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Investigating the Impacts of Artisanal and Small Scale Mining on Surface and Groundwater Quality in Madaka area of Niger State using Water Pollution Indices

A. N. Amadi*[1], A. Musa[1], E. E. Ebieme[1], C. I. Unuevho[1], I. M. Ameh[1] and U. N. Keke[2]
[1]Department of Geology, Federal University of Technology, Minna, Nigeria
[2]Department of Biological Sciences, Federal University of Technology, Minna
[*]Corresponding Author's Email Address: an.amadi@futminna.edu.ng or geoama76@gmail.com

Abstract
The mining sector is an important contributor of Nigerian's foreign exchange and employer of labour. Artisanal and small-scale mining is a means of livelihood adopted primarily by people in rural areas with crude and uncivilized mining technique. The physical parameters were determined on site using the appropriate techniques while the chemical analysis was carried out using inductive coupled plasma-optical emission spectrometer (ICP-OES) model-optima 200. The observed wide range and deviation in the following water quality parameter: total dissolved solid (44.0-1123.0), electrical conductivity (35.0-1696.0), pH (5.54-10.60), iron (0.1-95.6), zinc (0.03-6.14), copper (0.03-3.13), chromium (0.02-0.36), manganese (0.06-1.36) and lead (0.0-11.0) are signatures that the water sources in the area have deteriorated. The result of water quality index indicates that the water is polluted and unsuitable for domestic use while metal pollution index revealed that the water is lightly to very highly polluted. The study attributed the poor condition of the water sources in the area to long term environmental abuse in the area arising from artisanal and illegal mining. The practice of bringing rock boulders from site to the house for crushing, milling and processing with the same equipment used in grinding and processing of foodstuff should stop immediately. The use of mining buckets to fetch water directly from surface water and hand-dug well should discontinue. Regulatory agencies should ensure that global minimum mining standard is maintained in every mining site in Nigeria.

Keywords: Quality Assessment, Surface and Groundwater, Madaka Mining Sites, Pollution Indices, Niger State, North-central Nigeria

Introduction

Globally, mining is usually accompanied by series of environmental hazards with far reaching health implications. Most artisanal miners work in difficult and often very hazardous conditions in the absence of the required safe mining regulations. Apart from environmental problems, the use of gravity concentration methods such as panning and sluicing during processing poses health challenges. Toxic materials are released into the environment, posing large health risk to the miners, their families and surrounding communities. Also, gold mining operations are compounded by the use of mercury amalgamation process to extract gold from ores. Despite serious health and environmental impact posed by this activity, artisanal gold mining operations continue to spread into many rural communities in Niger State due to the increase in the demand for gold compared to farming.

In March 2010, Medecins Sans Frontieres (MSF) discovered an epidemic of lead poisoning in Zamfara state in North–Western Nigeria particularly in Anka and Bukkuyum Local Government Areas of the state (MSF, 2010). Subsequent investigations by the Centers for Disease Control (CDC), the World Health Organization (WHO) and the Zamfara State Ministry of Health (ZMoH) confirmed that hundreds of children under ages of five were at risk of death or serious acute and chronic health effects due to extremely high levels of lead and mercury (WHO, 2011). At least 10,000 people were estimated to be affected overall (MSF, 2010). The medium through which the people were affected include drinking water, food, inhalation of contaminated dust, oral ingestion of particles especially by children and through breast feeding. Mining of gold has been left in the hands of artisanal miners who do not have enough resources and adequate equipment and technology required for the mining activities.

The chemical composition of soil, surface and groundwater found in any environment is greatly influenced by the lithology in the area as well as dominant anthropogenic activities in the area. Studies have shown that human activities such as mining, waste dumpsites, application of fertilizer and agro-chemicals are major sources of environmental contamination (Amadi *et al*., 2015). Apart from soil and water contamination, artisanal mining though associated with economic benefit, leads to destruction of the vegetation, land degradation, air pollution and heavy metal contamination of the soil, surface and groundwater. Toxic metals released into the environment due to mining of ore bodies can be disastrous to man and his environment. In 2010, several children lost their lives due to contamination arising from artisanal mining in Zamfara State, Nigeria. Studies attributed such avoidable deaths due to crude and unhealthy mining methods. In May 2015, exactly five years later, 28 children (17 females and 11 males) below the age of five lost their lives owing to the illegal and poor mining practices in Madaka District, Rafi Local Government Area of Niger State (Sun Newspapers of 15th May, 2015). Unlike the Zamfara episode, it was reported that livestocks such as cow, ram and goat were also affected (Guardian Newspapers of 15th May, 2015). The need to evaluate the pollution status of the surface and groundwater sources in Madaka area cannot be overemphasized, and it is on this platform that the present study was conceived.

According to Bellinger (1992), metals are defined as the metallic chemical element that has a relatively high density and are toxic or poisonous at a low concentration. Heavy metals are a general collective term, which applies to the group of metals and metalloids with atomic density greater than 4 g/cm3 or 5 times or more, greater than water (Vasanthavigar *et al*. 2010). Amadi *et al*. (2014) and Kraft *et al*. (2006) mentioned that heavy metal toxicity is one of the major current environmental health problems and is potentially dangerous because of bio-accumulation through the food chain. Heavy metals are natural components of the Earth's crust, and trace elements, some heavy metals such as copper, selenium, zinc are essential to maintain the metabolism of the human body. However, at higher concentrations, they can lead to poisoning because they cannot be degraded or destroyed (Nwankwoala and Mmom, 2007).

The daily accumulation of heavy metals in our environment (particularly coastal waters) has intensified in recent years with population growth, industrialization and new technological developments (Adelana *et al*. 2000; Amadi *et al*. 2015). Contaminants generally enter the rivers through two pathways: (a) identifiable point sources such as municipal and industrial waste water effluents and (b) diffuse source closely related to the meteorological factors. Major diffuse sources include surface runoff, erosion, and atmospheric deposition. Both point and diffuse sources contribute to the total contaminant load of the rivers (Singh *et al*. 2008).

Some heavy metals such as Fe, Zn, and Mg have been reported to be of bio-importance to man and their daily medicinal and dietary allowances had been recommended. Environmental factors like temperature, pH, water hardness, dissolved oxygen, light, salinity and organic matter can influence the toxicity of metals in solution (Akoto *et al*. 2008; Lohani *et al*. 2008). Heavy metals in aquatic environment can remain in solution or in suspension and precipitate on the bottom or be taken by organisms. Therefore, assessment of these heavy metals is important for environmental and human safety, hence the need for the present research.

Study Area Description

Madaka District in Rafi Local Government Area of Niger State, North-central Nigeria lies between Longitudes 6º26'00''E to 6º34'00''E and Latitudes 10º00'00''N to 10º04'30''N (Fig. 1). The area is accessible through Minna-Kotangora road and a host of other minor roads and footpaths. The area is well drained by many rivers and their tributaries (Fig. 1) while the climate varies between dry and rainy season. The area lies within the savanna belt of Nigeria with a total annual rainfall between 1270 mm and 1524 mm (Ajibade, 1982). The vegetation of the area is that of the guinea savannah which comprises of various species of shrubs and high forest trees especially along the river channels. The mapping of the area revealed schist and granite as the rock types that makes up the local geology of the area. The granites intrude the older and moderately weathered schist (Fig. 2). The miners identified pegmatitic or quartzite vein and concentrate their mining activities along such vein. The schist belts are potential sites for gold mineralization based on the structural configuration as well as granites with quartz vein, felspathic vein or pegmatites (Akindere, 2007; Ajibade *et al*. 2008)

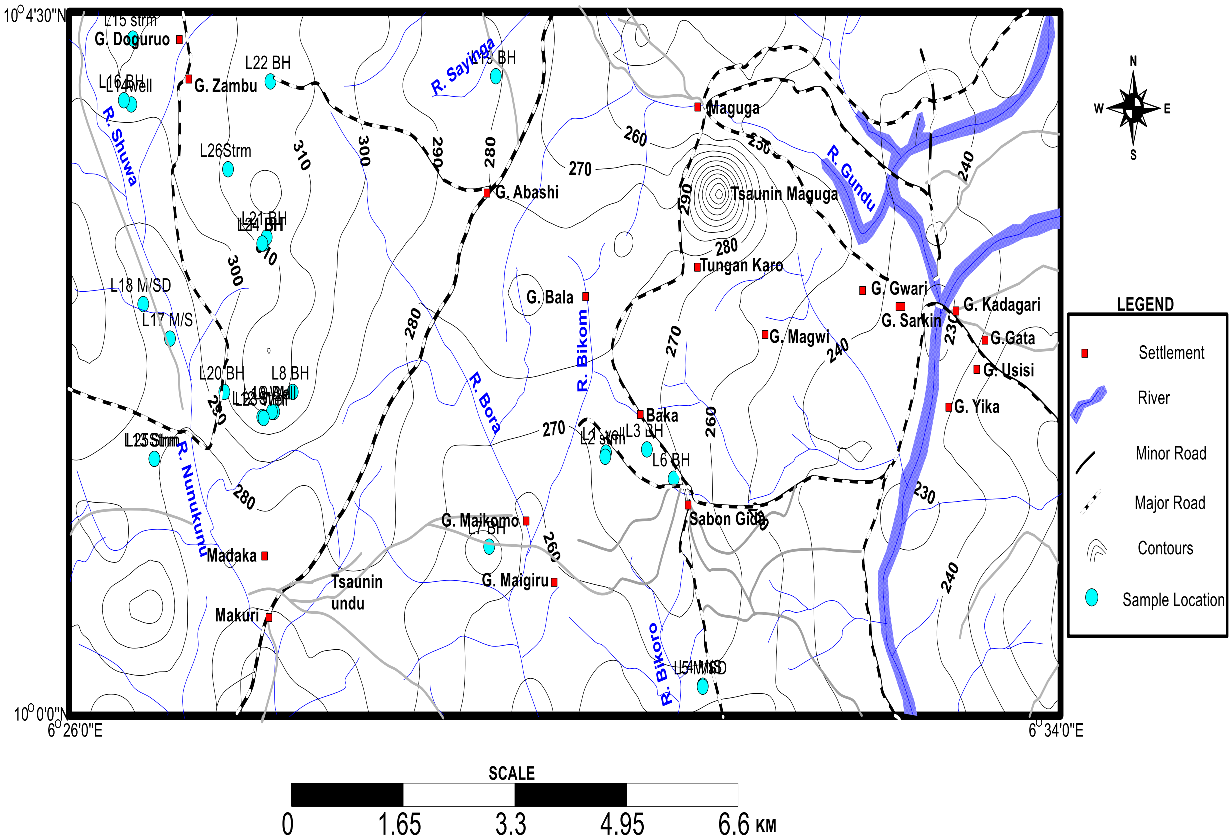

Fig. 1: Map of Madaka and environs

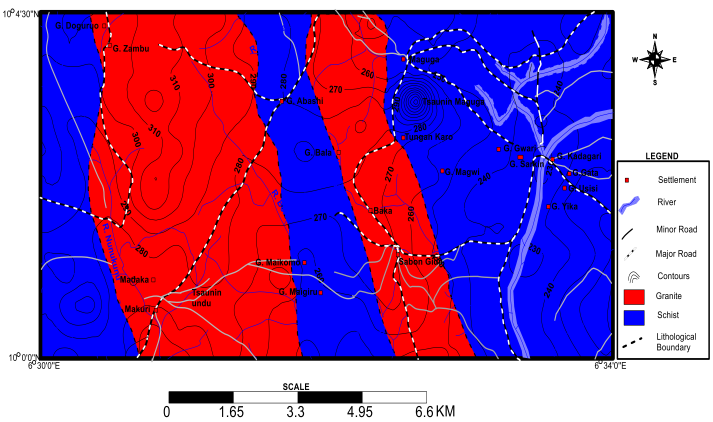

Fig 2: Geology map of the Madaka and environs

MATERIALS AND METHODS

Water Sampling and Laboratory Analysis

Water samples were collected in the month of November, 2015, which comprises 10 surface water samples, and 25 hand dug wells as well as 5 mine pits were sampled and analyzed at the National Geoscience Laboratory, Kaduna, Nigeria using Inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES) Model- Optima 200. Physical parameters such as pH and conductivity were determined in the field using Martini instrument (Mi 806) in accordance with the American Public Health Association standards (APHA, 2005).

Pollution Indices

Metal pollution index

Metal pollution index (MPI) is a method of rating that shows the composite influence of individual parameters on the overall quality of water. The rating is a value between zero and one, reflecting the relative importance individual quality considerations. The higher the concentration of a metal compared to its maximum allowable concentration, the worse the quality of the water (Amadi, 2011). It has wide application and it is used as the indicator of the quality of surface and groundwater (Amadi *et al*. 2012). The MPI is calculated using the equation below:

$$MPI = \sum_{i=1}^{n} \left[\frac{Ci}{(MAC)i}\right]$$

where: C_i: mean concentration

MAC: maximum allowable concentration

Water Quality index

Water quality index is a very efficient and effective tool used to convey information on the overall quality of water in an area based on water quality parameters. It expresses the overall water quality at a given place over a period of time on the basis of water quality parameters (Tiwari and Mishra, 1985; Amadi *et al*. 2014). The goal of WQI is to transform complex water quality data into information that is understandable and useable by stake holders in the water sector as well as the general public.

Calculation of WQI

The weighted arithmetic index method was used to calculate WQI. The quality rating scale q_i for each parameter was calculated using the expression below:

$$q_i = (Ci / Si) \times 100$$

where: C_i = mean concentration of the parameters; S_i = Nigerian Standard for Drinking Water Quality (NSDWQ, 2007).

Relative weight (W_i) was calculated by a value inversely proportional to the standard value (S_i) of each respective parameter:

$$W_i = 1/S_i$$

Generally, WQI is estimated for a definite and planned use of water and it is a function of the anthropogenic activities domiciled in the area over a given period of time. In the present study, the WQI was calculated (Tables 3 and 4) for domestic purposes using the formula:

$$\text{Overall WQI} = \frac{\sum q_i w_i}{\sum w_i}$$

Where: q_i: the quality of the ith parameter,

w_i: the unit weight of the ith parameter

n: the number of the parameter considered

RESULTS AND DISCUSSION

The statistical summary of the analyzed parameters are contained in Table 1. The pH is an important water quality parameter used to determine the degree of acidity or alkalinity of the water. The values of pH in the water from the study area ranged from 5.54 to 10.60 with an average value of 6.55 as against the permissible limit of 6.5-8.5 recommended by World Health Organization (WHO, 2010) and Nigerian Standard for Drinking Water Quality (NSDWQ, 2007). Eighteen locations within the mining sites had their pH values less than 6.5. Acidic water enhances chemical weathering and rock dissolution and may be responsible for the enrichment of the water in the area by metals. The concentration of electrical conductivity (EC) varied from 35.0 µs/cm to 1696.0 µS/cm, with a mean value of 447.2 µS/cm as against the maximum permissible limit of 1000.0 mg/l (WHO, 2010; NSDWQ, 2007) while the value of total dissolved solid (TDS) ranged between 44.0 mg/l to 1123.0 mg/l with mean value of 285.0 mg/l as against 500.0 mg/l recommended by WHO, (2010) and NSDWQ, (2007). Electrical conductivity of water measures the ability of water to conduct electric current and it is a function of the amount of dissolved ion in water (Hatje *et al*. 1998; Amadi *et al*. 2010). The wide range observed in pH, EC and TDS are indication that the water system in the area has been contaminated due to unsafe mining practices going on in the area

Table 1: Statistical Summary of the water quality parameters analyzed

Parameters (mg/L)	Range	Mean	Standard Deviation	NSDWQ, (2007)
pH	5.54-10.60	6.55	0.9843	6.5-8.5
Conductivity	35.00-1696.00	447.23	518.1057	1000.0
TDS	44.00-1123.00	285.538	311.9827	500.0
Fe	0.10-95.60	5.02	18.5391	0.003
Cr	0.02-0.36	0.115	0.0923	3.0
Zn	0.03-6.14	1.753	1.7309	0.003
Cu	0.03-3.13	0.517	0.6783	1.0
As	0.00-0.02	0.002	0.0055	0.01
Ni	0.00-0.143	0.025	0.0437	0.02
Co	0.00-0.01	0.0016	0.0031	0.001
Cd	0.00-0.014	0.001	0.0037	0.003
Hg	0.00-0.012	0.002	0.0035	0.001
Pb	0.00-11.05	0.846	2.9892	0.01
Mn	0.06-1.36	0.342	0.3532	0.2

The concentration of lead in the water ranged between 0.00 mg/l to 11.05 mg/l with an average value of 0.85 mg/l. A total of 22 water samples had their values higher than the maximum permissible limit of 0.01 mg/l (WHO, 2010; NSDWQ, 2007). The high concentration of lead in the water sources in the area are likely the footprint of artisanal mining in the area (Plates 1-2). Indiscriminate dumping of the gangue on the surrounding soil and nearby surface water (river channels) in course of gold exploration and exploitation via crude techniques, coupled with runoff, leaching and other geochemical processes culminates in the observed high concentration of lead in the water from the area. The abandoned gangue get weathered after a long period and get to surface water through run off and into shallow groundwater via infiltration and dilution processes (Kar *et al.* 2008; Amadi and Olasehinde, 2009). Since there are no industries in the area, the potential possible channel of lead enrichment in the water system is via mining. Mining activities in the area is the route through which the lead contained in the host rock is release into the surrounding soil and streams thereby constituting environmental and health hazards. Studies have shown that high concentration of lead in human body either through water, food or air causes cancer, interferes with vitamin D metabolism, affect mental development in children, toxic to the central and peripheral nervous system (Ahmad *et al.* 2010).

Water samples from the mine-pit water, the surface water samples and selected hand-dug well samples have their concentration higher than the permissible limit of 0.01 mg/l (NSDWQ, 2007). The mine pits serves as washing points apart from mining tailings that drain and settle in these pits. The river channels serves as panning centres for gold and such activities are capable of contaminating the surface water. The mining buckets are used to fetch water from the shallow hand dug wells and over time such wells become contaminated. Furthermore, the quartzite or pegmatite are backed and transported to their home for crushing (Plates 3-4). After the crushing the same machine used to grind foodstuff such as maize, guinea corm and millet are used grind the crushed quartzites or pegmatites and practice has the potential of contaminating the food chain. The present study has established that the May 15th episode in Madaka, Niger State is strongly connected to the contamination of water sources by heavy metal through unhealthy artisanal mining practices going on in the area unabated. The concentration map of lead in the area is shown in Figure 3. The mining sites are located in the eastern part of the study area. The concentration of lead decreases westward, away from the mining sites which imply that their concentration in the water system in the area can be linked with the artisanal mining activities domiciled in the area. High lead concentration is observed in the eastern portion of the study area and it reduces drastically towards the west, away from the mining sites (Fig. 3).

Plate 1: Devastation of the vegetation due to Artisanal mining

Plate 2: Hand-dug wells used to source for water used in washing gold

Plate 3: Gold bearing quartzite bagged for further crushing, milling and processing

Plate 3: Women with children crushing quartzite and selling yams #

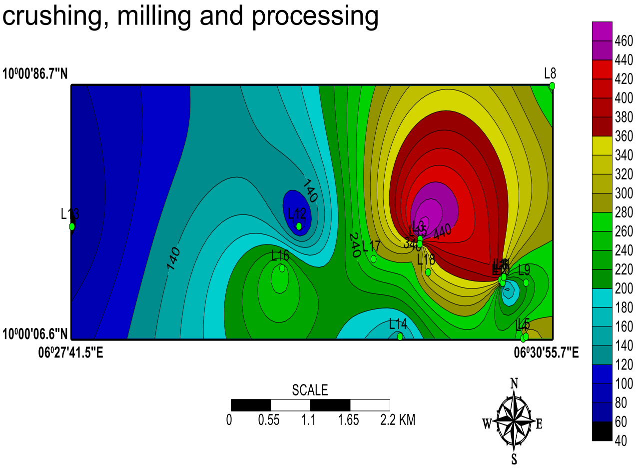

Fig. 3: Concentration map lead in the study area

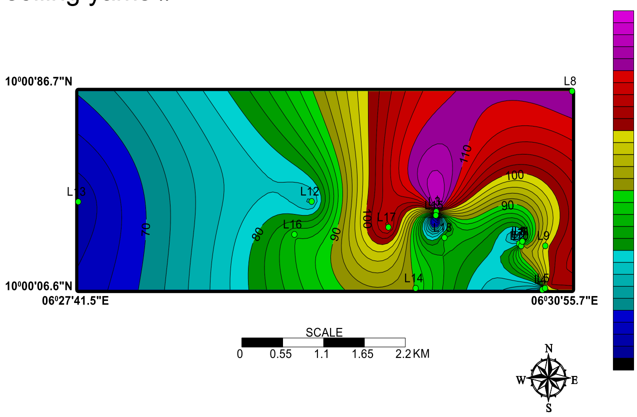

Fig. 4: Cadmium Concentration Map for the study area

The concentration of cadmium varied between 0.00-0.014 mg/l with a mean value of 0.0012 mg/l as against the maximum allowable limit of 0.003 mg/l (NSDWQ, 2007). The result of the analysis implies that cadmium concentrations in 17 locations are slightly higher than the recommended value even though the mean value was lower. Research has shown that the kidney, especially the renal tract, is the critical organ of intoxication due to exposure to cadmium as well as prostate and lung cancer (Adams *et al.* 2008; Amman *et al*. 2002; Kar *et al*. 2008). Several renal dysfunction and damage to the bone structure, a syndrome known as itai-itai disease, have been associated with long-term exposure to cadmium in food (mainly rice) and water (USEPA, 1997). The concentration map of cadmium in the study area revealed that within the mining areas (eastern part), the concentration of cadmium is very high while away from the mining sites (western portion), cadmium concentration decreases (Fig. 4). Similar signature was observed for lead concentration and it further confirmed the fact that artisanal mining activities in Madaka area have deteriorated the surface and groundwater system.

The concentration of copper ranged between 0.03-3.13 mg/l with an average concentration of 0.52 mg/l. Water samples 13 locations have their concentrations above the maximum recommended value of 1.00 mg/l (NSDWQ, 2007). Gastrointestinal disorder in human can be due to elevated copper concentration in drinking water (USEPA, 1997; NSDWQ, 2007). The occurrence of cadmium and copper in the water system in the area can be linked to the artisanal mining activities domiciled in the area. Nickel values ranged between 0.00-0.143 mg/l with an average value of 0.025 mg/l. Fourteen water samples have their nickel concentration higher than the maximum acceptable limit of 0.02 mg/l and it can be attributed to artisanal mining in the area. Human activities such as mining provide good platform for the release of potentially metals in the environment (soil, water and air). Nickel is a very abundant element in the environment, and is found primarily combined with oxygen (oxides) or sulfur (sulfides). The most common adverse health effect of nickel in humans is an allergic reaction (USEPA, 1997).

The concentration of zinc varied from 0.03 mg/l to 6.14 mg/l and a mean value of 1.75 mg/l. The mean values fall below the permissible limit of 3.00 mg/l (NSDWQ, 2007) though 12 water samples recorded higher values. Zinc is one of the commonest elements in the earth's crust. The WHO recommended dietary allowance of zinc is 15 milligrams a day for men (15 mg/day); 12 mg/day for women; 10 mg/day for children; and 5 mg/day for infants (WHO, 2010; Lee *et al*. 2007). Zinc is an essential element in our diet. Too little zinc can cause health problems, but too much zinc is also harmful. Acute toxicity may result in sweet taste, throat dryness, cough, weakness, generalized aching, chills, fever, nausea and vomiting. Chronic toxicity can cause stomach cramps, nausea, vomiting, anemia and pancreas damage (Nouri *et al*. 2008).

The concentration of chromium in the water ranged from 0.02-0.36 mg/l with a mean value of 0.115 mg/l. The mean concentration is higher than the maximum permissible limit of 0.05 mg/l recommended by (WHO, 2010; NSDWQ, 2007). Chromium is a naturally occurring element found in rocks, soil, plants, animals, and in volcanic dust and gases. Chromium (III) helps insulin maintain normal glucose levels (Bellos and Swaidis, 2005; Nikoladis *et al.* 2008). All forms of chromium can be toxic at high levels, but chromium (VI) is more toxic than chromium (III) and chromium (0). High chromium concentration can damage and irritate your nose, lungs, stomach, and intestines (USEPA, 1997).

The concentration of cobalt in the water ranged from 0.00-0.01mg/l with an average value of 0.0016 mg/l. These values fall within the permissible limit. The International Agency for Research on Cancer has revealed that cobalt is a possible carcinogen to humans. The value of mercury ranged from 0.00-0.012 mg/l and an average value of 0.0022 mg/l. Fifteen water samples have their concentration higher than the maximum permissible limit of 0.001 mg/l (WHO, 2010; NSDWQ, 2007). Mercury is used by miners to concentrate the gold and such process has led to deterioration of water quality in the area. High concentrations of mercury can cause severe respiratory irritation, central nervous system, digestive disturbances, developing fetus, brain and kidney damage (Mohanty *et al.* 2001; Prasad and Kumari, 2008). The concentration map of mercury in the area is contained in figure 5 with similar trend as revealed by lead and cadmium concentration maps. It is an indication that the metals have similar source and is attributed to artisanal mining activities in the area as they concentration of the metals are higher within the vicinity of the mining sites.

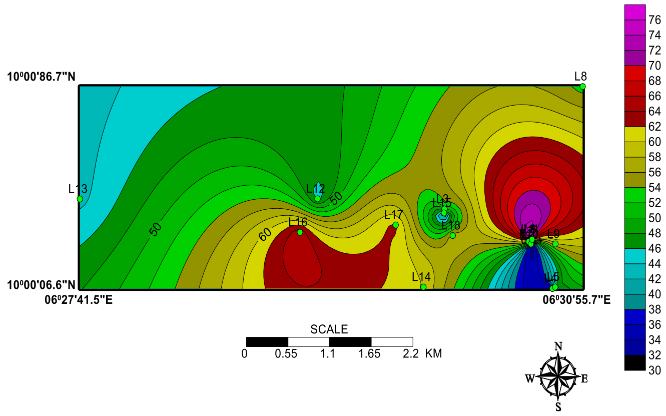

Fig. 5: Concentration map of mercury in soils within the study area

The concentration of arsenic ranged between 0.00-0.02 mg/l with a mean value of 0.002 mg/l. When arsenic enters the environment, it does not evaporate, instead it can be absorbed in the soil, dissolve in groundwater or release in the atmosphere via burning of arsenic compounds (Karbassi *et al*. 2008). Arsenic is the most common cause of acute poisoning in adults and can be released into the environment by mining. Arsenic is pathfinder elements to gold and therefore gold mining releases it to the environment (Khadse *et al.* 2008). The concentration of manganese ranged from 0.06-1.36 mg/l with an average value of 0.29 mg/l. The concentration of manganese in 9 locations were higher than the WHO and NSDWQ maximum acceptable limit of 0.2 mg/l. The prolonged mining activities in the area may have resulted in the enrichment of water sources in the area with manganese. Manganese is essential for plants and animals, and is used in products such as batteries, glass and fireworks (Aboud and Nandini, 2009; Amadi *et al*. 2013). Potassium permanganate compounds are used in fertilizer, fungicides and as livestock feeding supplements (Huang and Lin, 2003).

The concentration of iron ranged from 0.01-95.60 mg/l with a mean value of 5.02 mg/l as against the maximum recommended value of 0.30 mg/ by WHO, (2010) and NSDWQ, (2007). Iron is an essential nutrient that is vital to the processes by which cells generate energy. Iron can also be damaging when it accumulates in the body. The implication of the high iron content is that the water may have taste, colour and other aesthetic problems such as hemochromatosis. Because iron can exist in different ionic states, iron can serve as a cofactor to enzymes involved in oxidation-reduction reactions. In every cell, iron works with several of the electron-transport chain proteins that perform the final steps of the energy yielding pathways (Mohan *et al.* 1996). .

The rapid growth of adolescence, especially for males, and the menstrual losses of teen females demand extra iron that a typical teen diet may not provide. Organs that may be most affected by iron are the pancreas, liver, kidneys, brain, heart, arteries, and joints (Nouri *et al.* 2008). The analyses of some control water samples collected far away from the community that are not involved in the artisanal and mining showed very low concentration the analyzed heavy metals while around the vicinity of the mining sites, higher values were recorded. It is a confirmation that mining is the route through which the analyzed metals got into the water system in the area. This is because heavy metals in rocks are not harmful but when found in water they bioaccumulate and becomes toxic to human since they cannot be destroyed (Amadi *et al*. 2015).

Metal Pollution Index

The metal pollution index (MPI) represents the sum of the ratio of the analyzed parameters and the Nigerian Standard for Drinking Water Quality as shown in Table 2. The computed MPI revealed that groundwater system in madaka area are very highly polluted with iron and lead and moderately polluted with chromium, manganese, mercury and nickel while arsenic, cadmium, cobolt, copper and zinc were lightly polluted (Table 2). The mining activity in the area enabled these metals contained in the rock to be released into the surrounding and they eventually find their way into the surface and groundwater system thereby contaminating it. Chemical weathering and runoff as well as leaching enhance the pollution process.

Table 2: Calculated Metal Pollution Index for the Groundwater in the Area

Parameters (mg/l)	C_i	MAC_i	MPI Value	Rating
Arsenic	0.0023	0.01	0.200	Lightly polluted
Cadmium	0.0012	0.003	0.400	Lightly polluted
Cobalt	0.0016	0.01	0.200	Lightly polluted
Chromium	0.115	0.050	2.300	Moderately polluted
Copper	0.520	1.000	0.520	Lightly polluted
Iron	5.020	0.300	16.700	Very highly polluted
Lead	0.846	0.010	84.600	Very highly polluted
Manganese	0.342	0.200	1.700	Moderately polluted
Mercury	0.0022	0.001	2.200	Moderately polluted
Nickel	0.025	0.020	4.000	Moderately polluted
Zinc	1.754	3.000	0.600	Lightly polluted

< 0.01= Very lightly polluted; 0.01-1.0= Lightly polluted; 1.0-5.0= Moderately polluted; 5.0-10.0= Highly polluted; > 10.0= Very highly polluted

The computed overall water quality index (WQI) value was 642.50 and it imply that the water in the area is unfit for drinking and domestic purposes. The wide range observed in electrical conductivity (35-1696 mg/l) and TDS (44-1123 mg/l) as against their respective maximum permissible limit of 1000 mg/l and 500 mg/l is a confirmation that both the surface and groundwater system in Madaka area contains metals. Amount of materials dissolved in water accounts for wide variability in EC and TDS values. The long term artisanal mining in the area are responsible for the presence of these metals in surface and groundwater and by extension the wide range in EC and TDS values. The results of the laboratory analyses and the concentration maps of some selected metals has shown that mining in the area provide the conduit for the water pollution in the area.

$$\text{Overall WQI} = \frac{\sqrt{q_i w_i}}{\sqrt{w_i}} = \frac{1100528.50}{1712.90} = 642.50$$

Table 3: Computed WQI values for Madaka and environs

Parameters (mg/L)	*Ci*	*Si*	*Qi*	*Wi*	*QiWi*
As	0.0023	0.010	23.00	100.00	2300.00
Cd	0.0012	0.003	40.00	333.30	13332.00
Co	0.0016	0.010	16.00	100.00	1600.00
Cr	0.1150	0.050	230.00	20.00	4600.00
Cu	0.5200	1.000	52.00	1.00	52.00
Fe	5.0200	0.300	1673.30	3.30	5521.90
Pb	0.8460	0.010	8460.00	100.00	846000.00
Mn	0.3420	0.200	171.00	5.00	855.00
Hg	0.0022	0.001	220.00	1000.00	220000
Ni	0.0250	0.020	125.00	50.00	6250.00
Zn	1.7540	3.000	58.70	0.30	17.61
Sum Total			*11069.00*	*1712.90*	*1100528.50*

Table 4: Classification of Water based on WQI value

S/No	WQI value	Water Class	Percentage (%)
1	< 49.99	Excellent	2
2	50.00 – 99.99	Good	5
3	100.00 – 199.99	Poor	8
4	200.00 – 399.99	Very Poor	15
5	> 400.00	Unsuitable for Domestic Use	70

Conclusion

The quality and suitability of the surface and groundwater in Madaka area was examined in this study using pollution indices. The wide range and deviation observed in the water quality parameter is an indication that the water sources in the area have deteriorated. The outcome of the metal pollution index revealed that groundwater system in the area are greatly polluted with iron and lead and moderately polluted with chromium, manganese, mercury and nickel while arsenic, cadmium, cobolt, copper and zinc were lightly polluted. The water quality index confirms that the water in the area is not good for domestic use. The concentration maps of lead, cadmium and mercury show similarity as their concentrations decreases from the east (mine sites) to the west (away from the mine sites) which attributes their source to mining activity in the area. The study has established that the mining activities domiciled in the area have constituted serious water quality problems which have resulted to environmental and health challenges in their host communities. Mining techniques and laws that guarantee adequate protection of the natural environment especially soil and water should be enforced in the area.

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