GEOCHEMICAL CHARACTERIZATION OF SOIL AND STREAM SEDIMENTS AND IT'S ENVIRONMENTAL IMPLICATIONS FROM KPAPI ARTISANAL GOLD MINING SITES, NIGER STATE NIGERIA

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Abstract

Artisanal mining, an informal and poverty driven activity, is often criticized for its potential to cause environmental damage through the release of toxic materials and degradation of ecosystems. This study investigates the environmental impact of artisanal gold mining in the Kpapi area of Minna, North-Central Nigeria, by evaluating trace metal contamination in soils. Field observations were combined with laboratory analysis, where ten soil samples were collected, air-dried, crushed, and sieved through a 150 µm mesh. The prepared samples were analyzed using X-ray Fluorescence (XRF) spectrometry to determine the concentration of elements including Cu, Zn, Cr, Ni, V, and Co. The results were compared to the average concentration of elements in the upper continental crust and used to compute geochemical indices. The Contamination Factor (CF) and Geoaccumulation Index (Igeo) revealed predominantly low contamination, with all values falling below the threshold for moderate pollution. The Degree of Contamination (Cd) and Metal Pollution Index (MPI) further confirmed a low level of metallic pollution across all samples. The study concludes that the soils in the Kpapi artisanal mining site are currently unpolluted with respect to the analyzed trace elements. The observed elemental presence is likely attributable to natural geochemical processes like bedrock weathering and mineral dissolution, rather than significant anthropogenic input from mining activities.

Keywords: Geochemical, Characterization, Artisanal Gold Mine

Introduction

Mining can be described as the processes involved in the extraction of mineral deposits from the surface of the earth or from beneath the surface. The exploitation of natural resources of any type, be it metallic, non-metallic minerals and fossil fuels (petroleum, coal and natural gas) play pertinent role in the economic development of any nation (Ako et al., 2014). These include the potential rise in the level of foreign exchange earnings and gross domestic products of such countries. Mining activities may ultimately lead to the diversification of countries' economy and promotion of job creation in both private and public sectors. To this end, the importance of the mining sector can never be over emphasized and has been published by several authors (Obaje and Abba, 1996; Obaje et al., 2005).

Artisanal Mining is a low resource, poverty driven and localized mining operation where simple, inexpensive tools and equipment are utilized in the extraction of mineral (Bradshaw et al., 1997). This type of mining is commonly practiced in the poorest areas of a country and has been identified as a means of livelihood adopted primarily in rural areas (Veiga, 2003). It is sometimes referred to as the "informal sector", which is usually outside the legal and regulatory framework (Azubike, 2011). Opafunso (2010) reported that the informal, unorganized, unplanned and uncontrolled nature of artisanal mining can be viewed negatively by governments and environmentalists because of its potential for environmental damage, social disruption and conflicts.

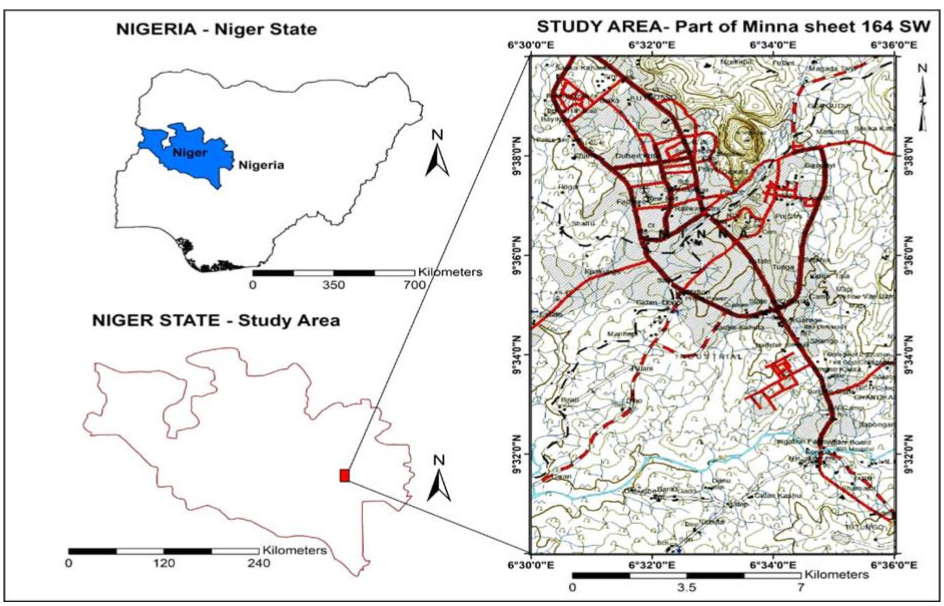
Artisanal mining is one of the mechanisms by which air, land, soil and water are polluted and degraded (Ademoroti, 1996; Ako et al., 2014). It also has considerable effect on the ecosystem and biodiversity. Furthermore, artisanal mining may result in clearing of vegetation which reduces essential nutrients and organic matter of the soil, thus reducing biological activity and leading to decreases in productivity (Pandey and Kumar, 1996). The act of artisanal mining operations directly or indirectly affects both living things (including humans) and non-living things through the physical and chemical modification of the soil environment (Ratcliffe, 1974). The use of gravity concentration methods such as panning and sluicing during processing poses health problems. Toxic materials are released into the environment, posing huge health risks to the miners, their families and the immediate communities (Azubike, 2011). Despite the imminent dangers posed by artisanal mining to humans and the environment, it has continued to spread due to large scale poverty, lack of jobs, growing unemployment and lack of political will on the part of government to formalize the sector. Other means through which people may be affected include drinking contaminated water, food, inhalation of dust, oral ingestion of particles especially by children and through breastfeeding (Ako et al., 2014).

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 mining activities. Minna and its environment, particularly the Kpapi area, suffer in the hands of artisanal miners. This work therefore studies the environmental problems associated with artisanal gold mining in Kpapi using both field observations and laboratory analysis of soil samples. Mining of solid minerals has been identified as a major entry point of toxic heavy metals into the environment, consequently polluting soil, water and air (Ajai et al., 2019). In the process of mining and extraction of a particular metal, the entire soil mass is excavated, laid bare and exposed to hazards of weathering, degradation as well as pollution of underground water by scattered tailings and discharged leachate (Abera, 2014).

Mining can be said to be an occupation involving the extraction of minerals which include petroleum oil, coal, baryte-limestone, lignite and quartz (Ezeaku, 2012). Mining generates wealth but at the same time affects the environment negatively (Ako et al., 2014). One of the most important sources of contamination of the environment is mining activities because mineral processing, metal recovery, dust control and supply of water needs of workers all revolve around the use of water (Aziz et al., 2024). The water used percolates into the ground and is taken up by plants along with heavy metals. Mining impacts also include soil structure alteration, instability of soil and rock masses, soil, water and air pollution, loss of fertile topsoil, destruction of flora and fauna and noise pollution (Ojo and Adeyemi, 2003; Aigbedion and Iyayi, 2007; Adegboye, 2012). Mapanda et al. (2009) stated that dirty gold mining has contributed to the destruction of vital ecosystems, contaminated water supplies, and ravaged landscapes. Mercury, cyanide, and other toxic substances are released into the environment on a regular basis due to dirty gold mining

(Dube, 2000). Modern industrial gold mining creates huge amounts of toxic waste and destroys landscapes (Aucamp, 2003).

Minna which is presently the administrative capital of Niger State is geographically lies between latitude 09^{o}34’50’’N to 09^{o}35’10’’N and longitude 006^{o}34’30’’E to 006^{o}34’50’’E. It is situated within the Minna Sheet 164SW. The study River Kpapi is a tributary to the main River Chanchaga that serves as a municipal water supply to Minna. The study area is accessible through the Eastern Bypass Road, branching off behind the Independent National Electoral Commission (INEC) office in Minna. From this road, several feeder routes and footpaths lead directly to Kpapi area, allowing for movement of both vehicles and pedestrians. In addition to the eastern bypass, the study area is also approachable through minor access roads linking nearby settlements such as Kpapi, Tayi, and Maikunkele. These routes are frequently used by local farmers, artisanal miners, and residents. The presence of these access routes enhances field investigations by providing convenient entry points to different segment of the study area. However, accessibility is influenced by seasonal conditions. During the rainy season, some of the footpaths leading to the study area become waterlogged, limiting vehicular movement and requiring foot travel. Conversely, in the dry season, the roads and footpaths remain firm, thus making the area easily accessible for both research and economic activities. Overall, Kpapi area is considered highly accessible due to it’s proximity to major roads within Minna and the network of community footpaths that connect the area to surrounding villages and artisanal mining sites. The accessibility facilitated sample collection of soils and stream sediments during the course of this study.



The relief of the study area is relatively flat and rocky at the river channel drained by River Chanchaga. It falls within the Guinea Savanna and consists of shrubs, grassland and trees especially along river channels. The area is also characterized by two climatic seasons: the dry and rainy seasons, each season lasting for approximately six months. The total annual rainfall of the area is between 1200 mm in the north to 1600 mm in the south. The mean maximum temperature remains high throughout the year, hovering about 32°C, particularly between March and June, while the lowest temperatures occur usually between the months of December and January during the harmattan period (Adedeji, 2011)**.** 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 (Ajibade, 1989).

Statement of the Problem

Artisanal mining of Gold has increasingly become a major business for most inhabitants in and around Minna metropolis. It is clear that a lot of contamination will be affecting the environment in terms of the conditions of water, soil and air. Work has been done on some of these components of the environment on some of the mining sites. (Idowu et al, 2012, Adegbe et al, 2018 and Alexander et al, 2019). The current study sought to determine the level of contamination within the soil and stream sediments.

Objectives of the Study

The aim of this study is to conduct a geochemical investigation and characterization of soil and stream sediment quality around the Kpapi artisanal gold mining sites in Minna, North Central Nigeria. To achieve this, the study involves geological mapping to determine rock mineralogy through thin section petrography, geochemical characterization of soil and stream sediments, assessment of contamination levels in these environmental media, and determination of the source provenance of the sediments.

Research Questions

1. What are the concentration and distribution of geochemical elements within the soil and stream sediments?
2. What are the potential environmental impacts of the mining activity to the chemical nature of the stream sediments?

Methodology

The debris were cleared and a hand scoop, ten (10) soil samples were collected at a depth of 0-15 cm at intervals of about 20 m from one sampling point to another at the gold mines sites.. The fresh samples were kept in polythene bags and labeled as ABK 1-8 for easy identification and to avoid contamination. The collected soil samples were transported to the laboratory where they were air dried at room temperature. The dried samples were crushed using mortar and pestle and the sieved through 150 µm mesh and packaged in smaller polythene bags. The prepared soil samples were then analyzed for the elemental composition at the National Steel and Raw materials Laboratory Agency, Kaduna State, Nigeria.

About 55 – 60g of the soil samples were pulverized (grind to fine powder) using agate pulverizing machine (planetary micro mill pulverisette 7) to pass 150 micro mesh sieves (British Standard).

The samples were further re-crushed and re-sieved to ensure homogeneity of the samples and maximum passage through the sieve. From these prepared samples, powdered pellets were produced for each of the sample by weighing 5g of the pulverized sample into a beaker, 1g of binding aid (starch soluble). The mixture was thoroughly mixed to ensure homogeneity, which was pressed under high pressure (6 "tones") to produce pellets; labelled and packaged for analysis. The analysis was carried out using X-ray Fluorescence (XRF) spectrometer of model "Minipal 4" software as analysed according to the method described by Ezeaku, 2012. In this method, the prepared pellet from each of these ten (10) samples was carefully placed in the respective measuring positions on a sample changer of the X-ray machine. The current used was 20kv for the trace elements/rare earth metals and 14kv for major elements. Selected filter was Ag/Al-thin for the trace elements/rare earth metals. The filters were selected based on a guided periodic table for elemental determination. The elements analyzed include Cu, Zn, Ag, Ga, As, Pb, Mn, Y, Cr, Ni, V, Sr, Th, Zr, Co, Na, K, Al, Ca, Mg, Fe, Ti, Cd and Si elements in soil samples. The mean concentration of each element in the samples was compared with Wedepohl, (1995) and Taylor and McLennan, (1985) average concentration of elements in upper continental crust. The current used was 20kv for the trace elements/rare earth metals and 14kv for major elements. Selected filter was Ag/Al-thin for the trace elements/rare earth metals. The filters were selected based on a guided periodic table for elemental determination. The elements analyzed include Cu, Zn, Ag, Ga, As, Pb, Mn, Y, Cr, Ni, V, Sr, Th, Zr, Co, Na, K, Al, Ca, Mg, Fe, Ti, Cd and Si elements in soil samples. The mean concentration of each element in the samples was compared with Wedepohl, (1995) and Taylor and McLennan, (1985) average concentration of elements in upper continental crust.

Figure 2: (a) Soil sampling, (b) Stream sediment sampling within the study area

Results

Table 1A: Statistical Summary of indices of contamination factor for trace elements in sediments from Gold Site in North Central Nigeria

CONTAMINATION FACTOR				
Parameters	Min.	Max.	Mean	Std. Dev.
Fe	3.20E-06	4.80E-06	3.70E-06	7.39369E-07
Cu	0.00071	0.00107	0.000845	0.000172337
Zn	0.000084	0.00084	0.000295	0.000365919
Cr	0.0003	0.00057	0.000418	0.000113248
Mn	0.000027	0.000082	5.25E-05	2.28692E-05
V	0.23	0.27	0.2575	0.018929694
Co	0.44	0.84	0.575	0.180462369
Nb	0.0013	0.0019	0.00165	0.0003
Ta	0.014	0.018	0.017	0.002
Ti	0.00019	0.00027	0.000238	3.59398E-05
Ba	ND	ND	ND	ND
Zr	0.00037	0.00065	0.000555	0.000125565

Table 1B: Statistical Summary of indices of contamination factor for trace elements in Soil from Gold Site in North Central Nigeria

CONTAMINATION FACTOR				
Parameters	**Min.**	**Max.**	**Mean**	**Std. Dev.**
Fe	1.80E-06	6.90E-06	4.53E-06	1.83113E-06
Cu	0.00053	0.00124	0.000769	0.0002794
Zn	0.000084	0.00074	0.000291	0.000280462
Cr	0.00011	0.00046	0.000284	0.000122234
Mn	0.000016	0.00038	0.000151	0.000142555
V	0.08	0.26	0.20125	0.060812945
Co	0.41	0.87	0.68	0.16518388
Nb	0.00064	0.00222	0.00143	0.000479076
Ta	0.005	0.1	0.028375	0.030033018
Ti	0.000089	0.000245	0.000202	5.21576E-05
Ba	0.000031	0.000062	4.13E-05	1.78979E-05
Zr	0.00028	0.00074	0.000551	0.000181536

$CF < 1$ = Low CF; $1 \leqq CF < 3$ = Moderate CF3 $\leqq CF < 6$ = Considerable Contamination Factor; $CF \geqq 6$ = Very High Contamination Factor

The results of the contamination factor computed for soil and stream sediments around the Gold Site in North Central Nigeria are presented in Tables 1A and 1B. The findings revealed that both soil and stream sediments in the vicinity of the mining site are predominantly low in contamination, with all CF values falling below 1, Vanadium and Cobalt exhibited relatively elevated CFs, approaching or slightly exceeding 0.6, yet still within the low contamination range. Other elements such as Niobium, Tantalum, Zinc, Chromium, Copper, Zirconium, Titanium, Manganese, Iron, and Barium showed minimal contamination levels. The contamination intensity of the analyzed trace elements decreases in the following order: Co > V > Nb > Ta > Zn > Cr > Cu > Zr > Ti > Mn > Fe > Ba. The presence of these elements in the soil and sediment may be attributed to both anthropogenic activities such as artisanal gold mining and natural geochemical processes including bedrock weathering and mineral dissolution. Many of the observed elements are naturally hosted in the mineral composition of the surrounding rocks and are released into the environment through surface run off and mining-related disturbances or activities. The consistency in pollution intensity patterns observed across contamination factor and other geochemical indices supports the conclusion that the site has experienced limited but detectable influence from mining activities.

Table 2A: Summary of indices of geoaccumulation, Igeo for trace elements in sediments

GEOACCUMULATION INDEX				
Parameters	**Min.**	**Max.**	**Mean**	**Std. Dev.**
Fe	-18.92	-18.36	-18.705	0.240624188
Cu	-11.04	-10.49	-10.83	0.264701089
Zn	-14.16	-13.2	-13.92	0.48
Cr	-12.29	-11.43	-11.875	0.359119293
Mn	-15.6	-14.26	-14.9075	0.555660268
V	-2.77	-2.48	-2.5625	0.138894444
Co	-1.76	-0.85	-1.4325	0.402606094
Nb	-10.21	-9.65	-9.8175	0.266755194
Ta	-6.72	-6.37	-6.4575	0.175
Ti	-12.96	-12.18	-12.4525	0.349034382
Ba				
Zr	-11.35	-11.23	-11.2767	0.064291005

Table 2A: Summary of indices of geoaccumulation, Igeo for trace elements in Soil

GEOACCUMULATION INDEX				
Parameters	**Min.**	**Max.**	**Mean**	**Std. Dev.**
Fe	-1.08	0.76	0.145	0.621473
Zn	-17.85	-13.85	-14.71	1.35478
Cr	-13.75	-11.47	-12.3363	0.920216
Mn	-16.55	-11.65	-14.1838	16

V	-12.75	-11.18	-11.7575	0.514136
Co	-2.21	-1.1	-1.49375	0.398172
Nb	-11.87	-9.43	-10.21	0.734847
Ta	-8.49	-4.08	-6.51	1.614992
Ti	-0.76	0	-0.35375	0.277794
Ba	-15.59	-14.59	-15.2567	0.57735
Zr	-13.75	-11.66	-12.465	0.800357

< 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

Table 4 is a summary of the results, based on the Igeo classes in Tables 3 and 4, the results of this study show that the Gold Site area in North Central Nigeria does not exhibit significant pollution from any of the analyzed trace elements. The mean Igeo values for all elements in stream sediments fall well below zero, corresponding to Class 0 on the Müller scale, which indicates an unpolluted condition. Specifically, the mean Igeo values for Fe (–18.705), Mn (–14.91), Cr (–11.88), Zn (–13.92), Cu (–10.83), and Zr (–11.28) confirm that the sediments are not contaminated with respect to these elements.

In the soil samples, Iron (Fe) shows slightly positive Igeo values in some locations (ABK 1 = 0.42, ABK 6 = 0.62, ABK 7 = 0.76), suggesting very light pollution (Class 1), while the remaining samples fall within Class 0, indicating no pollution. Tantalum (Ta) and Titanium (Ti) also show near-zero values in some samples, suggesting minimal enrichment but still within the unpolluted range. All other elements including Vanadium (V), Cobalt (Co), Niobium (Nb), Zinc (Zn), Chromium (Cr), Manganese (Mn), Barium (Ba), and Zirconium (Zr) have strongly negative mean Igeo values, placing them in Class 0 and confirming the absence of contamination.

The soils and stream sediments in the Gold Site area are unpolluted with respect to the analyzed trace elements. The consistency in the pollution intensity patterns across both geoaccumulation index and contamination factor supports the conclusion that the area has not been significantly impacted by mining-related pollution, and the trace elements present are likely derived from natural geological processes such as bedrock weathering and mineral dissolution.

Table 3A: Degree of contamination for Stream

Sample	**C_e**	**Contamination level**
Sample A	0.723	Low degree of contamination
Sample B	0.816	Low degree of contamination
Sample C	1.077	Low degree of contamination

Sample D	0.773	Low degree of contamination

Cd<6= Low, 6= Cd<12 Moderate, 12= Cd<24 Considerable degree of contamination, Cd≥24 High degree contamination

Table 3B: Degree of contamination for Soil

Sample	**C_e**	**Contamination level**
ABK1	4.59	Low degree of contamination
ABK2	3.92	Low degree of contamination
ABK3	4.48	Low degree of contamination
ABK4	3.17	Low degree of contamination
ABK5	4.14	Low degree of contamination
ABK6	5.39	Low degree of contamination
ABK7	5.88	Low degree of contamination
ABK8	5.56	Low degree of contamination

Cd<6= Low, 6= Cd<12 Moderate, 12= Cd<24 Considerable degree of contamination, Cd≥24 High degree contamination

The assessment of the Degree of Contamination based on the established framework by Hakanson (1980), indicates a uniformly low level of environmental impact across the study area as seen in Table 3A and 3B respectively. All stream sediment and soil samples record values significantly below the threshold of 6, which defines the upper limit for a low contamination level. This consistent data confirms that the concentrations of the studied elements remain within background levels, showing no significant enrichment from human activities in these environments.

Table 4A: Metal Pollution Index for Stream Samples

Sample	MPI	Pollution level
Sample A	0.012	Low

Sample B	0.014	Low
Sample C	0.021	Low
Sample D	0.013	Low

<1= Unpolluted; 1 – 4.99 = slightly polluted; 5 – 19.99 = moderately polluted; 20 – 40 = strongly polluted; > 40 = Very strongly polluted

Table 4A: Metal Pollution Index for Soil Samples

Sample	MPI	Pollution Level
ABK1	0.012	Low degree of contamination
ABK2	0.009	Low degree of contamination
ABK3	0.011	Low degree of contamination
ABK4	0.007	Low degree of contamination
ABK5	0.008	Low degree of contamination
ABK6	0.018	Low degree of contamination
ABK7	0.018	Low degree of contamination
ABK8	0.015	Low degree of contamination

<1= Unpolluted; 1 – 4.99 = slightly polluted; 5 – 19.99 = moderately polluted; 20 – 40 = strongly polluted; > 40 = Very strongly polluted

The results of the computed metal pollution index on the soil analyzed are illustrated in Table 4A and B. It can be observed from these tables that the degree of metallic contamination in the study area exhibits a uniformly low level of metal pollution, with all analyzed stream sediment and soil samples MPI values far below the threshold for moderate contamination, confirming that the measured metal concentrations pose no significant environmental risk. The decreasing order of the contamination of the stream samples is: SAMPLE C>D>B > A and for Soil is: ABK6 &7 > 8 >1 > 3> 2 >5>4.

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