Environmental Assessment of Surface Water/Coal Deposit Interaction from Trace Minerals in Okaba Coal Field, Okaba North Central Nigeria

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Abstract: The concentration of inorganic chemical substances released into surface water from Okaba coal deposit were measured using spectroscopic techniques in order to assess the extent of pollution. Parameters measured (Pb, Fe, Cu, Cr, SO\text{2-}, Cl, Mn, Zn and pH) showed that water samples within the mine area contain Pb, Fe, Cr, Cl, Mn and Zn in concentrations beyond permissible intake limits; and the concentration of chloride measured (3000 mg/L) is capable of causing acid mine drainage (AMD). Concurrent evaluation of these inorganic substances using quantitative assessment reveal the possible presence of trace minerals like galena, sphalerite, chalcopyrite, pyrite and clay in Okaba coal deposit.

Keywords— Acid mine drainage (AMD), Coal, Trace minerals, Water pollution

1 INTRODUCTION

In view of the abundant coal deposits in Nigeria (Oboirien, North, Obayopo, Odusote, & Sadiku, 2018), the renewed foreign investment interest in Nigerian coal (Gatugel Usman, Abbasoglu, Tekbiyik Ersoy, & Fahrioglu, 2015; Knoema Corporation, 2019) and global interest in cheaper and available energy sources (Barreto, 2018; Dincer & Zamfirescu, 2014), it is obvious that attention is shifting to coal again as a complementary source of energy (International Energy Agency (IEA), 2017).

![Fig. 1: Nigeria’s primary coal production from 1980 (Knoema Corporation, 2019.)](image)

Over the years, concerns of pollution arising from coal production and utilization have earned global attention due to some negative effects like acid mine drainage (AMD), water and soil contamination etc (Lin, Omoju, & Okonkwo, 2015). The history of coal production and utilization in Nigeria in the past had its share of negative impacts on the environment (Balogun, Mokobia, Fasasi, & Ogundare, 2003; Oboirien et al., 2018; Oliveira et al., 2019; Omotehinse & Ako, 2018; Sun, Cheng, Wang, & Wang, 2018). Zhao et al. (Zhao et al., 2018) reported the leaching attributes of seven hazardous trace elements in a coal deposit and concluded that some of the identified trace elements could pose very high risk to the environment. In a related study, Chelgani (Chelgani, 2019) investigated the occurrences of trace elements in some African coal and found out that trace elements identified were sources of potential by-products of coal and coke production.

Okaba community is strategic in the history of coal production in Nigeria because it was a major part of the then Nigerian Coal Cooperation which was created shortly after the civil war (Heinrich Böll Stiftung (HBS), 2015; Nwaobi, 1987). Okaba coal deposit is the second largest in Nigeria with a proven reserve of 73 million tonnes (an estimated reserve of 250 million tonnes) (Akujor, 1985). With a total proven coal reserve of 367 million tonnes (and total estimated reserve of 393 million tonnes), Nigeria’s coal reserve could be exploited for close to 1,000 years at a production rate of 400,000 tonnes per year (Akujor, 1985; Ezekwe & Odukwe, 1980). As at 2016 however, Nigeria’s total primary coal production was 51,000 tonnes (Knoema Corporation, 2019). Annual coal production in Nigeria had been quite lower in previous years except for year 2012 when it was slightly increased (see Fig. 1). However, coal production in Nigeria is currently on the increasing trend (Knoema Corporation, 2019). The trend is expected to continue as Nigeria makes efforts to revamp the industry.

Surface water like river and streams play major role in many communities in Nigeria. In Okaba community, surface water is the main sources of water for domestic uses. Drainages of water from Okaba coal mine are however naturally released into surrounding water bodies like rivers and streams in the community which could be capable of causing pollution. In this study, pollution of water samples collected over exposed surfaces of coal pits in Okaba coal mine were evaluated in order to assess the tendency of the coal at causing environmental hazards. In addition, attempt is made to predict the presence of trace mineral sources in the deposit in order to provide additional information useful for the coal combustion and waste disposal.

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Materials

Water representative samples were collected from 10 (ten) different spots in Okaba community out of which 8 are located within Okaba coal field. Samples were collected during the late rainy season. Four samples collected from stagnant water over the surface of coal pits at different spots in the mine are tagged Sites 1-4. Samples collected from a flowing stream through the coal field (at distance of 15m apart) are tagged Sites 5-8 while Sites 9 and 10 are water samples collected from boreholes around Okaba city center (outside the coal field) and used as ‘control’ specimens.

Experiments

Analyses of water samples were done using ultraviolet/visible spectrometer at 420nm. The concentration of heavy metals: Fe, Pb, Cu, Cr, Mn, and Zn in the collected water samples was determined using procedures described in ASTM D 4658 (EPA, 1986) and ASTM D 512 (Walter, 1961) respectively.

Results

The results obtained from the various tests are presented in Table 1.

Discussion

5.1 Iron (Fe²⁺) Pollution in Water

The concentration of iron in examined surface water ranges from 61-242.50 mg/L with a mean value of 139.97 mg/L which shows that surface water in the study area is high in iron content (Table 1, Fig. 3). These values are far above the maximum permissible level by global standards (Nigerian Industrial Standards (NIS), 2007; Dietrich, 2015; World Health Organization (WHO), 2003). Although, the mean value of 59.73 mg/L for the control samples (Sites 9 and 10) are low compared to others; iron concentration in all collected water samples are higher than required and may lead to serious health problems like cancer and liver problems when consumed (World Health Organization (WHO), 2003).

In coal seams, iron basically occur as pyrite (FeS₂) (Finkelman, 1993). Iron in coal therefore occurs in association with sulphur which means that the possibility of the presence of pyrite in Okaba coal deposit can only be predicted relative to the concentration of sulfate in the selected water samples (see Section 5.2). Test results reveal that water samples collected within the coal field (Sites 1-8) contain iron in excess amount with Site 4 showing the highest concentration of 242.50 mg/L. This shows possibility of the traces of pyrite in Okaba coal deposit, particularly if sulfur/sulfate is tested and confirmed to be present in considerable amount.

| Sample Code | Pb⁺⁺ (mg/L) | Fe⁺⁺ (mg/L) | Cu⁺⁺ (mg/L) | Zn⁺⁺ (mg/L) | SiO₂⁻ (mg/L) | Cr⁺⁺ (mg/L) | Mn⁺⁺ (mg/L) | SO₄⁻² (mg/L) | pH |
|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-----|
| Site 1      | 0.05        | 227.50      | 0.975       | 3.35        | 38.90       | 0.003       | 579.00      | 37.20       | 7.0 |
| Site 2      | 0.22        | 211.78      | 1.269       | 2.16        | 47.90       | 0.080       | 540.70      | 22.90       | 3.12|
| Site 3      | 0.05        | 64.02       | 1.000       | 1.95        | 31.75       | 0.003       | 322.90      | 20.50       | 7.15|
| Site 4      | 0.14        | 292.50      | 1.800       | 13.65       | 39.75       | 0.125       | 4103.00     | 17.00       | 7.15|
| Site 5      | 0.05        | 92.25       | 0.002       | 1.78        | 25.70       | 0.003       | 815.42      | 11.20       | 7.42|
| Site 6      | 0.05        | 108.59      | 0.002       | 1.83        | 17.90       | 0.193       | 718.10      | 11.10       | 7.42|
| Site 7      | 0.05        | 61.25       | 0.002       | 2.42        | 38.90       | 0.003       | 318.70      | 16.70       | 7.54|
| Site 8      | 0.05        | 10.25       | 0.002       | 2.63        | 40.25       | 0.003       | 349.90      | 19.90       | 7.30|
| Mean        | 0.05        | 92.97       | 0.036       | 4.10        | 34.49       | 0.060       | 8096.59     | 15.95       | 7.33|
| Site 9      | 0.05        | 72.25       | 0.002       | 1.10        | 0.00        | 0.003       | 627.00      | 7.10        |    |
| Site 10     | 0.05        | 47.25       | 0.002       | 1.25        | 0.00        | 0.003       | 735.20      | 7.10        |    |

Fig. 2: Okaba coal deposit Geological Map revealed from Geological Map of Nigeria (Akande & Onifade, 2013)

Fig. 3: Fe²⁺ concentration in collected surface water samples
5.2 Sulfate ($SO_4^{2-}$) Pollution in Water

Sulfur movement in natural deposits involves a combination of processes called sulfur cycle by which sulfur is converted into sulfate through biogeochemical processes. Evidences of the presence of sulfur in coal have been traced to biosynthesis in plants (Swaine, 1983). The presence of sulfur in water is usually tested by the concentration of sulfate (Nigerian Industrial Standards (NIS), 2007; World Health Organization (WHO), 2004). Sulfate is relatively of little occurrence in fresh coal samples and only in uncommon instances occur in considerable amount as the coal oxidizes or weathers (Swaine, 1983). Most sulfur present in coal are found as a result of trace amount of pyrite ($FeS_2$), galena ($PbS$) and sphalerite (($Zn,Fe)S$) (Gluskoter, 1977; Swaine, 1994). The concentration of sulfate in surface water (Sites 1-8) ranges from 11.2-37.2 mg/L (see Table 1) and no sulfate was detected in the control samples (Sites 9-10). This shows that the concentration of sulfate in all tested samples are within the level permissible by both national and global standards for drinking water (Nigerian Industrial Standards (NIS), 2007; World Health Organization (WHO), 2004). Though, sulfate average concentration of 19.6 mg/L in water samples from Sites 1-8 (Fig. 4) and the value is relatively low to suggest appreciable presence of sulfur in the examined water samples, the high iron concentration discussed in previous section largely imply the presence of iron bearing trace mineral (pyrite) in Okaba coal deposit (Adedosu, Adedosu, & Adebiyi, 2007).

5.3 Lead ($Pb^{2+}$) Pollution in Water

Concentration of lead beyond 0.01 mg/L in drinking water is hazardous to human health (Nigerian Industrial Standards (NIS), 2007). For aquatic and other terrestrial animals however, permissible lead intake limits vary in various quantities (Environmental Protection Agency (EPA), 2013; Nigerian Industrial Standards (NIS), 2007; World Health Organization (WHO), 2011). The concentration of lead in each of the water samples examined exceeds 0.01mg/L which shows that consumption of such water could lead to health challenges associated with lead poisoning like dullness and kidney damage (see Table 1 and Fig. 5). This confirms a recent study which reveals that the concentration of lead in Okaba coal deposit is harmful to both plants and animals (Okorie, Egila, & Jacob, 2014).

The earliest reference to the occurrence of lead within coal seams was in Upper Silesian in Central Europe (Swaine, 1983). Besides occurrence as a trace element, lead could be found in coal as galena which is primarily lead (II) sulfide ($PbS$) (Swaine, 1983), while natural and anthropogenic motivated activities such as weathering and mining influence its decomposition into water bodies -causing pollution (Keim & Markl, 2015). The mean concentration of lead is found to be 0.05 mg/L. It is observed that the concentration of lead in Sites 2 and 4 are higher than others which show that lead mineral could be a trace impurity present in rarely distributed occurrence in Okaba coal deposit. Relative to the presence of sulfate in Okaba coal as well as determined concentration of lead in the deposit, galena could only be possibly present in very rare occurrence.

5.4 Copper ($Cu^{2+}$) Pollution in Water

Water samples from Sites 1-4 have very high concentration of copper (i.e. > 0.975 mg/L) which exceeds the maximum limit acceptable for drinking water (Nigerian Industrial Standards (NIS), 2007). Other surface water samples collected from the stream (Sites 5-8) as well as the control water samples (Sites 9 and 10) have copper concentration of 0.002 mg/L each which are within the acceptable limits for human consumption (Nigerian Industrial Standards (NIS), 2007). Commonly, the most probable mode of occurrence of copper mineral in coal is chalcopyrite ($CuFeS_2$) (Finkelman, 1993). Chalcopyrite have been reported in coal from UK (Leicestershire) and Belgium besides many other coal deposits around the world (Swaine, 1983). In a speciation study of selected heavy metals in coal ash from Okaba coal, copper and zinc was found in appreciable amount in the coal residue (Okorie et al., 2014). On the average, the concentration of copper in tested samples is 0.635mg/L. Results (see Fig. 6, section 5.1 and section 5.2) therefore reveals the possible presence of chalcopyrite (as a copper bearing mineral) in likely scarcely distributed and minute amount in Okaba coal deposit.

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5.5 Zinc (Zn$^{2+}$) Pollution in Water

Similar to the concentration of copper in the selected water samples around Okaba coal mine, water sample Site 4 was observed to have the highest zinc concentration of 13.65 mg/L (see Table 1). Despite the importance of zinc in nutrition, excess of it could be detrimental to health (World Health Organization (WHO), 2012). The concentration of zinc from collected water samples ranges from 1.78-13.65 mg/L. Notable regulatory organizations however specifies 3-5mg/L zinc concentration level in drinking water (Nigerian Industrial Standards (NIS), 2007; World Health Organization (WHO), 2012)

The main source of zinc in coal comes from detection of sphalerite ((Zn,Fe)S) in the coal seam. In the past, zinc have been detected in coal seams in Germany and England (Swaine, 1983). Site 1 and Site 4 have zinc concentration above the maximum permissible level of 5 mg/L (Fig. 7). With references to the concentrations of iron (Section 5.1) and sulfate (Section 5.2) earlier discussed, Okaba coal deposit also shows chances of the presence sulphaterite minerals in rare quantity.

![Fig. 7: Zinc concentration in collected surface water samples.](image)

5.6 Manganese (Mn$^{2+}$) Pollution in Water

Manganese in drinking water in excess of 0.2 mg/L have been known to cause neurological disorder (Nigerian Industrial Standards (NIS), 2007; World Health Organization (WHO), 2011). The concentration of manganese in the water samples within Okaba coal mine ranges from 17.5-47.0 mg/L which are beyond acceptable limit permissible for drinking (Fig. 8). Presence of manganese in Okaba coal have been revealed in the past (Adedosu et al., 2007). However, no traces of manganese were seen in the water samples from Sites 9 and 10; indicating that water taken from distant location (about 1km) from Okaba coal field could be safe from some water leachable chemical substance released into the water bodies from the coal deposit.

Though the presence of manganese have been confirmed in many coal samples around the world, studies of the mineral occurrence of manganese in coal is quite tricky as it is mostly found in clay (Swaine, 1983). Therefore, no mineral occurrence related to manganese could be said to be present in Okaba coal deposit on this study. However, the concentrations of manganese revealed in test samples could be attributed to indications of the possible presence of clay in the deposit.

![Fig. 8: Manganese concentration in collected surface water samples.](image)

5.7 Chromium Pollution in Water

Test samples from Sites 1-8 reveals chromium concentration in the water samples as ranging from 0.003-0.58 mg/L. Chromium concentration in the control water samples (Sites 9-10) is, however, less than 0.003 mg/L (Fig. 9). The primary source of chromium in coal is clay (Finkelman, 1993). Ordinarily, chromium is a fundamental trace element needed by plants and animals for growth. It is basically not toxic, except in its hexavalent state. Most modern analytical methods including X-ray fluorescence, atomic absorption spectroscopy, neutron analysis and emission spectroscopy are appropriate for determining total chromium in coal (World Health Organization (WHO), 1996). However, analytical methods for the determination of chromium species in coal are quite rare and sophisticated. Prominent among these sophisticated techniques is the determination of metal/chromium species using synchrotron facilities. Synchrotron facilities are still very scarce to come by in most continents. For this reason, the specie of chromium in the test samples could not be presently determined.

It is however important to mention that the permissible level of chromium (Cr$^{6+}$) in drinking water is 0.05 mg/L (Nigerian Industrial Standards (NIS), 2007; World Health Organization (WHO), 1996). Noticeable presence of chromium in tested samples further reveals the possible presence of clay in Okaba clay deposit.

![Fig. 9: Chromium concentration in collected surface water samples.](image)

5.8 Chloride (Cl$^-$) Pollution in Water

Permissible limit of chloride in drinking water is 250 mg/L (Nigerian Industrial Standards (NIS), 2007). Sites 1-8 have chloride concentration values beyond 250 mg/L (See Table 1). This shows that water samples Sites 1-8 do not qualify for use in consumption purposes.
Situations surrounding the presence of chloride in coal was initially not clear until recently (Swaine, 1983; Yudovich & Ketris, 2006). Studies have shown that coals with chloride concentration greater than 3000 mg/L are likely to produce hazardous deposits like the formation of hydrogen chloride (Swaine, 1983) which could lead to acid mine drainage. Site 4 have chloride concentration >3000 mg/L (see Fig. 10), which shows that Okaba coal deposit may be capable of causing AMD.

On the other hand, the concentrations of the inorganic pollutants (Pb, Fe, Zn, Cu, Mn, Cl- and SO42-) measured reveal that Okaba coal deposit could contain traces of pyrite, sphalerite, clay, chalcopyrite and galena minerals in minute quantities. Knowledge of the presence of discrete mineral grains in coal deposits could have meaningful impact on coal combustion and waste disposal.

5.9 PH OF OKABA COMMUNITY WATER SAMPLES
The pH value recorded for water samples from Sites 1-8 ranges between 2.15-4.72 with a mean value of 3.33 (Table 1 and Fig. 11). Considering the concentrations of chloride in collected water samples from Okaba coal mine (Section 5.8), sample Site 4 have the most acidic pH value of 2.15. This further confirms that Okaba coal deposit contains hazardous inorganic associates (e.g. chloride) capable of putting close environment of the coal in danger of AMD. These pH values falls short of acceptable pH level (6.50-8.50) set by global regulatory agencies for drinking water (Nigerian Industrial Standards (NIS), 2007; Dietrich, 2015; World Health Organization (WHO), 2003). On the other hand, the control samples (Sites 9 and 10) have a pH 7.1 each which falls within acceptable limits for drinkable water (Nigerian Industrial Standards (NIS), 2007; World Health Organization (WHO), 2003).

6 CONCLUSIONS
This study evaluates the concentrations of inorganic chemical substances released into surface water bodies from Okaba (Nigeria) coal deposit. Analysis of selected surface water samples shows that the coal deposit could constitute environmental challenge to human life through interactions between surface water and inorganic substances like Fe, Mn, Pb, Cr, Zn, Cu, Cl and SO4 present in the coal. While the mean concentration of copper and sulfate in surface water samples collected from the coal mine falls within the acceptable limit specified by regulatory bodies for drinking water (Nigerian Industrial Standards (NIS), 2007; World Health Organization (WHO), 1996, 2004), the mean concentrations of lead, iron, zinc, chromium, manganese and chloride largely exceeds the acceptable limits (Environmental Protection Agency, (EPA), 2013; Nigerian Industrial Standards (NIS), 2007; WHO, 2011; World Health Organization (WHO), 2003, 2011, 2012; Yudovich & Ketris, 2006). This contamination is capable of AMD as well as serious health challenge to human health in the area.

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