Vol. 12(2), pp. 10-21, April-June 2020
DOI: 10.5897/JTEHS2020.0456
Article Number: E0AE3F163601
ISSN: 2006-9820

http://www.academicjournals.org/JTEHS

ACADEMIC JOURNALS

Journal of Toxicology and Environmental Health Sciences

Full Length Research Paper

Heavy metal pollution status and risk assessment on area with artisanal mining activities

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Received 23 February, 2020; Accepted 10 April, 2020

This study was undertaken to re-evaluate the heavy contamination level of Bagega community which recorded acute lead poisoning in 2010 and was reclaimed between 2010 and 2012. The levels of the following heavy metals (Zn, Pb, Hg, As and Cd) was measured in sixteen sampling sites around Bagega and its environs using Varian AA240 Atomic Absorption Spectrophotometer. The assessment of pollution was achieved using the Effect Range Low (ERL) and Effect Range Median (ERM), pollution index (PI) and geoaccumulation index (Igeo). The result revealed that the soil samples within Bagega community recorded concentration below the geochemical background for analyzed heavy metals. Soils around abandoned gold mine fields show high concentration of Pb, Cd, Hg and As. Based on the ERL and ERM values, Bagega and Topeki communities recorded low to high contamination of heavy metals, while abandoned mine fields and within farmland recorded moderate to very high contamination. Pollution index analysis show insignificant contamination within Bagega and Topeki communities while farmland and abandoned mining axis recorded significant contamination of Pb, Hg and As. The Igeo indicates that relatively higher levels of Pb, Cd and Hg was recorded; suggesting heavy metalcontamination. Generally, soils around Bagega community were found to range from uncontaminated to moderately contaminated. Though land reclamation within Bagega community may have reduced heavy metal levels, the study reveals high risk of heavy metals toxicity to inhabitants due to farming of arable land around mining areas.

Keywords: Lead poisoning, risk, toxicology, effect range low, effect range median, pollution index, geoaccumulation.

INTRODUCTION

Heavy metal pollution in Nigeria environment is a concern due to their toxicological effect on human and plants. Heavy metals are natural constituents of earth crust and through natural processes such as erosion and volcanic eruption, they are transported and deposited in the environment. Significant amount of wastewater, generated from anthropogenic activities such as mining and smelting, fertilizer production, battery manufacturing, electroplating, wood preservation and agricultural activities pose a high risk to the environment, ecosystem and human health (Gosar, 2004; Xiao et al., 2017). There is evidence of mining activities being responsible for

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heavy metal contamination of both land and water (Johnston, 2004; Foulds et al., 2014). Floods occurring at mining sites are considered to be serious contaminant dispersion agent (Mayes et al., 2013). Crude oil mining hasbeen shown to contribute lead (Pb) and cadmium (Cd) contaminant to an industrial area (Uzoekwe and Aigberua, 2019).

In Nigeria, solid mineral exploitation is underdeveloped giving rise to artisanal and small-scale mining (ASM) with attendant pollution problems. Artisanal mining is illegal in many cases, and thus degrade the environment (ILO, 1999). ASM has experienced explosive growth in recent years due to the rising value of mineral prices and increasing difficulty of earning a living from agricultural and other rural activities. In 2017, an estimated population of 40.5 million people worldwide were directly engaged in ASM, up from 30 million in 2014, 13 million in 1999 and 6 million in 1993 (IGF, 2017).

Every state in Nigeria is endowed with one solid mineral or the other including ZamfaraState. In 2010, widespread and acute lead poisoning in ZamfaraState, affected over 3500 children and over 400 deaths were recorded (Medecine Sans Frontieres, 2012). In adults, high rate of infertility and miscarriages were recorded (WHO, 2012). The incident was due to activities of gold artisanal miners in Pb-rich ore deposit area.Therehave been other reports on heavy metal pollution arising from artisanal mining in the study area (Azubike, 2011, Babajide, 2011, Olafunso, 2011, UNICEF, 2010-2011; Uriah et al., 2013). Nonetheless, there is need for continuous monitoring because heavy metals persist in the environment for a long time and it is ubiquitous in nature. However, the impact of mining activities on given sites is controlled by several factors including climate, mining methods, geological conditions, and whether the mine is active or abandoned (Bell et al., 2001). Acid mine drainage which is due to oxidation of metal sulphides (e.g pyrite FeS_2) lead to the acidification of the drainage water (Bell et al., 2001; Baker and Banfield, 2003).

Heavy metal concentration in the soil plays an important role in controlling metal bioavailability to plants. Studies show that the use of waste water contaminated with heavy metals for irrigation over long period of time increases the heavy metal contents of soils above the permissible limit. Ultimately, increasing the heavy metal content in soil also increases the uptake of heavy metals by plants. Heavy metal like, Cd, Pb and Ni are not essential for plant growth, but they are readily absorbed and accumulated by plants in toxic forms (Mohammad et al., 2011). An intake of vegetables grown in soils contaminated with heavy metals or irrigated with waste water poses a possible risk to human health and wildlife. Therefore, the determination of free metal ion concentrations in soil solution becomes important.

Surface water run-off from fields of both active and abandoned pits, mineral processing areas and agricultural waste, get contaminated by heavy metals. As heavy metals cannot be degraded, they are continuously being deposited and incorporated in water, thus causing heavy metal pollution in water bodies.Agricultural activities within the heavy metal contaminated areas can result to plant accumulation of Pb, Hg and other associated heavy metals like Cd and Zn. Pb and Hg pose significant risk to the quality of soil, plants, natural waters and human health within the mining axis. However, heavy metals like 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 (Uriahet al., 2013). The aim of this study is to evaluate risk of heavy metal pollution on the environment of agrarian communities with artisanal mining activities.

MATERIALS AND METHODS

Study area

The area is bounded by longitudes 5° 58'09''E to 6° 1'51''E and latitudes 5° 00' 00"N to 5° 30' 00" N. The area can be accessed through Anka-Bagega Expressway (Figure 1). It falls within the humid tropical region with two distinct seasons, the rainy season, from March to October, and dry season, from November to March.

Collection of samples

Soil samples were collected from stream sediments at various locations from the major tributaries and distributaries of Anka River (which controls the drainage of the area), mine sites, and agricultural (crop) lands to assess the distribution of ionic species in the ecosystem (Figure 2). The artisanal mines are mostly located in southeast, southwest and northwest of Bagega and Topeki communities. These locations include BGG3, BGG6, BGG9 and BGG11. Similarly, the locations around the farmland include BGG1, BGG5, BGG9, BGG11, BGG12 and BGG14. A total of one hundred and twelvesoil samples (seven from each location) were collected. Pre–test systematic sample preparation was done for each soil sample analysed, including drying, screening, and digestion.

Sample preparation

The soil samples were firstly dried and disaggregated prior to sieving. The samples were laid out in pre-numbered evaporating dishes and sun-dried for three days. Each sample was disaggregated and homogenized by the use of agate pestle and mortars (Mendoza et al., 2000).

About 2 g of the dried samples were weighed into a digestion flask and 20mL of the acid mixture (650mL concentrated HNO_3; 80mL per hydrochloric acid; 20mLconcentratedH_2SO_4) was added following 10mL of aqua regia using syringe and stirred. The resulting mixture was heated on a Bunsen burner to a volume of 2.5mL, then 10mL of de-ionized water was added and again heated gently to a volume of 5mL, it is then removed and allowed to cool. After this, it was filtered into measuring cylinder with the help of filter paper and de-ionized water was added to an appreciable level of about 25 mL. This is called aliquot. This aliquot was put in a

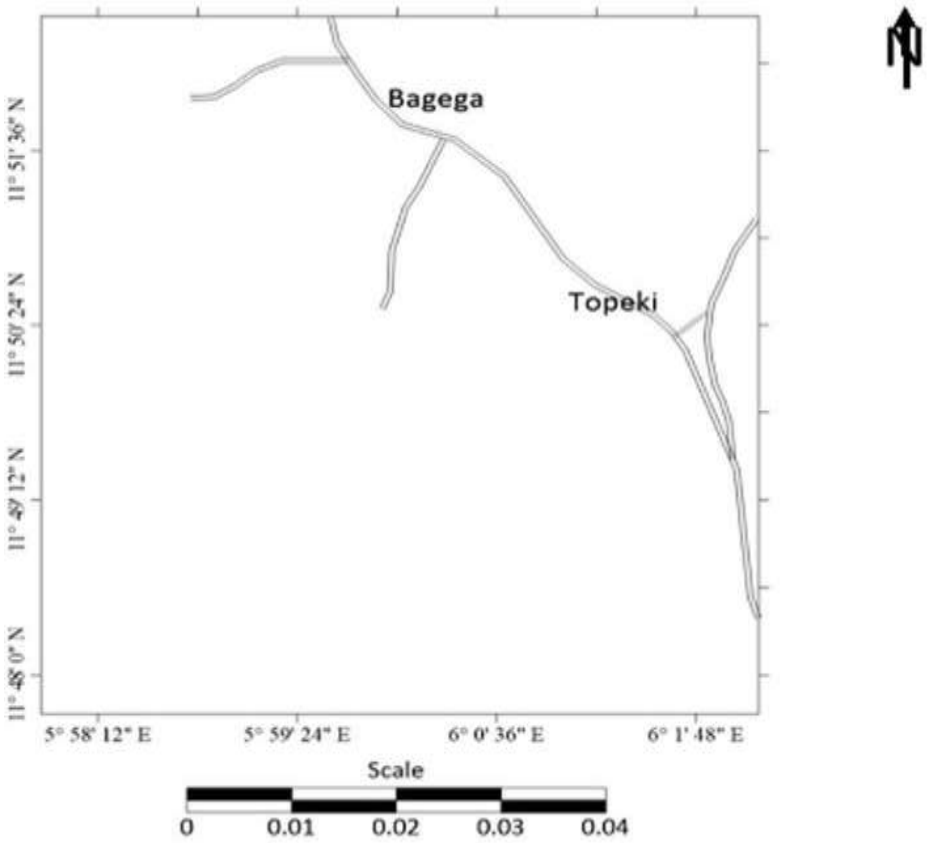

Figure 1. Map of the study area.

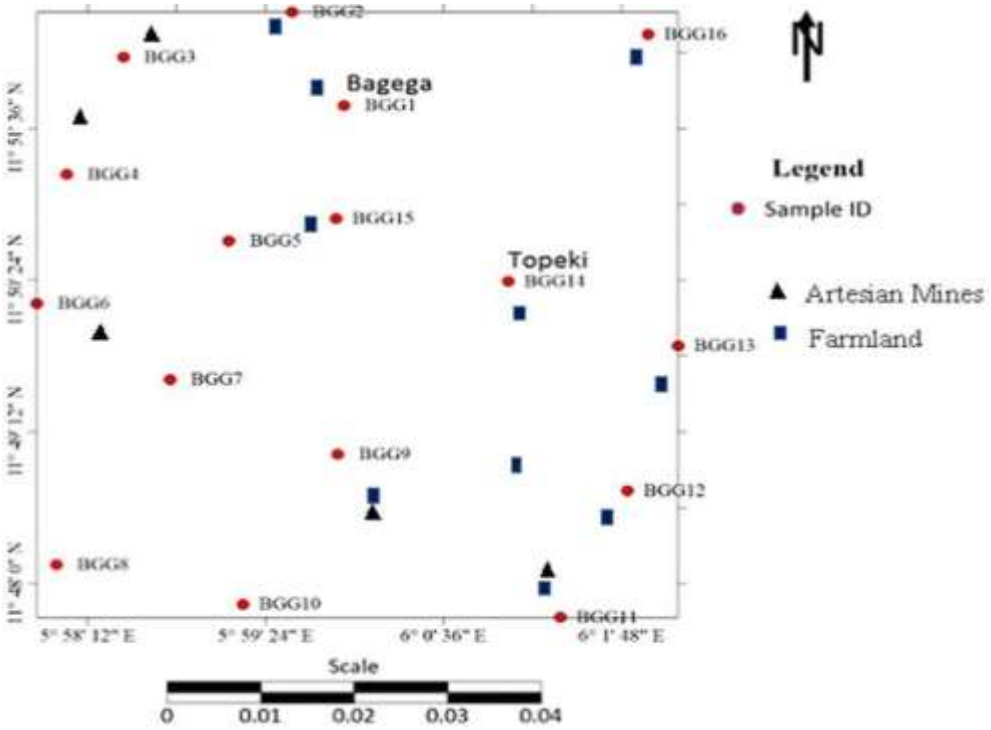

Figure 2. Map of the study area showing stream sediments/soil sample location.

Table 1. ERL and ERM limits for metals.

Metal	ERL values (mg/kg)	ERM values (mg/kg)
Zinc (Zn)	150	410
Copper (Cu)	34	270
Lead (Pb)	47	220
Cadmium (Cd)	1.2	9.6
Chromium (Cr)	81	370
Mercury (Hg)	0.15	0.71
Silver (Ag)	1	3.7
Arsenic (As)	8.2	70

Source: US- EPA - MAIA (1998).

Table 2. Classes of geoaccumulation index (Igeo).

Class	Value	Soil/ sediment quality
0	Igeo ≤ 0	Uncontaminated (UC)
1	0 <Igeo< 1	Uncontaminated (UC) to moderately contaminated (MC)
2	1<Igeo< 2	Moderately contaminated
3	2 <Igeo< 3	Moderately contaminated (MC) to heavily contaminated (HC)
4	3 <Igeo< 4	Heavily contaminated (HC)
5	4 <Igeo< 5	Heavily contaminated (HC) to extremely contaminated (EC)
6	5 <Igeo< 6	Extremely contaminated (EC)

container with a tight lid and used for analysis of Zn, Pb, Cd, Hg and As (APHA, 1998).

Heavy metal analysis

The heavy metal analysis in triplicate was conducted using Varian AA240 Atomic Absorption Spectrophotometer as described by American Public Health Association (APHA) (1998). The result of the analysis was reported in mg/L and was converted to concentration of metal in mg/kg of dry sediment.

Geochemical assessment

Effect range low (ERL) and effect range median (ERM)

The metal concentration of stream sediments/soils was compared with the Effect Range Low (ERL) and Effect Range Median (ERM) values used by United States Environmental Protection Agency (USEPA), Mid Atlantic Integrated Assessment (MAIA) for estuaries (1997-98 Summary Report). This was in line with the sediment quality guideline established by Levinson (1974). ERL is the lowest concentration of metals in stream sediments that produced adverse effects in 10% of organisms reviewed in MAIA project. The ERM shows the 50% of the organism's studiedand reported to have harmful effects. Based on ERL and ERM values, metal concentrations below the ERL values are not expected to pose any adverse effects, while levels above the ERM values are likely to be very toxic. Table 1, shows the ERL and ERM limits for metal concentrations by USEPA, MAIA project (1997- 1998).

Pollution Index (€)

Pollution index (€) as proposed by Powell (1992) is the ratio of individual metal concentration in soils to the ERM value for that particular metal. It expresses how many times the concentration of the individual metal is higher than the ERM for that metal in soil samples.

Mathematically,

$$\text{Pollution index } (€) = \frac{C}{ERM} \quad (1)$$

Where C is the concentration of the individual metal in bed sediments (in mg/kg), ERM is the effect range median (in mg/kg); € > 1 is Significant Contamination and € < 1 is Insignificant Contamination.

Geoaccumulation Index (Igeo)

Geoaccumulation index (Igeo) is the measures of the geologic accumulation of pollutants and contamination in sediments (Obasi and Akudinobi, 2015).The constant 1.5 allows for natural fluctuations in content of a given substance in the environment and very small anthropogenic influences. The geoacculation index class is shown in Table 2. Geoaccumulation index (Igeo) is defined by the formula;

$$Igeo = \log_2 Cn/1.5Bn \quad (2)$$

Where Cn is the measured concentration of metals in sediment fraction and Bn is the geochemical background value for the metal.

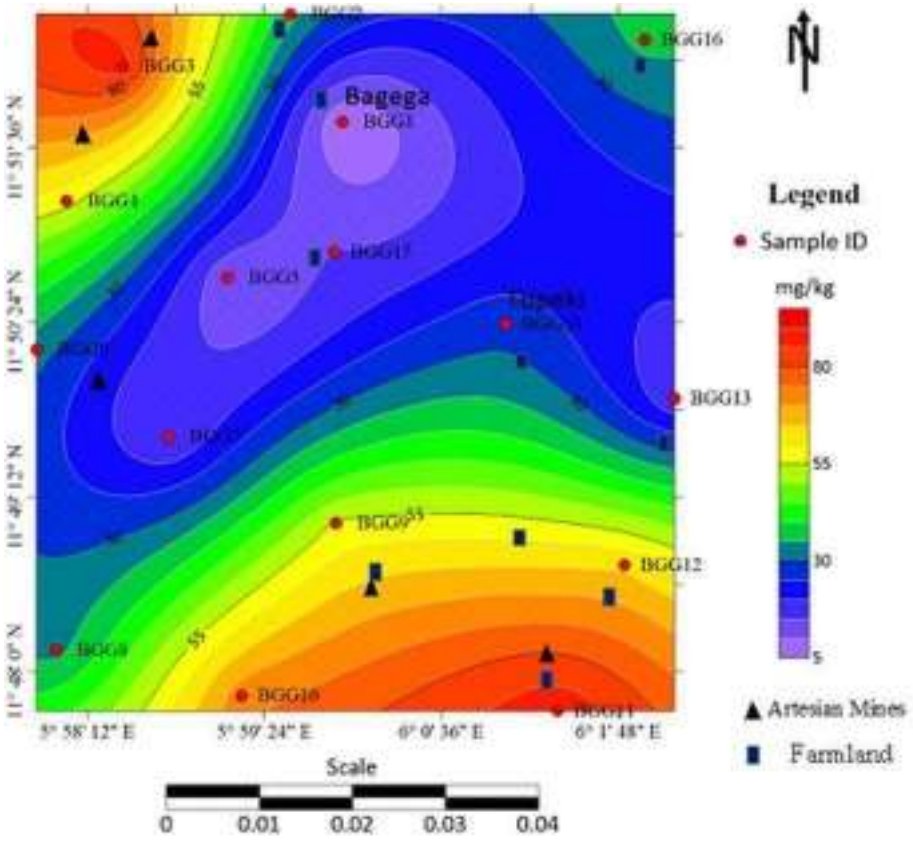

Figure 3. Contoured distribution of zinc in stream sediments/soils.

RESULTS AND DISCUSSION

The results of levels of heavy metals (Zn, Pb, Cd, Hg, As) analysis of the studied area is presented in Figures 3 to 7. The results showed presence of Zinc in all the samples with the concentration range of 5.12-88.8 mg/kg and mean concentration of 40.9 mg/kg.The geochemical background value has been set at 70mg/kg in the earth's crust (Levinson,1974). The highest concentrations of zinc were recorded at the areas around west of Bagega and south of Topeki, where mining activities was intense in the early 2000. The result shows higher concentrations in soils in the derelict mines than stream sediments in the area. The lowest concentration was recorded in Bagega community.

The distribution and transport of zinc in water, sediments and soils are dependent upon the species present and characteristics of the environment, especially pH, redox potential (Eh), salinity, nature and concentrations of complexing ligands, cation exchange capacity, and the concentration of zinc (Gundersen and Steins, 2003). Sorption is the dominant reaction, resulting in the enrichment of zinc in suspended and bed sediments (ATSDR, 2005; EPA, 1979d). ATSDR (2005) stated that increased levels of zinc in soils can be attributed to natural occurrence of zinc enriched ores (as in the study area). Toxicity in human may occur if zinc concentration in water approaches 400mg/kg. This is characterized by symptoms of irritability, muscular stiffness, pain, loss of appetite and nausea (Fergussion, 1990).

The geological source of Pb within the study area is artisanal gold mining in Pb-rich ore. The result of the analysis shows that lead was well dispersed in the study area. Pb has mean concentration of 108.6 mg/kg with range of 1.49-447.4 mg/kg. The maximum concentration was recorded in samples collected around the southern part of the study area. Geochemical background value of Pb was set as 12.5 mg/kg in earth's crust (Levinson, 1974). Bagega and Topeki communities recorded the lowest concentration. Apart from the Pb ores which has high occurrence in the study area, the chemistry of lead contributes to its higher concentration recorded. Once lead falls onto soil, it sticks strongly to soil particles and remains in the upper layer of soil (ATSDR, 2007). Reddyet al.(1995) concluded that the accumulation of lead in most soils is primarily a function of the rate of deposition from the atmosphere, as in the case of dispersion during blasting stage and crushing of ore during mining. Most lead is retained strongly in soil, and very little is transported through runoff to surface water or leaching to groundwater except under acidic conditions

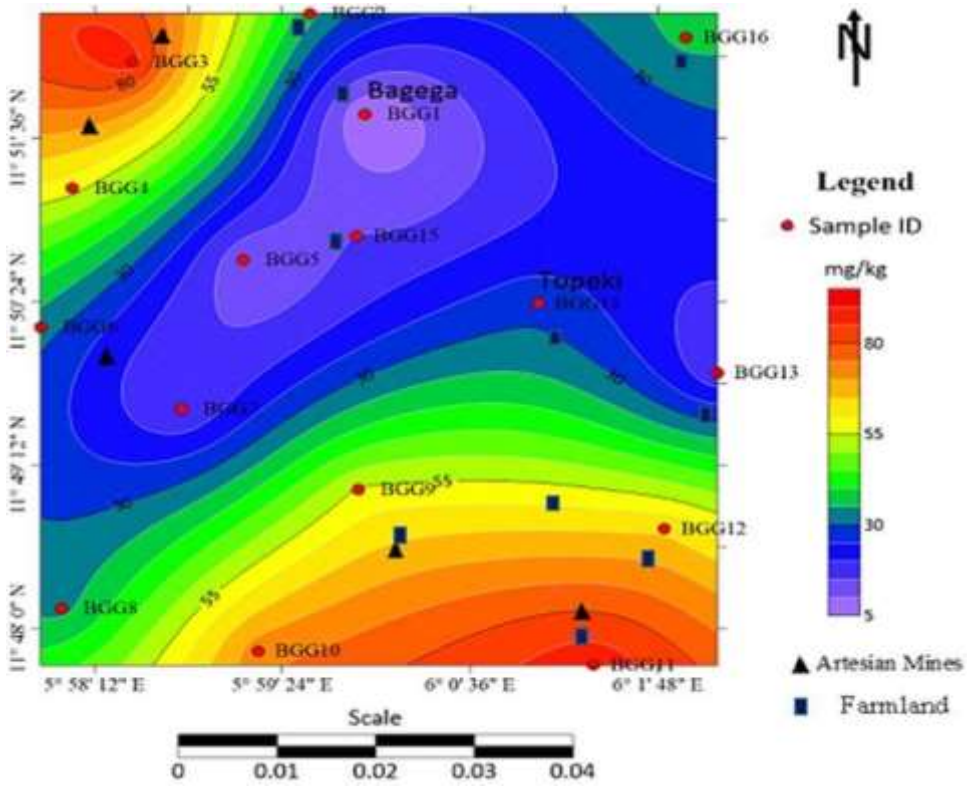

Figure 4. Contoured distribution of Lead in stream sediments/ soil samples.

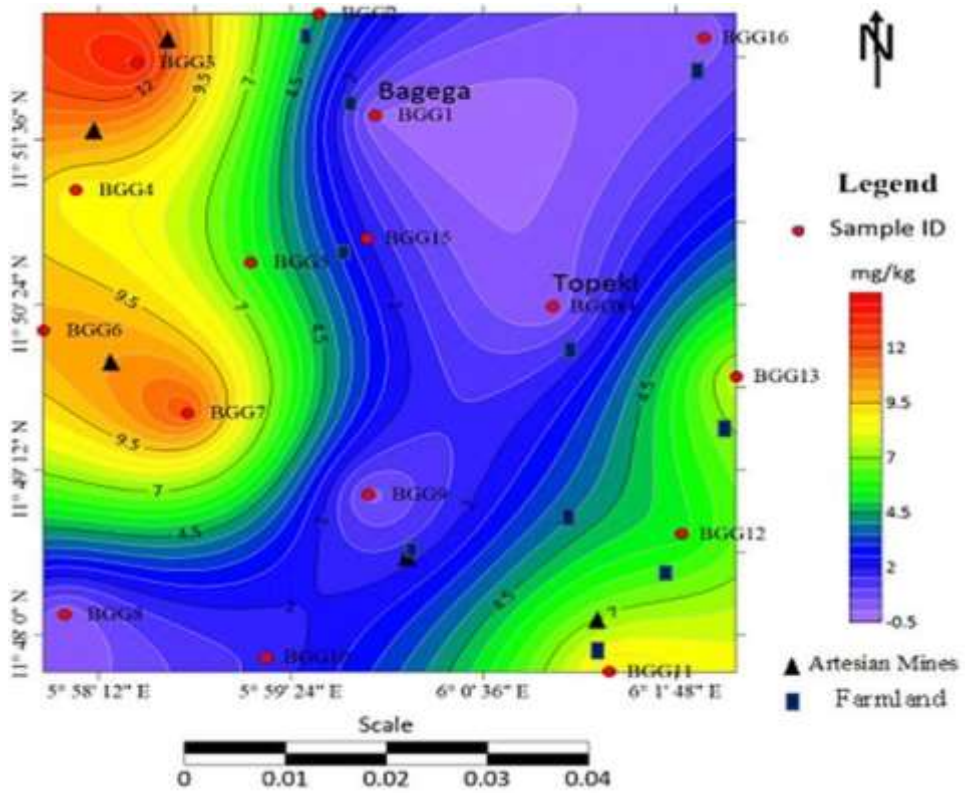

Figure 5. Contoured distribution of Cadmium in stream sediments/ soil samples.

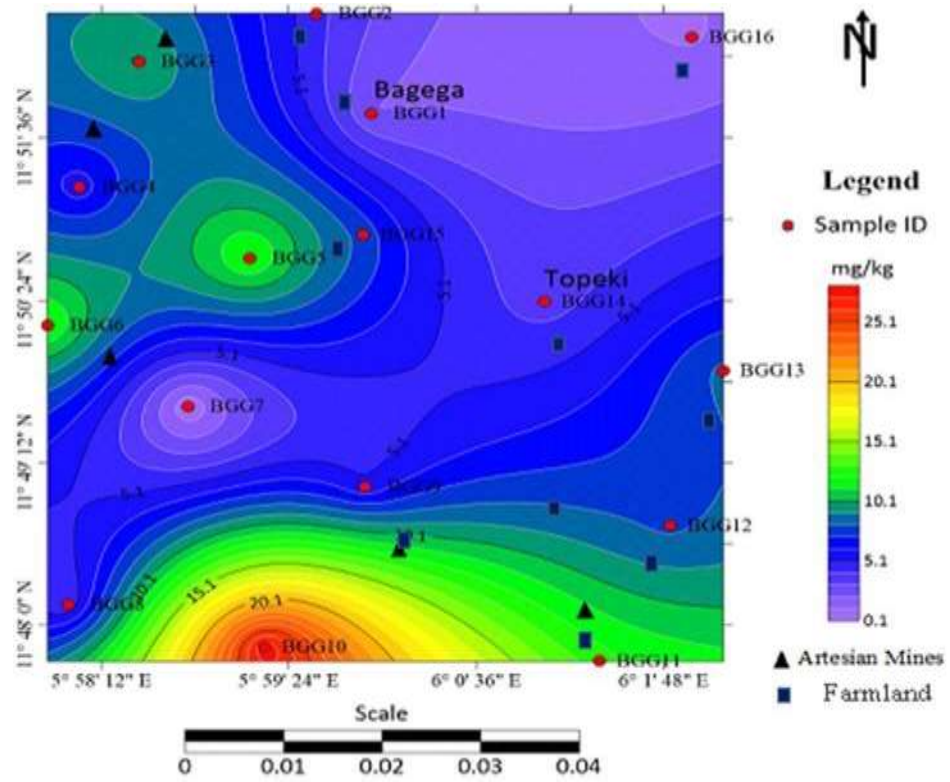

Figure 6. Contoured distribution of Mercury in stream sediments/soil samples.

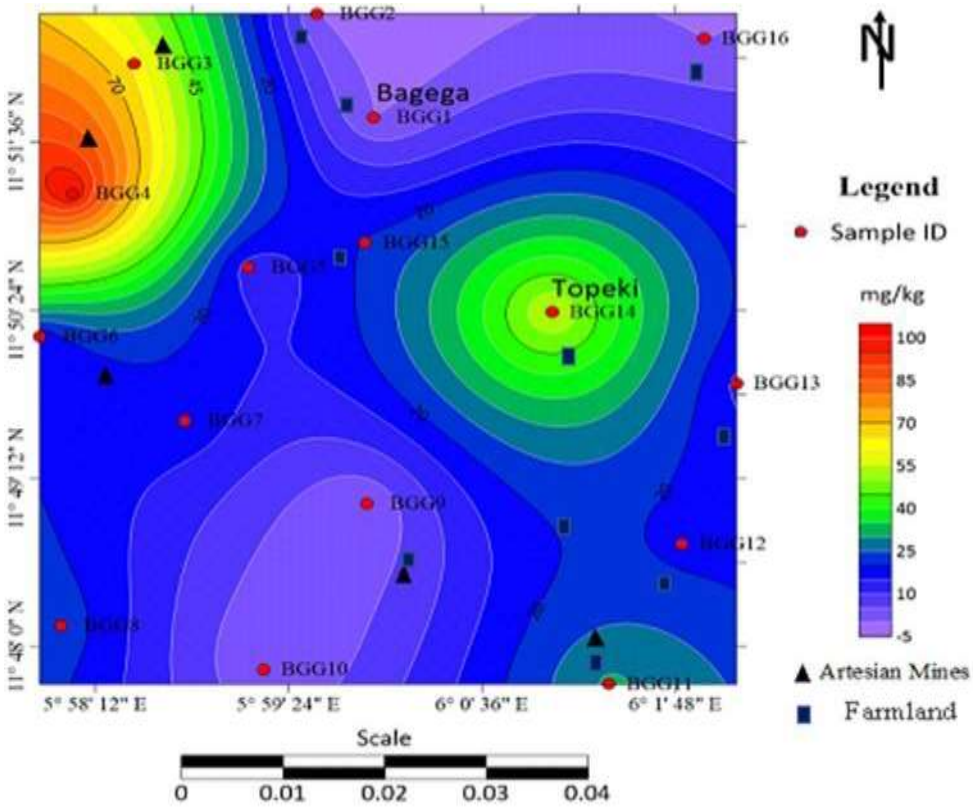

Figure 7. Contoured distribution of Arsenic in stream sediments/soil samples.

(EPA, 1986a; NSF, 1977).

For Cd, the concentration measured ranged from 0.00-13.65mg/kg, with mean concentration of 5.08mg/kg. Geochemical background value was set as 0.15mg/kg on the earth's crust (Levinson, 1974). The result revealed relatively higher Cd level for the northwestern, western and southeastern part of the study area. These are the major mining axis within the study area in the early 2000. But Bagega and Topeki communities recorded relatively lowerCd concentrations.The higher concentration of Cd recorded is as a result of its association with zinc, lead, and gold ores (as in the study area) (MSF, 2012). Generally, Cd will bind strongly to organic matter and this will, for the most part, immobilize Cd (Autier and White, 2004). While soluble forms may migrate in water, Cd is relatively nonmobile and insoluble complexes or adsorbed to sediments. Cd can participate in exchange reactions on the negatively charged surface of clay minerals. Cd also may precipitate as insoluble cadmium compounds, or form complexes or chelates by interaction with organic matter. Available data suggest that organic matter is more effective than inorganic constituents in keeping Cd unavailable (McBride, 2002).

During processing of mined ore, mercury is added to amalgamate the gold, hence, introduced into the ecosystem. The mean concentration of mercury is 7.90 mg/kg with the range of 1.00-28.00mg/kg. Its maximum concentrations were recorded at the southern and western part of the study area.

Human activities such as mining and burning of fossil fuels resulted in the release of mercury to the environment. In soils and surface waters, mercury can exist in the mercuric (Hg^{2+}) and mercurous (Hg^{+}) states as a number of complex ions with varying water solubility (Meili, 1991).Vaporization of mercury from soils may be controlled by temperature, with emissions from contaminated soils being greater in warmer weather when soil microbial reduction of $Hg^{2+}$to the more volatile elemental mercury is greatest (Lindberg et al., 1991).Atmospheric deposition of mercury from both natural and anthropogenic sources has been identified as an indirect source of mercury to soil and sediments (Sato and Sada, 1992; WHO, 1990, 1991).

Finally, the results of arsenic metal analysis showed that arsenic was well dispersed in the study area. Many of the sample's locations recorded high concentrations of arsenic. It has a maximum concentration of 100.6 mg/kg with mean concentration of 23.53 mg/kg and minimum concentration values of 0.00mg/kg. Geochemical background value was set as 1.8mg/kg in earth's crust (Levinson, 1974). The result revealed relatively higher arsenic contamination for the area, especially in the abandoned mining fields of the western part of Bagega. Arsenic may enter the environment during the mining and smelting of these ores. Moore et al. (1988) noted that arsenic in soil may be transported by wind or in runoff or may leach into the subsurface soil. However, because many arsenic compounds tend to partition to soil or sediment under oxidizing conditions, leaching usually do not transport arsenic to any great depth (EPA, 1982b; Pantsar-Kallio and Manninen, 1997).

Pollution status of the study area

In characterizing and re-evaluation of contamination level in soils from gold mining fields of Bagega and environs after the land reclamation, these evaluation parameters: Effect Range low (ERL) and Effect Range Median (ERM), Pollution index, Geoaccumulation index, Contamination factor, Pollution load Index and Contamination Degree were employed.

Effect range low (ERL) and effect range median (erm)

The results of ERL and ERM of the metals analysed are presented in Table 3. From Table 1, the ERL value of Zn is 150 mg/kg and the ERM value is 410 mg/kg. Result of the analysis shows that zinc has a maximum concentration of 88.8 mg/kg. This is below both the ERL and ERM value. However, 100% samples show low concentrations below the ERL. This shows less risk to Zn toxicity to the inhabitants of the area. Though, Zn was evenly distributed in all the soils of the study area, the ERL and ERM suggests low pollution status in the study area.

For Pb, level as high as 447.4 mg/kg was recorded, while the ERL is 47mg/kg and ERM value is 220mg/kg. However, 37.5% of the samples showed Pb concentration below the ERL value while 62.5% samples are above the ERL and 12.5% of the samples are above the ERM value. This suggests contamination at the southwestern part of Topeki area earlier known for mining but presently used as farmland.

Relatively, higher value of cadmium (up to 13.65mg/kg) was measured. The ERL value for Cd is 1.2mg/kg while the ERM value is 9.6mg/kg. About 43.75% of the sample's concentrations are below ERL value while, about 56.25% of the samples analysed are above the ERL value. Only 18.75% of the samples are above the ERM value and these are samples obtained in the abandoned mines sites, west of Bagega and southeast of Topeki. This indicates relatively higher Cd concentration and thushigher risk of Cd poisoning in the mining areas.

For Hg, a concentration as high as 28mg/kg was measured. The ERL value is 0.15mg/kg and ERM value is 0.71mg/Kg. All samples recorded concentrations above the ERM value. Higher levels of Hg were evenly distributed over the study area (values more than 1mg/kg), lower mercury pollution was observed around Bagega and Topeki communities.Thus, Bagega and Topeki show good – intermediate contamination. This

Table 3. Quality of sediments/soils for samples using ERL and ERM.

Metal	Below ERL (%)	Above ERL (%)	Above ERM (%)	Remark
Zn	100	-	-	Poor Contamination
Pb	37.5	62.5	12.5	Good - Intermediate Contamination
Cd	43.75	56.25	18.75	Good - Intermediate Contamination
Hg	-	100	100	Toxicity
As	31.25	68.75	6.25	Good - Intermediate Contamination

Source: US-MAIA (1998).

Table 4. Pollution index (€) for soil/stream sediments samples.

Sample ID	Zn	Pb	Cd	As	Hg
BGG1	0.012488	0.006773	0	0	2.957746
BGG2	0.089244	0.030182	0.456563	0.003429	6.264789
BGG3	0.21361	0.497591	1.421875	0.911143	14.47465
BGG4	0.138537	0.436409	0.901563	1.437143	7.719718
BGG5	0.026585	0.043636	0.597917	0.178429	17.35915
BGG6	0.07878	1.196364	1.063542	0.235714	17.35915
BGG7	0.036341	0.221227	1.25625	0.271429	0.302817
BGG8	0.081463	0.093636	0.004854	0.334857	6.053521
BGG9	0.135854	2.033636	0.032292	0.008143	7.51
BGG10	0.178073	0.960909	0.16875	0.001714	39.43662
BGG11	0.216585	0.696364	0.947917	0.445714	17.66338
BGG12	0.155756	0.581364	0.554167	0.261429	11.05775
BGG13	0.038829	0.464091	0.820833	0.197143	11.77606
BGG14	0.069512	0.336591	0.006833	0.799571	5.098592
BGG15	0.037024	0.134545	0.212188	0.293286	10.9
BGG16	0.089244	0.164864	0.026042	0	1.408451

implieshighertoxicity and therefore higher risk in the study area. The higherlevel may be due to poor disposal method of mercury by locals when illegal mining activities were put to an end.

Arsenic concentration of 100.6 mg/kg was measured. It has ERL value of 8.2mg/kg and ERM value of 70mg/kg. About 68.75% of the samples are above the ERL value while 31.25% are below and 6.25% is above the ERM value. This means good As metal contamination status of the study area.

The results of pollution index (€) for the metals analysed in all the location are presented in Table 4. Generally, the results in most locations recorded insignificant pollution index (€) except BGG3, BGG4 and BGG6 where there is obvious pollution from Cd, As and Hg. Among these are locations around Bagega and Topoeki communities where pollution status ranges from 0.006 to 0.960€. Locations found in southwest of Topeki however, shows pollution index with significant contamination (1.196-2.033€). Hg recorded significant contamination in all locations except BGG7. Also, two locations BGG6 and BGG9 were contaminated by Pb. These contaminations may be due to transportation of wastewater from some mining fields to various soil, stream and rivers within the study area.

Pollution index (€) and geo-accumulation index (Igeo)

The results of pollution index (€) is presented in Tables 4 and 5 while that of geoaccumulation index (Igeo) is presented in Table 6. The results of the computed geo-accumulation index are summarized in the Table 7. Here, Zn was found to be classified as 0 (practically uncontaminated), Pb had 31.25% of samples in class 0 (practically uncontaminated), 12.5% class 1 (uncontaminated to moderately contaminated), 12% class 2 (moderately contaminated), 18.75% class 3 (moderate to contaminated) and 6.25% were found in class 4 (Heavily contaminated).For Cd, the geo-accumulation index: 31.25% of samples are practically uncontaminated, 6.25% are moderately contaminated, 6.25% are moderately to heavily contaminated, 18.75%

Table 5. Quality of soils/sediments using pollution index.

Metal	Index range	Percent range	Remark
Zn	0.012 - 0.216	100% < 1	IC
Pb	0.006 - 0.096 (Bagega, Topeki) 1.196 - 2.033	75% < 1 25% > 1	SC
Cd	0.00 - 0.82 (Bagega, Topeki) 1.06 - 1.421	81.25% < 1, 18.75% > 1	SC
Hg	0.302 - 2.957 (Bagega, Topeki) 5.098 - 39.43	6.25% < 1, 93.75%> 1	SC
As	0.00 - 0.8 (Bagega, Topeki) 1 - 1.437	93.25% < 1, 6.25%> 1	IC

Source: Powell (1992).

Table 6. Geo-accumulation index value for stream sediments/soil samples analyzed.

Sample ID	Zn	Pb	Cd	As	Hg
BGG1	-5.0617	-4.33158	-	-	2.222392
BGG2	-2.2244	-2.17571	3.283922	-6.3443	3.30516
BGG3	-0.9653	1.867501	4.922832	1.70963	4.51335
BGG4	-1.5900	1.678222	4.265537	2.367084	3.606442
BGG5	-3.971	-1.64386	3.673054	-0.6427	4.775519
BGG6	-2.4043	3.133125	4.503914	-0.24101	4.775519
BGG7	-3.5206	0.69807	4.744161	-0.03747	-1.06559
BGG8	-2.3560	-0.54232	-3.27152	0.265498	3.255669
BGG9	-1.6182	3.898531	-0.53766	-5.09637	3.566707
BGG10	-1.2278	2.816941	1.847997	-7.3443	5.959358
BGG11	-0.9456	2.352382	4.33787	0.678072	4.800584
BGG12	-1.4210	2.091982	3.563429	-0.09163	4.12488
BGG13	-3.4250	1.766948	4.130199	-0.49881	4.215679
BGG14	-2.5849	1.303537	-2.77816	1.52118	3.007993
BGG15	-3.4937	-0.01937	2.178449	0.07426	4.10415
BGG16	-2.2244	0.273814	-0.848	-	1.152003

Table 7. Quality of soils/stream sediments using geo-accumulation index.

Metal	% UC	%UC- MC	%MC	%MC -HC	%HC	%HC - EC	%EC	Remark
Zn	100	-	-	-	-	-	-	Uncontaminated
Pb	31.25	12.5	25	18.75	6.25	-	-	Heavy Contamination
Cd	31.25	-	6.25	6.25	18.75	3.25	37.5	Heavy Contamination
As	62.5	18.75	3.25	12.5	6.25	-	-	Moderate Contamination
Hg	6.25	-	6.25	6.25	31.25	43.75	6.25	Heavy Contamination

are heavily contaminated, 3.25% are heavily to extremely contaminated and 37.5% are extremely contaminated in the analyzed sample. For As, 62.5% of samples are practically uncontaminated, 18.75% are uncontaminated to moderately contaminated, 3.25% are moderately contaminated, 12.25% are moderately to heavily contaminated and 6.25% showed heavy contamination of the analyzed samples.

The geo-accumulation index for Hg reveals6.25% of samples were practically uncontaminated, 6.25% were moderately contaminated, 6.25% were moderately to heavily contaminated, 31.25% were heavily contaminated,

43.75% were heavily to extremely contaminate and 6.25% were extremely contaminated in the analyzed sample.

Generally, the uncontaminated areas were found within Bagega and Topeki communities, while the heavily contaminated areas were found around the abandoned mining sites, west of Bagega and south of Topeki. This area witnessed high level of illegal mining activities, hence the relatively higher level of contamination despite years of abandonment. The activities of illegal miners are also responsible for the high Hg and Cd geoaccumulation index observed within Bagega and Topeki communities.

Conclusion

Geochemical re-evaluation of Bagega community and its environment in northern Nigeria, six years after reclamation was undertaken. The results revealed that soil samples collected within Bagega and Topeki communities recorded relatively lower levels of heavy metals (Pb, Cd, Zn and As). However, high Hg level (Class 1) was recorded in the communities. This may be due to illegal small scale mining of gold and metal ore processing currently ongoing in the mining district and in the communities. Also, old and abandoned gold fields at the western fields of Bagega and south of Topeki recorded high pollution indices of Cd, Hg, Zn, Pb and As. The results of the Effect Range Low (ERL) and Effect Range Median (ERM), pollution index (PLI) and geo accumulation index vary from insignificant to moderate contamination within the two communities in the study area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors are grateful to the Chairman and all staff of Geodynamics Ltd, Abuja for their role in data acquisition and other logistics that facilitated this study.

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