Assessment of the Implications of Coal Post-mining Impact on Surface Water at Abandoned Okpara mine in Enugu State

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Abstract

This study examines the coal post-mining impact on surface water at abandoned Okpara mine in Enugu State. Experimental research design was adopted to test the water quality. The water samples were collected and analysed to determine the level of pollution. Hhypotheses were tested using analysis of variance (ANOVA) and the treatment means were separated using Duncan's multiple range test (DMRT). The result of the test of hypothesis one shows that there is no significant difference in the parameters of the water samples within months. For all the parameters, α-significant at P≤0.05 fall within .207 and .995. DMRT shows that with the exception of temperature, that there is significant difference in other parameters of the water samples collected at different stations. For the parameters, alpha (α) is significant at P≤0.05. The result also shows that with the exception of Lead (Pb), that there is significant difference (p≤0.05) in the heavy metals found in the water samples collected at different stations. The total viable count (TVC) of the bacteria Pseudomonas *aurogenosa* and Bacillus *substilis* were 9.0×10^3 cfu/ml and 1.2×10^4 cfu/ml for the month of July, while in the month of August it was 9.0×10^3 cfu/ml and 1.3×10^4 cfu/ml respectively. The study concludes that the abandoned coal mine sites contribute to the type of microorganisms found in the water and concentration of heavy metals present in the water samples as well as other physicochemical parameters/indicators of water quality.

Keywords: Coal post-mining, Water quality, Microbial load, Pollution, Trace metals
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1.0 Introduction

Mining has been an important industry involved in the economic development of human society. In Nigeria, huge deposits of coal are found in Enugu state and were extensively mined for more than 50 years (Awaomim, 2013). The mining activities left behind nasty sites along with environmental health consequences. In other words, coal sites have been abandoned without any restoration or cleansed of harmful residues therefore, beaming threats to the surrounding environment. Research has shown that though, coal mined years ago is viewed as one of the important economic activities that contributed to the growth and development of Nigeria (Odoemene, nd; Mba, 2004), the threat posed by the abandoned mines to the surrounding communities ought to have been a major concern to governments, the general public, organizations, individuals and other stakeholders. The researchers report that the overburdens removed from coal mining during the mining activities were usually dropped into low-lying areas, most times filling wetlands, tunnels or other water sources. This made the heavy metals and other contaminants from the abandoned coal mine sites to dissolve and trickle into nearby surface water which disrupt water habitats and pollute drinking water sources. When Pyrite that is present in rocks containing coal seams are exposed to air and water, it forms sulfuric acid and iron hydroxide. Again, in some of the coal mines, acidic water is also found in the underground aquifers. When rain water runoff wash over the rocks, the water becomes acidified and then affect local soils, surface water (rivers, streams and lake) and underground water. This phenomenon is known as Acid Mine Drainage (AMD) and it is very high in active coal mining sites (Chayanan *et al.,* 2014; Geller *et al.,* 1998; Gyang and Ashano, 2010; Williams *et al.,* 1996; Wood *et al.,* 1999). It may still be happening in abandoned sites. Moreover, the microbial growth/survival in any environment is a function of the environment. As a result, the microbial population of the water environment is such that the acidic environment created by the mine waters are supportive.

Enugu, having a long history of intensive mining, provides an excellent place to study the potential long-term consequences of abandoned mine on water environment. Assessment and understanding of these consequences may confidently allow the prioritization of actions to lessen possible imminent impacts connected to abandoned

mine. The incidence of historic mining in countries with the natural resources implies that mine water discharge is responsible for the single largest source of metals like iron (Fe), zinc (Zn) and copper (Cu) in moving waters (Johnston *et al.,* 2008).

Kitula (2005) asserts that there are some strong scientific bases for concern about chemical pollution originating from coal however, it has not been carefully examined. For instance, a study in Italy found the presence of coal in the water can be a source of some water quality parameters such as chemical oxygen demand (COD), trace metals, acidity, salinity, hydrocarbons as well as possible source of macronutrients (Cidu *et al.,* 2009). In fact, Washington Department of Natural Resources (1996) reports that materials in coal is capable of reacting with seawater to form "localized ocean acidification". All these factors present probable hazards to aquatic organisms as they increase the risk of invasive species taking hold. Though, US EPA (2009) reports that the threshold of the runoff concentrations from an evaluated coal piles were far below and therefore not capable of stressing aquatic organisms, Kitula (2005) reveals that in freshwater streams, runoff concentration can contribute in biodiversity reduction of aquatic creatures in Maryland US. Kitula (2005) further reports that coal can also increase the concentration of macronutrients, more importantly nitrogen and phosphorus in water which may cause eutrophication. Ripley *et al.,* (1996) in a study on environmental effects of mining of Spanish coals found that little phosphorus was mobilized by water. Prasad *et al.,* (2012) in a study of coals in different countries found that 60% of the phosphorus content in the coal could seep into surrounding surface water. At the same time, heavy metals can seep from coal, though the risk differs significantly and the difference depends on the type and purity of the coal. The authors found that for virtually all the water samples analyzed, there were heavy metal seepages which surpassed international water quality standards. For instance, the concentration of some metals in leachate samples from low-sulfur western US coals surpassed the Canadian water quality standards for protection of aquatic lives. Johnston (2008) found that snails in the Mediterranean around an Israeli power plant were hurt owing to the presence of coal in the water which may be due to high levels of cadmium (Cd).

Production of discharge waters highly rich in mineral is an incidence that has been noticed throughout the world at both active and abandoned mine sites (Wood *et al*., 1999; Blowes *et al*., 2003). Mine closure usually brings about increase in the concentrations of dissolved ions, most especially, iron (Fe^+) and sulphate (SO_4^{2-}) in mine discharge waters owing to the dissolution of pyrite oxidation products formed majorly in the time of operational phase of the mining activities (Younger, 2000). Rock dumped to the surface during mining can also produce the same mine waters through pyrite oxidation, when exposed to oxygen and water (Lottermoser 2010; Nordstrom, 2011). As soon as it is discharged at the surface mine, waters can have costly environmental consequences because the water quality of the recipient streams and rivers would be compromised (Younger, 1995). The pollution of the nearby water sources by AMD is a global issue and basically occur in places where coal or ore sulfides are mined (Young, 1992; Younger, 1992).

Geller *et al.,* (1998) report that in more than hundred acid lakes that were sampled, the values of the pH were <4. These conditions were as a result of the ascending groundwater which brought about the oxidation of the sulfide minerals in the presence of air in the mine dumps. The sulfuric acid (H_2SO_4) was unceasingly produced which resulted in continual acidic states of the lakes even after the mining operations have been ceased for long. The acid dropped the pH of the natural water, made it corrosive and incapable of supporting numerous lives in the aquatic environment. AMD often contains, in high concentrations, heavy metals, like iron, Manganese, Aluminum and anions like sulphate (SO_4^{2-}) as well as elements such as Zinc (Zn), Cobalt (Co), Lead (Pb), Chromium (Cr), Copper (Cu) in trace concentrations (Chayanan *et al.,* 2014; Geller *et al.,* 1998; Gyang and Ashano2010). This led to the suggestion that if such water is to be used, it must be treated. Chayanan *et al.,* (2014) report that Cl^-, NO^{3-}, SO_4^{2-}, Na^+, K^+, Ca^{2+} and Mg^{2+} were found in the lake water of an acidic coal mine reservoir and the major ion concentrations of the 1st three points of sample collection were reported to be SO_4^{2-} and Ca^{2+}, while the 4th point was different. The key source of the dissolved SO_4^{2-} in the lake is the oxidation of pyrite in the presence of air and reservoir water. Heavy metal concentrations in the water and the soil were observed to be As, Cd, Cu, Fe, Mn and Zn. Mn has the highest concentration of all the heavy metals found and was found in both the water and soil at the 2nd point of sample collection. The study found low pH levels in the 2nd point of water sample collection and a high level of electrical conductivity (EC), total dissolved solid (TDS),

SO_4^{2-}. Jarvis and Younger (1997), on investigating the response of benthic invertebrates to AMD pollution, found that the streams showed typical signs of mine drainage pollution: higher EC, high concentration levels of Fe, Al, Zn and Cu and accumulations of ferric precipitates. EC strongly correlated to most of the studied elements (weighted mean absolute correlation = 0.95) and, then, can be taken as a good proxy indicator for assessments of AMD pollution in water. A study by Williams *et al.,* (1996) on 270 mine discharges found that many of the discharges had a pH < 3.0. Generally, water samples from these discharges had high concentrations of acidity, Fe, Mn, Al, and SO_4^{2-}. Water quality is therefore sternly degraded when mine discharges like this run into streams and rivers. KnÖller *et al.,* (2004) used sulfate as an indicator of the presence of AMD in streams and found that water samples collected from 1978 - 1994 show relatively low level of sulfate prior to 1985, when coal mining began in the basin (secondary data was used here). The median level of sulfate in the collected samples after mining began was about 5 times > the median level in the collected samples before mining.

The subsurface has for long been considered a sterile environment however bacteria play an important role in subsurface chemistry, especially at mining sites. Certainly, all the reaction pathways for pyrite oxidation are usually facilitated by bacteria. The role of the Sulphur bacterial cycle is important at practically all the mine sites because of the biogenesis of metal ores through Sulphur oxidation bacteria (Natarajan, 2008). For instance, the acidithiobacillus group of bacteria play a part in the dissolving and mobilising of copper, iron, zinc, cadmium, arsenic and nickel in mine sites acidic solutions (Natarajan 2008). Pyrite oxidation for a long time has been revealed to be the major control on pollutant release from coal mine sites nevertheless, this oxidation reaction is facilitated by the acidophilic autotrophic bacteria of the acidithiobacillus group which poses as a catalyst in the chemical reactions. These bacteria utilise ferrous iron and Sulphur compounds as a form of energy for reproduction and growth (Mayes *et al.,* 2008). Acidithiobacillus *ferrooxidans* and Acidithiobacillus *thiooxidans* are almost ubiquitous at most mine sites and take the responsibility of accelerating the oxidation of metal sulphide (Natarajan, 2008). Acidithiobacillus *ferrooxidans* is the major actor in the oxidation of pyrite at mine sites, whereas Acidithiobacillus *thioxidans* cannot oxidize pyrite however, grows through the oxidation of sulphur released from pyrite oxidation. (Natarajan, 2008). Sulphate Reducing Bacteria (SRB) are also of importance at mine sites since they can successfully remove Fe, Zi and Cu as sulphide precipitates (Natarajan, 2008). Nevertheless, this process happens to be time-dependent as SRB are established in anoxic conditions following rebound (Wood *et al.,* 1999). Mayes *et al.,* (2008) state that one of the main influences on net alkaline discharges in mine sites is the outcome of microbial sulphate reduction in the low subsurface preceding the surface discharge (Mayes et al, 2008).

From the literature reviewed here, the compounding environmental and health cost and damages of post impact mining activities on surface water far outweigh their economic and social benefits, the magnitude of which cannot be quantified and such studies has not been conducted in Enugu where coal has also been mined for over five decades. Therefore, the environmental impacts of the abandoned coal mine in Enugu on the quality of the water within the vicinity needs to be investigated.

2.0 Materials and Methods

2.1 The Study Area

Enugu is located in the Eastern part of Nigeria. It lies about 112km East of the River Niger and is surrounded in the Northern hemisphere by many undulating hills together called the Udi hills for being located at the Udi escarpment. Enugu city lies approximately between longitude 07^0 26'E and 07^0 37'E and between 26°21'N and 06°30'N (Wikipedia, 2003). Enugu covers an area of about 200 square kilometers. The area contains hydromorphic soil which is mineral soil morphology that is influenced by seasonal water logging due to underlying impermeable shales.

The Enugu shale underlines Enugu metropolis (see Fig.1). According to Larry (2002) crags of Enugu shale are scarce, but the cores of borehole present Enugu shale as light to dark grey containing bounds of clay ironstone. The uppermost area of Enugu shale weathered to a dirty brown lateritic regolith with a porous characteristic and varies in thickness up to a maximum of 20m. The water table is < 20m below the ground-surface. Enugu shale

basically constitutes the only known aquifers underneath the metropolis. The undulating terrain of many parts of Enugu accounts for its good natural drainage. Its physical geographies exhibit gradual changes from tropical rainforest to open wood land then to savannah. At present the primary forest land covers in the city of Enugu have reduced severely due to urban development, increased urban population and other anthropogenic activities.
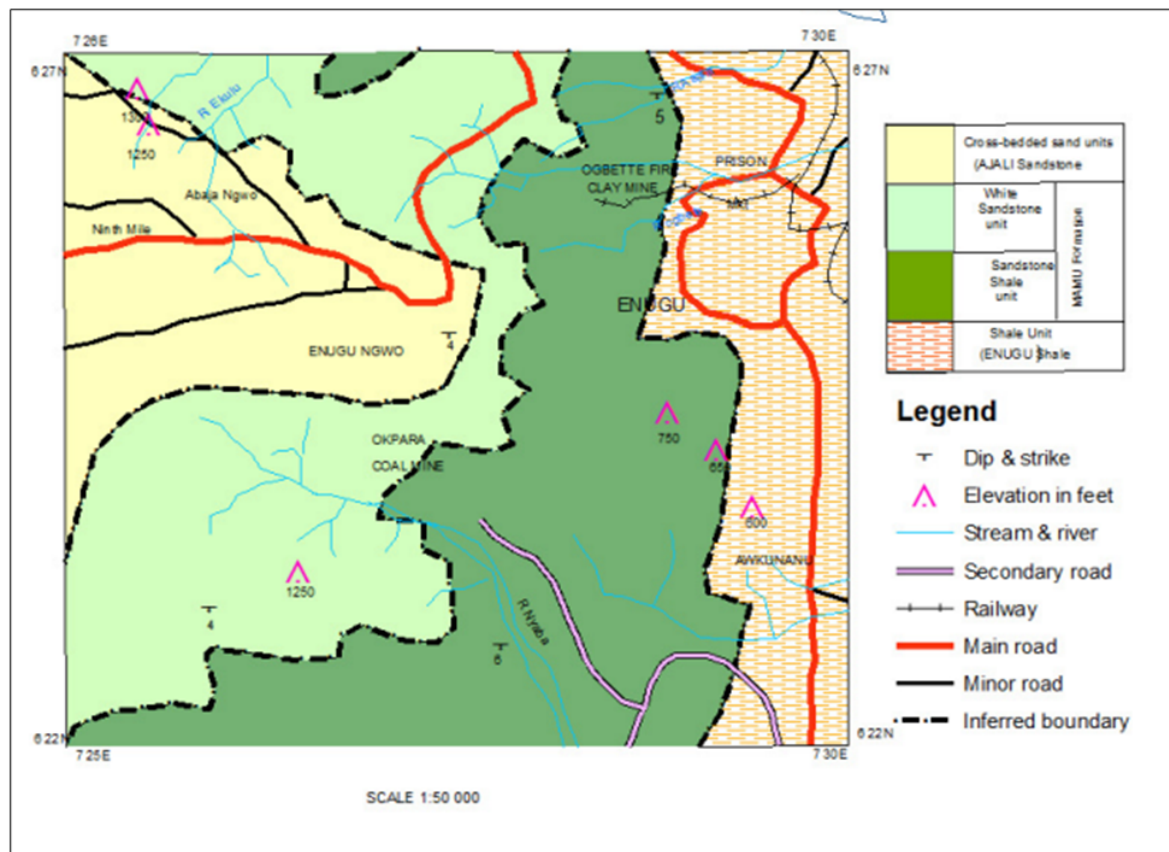

Fig 1: Physiographic and geologic map of the study area.
Source: Enugu State Ministry of Lands and Survey (2012)

Fig 2: Point source of Oro-obo River at Okpara mine

Fig 3: Onigbo mine at Okpara mine; another point source of Oro-obo river.

Fig 4: The meeting point of Oro-obo and Nyama River

2.1.1 Industrialisation

According to Floyd (1969), the Europeans came to the Enugu area in 1903 for an exploration of the Southern Nigeria Protectorate in search of valuable mineral resources. In 1909 coal was found first in the village of Enugu Ngwo in Udi and Okoga areas. By 1913 it was confirmed to be in commercial or viable quantity. The British, in 1915, began discussions with the indigenous people of the land to acquire the land area so as to lay the Eastern railway-line and build a colliery. After acquiring the land, the colliery was built at the bottom of the Udi Hills and was named Enugu Coal Camp to differentiate it from Enugu Ngwo which overlooks Enugu city from above a scarp on the western part of Enugu. Udi mine was opened in 1915 and happened to be the first coal mine in the Enugu area but was later shut down after two years and substituted with the Iva Valley mine.

Enugu became a major coal mining area and the only significant one in West Africa (Odoemene, nd). The Eastern railway-line linking Enugu and Port-Harcourt was constructed in 1916 to export the coal through the Port-Harcourt seaport. The built-up area of Enugu then comprised the part of Enugu that was reserved for Europeans set up by the colonial government and the section developed for African residents. By 1917 the city publicly gained township status and was nicknamed *Coal City*. On the African side of Enugu city, a fast entry of migrant workers stimulated the development of squatter camps on the Udi Hills near the coal mines and the Iva Valley area (Mba, 2004). The population of coal miners that were employed in Enugu rose from 6,000 (of mostly Udi men) in 1948 to 8,000 in 1958. The mining continued till when the demand for coal as source of energy dropped and the mining activities ended which resulted to the mine sites being abandoned. Some of the abandoned mines turned to point source of flowing waters. The Point source of Oro-obo river at Okpara mine is shown in Figures 2 and 3 to where it meets with the Nyama river as shown in figure 4. The general flow of water towards the stream channels from ground water is common in the abandoned mines especially as seen in Okpara mine and Onigbo mine respectively. These mines are located in Enugu South local government area of Enugu State, Nigeria.

2.2 Sample Collection

Eight (8) samples were collected, four (4) samples in the month of July and another four (4) in the month of August. In the month of July, first sample was collected 100m upstream of Nyama river from the point of discharge and labeled Upstream primary (USp). Second sample was collected at the point of discharge (PD) of the waste water from the abandoned mine. Third sample was collected 100m upstream of Orobo River from the point of discharge and labeled USs (Upstream secondary). Fourth sample was collected 100m downstream from the point of mine water discharge and labeled Downstream primary (DSp). The samples were labelled for easy identification. In the month of August, sample collection was repeated at the same stations. These water samples were subjected to laboratory analysis of which relevant parameters of water quality, that is, the physical, chemical, and biological compositions were analysed.

For quality control, surface water samples were collected with sterilized new plastic gallons free of oil and grease or other sources of water pollution were used. The one (1) liter capacity gallons were first rinsed with hydrogen peroxide kept at room temperature to prevent volatilization and condensation or oxidation and absorption on the walls of the container. The GPS readings were taken as soon as the calibrations normalize.

2.3 Water Quality Parameter Determination/Laboratory analysis

The water samples collected were analysed in the laboratory to determine its quality using the following parameters: pH, electrical conductivity (EC), acidity (AC), alkalinity (AL), total solids (TS), total dissolves solids (TDS), total suspended solids (TSS), calcium, magnesium, phosphate, nitrate. Heavy metals like lead, copper, iron and zinc were also analyzed as well as *E-coli* and total coliform. This determines the status of both the physico-chemical and microbial quality of the water samples. Analytical methods for determining physico-chemical parameters were used in line with methods of the Association of Official Analytical Chemists (AOAC, 2005). The microbial loads of the water samples were determined using serial dilution techniques while characterization was done by macro- and microscopic examination of colonial morphology, Gramm-staining techniques and biochemical tests using Bergey's Manual of Determinative Bacteriology (Holt, 1993).

3.0 Results and Discussion of Findings

3.1 Physico-chemical parameters and Trace Metals of the water samples

Results of the mean values of physicochemical parameters of the water samples from the coal mined site are shown in table 1 (see Appendix I). The table shows that TDS mean values at USp, DP, USs and DSp are 62.5mg/l, 20.25mg/l, 10.0mg/l and 20.0mg/l respectively. However, all the recorded values are within WHO acceptable limit. EC recorded 49.7µs/m, 49.54µs/m, 200µs/m and 30µs/m at USp, DP, USs and DSp respectively, which are all within WHO limit. Recorded mean values of temperature were 27.45^0C, 28.0^0C, 27.5^0C, 30^0C at points of USp, DP, USs, Dsp respectively. The mean values of TSS at USp, DP, USs and DSp were 121.65mg/l, 111.0mg/l, 116.45mg/l and 20.99mg/l respectively. The mean values of TS at USp, DP, USs and DSp were 103.7mg/l, 106.7mg/l, 111.55mg/l and 11.0mg/l respectively. Potential Hydrogen (pH) values of the water samples at respective points of USp, DP, USs and DSp are 5.95, 6.90, 7.60 and 6.00 which are within WHO acceptable limit. Nitrate (NO_3) recorded 10.13 mg/l, 5.69 mg/l, 5.46 mg/l and 2.25 mg/l at USp, DP, USs and DSp respectively. The mean values of SO_4 were 430.0, 79.52, 79.82 and 64.90 at USp, DP, USs and DSp respectively. Recorded Cl_2 mean values were 279 mg/l, 94.6mg/l, 94.1mg/l and 45.1mg/l at USp, DP, USs and DSp respectively. The mean values of PO_4 at USp, DP, USs and DSp were 2.08mg/l, 0.80mg/l, 0.78mg/l and 0.47mg/l respectively. The mean values of AL at USp, DP, USs and DSp were 13.4mg/l, 10.09mg/l, 10.09mg/l, 10.12mg/l and 13.10mg/l respectively. Recorded AC mean values were 3.20mg/l, 1.95mg/l, 1.95mg/l and 2.93mg/l at USp, DP, USs and DSp respectively. Recorded values of SO_4, NO_3, PO_4 and Cl_2 are within the WHO acceptable limit.

Results of the concentration of trace metals in the water samples from the coal mined sites are shown in table 2 (*see Appendix II*). The table shows that the values of Zn at USp is 1.51mg/l, 1.32mg/l at both DP and USs but 1.04mg/l at DSp. However, the mean values are within WHO acceptable limit of surface flowing water. Potassium (K) recorded 26.11mg/l, 15.90mg/l, 15.84mg/l and 8.34mg/l at USp, DP, USs and DSp respectively. The recorded mean value of Cu at USp was 0.06mg/l and 0.02mg/l for DP and USs. Cu was not available for detection at DSp. The values of Na were 54.5mg/l, 8.45mg/l, 8.40mg/l and 6.28mg/l at USp, DP, USs and DSp respectively. From indication, it is only the value of Cu at USp that is above WHO accepted limit. The mean values of Ca at USp, DP, USs and DSp recorded 22.12mg/l, 9.17mg/l, 9.1mg/l and 3.66mg/l respectively. Iron (Fe) recorded 12.58mg/l, 11.90mg/l, 11.56mg/l and 4.79mg/l at USp, DP, USs and DSp respectively. The result of Pb at USp was 0.2mg/l, 0.01mg/l in DP, 0.15mg/l in USs and 0.015mg/l in DSp. However, the results of Pb at USp and USs were above WHO acceptable limit for Pb concentration. The concentration of Mg at locations USp, DP, USs and DSp were 12.12mg/l, 8.75mg/l, 8.47mg/l, and 2.17mg/l respectively. Meanwhile, all the results are below the WHO acceptable limit for Mg. The mean values of Co at USp, DP, USs and DSp recorded 0.47mg/l, 0.33mg/l, 0.29mg/l, and 0.65mg/l respectively.

These outcomes are in line with Prasad *et al.,* (2012) who found that for nearly every water sampled from abandoned coal site and analyzed, there were heavy metal leachates that exceeded international water quality guidelines. It is also in line with Chayanan *et al.,* (2014) and Geller *et al.,* (1998) who confirmed that AMD often contains high concentrations of heavy metals, such as Fe, Mn, Al and anions like SO_4^{2-} and PO_4^{2-} in addition to elements like Zn, Co, Pb, Cr, Cu in trace concentrations. Production of heavily mineralised discharge waters is a phenomenon observed worldwide at active and abandoned mine sites (Wood *et al.,* 1999; Blowes *et al.,* 2003). Mine closure commonly results in increased concentrations of dissolved ions, particularly iron and sulphate, in mine discharge waters due to the dissolution of pyrite oxidation products formed, mainly, during the operational phase of the mine (Younger, 2000). The mean values of total dissolved solids (TDS) at the different stations may be attributed to the mineral contents of the water due to the elements present in the abandoned coal mine site. The level of EC at the stations may also be attributed to the presence of mineral ions in the water since. The recorded level of electrical conductivity (EC) is a function of TDS. Recorded mean values of temperature at the different stations are within the same range except for USp which may be due to exposure of the samples to sunlight since there were no trees. TS is the matter suspended or dissolved in water or wastewater, and is related to both specific conductance and turbidity. Total Solids includes both total suspended solids (TSS), the portion of total solids retained by a filter, and (TDS), the portion that passes through a filter. By the virtue of these explanation, TS and TSS concentrations in the water samples may be due partly to the leaves and other parts of the trees and grasses (which form debris) from near, far and wild areas of the water samples.

The presence of Cl_2 and NO_3 in the water samples may be due to the presence of metals (cations) which could bind freely with the anions to form normal salt and/or acidic salts. Potential Hydrogen (pH) of the water samples at respective points are within the WHO standard. This may be due to dilution by rain water since the samples were collected during the rainy season. However, this refutes the reports of Geller *et al.,* (1998) and Williams *et al.,* (1996) who found pH value to be less than 4. The acidic level of the water sample at USp is high however, less than those of DP, USs and DSp stations. The high acidic level of the water samples from stations DP, USs and DSp may be due to AMD in the abandoned mining site which moves from upstream secondary (USs) to discharge point (DP) through downstream primary (DSp). The acidic level at USp may be due to contamination from other sources like detergents used in washing since it is an open surface water where people living around the area wash their cloths and take their bath. The discussions above are in line with Gzyl and Bank (2007) who stated that the main contaminants found in coal mine waters are high levels of proton acidity, H^+, high metal concentrations, majorly Fe, Mn, Al, Ni and very high concentrations of sulphate, $SO4^{2-}$, often collectively termed Acid Mine Drainage (AMD).

3.2 Microbial load of the water samples from the coal mined site

At upstream primary (USp) in the month of July, the total viable count (TVC) of the bacteria Pseudomonas *aurogenosa and* Bacillus *substilis* were $9.0×10^3$cfu/ml and $1.2×10^4$cfu/ml while in the month of August it was $9.0×10^3$cfu/ml and $1.3×10^4$cfu/ml respectively. The presence of these microorganism could be due to the fact that the mine water is acidic as earlier mention and so can sustain the lives of *acidithiobacillus* group like Bacillus and Pseudomonas *auroginosa*. These findings are in line with the reports of Mayes *et al.,* (2008) and Natarajan (2008). Fungi present at this point were Aspergillus *niger* and Aspergillus *flavus* which were $1.2×10$cfu/ml and $1.0×102$cfu/ml respectively in the month of July and $1.3×10$cfu/ml and $1.0×102$cfu/ml by August. The presence of fungi could be due partly to the presence of debris in the water and the fact that microorganisms are ubiquitous. At point of discharge (PD), Streptococcus *faecalis* ($2.3×10^4$cfu/ml) and Klebsiella *Spp* ($2.4×10^4$cfu/ml) were bacteria recorded in July. Streptococcus *faecalis* present was $2.3×10^4$cfu/ml and Klebsiella *Spp* was $2.4 ×10^4$cfu/ml in August. The presence of these two organisms could be attributed to the faecal matters around that found their way into the river water. The type and number of bacteria present at this station may still be attributed to the faecal particles in and around the water bodies. The same fungi present at USp were also present at PD at the same concentrations in the month of July. However, in August, Aspergillus *niger* increased to $1.3 ×10^2$. At 100m upstream of Orobo river from the point of discharge labeled USs (Upstream secondary), E. *coli* ($1.2 ×10^2$cfu/ml), Pseudomonas *aurogenosa* ($1.0 ×10^2$cfu/ml), Salmonella *Spp* ($1.0 ×10^3$cfu/ml) were present while the only fungus present was Aspergillus *niger* ($1.0 ×10^2$mg/l) in the month of July. In August, it was only the total viable count (TVC) of E. *coli* and Bacillus *subtillis* that increased to $2.7 ×10^3$ cfu/ml and $3.4 ×10^2$cfu/ml respectively. The faecal coliform (E. *coli,* Salmonella *Spp*) are indications that

outside the AMD, the water bodies are contaminated with faecal matter. The presence of Bacillus *subtillis* and Pseudomonas *aurogenosa* at this point is an indication that the same quality of water at upstream primary flows down to the point of discharge. The presence of these two microbes is also in line with the reports of Mayes *et al.,* (2008) and Natarajan (2008). At the fourth location, 100m downstream from the point of mine water discharge labeled DSp (Downstream primary), the bacteria present in the July include E. *coli* (2.4 ×10^3cfu/ml), Bacillus *substillis* (3.8 ×10^2cfu/ml), Salmonella *Spp* (1.9 ×10^3cfu/ml) and Streptococus *faecalis* (1.9 ×10^4cfu/ml). The bacteria present at downstream primary are indications that at the meeting point of Orobo and Nyama rivers, the microbial load of the water sample remains the same as it flows down the major river. Aspergillus *flavus* of 1.3 ×10^2cfu/ml was the only fungus recorded present at this point. In August, the TVC of other microbes remained the same except for E. *coli*, Salmonella *Spp* and Aspergillus *flavus* which were 1.8 ×10^2cfu/ml, 1.2 ×10^3cfu/ml and 1.4 ×10^2cfu/ml respectively. The reduction in the microbial load in August may be due to lack of required nutrients for the microbial growth.

3.3 Statistical analysis

To test the hypotheses that guide this study, Analysis of variance (ANOVA) was used to test for significant differences at P≤0.05. The treatment means were separated using Duncan's multiple range test (DMRT). At 95% confidence level, there is no statistically significant difference in the parameters of the water samples within months (July and August). For all the parameters, α-significant at P≤0.05 fall within .207 and .995.

Duncan's multiple range test (DMRT) shows that with the exception of temperature, there is significant difference in the parameters of the water samples collected at different stations (Table 3). For all the parameters, alpha (α) is significant at P≤0.05. In table 4, DMRT shows that with the exception of Lead (Pb), there is significant difference (p≤0.05) in the heavy metals found in the water samples collected at different stations.

Table 3: Physico-chemical composition of the water samples

Stations	Physicochemical Parameters											
	TDS (mg/l)	EC (μs/m)	Temp (^{0}c)	TS (mg/l)	TSS(Mg/l)	pH	AL(mg/l)	AC(mg/l)	PO$_4$(mg/l)	Cl$_2$(mg/l)	NO$_3$(mg/l)	SO$_4$(mg/l)
USp	62.5±3.53[a]	49.7±042[a]	27.45±1.34[a]	103.70±0.85[a]	121.65±2.05[a]	5.95±0.07[a]	3.20±0.15[a]	15.40±0.148[a]	2.08±0.42[a]	279±1.4[a]	10.13±0.064[a]	430.0±14.1[a]
Dp	20.25±0.35[b]	49.54±0.65[a]	28.0±0.14[a]	106.7±0.57[b]	111.0±1.4[b]	6.90±0.00[b]	1.95±0.78[b]	10.09±0.85[b]	0.80±0.03[b]	94.6±0.79[b]	5.69±0.18[b]	79.52±0.7[b]
USs	10.0±0.00[c]	200.0±0.00[b]	27.5±0.10[a]	111.55±0.64[c]	116.45±0.21[c]	7.60±0.14[c]	1.95±0.78[b]	10.12±0.63[b]	0.78±0.64[b]	94.1±1.47[b]	5.46±0.15[b]	79.82±0.18[b]
DSp	20.0±0.00[b]	30.0±0.00[c]	28.40±0.28[a]	11.0±0.14[d]	20.99±0.156[d]	6.00±0.00[a]	2.93±1.0[a]	13.10±0.00[c]	0.47±0.14[c]	45.1±0.07[c]	2.25±0.21[c]	64.90±0.14[b]
WHO Limit (2006)	500	500	30	30		6.5-9.5			5	250	50	500

Data are presented as MEAN + SEM, n=4.
Means with the same superscript in the same column are not statistically significant at (P≤0.05)
WHO standard is included for comparison.

Table 4: Trace metal composition of the water samples

Stations	Elements								
	Zn (mg/l)	K (mg/l)	Cu (mg/l)	Na (mg/l)	Ca (mg/l)	Fe (mg/l)	Pb mg/l	Mg (mg/l)	Co (mg/l)
100m USp	1.51±0.57 [a]	26.11±0.1 [a]	0.06±0.014	54.5±0.262 [a]	22.12±0.85 [a]	12.58±0.21 [a]	0.2±0.00 [a]	12.12±0.03 [a]	0.47±0.7 [a]
DP	1.32±0.01 [b]	15.90±0.078 [b]	0.02±0.007	8.45±0.78 [b]	9.17±0.28 [b]	11.90±0.01 [a]	0.01±0.00 [a]	8.75±0.22 [b]	0.33±0.78 [a]
100m USs	1.32±0.06 [b]	15.84±0.148 [b]	0.02±0.014	8.40±0.15 [b]	9.1±0.13 [b]	11.56±0.69 [a]	0.15±0.00 [a]	8.47±0.69 [b]	0.29±0.13 [(b) (a)]
DSp	1.04±0.57 [c]	8.34±0.20 [c]	NAD	6.28±0.17 [c]	3.66±0.28 [c]	4.79±0.23 [b]	0.015±0.01 [a]	2.17±0.40 [c]	0.65±0.35 [b]
WHO Standard	5.0		0.2				0.01	200	

Data are presented as MEAN + SEM, n=4.

Means with the same superscript in the same column are not statistically significant at (P≤0.05).

WHO standard is included for comparison.

NAD= Not available for detection

4.0 Conclusion and Recommendations

The abandoned coal mine sites contribute to the type as well as the concentration of microorganisms and heavy metals present in the water samples. Consequently, the microbial load and the physicochemical parameters/indicators of water quality are affected negatively. Statistically, there is no significant difference in the quality of the surface water samples between the months of July and August and therefore, the level of pollution is the same. Faecal coliforms are the major microbial contaminants of the surface waters investigated and may be due to open defecation system within the vicinity of the abandoned mine sites which are point sources of surface water. The consideration of the health effects of the cessation of coal mining in Okpara mine within the area has been a worthwhile endeavour especially in the light of the fact that the source of drinking water for the people largely depend on the contaminated surface water. The health issue which anchors this study form an integral part of the principles of sustainable drinking water supply. Hence, an integrated approach involving all stakeholders is needed to address the potential health reality of the community members. Any programme of intervention now should target the broadening of alternative sources of drinking water for the community.

Appendix I

Table 1: Mean values of physicochemical parameters of the water samples from the coal mined site

Stations	Physicochemical Parameters											
	TDS (mg/l)	EC (µs/m)	Temp (^{0}c)	TS (mg/l)	TSS (mg/l)	pH	AL (mg/l)	AC (mg/l)	PO$_4$ (mg/l)	Cl$_2$ (mg/l)	NO$_3$ (mg/l)	SO$_4$ (mg/l)
USp	62.5	49.7	27.45	103.70	121.65	5.95	3.20	15.40	2.08	279	10.13	430.0
Dp	20.25	49.54	28.0	106.7	111.0	6.90	1.95	10.09	0.80	94.6	5.69	79.52
USs	10.0	200.0	27.5	111.55	116.45	7.60	1.95	10.12	0.78	94.1	5.46	79.82
DSp	20.0	30.0	28.40	11.0	20.99	6.00	2.93	13.10	0.47	45.1	2.25	64.90
WHO Limit (2006)	500	500	30	30		6.5-9.5			5	250	50	500

Key: USp= Upstream primary, DP= Discharge point, USs= Upstream secondary, DSp= Downstream primary, TDS = Total Dissolved Solid, EC = Conductivity, TSS = Total Suspended Solid, TS= Total Solid, pH= Potential hydrogen, AL=Alkalinity, AC= Acidity, PO$_4$= Phosphate, Cl= Chloride, NO$_3$ = Nitrate, SO$_4$ = Sulphate

Appendix II

Table 2: Mean values of the Elements in the water samples from the coal mined site

Stations	Elements (Trace Metals)								
	Zn(mg/l)	K (mg/l)	Cu (mg/l)	Na (mg/l)	Ca (mg/l)	Fe (mg/l)	Pb (mg/l)	Mg (mg/l)	Co (mg/l)
USp	1.51	26.11	0.06	54.5	22.12	12.58	0.2	12.12	0.47
DP	1.32	15.90	0.02	8.45	9.17	11.90	0.01	8.75	0.33
USs	1.32	15.84	0.02	8.40	9.1	11.56	0.15	8.47	0.29
DSp	1.04	8.34	NAD	6.28	3.66	4.79	0.015	2.17	0.65
WHO Standard	5.0		0.2				0.01	200	

Key: USp= Upstream primary, DP= Discharge point, USs= Upstream secondary, DSp= Downstream primary, Zn = Zinc,

K = Potassium, Cu = Cupper, Na = Sodium, Ca = Calcium, Cd =Cadmium, Cu = Copper, Fe = Iron, Pb = Lead,

Mg = Magnesium, Co = Cobalt, NAD = Not Available for Detection.

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