AMD Characterization of Surfacewater and Groundwater in Jos-Bukuru Rayfield Area of Plateau State, Nigeria.

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Abstract
Extensive mining of cassiterite and columbite ores in the Jos-Bukuru parts of Plateau State, Nigeria have precipitated conditions for the formation of acid mine drainage (AMD) in the area. To check for contamination of water sources, geological, hydrogeological and hydrochemical investigations were carried out. This is to improve the current status of knowledge on the occurrence of AMD in the Plateau. The Rayfield area of Jos-Bukuru is underlain by pink, medium to coarse grained biotite granites. The upper 5m of the rock is highly weathered, jointed and fractured. This forms a shallow unconfined aquifer which is tapped by hand-dug wells and small streams. A total of sixteen water samples drawn from hand-dug wells, mine ponds and streams were analysed for major element chemistry and heavy metals. All the samples (except two) have pH values which range from 5.1 to 6.9 which indicate acidic conditions. The two samples which indicate alkaline conditions were drawn from a river and an industrial discharge pond. The value of sodium (Na^+) concentration range from 2.5mg/l to 43.9mg/l while calcium (Ca^{2+}) is from 0.31mg/l to 7.6mg/l. Values for potassium (K^+) range from 0.67mg/l to 108.85mg/l. Magnesium ion concentration is rather low (0.02mg/l to 1.13mg/l). Concentration values for major anions are very low especially in the case of bicarbonate ($HC0^-_3$). Its concentration in most of the samples was below detection levels. It could be detected only in 4 samples where it ranges from 6.10mg/l to 24.40mg/L. Chloride (Cl^-) values range from BDL(Below detention level) to 198.52mg/l (a river sample). For sulphate ($S04^{2-}$), the range is 3.21mg/l to 6.31mg/l. The values for iron concentration range from 0.16mg/l to 10.27mg/l which certainly exceed all guidelines for iron in water. The geochemical qualities of acid mine drainage include low pH, high fe and sulphates. Whilst the waters of Rayfield area show low pH and high Fe values, the concentration values for sulphate are low but lead (Pb) concentrations exceeds W.H.O.
Key words: AMD (acid mine drainage); Jos-Bukuru; Rayfield; Lead; Iron)

1. Introduction

Acid Mine Drainage (AMD) is one of the negative impacts of mining on the environment. Although its formational processes can occur naturally, mining or construction activities can trigger it due to the exposure of increased volumes of sulphide-bearing minerals to oxygen and water. The processes of AMD formation tend to be increased above the water table than below it.

Typically, AMD is produced when sulphide-bearing rocks are exposed to oxygen and water. The processes can be catalyzed chemically or microbially but the final chemical composition of the AMD formed would depend largely on the local mineralogy of the host rocks. Because of in-situ variations in mineral content, the prediction of AMD potentials cannot be generalized. It would require a site-by-site assessment in order to establish the potentials and mechanism of AMD formation unique to each site.

Most AMD occurrence around the world are commonly associated with iron-sulphide aggregated rock deposits and also with coal mines but Wan Yaacob *et. al.* (2009) has documented the occurrence of AMD in various tin mines in Malaysia.

2. THE STUDY AREA

The study area lies between latitudes 9° 45’ and 9° 54’ N and longitudes 8° 50’ and 8°53’ E. It is located within the Jos Plateau State, Nigeria covering an area of about 60 km. Two out of the six major tin mining fields in the state are within the study area. These are the Jos-Bukuru field and the Rayfield areas.

Tin mining in the Plateau spans at least 80 years of large scale mining and some additional 21years of small scale mining. The total land area affected by these mining activities is roughly 325km² out of the 8,689km² of the Jos Plateau. These mining activities have negatively impacted the environment. Efforts made at reclaiming damaged lands have benefited only 12.37km² out of the 325km² of damaged lands (Haruna. I., 2009). Apart from the ugly picture of abandoned mine pits here and there, a more serious problem of mine is the problem of acid mine drainage. Adiukwu –Brown (1997) described the problems of abandoned mining ponds and Lotto mines in Jos Plateau while Haruna 2009 outlined the trace elements found in the mining ponds associated with tin mining areas.

The present study is aimed at finding if AMD actually occurs at the mines round the study area and characterizing it geochemically.

3. GEOLOGY AND HYDROGEOLGY

There are three groups of rocks in the Jos Plateau. The oldest group is the Basement complex (Precambrian) which comprises the Older Granites, gneisses and migmatites. The second group is the Younger Granites (Jurassic to Triassic) which are uniquely alkaline. The third is the Older and Newer Basalts (Quarternary). The Younger granites form ring complexes throughout the Plateau which have been associated with tin occurrence. The most predominant type among the younger granites are biotite granites which has three distinct groups (Mc Leod et al, 1971; Olade,1980.). They are (from the oldest to youngest) the Rayfield – Gona biotite granite, N' Gell biotite granite and Jos biotite granite. Fig 1 shows the geologic map of the area.

Field mapping confirmed two lithologic units in the study area. Unit A is Jos biotite granites and occupies the northern part of the study area including Dadin Kuwa and some parts of Rayfield. It is a coarse grained pink coloured biotite granite with a regular set of joints. It contains large crystals of orthoclase that range from 0.5 to 2.0cm. it weathers to a coarse, quartzose soil which aids in identifying the unit in poorly exposed areas.

Unit B comprises two sub-units of N'Gell biotite granite and Rayfield –Gona biotite granite. It underlies most of the north-central, southern and western parts of the study area. Subunit 1 (ie N'gell Biotite granite) consists of pink, medium grained biotite granite which weathers to rough boulders. The pink colour changes to white as one traverses the unit. This unit has characteristic E-W trending joints.

The sub-unit II consists of fine grained white biotite granite which is known to be rich in minerals like columbite, thorite and cassiterite. This subunit is part of the Jos biotite granites. It underlies places like Donkeigam and Sabo Baraki (ie western parts of the mapped area). It constitutes less than 15% of the study area. It has quartz and feldsper crystals that are between 1 - 2 mm in diameter with pale green mica flakes. Its joints are irregularly spaced. Because of crystalline nature of the rocks of the Plateau, aquifers occur only in areas of weathering and fracturing. Schoeneiech and Mbonu (1991) grouped these aquifers into three basic types. These are a fractured crystalline aquifer; a soft overburden aquifer and volcanic aquifer (see fig 2). All these aquifers are shallow and unconfined. The aquifer in the study area is the fractured crystalline aquifer. It is tapped by boreholes, hand –dug wells and mining ponds.

4. METHODOLOGY

Geologic field mapping was followed by water sampling. A total of 16 samples, were collected from hand-dug wells, mining ponds and a river. The sampling design took into consideration areas that could be exposed to AMD formation or occurrence. Samples were collected in 500ml plastic bottles which had been previously rinsed with distilled water to reduce the risk of contamination. Each sample was rinsed with the water to be collected. The samples were also filtered to remove suspended particles and acidified in order to stablise chemical species that could alter before laboratory analysis.

Before the samples were taken it was considered necessary to carry out some physico-chemical tests in-situ. These include tests for pH, Eh, temperature; electrical conductivity and total dissolved solids. These fields test were carried out with a water quality meter (Sanxin, S× 75.1 portable pH/ORP/conductivity do meter). The probe was immersed in the water on site and the measurement of pH, Eh, temperature, total dissolved solids and conductivity taken. In the laboratory, the relevant ions were analysed with the aid of atomic absorption spectrophotometer.

5. RESULTS AND DISCUSSION

Table 1 shows the physico-chemical characteristics of water samples drawn from hand dug wells, mining ponds and a river that receives most of the effluents from a manufacturing company. The results indicate pH values that range from 5.06 at L1 (Dadi Kuwa) to 7.85 at L8 (a mining pond). Most of the other pH values cluster around 6.5 which reveals predominant tendency towards alkaline conditions. Electrical conductivity measurements ranged from 3**µ**s/m in L3 which is a stream to 95**µ**s/m in L2 (a hand dug well at Dadi Kuwa)

Values of total dissolved solids (T.D.S) was found to have the lowest value of 4mg/l at L10 and the highest value of 66.5mg/l at L2 (Dadi Kuwa).

The results from hydrochemical analysis of the sample are given in table 2. cations occur in the following order: Na > K > Ca^{2+} > Mg^{2+}. This is not surprising. Bowen (1971) discussed the geochemistry of the Younger Granites of Jos. He found them to be peralkaline granite that has low alumina and magnesia. In other words the elemental abundance in ground water actually agree with this observation.

The sodium variation ranges from 2.50mg/l at L16 (which is a mining pond) to 43.9mg/l at a hand dug well in

Dadi Kuwa (L1). The primary source of sodium are the plagioclase feldspars which occur in Younger Granites. Potassium varies from 0.67mg/l at the mining pond in L16 to 11.48mg/l at another mining pond (L8). Possible sources of potassium in the water could be reactions involving microcline or biotites in the host rocks

Calcium, Ca^{2+} varies from 0.312mg/l at L11 (which is a small flowing stream at the School of Health Technology) to 66.76mg/l at the mining pond (L8). The Magnesium, Mg^{2+} varies from 0.03mg/l at the mining pond in L16 while the highest value of 1.14mg/l was found at L8 (which is a mining pond). The elemental abundance for cations indicate that the alkaline host rocks are definitely impacting the chemistry of ground water.

The anions occur in the following order: $Cl^{-} > NO_3^{-} > S0_4^{2-} > HCO_3^{-}$. This places the ground waters in the Na-Cl category in terms of hydrogeochemical facies. Though Cl^{-} is the dominant anion, it was not detected in the following locations L8, L10, L12, L13, L14 and L16. The highest value for the mapped area was in the hand dug well at L1 (Dadi Kuwa) while the lowest value was L6 (a hand dug well at New Layout). The range is 7.09mg/l to 180.8 mg/l.

The next anion is $N0_3^{-}$ which ranges from 7.21mg/l at L15 (a hand dug well) to 28.30mg/l at Dadi Kuwa. The slight rise in NO_3^{-} values may be due to anthropogenic activities

Sulphate ions SO_4^{2-} vary from 3.21mg/l at a hand dug well in L13 to 6.32mg/l which is a river sample. Since the study area was known for its mining activities, high sulphate concentration values was expected but surprisingly the values are low.

The values of bicarbonates HCO_3^{-} was not detected at all in L1, L2, L3, L4, L6, L7, L8, L12, L14, L15 and L16. It has very low concentrations of between 6.10mg/l at L10 to 24.40mg/l at L5.

The following heavy metals were tested for: Cadmium (Cd), Chromium,(Cr), Lead (Pb) and Iron (Fe). Only lead and iron occur in detectable concentrations. Pb varies from 0.0399mg/l at L16 to 0.0679mg/l at L10, (a mining pond). Iron ranges from 0.16mg/l at L1 to 10.27mg/l at L8. Although iron clearly exceeded the WHO limits for potable water (which is 0.01mg/l), lead does not. The W.H.O. limit for lead is 0.01mg/l.

The aim of this study was to find out if acid mine drainage was forming at the study area because of its past as a mining area. Although results from the chemical analysis of the waters indicate that the waters are slightly enriched in terms of chlorides, all other parameters of AMD formation such as low pH, high sulphate and iron remain normal except in very few cases. The pH range which is from 5.65 to 7.85 seems quite normal. It does not show that AMD is forming in the area. Again the low sulphate values does not suggest AMD formation. The only factors which suggest the possibility of AMD occurrence are the high concentration values of iron and chloride. It is therefore strongly suggested that the alkaline nature of the host rocks may be responsible for protecting this former mining site from experiencing AMD formation.

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Table1: Physico-chemical parameters for the study area

Sample No	Locations	pH	Temperature	Electrical Conductivity. µs/m	Total Dissolved solids (T.D.S) (mg/l)
L1	Hand-dug, well Dadi kuwa Junction	5.0	23.3	10	7.0
L2	Dadi Kuwa, Prof's house (HW)	5.3	29.3	95	66.5
L3	Building Materials near bridge (HW)	5.9	22.2	48	33.6
L4	Sabon Baraki, Nyanago	5.4	23.9	7	4.9
L5	Grace Bada,Nyayo New layout Bukuru (HW)	5.9	24.3	48	33.6
L6	New layout (HW)	5.4	24.7	75	52.5
L7	River Negel Banda New layout (S)s	7.0	25.5	5	10.5
L8	Atnl Mining Pond	7.9	26.6	44	30.8
L9	Dady Cpd, Bukuru	5.6	23.4	62	43.4
L10	Mining Pond near Aguidi	6.7	28.2	6	4.7
L12	Shambi House Agwadopi	5.6	23.1	69	48.3
L13	Yelwa Club house Bukuru	6.1	25.5	30	2.1
L14	Stream along Bukuru Rayfield Rd	6.7	24.2	3	2.1
L15	Rayfield (Dara Gyaugi)	5.2	24.6	79	58.3
L16	Baraki Maidiko (Mining) Pond	5.6	23	28	19.6

Table 2: Hydrochemical data of samples in study in area (all concentration values in mg/l)

Sample No	Locations	Na^+	Ca^{2+}	K^+	Mg^{2+}	SiO_2	Cd	Cr	Pb	Fe	HCO_3^-	Cl^-	SO_4^{2-}	$N0_3^-$
L1	Hand-dug, well Dadi kuwa Junction	43.95	3.73	108.86	0.81	0.42	ND	ND	0.05	0.16	ND	19.63	4.71	28.30
L2	Dadi Kuwa, Prof's house (HW)	25.57	2.83	6.25	0.62	0.28	ND	ND	0.05	0.21	ND	24.82	6.31	16.50
L3	Building Materials near bridge (HW)	8.01	3.12	4.59	0.36	0.25	ND	ND	0.06	0.88	ND	7.09	5.47	7.30
L4	Sabon Baraki, Nyanago	4.76	0.68	4.30	0.15	0.21	ND	ND	0.05	0.29	ND	180.80	4.32	12.70
L5	Grace Bada,Nyayo New layout Bukuru (HW)	16.48	5.87	10.32	0.84	0.24	ND	ND	0.06	0.26	24.40	14.18	3.21	27.31
L6	New layout (HW)	6.10	0.35	3.91	0.06	0.18	ND	ND	0.07	0.25	ND	3.55	3.53	14.60
L7	River Ngel Banda New layout (S)s	5.81	2.47	3.85	0.25	0.23	ND	ND	0.05	1.58	ND	198.52	6.42	7.30
L8	Atnl Mining Pond	13.58	6.68	11.48	1.14	0.25	ND	ND	0.05	10.27	ND	ND	5.47	9.30
L9	Dady Cpd, Bukuru	10.46	1.75	4.54	0.41	0.22	ND	ND	0.06	0.33	14.18	14.18	4.82	8.04
L10	Mining Pond near Aguidi	21.07	7.68	5.71	0.99	0.20	ND	ND	0.07	0.56	ND	ND	5.31	17.80
L12	Shambi House Agwadopi	3.62	5.19	10.27	0.72	0.16	ND	ND	0.07	0.28	ND	ND	4.37	7.30
L13	Yelwa Club house Bukuru	5.82	2.30	3.02	0.82	0.18	ND	ND	0.06	0.31	ND	ND	3.21	19.41
L14	Stream along Bukuru Rayfield Rd	3.60	2.09	2.90	0.38	0.23	ND	ND	0.06	0.86	ND	ND	4.34	5.64
L15	Rayfield (Dara Gyaugi)	15.41	1.30	3.57	0.33	0.23	ND	ND	0.07	0.27	7.09	7.09	3.72	7.21
L16	Baraki Maidiko (Mining) Pond	2.50	0.31	0.67	0.03	0.17	ND	ND	0.04	0.32	ND	ND	4.11	9.43

ND=Not detected; HW=Hand-dug well

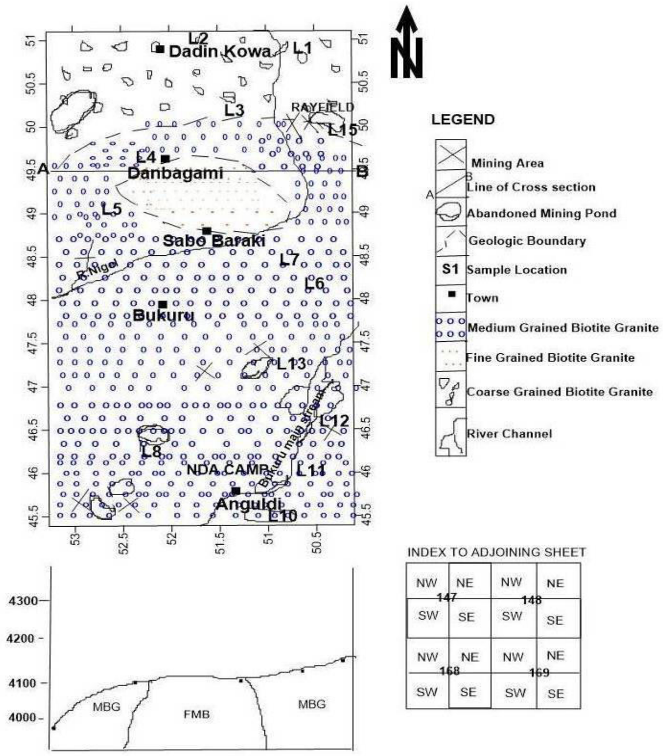
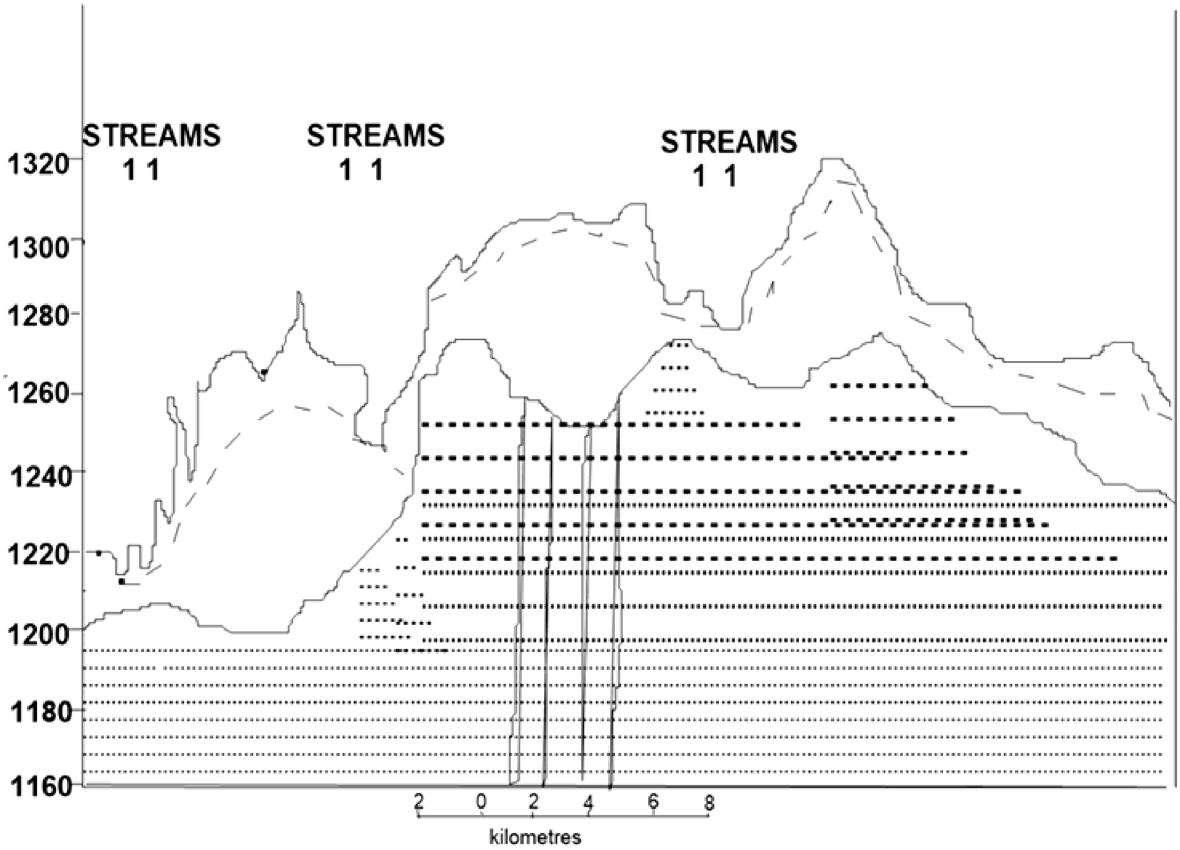


Fig.1 The Geologic map of Bukuru-Ray field areas (Naraguta sheet 158NE)



Key: 1.Tectonically fractured zone of regional extend
2. Fractured Crystalline Aquifer
3.Soft overburden Aquifer
4.Volcanic Aquifer
5. Groundwater table, Peak of the dry season

Fig 2: Hydrogeological cross-section, showing the three aquifer of Jos-Plateau (after and Mbonu1991).