

Heavy Metal Geochemistry of Acid Mine Drainage in Onyeama Coal Mine, Enugu, Southeastern Nigeria

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ABSTRACT

This paper is aimed at evaluating the chemistry of the Onyeama Coal Mine and Ekulu River with respect to their heavy metal content. Onyeama Coal Mine is one of Nigeria's oldest coal mines. Production activities stopped there in 1978 due to constant flooding of the mine with very acidic water. pH values range from 2.8 to 4.1. The rainy/dry season cycles affects the chemical composition of the drainage. Major elements characteristics of the AMD include high sulphates (>300mg/l) dissolved sulphides (1.4mg/l)) and high iron (between 8.4mg/l to 73.11mg/l). Chemical analysis for lead (Pb^{2+}); iron (Fe^{2+}); arsenic (As^{3+}) and cadmium (Cd^{2+}) showed that the AMD and Ekulu River are heavily polluted with respect to these heavy metals. The average value for lead (Pb^{2+}) was 278.59mg/l which is 18570 times greater than the maximum contaminant level suggested by United States Environment Protection Agency. Iron (Fe^{2+}) had an average of 25.89mg/l which is 86times greater than the maximum contaminant level. Arsenic (As^{3+})'s average value is 21.63mg/l which exceeds the stipulated limit by 2163 times while cadmium Cd^{2+} (34.14mg/l) exceeds it by 7000 times. These anomalous concentration values for heavy metals is caused or enhanced by the low pH of the waters. The v. of AMD discharged into Ekulu Rivers is much and with these elevated concentration of heavy metals, the Ekulu River will pose great health risks to those who use it for recreation or laundry.

Key words: acid – mine drainage; Onyeama coal mine; heavy metals; maximum contaminant levels.

A. INTRODUCTION:

Enugu Metropolis in 2014 had an estimated population of 915,025 people and had been the capital of Eastern Region, East Central State, Anambra State and now Enugu State. The rise of this city to great heights was probably due to discovery of coal there in 1909. This discovery by the British Colonial Government led to the development of a number of mines including Ogbete, Asata, Onyeama, Okpara, Ribadu and Iva mines. These mines constitute what is today known as the Enugu Coal Fields. The growing population of people that flocked to the city gradually formed one of the important epicenters of development in pre - colonial and post – independent Nigeria. Coal production slowed in 1950's and 1960's due to the discovery of vast reserves of crude oil in Nigeria's Niger Delta. When the Nigerian Railway Corporation stopped using coal to power their steam engines, coal production virtually come to a stop. Another factor that helped kill the exploitation of the vast coal reserves in Enugu Coal Field was the rising costs in production which resulted from the mismanagement of flooding problems in virtually all of the mines. The dewatering of the mines proved to be quite insurmountable due to epileptic power supply for powering the pumps and the costs of using generators. In addition, the price of coal fell at that time in the international markets and this sealed the fate of mines – they became abandoned.

The abandonment of the mines did not stop the problem of flooding. The mines particularly Onyeama has continued to be flooded. Mine water from Onyeama continues to discharge into the Ekulu River which criss – crosses Enugu Metropolis. Any attempt to revive the mine would first of all address the twin problems of flood control and acid mine drainage. A number of studies such as Offodile, (1975 and 2002); Egboka and Uma (1983); Ezeigbo and Ezeanyim (1993) and Salufu and Salufu (2014) have shown that the waters discharged from the mine into the Ekulu River are polluted and may pose great risks to the greater Enugu population.

Previous Work and Literature Review

Coal was discovered at Enugu in 1909. The reserves were estimated to be about 1.5 million tonnes but mining began in 1915 (Dialla, 1984). Tattam (1944) discovered that the coal deposits were not only in the Lower Coal Measures (Mamu Formation) but also in the Upper Coal Measures (Nsukka Formation). He found that both formations were lithologically similar but separated by False Bedded Sandstone (Ajali Formation). De Swardt and Casey (1963) carried out detailed mapping of the Enugu Coal field.

As mining continued, the problem of flooding came up. Offodile (1975) estimated the v. of water entering the mine to be about 90,909m^3/day. This v. of water proved to be difficult to remove from the mine. The problem of flooding was due to the fact that the mine adit was located below the water table and the presence of faults, fracture and joints facilitated the migration of water from the overlying of Ajali aquifers into the mine. Uzuakpunwa (1979) used vertical electrical sounding (VES) to map the fractures and joints in the mines. The migration of groundwater was shown to be clearly influenced by the joint/fracture/fault direction and density.

Offodile (1975) and Egboka and Uma (1985) raised the issue of Acid Mine drainage (AMD). Egboka and Uma (1985) found that the AMD had pH values of 3.7 during normal weather but 4.1 after heavy rains. The water also had high concentrations of iron and sulphate. Later studies by the same authors revealed that the major element chemistry of the AMD varied between rainy seasons and dry seasons. They checked the chemistry of Ekulu River which receives all the water coming from Onyeama Coal Mine and found that the low pH of the mine water rose significantly after emptying into the river.

Ezeigbo and Ezeanyim (1993) also carried out major element analysis of the AMD and found that the pH was 2.8 (i.e. lower than the values from Egboka and Uma (1985).

They found that the silica content of the AMD rose from 20mg/l (in 1985) to 30 mg/l in 1992. The iron concentration was 8400µg/l (or 8.4 mg/l) while the sulphate was in excess of 300mg/l. Interestingly, they also found the presence of dissolved sulphides (1.4 mg/l). This indicates the possibility of sulphate – reducing processes but they did not pursue that idea. High values of dissolved CO_2 (up to 230mg/l) was also discovered.

Ari (2006) used a different sampling design in studying the composition of the AMD. He sampled the mine water found at the main adit then midway between the mine and Ekulu River inside Ekulu River itself and a good distance far from the point where mine drainage enters the river. The main idea was to check for compositional variations with respect to distance travelled. He found that all the samples remained acidic (i.e. low pH) had excess iron but some samples had low sulphate values. This again suggested the possibility of sulphate – reduction processes. Some of the samples had excess values for iron (up to 73,113µg/l (or 73.113mg/l).

Salufu and Salufu (2014) carried out an integrated study of Onyeama Coal Mine that involved detailed geologic petrographic, geophysical and geochemical studies of the mine and its drainage. Results from their petrographic examination of the Mamu and Ajali Formations revealed the sandstone/shales of the formation have disseminated pyrite minerals in fine to medium grained forms. The coal seams occurred in association with flakes of pyrites. There is also evidence of arseno – pyrites in the rocks. Two dimensional (2D) tomography imaging confirmed that the formations at the mine were not only faulted but also provided hydraulic connectivity between Mamu and Ajali Formations thus enhancing flooding and AMD formation. Geochemical evaluation of the AMD confirmed the impact of rainy/dry seasons on its composition in terms of low pH (between 3.2 to 3.6), high concentrations of iron 16.200mg/l to 18.400mg/l, dissolved sulphides and dissolved oxygen. The waters also had high carbonate (CO_3^{2-}) concentrations (between 210 to 280mg/l). They discovered that the water had high concentration of dissolved acidic oxides i.e. silica (between 30 – 40 mg/l) but low values for basic oxides which proved that AMD was actually forming at Onyeama Coal Mine.

Purpose of the present investigation

Acid Mine Drainage (AMD) is one of the most serious challenges facing the coal mining industry worldwide. Hounslow (1995) and Saria et al., (2006) agree that AMD with low pH values (<4) usually enhance the dissolution of heavy metals and silica in the water. From the previous work and literature review, it is clear that no attempt has ever been made to find out the heavy metal concentration of the AMD in Onyeama Coal Mine (OCM). The aim of this paper is to determine levels of heavy metals in the drainage and characterize them.

B. THE STUDY AREA

i. Mining activities

Onyeama Coal Mine is part of a slighter larger study area enclosed within the latitudes $6^0 29^I$ and $6^0 34^I$ N and longitudes $7^0 30^I$ E (see Figures 1 and 2) but the mine itself is part of the Enugu Coal Field and of the catchment area of the Ekulu River. The mine is located about 6.5km northwest of Enugu Metropolis in Enugu State southeastern Nigeria. (See figures1 and 2). In the coal field, it is flanked on its northeastern side by Ribadu Mine while Iva Mine is located south of it. Onyeama Coal Mine (OCM) is an underground mine that exploits sub – bituminous coal from the coal seams 2, 3, 4 of the Mamu Formation. There are a number of adits that facilitate the removal of coal from the mine but the main adit of the tunnel is about 165m long and taps the coal seams located at the base of Enugu escarpment. A few other adits branch out in different directions from the main adit.

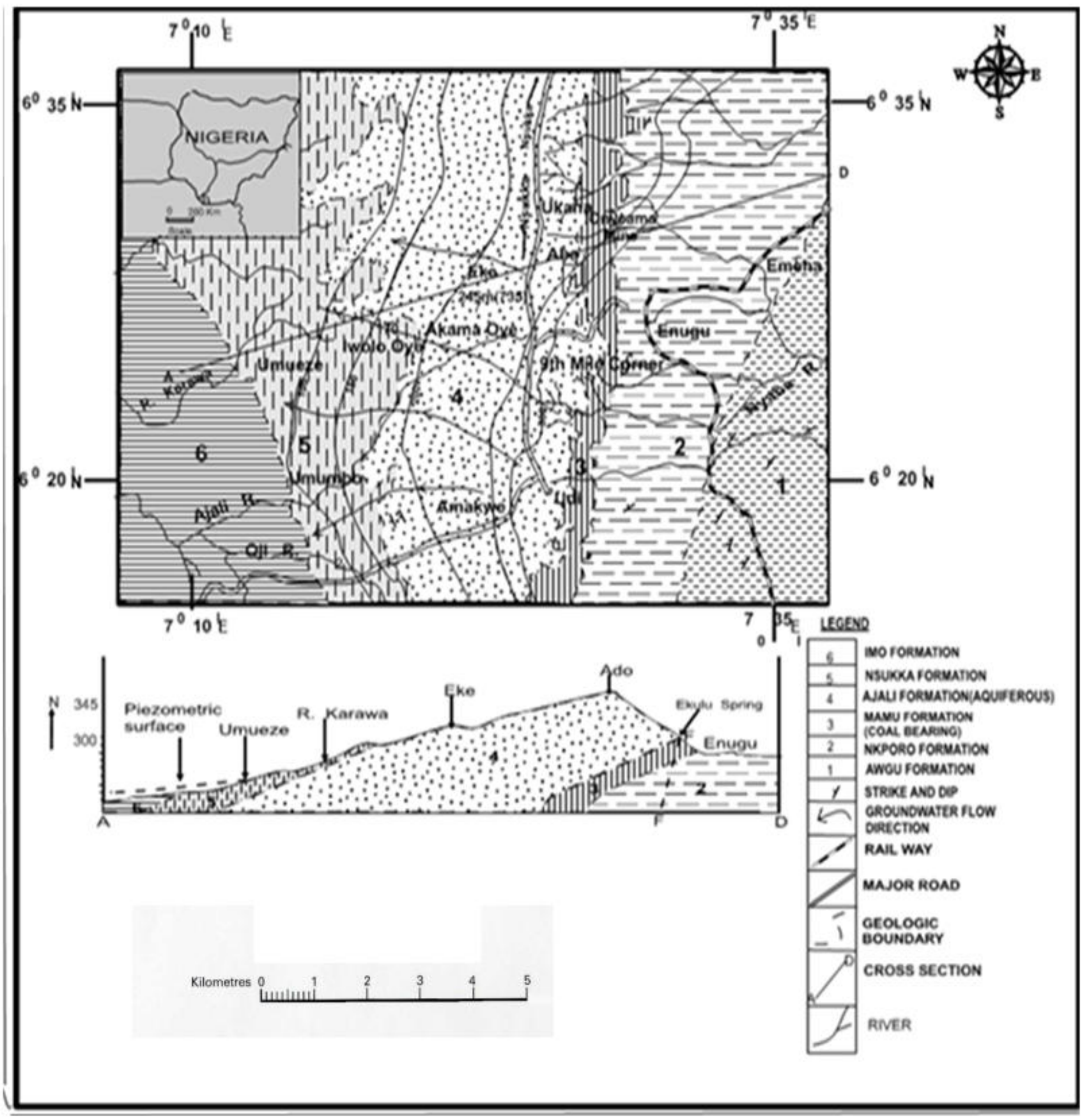

Figure1: Geologic map of the Enugu Coal Fields showing Onyeama Coal Mine (after Ofodile,2002).

ii. Relief and Drainage

The Onyeama Coal Mine (OCM) basically exploits Coal Seams 2, 3, and 4 which are located at the base of the Enugu Escarpment.The area around the OCM and other mines is dominated by N- S trending Escarpment with the cuesta face. The cuesta separates the Anambra basin from the Cross River Plains (Ofomata, 1973). Slope failures, landslides and heavy gullying are frequent on the scarp face of the escarpment (Egboka et al., 1989). Drainage in the area is dendritic and besides, Ekulu River which drains the OCM, there are a few other rivers like River Nyaba which occur further south of the area (see figure 2).

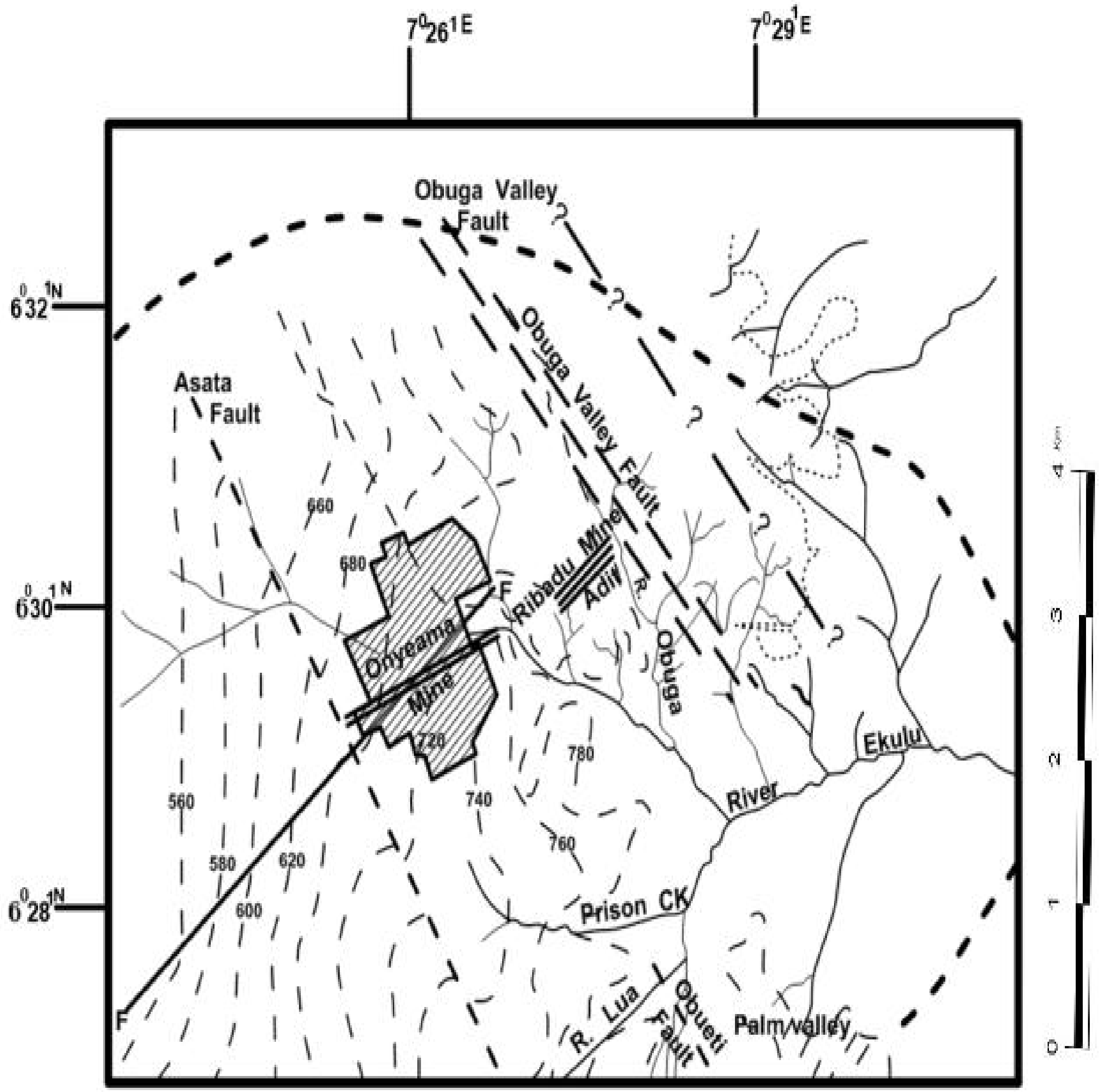

Figure2: Physiography of the Enugu Coal fields showing the location of Onyeama Coal Mine(after Offodile, 2002)

iii. Climate

Onyeama Coal Mine is located in the eastern part of Nigeria which has a typical rain forest climate. Onyemaobi (2012) reports an average annual precipitation of 1895mm and total evaporation of around 724mm/year. The rains are usually heavy during the rainy season which lasts from March to October. The heavy rains precipitate flows which affect the mine and the rivers/streams around it. During the rainy season, the mine is noticeably flooded.

iv. Geology and Geohydrologic setting

The main geologic formations specific to the Onyeama Coal Mine (OCM) itself are Mamu Formation and Ajali Formation (see Figure 1). Mamu Formation (Lower Maastritchian) comprises an alternating sequence of sandstones, siltstones, shales, mudstones and coal seams. All the coal seams tapped by Onyeama Coal Mine (Seams 2, 3 and 4) are from Mamu Formation. The coal seams range from 0.1 to 0.8m in thickness. Salufu and Salufu (2014) reported that the coal occurs in association with pyrite flakes.

Mamu Formation is conformably overlain by Ajali Formation (upper Maastritchian) which consists of over 400m of medium to coarse grained sandstones and sandy clays. Mamu Formation and Ajali Formation both dip between $3^0 – 5^0$ west and southwest. Offodile (1975) reports higher dip amounts up to 25^0 but this is probably due to faulting processes. Ajali Formation is a prolific aquifer that is unconfined at the Onyeama Mine area but confined in areas west of Enugu. Agbo and Onuoha (1989) determined the average value of hydraulic conductivity in the mine area to range from 6.95×10^{-5} to 2.6×10^{-3}m/s while Offodile (2002) determined the average value of specific capacity to be $161.2m^2$/day in the areas where it is confined.

v. Structural controls on groundwater flow

Onyeama Coal Mine is flanked by Asata fault and Obuga (Obwetti) valley faults. The two subsurface faults trend $N30^0$ W and $N40^0$ W respectively. Uzuakpunwa (1979) found that the structure of theses faults actually defined groundwater circulation patterns within the mine. He observed a fault trending NNW- SSE with a throw of about 20m at Onyeama Mine.

Another factor controlling the flow of groundwater into the mine is the position of the mine adit with respect to the rivers and Ajali Formation. The work of Offodile (2002) shows that the flood problem in the mine is also due to the fact that the mine is located below the water table. (See figures 3).

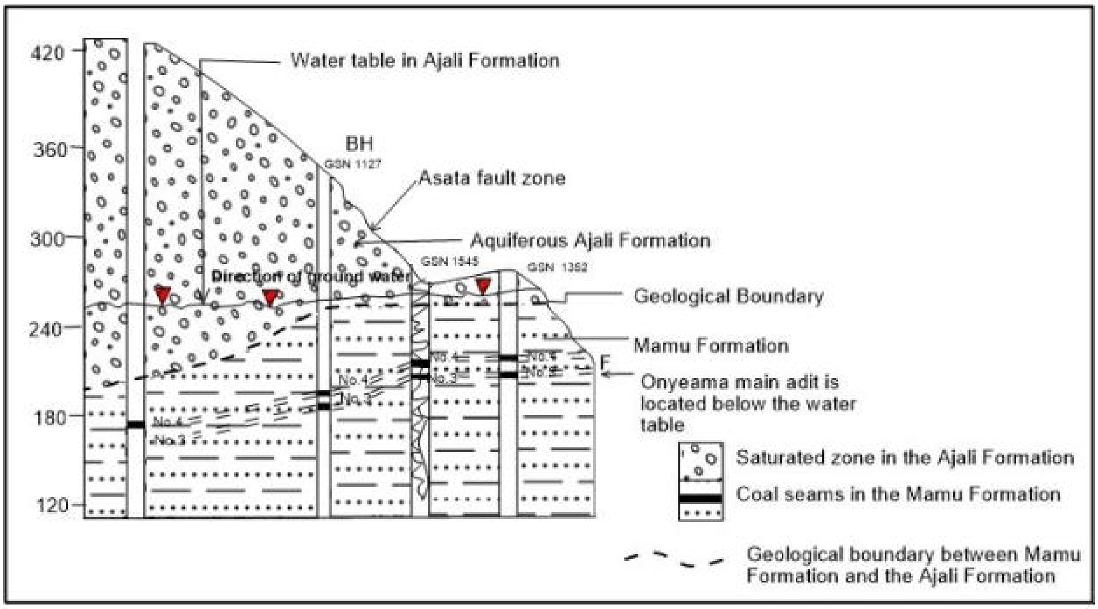

Figure 3: The major cause of the mine flooding: location of the Onyeama main adit below the water table (after Offodile, 2002)

C. Methodology:

The approach taken was to evaluate all published and unpublished works on the acid mine drainage of Onyeama Coal Mine in order to obtain baseline information on the mine. The second stage was to use the major element chemistry from published and unpublished works to define the possible processes going in the mines. The final stage was to sample the mine water for their heavy metal content. Sampling design took into the consideration locations before groundwater enters the mine adit and after it leaves. Samples for heavy metal analysis were collected in new 500ml plastic containers. Only containers that had been pre-cleaned were used for the sample collection. The sample were then taken to the laboratory and analysed by cold vapour AAS methods. The unit of measurement was milligrams per litre.

D. Heavy Metal Geochemistry

The results from the chemical analysis for heavy metals in the AMD of the coal mine is given by table 1. The heavy metals chosen for analysis include lead, iron, arsenic and cadmium because previous petrographic studies showed that iron/lead sulphide minerals were present in the aquifers. The pyrites are known to be occurring in association with arseno – pyrites.

Table 1: Heavy Metal Concentration for AMD from Onyeama Coal Mines (mg/l)

s/n	Parameters	Sample 1 (Mine Adit) mg/l	Sample 2 (Groundwater before Mine Adit) mg/l	Sample 3 (Mine water of Proda) mg/l	Sample 4 (R. Ekulu at New Market Flyover) mg/l	Sample 5 (R. Ekulu at Trans Ekulu) mg/l
1	Lead, Pb^{2+}	309.636	300.324	360.854	290.140	141.001
2	Iron, Fe^{2+}	73.113	3.528	18.396	18.112	16.311
3	Arsenic, As^{3+}	39.568	9.892	19.784	19.114	19.790
4	Cadmium, Cd^{2+}	111.000	11.442	17.736	21.080	14.455

The result from table above indicates very anomalous concentrations of heavy metals in the AMD of the Onyeama Coal Mine. Lead (Pb^{2+}) concentration varies from 141.001mg/l in R. Ekulu (far from the mine Adit) to 360.854mg/l (Mine water around Proda, Enugu). The value for iron ranges from 3.528mg/l at R. Ekulu before the main Mine Adit to 73.113mg/l at the major adit. Arsenic (As) ranges from 9.892mg/l before the water enters the adit to 39.568mg/l at the main adit. Cadmium, Cd^{2+} varies from 11.442mg/l to 111.000mg/l at the main adit. Table 2 compares the concentration of heavy metals in the AMD with U.S.E.P.A. and W.H.O standards.

Table 2: Comparison of Heavy Metal concentration levels with W.H.O. (2006) and U.S.E.P.A (2010) standards.

s/n	Parameter	W.H.O. standards (2006) mg/l	U.S.E.P.A. standards (2010) mg/l	Average concentration for all samples mg/l	Number of times by which parameter exceeded U.S.E.P.A.
1	Lead, Pb^{2+}	0.01	0.015	278.59	18,570
2	Iron, Fe^{total}	No guildeline	0.3	25.89	86
3	Arsenic, As^{3+}	0.01	0.01	21.63	2163
4	Cadmium, Cd^{2+}	0.003	0.005	34.14	7000

* W.H.O. = World Health Organisation ** U.S.E.P.A. = United States Environment Protection Agency

The average value for lead is 278.59mg/l and it exceeds the recommended maximum contaminant level (MCL) by 18570 times according to U.S.E.P.A. (2010) standards. Iron has the average value of 25.89mg/l which is 86 times greater than the maximum contaminant level. The average value for arsenic (21.67mg/l) exceeds the allowed level by 2163 times. Cadmium (Cd^{2+}) values (35.14mg/l) exceeds the allowed level by more than 7000 times.

E. Discussion

From the review of the geology and hydrogeological information of the Onyeama Coal mine there has been problematic issues in this mine. The flooding is as a result of two factors. First, the mine adits are located below the water table hence making it easy for groundwater from overlying the Ajali Formation to flow into the adit. Again, the extensive jointing, faulting and fractures in the area control or influence the migration of water into the mine. The problem of AMD formation has been fairly well documented. From the records, it is clear that rainy season runoff contribute to the AMD composition. An evaluation of major element chemistry showed that possible reactions or process controlling drainage composition includes redox processes like sulphate reduction and dissolution of metallic sulphides and arseno pyrite. Most of the records suggest that groundwater remains fairly potable before entering the mine but results from table 1 indicate that there is some level of mixing of the AMD with Ekulu River water which explains why the anomalous concentrations of heavy metals occur both in the AMD and River water. Offodile (2002) suggests that the mechanism for the promotion of AMD formation is influenced by rising groundwater temperatures where the Ajali aquifer is confined. Temperature of $30^0 – 40^0$c are known in some of the boreholes.

Offodile also stated that the chemical composition of the AMD becomes increasingly acidic as the groundwater flows closer to Mamu Formation. He suggested that higher pH levels (i.e. less acidic conditions) occur in areas where groundwater flows through sandstones alone.

The analysis for heavy metals in the AMD has shown that low pH enhances the dissolution or leaching of heavy metals into the water. Anomalous concentrations of heavy metals like lead, iron, arsenic and cadmium are being discharged into Ekulu River daily from the mine. Table 2 shows that the concentration of these 4 (four) metals exceed the maximum containment levels provided by W.H.O. (2006) and U.S.E.P.A. (2010). Once lead is discharged into surface water, it is adsorbed to minerals and organic matter in soils and sediments of the river (Sauve et al., 1997). Human exposure to lead may be through skin contact with lead – bearing water. Lead can also be taken up by plants and thus affect plant/animal ecosystems. Excess lead in the human body can negatively impact red blood cells according to Popcock et al., (1983).

U.S.E.P.A. set a limit of 0.3mg/l for iron but the average values in the area is 25.89 mg/l. this is not good for laundry. Unfortunately Ekulu River is used by many residents of Trans Ekulu/Abapka sections of Enugu for laundry.

ASTRD (2007) states that excess arsenic in water can damage human intestines, stomach and nerves. Since the Ekulu River is constantly used by members of the public for laundry and recreational activities, the people are being exposed to the arsenic via skin contact with the river water. The same ASTRD report shows that direct skin contact with arsenic bearing water may cause redness, swelling, fatigue, ulceration of the skin and sensory problems.

The maximum contaminant level (MCL) for Cadmium is 0.005mg/l according to U.S.E.P.A. The average value for the AMD/Ekulu River water is 35.14mg/l. Exposure to excess cadmium can lead to stomach problems, vomiting, diarrhoea and death.

The final fate of these heavy metals in the Enugu environment is yet to be fully assessed. The greatest danger is that some of them like Cadmium has a very long life and will take years to build up in the human body. Moreover, lead can be quite persistent in the environment. More work is needed to actually determine the fate of these heavy metals in the environment.

F. Conclusion:

The geology and hydrogeology of Onyeama Coal Mine has provided key insights into the twin problems of flooding and acid mine drainage in the mine. Major element chemistry helped to provide baseline information on the geochemical processes that determine AMD composition while heavy metal chemistry showed that anomalously high concentrations of lead, Iron, arsenic and cadmium are being continuously discharged into the Ekulu River thereby putting the residents at Enugu Metropolis at great risk. It is therefore suggested that a proper mine abandonment plan (M.A.P) be initiated to help mitigate the effects of this situation. Aggressive steps also need to be put in place to restore the Ekulu River.

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