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Lead and Mercury Contamination Associated with Artisanal Gold Mining in Anka, Zamfara State, North Western Nigeria: The Continued Unabated Zamfara Lead Poisoning

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Abstract: A total of 24 soil samples were collected from areas around Artisanal Gold and associated Pb-Zn-Cu sulfide mining and mineral processing sites in the Anka mining district of Zamfara State, NW Nigeria. The samples were geochemically analyzed with the main objective of assessing the degree of Pb and Hg pollution in the environment resulting from the mining and mineral ore processing activities in the mining district and to consider the effect on human health. The assessment of the degree of pollution or toxicity was based on the Igeo (index of geoaccummulation) and EF (enrichment factor) where the former gives a quantitative pollution class with respect to the quality of the medium analyzed, while the latter differentiates between metals originating from anthropogenic activities and those from natural processes. The geochemical results show that the concentrations of Pb and Hg especially at the mineral processing sites significantly exceed the established thresholds (4,152 ppm and 12.92 ppm respectively). The calculated EF values for both Pb and Hg revealed that the soils from the entire mining district are extremely enriched in these elements, essentially originating from the anthropogenic activities (EF= >> 40). Lead and Mercury are toxic heavy metals with documented long-lasting adverse human health effects. These calls for efficient bioremediation measures for the removal of Pb and Hg from the contaminated soils that take into account the geochemical peculiarities of the mining district.

Key words: Lead, mercury, polluted soil, environment, human health, gold, artisanal mining.

1. Introduction

Widespread artisanal gold mining has continued unabated in the Anka mining district of Zamfara State of Nigeria (Fig. 1) despite its adverse environmental consequences and associated human tragedy. An epidemic of lead poisoning was reported in the area in 2010 which caused the death of more than 400 children and more than 4,000 under age of five years at risk of death or of serious short and long-term irreversible health effects Vanguard [1], Saleh [2], UNICEF(Uniited Nation Children’s Fund) [3]. Gold and associated Pb-Zn-Cu sulfide ore is mined artisanally from nearby mines and processed manually in residential areas. The mineral ore is mined, crushed and pulverized using simple tools such as diggers, shovels, pans, pestle/mortar and locally fabricated machines. Mercury is added to the mineral ore to amalgamate the gold. The miners employed the services of men, women and children. Infact, women make up more than 60% of the workforce. The tailings are indiscriminately dumped in residential areas and constitute the main source of Pb and Hg and others heavy metals (e.g., Cd, Zn, Cu, As, and Se). Water irrigation, a common farming practice in the mining district, is another practice that aid in the distribution and accumulation of Pb and Hg in the soils.

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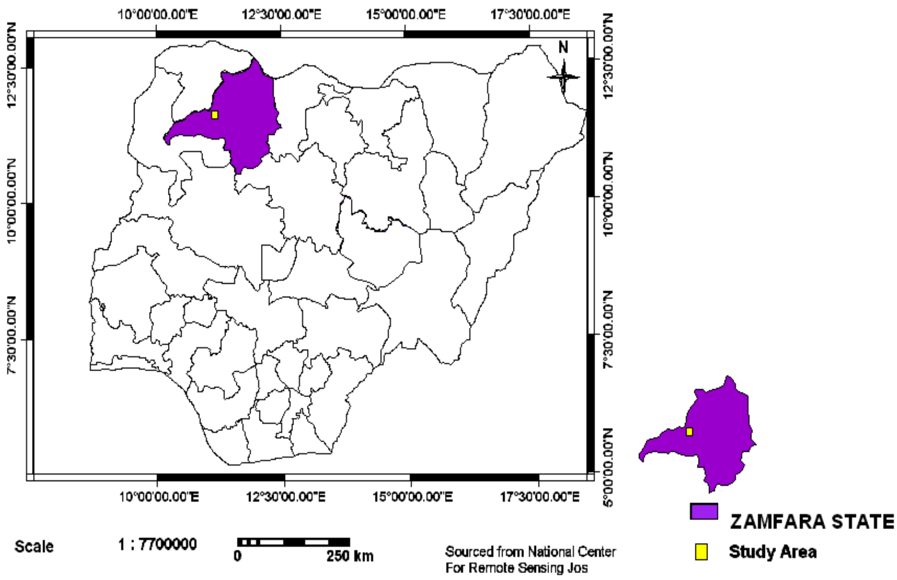

Fig. 1 Map of Nigeria showing the study area located in Zamfara State.

Pb and Hg pose significant risk to the quality of soil, plants, natural waters and human health. However, other heavy metals such as Zn and Cu are essential for the normal growth of plants and human beings. The exposure pathways are through atmospheric soil dust (coming from grinding and/or contaminated soil) mostly ingested through inhalation and/or through ingestion via hand-to-mouth, contact by children, in drinking water and mother-to-child.

A number of studies have been undertaken to create public awareness on the risks of prolonged human exposure to Pb and Hg and the current efforts aimed at reducing environmental and human health impact arising from the artisanal mining and processing of the gold from the Anka mining district (Azubike [4], Babajide [5], Opafunso [6], Saleh [2], UNICEF [3]). In the same vein, this study seeks to assess the extent of the unabated Pb and Hg pollution of the soil and to proffer strategies aiming at reducing its adverse effects on the human population so as to sustainability.

The increased levels of the Pb in the human body system interfere with a variety of body systems such as the heart, kidneys, reproductive and nervous systems (Saleh [2]). The physical manifestations of this toxicity in children are potentially permanent learning and behavior disorders (Duggan et al. [7]). Other symptoms include abdominal pain, confusion, headache, anemia, irritability, and in severe cases seizures, coma and death (Wikipedia [8]).

2. Geologic Setting

The Anka mining district lies within the Anka Schist Belt composed of meta-conglomerates, meta-sandstones, phyllites inter-layered with acid volcanic rocks (rhyolite-dacite) (Holt et al. [9]) (Fig. 2). The meta-conglomerates form several units with thicknesses reaching 150-200 m, but which die out laterally; they are inter-bedded with feldspathic meta-sandstones. In the western part of the belt, phyllites are more dominant but occur together with some meta-siltstone, meta-sandstone, acid volcanics as well as serpentinite (meta-ultramafics) emplaced as lenticular to ovoid bodies within the meta-sediments (Fig. 2).

Gold mineralization in the Anka Schist belt occurs in association with lead-zinc-copper sulfide mineralization in the form of quartz-sulfide veins of about 1.5 m wide in places and stockworks hosted by the country rock (phyllites) (Garba and Akande [10],

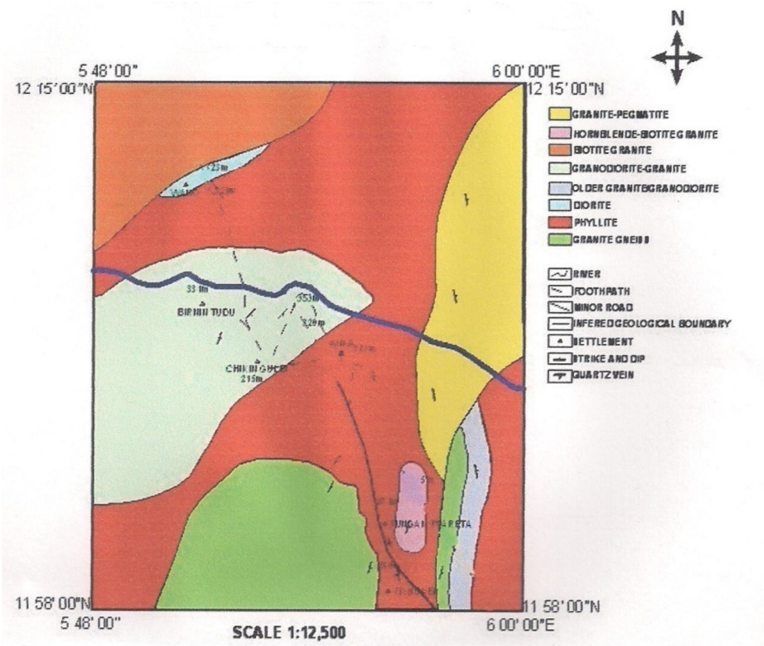

Fig. 2 Geological map of Anka Area, Nigeria.

Garba [11]). Gold occurs in a mineral paragenesis with pyrite, chalcopyrite, galena and minor sphalerite, magnetite and bismuth telluride in a gangue of mainly quartz with some carbonates, sericite, chlorite and tourmaline (Garba, [11]). The gold veins are surrounded by a narrow zone of hydrothermal alteration in which a chlorite-tourmaline-pyrite carbonates association overprints a dominantly sericitic fabric of the hornfels wall rocks (Garba [11]). The veins hosting the gold mineralization is apparently related to sub-regional fault structures following a general structural trend of $N18^0E$ which corresponds to the major structural control exhibited by the serpentinites emplaced at the margins of the Anka fault system (Garba [12] and [11]). Individual veins seldom exceed 0.5 km of strike length and are concordant with the host rock foliation (MMSD [13]). The gold mineralization is believed to be a product of K-metasomatism derived from hydrothermal fluid of upper crustal origin (Garba [11]), the same fluid responsible for the lead-zinc-copper mineralization (Garba and Akande [10]). Past mine records, reconnaissance exploration and studies have shown gold grades in the range 5-15 ppm (MMSD [13]).

3. Materials and Methods

3.1 Soil Sampling Procedure and Dissolution

A total of twenty four (24) soil samples were collected from the Anka mining district in clean polythene bags. Samples were taken at a depth of 0-20 cm with a hand auger (a stainless steel screw) from five villages namely Bagega, Dareta, Yalgama, Sunke and Abare. Soils collected were from the mining sites; mineral ore processing sites, uncultivated lands, farmlands and the village square (Fig. 3).

100 mg of the soil sample was weighed and attacked with aqua regia (2 mL HNO_3 + 6 mL HCl). The solution was heated for 6 h in a sand-bath at a temperature of 250 ºC in a fume cupboard to dryness and then left to cool; 2 mL of HCl were added to re-dissolve the dry sample. 10 mL of distilled water was then added and heated for 5 min. The extract were cooled and the content filtered (using size 42, 125 mm diameter, ash less filter paper) into 100 mL volumetric flask and make- up to 100 mL mark with distilled ready to be run on ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry) (Perkin Elmer, Optima 2000 DV) at the Geochemistry Laboratory,

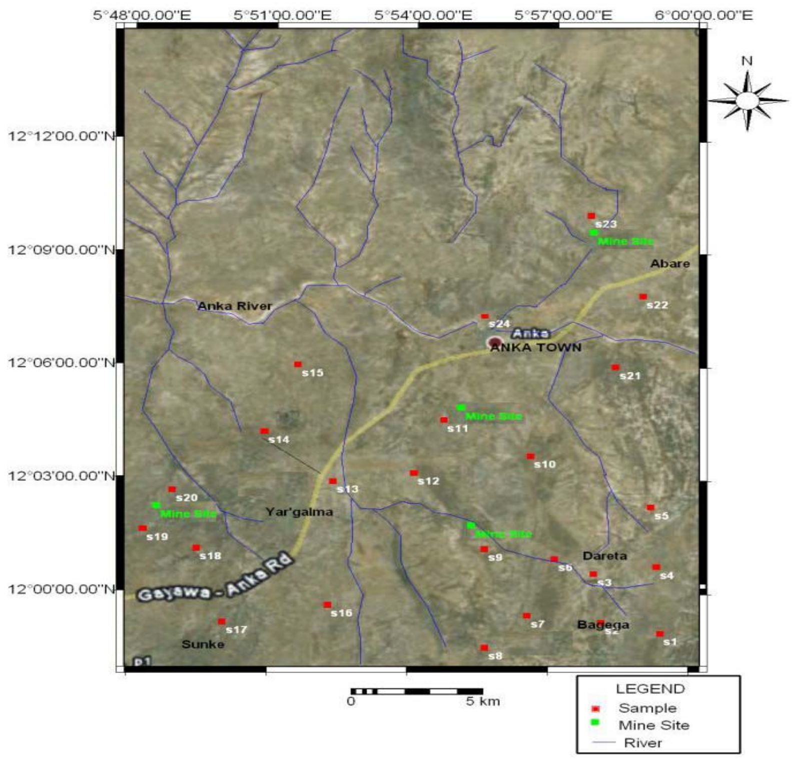

Fig. 3 Sample location map of the Zamfara Mining District.

Department of Geology and Mining, University of Jos, Nigeria. Quality control of analytical result was monitored by internal reference materials and replicate analysis. The values obtained by the instrument from the reagent blank are automatically subtracted from the raw data before print out. The results turn-out have an accuracy of ± 2%-5% depending on the number of standards used and concentration levels. The soil samples were analyzed for mainly Pb and Hg including the following heavy elements (As, Cd and Zn).

3.2 Artisanal Mining Method

The artisanal miners extract the mineral ore using rudimentary tools like diggers, pick axes and hammers (Fig. 4). The mineral ore is carried to the mineral processing site, where it is then crushed into smaller aggregates by mainly women and children using hammer or mortar and pestle (Fig. 5). The crushed lumps are then pulverized using a locally fabricated grinding mill (Fig. 6). Gold is separated from other minerals/impurities in the sluice boxes (Fig. 7). The gold concentrate collected from the sluice boxes is further re-concentrated by panning (Fig. 8). Gold is then separated from this concentrate by amalgamation using Hg (Fig. 9). Mercury is evaporized by heating with a blow torche (Fig. 10) or over an open flame, thereby leaving behind small gold nuggets.

3.3 Parameters for Estimating the Degree of Pollution

3.3.1 Index of Geoaccummulation:

The index of geoaccummulation (Igeo) allows the estimation of the enrichment of metal concentration above the background or baseline concentration and it is computed using the Muller [14] equation:

$$\text{Igeo} = \log_2 [Cm/1.5Bm] \qquad (1)$$

where, Cm is the measured concentration of element m (Pb and Hg) in the soil sample; Bm is the geochemical background for the element m. The constant 1.5 corrects for the natural fluctuations between the content of given metal in the environment and some anthropogenic influences (Loska et al. [15]).

Fig. 4 Artisanal gold mining pit.

Fig. 5 Children (mainly) using hammer to break gold mineral ore into smaller pieces.

Fig. 6 Local miners using bare hands in grinding of broken gold material into powder (pulverization) using a locally fabricated grinding mill.

Fig. 7 Washing of ground gold ore material in a sluice box to concentrate gold.

Fig. 8 Panning of gold to further eliminate impurities.

Fig. 9 A process of separating fine gold particles from the gangue minerals after mercury amalgamation.

Fig. 10 Burning of mercury amalgam using blow torch to evaporate mercury, leaving gold nuggets.

Muller [14] has distinguished six classes for increasing Igeo values (Table 1).

3.3.2 EF (Enrichment Factor)

EF estimates the amount of anthropogenically-introduced metal into the soil and it is measured as the amount or ratio of the sample metal enrichment above the concentration present in the reference material (Abrahim and Parker [16], Mediola et al. [17]). EF is here calculated using Huu et al. [18] formula:

$$EF = [C_{metal}/C_{normalizer}]\ \text{soil}/[C_{metal}/C_{normalizer}]\ \text{control} \quad (2)$$

where, C_{metal} and $C_{normalizer}$ are the concentrations of metal (Pb and Hg) and the normalizer in soil and in

Table 1 Six classes of the index of geoaccummulation (after muller [14]).

Class	Value	Soil quality
0	Igeo <0	Practically uncontaminated
1	0 < Igeo < 1	Unpolluted to moderately contaminated
2	1< Igeo < 2	Moderately uncontaminated
3	2 < Igeo < 3	Moderately to heavily uncontaminated
4	3 < Igeo < 4	Heavily polluted
5	4 < Igeo < 5	Heavily to extremely uncontaminated
6	5 < Igeo	Extremely uncontaminated

unpolluted control material. Five contamination categories are recognized on the basis of the enrichment factor (Sutherland [19]) (Table 2). As the *EF* values increase, the contributions of a given element from anthropogenic source also increase (Sutherland [19]).

3.4 Statistical Analyses

Statistical data processing based on Pearson correlation was done using SPSS 15.0 software. The multivariate correlations "r" shows the percentage of variance in the collectively dependent and the independent variables. A correlation coefficient defines the relationship between two variables and show how one variable differs from another. A high correlation coefficient (near 1 or -1) indicates a good relationship between two variables and a correlation coefficient around zero indicates no relationship. Positive values of "r" indicate a positive relationship and signify that such elements have close association and are indeed from the same source, while negative values indicate an inverse relationship, reflecting different sources. Multiple correlation values for Pb and Hg together with other associated elements are presented in Table 6.

4. Results and Discussion

Results of the geochemical analyses for Pb and Hg and other associated heavy metals (As, Cd and Zn) in 24 soil samples from the Anka mining district are shown in Table 3. The range of concentration of Pb in the samples is from a minimum of 6.91 ppm to a maximum of 4,152 ppm, with a mean of 1,171.43 ppm.

Table 2 Contamination categories recognized on the basis of the enrichment factor (after Sutherland [19]).

EF (Enrichment factor)	Category
EF < 2	Deficiency to mineral enrichment
EF > 2-5	Moderate enrichment
EF > 5-20	Significant enrichment
EF > 20-40	Very high enrichment
EF > 40	Extremely high enrichment

The maximum concentration of 4,152 ppm is recorded at a mineral ore processing site (sample S24). The concentration of Hg varies from 2.15 ppm in Bagega to 12.92 ppm (Sample S24) in the Anka processing sites with a mean of 6.25 ppm (Fig. 3). In respect of the other associated heavy metals, the highest concentration of As (173.20 ppm) and Cd (10 ppm) were also recorded at the Anka mineral ore processing site, while the maximum Zn concentration (1,657 ppm) was recorded at Kwalli mine site.

4.1 Mining and Mineral Ore Processing Sites

At the Anka mineral ore processing site, Pb and Hg display concentrations between 1,694-4,152 ppm and 7.38-12.92 ppm respectively (Table 3). The mining sites also display concentrations ranging from 1,146 ppm to as high as 2,637 ppm for Pb; the maximum recorded at the Jameson mine dump site (Sample S20). They also display Hg concentrations ranging from 2.84 ppm to 7.93 ppm; the maximum concentration of 7.93 ppm recorded at the Jameson mine. The other associated heavy metals Cd and As also display high concentration values in the mining sites; 10.01 ppm and 173 ppm respectively.

The *EF* values for Pb and Hg (41.83-84.54 and 76.88-159.23 respectively) (Table 5) from the mining sites suggest that they are anthropogenic in origin and have extremely enriched the soils. This result is further corroborated by the Igeo values of Hg and Pb (5.73-6.93 and 5.45-7.26, respectively), indicating that the soils in the mining area are extremely contaminated with these metals. In the mineral processing sites, both Pb and Hg present EF far above 40 (59.47-498.18), indicating extreme enrichment (Table 5).

Table 3 Concentration of Pb, Hg and other heavy metals (in ppm) in the soil samples.

Sample type	Locality	Coordinates	Pb	Hg	As	Cd	Zn
S9	Mine site	12º01'09.79" N 5º55'36.22" E	1,946	2.84	98.03	<DL	332.3
S11	Mine site	12º04'34.56" N 5º54'40.96" E	1,218	4.448	99.17	4.383	1657
S20	Mine site	12 º02'04.72" N 5º 48'57.41" E	2,637	7.931	97.9	4.522	506.2
S23	Mine site	12º10'02.04" N 5º57'45.90" E	1,146	6.288	63.78	1.864	380.2
S6	Mineral ore processing site	12º00'55.23" N 5º57'06.56" E	1,740	7.38	82.41	1.779	358
S10	Mineral ore processing site	12º03'37.55" N 5º56'32.96" E	3,193	9.011	127.2	6.874	432.7
S12	Mineral ore processing site	12º03'10.08" N 5º54'05.05" E	3,920	10.277	100.6	8.655	492.4
S18	Mineral ore processing site	12º01'07.54" N 5º49'27.88"E	1,694	7.399	85.37	2.786	1600
S19	Mineral ore processing site	12º01'37.90" N 5º48'19.11" E	1,960	8.388	84.31	3.551	609.4
S24	Mineral ore processing site	12º09'10.16" N 5º54'18.66" E	4,152	12.924	173.2	10.005	411.3
S2	Village square	11º59'14.90" N 5º58'06.88" E	1,432	5.481	124.2	< DL	452.8
S3	Village square	12º00'32.07" N 5º57'56.32" E	17.36	4.577	12.49	5.74	196.3
S13	Village square	12º02'56.00"N 5º52'21.31"E	289.7	2.985	27.14	< DL	450.8
S17	Village square	11º59'11.36" N 5º50'03.04" E	3,326	12.325	110.4	6.87	710.5
S22	Village square	12º07'53.33" N 5º58'53.94" E	19.57	4.149	16.5	0.0097	336.2
S4	Farmland	12º00' 43.82" N 5º59'16.84" E	30.26	3.892	38.2	5.447	612
S5	Farmland	12º02'18.64" N 5º59'08.21" E	463.2	5.887	59.56	< DL	227.6
S7	Farmland	11º59'25.37" N 5º5632.97" E	25.73	-	24.05	2.41	426.9
S14	Farmland	12º04'14.94"N 5º50'52.18"E	19.8	-	24.7	DL	329
S15	Farmland	12º06'00.28"N 5º51'32.91"E	2,892	-	96.91	7.843	808.1
S1	Uncultivated land	11º58'58.82" N 5º59'23.43" E	6,909	-	7.434	4.658	447.7
S8	Uncultivated land	11º58'33.22" N 5º55'38.49" E	20.6	-	23.44	0.0466	213.4
S16	Uncultivated land	11º59'39.37" N 5º52'17.07" E	770.3	-	98.57	1.133	298.5
S21	Uncultivated land	12º06'00.42" N 5º58'20.67" E	447.4	-	55.97	0.0656	783.9

< DL = below Detection Limit.

However, Arsenic, Cd and Zn are significantly enriched (EF = 5.09-23.59, 11.68-19.12 and 2.59-9.23 respectively) and therefore have moderately to heavily contaminated the mineral processing sites (Igeo = 2.87-3.94, 1.89-3.20 and 2.73-4.89 respectively).

Positive correlation coefficients (Table 6) were observed between the elements Pb and As, Cd, Hg in view of their close association with Pb (Greenword and Earnshaw [20], Levison [21]), thus the observed soil contamination by Cd and As is also implicitly linked to Pb-Zn mineralization.

Table 4 Summary of Igeo values for Pb and Hg and other associated heavy metals.

S/No	Pb	Hg	As	Cd	Zn
S1	-1.88	5.36	-0.60	2.63	3.05
S2	5.81	6.03	3.46	DL	3.07
S3	-0.55	5.77	0.15	2.94	1.86
S4	0.25	5.53	1.76	2.86	3.50
S5	4.18	6.13	2.40	DL	2.08
S6	6.09	6.46	2.87	1.25	2.73
S7	0.01	4.68	1.10	1.68	2.98
S8	-0.31	4.70	1.06	-4.01	1.98
S9	6.97	5.08	3.12	DL	2.62
S10	-0.39	6.75	3.50	3.20	3.00
S11	5.58	5.73	3.14	2.55	4.94
S12	7.26	6.93	3.16	3.53	3.19
S13	3.51	5.15	1.27	DL	3.06
S14	-0.36	5.55	1.13	DL	2.61
S15	6.83	6.93	3.11	3.39	3.90
S16	4.92	6.24	3.13	0.60	2.47
S17	7.03	7.20	3.29	3.20	3.72
S18	6.05	6.46	2.92	1.89	4.89
S19	6.26	6.64	2.91	2.24	3.50
S20	6.69	6.56	3.12	2.59	3.23
S21	4.13	6.09	2.31	-3.52	3.86
S22	-0.38	5.63	0.55	-6.27	2.64
S23	5.49	6.23	2.50	1.31	2.82
S24	7.35	7.27	3.94	3.74	2.93

DL = below detection limit.

In summary, Pb and Hg and particularly As, Cd and Zn are extremely enriched in the top soils of the mining and processing sites relative to the farmland and the uncultivated land (non-mining areas). There is a general decrease in the concentrations of Pb and Hg with increasing distance away from the mines and processing area confirming that mining/mineral processing activities are the main causes of soil contamination.

4.2 Uncultivated Land and Farmland

In the uncultivated land and farmland, a range of Pb concentration in the soil between 6.09 ppm to 2,892 ppm was recorded. Mercury display concentration values between 2.15 ppm to 10.23 ppm with a mean concentration of 5.11 ppm. Other elements like As, Cd and Zn on the other hand display noticeably high concentrations 98.57, 7.84 and 808.1 ppm, respectively.

Table 5 Summary of EF values for Pb and Hg and other heavy metals analyzed.

S/No/Elem	Pb	Hg	As	Cd	Zn
S1	0.50	77.05	1.22	11.49	15.34
S2	17.90	20.80	3.52	0	2.67
S3	3.57	285.82	5.82	40.15	19.07
S4	1.60	101.92	4.59	9.81	15.31
S5	14.48	95.39	4.22	0	3.36
S6	47.40	93.03	5.09	1.65	4.60
S7	3.99	101.37	8.45	12.70	31.25
S8	2.97	93.80	7.66	0.23	14.52
S9	52.72	14.24	3.67	0	2.59
S10	1.59	498.18	23.59	19.12	16.72
S11	15.66	17.36	2.89	1.92	10.06
S12	155.65	269.05	9.05	11.68	9.23
S13	19.93	61.97	4.23	0	14.64
S14	1.53	89.78	4.31	0	11.97
S15	42.72	86.78	3.25	3.94	5.64
S16	33.42	83.57	9.69	1.67	6.12
S17	169.50	335.55	12.75	11.90	17.10
S18	21.62	59.47	2.47	1.21	9.64
S19	34.62	92.60	3.38	2.13	5.08
S20	84.54	159.23	7.11	4.93	7.66
S21	7.31	43.22	2.07	0.04	6.05
S22	1.17	75.53	2.24	0.02	9.52
S23	41.83	76.88	5.28	2.31	6.55
S24	178.77	376.18	16.90	14.65	8.36

Table 6 Correlation table for various elements within the study area.

		As	Cd	Hg	Pb	Zn
As	Pearson correlation	1	.470*	.761**	.815**	.245
	Sig. (2-tailed)		.020	.000	.000	.249
	N	24	24	24	24	24
Cd	Pearson correlation	.470*	1	.714**	.750**	.193
	Sig. (2-tailed)	.020		.000	.000	.367
	N	24	24	24	24	24
Hg	Pearson correlation	.761**	.714**	1	.938**	.161
	Sig. (2-tailed)	.000	.000		.000	.451
	N	24	24	24	24	24
Pb	Pearson correlation	.815**	.750**	.938**	1	.207
	Sig. (2-tailed)	.000	.000	.000		.333
	N	24	24	24	24	24
Zn	Pearson correlation	.245	.193	.161	.207	1
	Sig. (2-tailed)	.249	.367	.451	.333	
	N	24	24	24	24	24

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

The calculated EF values for Hg show that even the soils from the farmlands and uncultivated lands are equally extremely enriched in Hg (EF = 43.22-101.92) (Table 4), and therefore have been heavily contaminated with Hg from the mining activities (Igeo = 4.76-6.93). Except in some isolated areas, where Pb is very highly enriched to extremely enriched (EF = 33.42-42.72), most parts of the uncultivated and farmlands are moderately enriched in Pb (EF = 0-3.99), and therefore are mostly uncontaminated by Pb (Igeo = 0.01-1.88). However, Arsenic and Cadmium like Pb are moderately enriched and of anthropogenic source (EF = 1.22-9.69 and 0-11.49 respectively). These elements have moderately contaminated certain parts of the farmlands (Igeo = 0-3.13 (As) and 1.68-3.39 (Cd) respectively).

Zn with EF ranging from 3.36-15.34 is highly enriched in the soils of the uncultivated and farmlands presumably from external sources, and therefore have moderately to heavily contaminated the soils (Igeo = 2.08-3.90).

4.3 Village Squares

The village squares are the centers of the mining settlements where in most cases the buying and selling transactions of the mineral commodity takes place. A range of concentrations of Pb between 19.57-3326 ppm (with a mean of 1,016 ppm) was recorded in the Village Square. Mercury also displays concentration values from 2.98-12.33 ppm. Lead and Mercury are extremely highly enriched in the village squares (EF = 17.90-169.50 and 61.97-335.55, respectively) and thereby extremely contaminated the soils (Igeo = 5.75-7.20 and 5.81-7.03, respectively)

Arsenic is moderately enriched in the village squares (EF = 3.52-4.23), while Cd and Zn are significantly enriched (EF = 9.81-40.15 and 2.67-15.31, respectively), indicating that the village squares are moderately to heavily contaminated by these elements (Tables 1 and 2).

The enrichment of Pb in the aforementioned areas is attributable to releases from the mine dumps sites (Kuba mines, Kwalli and Zuzzurfa mines) (Fig. 3). The highest concentration of Hg (12.92 ppm) has been recorded from a mine dump site and apparently its release from these dumps (tailings) overtime into the surrounding soils and underground water systems could be disastrous to human health.

4.4 Environmental Human Health Risk of Exposure to Lead and Mercury

An assessment of Pb in blood of mainly children (the most vulnerable group) in the Anka mining district were determined (CDC [22, 23]) and revealed blood Pb concentration levels of between 50 mg/dL and 100 mg/dL, with values as high as 200 mg/dL. Also, potable water collected from the wells and stream channels within the mining district display Pb concentrations ranging from 10-50 ug/L and 200 ug/L Pb respectively as against WHO/USEPA [24, 25] admissible limit of 10 µg/L for Pb for potable drinking water. Water in ponds, the major sources for domestic use and for livestock, is often highly contaminated (Vanguard Newspaper [1]). The exposure of children to Pb has been known to impair their physical and mental development (WHO [24]). Human exposure to high lead levels in adults affects the intestinal tract, kidneys, joints and reproductive system (Lovel et al. [26]). The overexposure to Pb, especially in children is known to lead to seizures, comas and death, if not detected early (Azubike [4]). The 2010, about 400 children died as a result of lead poisoning in the Anka mining district (Vanguard Newspaper [1]).

Mercury is being introduced into the mining environment from the amalgamation process for gold recovery. It is during the removal process of Hg from the amalgam that it is vaporized into atmosphere where the vapor is inhaled or may fall as droplets in the surrounding soil. There were newspaper reports that mercury levels in the air in the affected areas were nearly 500 times the acceptable limit (Vanguard Newspaper [1]). As revealed from this study, the mine tailings constitute environmental risk as potential secondary source of mercury. The mine tailings are discharged directly into the small creeks and stream channels. However, the inhalation of Hg vapor constitutes the greatest risk to the miners. The lungs easily absorb particles in the vapor form and circulate them via the blood stream into the human body system (Alloway [27]). 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 [27], Adriano [28, 29]).

Other heavy metals, in association with the gold mining in the area and which have adversely affected the quality of the soil are As, Cd, and Zn. The main symptoms of Arsenic poisoning are nausea, vomiting, abdominal cramps and headaches (Nogawa et al. [30]). Zinc on the other hand, is an essential element for humans and is required in various enzymatic reactions; however, high levels, long-term exposure of Zn could be carcinogenic, mutagenic and tetratogenic (Kabata-Pendias and Pendias [31]).

5. Conclusions

Artisanal gold mining and associated mineral ores has continued unhindered in Anka mining district despite its attendant environmental degradation and the adverse human health problems sometimes leading to death. About 66% of households in the mining district undertook at least one mining activity within their compound (UNICEF [3]). This study has established that artisanal gold mining and associated Pb-Zn mineralization in the Anka mining district has led to the extreme contamination of the environment with Pb and Hg, and other associated heavy metals (As, Cd and Zn). It has also established the main route of human exposure to Pb and Hg in the Anka mining district to be through their inhalation from mine dusts. These elements are subsequently released from the contaminated top soils into sources of drinking water thereby contaminating them. The direct or indirect exposure of human and/or animals to these Pb and Hg overtime predisposes them to various health complications, severe damage of biological tissues, epidemics disease such as cancer, skin disease, neurological problems, malfunction of several vital organs and probable death.

To ensure sustainability and to secure a quality of environment adequate for good health and well-being of the communities in the mining district, the following mitigation measures are here proposed:

(1) As a long term measure, phyto-remediation; a vegetative environmentally friendly and nascent green technology could be an option as a very cost effective and a safe method to remediate the contaminated mining environment (Medina et al. [32]). Also, the appropriate adaptation of some emerging new methods for removing lead from water (Mataka et al. [33], Nemr et al. [34], Baral et al. [35] and Rate [36]) could be tested.

(2) The enforcement of mining laws by the relevant 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 the area.

(3) The mining communities should be enlightened on the need to adhere to safe and environmentally friendly mining practices and the danger posed by exposure to excessively high levels of toxic Pb and Hg in the environment.

(4) There should be support and incentives by the government in creating alternative jobs and opportunities for the miners so as to dissuade them from engaging in the unsafe practice. This is a difficult task, since poverty is the main drive, but so long as poverty remains, artisanal mining in the area will continue unabated.

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