon consumption. Also, the mean concentration of the heavy metals in various water sources at Igade mining site decreased in the order Zn > Fe > Cr > Cu > As > Hg > Pb > Cd > Ni. Levels of As, Hg, Pb, Fe, and partly Cr in water sources were observed to be higher than the WHO and NSDWQ recommended standards for drinking water. Thus, their continuous consumption poses potential health risk to inhabitants, and therefore, there is need for the provision of safe alternative water sources; proper sensitization and monitoring of the mining activities to curb health risks and the extent of heavy metal contamination.

Keywords: Ecotoxicological; Heavy metals; Contamination; Bioaccumulation; Staple food cultivars

1 Introduction

Heavy metals are found everywhere in the environment, however, their concentration differs according to geologic formations (Li *et al.,* 2020). Natural processes and human anthropogenic activities further escalate the release of these toxic metals in hazardous proportions into the environment; accumulating in air, soils and food crops, and into the aquatic habitat (Madzunya *et al.,* 2020). Exposure to heavy metals results from ingestion of contaminated food and water as well as inhalation of contaminated air (dust) (Singh *et al.,* 2018). Soil as the fundamental sustenance of food crops can be greatly perturbed by heavy metals from point sources (e.g., goldmines, smelting, leather, e-waste processing etc.) (Rai *et al.,* 2019). In addition to their human health implications, heavy metals adversely affect soil biota through microbial processes and soil-microbe interactions (Gadd, 2010; Gall *et al.,* 2015). Because most heavy metals in soil can accumulate in crops, they can be transferred to other media through the food chain. The bioconcentration factor (BCF) of several heavy metals in the crop–soil interface, particularly in major global staple crops such as wheat and corn, has been documented (Wang *et al.,* 2018). The ingestion of vegetables contaminated with heavy metals cause serious human health issues, such as gastrointestinal cancer, fragile immunological mechanisms, mental growth retardation, and mal-nutrition (Hu *et al.,* 2013; Dickin *et al.,* 2016; El-Kady and Abdel-Wahhab, 2018). Beneficial

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agricultural soil insects, invertebrates, and small and large mammals are all affected (Gall *et al.,* 2015; Rai *et al.,* 2019). Heavy metals are transferred from soil pores to plants in ionic forms, which can vary by metal (McLaughlin *et al.,* 2011). The biospeciation of heavy metals can also vary by food crop. Vegetables such as iceberg lettuce, cherry belle radishes, Roma bush beans, and Better Boy tomatoes all accumulate heavy metals with different concentrations in the roots, leaves, and fruits (Yabanli *et al.,* 2014). It is also vital to examine medicinal plants used for traditional human health care to prevent adverse effects, as many medicinal plants grown near smelting, mining areas has been shown to bioaccumulate various metals (e.g., Cd, As, Fe, Pb, Cu and Cr) (Kim *et al.,* 2017; Yabanli *et al.,* 2014).

The soil–plant transfer factor (TF) of metals and metalloids is an important criterion to assess global human health concerns (Navas-Acien *et al.,* 2007; Woldetsadik *et al.,* 2017). Human health hazards are closely linked to the intake of metal-contaminated food crops. Heavy metals can accumulate in human bones or fatty tissues through dietary intake, thereby leading to the depletion of essential nutrients and weakened immunological defenses.

Certain heavy metals (e.g., Al, Cd, Mn, and Pb) are further suspected to cause intrauterine growth retardation (Rai, 2018). Lead contamination adversely affects mental growth, causing neurological and cardiovascular diseases in humans, especially children (Navas-Acien *et al.,* 2007; Al-Saleh and Abduljabbar, 2017). Certain heavy metals, especially Pb and Cd, have carcinogenic effects (Khalid *et al.,* 2020) and can also lead to bone fractures and mal-formation, cardiovascular complications, kidney dysfunction, hypertension, and other serious diseases of the liver, lung, nervous system, and immune system (Al-Saleh and Abduljabbar, 2017; Khalid *et al.,* 2020). Excessive levels of As in soil, food crops, and groundwater can cause cancer, dermal problems, respiratory complications, and many other diseases in the cardiovascular, gastrointestinal, hematological, hepatic, renal, neurological, developmental, reproductive, and immune systems (Hu *et al.,* 2013; Li *et al.,* 2020; Zhou *et al.,* 2016; Islam *et al.,* 2017; El-Kady and Abdel-Wahhab, 2018). Cd contamination in food crops and its effects on human health have also been extensively reported (Yang *et al.,* 2018).

Excess Zn levels in the human body can affect the concentration levels of high-density lipoproteins and disturb the immune system (Zhou *et al.,* 2016). Likewise, excess Cu intake can induce liver damage and other gastric-related problems in humans (Rahman *et al.,* 2014; Zhou *et al.,* 2016). Heavy metals (e.g., Cr, Cu, and Zn) in soil can cause non-carcinogenic human health hazards such as neurologic complications, headaches, and liver disease (US EPA, 2006; Liu *et al.,* 2013). Cr (VI) is more hazardous than Cr (III) and other ionic forms in terms of its stability. As such, the former form is suspected to have enhanced potential to cause lung cancer compared with the latter form (Liu *et al.,* 2013; Yang *et al.,* 2018). Cd is highly carcinogenic, typically ingested by humans through contaminated food crops, especially rice, and causes postmenopausal breast cancer.

Precise understanding of the routes and mechanisms by which heavy metals pose a risk to human health through the consumption of grains and vegetables enables the adoption of suitable strategies to manage and mitigate heavy metals for the benefit of local people, artisans, farmers, researchers and policy makers (Oves *et al.,* 2012).

Plant roots play the most vital role in the uptake and translocation of heavy metals. The entry of metals into a root depends on its anatomy (especially the cell wall) and environmental adaptability. For example, Zn uptake in mangrove seedlings adversely affected their environmental adaptability through radial oxygen loss (Cheng *et al.,* 2010). Heavy metals enter the roots from the soil through the intake of water mixed with minerals and nutrients and then bind to low-methyl-esterified pectins, whose levels increase under metal stress (Krzeslowska, 2011). Pb binds to the cell wall of the root primarily through esterified pectins, as demonstrated in the protonemata of a moss plant (*Funaria hygrometrica*), and can be remobilized (Krzeslowska, 2011). Polysaccharides (with –COOH, –OH, and –SH functional groups assisting in binding heavy metals to the root) in the root cell walls of food crops also play an important role in the avoidance and tolerance of metal stress. Polysaccharide remodeling under heavy metal stress in food crops results in perturbations of the structural integrity of the cell membrane and organelles (especially chloroplasts and mitochondria), enzyme inactivation through the replacement of integral components or binding to the sulfhydryl or carboxyl group, and nucleic acid conformation changes.

Niger State is blessed with abundant solid minerals deposits of different categories made up of precious metals, industrial minerals like coal, tin, gold, marble, limestone and others, and have attracted several individuals into the exploitation in both legal and illegal manner (Mallo, 2012). Artisanal and small-scale mining (ASM) has experienced explosive growth in recent years due to the rising values of mineral prices and the increasing difficulty of earning a living from agriculture and other rural activities. The devastating environmental and land use expansion for the activities of ASM in various parts of the world and Nigeria will continue to cause severe damage to the landscape, destruction of the ecosystem and dire catastrophic health tendencies. The peculiar rise in poverty and ASM will make more people to engage in ASM practices especial in the rural areas. With continuous troubling impact witnessed over the years as a result of the crude rudimentary processes of mining and processing activities; without safety precautions or required government permit. (Ako *et al.,* 2014).

The major routes of heavy metal uptake by man are food, drinking water and air, for example, aquatic fauna especially fish are the most important source of mercury (Hg). As trace elements, some heavy metals (e.g. Cu, Se, Zn) are essential to maintain the metabolism of the human body. However, at higher concentrations, they can lead to poisoning. The heavy metals linked most often to human poisoning are lead (Pb) mercury (Hg), arsenic (As) and Cadmium (Cd). Others including copper (Cu), Zinc (Zn) and Chromium (Cr) are actually required by the body in small amounts, but can also be toxic in larger doses. Unlike other pollutants like petroleum hydrocarbons and litter which may visibly build up in the environment, trace metals may accumulate, unnoticed, to toxic level. 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 (Hembrom *et al.,* 2020). For effective water pollution control and management, there is a need for a clear understanding of the inputs (loads) distribution and fate of contaminants, especially heavy metals from mining, industrial discharge and other land-based sources into aquatic ecosystems. The need to evaluate the quality status of drinking water sources and food consumption around Igade mining sites in Mashegu Local Government Area of Niger State, North-Central Nigeria cannot be overemphasized owing to the lead poisoning disasters in Zamfara (2010) and Niger States (2015), Nigeria, which were described as largest in modern times by scope and magnitude. Events which were particularly due to artisanal gold-ore processing activities which affected children less than five years old with acute severe outbreaks (Umar-Tsafe *et al.,* 2019). This study is aimed at assessing the heavy metal contamination of drinking water sources and food cultivars around artisanal mining site in Igade-Mashegu, Niger State, Nigeria. Thus, providing an update to help situate a forecast on the environmental pollutant baselines as well as to evaluate exogenous sources of these metals through water and food stuff to humans around the mining vicinity.

2 Material and methods

2.1 Study area

The study in Igade mining site was conducted in Mashegu Local Government Area (LGA). The study area is one of the twenty five (25) Local Governments Areas of Niger State, Nigeria. The LGA was carved out of Wushishi LGA in 1996 and it is located in the eastern part of Niger State in northern Nigeria. Mashegu is bounded by the Niger River by the west and Kaduna River in the northeast. It lies between latitude 9°57N and longitude 5°13E with Mashegu town being the headquarters of the LGA, covering ten wards. It covers a land area of about 9,182 sq km (Ayodeji *et al.,* 2014). The LGA experiences rainfall of between 100 mm and 1200 mm from July to October. Between February and May, just before the rain sets in, the cold dry harmattan wind and the arid season becomes hotter. The mean daily temperature is high throughout the year and it is about 32^0C, varying between 21^0C to 37^0C. The vegetation is mainly short grass and shrubs with scattered trees. The LGA has an estimated population of 215,022 (NPC, 2006), with mixed tribes of Hausa, Fulani, Dakarkari, Nupe and Gbagyi. The main occupation of the people is farming while the major crops grown are yam, rice, cowpea, sorghum, maize, groundnut, tomato and sweet potatoes, amongst others (Ayodeji *et al.,* 2014; Environmental Protection Agency (EPA), 2005).

2.2 Sample Collection

2.2.1 Water samples

Fifteen (15) water samples comprising five (5) surface water; river water- five (5), and ten (10) ground water samples; five (5) from well and five (5) from borehole were collected using Grab method from the available water sources (river, stream, well and borehole) around Igade mining site and environs, into appropriately-labeled stoppered-plastic bottles thoroughly washed and rinsed with deionized water and fixed with few drops of nitric acid to prevent matrix contamination and adsorption of metals onto the container walls (Miller, 2009). The samples were then stored in a refrigerator throughout the period prior to analysis.

2.2.2 Food crops samples

The selected food crop samples 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*). Garri, a processed form of cassava and powdered yam to be bought from farmers at the nearby community market. Quintuplet samples of each cultivar were randomly collected at study sites before being washed to prevent airborne contaminants.

2.3 Chemicals

All chemicals and reagents used were of analytical grade, and from which standard solutions were prepared. Glassware were thoroughly washed with detergent and rinsed with distilled water.

2.4 Sample preparation and Digestion

The procedure outlined by Akubue (1997) with slight modifications was adopted for the extraction of heavy metals in this water and food samples. One gram (1.0 g) each of air and oven-dried powdered pulverized food cultivar sample previously sieved through a 2mm mesh-size was weighed and quantitatively transferred into a 25 mL volumetric flask containing 5 mL perchloric and concentrated nitric acid mixture in a ratio of 1:2. The vessel was gently swirled and kept in a fume cupboard overnight. The samples were subsequently digested at a temperature of 150^{o}C on a hot plate for 3 hours or until frothing ceased. The solution was allowed to cool and filtered through Whatman No. 40 filter paper before being made up to the 25 cm^3 mark with distilled water. All samples types (water and food cultivars) were then analyzed using Shimadzu AA 500 Atomic Absorption Spectrophotometer (WINPRO-AAS500VGP. Spectrum, USA), attached to graphite atomizer with specific hollow cathode lamps for various elements and a HP LaserJet printer (P1005).

2.5 Laboratory analysis

Portions of homogenized food cultivars and water samples digested were quantified for the heavy metals; As, Cd, Co, Cr, Cu, Fe, Hg, Ni, Pb and Zn, adopting various analytical techniques and instrumentation in the evaluation of each trace metal, since each element has its peculiar matrix and detection levels.

2.6 Metal analysis

The metal analysis was determined by comparing the absorbance I_o when no analyte exist and I_{trans} when analytes are present.

Table 1 Instrumental description of the AAS

S/N	Metals	Lamp description	Slit width (mm)	Wavelength (nm)
1	Lead	Lead hollow cathode lamps operated at 10mÅ	0.7	253.7
2	Cadmium	Cadmium hollow cathode lamp operated at 4 mÅ	0.7	228.8
3	Arsenic	Arsenic ultra-lamp operated at 10 mÅ	1.0	189.0
4	Copper	Multi-element hollow cathode operated at 15 mÅ	1.0	324.7
5	Cobalt	Cobalt hollow cathode lamp operated at 10mÅ	0.7	189.0
6	Mercury	Mercury hollow cathode lamp operated at 10 mÅ	0.7	253.7
7	Iron	Multi-element hollow cathode lamp operated at 12 mÅ	0.2	248.3
8	Chromium	Chromium hollow cathode lamp of current 10 mÅ	1.0	540.0
9	Nickel	Multi-element hollow cathode lamp operated at 7 mÅ	0.15	232.1
10	Zinc	Multi-element hollow cathode lamp operated at 12 mÅ	3.0	213.8

Procedural blanks were prepared and aspirated along with the analytical samples in order to correct for background absorption. The limit of detection for the metal was 0.001 ppm while that of the blank was 0.00 ppm. The instrumental description for each analyzed metal is presented in Table 1.

2.7 Quality Control and Statistical Analysis

Precision, accuracy and sensitivity of the analytical techniques adopted in this research were assured by quadruplet samples, blanks and the method of standard addition. Solution of all metals were prepared by successive dilution of certified standards (1000 mg/dm^3) procured from Sigma Aldrich and calibration curve of each metal was constructed. Blank determinations were carried out to correct any background contamination from reagents, filter papers or other systemic sources of error. Statistical analyses were carried out using IBM SPSS 28.0 (SPSS Inc., Chicago, USA). Graphs were plotted using OriginPro Software 2020 (version 8; OriginLab Corporation, Northampton, MA, USA). Results were expressed as the mean ± standard deviation.

3. Results

The results of the heavy metal concentrations obtained from the assessment of the quality of the different water sources and food crop samples from the study location in comparison with the permissible limits of conventional standard(s) are presented in Tables 1–6.

Table 2 Comparison of minimum and maximum physicochemical parameters of water samples from Igade-Mashegu, Nigeria with Standards (WHO 2008 & NSDWQ, 2015)

Parameters	Methods	Minimum	Maximum	WHO	NSDWQ
Temperature (°C)	APHA 2550 B	30.4	37.6	35-40	-
(pH)	APHA 4500H*B	6.6	7.2	7-8.5.5	6.5-8
Electrical conductivity (µhos/cm)	APHA 2510 B	342	610	1000	1000

Physiochemical parameters determined, with recommended standards published by the World Health Organisation (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ).

Table 3 Ranges and mean values of As, Cd and Hg in various water sources in Igade-Mashegu, Nigeria

Water sources	As (mg/L)		Cd (mg/L)		Hg (mg/L)	
	Ranges	Mean value	Ranges	Mean value	Ranges	Mean value
Well	0 0.004-0.019	0.017±0.006	0.001-0.005	0.002±0.001	0.004-0.101	0.010±0.008
Borehole	0.001-0.019	0.012±0.003	0.000-0.002	0.003±0.002	0.001-0.009	0.005±0.002
River	0.002-0.011	0.007±0.002	0.001-0.012	0.005±0.002	0.001-0.107	0.012±0.002
WHO	0.001		0.009		0.006	
NSDWQ	0.001		0.019		0.001	
USEPA	0.002		0.015			

Values are ranges, mean ± standard deviation (n = 5), WHO = World health Organization, NSDWQ = Nigerian Standards for Drinking Water Quality, USEPA = United State Environmental Protection Agency. ND: Not detected.

Table 4 Ranges and mean values of Pb, Zn and Ni in various water sources in Igade-Mashegu, Nigeria

Water sources	Pb (mg/L)		Zn(mg/L)		Ni (mg/L)	
	Ranges	Mean value	Ranges	Mean value	Ranges	Mean value
Well	0.004-0.013	0.008±0.004	0.041-1.400	0.933±0.524	ND	ND
Borehole	0.002-0.005	0.004±0.002	0.017-1.211	0.634±0.534	ND	ND
River	0.003-0.011	0.007±0.003	0.009-1.011	0.291±0.408	0.000-0.007	0.002±0.001
WHO	0.001		5		0.02	
NSDWQ	0.001		3		-	
USEPA	-				5	

Values are ranges, mean ± standard deviation (n = 5), WHO = World health Organization, NSDWQ = Nigerian Standards for Drinking Water Quality, USEPA = United States Environmental Protection Agency. ND: Not detected.

Table 5 Ranges and mean values of Cr, Cu and Fe in various water sources in Igade-Mashegu, Nigeria

Water sources	Cr (mg/L)		Cu (mg/L)		Fe (mg/L)	
	Ranges	**Mean value**	**Ranges**	**Mean value**	**Ranges**	**Mean value**
Well	0 0.004-0.019	0.027±0.016	0.001-0.205	0.102±0.014	0.004-10.101	0.710±0.008
Borehole	0.001-0.019	0.010±0.013	0.000-0.302	0.232±0.032	0.001-7.009	0.805±0.002
River	0.042-0.111	0.074±0.002	0.001-0.412	0.345±0.032	0.001-10.007	0.640±0.002
WHO	0.05		2.0		0.3	
NSDWQ	0.05		-		0.3	
USEPA	-		-		-	

Values are ranges, mean ± standard deviation (n = 5), WHO = World health Organization, NSDWQ = Nigerian Standards for Drinking Water Quality, USEPA = United State Environmental Protection Agency. ND: Not detected.

Table 6 Ranges and mean values of As, Cd, Cr, Co, Cu and Fe in various food crops in Igade-Mashegu LGA, Nigeria

Food crops		**As**	**Cd**	**Cr**	**Co**	**Cu**	**Fe**
Cereals							
	Mean	0.210 ± 0.154	0.328 ± 0.012*	0.172 ± 0.1208	ND	17.141 ± 1.356	110.21 ± 11.172
	Ranges	0.0120 – 0.301	0.167 – 0.582	0.091 – 0.374	ND	3.337 – 29.610	91.70 – 120.191
CODEX/FDA		1.4	0.1	1.0		-	-
WHO/FAO		-	0.2	2.3		73.3	425.5
Legumes							
	Mean	1.510 ± 0.169*	0.011 ± 0.123	0.441 ± 0.167	ND	17.412 ± 1.563	106.172 ± 15.120
	Ranges	0.902 – 1.701	0.008 – 0.015	0.310 – 0.516	ND	4.071 – 30.618	78.610 – 253.710
CODEX /FDA		1.4	-	-		-	-
WHO/FAO		-	0.2	1.3		73.3	425.5
Tubers							
	Mean	0.121 ± 0.617	0.421 ± 0.176*	0.171 ± 0.146	ND	7.441 ± 0.194	92.010 ± 14.112
	Ranges	0.090 – 0.410	0.112 – 0.529	0.103 – 0.274	ND	4.021 – 19.170	78.610 – 253.710
CODEX /FDA		1.4	-	-		-	-
WHO/FAO		-	0.2	1.3		73.3	425.5
Vegetables							
	Mean	1.666 ± 0.154*	0.081 ±0.125	0.3401 ± 0.112	ND	24.517 ± 1.219	212.6 ± 16.212
	Ranges	1.010 – 1.778	0.004 – 0.097	0.201 – 0.412	ND	7.777 – 42.612	92.016 – 253.720
CODEX /FDA		-	0.01	1.0		-	-
WHO/FAO		1.4	0.2	5.0		73.0	425.5

Key: (*) Value significantly higher than the stipulated standards. Values are ranges, mean ± standard deviation (n = 5), WHO = World health Organization, FAO = Food and Agricultural Organization. ND: Not detecte

Table 7 Ranges and mean values of Hg, Ni, Pb and Zn in various food crops in Igade-Mashegu LGA, Nigeria

Food crops		**Hg**	**Ni**	**Pb**	**Zn**
Cereals					
	Mean	0.0120 ± 0.1027	ND	0.032 ± 0.124	34.128 ± 0.132
	Ranges	0.005 – 0.0183	ND	0.014 – 0.096	44.774 – 77.881
CODEX/FDA		0.5		0.6	99.4
WHO/FAO		0.3		0.3	60
Legumes					
	Men Value	0.0321 ± 0.102	ND	0.1612 ± 0.214	22.411 ± 0.113
	Ranges	0.010 – 0.078	ND	0.127 – 0.601	82.610 – 120.701
CODEX /FDA		0.5		0.6	99.4
WHO/FAO		0.3		0.3	60
Tubers					
	Men Value	0.0145 ± 0.119	ND	0.662 ± 0.327*	47.901 ± 0.111
	Ranges	0.011 – 0.068	ND	0.210 – 0.710	30.33 – 56.772
CODEX /FDA		0.5		0.6	99.4
WHO/FAO		0.3		0.3	60
Vegetables					
	Men Value	0.006 ±0.1210	ND	0.212 ± 0.152	54.601 ± 0.147
	Ranges	0.001 – 0.020	ND	0.039 – 0.317	37.86 – 136.061
CODEX /FDA		0.5		0.6	99.4
WHO/FAO		0.3		0.3	60

Key: (*) Value significantly higher than the stipulated standards. Values are ranges, mean ± standard deviation (n = 5), WHO = World health Organization, FAO = Food and Agricultural Organization. ND; Not detected

3 Discussion

Table 2 shows the values of physicochemical parameters determined, with recommended standards published by the World Health Organisation (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ). The temperatures ranged from 30.4 to 37.6°C which falls slightly within and mostly lower than the World Health Organisation (WHO) limit. Lower temperature may indicate the presence of pollutants (Omanayin *et al.,* 2017). The pH values ranges from 6.60 to 7.24 which is within the limit and within the allowable consumption limit. Observed pH in all water samples investigated and the variation in pH due to change in sampling location, collection and source was also insignificant (Table 1). The values of conductivity ranged from 0.342 to 0.610 with an overall mean of 0.395 µhos/cm. The observed values, however, were well within the safe limits for drinking (WHO, 2018).

The mean concentrations of As, Cd, Co, Cu, Cr, Fe, Ni, Hg, Pb and Zn of quintuplets of water (mg/L) and staple food cultivars (mg/kg) collected in and around the vicinity of artisanal gold mining site at Igade-Mashegu are given in Tables 3, 4, 5, 6 and 7.

The mean concentrations of As in well, borehole and river water were 0.017 mg/L, 0.012 mg/L and 0.007 mg/L respectively (Table 3). These values exceed the 0.01 mg/L limit for As in drinking water by World Health Organisation (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ), and 0.002 mg/L United State Environmental Protection Agency (USEPA) standard for potable drinking water. This was in good agreement with results reported by Prasad et al. (2018) and Singh et al. (2018). The high concentration could be due to active mining activities (like grinding and washing), and runoffs from agricultural areas, where materials containing arsenic such as fertilizer and pesticides were used (Cobbina *et al.,* 2015).

The mean As concentrations of cereal (0.210 mg/kg) and tuber cultivars (0.121 mg/kg) presented in Table 6 were below the Codex Alimentarius/FDA stipulated limit of 1.4 mg/kg. The mean concentration of As in legumes (1.510 mg/kg) and vegetables (1.666) were higher than the recommended safe limit of FAO/WHO (1.4 mg/kg). The mean concentration of As in food crops at Igade-Mashegu decreased in the order vegetables > legumes > cereals > tuber (Table 3.5). Arsenic (As) has been reported to be a serious carcinogen manifesting into skin cancer upon long term exposure in drinking water (50 µg/L or even lower), exposure could also result from inhalation or ingestion, thus affecting the lungs, liver, bladder; causing cardiovascular and neurological disorders upon accumulation (Milton *et al.,* 2018).

Mean values for Cd in well, borehole and river water were 0.002 mg/L, 0.003 mg/L and 0.005 mg/L respectively, as observed from the analysis, were below the acceptable limit of 0.009 mg/L of WHO standard and 0.019 mg/L NSDWQ standard. These which fall in disagreement with the reports on the evaluation and assessment of heavy metals in mine water by Mahato et al. (2014). And in concordance with the findings of Gupta (2017) and Prasad et al. (2017). The results for the concentration of Cd revealed that the maximum mean concentration of Cd (0.421 mg/kg) was recorded in tubers and lowest mean concentration of 0.011 mg/kg was recorded in legumes, with cereals having a mean concentration of 0.328 mg/kg. The mean concentration of Cd in food crops at Igade-Mashegu decreased in the order tuber > cereals > vegetables > legumes (Table 6). The mean concentration of Cd in tubers and cereals were higher than the recommended safe limits of FAO/WHO (0.2 mg/kg). The concentration of Cd in this study is similar to the values reported by Ametepey et al. (2018) and Orisakwe et al. (2017). However, the study by Latif et al. (2019) showed higher concentrations of Cd in the vegetables studied. These high levels can be linked to the bioaccumulation from soils and the dissolution of the chalcopyrite and pyrite ores in the area. Contamination by cadmium and its compounds poses exacerbating health effects in humans, due to the body's inability to excrete Cd. The metal is re-absorbed by the kidney, accumulating in the proximal tubular cells causing renal dysfunction and kidney disease (Davies *et al.,* 2005). Also, Cd, which is classified as group 1 carcinogens for humans by the International Agency for Research on Cancer can cause osteoporosis (severe bone damage) and lung cancer.

The mean concentration of Hg in the three water sources analyzed (0.012; 0.005; 0.010) mg/L did not conform to the 0.006 mg/L of WHO standard and the 0.001 mg/L as stipulate by NSDWQ (Table 3.2). Indicating high level of contamination of mercury in the water sources of the area (particularly around Igade mining areas). Upper limit ranges were higher in well water samples (0.004-0.101) and highest in river water samples (0.004-0.107). With over 60% of the samples above the WHO (2011) guideline of 0.001 mg/kg for drinking water quality. These findings corroborate the work of Obasi and Akudinobi (2020), however, the mean values showed higher values in the water samples studied when compared to the present study. The high levels of Hg were not unexpected because of the crude-rudimentary and mercury amalgamation techniques adopted in the mining and processing of lead-rich gold ore at Igade mining site. Mercury associated with soil can be directly washed into surface waters during rain events (Meili, 2021). Considered to be the most toxic heavy metal in the environment (Obasi and Akudinobi, 2020), its toxicity is termed acrodynia (pink disease). Mercury and its compounds affect the nervous system, and thus, increased exposure to mercury can alter brain functions, causing irritability, tremors, memory problems and changes in hearing or vision, apart from its short-term effects of diarrhea, nausea, hair loss, skin rashes, lung damage etc.

When the mean concentration of Pb in water sources (well, borehole and river) 0.008 mg/L, 0.004 and 0.007 mg/L respectively, are compared with both WHO and NSDWQ guidelines for potable drinking water, the values are higher than the acceptable limit (0.001 mg/L) as seen in Table 3.With Pb concentrations highest in well water and river water. Other results obtained showed Pb concentration was least in borehole water samples analyzed (WHO, 2020). The concentrations of Pb in this study are similar to the values reported by Biswas et al. 2017 in their study on the heavy metals pollution indices in irrigation and drinking water systems of Barapukuria coal mine area, Bangladesh, their findings indicate that most of the groundwater samples showed high concentrations of heavy metals. The high content of lead in various water sources around the mining site could be due to weathering, leaching of lead ores (galena) from gangues and mine wastes. Other factors such as high immobility (Davies *et al.,* 2005), the low pH, the salinity and presence of CO_2 in water sources could cause faster dissolution of lead in water (ATSDR, 2007). Pb poisoning, which is a major public health challenge has become a global health problem displaying as anaemia when lead ions interferes with the formation of haemoglobin and prevents iron uptake (Obasi and Akudinobi, 2020). Pb has also been mostly attributed to the gastrointestinal tract and nervous system in children and adults (Engwa *et al.,* 2018). Acute exposure to lead causes headache, abdominal pain, loss of appetite, renal dysfunction, hypertension and arthritis while chronic exposure can result in birth defects, allergies, autism, dyslexia, paralysis, hyperactivity, psychosis, mental retardation, coma and even death (Engwa *et al.,* 2018).

The mean concentrations of Fe in well, borehole and river water were 0.710 mg/L, 0.805 mg/L and 0.640 mg/L respectively (Table 5). These values are significantly above the 0.3 mg/L safe limit for Fe in drinking water by WHO and NSDWQ, standards for potable drinking water. This was in good agreement with results reported by Warren et al. (2019) and Odigie and Adejumo (2018).Fe being a useful heavy metal in human body constitutes the hemoglobin and is involved in various physiological activities. However, in its free state, it generates hydroxyl radicals causing, DNA and cell damage leading to carcinogenesis.

The mean levels of Zn (0.9334 mg/L) in well, (0.6344 mg/L) in borehole and (0.2918 mg/L) in river were within the acceptable limit for Zn in drinking water; 5.0 mg/L by WHO, and 3.0 mg/L NSDWQ standards. These findings were consistent with those of Prasad et al. (2018) and Boateng et al. (2019). Ghaderpoori et al. (2018) proposed HEI pollution level classification of surface and groundwater. According to their classification, HEI of less than 10.00 indicates low-level pollution. HEI values between 10.00 and 20.00 indicate medium-level pollution, while HEI values greater than 20.00 indicate high-level pollution. The permissible limit of Zn in water according to WHO standards is 5 mg/L. In all the collected water samples concentration of Zn was recorded below the permissible limit. Although (Zn) levels in the present studies were seen to be below detrimental levels, several toxicity complications associated with overloads of these metals are well documented (Abdu, 2010; Engwa *et al.,* 2019). Consequent upon consumption of high amount of zinc could lead to side effects such as slowed growth, low insulin levels, irritability, hair loss, loss of appetite, diarrhea, and nausea (Dooyema, 2010; Akubue, 1997).

The mean levels of Cr (0.027 mg/L) in well, (0.010 mg/L) in borehole and (0.074 mg/L) in river were within the acceptable limits for Cr in drinking water; 0.005 mg/L by WHO and NSDWQ standards. These findings were consistent with those of Boateng et al. (2019) and in contrast with the findings of Prasad et al. (2018). The maximum concentration of Cr in food crops analysed at Igade mining site was 0.516 mg/kg which was recorded in legumes, with the highest mean concentration of 0.441 mg/kg (Table 6). The mean concentration of Cr in staple food crops at Igade decreased in the order legumes > vegetables > Cereals > tubers (Table 6). Generally, the Cr mean concentrations in staple food crops were below WHO/FAO (2011) stipulated limits of 2.3 mg/kg for cereals, 1.3 mg/kg for legumes and tubers, and 5.0 mg/kg for vegetables published by Codex Alimentarius. This study revealed that Cr level in the various food crops consumed at Igade-Mashegu might not pose health risk. Cr which is crucial for insulin activity and deoxyribonucleic acid transcription in organisms particularly humans (Rapheal and Adebayo, 2011). The mean Cr concentrations in this study are similar to the values by Ametepey et al. (2012) but lower than the values reported by Nimyel and Chundusu (2021) and Hussain et al. (2019).

The sequence of mean concentration of heavy metals in food crops analysed in this study exhibited the following pattern: Fe > Zn > Cu >As >Pb>Cr> Cd > Hg. It is also worth noting that the mean concentration of Cu, Cr, Fe, Hg, Zn, Ni and Pb in food crop samples evaluated were less than their respective legislated values for the various food crops, except the mean contents of Pb in tubers (0.662 mg/kg), which falls significantly above the WHO/FDA(0.3 mg/kg) (Table 6&7).

4 Conclusion

From this study, it can be concluded that the surface and underground water sources at Igade-Mashegu mining site and its environ are contaminated by As, Hg, Pb, Fe, and partly Cr, hence considered unfit for human consumption and agricultural uses, coupled with the increased levels of As and Cd in legumes and vegetables; and cereals and tubers respectively. These contaminations could be attributed to input from the local geology of the area, coupled with human agricultural practices and crude rudimentary processes involved in artisanal mining. The finding from this study is particularly worrisome since exposure to elevated levels of these heavy metals over time predisposes humans to various health consequences, culminating in disease conditions such as cancer, dermal disease, neurological problems and dysfunction of vital organs such as the brain, lungs, liver and kidney causing exacerbating health complications.

Authorities should institute proper environmental monitoring and evaluation as well as a standard environmental impact assessment program to prevent heavy metal poisoning, outbreak of disease and control activities of illegal mining. Also, safe alternative sources of potable drinking water should be provided in the mining community, thereby reducing the exposure of inhabitants to contaminated water. Meanwhile, sensitization and awareness on the health risk of the consumption of mine-tailings affected water sources should be carried out intensively through all positive channels especially in the local dialect of the inhabitants.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors have no conflicts of interest to disclose.

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