Effects of Mining on Water Quality and the Environment: A Case Study of Parts of the Jos Plateau, North Central Nigeria.

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ABSTRACT

Tin mining flourished in the study area from the beginning of this century to the early 1980's and left behind a post-mining environment scarred by numerous mine ponds and dams surrounded by heaps of mine spoils (dumps/overburden) and a devastated landscape. Twenty water samples from mine ponds, wells, and boreholes were collected and analyzed to evaluate for possible pollution arising from leachates. A manganese value of 0.9 mg/l which is higher than the WHO highest desirable level of 0.05 mg/l was recorded from a mine pond, while two other samples, also collected from mine ponds, showed chromium values of 0.1mg/l and 0.12mg/l, respectively, which exceeds the maximum admissible concentration of 0.005 mg/l.

On the whole, the water samples did not show any significant pollution of public health concern. This is possible due to the fact that the minerals mined (tin and columbite) are not easily soluble in water. The mine ponds are presently used as source of water for irrigation and other domestic and industrial purposes. However, the major problem of the area still remains the devastated and devegetated land and mine spoils depriving the inhabitants of fertile farmland.

(Keywords: mine ponds, overburden, mine wastes, tailings, leachates, tin, chromium, columbite)

INTRODUCTION

Formal mining started on the Jos Plateau as far back as 1902 with tin and collumbite as the major targets (Federal Department of Museum and Monuments, 1979). Prior to this period, mining was limited to shallow excavations of laterite for extraction of iron to be fashioned into farm implements (Ngyang, 2007). The occurrence of these minerals brought about intense mining activities in the state at the beginning of this century, and in fact, the early growth and development of the Jos City was closely related to commercial tin mining activities on the Plateau (Schoeneick and Aku, 1998). Commercial tin mining activities commenced about 1914 through the Royal Niger Company, and by late 1920's the industry had been established, expanded, and linked to the outside world, creating new communities and flourishing mining companies.

Mining is achieved through several activities from exploration through exploitation to processing and finally to the consumer (Ogezi, 1998). The open cast mining method was generally used in predominantly flat plains of the Plateau, as tin and columbite were concentrated in old stream beds (alluvial), having been washed down from the younger granite outcropping units (Falconer 1921). The tin mining industry on the Jos Plateau has caused extensive man-made environmental damage, with vast tracks of pastoral land systematically destroyed in the quest for cassiterite and columbite, with increased radioactive waste as a result of dumping of mine tailings and several heaps of mine dumps (overburden) and also mine ponds scattered all over the area. These mine ponds have resulted in several deaths, with about 106 recorded from the years 1980 to 1993 (Adiuku – Brown, 1999).

The objective of this study therefore is to examine the effects of mining on water quality and the environment of selected parts of Jos Plateau, North-Central Nigeria where tin mining took place.

These locations are located on latitude 9^{o} 30'N and 9^{o} 33'N and longitude $8^{o}53'$E and $8^{o}59'$E, on the topographical sheet Naraguta 168, on a scale of 1: 100,000, and covers a distance of about 70km^2. The administrative map of Plateau State showing the location of the study area is given in Figure 1.

It is underlain in most parts by rocks of the basement complex, which are the oldest rocks of the area and are found as small and widely scattered outcrops (Macleod, 1956). It falls within the granite complexes of Central Nigeria, which represents one of the classical areas of occurrence of ring complexes in the world (Buchanan and Macleod, 1971). It has three main geological units: basement rocks, younger granite complex, and regolith. The basement rocks occur as highly metamorphosed and folded masses in contrast to the surrounding younger granite complex. The younger granite formation consists of various types of rocks, ranging from biotite granite, quartz-fayalite porphyry, and hornblende-porphyry (Black,1971).

Hydrogeological studies revealed three hydrological units; quaternary sedimentary deposits, weathered zone of crystalline rocks, and tectonically fractured zone of crystalline rocks. The fractured crystalline aquifer water relates to tectonically fractured zones and can be from open wells, blasted wells, and sometimes bore holes. The soft overburden aquifer consist predominantly of clayey materials of alluvial, elluvial and deluvial origin, as well as *in situ* chemically weathered crystalline rocks (Schoeneick and Aku, 1998). The volcanic aquifer occurs only locally, and consists of volcanic ash or basalts interbeded with volcanic ash. Its thickness is normally small, and is mostly tapped jointly with the underlying soft overburden aquifer.

To extract minerals for use by industries, the Earth's crust must be disturbed (Howard and Ramson, 1998). On this crust are living things whose life patterns are disturbed when mining is undertaken, resulting in a loss of biodiversity. Mines, both active and inactive, are potential water contamination sources (Davis, 1966). The Mining excavations create direct connection between ground water and the land surface. Oxidation of exposed minerals can lead to acid mine drainage (Domenico and Schwartz, 1990). Leaching of heavy metals is also a threat. Drainage of materials from abandoned mines can act as ground water contamination source for years after mining operations have stopped (Freeze and Cherry, 1979).

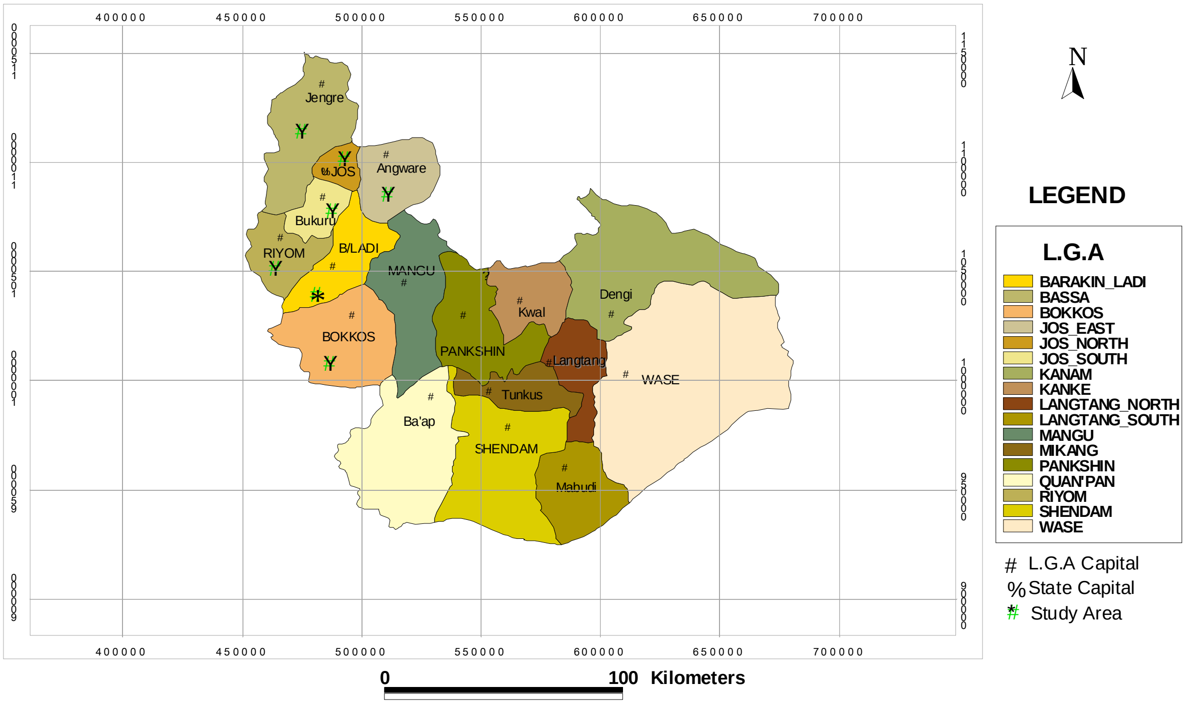

Figure 1: Administrative Map of Plateau State Showing the Location of the Study Area.

On the Jos Plateau, exploration, exploitation and processing of tin ore known to be associated with the alluvial sediments has left behind numerous ponds, Lotto, and prospecting pits, as well as heaps of mine waste in the course of mining.

Since the minerals exploited are commonly associated with a variety of others, which are not needed, they were simply thrown away or heaped within the tin shed as tailings. Among the waste are minerals like magnetite, zircon, ilmenite, monazite, silica sand, thorite, amethyst, etc. (Ngyang, 2007). The abundant mine ponds, heaps of overburden and mine tailings are believed to have negative impact on the environment in the sense that the mine ponds and Lotto pits are considered to be death traps (Adiuku- Brown 1999), while the once flat land have been defaced by heaps of over burden with gully erosion taken over in many places. The tailings could be a silent and unnoticeable time bomb, as they are replete with radioactive materials excessively enhanced through the mineral processing. The mine ponds left by these mining activities are today used for irrigation, domestic, and industrial purposes. The quality of these waters, and indeed that of the underground water with which they may possibly interact, are not known.

Leachates from mine waste can pollute the water in the mine ponds, which in turn can infiltrate the ground and pollute the ground water if it gets at it (Lindslay, 1975), while the rains could also wash off heavy metals and radioactive materials in mine tailings, which as surface run off could pollute the water. The use of mine tailings for baking and frying as well as for plastering of houses could result in exposure to radiation from naturally occurring radioactive materials as well as from technologically enhanced naturally occurring radioactive materials (Solomon, 2005).

It is also possible that the exposed heaps of mine waste and rock formation as a result of mining activities will be subjected to weathering and leaching of some of its elements which can contaminate the surface water (mine ponds) and also ground water in wells and boreholes around the study area. The extent of the landscape originally disturbed by the large scale commercial tin mining operations on the Jos Plateau is put at 325 km^2 (Aguigwo, 1997) and represents more than 17% of the agricultural land with 8,600 km^2 of the entire Jos Plateau region, the bulk of which is virtually covered by rock outcrops.

MATERIALS AND METHODS

The procedure used for this work was systematic sampling of mine pond water, water wells, and boreholes in the study area. The water samples were collected in polyethylene 250 ml screw cap bottles. The location of sample collection points is taken using Etrex Garmin global positioning system (GPS), while the depth at which the ground water samples were collected was also recorded. All vessels used for the collection of water samples were previously soaked in dilute acid and rinsed several times with distilled water. The vessels used for cation analysis were soaked in 2% HNO_3, while that for anion were soaked in 6% HCl (except for Cl analysis). *In situ* tests were made for conductivity, pH, and temperature using Esticks EC500 conductivity meter and Jenway 3150-pH/temperature meter, respectively. Total hardness was determined using titrimetric method, while turbidity was measured using Secchi's Disk.

Groundwater from boreholes and pumped wells were purged before sample collection to eliminate stagnant water, as this will not be representative of the water. Immediately before sample collection, bottles are rinsed again several times with water to be sampled, while water from mine ponds were as much as possible taken from 30-50 cm below the surface directly into sample bottle. Anions were analyzed using gravimetric method. About 2 cm^3 of concentrated nitric acid was added to water sample collected, for cation analysis using a dropper to reduce the pH to 2.0 or 1.5, and then shaken. Litmus paper is then used to measure the pH, and thereafter sample is sealed and labeled accordingly. Samples for anion analysis were not acidified, and the analysis was done using the atomic absorption spectrophotometer. The sample collection points in the study area are given in Table 1.

RESULTS AND DISCUSSION

A total of twenty water (20) samples were collected in the study area, twelve (12) of which are ground water samples, while eight (8) are surface water samples (a stream) and (mine ponds). They were analyzed for various parameters as given in Table 2.

Table 1: Sample Collection Points and Coordinates.

S/N	Sample Identity	Water Type	Location	Coordinates
1	GW 01	Borehole	Highland Bottling Company B/Ladi	N 09^0 33.534’ E08^0 54’
2	MP 02	Mine pond	Behind Highland Bottling Company B/Ladi	N09^0 33.713’ E080 54.439’
3	GW 03	Shallow well	Barkin Ladi	N09^0 32.861’ E08^0 53.00’
4	GW 04	Shallow well	Zat, Barkin Ladi	N09^0 32.451’ E08^0 53.219’
5	GW 05	Shallow well	Gangare, B/Ladi	N09^0 32.327’ E08^0 53.369’
6	GW 06	Shallow well	Gangare, B/Ladi	N09^0 32.542’ E08^0 54.305’
7	GW 07	Shallow well	Dorowa	N09^0 32.922’ E08^0 52.931’
8	GW 08	Shallow well	Zim	N09^0 31.678’ E08^0 52.475’
9	GW 09	Bore hole	Dorowa	N09^0 31.678’ E08^0 58.45’
10	MP 10	Mine pond	Pwomol	N09^0 32.688’ E08^0 53..475’
11	GW 11	Shallow well	Rabok	N09^0 32.823’ E08^0 53.596’
12	MP 12	Mine pond	Gwol	N09^0 32.855’ E08^0 53.610’
13	GW 13	Shallow well	Barkin Ladi	N09^0 32.823’ E08^0 53.596’
14	MP 14	Mine pond	Rakun	N09^0 3.441’ E08^0 53.154’
15	MP 15	Mine pond	Barkin Ladi	N09^0 32.854’ E08^0 5.447’
16	MP 16	Mine pond	Kwa Kopp	N09^0 33.088’ E08^0 53.717’
17	GW 17	Shallow well	Barkin Ladi	N09^0 32.745’ E08^0 53.542’
18	MP 18	Mine pond	Bet	N09^0 32847’ E08^0 53.447’
19	GW 19	Shallow well	Barkin John	N09^0 32.802’ E08^0 53.450’
20	MP 20	Mine pond	Dan Mangu	N09^0 32.902’ E08^0 53.517’

Table 2: Summary of the Geo-Chemical Composition of Water of the Study Area.

Summary of the geochemical analysis results of the study area						
Parameter	**Ground water**		**Surface water**		**WHO Standard**	
	Range	**Mean**	**Range**	**Mean**	**Recommended level**	**Maximum permissible level**
Temperature (0c)	24 - 27	25.04	21 – 25	23.20	Variable	Variable
pH	6.5 – 7.18	6.2	6.63- 7.99	7.30	6.5	9.5
Conductivity (usm/cm)	23.7-126.3	67.1	12.3-110.2	64.45	400	1480
Total hardness (mg/l)	32 – 72	52.83	2.0 –104.0	61.25	100	500
Turbidity	1.0 –130	20.33	0.0 – 3761.0	478.79	<5	
$Cl^{-(}$ (ppm)	17.04-191.7	73.34	22.72-102.24	77.623	250	600
NO_3 (mg/l)	0.0 –10.0	1.7	0.6 –2.40	1.163	25	50
SO_4 (mg/l)	0.00 –17.0	3.23	0.00-14.00	5.063	250	400
Fe^{2+} (mg/l)	0.01-04	0.14	0.00-0.48	0.133	0.3	1.0
Cu^{2+} (mg/l)	ND – 0.05	0.05	ND – 0.05	0.05	1.0	1.5
Zn^{2+} (ppm)	0.02 –0.03	0.025	0.05 –0.08	0.053	-	3.0
Mn (ppm)	0.0-0.1	0.10	0.0-0.9	0.65	0.01	0.2
Ni	0.0-0.70	0.182	0.10-0.94	00.294		
Pb^{2+} (ppm)	Nil	Nil	Nil	Nil		
Cr^{6+} (mg/l)	0.0-0.01	0.01	0.0-0.12	0.0175	-	-

ND-Not detected

The chemical parameters used in characterizing the waters are pH, conductivity, total hardness, Cl^-, $S0_4^-$, $N0_3^-$, Mn $^{2+}$, etc.

The **conductivity** values observed ranged from 23.7 – 126.3 with a mean value of 67.1 us/cm for ground water samples, and 12.3 – 110 for surface waters, with a mean value of 64.45 us/cm. It can be seen here that the ground water seems to have higher values, and this can be as a result of its close contact to earth materials and minerals it comes in contact with (Hem, 1998). It however falls within the recommended level by the WHO.

The **chloride** (Cl^-) values ranged from 17.04 – 191.7, with a mean value of 73.34 for ground water, and 22.72 – 102.24, with a mean value of 77.623 for surface water and both values fall within the limit of WHO's highest desirable limit for drinking water. The somewhat high values observed in a few samples in both surface and ground water could be an indication of pollution from effluents, even though not significant enough to warrant concern.

The **manganese** (Mn $^{2+}$) values ranged from 0.0 – 0.1 for ground water and 0.0 - 0.9, for surface water. The value of 0.9 as observed in the surface water is above the highest desirable, and also above the maximum permissible (WHO, 2006) of 0.5 mg/l.

Iron values ranged from 0.01 – 0.4 in ground water, and 0.00 – 0.48 in surface water. The highest desirable value of 0.1 (WHO, 2006) is exceeded by seven samples; they however fall within the maximum permissible value of 1.0

mg/l. The value 0.48 was recorded from an active mining site indicating the possibility of acid mine drainage.

Zinc was detected in only four samples, two each from ground water and surface water. For ground water, the value ranged from 0.02 – 0.03, with a mean value of 0.025, while for surface water it ranged from 0.025 – 0.08, with a mean value of 0.053. These values fall within the WHO permissible value.

Copper (Cu) was detected in only one sample each from ground water and surface water, and they both show values of 0.05 mg/l. This value is within the recommended value by the WHO.

Lead (Pb $^{2+}$) was not detected in any of the samples analyzed.

Nickel (Ni) value ranges from 0.0 – 0.70 in ground water to 0.10 – 0.94 in surface water. This falls below the 1.0 mg/l given as guideline for effluent limitations in the mining and metallurgical industries.

Chromium values range from 0.0 – 0.01 in ground water, and 0.0 – 0.12 in surface water. The values 0.1 and 0.12 as recorded in surface water, one of which is an active mine site, while the other an abandoned mine site exceeds the maximum admissible concentration of 0.025.

Sulphate ($S0_4^-$) - The sulphate values obtained ranged from 0.00 – 17.0 for ground water, and 0.00 to 14.00 for surface water. This figures falls within the WHO's desirable and permissible level as can be seen from Table 2.

Nitrate ($N0_3^-$). The nitrate values obtained ranged from 0.0 – 10.0 for ground water, while that of surface water ranges from 0.6 – 2.40. This falls within the recommended value of the WHO.

Temperature – The temperatures recorded were in the range of 24– 27 ^{O}C in ground water, with a mean value of 25^{O}C while the surface water value ranged from 21 – 25 ^{O}C, with a mean value of 23.20 ^{O}C. The surface water temperature could be influenced by the atmospheric temperature, as well as evaporation, while ground water will normally be warmer.

pH readings recorded for ground water were in the range of 6.5 –7.18, with a mean value of 6.2, while the surface water reading, ranged from 6.63 –7.99, with a mean value of 7.3. From the above readings, it can be noted that the ground water are weakly acidic which may be due to the breakdown of organic matter. However, both the surface and ground water fall within the WHO recommended and maximum permissible levels (WHO, 2006).

Total Hardness measured on the study area was within the range of 32- 72, with a mean value of 52.83 for ground water and 2.0 –104.0 and a mean value of 61.25 for surface water, respectively. The values recorded fall within the WHO's highest desirable value of 100 mg/l, except one sample, from a mine pond with a value of 104 mg/l. Excessive total hardness affects taste of water, and low hardness causes flat taste of water. High total hardness, on the other hand, increases soap consumption. Classification of the water of the study area is given in Table 3

Table 3: Percentage Hardness of Ground and Surface Water of the Study Area.

Hardness	Water classification	Percentage hardness (%)	
		Ground water	Surface water
0 – 75	Soft	91.67	87.50
75 – 150	Moderately hard	8.33	12.50
150 – 300	Hard	Nil	Nil
> 300	Very hard	Nil	Nil

From the above table, most of the waters from the (over 87%) study area can be classified as soft water; while over 8% can be classified as moderately hard.

Turbidity, which is an indication of the presence of suspended materials such as clay, silt, finely divided organic material, plankton, and other organic and inorganic materials as measured in the study area was within the range 1.0 – 130 units, with a mean value of 20.33 for ground water, and 0.0 – 3761.0, with a mean value of 478.79 units for surface water. The high turbidity as observed in the surface water (mine pond) can be associated with the pumping of the water for irrigation, and also its use by the people for laundry and other domestic purposes, and also its use for drinking by cattle, which sometimes walk right into the ponds to drink water. The values recorded for seven (7) samples are above the highest desirable for drinking water (WHO) of 5NTU, but this can be attributed to the time and season of sampling, as it was sampled towards the end of dry season when water is sought the most within the study area. Furthermore, sample with the highest reading of 3,761 was recorded from a pond on an active mine site, into which water used for beneficiation is recycled. Five of the samples with high turbidity values are from mine ponds, while the remaining two samples are from shallow wells. The heaps of mine spoils (overburden) on the study area are given in Figure 2.

CONCLUSION

It can be observed from the results of water analysis that the tin mining activities carried out on the project area did not significantly affect its quality. The small traces of manganese, iron, and chromium observed in some samples cannot be said to be significant enough to warrant panic, except for fear of bioaccumulation. The major problem however, as observed from this study, is the several abandoned mine ponds and heaps of mine spoils that abound on the project area and are spoiling the scenic beauty as well as serving as contaminants for both humans and animals (Adiuku – Brown, 1994). Some authors (Schoeneick *et al*, 1998) are of the opinion that the area was left in a confused state. The several abandoned mine ponds have however, found use in irrigation, fishing, and other domestic and industrial purposes such as, laundry, bathing, and block making.

Figure 2: Heaps of Mine Spoils (Overburden) in the Study Area.

Finally, mineralization is a blessing wherever it occurs; however, sustainable mining should be carried out for the purpose of mineral exploitation, while the lands should be restored to their original state after mining. A situation where these fields are left unreclaimed all over the place renders the soil infertile thereby depriving the people of farmlands, while the ponds act as death traps. The dangers of such unreclaimed activities could be summarized as follows:

- Mine ponds
- Heaps of over burden
- Loss of arable land
- Loss of bio – diversity
- High accumulation of mine tailings containing radioactive minerals.

Environmental hazards posed by mining activities can be reduced by adapting best mining practice such as mine reclamation after mining (Alford and Tulay, 1974), while mine waste should be properly disposed. Furthermore, current mines should be properly planned to minimize the amount of hazardous waste they produce (Sawyer and McCarthy, 1967), while on historical mines where waste already exist, remedial action maybe required, such as suitable land use planning, so as to restrict the use of contaminated sites.

Mining laws enacted by the Government should be strictly enforced to ensure compliance and prevent future unwholesome practices. It is the view of the authors that more detailed investigation be carried out on these mine ponds, with a view to reclaiming those not found to be useful, while others could be put to proper use such as irrigation, fishing, industrial and public water supply. The heaps of mine waste, which is mostly laterite, can be used as a source of raw material for compressed earth bricks after confirmation that they do not contain high levels of radioactive materials.

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