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UTILITY OF POLLUTION INDICES IN ASSESSMENT OF SOIL QUALITY AROUND MADAGA GOLD MINING SITE, NIGER STATE, NORTH-CENTRAL NIGERIA

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ABSTRACT

The quality of soil in the vicinity of Madaka mining sites were investigated in this study using Environmental Pollution Indices. Geological mapping of the study area indicated that the area was dominated by schist and granite. The static water level measurement revealed a westward groundwater flow direction which also coincides with the regional structural trend of the area. Laboratory analyses of soil and stream sediment were carried out in National Geosciences Research Laboratory Kaduna. The results of the soil analyses revealed high concentrations of mercury, cadmium, lead and arsenic. The results of the laboratory analysis were further elucidated using pollution indices such as geo-accumulation index, contamination factor, degree of contamination, elemental contamination index and metal pollution index. These environmental indices revealed that the soil is seriously polluted with mercury, cadmium and lead, moderately polluted with arsenic, lightly polluted with iron and copper and very lightly polluted with manganese, zinc, nickel and cobalt in the order of: Hg > Cd >Pb> As > Fe > Cu > Mn > Zn > Ni > Co. The mean concentrations of the first four metals (Hg, Cd, Pb and As) exceeds their average crustal abundance, which is an indication of possible pollution. The concentrations map of the analyzed heavy metals indicated a westward decrease in concentration away from the mine sites. This was in agreement with the flow direction and the possible reduction in pollution intensity away from the mine sites could be attributed to the natural attenuation mechanism of soil in the course of groundwater migration as well as hydrogeological attributes of the area. The study recommends that the miners be grouped into association and trained on modern mining techniques that are environmental friendly. The polluted soils in the area should be remediated and proper sensitization on the dangers associated with artisanal mining should be carried out in the area. Periodic monitoring of the soil quality in the area is advocated.

Keywords: Utility, Environmental Pollution Indices, Impact, Artisanal Gold Mining, Madaga, Niger State, North-central Nigeria

INTRODUCTION

Soil quality determines the sustainability and productivity of agro-business of any nation. Soils are precious natural resources widely used as environmental indicators and their chemical analysis provide significant information on the assessment of anthropogenic activities of an area. They are important sinks for heavy metals and also play a significant role in the remobilization of contaminants under favourable conditions and interaction between soil and as well as water and sediments (Grosheva *et al.,* 2000; Amadi *et al.*, 2013). In recent years there have been increasing interests regarding heavy metal contaminations in soils, apparently due to their toxicity and perceived persistency within the aquatic systems and analysis of soil is a useful method of studying environmental pollution with heavy metals (Tijani *et al.,* 2005).

They are essential requirements of human and industrial development and the most delicate part of the environment and so continuous monitoring of their quality status is essential to guarantee a safe environment. Therefore, a continuous monitoring of their quality is very essential to determine state of pollution in our environment. Stream sediment represents one of the ultimate sinks for heavy metals discharged into aquatic environment. Therefore, soil quality is a good indicator of pollution in water column, where it tends to concentrate the heavy metals and other organic pollutants (Saeed and Shaker, 2008; Amadi *et al.*, 2014). Soil pollution, especially with heavy metals, has an important impact on environment and a direct potential threat on animal life (Wang *et al.,* 2011, Amadi *et al.*, 2012). Due to the ecological importance and the persistence of pollutants in the ecosystem, soils are more appropriate to be monitored in environmental evaluations and understand their potential toxic impacts (VonGunten *et al.,* 1997; Kwon and Lee, 2001; Cesar *et al.,* 2006). The research is aimed at determining the pollution level in soils around Madaka mining sites in Rafi Local Government Area of Niger State, North-central Nigeria.

Statement of the Research

The death of 28 children below the age five (17 female and 11 male) in Shikira and Madaka attributed to lead poisoning arising from artisanal gold mining in Madaka community was disturbing (The Guardian Newspaper 14th May 2015). Unlike the Zamfara episode, livestock such as cows, goat and ram were affected. In order to protect the environment, comprehensive methods for identifying and assessing the severity of soil pollution was employed in order to ascertain the degree of pollution in soil, hence the need for the present study.

Justification for the research

The need to evaluate the quality status of soil and stream sediments around Madaka mining sites in Rafi Local Government Area of Niger State, North-Central Nigeria cannot be overemphasized owing to the 14th May, 2015 episode. The investigation of the soil around the study area will provide baseline information for stakeholders on the causes and extent of pollution caused by artisanal mining in the area.

Study area description

The study area is part of Tegina Sheet 142SE and Alawa sheet 143SE. It lies between latitudes N10°00' to N10°04' of the Equator and longitudes E06°26' to E06°34' of the Greenwich Meridian (Fig. 1). The study area is drained by River Kaduna and its tributaries. The study area is accessible through Minna-Kagara road and other minor roads.

Climate and vegetation

The study area is characterized by two distinct seasons: the dry and rainy season. The mean annual rainfall in the area is 1200 mm while the minimum and maximum temperatures are 26 ºC and 34 ºC respectively. The vegetation of the study area is typical Guinea savannah which comprises tall grasses with series of tall trees within the vegetation. The trees become more populated along river channels (Federal Meteorological Agency, Minna, 2011, Ajibade, 1982).

Geology of the Area

The Madaka area is part of the Precambrian Basement Complex of Nigeria and the area is characterized by two distinct lithological units which comprises schist and the Older Granite suite. Russ (1957) categorized the schist in the area as Kushaka Schist Belt, which he described as multi-compositional (meta-siltstones, tremolite-schist, garnet-rich bands and carbonaceous schists). The abrupt changes in the schist (metasediment) conform to the finding of Russ, (1957) that the schist in the area lies unconformably with the underlying granitic rocks (Fig. 1). The schist in the area is commonly intruded by quartzites which are usually iron-stained on weathered surfaces and along joints. The quartzites are fine grained and represent original siltstone or sandstone often of high ferrugious origin and this is also reported by Trustwell *et al.*, (1963). The granitic rocks in the study area are predominantly granodiorite which covers most part of Madaka town. The previous work of Russ (1957) described the granodiorite in the area to be medium-porphyritic biotite-rich granodiorite. The granodiorite in the area has undergone intense structural deformation with different structural elements prominent on the rock.

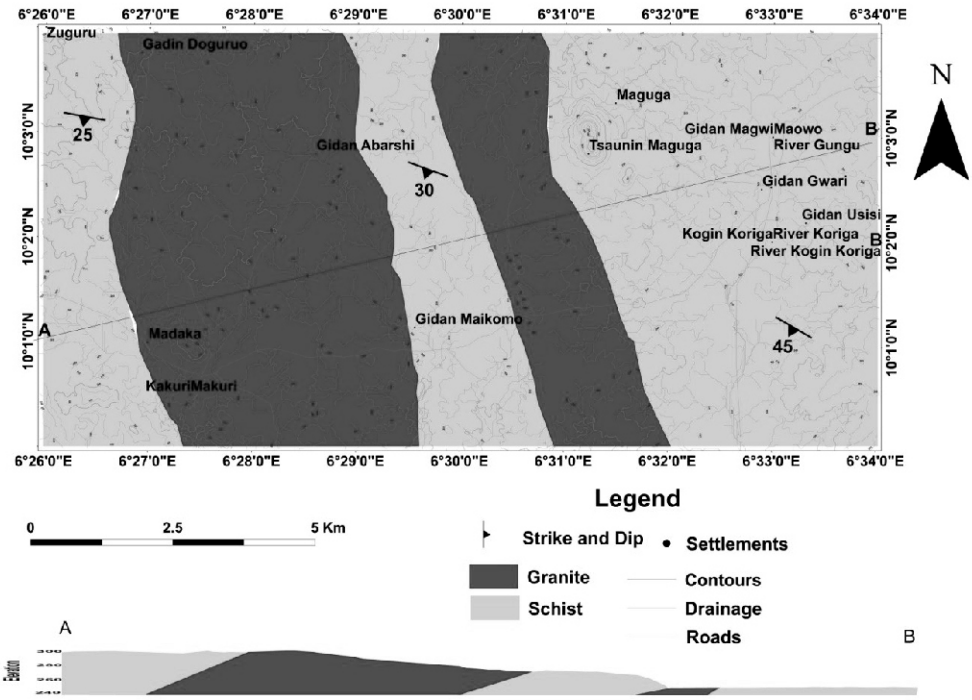

Fig. 1: Map of the Study Area

MATERIALS AND METHODS

Soil Samples, Preparation and Analysis

A total of thirty-five soil samples were collected in separate polythene bags for the present study. Thirty samples were collected within the vicinity of the mining sites while five samples were collected far away from the mining sites which serve as control samples. The soil samples were air-dried under shade and ground to pass through a 0.5 mm sieve for metal determinations and analyzed using the total digestion method. 0.5 g soil was weighed into a 100 cm^3 beaker. 5 cm^3 of concentrated HNO_3 was added and this was boiled gently for 30 min on a hot plate. The beaker was cooled and 2 cm^3 $HClO_4$ and 5 cm^3 concentrated HNO_3 were added. The mixture was heated to near dryness. The corners and walls of the beakers were washed with distilled water, and the solution was again heated until dense white fumes developed. The beaker was cooled and 10 cm^3 HNO_3 was added to dissolve the salts in accordance with the USEPA method for soil analysis. The solution was transferred into a 50 cm^3 standard flask and then diluted with distilled water. The extracts were analyzed by atomic absorption spectrophotometer (Perkin Elmer, Model No. 2380). The analyses were carried out at the National Geosciences Laboratory, Kaduna, Nigeria.

Environmental Pollution Indices

The results of the laboratory analyses were further interpreted using index of geo-accumulation, contamination factor, degree of contamination, metal pollution index, elemental pollution index and correlation analysis. The results of soil analysis were further compared with Wedepohl, (1995) as well as Taylor and Mclaennan, (1995) recommended elemental average crustal abundance/background values.

RESULTS AND DISCUSSIONS

The statistical summary of the results of laboratory analysis of the heavy metals in soils around Madaka mining sites are contained in Table 1, while Table 2 shows the average crustal abundance of the analyzed metals according to Wedepohl, (1995) as well as Taylor and Mclaennan, (1995). Ten metals (Mn, Cd, Hg, Pb, Cu, Zn, Co, Ni, As and Fe) were used in the present study. The use of agro-chemical in intensive agriculture as well artisanal mining in the area are the potential pathways through which soils are enriched with heavy metal and it reduces the soil cohesiveness leading to an increase of erosion and leaching. The enrichment of soil by these metals is a function of soil pH, grain size, organic matter, cation exchange capacity and hydraulic conductivity (Amadi, 2013). The pH of soils in the area ranged from 3.2 to 7.8 with a mean value of 4.7, indicating that the soils in the area were acidic. The low pH of soils in the area increases the sorption rate of these metals. That is, the lower the pH value the more metal can be found in solution and thus more metals is mobilized into the surrounding soils.

The soil organic matter is important for the retention of metals by soil solids, thus decreasing mobility, however at lower pH, metals tend to be more soluble and mobile in soils (Nachtergaele *et al.,* 2002). Grain size plays an important role in the mobility of metals in soils. The grain size helps in diffusion of metal ions into and out of soil aggregates. The soils in the area were loose due to the agricultural and mining activities in the area thereby enhancing the permeability. The concentrations of manganese in the soil samples analyzed ranged from 57.21 – 504.42 ppm with a mean value of 249.05 ppm. The mean concentration of manganese in the soils was lower than the standard of 527 ppm given by Wedepohl (1995) and 600 ppm given by Taylor and Mclenna (1995).

Table 1: Statistical Summary of Metal Concentrations in Soil from Madaka Area

Parameters (ppm)	Minimum	Maximum	Mean	Std. Deviation
Manganese	57.21	504.42	249.06	117.44
Cadmium	55.30	116.91	87.57	16.87
Mercury	28.49	70.25	50.17	12.12
Lead	0.92	808.16	194.41	265.87
Copper	ND	217.22	32.94	66.84
Zinc	18.55	119.81	38.54	28.35
Cobalt	0.00	7.76	0.99	1.88
Nickel	2.87	38.48	8.95	8.19
Arsenic	ND	3.05	0.35	0.81
Iron	5960.01	98005.36	27511.52	21128.16
pH	3.20	7.80	4.70	5.60

ND = Not detected

Table 2: Mean concentration of Metals in soils around Madaka Mining Sites compared their Average Crustal Abundance (Wedepohl,(1995); Taylor and Mclenna, (1995)

Parameters	Mean conc. (ppm)	Guideline for maximum allowable limit in upper continental crust			
		Wedepohl,(1995)	Status	Taylor and Mclenna (1995)	Status
Mn	249.05	527 ppm	Low	600 ppm	Low
Cd	87.57	0.102 ppm	High	0.098 ppm	High
Hg	50.16	0.056 ppm	High	0.040 ppm	High
Pb	194.41	17 ppm	High	20 ppm	High
Cu	32.94	14.3 ppm	High	25 ppm	High
Zn	38.54	52 ppm	Low	71 ppm	Low
Co	0.99	11.6 ppm	Low	10 ppm	Low
Ni	8.95	18.6 ppm	Low	20 ppm	Low
As	0.35	0.055 ppm	High	0.050 ppm	High
Fe	27511.52	30890ppm	Low	7.07%wt	Low

Classification by Wedepohl, (1995) and Taylor and McLennan (1995)

Heavy metals associated with gold mining are of particular interest due to their accumulation effects in soils as well as non-biodegradable nature, they tend to remain in soils for a very long time. The mean concentration of the ten elements used in the study was compared with maximum allowable limit in upper continental crust (Table 2). The classification by Wedepohl, (1995) as well as Taylor and McLennan (1995) indicate that the concentration of cadmium, lead, mercury and arsenic were high in soils from Madaka mining sites. However, copper was classified high based on Wedepohl, (1995) and Taylor and McLennan (1995) classification model (Table 2; Adams *et al.*, 2008; Anglin-Brown *et al.*, 1995; Ali and Fisher, 2005). This showed that there was no contamination in any of the locations. Manganese is an essential element for plant and animal growth and development. Manganese can be adsorbed by soil, depending on the organic content and cation exchange capacity of the soil. The concentration map of manganese in soils around Madaka mining sites is shown in Figure 2. Cadmium concentration in the soil samples analyzed varied between 55.30 – 116.91 ppm with an average concentration of 87.57 ppm (Table 1). Cadmium is a relatively rare metal and is the 67th most abundant elements in the earth crust with crustal abundance of 0.15 ppm in soils. The results of the analyses revealed that the samples of soil in the area were highly polluted with cadmium.

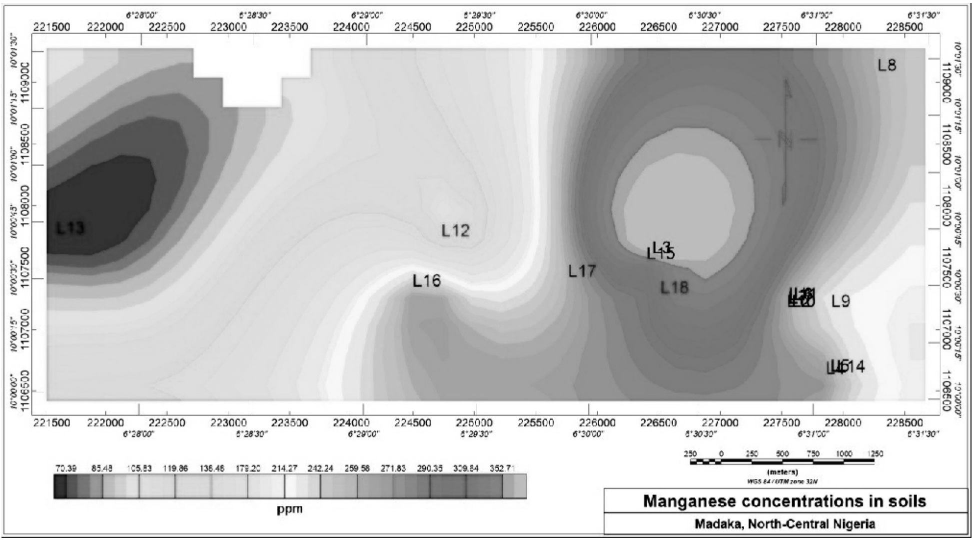

Fig. 2: Map of manganese concentration in soils from Madaka area

All the values are above the specifications of 0.102 ppm of Wedepohl (1995) and 0.098 ppm given by Taylor and Mclenna (1995). Cadmium is extremely toxic and the primary use of soil high in cadmium in form of manure for the cultivation of vegetables and other food crops could cause adverse health effect to consumers such as renal disease and cancer (Gorenc *et al.,* 2004). The concentration map of cadmium in the study area (Figure 3) revealed that the concentration of cadmium decreases away from the mining sites, which is an indication that anthropogenic activities in the area is responsible for high cadmium concentration in soils in the area. Cadmium solubility increases under low pH and forms soluble complexes which greatly increase its mobility and very little adsorption of cadmium by soil colloids, hydrous oxides, and organic matter takes place. At higher pH values greater than 6, cadmium is absorbed by the soil solid phase or is precipitated, and the solution concentrations of cadmium is greatly reduced (Che *et al.* 2003; Aktar *et al.*, 2010;). The concentration of lead in the soil from the area ranged between 0.92 – 808.16 ppm with a mean concentration of 194.41 ppm (Table 1). The concentration of lead was found to be high in locations 1, 2, 3, 4, 5, 6, 7, 8 and 11. There values are above the recommended 17 ppm by Wedepohl (1995) as well as 20 ppm by Taylor and Mclenna (1995). The high pollution of the soil in the area by lead can be linked to the gold mining in the area.

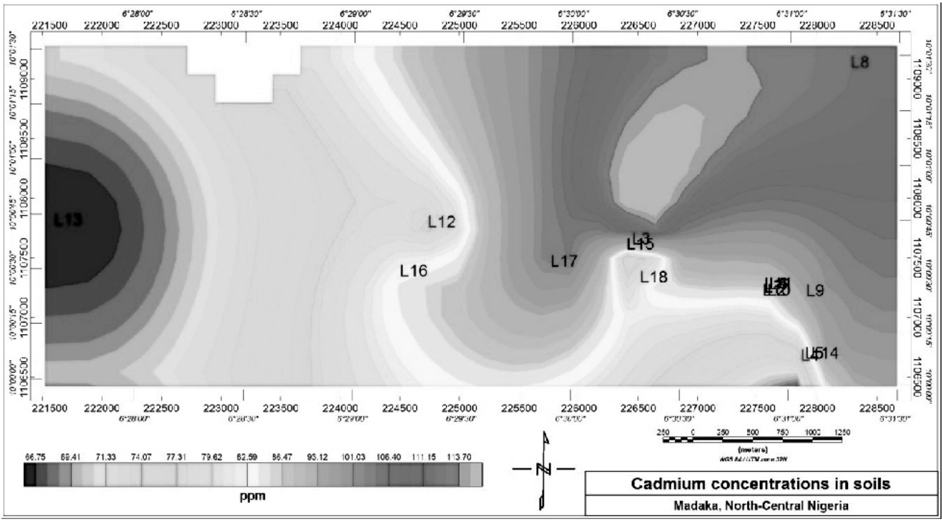

Fig. 3: Map of cadmium concentration in soils from Madaka area

Galena (PbS) is the ore hosting the gold in the area. It is most often discarded by the miners as gangue on the`surrounding soils where they are weathered and subsequently leached into the subsurface. Lead toxicity causes cancer and anaemia by impairment of haemo-biosynthesis and acceleration of red blood cell destruction. The solubility of lead in soil solution is strongly influenced by the pH. At pH values above 6, Pb is either adsorbed on clay surfaces or forms lead carbonate. At near neutral pH range, higher organic matter promotes the formation of organo-lead-complexes thereby increasing lead solubility (Ankley et al., 1992; liu et al., 2009). The concentration of lead in the study area is pictorially shown in figure 4.

Concentrations of copper in the analysed soil samples varied from 0.00 – 217.22 ppm with an average value of 32.94 ppm (Table 1). Samples from locations 3, 4, 6, 7 and 8 are contaminated with copper. Locations 3, 4 and 7 have values exceeding Taylor and Mclenna (1995) acceptable value of 25 ppm while values of locations 3, 4, 6, 7 and 8 also exceed Wedepohl (1995) acceptable value of 14.3 ppm. Copper is widely used in electrical wiring, roofing, various alloys, pigments, cooking utensils, piping and in the chemical industries (Aboud and Nandini, 2009).

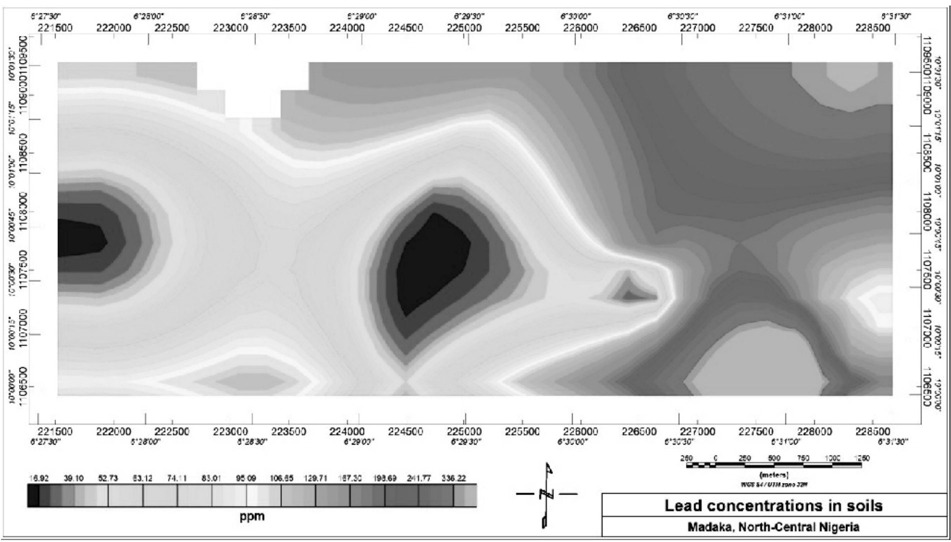

Fig. 4: Lead concentration map in soils from Madaka Area

Copper compounds are used in fungicides, insecticides, electricity wires, wood preservation, electroplating, dye manufacture, engraving, lithography, petroleum refining and pyrotechnics. It is also added to fertilizers and animal feeds as a nutrient to support plant and animal growth (Mielke et al. 1991). Copper contamination in soils could result from weathering of copper-rich rocks discarded on the environment in the course of gold mining as well application of agro-chemicals on the farmland in the area. Exposure to high concentration of copper can lead to health problems such as pulmonary oedema, lung carcinoma and transitory fever (Pascual et al., 2004). In terms of rock types, gabbro and basalt have the highest concentration while granodiorite and granite have the lowest copper contents. This implies that soils derived from mafic rocks would have higher natural copper contents than those from felsic varieties (Pascual et al., 2004; Okunlola et al. 2016; Alloway, 1990; Nwankwoala et al., 2017).

The concentrations of mercury in soil samples varied between 28.49 – 70.25 ppm with a mean value of 50.17 ppm. The area is highly polluted with mercury as all the samples from all the locations were above the acceptable limits of both Wedepohl (1995) of 0.056 ppm and the Taylor and Mclenna (1995) of 0.040 ppm (Table 2). The use mercury by the miners in the processing of gold in the area may be responsible for the high content in soils and sediments. Mercury is a chemical element with atomic number 80 and a silvery-white metal which is liquid at ordinary temperature. It is a rare element with a crustal abundance of 0.08 ppm. It is found either as a native metal (rare) or in cinnabar (HgS) and corderoite. The mobility of mercury increased with pH making mercury more soluble in water (Amadi et al., 2017). The distribution of mercury within the soils in the area is shown in Figure 5.

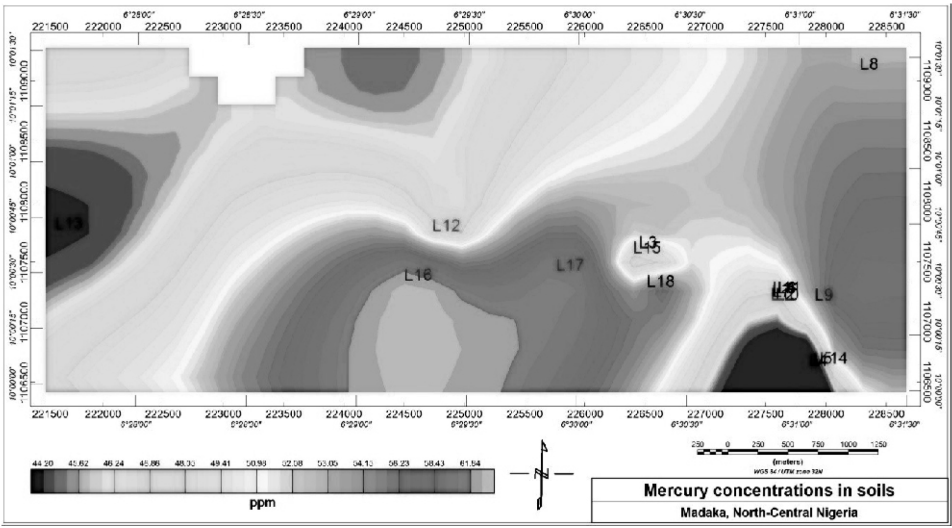

Fig. 5: Mercury concentration map in soils from Madaka area

The concentration of zinc in the study area ranged between 18.55 – 119.81 ppm and a mean value of 38.54 ppm (Table 1). Soil sample from locations 3 and 10 are found to exceed the acceptable limit of 52 ppm of Wedepohl (1995), and only location 3 exceed 71 ppm of Taylor and Mclennan (1995). The other concentrations of zinc in soils from the study area are within the stipulated guideline limits for an uncontaminated soil (Preda and Cox, 2002). Zinc is an essential element for plants, animals and human beings. Zinc concentration in soil is a function of the composition of parent rock, as well as anthropogenic activities such as mining. It is an essential growth element for plants and animals but can be toxic at elevated concentration. One main problem associated with high levels of zinc in the environment is its inhibitory effect to the uptake of copper, which is an essential element for plants. Excessive concentration of zinc in soil leads to phyto-toxicity. Acute zinc intoxication leads to nausea, vomiting, severe anaemia and renal failure (Aboud and Nandini, 2009).

Nickel concentrations in the soil samples ranged between 2.87 – 38.28 ppm with an average concentration of 9.95 ppm (Table 1). These values are below the average crustal abundance of 80.00 ppm for an uncontaminated soil postulated by Dineley *et al.* (1976), which implies that the soil from the area is uncontaminated with respect to nickel. It is a major component in the production of stainless steels, non-ferrous alloys and super alloys. Other application of nickel includes electroplating, as catalysts, in nickel-cadmium batteries, coins, welding and electronic products (Pascual *et al.,* 2004).

The concentration of arsenic ranged from 0.00 – 3.05 ppm with a mean concentration of 0.35ppm. Soils samples from locations 1, 3 and 5 have concentration exceeding the average crustal abundance. Arsenic is found to be above the acceptable limit of 0.055 ppm and 0.050 ppm of both Wedepohl (1995) and Taylor and Mclennan (1995) and this signifies pollution by arsenic in those locations. Studies have shown that soils overlying sulphide deposits and those in which pesticides have been applied can have chances of having high arsenic concentration. Arsenic is a pathfinder element to gold and it is usually discarded as gangue in the course of gold exploration by the artisanal miners. Over time, the host rock containing the arsenic gets weathered and the metal is released into the soil (Prasad and Kumari, 2008). Anthropogenic source of arsenic in the environment include the use of phosphatic fertilizers in farming as well as artisanal mining. Both pH and ionic exchange are important in determining the mobility of arsenic in soils. At high redox levels arsenic (IV) oxide predominates and arsenic mobility is low, and as the pH increases and redox level reduces arsenic (III) oxide becomes predominant thereby increasing its mobility because of its high solubility. The concentration map of arsenic within soils in the area is shown in figure 6.

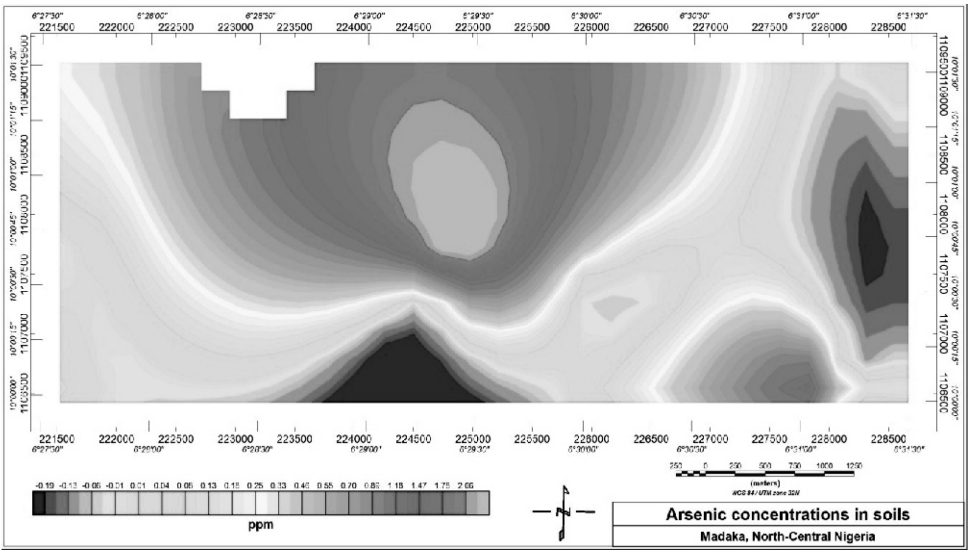

Fig. 6: Arsenic Concentration map in soils from Madaka area

The concentration of cobalt ranged from 0.00 – 7.76 ppm with a mean value of 0.99ppm. There is no pollution by cobalt from all the sampled locations. Concentration of cobalt in all the locations are below the 11.6 ppm of Wedepohl (1995) and 10 ppm of Taylor and Mclennan (1995) Cobalt is carcinogenic and the health effects of cobalt include bronchitis, dermatitis and inflammation of the tissue (Aboud and Nandini, 2009). The concentration of iron in the soils ranged between 5,960.01 – 98,005.36 ppm with an average value of 27,511.52 ppm (Table 1). The concentration of iron in soils is dependent upon the source rocks from which the soil was derived, transport mechanisms, and overall geochemical history. This is particularly true in soil and groundwater systems that have been environmentally impacted by mining. Iron occurs in one of two oxidation states: reduced soluble divalent ferrous iron (Fe^{+2}) or oxidized insoluble trivalent ferric iron (Fe^{+3}). It has been observed that the high iron value in soils from the area may be due to the interaction with iron contained in the lateritic soil.

Environmental Pollution Indices

In order to quantitatively ascertain the level and extent of heavy metal contamination in the soil around the vicinity of the mining sites, environmental pollution indices was applied which include: geo-accumulation index, contamination factor, degree of contamination, metal pollution index and elemental contamination index. The relationship among the metals was confirmed using Pearson's correlation analysis.

Geo-accumulation index (Igeo)

The results of the calculated Igeo for soils revealed that the soil from the area were highly polluted with cadmium, mercury and lead, lightly polluted with arsenic, very lightly polluted with iron and unpolluted with copper, manganese, zinc, cobalt and nickel (Tables 3). The enrichment of the soil by cadmium, mercury, lead and arsenic can be attributed to the artisanal mining going on in the area. They miners use mercury to concentrate gold in the course of processing, while lead, cadmium and arsenic occur as pathfinder elements to gold and are often discarded into the surrounding soil as gangue. Galena (PbS) is the ore hosting the gold in the area and associated with the galena are arsenic and cadmium. This may explain why the concentrations of some metals are high in soil in the order of: Hg > Cd >Pb> As > Fe > Cu > Zn Ni >Mn> Co. Geological phenomenon such as weathering and dissolution releases these metals from their host rock into the nearby soil.

Table 3: Computed Geo-accumulation Index (Igeo) values for soil from Madaka mining sites

S/No	Parameters	Igeo	Pollution Intensity
1	Mn	-0.59	Unpolluted
2	Cd	6.35	Very highly Polluted
3	Hg	6.72	Very highly Polluted
4	Pb	5.16	Very highly Polluted
5	Cu	0.38	Unpolluted
6	Zn	-0.16	Unpolluted
7	Co	-2.36	Unpolluted
8	Ni	-0.52	Unpolluted
9	As	2.44	Lightly polluted
10	Fe	1.85	Very lightly polluted

< 1 = Unpolluted; Igeo>1 - ≤ 2 =Very Lightly Polluted;
2 <Igeo ≤ 3 = Lightly Polluted; 3 <Igeo ≤ 4 = Moderately Polluted;
4 <Igeo ≤ 5 = Highly Polluted; Igeo> 5 = Very highly Polluted.

Contamination Factor (CF)

The result of the computed contamination factor for soil is shown in Table 4. The results revealed that the soil in the vicinity of Madaka mining site are highly contaminated with cadmium, mercury and lead, considerably contaminated with arsenic and iron, while the intensity of contamination by copper, manganese, zinc, cobalt and nickel were low. The contamination intensity of the analyzed heavy metals in soils decreased in the following order: Hg > Cd >Pb> As > Fe > Cu > Zn > Ni >Mn> Co. The enrichment of these metals in the soil may be attributed to the anthropogenic activities going on in the area as well geogenic processes such as bedrock dissolution and chemical weathering (Amadi and Nwankwoala, 2013; Amadi, 2011). Majority of the observed elements are contained in the minerals that make up the host rock in the area and are exposed and subsequently released into the soil through human activities such as mining and farming. The similarity in the computed pollution intensity of both Igeo and CF is confirmation of the utility of environmental pollution indices in pollution studies.

Table 4: Calculated Contamination Factor (CF) values for soil from Madaka mining sites

S/N	Parameters	CF	Contamination Factor
1	Mn	0.47	Low Contamination
2	Cd	85.85	Very High Contamination
3	Hg	89.51	Very High Contamination
4	Pb	11.43	Very High Contamination
5	Cu	2.30	Moderate Contamination
6	Zn	0.74	Low Contamination
7	Co	0.08	Low Contamination
8	Ni	0.48	Low Contamination
9	As	4.36	Considerable Contamination
10	Fe	1.45	Moderate Contamination

$CF < 1$ = Low CF; $1 \leq CF < 3$ = Moderate CF$3 \leq CF < 6$ = Considerable Contamination Factor; $CF \geq 6$ = Very High Contamination Factor

Degree of Contamination (C_d)

Four classes were used to describe the degree of contamination (Table 5). The summation (addition) of the contamination factors from Tables 3 for soil gave the corresponding **Cd** value of **196.67**, which falls in the class of very high degree of contamination (Table 5). The computed degree of contamination for the selected metals confirms that soils around Madaka mining sites are seriously contaminated with cadmium, lead and mercury and moderately contaminated with arsenic and the observed contamination may be coming from the various human activities domiciled in the area most especially the farming and mining.

Table 5: Degree of Contamination of soil from Madaka mining sites

S/N	Cd Range	Degree of Contamination
1	Cd < 6	Low degree of contamination
2	6 = Cd < 12	Moderate degree of contamination
3	12 = Cd < 24	Considerable degree of contamination
4	Cd ≥ 24	Very high degree of contamination

Metal Pollution Index (MPI)

The results of the computed metal pollution index on the soil analyzed are illustrated in Table 6. It can be observed from these tables that the degree of metallic contamination in the soil ranges from strongly polluted (mercury, lead and cadmium), slightly polluted (arsenic, copper and iron) to unpolluted (manganese, zinc, cobalt and nickel). The decreasing order of the contaminant is: Hg >Pb> Cd > As > Cu > Fe >Mn> Zn > Co > Ni. The leachate from the various human activities in the area is potential pathway through which the soil gets polluted.

Table 6: Calculated Heavy Metal Pollution Index for Soils from Madaka mining sites

Parameters (ppm)	HMPI Value	Rating
Mn	0.97	Unpolluted
Cd	22.50	Strongly Polluted
Hg	35.60	Strongly Polluted
Pb	26.80	Strongly Polluted
Cu	1.20	Slightly Polluted
Zn	0.95	Unpolluted
Co	0.56	Unpolluted
Ni	0.89	Unpolluted
As	1.50	Slightly Polluted
Fe	1.05	Slightly Polluted

<1= Unpolluted; 1 – 4.99 = Slightly polluted; 5 – 19.99 = Moderately polluted; 20 – 40 = Strongly polluted; > 40 = Very strongly polluted

Elemental Pollution Index (EPI)

The results of the computed elemental pollution index (EPI) for soil are contained in Table 7. Interestingly, in addition to index of geo-accumulation, contamination factor, degree of contamination and metal pollution index, the computed elemental pollution index values were similar, which is a clear indication that the soil in the vicinity of the mining sites within Madaka area are polluted mercury, cadmium lead and arsenic. The consistency in the pollution status of these four metals (mercury, cadmium lead and arsenic) across the five environmental indices used in this study justifies the efficiency of these pollution indices in environmental studies.

Table 7: Calculated Elemental Pollution Index for Soils from Madaka mining sites

Parameters (ppm)	ECI Value	Rating
Mn	-0.52	Very Low Contamination
Cd	75.30	Very High Contamination
Hg	84.24	Very High Contamination
Pb	60.43	Very High Contamination
Cu	1.27	Very Low Contamination
Zn	-0.25	Very Low Contamination
Co	-0.91	Very Low Contamination
Ni	-0.52	Very Low Contamination
As	5.36	Moderate Contamination
Fe	3.05	Very Low Contamination

< 5 = very low contamination; 5 – 9.99 = low contamination; 10 – 24.99 = medium contamination; 25 – 49.99 = high contamination; 50 – 100 = very high contamination; > 100 = extremely high contamination

Correlation Analysis

A strong positive correlation (Table 8) for the metals exists for all the metals except copper and arsenic. The two classes displayed in correlation coefficient suggest two potentials sources for the metals in soils in the area which can be linked to mining and agro-chemicals used in farming as well as weathering and bedrock dissolution and infiltration processes.

Table 8: Pearson correlation coefficient matrix for heavy metals in soils from Madaka area

	Fe	Cu	As	Ni	Co	Cd	Hg	Pb	Mn	Zn
Fe	1.000									
Cu	.155	1.000								
As	-.042	-.114	1.000							
Ni	.797*	.134	-.135	1.000						
Co	.999**	.161	-.007	.792**	1.000					
Cd	.997**	.156	.034	.785**	.999	1.000				
Hg	.731**	.123	-.107	.613*	.720	.711	1.000			
Pb	.997**	.174	-.103	.801**	.995**	.990**	.734	1.000		
Mn	.937**	.089	-.127	.723**	.930**	.923**	.680*	.940**	1.000	
Zn	.563*	.184	-.050	.659*	.558*	.547*	.605*	.578*	.633*	1.000

**. Correlation is significant at the 0.01 level (1-tailed)

*. Correlation is significant at the 0.05 level (1-tailed)

CONCLUSION

This study has clearly established that artisanal mining and use of agro-chemicals in farming constitute a major source of soil pollution in the study area. It should be noted that the concentration of the metals decreased away from the mining sites and farm lands. The concentration maps of the analyzed metal in soils decreases away from the eastern portion (mining sites and farm land) to the western part (community). Natural attenuation mechanism such as ionic exchange, adsorption, absorption and dilution help in reducing the concentration of contaminant in the course of migration away from the mining sites. Environmental quality indices are powerful tools used in quantifying the pollution status of an area. The environmental pollution indices such geo-accumulation index, contamination factor, degree of contamination, elemental contamination index and metal pollution index revealed that the soil in the area are highly polluted with mercury, cadmium and lead, moderately polluted with arsenic, lightly polluted with iron and copper and unpolluted with manganese, zinc, cobalt and nickel in the order of: Hg > Cd > Pb > As > Fe > Cu > Mn > Zn > Co > Ni. Among significant variables that control the distribution and enrichment of heavy metals in soils are pH of soil, grain size of the soil, amount of organic matter in the soil and the cation exchange capacity of the soil (Lin *et al.,* 2002). The soil pH is slightly low, signifying acidic soil while sandy-loamy soil characterize the top soil at the mine sites and farm-lands and these condition enhances the precipitation and bio-accumulation of heavy metals in soil. It is recommended that soils within the mining sites be remediated and Proper sensitization should be carried out in the area of the dangers of artisanal mining. Also the miners should be grouped into associations and equipped with modern mining tools.

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