

Environmental health impact of potentially harmful element discharges from mining operations in Nigeria

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Abstract: Widespread artisanal, alongside small-scale mining operations are currently increasing in intensity in Nigeria. These activities are causing immeasurable damage to the environment and populations that live in the vicinity of these mine fields. The discharges of Potentially Harmful Elements (PHEs) from the exposed mine-out /mineral processing sites and their subsequent remobilization into the soils, and natural water bodies constitute serious human health problems. A study aiming at understanding the extent by which these elements contaminate the soils at the vicinity of the mining operations was conducted. This study also sought to identify the possible effects on human health and how it can be best mitigated. Geochemical results suggest that the discharges of PHEs from the mining/mineral ore processing operations have contributed significantly to the enrichment of these elements in the surrounding environment, thereby contaminating drinking water sources, food crops, and are disposed to subsequent entry into the human body through the food chain. Many of the mining communities make their living from subsistence farming, growing food from the surroundings, and obtaining drinking water from nearby surface and sub-surface water resources. The direct or indirect exposure of the human population to PHEs constitutes a potential risk to human health if not monitored and abated. Reports of in-vitro bio-accessibility tests show that less than 50% of bio available heavy metal contaminants in ingested soil are bio accessible during digestion process. Thus, there is need for the reduction of bio-available PHE in the soil by ensuring that mining operations generally are done in a manner that will secure a quality of environment adequate for good health and well-being of the communities around.

Keywords: Potentially Harmful Elements (PHEs), Mill/Mine Tailings, Contamination, Environment, Human Health, Artisanal Mining, Nigeria

1. Introduction

Indiscriminate artisanal/small scale mining and manual processing of metal ores has continued unabated in parts of Nigeria. This study focuses on two mining districts !, Anka, Zamfara State, Mining district in the north western region of Nigeria and Zurak, Plateau State, in central Nigeria (Fig.1) where Pb-Zn mineralization, (like in Zurak or associated with gold, like in Anka), are being mined for lead and gold respectively. The continued unsafe and rudimentary method of mining employed, not adhering to environmentally friendly practices will aggravate to inestimable magnitude - hampering agricultural productivity and affecting the health of nearby residents and other ecosystem components (Lar et

al., 2013). The miners employed the services of men, women and children to mine and process the ore. In fact, women make up more than 60 percent of the workforce.

Discharges from these mining activities contain Potentially Harmful Elements (PHEs) such as Pb, Hg, As, Zn, Cd, Cu, Se etc. Mercury is introduced into the environment through the gold amalgamation process. The tailings are indiscriminately dumped in residential areas and constitute the main source of PHEs. Water irrigation, a common farming practice in the area, is a factor that aid in accumulation of PHEs and their availability in the soils. Pb and Hg constitute the most toxic heavy metal arising from the artisanal mining activities and could pose significant risk to the quality of soil, plants, natural waters and consequently

human health (Lar et al., 2013).

Children apart from engaging in processing the mineral ore commodities, they play on the mill/mine tailings and dumps. During these activities, they inhale PHEs (Pb and/or Hg) in the atmospheric dust or ingest it through hand to mouth contact. Other routes of exposure to these elements are through drinking water and diet. Groundwater constitutes a major source of potable water for the mining communities. An epidemic of lead poisoning was reported some 4 years ago (June, 2010) in mining communities of Zamfara State, north-western Nigeria, (Fig.1) which caused the death of more than 400 children between the ages of 5 and 11 years and more than 4000 under age of five years at risk of death or of serious short and long-term irreversible health effects (CDCP, 2012; UNICEF, 2011; Saleh, 2011). Although the death toll from Pb poisoning in this episode is on the rise, the local miners continue to ignore advice from local environmental auditors. This is a wake-up call to averting further calamity in similar mining operations. A new approach is needed to prevent these consequences before more damage is done.

It is known that Lead exposure causes impaired physical and mental development in children and in severe cases, could cause seizures, comas and death, if not detected early (Duggan, 1985). Reports have shown that the ingestion of Hg polluted soil result in stagnation in body weight increase and Hg accumulation in the liver and kidney (Alloway, 1995, Adriano, 2001).

This paper summarized our findings on the level of contamination of PHEs resulting from releases from Pb-Zn \pm Au sulphide ore mining in two regions of Nigeria, and considered the effects on human health. Remediation measures are proffered that would help to obviate negative effects on the human population. Strategies are outlined for creating public awareness on the risks of prolonged human exposure to PHEs, especially Pb and Hg..

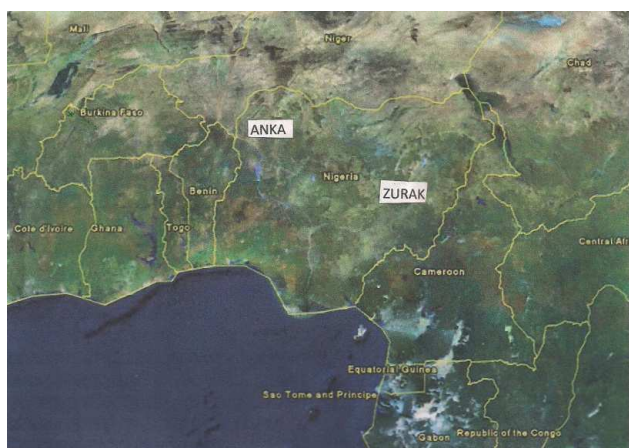


Fig 1. Map of Nigeria showing the location of the Anka and Zurak Mining districts (Modified from Google Earth).

2. Materials and Methods

Representative soil, water and vegetable samples were

collected. The soil samples were collected from the mining sites, mill/mine dumps, mineral ore processing sites as well as village and market squares, farmlands and uncultivated lands using a hand auger. Water samples from surface and borehole water supplies were collected in 250 ml polyethylene bottles and acidified with one to three drops of Nitric acid. Samples of sweet potatoes, onions and spinach from farmlands, were also taken. Physical parameters of water, viz., pH and EC were taken in-situ in the field.

The soil samples were pulverized to pass through 0.067 mm mesh size. 100 mg of the powdered soil sample was weighed into a Teflon crucible and dissolved in aqua regia ($\text{HCl} + \text{HNO}_3 + \text{HClO}_4$ (3:2:1)) after 6 hours of heating the solution to dryness on a hot-plate (250 °C). After, the crucible containing the sample is allowed to cool, 2 mls of 2M HCl is added and is topped with de-ionized water to about $\frac{3}{4}$ full and return to the hot-plate to warm for not more than 15 minutes. The crucible + sample solution is removed from the hot plate and allowed to finally cool. The content is diluted to 100mls and filtered (using size 42, 125 mm diameter, ashless filter paper) into a flat bottom flask ready for analysis. Vegetable Samples were oven-dried and pulverized to powder. 500 mg of the sample powder was weighed and digested the same manner as the soil sample. All the soil, vegetables and water samples were analyzed for the following PHEs (Pb, Hg, As, Cd, Se, Co, Cr, Cu, Fe, Ni, U, V and Zn) using Inductively Coupled Plasma Optical Emission Spectrometry (ICP OES), at the Geochemistry Laboratory of the Department of Geology and Mining, University of Jos, Nigeria. The quality of the analysis was controlled through the analysis of samples of known compositions along with the unknowns. The values obtained by the instrument from the reagent blank are automatically subtracted from the raw data before print out. This makes the data free from whatever impurities inherited from the reagents including distilled and de-ionized water. The results turn-out have an accuracy of ± 2 -5% depending on the number of standards used and concentration levels.

3. Results and Discussion

3.1. Zurak Galena Mining District

3.1.1. Surface/Underground Water

Pb, Zn and U (0.25, 4.9 and 1.71 ppm respectively) levels in all surface waters (River Pai and Gero) are high above WHO admixive limits for drinking water (0.01, Nil, and 1.4 mg/l respectively). Other elements (Co, Cr, Cu, and Ni) present concentrations below WHO permissible limits and therefore pose no problem to human health. These elements are completely or almost absent in the borehole and well water, except for the presence of Pb (0.03 ppm) in the well water.

3.1.2. Soils from Mine Pits, Market, Farmland and Uncultivated Lands

The soils of New-Zurak market, farmlands and uncultivated lands are moderately to extremely contaminated

with Pb, Cd, As, Zn, and U (Igeo. Of these elements, Zn appears to be the most enriched in the soils from the New Zurak market (Zn = 16.7 wt %) followed by U (0.32 Wt %) and As (118.3ppm).

3.1.3. Vegetables

The Spinach (*Amarranthus shistylis*) display significantly high concentrations in Pb (9.4 ppm), Zn (1309ppm) and U (159.3ppm), followed by As (32.06ppm), Se (14.68ppm), Cu (8.57), Cd (0.67ppm), Co (0.14ppm), and Ni (1.07ppm) (Table 1) in that decreasing order. The onions (*Allum cepa*) vegetable present extremely high concentrations in Zn (883.6ppm) and U (38.35ppm), followed by Ni (8.65ppm), Cu (7.98ppm) and Cd (0.23ppm) (Table 1). Pb, like As, Co and Cr are not present in the onions suggesting its inability to retain Pb and its capacity to preferentially absorb Zn. The sweet potato (*Ipomoea batatas*) like the spinach, present similar concentration in Pb (10.50ppm), with significantly high concentrations in Zn (136.7ppm) and As (33.56ppm) (Table 1). The concentrations of Zn, U and Cd in these vegetables are above the FAO safe permissible levels (49.40ppm, Nil and 0.20ppm respectively)..

3.2. Anka Gold/Galena Mining District

Results of the geochemical analyses are shown in Table 2.

3.2.1. Mining and Processing Sites

The concentrations of Pb, Hg, As, Cd, Cu and Zn are significantly high in the mining and processing sites (Table 2), decreasing with increasing distance away from these areas.

3.2.2. Uncultivated Land and Farmland

There are significant enrichment of Pb, Zn and Hg in the soils from the farmlands and uncultivated lands (Table 2), suggesting a contribution from dust circulation and the anthropogenic activities. Other PHE As, Cd, Co, Cr, Fe, Cu, and V did not affect the soils in some parts but with moderate contamination in other parts.

3.2.3. Village Square

The village square is equally extremely significant enriched with Pb and Hg (Table 2), there by extremely contaminating the area. Zinc shows some moderate enrichment in the soil. The soil is uncontaminated with Co and Cr.

3.2.4. Bioavailability/Bio Accessibility of PHE and Human Health

Our findings reveal that the soils in the mining and processing sites serve as a sink for PHE, particularly Pb, Hg, As, Cd, Cu and Zn, confirming that mining/mineral processing activities are the main causes of PHE soil contamination thereby constituting a potential risk to human health (Lar et al 2013 and in press). The total concentrations of PHE in the vegetables are significantly high. Notably Pb concentration in the spinach and sweet potatoes are greater than WHO admissible limit of 1mg Pb/kg in foodstuff. A country like the United Kingdom (UK) is attempting to restrict importation of foodstuff with Pb > 1 mg/kg (Abraham et al., 2013). The ingestion of the PHE contaminated soils is a major route of exposure of many of these PHE soil contaminants. Thus, in determining the human health risk assessment, the oral bioavailability of PHE soil contaminants (the fraction of the PHE that reaches the systemic circulation) is of relevance to assess (Oomen et al., 2002). Reports from most in-vitro digestion models simulating the human gastrointestinal tract to assess bio accessibility of PHE contaminants (the maximum amount of PHE available for intestinal absorption) from soil during digestion show that bio-accessibility differs between individual chemical elements (contaminants) as well as the pH of the gastric juice where a pH of about 1 might lead to a liberation of PHE into the system (Oomen et al., 2002). According to the works of Oomen et al., 2002, they concluded that in most cases < 50% of bio-available PHE contaminants are bio-accessible during digestion, indicating that a reduction of bioavailability will minimize the human health risk.

Table 1. Average Concentrations of Potentially Harmful Elements (PHEs) (in ppm) in the soils (from mining pits, mining dumps, the market place, farmland and uncultivated land), Water and Vegetables of New Zurak, Mining District.

LOCALITY	SAMPLE ID	Pb (ppm)	As (ppm)	Cd (ppm)	Co (ppm)	Cr (ppm)	Cu (ppm)	Ni (ppm)	U%	Zn%
Mine pits	ZNS1	144.86	170.1	5.20	10.55	12.15	15.71	22.79	0.42	1.56
Mine Dumps	ZNS2	824.80	85.52	4.58	9.38	15.27	36.27	20.83	1.04	9.39
Market Place	ZNS3	1806	118.3	16.60	8.14	27.84	30.80	9.20	0.32	16.68
Farmland	ZNS4	17.52	1.770	0.229	1.88	17.41	5.61	6.43	0.13	0.06
Uncultivated land	ZNS5	17.59	41.14	0.08	1.77	11.91	3.77	4.07	0.45	0.13
Boreholes	BH	< DL	<DL	<DL	< DL	< DL	0.001	< DL	0.26	< DL
Well	WW	0.03	"	"	"	"	0.02	< DL	0.26ppm	1.60ppm
Surface Water	SW	0.25	"	"	0.014	0.003	0.04	0.016	1.68ppm	4.85ppm
Sweet potato	SP	10.50	33.55	0.59	0.66	<DL	4.12	<DL	<DL	136.7ppm
Onions	ON	<DL	<DL	0.23	<DL	"	7.98	8.65	38.35ppm	883.6ppm
Spinach	SP	9.46	32.06	0.67	0.14	"	8.57	1.07	159.3ppm	1309ppm

<DL: Below Detection Limit, ppm : parts per million = $\text{mg kg}^{-1} = \mu\text{g g}^{-1} = \text{mg/l}$; ppb : parts per billion = $10^{-3} \text{ ppm} = \mu\text{g kg}^{-1} = \text{ng g}^{-1}$

Table 2. Average Concentrations of PHE's (in ppm/Wt %) in Soil Samples from Anka Mining District, Zamfara State, Nigeria.

Sample type	Locality	Pb	Hg	As	Cd	Co	Cr	Cu	Ni	V	Zn	Fe ₂ O ₃ Wt%	U ₂ O ₅ Wt %
MS	Mine site	2637	7.931	97.9	4.522	13.57	85.26	159.8	17.15	43.43	506.2	5.51	0.06
OMPS1	Ore Mineral Processing site	3920	10.277	100.6	8.655	14.58	106.1	159.2	24.66	59.33	492.4	4.45	0.05
OMPS2	Ore Mineral Processing site	1960	8.388	84.31	3.551	7.102	60.69	117.3	15.93	123.8	609.4	10	0.11
VA1	Village Square	289.7	2.985	27.14	<DL	7.553	37.08	28.93	15.97	37.49	450.8	2.57	0.03
VA2	Village Square	3326	12.325	110.4	6.87	14.77	106.3	222.6	54.29	27.97	710.5	3.47	0.04
FL1	Farmland	30.26	3.892	38.2	5.447	10.59	32.15	23.44	20.1	14.18	612	3.33	0.04
FL2	Farmland	25.73	NA	24.05	2.41	4.93	19.17	10.98	7.835	18.79	426.9	1.14	0.01
UCL1	Uncultivated land	770.3	NA	98.57	1.133	0.81	50.6	53.17	10.57	28.72	298.5	4.07	0.04
UCL2	Uncultivated land	447.4	NA	55.97	0.0656	3.587	3.587	50.37	18.99	77.38	783.9	10.8	0.12

<DL = below Detection Limit

NA = Not Analyzed

4. Conclusion

This study has established that artisanal/Small scale mining of Pb-Zn sulfides (\pm gold) in the two mining regions of Nigeria (Anka and Zurak) has led to the pervasive contamination of the environment from particularly PHEs, especially Pb Cd, As and Hg. It has also established the main route of human PHE exposure in these mining districts to be through inhalation from mine dusts, diet and water. It is further revealed that the main sources of drinking water in the mining district are contaminated with Pb, U, Zn, Cd and As. Food cultivated in and around the mining district is also contaminated with Pb, Zn, U and As (Lar et al., 2013 and in press).

Although, it is not within the scope of this study to conduct a human health risk assessment through in-vitro bioaccessibility tests, a report from the study with different digestion models indicate that in most cases, less than 50% of bio-available heavy metals contaminants is bio-accessible (i.e mobilized from the contaminated soil into the digestive system (Oomen et al., 2002). However, how much heavy metals are liberated into the digestive system will depend on the type and the pH of the gastric juice (Oomen et al., 2002). Thus bio-availability of PHE will be dependent on bio-accessibility since the latter is a function of the maximum amount of the chemical element available for intestinal absorption (Cave et al., 2011). This calls for the reduction of bio-available PHE contaminants in the soils in the vicinity of mining operation through the following mitigation measures:

- 1 Presently, one of the remediation strategies Government has put in place in the Anka mining district is where the contaminated soils are replaced with clean soils of suitable compaction quality at all excavated surfaces and the removed contaminated soils dumped in constructed landfills (UNICEF, 2011). This should be seen as a temporary measure, since it is difficult to control the artisanal mining practices. Alternatively and as a long term measure, phyto remediation appears to be a better option (Medina et al., 2004). Also, many new methods for removing lead from water are beginning to emerge which may compliment these measures (Mataka et al., 2006, Nemr et al., 2007, Baral et al., 2007, and Rate et al., 2010).

- 2 The enforcement of mining laws by the relevant Nigerian Government Agencies as well as a close working relationship between the artisans and the Government, Non Governmental Associations (NGO) and other relevant agencies are essential to developing Best Management Practices (BMP). Nevertheless, this has not reduced artisanal mining in Nigeria.
- 3 The mining communities should be enlightened on the need to adhere to safe and environmentally friend mining practices and the danger posed by exposure to excessively high levels of toxic metals in the environment e.g. Safe working techniques to minimize Hg emission from occupational and environmental pollution should be put in place.
- 4 The mining communities should be counselled and tested periodically especially children to determine level of lead in their blood so as to prevent deaths and diseases due to Pb and Hg poisoning.
- 5 Support and incentives by Government in creating alternative jobs and opportunities for the miners may dissuade them from engaging in the unsafe practice. This is a difficult task, but so long as poverty remains, artisanal mining will continue unabated.

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