INTEGRATED STUDY OF ACID MINE DRAINAGE AND ITS ENVIRONMENTAL EFFECTS ON ONYEAMA MINE AND ENVIRONS, ENUGU, NIGERIA

Salufu Samuel O.
Department of Geophysics,
Ambrose Alli University,
Ekpoma, Edo, Nigeria
(just4samuel@gmail.com

Salufu Emmanuel O.
Department of Geology,
University of Ibadan, Ibadan,
Oyo State, Nigeria
emmanuelreal.salufu@gmail.com

***Abstract*—Integrated study of Onyeama mine was done, by carrying out detailed geologic study, petrographic study, geophysical study (2D resistivity tomography imaging), and hydrogeochemical analysis of six samples collected from the underground mine, surface mine, and Ekulu River during dry season and rainy season, in order to identify occurrence of acid mine drainage (AMD) in Onyeama mine, to know the causal factor(s) of AMD in the mine, and its environmental effects on the ecosystem around Onyeama mine and its environs.**

The result of detailed geologic study shows that three major formations (Ajali Sandstone, Mamu Formation, and Enugu Shale) underlay Onyeama mine. The formations are faulted (Normal fault). Mamu Formation contains coal seams and the sandstone beds that make contact with the coal seams have flakes of pyrite mineral. The petrographic study shows that the sandstones have disseminated pyrite mineral that occurs in fine-medium grain forms. The result of 2D resistivity tomography imaging shows that the formations are faulted, and the fault connects the aquiferous units of Mamu Formation and Ajali Sandstone to the coal seams within the Mamu. Thus, enhancing oxidation of disseminated pyrite within the sandstone beds to form AMD.

Hydrogeochemical analysis result shows that there is seasonal variation in concentration of chemical parameters in three collection points. In the dry season, underground mine has the highest concentration of sulfide ranging from 1.47-1.5mg/l while rainy season concentration ranges from 1.3-1.39mg/l. The acidic metal (Si) has the higher concentration (30.1-40.01mg/l) compare to basic metal (Na, Ca, Mg) concentration (0.31-5.71mg/l), and the ph values from the three point are less than 3.6 and the TDS values are very high (314-400 mg/l). The result of integrated study shows that there is occurrence of AMD in Onyeama mine, and the AMD has polluted the surface water, groundwater, and severely affected the ecosystem of the area.

***Keywords*—Onyeama mine, AMD, 2D resistivity tomography imaging, coal seam**

I. INTRODUCTION

Acid mine drainage (AMD) is a metallic rich water from chemical reaction between water and rocks bearing sulfide minerals such as pyrite, sphalerite, marcasite, galena, chalcopyrite etc. AMD normally forms when sulfide minerals are exposed to oxidizing condition in coal and metal mining, and large scale excavations. When it's exposed to water and oxygen, sulfide minerals oxidize to form acidic sulfate rich drainage. Finkelman [1] and Lapakko [2] observed that formation of AMD and the contaminants associated with it contribute the largest environmental problem.

In 1909, British geologists discovered coal deposits in Enugu [3]. The deposits is estimated as 1.5million tons [4]. Mining commenced in 1915 [3]. However, the discovery of crude oil in the middle fifty's led to abandonment of coal exploration. Onyeama mine comprises both surface and underground mines. The abandonment of explortation activities for long led to floading of the mines by groundwater and surface water.

Offodile (1980) estimated the groundwater flow to be about 90,000M^{3}dy-^{1} which is as indication of a good yielding aquifer. Ezeigbo and Ezenyin [6] observed high sulfate content, and low Ph value in the mine water from the hydrogeochemical studies of water samples in the mines.

However, this present work is aimed at using integrated approach that is, integrating geologic, petrologic, hydrogeochemical, and geophysical data, to study the occurrence of AMD in onyeama, in order to identify the causal factor(s) of AMD generation in Onyeama mine, and its environmental effects on the ecosystem around Onyeama and its environs, and to proffer ways/way of remediating its.

Local Physiography and Hydrology

Onyeama mine is located in Enugu, South Eastern Nigeria. It is bounded by Latitudes 6^{0}25'N and 6^0.29'N, and Longitudes 7^{0}25'E and 7^{0}30'E. The study area is characterized by hills and lowlands. The hilly parts are underlain by Mamu Formation and Ajali SandStone while the lowlands are underlain by Enugu Shale (Figure 1). The area is drained by minor streams and River Ekulu toward the Northern Part (Figure 2). Far from the mine in the southern part of the mine is drained by Asata River (Figure 2)

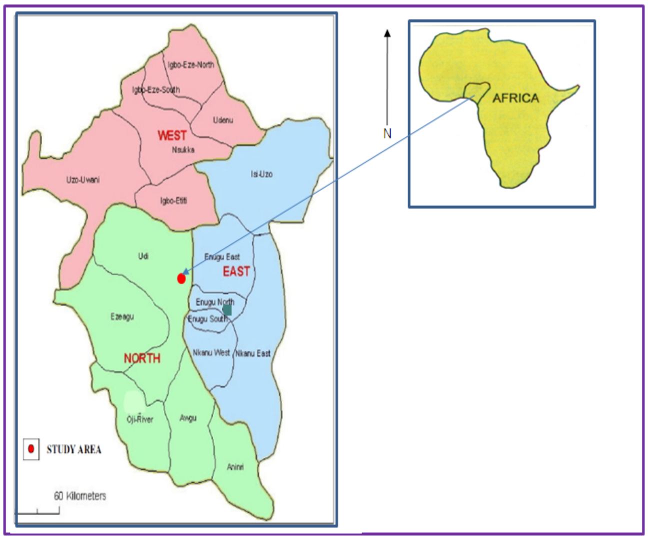

Fig.1: Map showing the study area

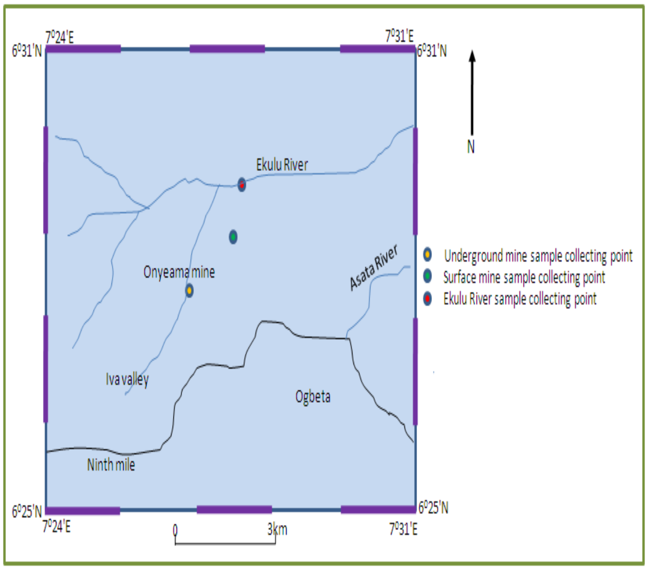

Fig. 2: Drainage and accessibility map of the study area

II. MATERIAL AND METHODS

Integrated study (Geologic study, geophysical study, hydrogeochemical study, and petrologic study) was adopted to study the area. Detailed geologic study was done in order to understand the geology of the area in details. 2D electrical resistivity tomography imaging was done in order to have clear picture of the subsurface geology and hydrogeology of Onyeama mine. The 2D resistivity survey was done using dipole-dipole array with electrode spacing, a =5m and data level, n from 1 to 4, along two transverses in the mine, using SAS 4000. Utility software was used to retrieve data acquired from the memory of SAS 4000. Similarly, Utility software was used to convert the data to Res 2D inverse format. Smoothness constrained inversion method was used after the method of deGroot-Hedlin and Constable [7] to carry out the inversion, base on the following mathematical model:

$$(J^T J + \mathcal{U}\mathcal{F})d = J^T g \quad (1)$$

$$\mathcal{F} = \mathbb{f}_x \mathbb{f}_x T + \mathbb{f}_z \mathbb{f}_z T \quad (2)$$

where

$\mathbb{f}_x = horizontal\ flatness\ filter$

$\mathcal{F} = vertical\ flatness\ filter$

$\mathcal{U} = damping\ factor$

$\mathrm{d} = \mathrm{model\ perturbation\ vector}$

$g = discrepancy\ vector$

Hydrogeochemical analysis was done on three water samples from surface mine, underground mine, and Ekulu River in dry and rainy season respectively in order to determine drainage water qualities and seasonal variation in hydrogeochemical parameters. Petrographic study was done on two samples of sandstone beds directly below and above the coal seam in Mamu Formation in order to have clear understanding about the mineralogy composition of rocks in the mine. Static test was finally conducted in order to determine acid generation potential of the coal seams in Onyeama. Static test parameters were computed using the following formula:

AP = 31.25*%S (3)

NNP or AB = NP-AP (4)

Similarly, eq (4) can be computed as:

$$\frac{NNP}{AB} = \frac{NP}{AP} \quad (5)$$

where

AP = Acid Production

NNP = NON-acid Production

%S = Total % of Sulfide

AB = Acid base account

III.RESULTS PRESENTATION

Result of Geologic and Petrographic studies

Geologic study of Onyeama mine reveals the local geology of the area to have comprised three formations: Ajali Sandstone, Mamu Formation, and Enugu Shale (Figure 3) Enugu Shale is the oldest; it is exposed at the extreme eastern part of the area. It is generally fissile grey shale, dipping in direction of 250^0 SW, strike in 150^0ES-330^0NW direction, with dip amount of 7^0. The total thickness of the outcrop is estimated as 48m. It is faulted (Normal Fault) (Fig. 4a). It graded upward to Mamu Formation. It is characterized by four major lithology units; shale, sandstone, coal, and siltstone. The sandstone is fine to medium grained and moderately to weakly consolidated. The coal is generally black (Fig. 4b), comprising three thin coal seams that varies in thickness from 0.1m-0.9m. They are intercalated by fine sandstone and shale beds. There are flakes of pyrite mineral (Fig. 4c) within the grains of sandstone beds that make contact with the coal seams. Ajali Sandstone overlies Mamu Formation. It is well exposed in the western part of the study area (Fig. 3). Ajali Sandstone is whitish to faint brown with patches of iron stains, highly friable, clayey poorly sorted coarse grained sandstone, and characterized by pronounced herring-bone cross bed (Fig. 4d).

The three formations are faulted. The fault is a normal fault with other associated fractures. The fault is obvious towards the western and eastern parts of Onyeama mine that is the fault is easily seen across Ajali Sandstone (Fig. 4a) in the western part of the study area and in the eastern part across Enugu shale (Fig. 4e). However, it is not easily identify as fault within Mamu Formation rather as fracture most often within the coal seam (Fig. 4f) the fault and fractures are localized fault, probable caused by the underground mining in the area resulting from pressure being exerted by overburden pressure within Ajali Sandstone and upper portion of Mamu Formation on the over stressed tunnel wall of the lower excavated portion of Mamu Formation where underground coal mining activities took place, this caused brittle deformation/failure. This also affected most of the houses in the area. The houses have fractures cutting across them.

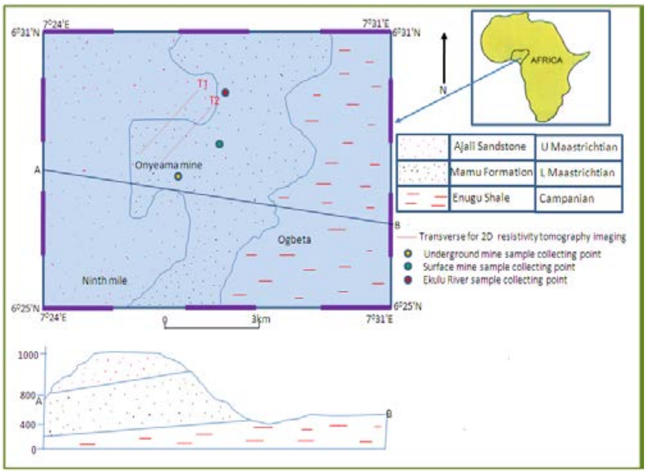

Fig. 3: Geologic map of the study area

The result of the petographic study of sandstone beds directly overlain and underlain the coal seams in Onyeama mine shows that the sandstone are fine-medium grained (Fig 5a) that is dominated by frame work element, monocrystaline rounded to sub round quartz (Fig. 5b) of about 65% of floating in a brownish red iron oxide cement (Figure 5c). The quartz grains make tangential to suture contact (Fig. 5d) with one another and, with the feldspar grains.

The feldspar is about 1.5%. There are disseminations of grains of pyrite (Fig. 5e) minerals within the suture and tangential points of contact made by the frame work elements and rock fragments. The pyrite mineral occurs as grains but not in crystal form, and the grains are about 0.7% of the slide.

Fig. 4: (a) Normal fault cutting across Ajali Sandstone in Onyeama mine, (b) Coal seam within Mamu in Onyeama mine, (c) Flake of pyrite mineral within the sandstone beds adjacent to the coal seam in Mamu, (d) Herring-bone cross bed in Ajali Sandstone at Onyeama mine, (e) Normal fault cutting across Enugu Shale in Onyeama mine, (f) Fractured coal seam in Mamu Formation, (g) Drainage of AMD from underground mine in Onyeama mine, (h) Drainage of mine water from surface mine in Onyeama mine, (i) Ekulu River passing thorough Onyeama mine

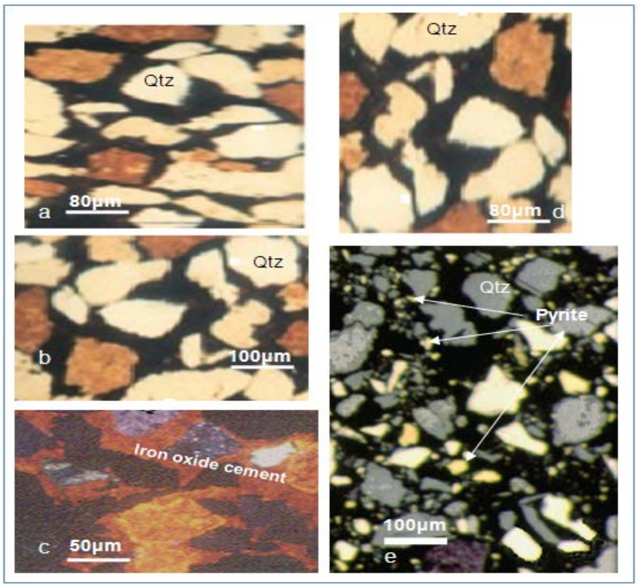

Fig. 5: (a) Fine-medium grained sandstone, (b) Rounded to sub-rounded quartz, (c) Iron oxide cement, (d) Suture-tangential point contact, (e) Disseminated pyrite grain

Result of Geophysical Study

The result of 2D electrical resistivity tomography imaging shows that the formations that under lay the study area have been faulted (Fig. 6 and 7). The fault is a normal fault. Ajali Sandstone is the hanging wall while Mamu Formation is the foothwall(Fig. 6 and 7). The fault cuts across the aquiferous layer in Ajali Sandstone and Mamu Formation, through the coal seams and other lithology within the Mamu Formation. The 2D resistivity imaging shows clearly significant large volume of water situation in the aguiferous units of Ajali Sandstone (Fig. 6), and two thin coal seams were identified (Fig. 6). They vary from 0.2m-0.7m and they are traceable to the three coal seams exposed in the outcrop section within the portion of the mine, close to surface mine.

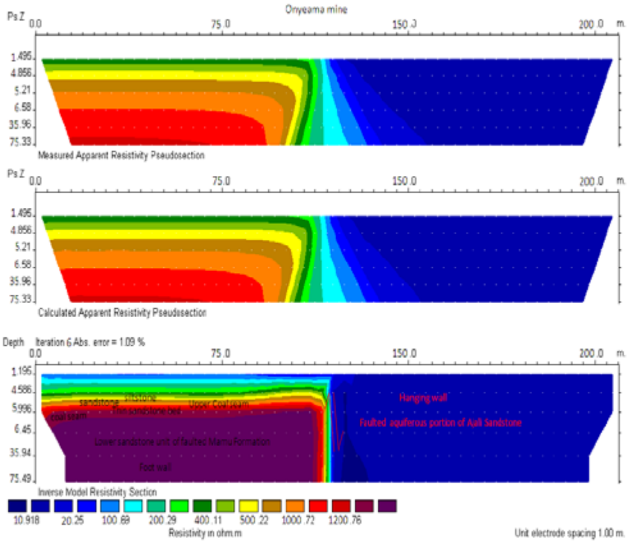

Fig. 6: 2D electrical resistivity tomography imaging along transverse 1, showing faulted Mamu Formation and aquiferous unit of Ajali Sandstone in Onyeama mine

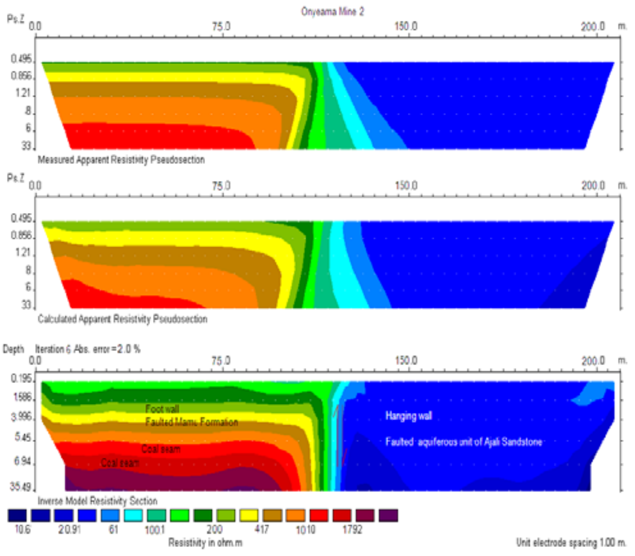

Fig. 7: 2D electrical resistivity tomography imaging along transverse 2, showing faulted Mamu Formation and aquiferous unit of Ajali Sandstone in Onyeama mine

Results of Hydrogeochemical Analysis and Static Test

The results of six water samples from the hydrogeochemical analysis of samples from underground mine, surface mine, and Ekulu River; two samples each from the three collecting points respectively; and one sample each from dry and rainy season, show that sulfide ranges from 1.47-1.5mg/l in dry season with the underground mining collecting point having the highest concentration and ranges from 1.3-1.39mg/l in rainy season (Table1). The concentration values of basic oxides (Mg, Ca, Na, and K) are very low, ranging from 0.31-5.71mg/l while that of acidic metal (Si) is very high, ranging from 30.1-40.01mg/l. TDS (Total dissolved solid) is high across the two seasons (314-400.1mg/l) in the three collecting points. Ph values range from 3.1-3.6 but generally low in dry season (Table1).

The static test result shows that AP at underground mine, surface mine, and Ekulu River in dry season are 46.88, 46.57, and 45.94mg/l respectively and in rainy season 40.46, 40.74mg/l respectively and rainy season 40.46, 40.74, and 43.44 mg/l respectively (Table 2).

NNP values for the two seasons in the underground mine, surface mine, and Ekulu River are generally negative, ranging from -17.44mg/l to -26.88mg/l (Table 2). The result of calcium ratio to addition of calcium and sulfate [$Ca^{2+}/(Ca^{2+}+SO4^{-2})$] across the two seasons for the three samples collecting points ranges from 0.015 to 0.017 (Table 2)

Table 1: Hydrogeochemical analysis result of underground mine, surface mine, and Ekulu River water samples for dry and rainy seasons in Onyeama mine.

Parameters	Dry season			Rainy season		
	UM	**SM**	**ER**	**UM**	**SM**	**ER**
Potassium (mg/l)	2.51	2.52	2.41	1.4	2	1.31
Silicate (mg/l)	32	33	35.2	34.2	40.01	30.1
Nitrate (mg/l)	1.01	1	1.1	2.9	1	1.4
Sulphide (mg/l)	1.5	1.49	1.47	1.3	1.31	1.39
Total iron (mg/l)	16.2	16.01	14.5	18.4	7.91	10.11
Sodium (mg/l)	5.2	5.2	5.3	5.15	4.9	5.01
Magnesium (mg/l)	1.28	1.29	1.78	0.52	0.12	0.31
Calcium (mg/l)	3.9	3.85	3.78	4.6	4.9	4.91
Chloride (mg/l)	11.21	11.19	10.91	13.21	10.2	11.1
Ph	3.1	3.2	3.5	3.4	3.4	3.6
Colour (units)	12	12.1	11.1	80	11	11.2
Total alkanity	20	21	22	27	21	26
Acidity	160	159	155	151	150	149
Bicarbonate	18	17.9	17.5	16	16.0	17.1
TDS	315	314	316	400	360	314
Free carbonate (mg/l)	210	210	211	280	215	220
Sulfate (mg/l)	320	321	319	330	320	315
E. conductivity (mhoms/cm)	600	559	550	520	540	530
Total hardness	99.5	99.4	100	100	98	97
Dissolved oxygen	0.18	0.18	0.2	0.21	0.19	0.17
Chemical oxygen	0.41	0.42	0.46	0.51	0.57	0.56
Biochemical oxygen	3.82	3.81	3.91	3.21	3.56	3.52

UM-Underground mine, SM-Surface mine, ER-Ekulu River

Table 2:Result of static test of water samples from underground mine, surface mine, and Ekulu River for dry and rainy seasons in Onyeama mine.

	Dry season			Rainy season		
	UM	**SM**	**ER**	**UM**	**SM**	**ER**
AP(mg/l)	46.88	46.57	45.94	40.63	40.94	43.44
NP(mg/l)	20	21	22	27	21	26
NNP(mg/l)	-26.88	-25.57	-23.94	-13.63	-1994	-17.44
$[Ca^{2+}/(Ca^{2+}+S04^{-2})]$	0.016	0.0157	0.016	0.017	0.0151	0.0154

AP-Acid production, NNP-Non-acid production, NP-Neutralization potential

IV.DISCUSSION

The results of hydrogeochemical analysis shows that acidic oxides (Silicates) are very high (30.1-40.01mg/l) compare to basic oxides (Ca^{2+}, Mg^{2+} , and K^{+}) that are very low (0.31-5.71mg/l). This result gives evidence of AMD generation in Onyeama mine similarly, high sulfide concentration, ranging from 1.3-1.5mg/l (Table 1), and low Ph less than 3.6 (Table 1) suggest strong evidence of acid mine drainage occurrence in Onyeama mine. The values of calcium ratio to addition of calcium and sulfide $[Ca^{2+}/(Ca^{2+}+S04^{-2})]$ in the two mines and Ekulu River are less than 0.1 (Table 2).These values buttress the fact that there is AMD generation in Onyeama mine as observed from the mine water that drains from underground mine (Fig. 4g) and surface mine (Fig. 4h) into the Ekulu River (Fig. 4i).

The normal fault identified by the geological and geophysical studies of Onyeama mine is a local fault that must been induced or originated by mine activities thus, caused local failure of the underlying rocks in the mine which resulted to localized normal fault (Fig. 4a, 4e, 6 and 7).

The 2D resistively tomography imaging shows clearly that the local fault connect the aquiferous unit of Ajali Sandstone above and aquiferous unit of Mamu Formation below to the coal seams consequently, causing influx of large volume of water into the coal seams. Thus, giving room for water contact with the flakes of pyrite mineral and pyrite grain within the sandstones bed that are in contact with the coal seams as revealed by geologic and petrographic studies. The water contact with pyrite causes dissolved oxygen to oxidize the iron content in pyrite. The oxidation of pyrite is being enhanced by the mode of it occurrence form (fine-medium grain form not crystal form) which favours large surface area exposure to react with water influx from the two aquifers and with the dissolved oxygen. Low basic oxides concentration (Table 1) in the mine and negative values of NNP (Table 2) suggest that there is no equivalent proportion of base or carbonate to neutralize the AMD generation minerals thus causing the fluid in the mine to have a very low Ph value of less than 3.6 and high TDS (Table 1).

The degree//rate of acid generation at Onyeama mine varies with season as shown by hydrogeo chemical result (Table 1). The concentration of AMD tends to be more in dry season than rainy season. This observation from the hydrogeochemical analysis of water samples from the mine gives strong evidence of seasonal variation in concentration of basic oxides, acidic oxides, TDS/ and Ph.

The above observations give clear evidence of pollution of Ekulu River, Streams and soil in Onyeama mine, and its environs, by the AMD that is being generated from the mine. No wonder, there is no aquatic organism in the Ekulu River as observed during hydrologic study of the area. The AMD that flows directly from both underground and surface mine (Fig. 4g-h) into the Ekulu River (Fig. 4i) makes the aquatic habitat unconducive for aquatic animals to thrive, thus make Ekulu River devoid of aquatic organism.

Similarly, the observations from this study show that both the underground water and surface water have been polluted by the AMD generation. This deprives people living close to be mine from having access to portable water thus, exposes them to all kind of health related diseases that are associated with consumption of polluted/and unhygienic water. The AMD generation in Onyeama will as well expose plants in the area to high heavy metal and iron content which in turn can be harmful to the consumers of such plants.

V.CONCLUSION

In conclusion, the geologic setting, hydrogeologic setting, structural setting and man-made factors (mining activities and abandonment of the mine activities) are the factors responsible for AMD generation in Onyeama mine. Subsequently, the generation of AMD in Onyeama mine caused the environmental problems that are associated with the area.

However, the environmental problems induced by AMD generation in Onyeama mine can be remediated/controlled by: (i) Active treatment of mine water, using appropriate proportion of lime that can neutralize the amount of acid produced in the mine before the mine water is allowed to drain into Ekulu River, (ii) and by backfilling the surface mine working, using mixture of earth material that are geotechnically stable and geochemically non-reactive.

REFERENCES

[1] Finkelman, R.B (1987). “A Rapid Procedure for Determining Pyritic Sulfur in Coal”. Journal of coal quality 50-52

[2] Lapakko, K. (1993). “Predictive Testing for Mine Waste Drainage Quality”. In Mine Operational and Closure Short Course sponsored by EPA and others. April 27-29, Helena, MT.

[3] Egboka, B.C.E. and Uma, O.K. (1986). "Acid Mine Drainage Problems in Enugu Coal Mines of Anambra State, Nigeria". IMWA proceedings 1985 International Mine Association.

[4] Dialla, H.N. (1984). "A Review of Some of the Future Problems and Possible Solutions Facing the Nigeria Coal Industry". Paper Presented at the 20th Annual Conference, Nigeria Mining and Geosciences at the University of Nigeria, Nsukka, Nigeria.

[5] Offodile, M.E. (1980). "A Mineral Survey of the Cretaceous of Benue Valley, Nigeria". Cretateous Res. 1, 101 124

[6] Ezeigbo, H.I and Ezeanyim B.N. (1993). "Environmental Pollution from Coal Minin in Activities Enugu Area, Anambra State Nigeria". Mine Water and Environment 12,53 62

[7] deGroot-Hedium, C and Constable, S. (1990). "Occans Inversion to Generate Smooth, Two Dimensional Models from Magnetotelluric Data". Geophysics 55(12), 1613-1624