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Review

An appraisal of the water related contaminants as they affect the environment around the Enugu coal mines of Enugu state, southeastern Nigeria

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Enugu metropolis is within the Anambra basin, which comprises mainly sedimentary rocks of sandstone, siltstone, mudstone and shales in the Lower Benue trough and as the capital of Enugu state in Nigeria and also as one of the major municipal and industrial centers in southeastern Nigeria experiences much groundwater contamination due to coal mining activity. The Area is richly endowed with sub-bituminous three-coal seams within the Mamu Formation. It also lacks prolific and potable groundwater due to the thinning-out of the Ajali sandstone aquifer through Udi town and Ninth-mile into Enugu metropolis. Generally, the specific discharge of Ajali sandstone (17.5 m^2/day) is higher than that of Mamu Formation (14.5 m^2/day). This appraisal becomes necessary to acquaint the Enugu city developers on the need for the prediction and understanding of the Environmental Impact Assessment (EIA) on the future development, management and maintenance of the mine water. The study also aims at identifying various contaminants, sources, level of concentrations, effects and control measures. Many springs, streams and seepages exist on the foot of most of the hills and ridges. The springs form the headwaters of the major streams and rivers like Ekulu, Iva and Nyaba at the base of the escarpment. Out of the streams and rivers in Enugu coal city, Ekulu River is the largest and thus very important for industrial and agricultural purposes. However, the coal mines discharge their effluents and waste waters directly into the Ekulu River with toxic heavy metals like As, Cd, Cr, Fe, Mn, Ni and Pb that contaminate the water and sediments. At the mines, most of the seepages, springs and streams rise directly from the perennial flood water from the mines. The water from the coal mines with special treatment for pH and iron contents can be employed in augmenting the present inadequate water supply that comes from the Ninth Mile borehole network and Ekulu River reservoir. The pH can be treated with hydrated lime, while iron (Fe^{2+}) can be treated with aeration and filtration.

Key words: Groundwater, coal mine, Ajali sandstone, sub-bituminous, coal, rivers, seepage.

INTRODUCTION

It is very important to note that coal is sediment, organoclastic in nature, composed of lithified plant remains, which has the important distinction of being a combustible material (Thomas, 1992). Using the inductively coupled plasma-optical emission spectrometry (ICP-OES) in laboratory analyses, two distinct relationships exist among the major and trace elements in the Maastritchian Coal Measures of Southeastern Nigeria. The first represents rocks from a detrital suite dominated by quartz and clay minerals while the second

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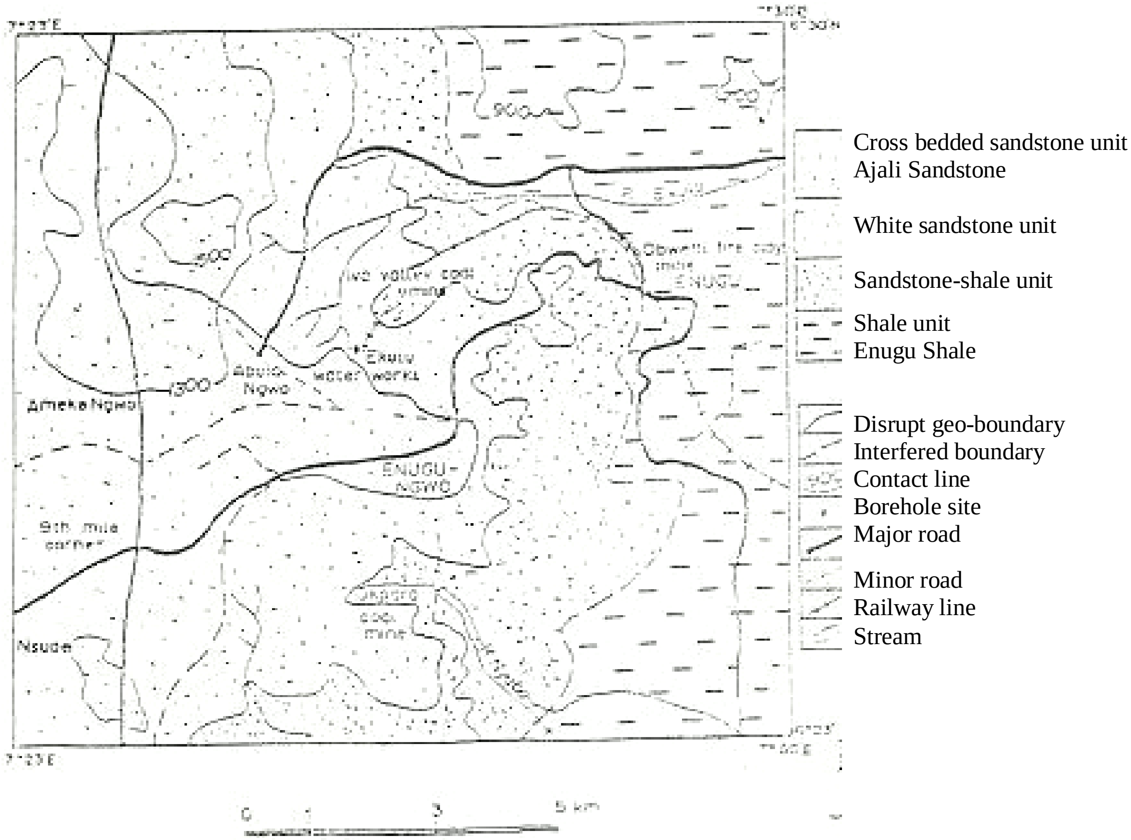

Figure 1. Physiographic and geological map of the area (Ezeigbo and Ezeanyim, 1993).

suite comprises the coal samples deposited in the peat swamp (Ogala et al., 2009). These suites are unrelated because there is no transition from one to the other.

The Ajali sandstone, which overlies Mamu formation (Figure 1) consists of thick friable poorly to moderately sorted highly cross-bedded sandstone that is generally whitish in colour, but sometimes stained red, yellow or brown due to the presence of iron oxide. Ajali sandstone is the main aquiferous unit supplying water to Enugu and environs. Water always drips downward from Ajali sandstone into underlying Mamu formation through the interconnected fracturing of the rock materials.

Major streams and rivers in Enugu metropolis include Ekulu, Asata, Ogbette and Nyaba (Figure 2). Ephemeral streams rise from about 300 m a.m.s.l. (above mean sea level) as springs and flow through deep V-Shaped valleys incised in the soil materials and the Ajali sandstone, but more perennial streams rise from the middle levels of the escarpment near the base of the Ajali sandstone. The area is well drained. The streams or rivers, some of which appear fracture-controlled in their flow paths give rise to dendritic drainage pattern (Ezeigbo and Ezeanyim, 1993). The flow pattern is provided by numerous fractures connecting the two aquiferous systems and the coal mines.

Vertical flows into the underlying Mamu aquifers also occur through the numerous fractures and stratigraphic discontinuities. The fractures act as vertical drains through which groundwater enters into the coal mines. Groundwater flows in the fractures from the overlying unconfined aquifer downward into the mines and laterally into the confined aquifers. This is because; the hydraulic head in the unconfined aquifer is always greater than in the confined aquifer.

DISCUSSION

There are two types of aquifer in Enugu metropolis, namely unconfined aquifer where there exist Ajali sandstone and an upper white sandstone member of Mamu formation, and a confined aquifer where there are lower and upper confined units within the Mamu formation (Figure 3). It must be noted that chromium contamination is common in soils in both ground and surface waters in industrial areas (Katz and Salem, 1994). Hence, metals are efficiently bound and accumulated by sediments, but are also subject to partial release into the overlying water (Jackson, 1998).

However, there is a pronounced shortage of potable

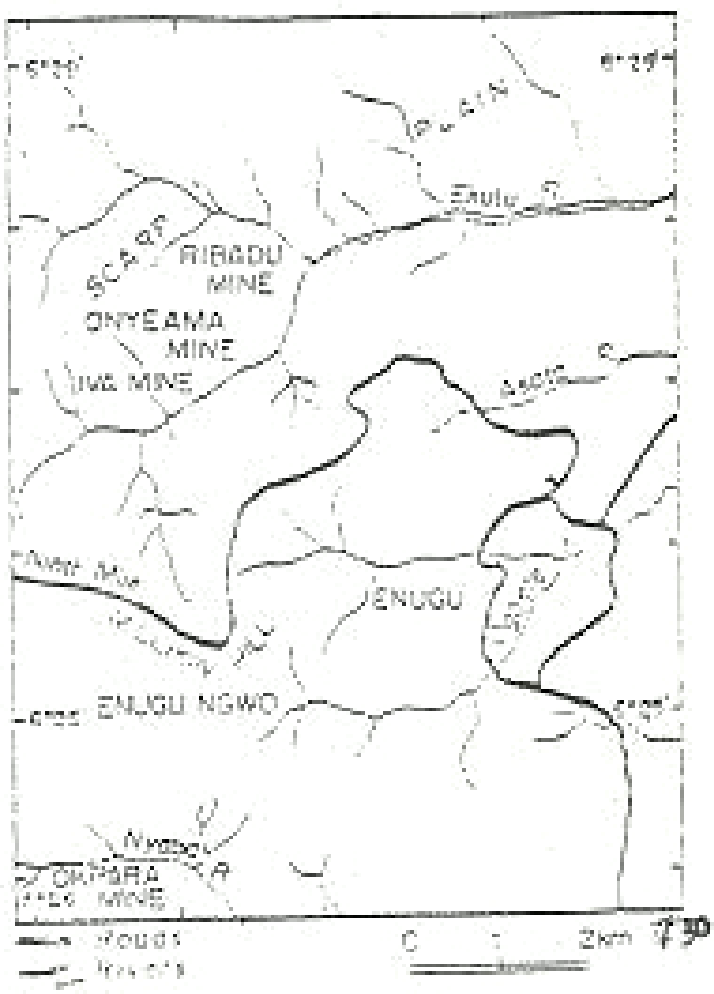

Figure 2. Drainage of the area (Ezeigbo and Ezeanyim, 1993).

drinking water within most parts of Enugu metropolis due to thinning out of Ajali sandstone (aquifer) and increase in Mamu formation (aquiclude), but in Ninth mile and Udi thickness of the Ajali Sandstone is greater than its thickness in other parts of Enugu metropolis.

The hydrodynamics and hydrology of the area indicate that the mines are overlain by unconfined and confined aquiferous systems. The mine water is derived principally from the unconfined aquifer (Uma, 1992). The flow-path is provided by numerous fractures that connect the two aquiferous units to the Onyeama and Okpara mines.

Acid mine drainage contamination is increased by the indiscriminate dumping of mine spoils whose leachates contaminate both surface water (springs, streams, rivers) and groundwater. Water seeping out through the fractures collect in sumps at the floor of the long walls (that is, active mine tunnels) and are subsequently pumped out of the mines through the main adit channel. The acid mine drainage water from the mines was pumped into the nearby streams and rivers, thereby contaminating the surface water that augment water supply to Enugu municipality.

It was observed during the fieldwork that some fractures were filled with compact clayey materials (mudrock). This was also peculiar in the minor joints of the coal seams (cleating). Therefore, seepage is confined to the major fractures that extended into the Ajali sandstone and upper part of Mamu formation. The major sources of the contaminants are the shales of Mamu formation which contain pyrite (FeS_2) flakes and show sulphur stains. When the pyrite flakes are exposed to air (oxygen), the water therein forms soluble hydrous iron sulphates. The soluble hydrous iron sulphates appear as white, red and yellow salt crusts on the surfaces of weathered rocks. As the natural water flows inside and outside the coal mines through these weathered rock surfaces, it readily dissolves the compounds, which hydrolyze the water to form acidic, high iron and high sulphate drainages. The shales of the Mamu formation contain pyrite flakes and sulphur stains. Pyrite is

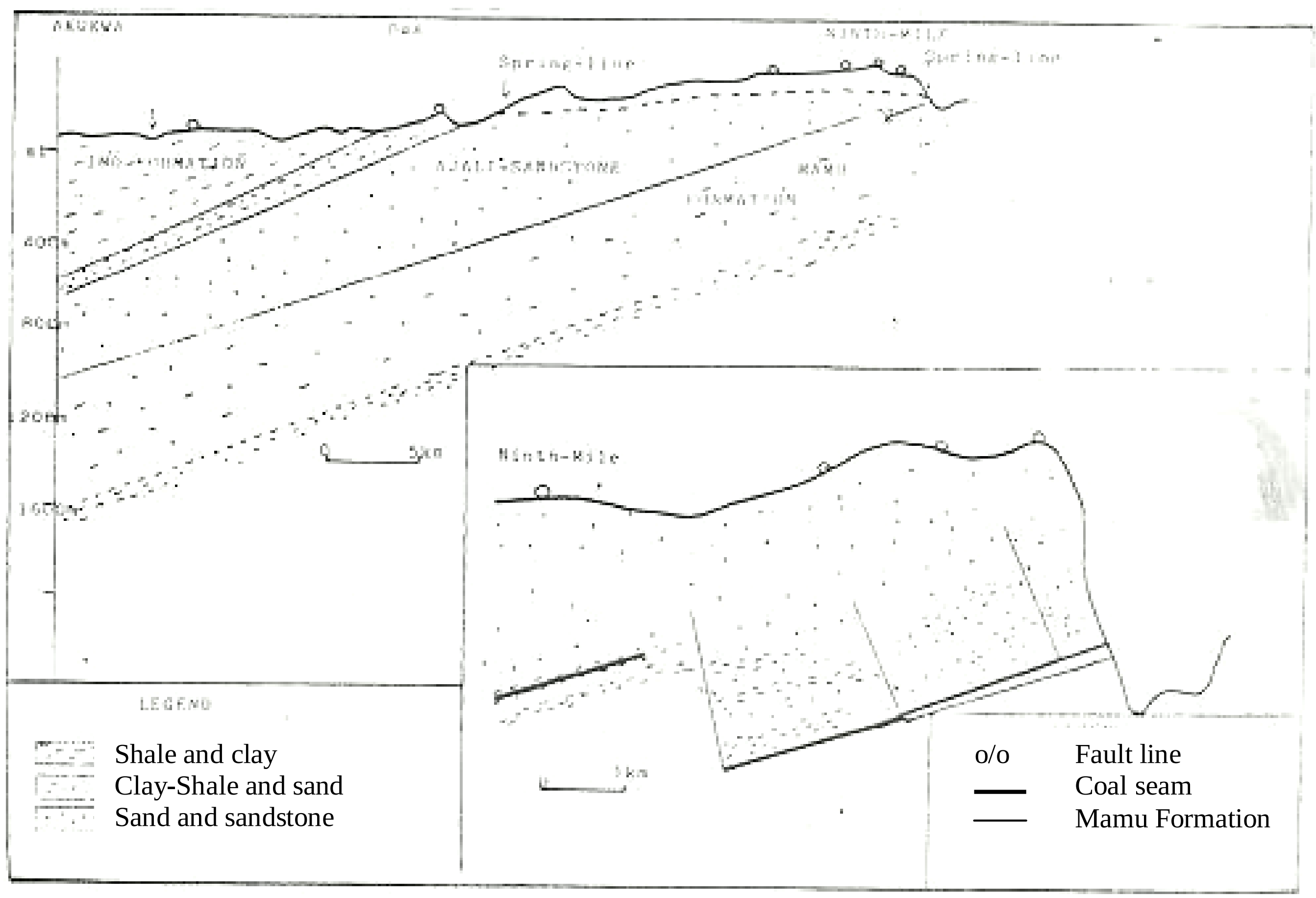

Figure 3. Generalized geologic sections across the area: figure shows regional features and inset the specific features in the mining environment (Uma, 1992).

associated with toxic heavy metals like Arsenic (As), Chromium (Cr), Cadmium (Cd), Nickel (Ni), Lead (Pb), Copper (Cu), Zinc (Zn), Aluminum (Al) and Manganese (Mn). The amount of iron, sulphates, Cu, Zn, Al and Mn discharged into the mine water and environment depends on the characteristics, amount and type of pyrite (FeS_2) in the overburden rock, time of exposure and amount of available water. The less time pyritic material is exposed to air, the less acid is formed. Therefore, it is advisable to cover pyritic material with earth to act as an oxygen barrier. Low pH values of the mine water indicate moderate hard water. The under-mining of the aquifers cause huge volumes of the polluted mine water to flood the mines which are subsequently channeled into some of the nearby streams and rivers like Ekulu, Nyaba and Ogbette.

The mine waters contain high contents of magnesium 12.16-158.08 mg/l and high iron 1.70-25.76 mg/l as major cations. Generally, other cations; calcium, sodium and potassium are less than 14.50 mg/l (Table 1). The major anion is sulphate 58.00-420.00 mg/l. Thus, the water is mainly of magnesium-sulphate type. Bicarbonate ranged from 9.60-80.50 mg/L, but the water that is not directly influenced by coal mining activity has bicarbonate as major anion. The mine waters have low pH 2.30-6.30, and thus, the water is moderately hard and corrosive with high leaching action, and an elevated total dissolved solid (65.00-785.00 mg/L). Aerial transport of precursors of acid rain cause leaching of heavy metals to sediments and suspension in the water column. Except for Mn, there is a steady decrease in the concentration of all metals from November to March corresponding to the decreasing run-off. Metal concentrations are generally higher in the coal samples than in the sediments, but seasonal fluctuations are higher in sediments than in the coal samples (Adaikpoh et al., 2005).

The coal mine spoils are most often dumped into the streams and on the river banks. Besides polluting these surface waters, the spoils increase total acidity, iron, sulphates and hardness. The spoils have been a major source of siltation, increased suspended matter (high turbidity) and total dissolved solids (TDS). The sediments destroy spawing grounds, shield sunlight and consume oxygen needed for aquatic life sustainability. These ions

Table 1. Hydrogeochemical data of Enugu Coal mine groundwater (Ezeigbo and Ezeanyim, 1993).

Geochemical parameter	Onyeama mine	Okpara mine	Iva valley mine	Ogbette Coal Preparatory mine
pH	2.80	2.30	6.10	6.30
Colour (platinum cobalt true colour)	5.00	10.00	20.00	25.00
Electrical conductivity (homs) u/cms	700.00	1550.00	110.00	800.00
Total hardness (mg/l)	100.00	100.00	80.00	-
Silica as SiO_2 (mg/l)	30.00	30.00	7.50	12.50
Nitrate (mg/l)	1.20	1.11	0.13	1.02
Total iron (mg/l)	8.40	25.76	1.70	6.40
Sulphide(mg/l)	1.40	-	1.80	-
Sulphate (mg/l)	310.00	420.00	58.00	174.00
Magnesium(mg/l)	158.08	85.12	12.16	111.87
Sodium (mg/l)	6.95	10.33	4.40	-
Potassium (mg/l))	9.46	2.19	2.35	-
Calcium(mg/l)	4.00	6.41	4.01	3.21
Chloride (mg/l)	10.42	1.99	-	8.93
Phenolp Acidity	124.00	320.00	10.00	10.00
Total alkalinity	20.00	16.00	80.00	90.00
Total dissolved solids	330.00	785.00	65.00	515 .00
Free carbondioxide	230.00	38.00	8.00	68.00
Bicarbonate	16.00	9.60	65.00	80.50

are highly toxic to man, plants and aquatic life, and thus render the water unfit for human drinking and agriculture; and unusable for other domestic and industrial purposes. The acidity of the streams and rivers does not support plants and animal life living within the water environment and thus, the re-establishment of this life will require several months.

The level of concentration of some heavy metals like Mn, Cr, As, Ni and Pb as analyzed in coal and sediments samples from River Ekulu in Enugu coal city using Atomic Absorption Spectrophotometer (AAS) model Spectra AA-10 Variant indicated mean concentrations of Mn 0.256-0.389 mg/kg and Cr 0.214-0.267 mg/kg which are high relative to concentrations of Cd 0.036-0.043 mg/kg, As 0.016-0.018 mg/kg, Ni 0.064-0.067 mg/kg and Pb 0.013-0.017 mg/kg (Adaikpoh et al., 2005).

The surface water needs protection from coal mine waste water by constructing sumps and treatment tanks where mine waste water will be discharged into. The sumps treatment involves removal of suspended solids in raw mine waste water by flocculation and settling processes using hydrated aluminum sulphate crystals (alum), while treatment tanks receive or contain the acid mine water free of suspended matter. Therefore, in order to control the acid mine water contamination of the streams and rivers, the acid mine water should be properly treated before being pumped into the surface water body. This is possible by aeration to remove dissolved iron and addition of lime to improve low pH concentration levels.

Calcination helps to control pollution in coal mines through its chambers that trap and retain gases. Calcination of coal waste spoils at high temperatures increases the pH of leachates from 2.3 to 8.5 and reduces the total dissolved solids (TDS) from 60 mg/l to nil. Calcinations can reduce heavy metals like iron in the coal wastes from 25.76 mg/l to less than 0.2 mg/l. However, calcination generates toxic gases.

The drainage of mine waste water is very important to avoid oxidation of metallic sulphides, improve slope stability and reduce corrosion of mining plants and equipment. Quality of the drainage water depends on geological, hydrogeological and mining factors, and this quality of mine waste water varies from one mine to another.

The quantity of mine waste water inflow from surface sources or rapid infiltration of rain water to underground workings will depend on transmissivity of the geological formations, dimensions of the fractures, hydraulic head, thickness of the projection layers, etc. The largest water inflows correspond with the area of higher rainfall (Raphael and David, 1993). In mine water management, opinions are divided into two groups due to the source of mine water. One opinion has it that the mine water comes from the overlying and highly prolific Ajali Sandstone, while the other opinion has it that the mine water comes from the aquiferous horizons of the Mamu Formation that are interlayered with coal seams. The total annual abstraction from the Ajali unconfined aquifer is about 1,750 m^3/yr, while Mamu aquifer is about 750 m^3/yr

(Ezeigbo and Ezeanyim, 1993). However, because the thickness of the Ajali sandstone (aquifer) thinned-out as it enters Enugu metropolis, the total discharge Qt m^3/yr will be less than that of the Mamu formation (aquiclude), but the Mamu formation contains the three coal seams and mine water. Therefore, the mine waters no matter the volume; it is generated mainly from the overlying Ajali Sandstone, and then it flows into and retained by the Mamu formation (aquiclude) where the coal seams occur.

CONCLUSION

Nigeria overdependence on petroleum and its derivatives for domestic and industrial purposes has led to the instability in the prices of oil, gas and other sources of energy (Onuegbu et al., 2010). The advantages of coal mining in Enugu municipality are enormous, with its unavoidable environmental problems. Besides the rapid remarkable growth of population, industrialization, agricultural activity and employment opportunity in the Enugu municipality, the environmental problems include water contamination, air pollution, faults reactivation and devegetation. The water contamination damages public and industrial water supply and endangers aquatic life.

Toxic heavy metals like As, Cd, Cr, Mn, Ni and Pb through sewage sludge and effluents application, mine waste, industrial waste disposal and application of fertilizers and pesticides. Generally, coal deposits contain great amounts of trace for example, Pb, As, Cd, Cr and minor elements in their overall composition. Water contamination can be controlled by treating the mine waste water before pumping it into the streams and by proper disposal of mine wastes and tailings so as to shed them from air and water environments. The enormous volume of mine waste water pumped out reactivates the faults of the Mamu formation in the mine environment. It was noted that the annual abstraction from the unconfined Ajali sandstone (aquifer) is about 1,750 m^3 /yr, while that of the Mamu formation (aquiclude) is about 750 m^3/yr.

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