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THE EFFECT OF COAL MINING ON THE WATER QUALITY OF WATER SOURCES IN NIGERIA

Oloche Robert Ekwule[1*], Gabriel Delian Akpen [1], George Moses Ugbede[1]
[1]Department of Civil Engineering, University of Agriculture, Makurdi, Nigeria.

Abstract

The aim of this study is to investigate the effect of coal mining on the drinking water quality of different water sources in Odagbo, Ankpa L.G.A., Kogi State, Nigeria. Five water samples each, were collected during the dry season, inception of wet and peak wet seasons from the community's three water sources. Physico-chemical properties such as electrical Conductivity (EC), Total Dissolved Solids (TDS), turbidity, pH, hardness of the water samples were analyzed. Heavy metal concentrations of the samples were also determined. The result of the chemical characterization placed the tailings in a semi-acidic group because 50% of its constituents oxides are of weak acid, therefore making the tailings a potential source of Acid mine drainage (AMD). The results for water quality test revealed that the values of EC, TDS, chloride, and sulphate for the three water sources (pond, borehole and river) were within World Health Organization (WHO) and Standard Organization of Nigeria (SON) safe limits for both the dry and wet seasons. The metallic levels of the metals studied were relatively low in all the water samples during the dry season with copper, chromium, manganese, cobalt, iron, lead and nickel not being detected. There was a reasonable increase in concentration of heavy metals during the wet seasons possibly as a result of AMD with metals like copper, chromium, cobalt and nickel not detected. The pollution indices of all the water samples during the sampled periods, exceeded the critical value of 100. The degrees of pollution of all the sampled water descended in the order; pond > river > borehole for all the seasons. Hence, borehole water is the best option for the community's consumption after lime treatment to correct its acidity level.

Keywords: Coal mining, water quality, acid mine drainage, heavy metals.

1. Introduction

Okaba district is a rural community in Nigeria, where coal mining was the central socio-economic activity for thirty-eight years (1967-2005). Odagbo coal mine is located in Okaba district, and was in operation before been ceased by the Federal government of Nigeria (Kogi State Solid Minerals Investment Prospects, 2005). Despite the cessation, the activities of illegal miners have thrived over the years with little or no confrontation from law enforcement agencies. Consequently, this had unleashed various degrees of damages to the environment. The effect of industrialization and technological advancement has long threatened the sustainability of a globally friendly environment. Industrial activities such as mining and combustion of fossil fuel are responsible for environmental problems such as environmental degradation and climate changes (Adejoke et al., 2018).In locations where there are mineral deposits, there is bound to be exploration or mining activities to get hold of the natural mineral resources available (Naveen-Saviour& Stalin, 2012). One of the proceeds from mining activities is coal, which is mostly used for electricity and heat generation. The adverse effect of coal mining activities is of enormous concern, knowing that the acidification of surface water bodies are as a result of heavy metal contamination from coal mining activities (Moschini-Carlos et al., 2011).

Koshal (2002) described coal mining activities as one that deteriorates land, surface and ground water. He also noted the difficulty in handling coalwhich is dirtier in combustion than either oil or natural gas. The most dominant of all mining activities responsible for environmental degradation is attributed to coal mining(Greb, 2002). Toxic pollutants

*** Corresponding Author:**
Oloche Robert EKWULE; Department of Civil Engineering, University of Agriculture, Makurdi Nigeria.
Tel: +2348139065007
E-mail: ekwule.robert.uam@gmail.com

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contained in coal that is formed during combustions is released into the air, water and the soil. Some of the pollutants are known to cause cancer, while some impair reproduction (Keating, 2001). Areas where coal mining was predominant in time past, and abandoned over a period of time are sources of water pollution (Moschini-Carlos et al., 2011). These abandoned sites often have deposits of coal tailings which are ore waste of coal mines, and are typically a mud-like material. Studies (Bell et al.,2001; Akcil & Koldas, 2006) have shown that coal tailings are potential source of Acid mine drainage (AMD). Acid mine drainage is the chemical process inwhich sulphide-bearing minerals are oxidised to produce acidic conditions in effluents (Johnson & Hallberg, 2005). According to Akcil & Koldas (2006), the mineralogy of coal, the surrounding atmospheric environment and local microbial activity all influence the potential for sulphur species mobilisation and AMD formation. Lawson(2011) observed that the acidity of a water body influences the concentration of metals by altering their availability and toxicity.This study is to investigate the impact of coal mining on the water quality of water sources in Odagbo Area of Kogi State, Nigeria.

2. Materials and Methods

2.1 The Study Area, Sampling procedure and Data Collection Techniques

The actual coal mining site is at Odagbo, on the outskirts of Okaba town in kogi state. Okaba district lies some 16 km NE of Ankpa town, headquarters of Ankpa Local Government Area, Kogi State. The study area is located between latitudes $7^0\ 20^1 - 7^0\ 43^1$N and longitudes $7^0\ 22^1 - 7^0\ 52^1$E. The area is within the tropical hinterland. Annual rainfall total ranges from 100- 200 cm and spreads over 6-8 months (Ogwuche & Odoh, 2013). According to Ogwuche & Odoh (2013), earlier investigations by researchers such as De Swardt & Casey (1961) indicated that the lower coal measured at Okaba contain a high proportion of shale and sandy shale. A few outcrops of the false-bedded sandstones occur. The soils are clayey, muddy and difficult to traverse when wet (FDALR, 1990).

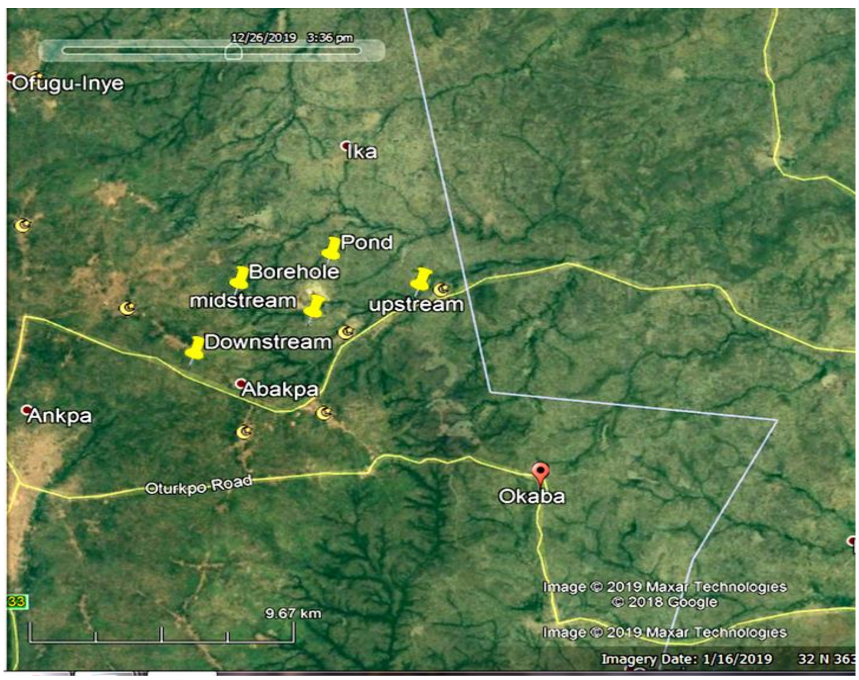

Figure 1. Aerial view of Okaba and its surrounding settlement

Sampling was done thrice and at different periods. Samples were collected during the dry season in March, at the inception of the rainy season in May and at the peak of rainy season in September. In all, fifteen water samples were used for the research. Grab water samples were collected each from the pond located at the coal mine, the borehole within the community, upstream, midstream point, and downstream discharge point of the stream in the location. The samples were labeled according to their sources and seasons of collection thus: samples collected in the dry season were assigned **DS**, while **WS** and **PWS** were assigned inception of rainy season and peak rainy season respectively. The subscripts **P**, **B** and **S** represent the water sources Pond, Borehole and Stream respectively. However, the stream has superscript labels (**U**, **C** and **D**) representing samples Upstream, midstream and downstream of pollution point

respectively. The water samples were transported to the quality control laboratory of the Greater Makurdi Water Board for analysis. Samples were analyzed for the following water quality parameters; Conductivity, Total dissolved solids (TDS), Turbidity, pH, Total Hardness, Chloride, and Sulphate following Standard Methods (APHA, 1998).
Coal tailings from the study area was chemically characterized using an X-ray fluorescence machine. The chemical composition of coal tailings from Odagbo coal mine and their corresponding characteristics as provided by March (1992) are presented in Table 1. The composition as observed indicated a silico-aluminous nature, bearing 55.3% of the total weight. This combined percentage of the silicon and aluminum oxides, places the tailing in the semi-acidic group as also observed by Stolboushkinoet al. (2016). It is a potential environment for acid mine drainage. Other oxides present were basic in nature except for those of sulfur and iron whose combined percentage presence was 10%. Based on this finding, the coal tailings of Odagbo can be said to be a potential source for AMD (Acid Mine Drainage).

Table 1. Chemical composition of coal tailing from Odagbo coal mine

Oxides	Percentage Composition (%)	Chemical Characteristic (March, 1992)
Silica or silicon oxide (SiO_2)	40.53	Very weakly Acidic
Aluminum oxide (Al_2O_3)	14.77	Amphoteric
Sulfur trioxide (SO_3)	0.67	Acidic
Calcium oxide (CaO)	1.78	Basic
Magnesium oxide (MgO)	2.50	Basic
Potassium oxide (K_2O)	2.34	Strong Basic
Sodium oxide (Na_2O)	0.65	Basic
Ferric oxide (Fe_2O_3)	9.43	Not Amphoteric but mostly acidic
Loss on Ignition (LOI)	27.33	-

2.2 Data Analysis:

Interpretation of the results was done using pollution factor indices and comparisons made with World Health Organization WHO (2011) and SON (2007) standards. Heavy Metal pollution index of water samples was determined using Equations 1 and 2

$$HPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \tag{1}$$

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i\}}{(S_i)} \times 100 \tag{2}$$

Where Q_i = the sub-index of the ith parameter, W_i = the unit weightage of the ith parameter, S_i = the standard value of the ith parameter, M_i = the monitored value of heavy metal of ithparameter, and n = the number of parameters considered.

3. Results and Discussion

3.1 Physico-Chemical Water Quality

The results of Physico-Chemical characteristics of the water samples (Pond, Borehole and Stream), are presented in Figure 2. World Health Organization (WHO, 2011) and Standards Organization of Nigeria (SON, 2007) limits were used to check the potability of the water sources.

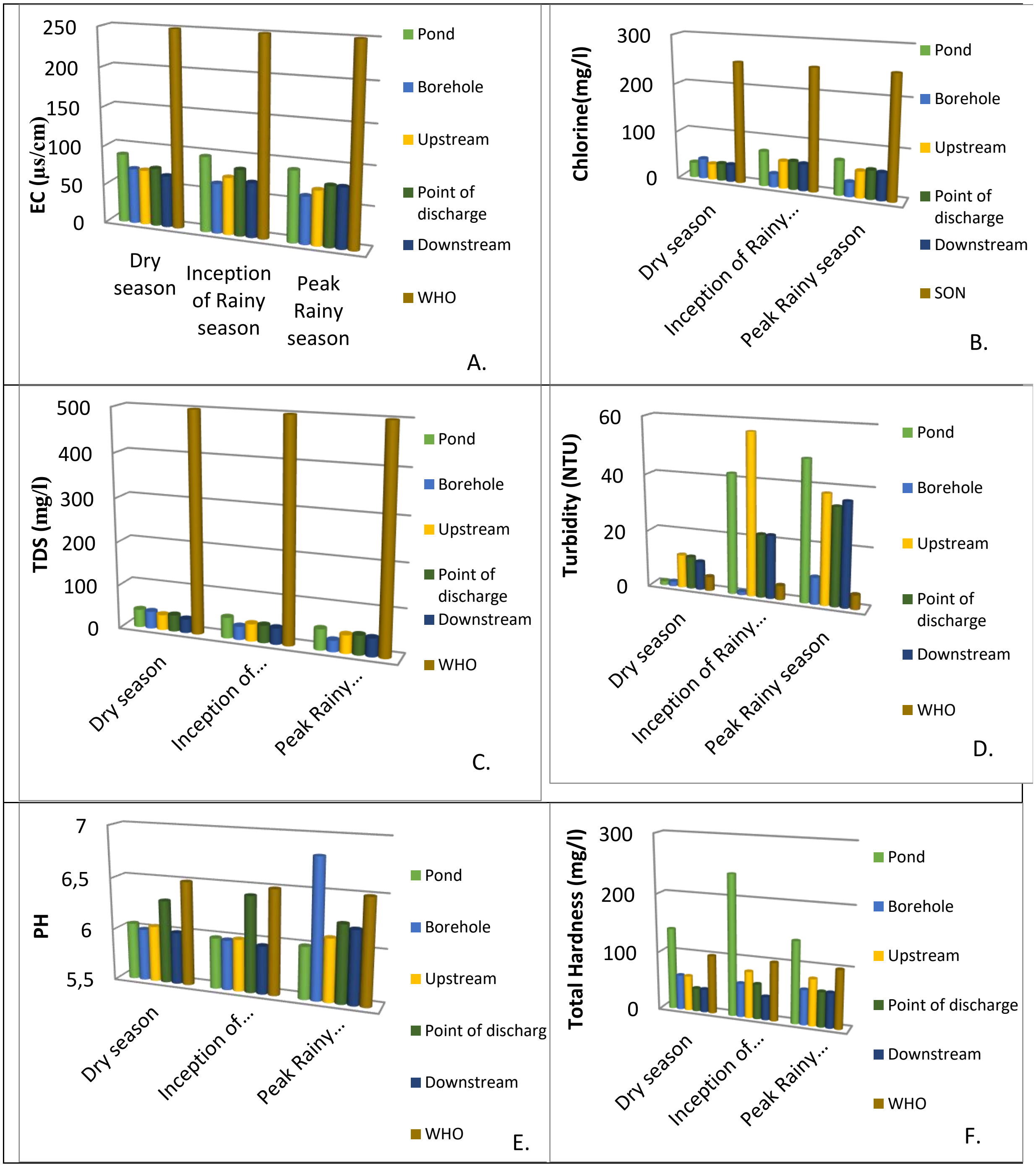

Figure 2. The Seasonal Physico-Chemical parameter concentration of water samples from the Pond, Borehole and River sources.

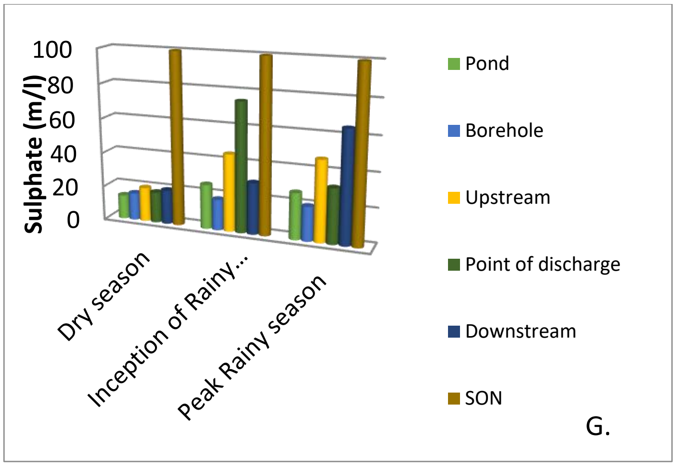

Figure 2 (continues). The Seasonal Physico-Chemical parameter concentration of water samples from the Pond, Borehole and River sources.

3.2 Electrical conductivity

Figure 2A presents the electrical conductivity of all the water samples observed during the dry season as 80 µs/cm, 60 µs/cm and 65 µs/cm for Pond, Borehole, and Stream sources respectively. At the inception of rainy season, 80µs/cm, 55 µs/cm and 60 µs/cm were obtained for Pond, Borehole, and Stream sources respectively. While the peak rainy season recorded 70µs/cm, 60µs/cm and 65 µs/cm for Pond, Borehole and Stream sources respectively. The values obtained were within WHO's standard of 1500 µs/cm and SON's standard of 250µs/cm for portable water. The EC of the pond is greater than those of the borehole and stream in both seasons as in the case of Verma et al. (2012). This is probably due to the fact that the pond receives effluents from the mine pits directly.

3.3 Total dissolved solids

Figure 2C shows the values of TDS of all the water samples during the sampling periods. The TDS indicates the presence of different materials in the water sources. It comprises of both colloidal and dissolved solids. In natural water, dissolved solids are composed of mainly Na^+, K^+, Ca^{2+} and Mg^{2+}(Prasanthi et al., 2012). Moderate levels of TDS concentration in water is emphasized, because having it in extremely low or high concentration affects the quality of the water. Extremely low TDS concentration is unacceptable and can lead to a flat and insipid taste (WHO, 1996). The TDS values were within WHO's standard of 1250 mg/l and SON's standard of 500 mg/l for potable water.

3.4 Turbidity

Figure 2D shows the values of turbidity of the pond water (DS_p) during the dry season and that of the borehole water (DS_B) during the dry season and at the inception of the wet season (WS).These values were within WHO and SON standards of 5 NTU. The rest samples were above these standards with the highest values experienced during the wet seasons. This scenario probably, is caused by runoff being emptied into the pond and river and possible downward movement of water as explained by Wu et al. (2008), Awalla (2014).

3.5 pH

Figure 2E presents the pH values for all the water samples during the periods of sampling. The pH values indicated acidity and were below WHO's standard of 6.80 - 8.40 for potable water. A condition that is common with water sources within mining location due to possible acid mine drainage as explained by Awalla (2014) and Matthew et al. (2012). This is also a possible scenario in Odagbo, with the chemical composition of coal tailings identified as acidic within the area. USGS (2016) stated that ground water, especially if the water is acidic in many places contain excessive amount of iron. This was observed in the case of borehole water that is located far away from the tailings deposit site. The lower pH of water, according to Adekunle & Mojisola (2009) is more likely to corrode household metals.

3.6 Hardness

Figure 2F presents the hardness of the water samples from all the water sources. There was a considerable increase in hardness of the pond water samples at the inception of the wet season compared to what was obtained during the dry and peak wet seasons (i.e 140 to 240 mg/l). Apart from the pond, all other samples were within WHO standard of 100 mg/l for the sampled seasons. Since the pond receives effluent/or runoff directly, the increase in hardness could be a resultant effect caused by the presence of multivalent ions from natural minerals which are known to dissolve in water (Eze & Chigbu, 2015).

3.7 Chloride

Figure 2B shows that the concentration of chloride in the water samples ranged from 27.9 mg/l to 73.0 mg/l. These were all within the recommended limit of 250 mg/l by SON. However, during the inception of the wet and peak wet seasons, the pond and river recorded higher chloride content than in the dry season. This is probably due to the process of weathering and runoff from the mine pit entering into them. Chloride ion is highly mobile and is transported to closed basins or oceans (WHO, 1996).

3.8Sulphate

Sulphate concentrations in the water samples ranged from 14 mg/l to 75 mg/l as presented in Figure 2G. These were all within the recommended limit of 100 mg/l by SON. The considerable increase in the sulphate content of both the pond and river for the wet seasons as compared to the dry season is probably due to runoff received from the mine pit. A similar observation was made by Wu et al. (2008), where they noted that seasonal variation had an effect on the sulphate concentration of the river especially during the dry season.

3.9 Heavy Metal Content of Water Samples

The results obtained for the concentrations of heavy metals (Cd, Cr, Cu, Mn, Ni, Pb, Fe, Zn, and Co) in the water samples collected from different water sources (pond, borehole and stream), were compared with the WHO/SON maximum permissible limit. The results are presented in Tables 2- 4. The observed metallic levels were generally low across the water sources in the dry season. Copper, chromium, manganese, cobalt, iron, lead and nickel were not detected. There was a noticeable increase in the concentration of heavy metals during the two sampled periods of the wet season. The highest metallic levels were observed in the peak wet season with Iron having the highest level in both the pond and the stream waters. This could probably be due to surface runoff carrying waste from the mine to these water sources just as reported by Wu et al .(2008).

Table 2. Heavy metal concentration of pond water

S/No	Heavy Metals	Dry Season (DS_p)	Inception of Wet Season (WS_p)	Peak wet season (PWS_p)	SON
1.	Copper (Cu)	0.000	0.00	0.000	1
2.	Chromium(Cr)	0.000	0.00	0.000	0.05
3.	Manganase(Mn)	0.000	0.506*	0.000	0.2
4.	Cadmium(Cd)	0.027*	0.029*	0.028*	0.003
5.	Cobalt(Co)	0.000	0.00	0.000	-
6.	Iron(Fe)	0.000	9.101*	3.010*	0.3
7.	Lead(Pb)	0.000	0.170*	0.224*	0.01
8.	Zinc(Zn)	0.047	0.315	0.750	3
9.	Nickel(Ni)	0.000	0.00	0.032*	0.02

* indicates experimental data whose value exceed standard permissible limit.

Note: $\mathbf{DS_p}$=Dry season for pond source, $\mathbf{WS_p}$=Wet season for pond source, $\mathbf{PWS_p}$=Peak wet season for pond source.

Table 3. Heavy metal concentration of borehole water

S/No	Heavy Metals	DrySeason (DS_B)	Inception of Wet Season (WS_B)	Peakwet season (PWS_B)	SON
1.	Copper (Cu)	0.000	0.000	0.000	1
2.	Chromium(Cr)	0.000	0.000	0.000	0.05
3.	Manganase(Mn)	0.000	0.000	0.000	0.2
4.	Cadmium(Cd)	0.025*	0.026*	0.019*	0.003
5.	Cobalt(Co)	0.000	0.000	0.000	-
6.	Iron(Fe)	0.000	0.000	0.657*	0.3
7.	Lead(Pb)	0.000	0.133*	0.212*	0.01
8.	Zinc(Zn)	0.014	0.000	0.625	3
9.	Nickel(Ni)	0.000	0.000	0.000	0.02

* indicates experimental data whose value exceed standard permissible limit.
Note: $\mathbf{DS_B}$ =Dry season for Borehole source, $\mathbf{WS_B}$ =Wet season for Borehole source, $\mathbf{PWS_B}$ =Peak wet season for Borehole source.

Table 4. Heavy metal concentration of stream water

S/No	Heavy Metals	DrySeason DS_S	Inception of Wet Season WS_S	Peakwet season PWS_S	SON
1.	Copper (Cu)	0.00	0.00	0.000	1
2.	Chromium(Cr)	0.00	0.00	0.000	0.05
3.	Manganase(Mn)	0.00	0.00	0.000	0.2
4.	Cadmium(Cd)	0.026	0.025	0.025	0.003
5.	Cobalt(Co)	0.00	0.00	0.000	-
6.	Iron(Fe)	0.00	0.879*	50.12*	0.3
7.	Lead(Pb)	0.00	0.179*	0.207*	0.01
8.	Zinc(Zn)	0.00	0.028	0.119	3
9.	Nickel(Ni)	0.00	0.00	0.091*	0.02

* indicates experimental data whose value exceed standard permissible limit.
Note: DS_S =Dry season for stream source, WS_S =Wet season for stream source, PWS_S =Peak wet season for stream source.

Another reason for the few observed higher metallic level during the wet season is Acid mine drainage (AMD). AMD is the interaction of rain water with the mine spoils scattered around containing trace elements mixed with other pollutant sources such as agricultural product Fertilizer, Pesticide etc. which are emptied into the stream and the pond from surface runoff. A similar observation was made by Matthew et al. (2012) who reported that the interaction of rain with mine tailings resulted in the increased level of acidity of River Pomponthus, making more metals available. Likewise, Lawson (2011) observed that the acidity of a water body influences the concentration of metals by altering their availability and toxicity.

3.10 Heavy Metal Pollution index of water samples

Heavy metal pollution index (HPI) is an effective tool to characterize surface and ground water pollution as it combines several parameters to arrive at a particular value which can be compared with the critical value to assess the level of pollution load (Prasad &Kumari, 2008). The Mean concentration of nine heavy metals (Cd, Cr, Cu, Mn, Ni, Pb, Fe, Zn, and Co) heavy metals were used for the HPI determination. The mean HPI for each of the water sources during the three sampling periods was found to be more than 500, which is above the critical value of 100. HPI was also calculated separately for each heavy metal for all the sampling sources during the periods under study to compare the pollution load and assess the water quality of the selected sources with respect to individual heavy metals.
For the water samples taken from the pond and borehole during the dry season, it was observed that only Cadmium and Zinc were detected as pollutants with zinc showing no threat of contamination because it is below SON (0.003 mg/l) and WHO's (0.003 mg/l) permissible limits. The values of Cd for both water sources were above the permissible limit of both SON and WHO, which may pose serious contamination threat to these water sources. The overall

pollution index for these water sources are 641.03 and 593.55 for the pond and borehole respectively. Table 5 shows the mean HPI of the water sources as well as the sampling periods considered.

Table 5. Mean HPI of different water sources and sampling periods.

	Pond			Stream			Borehole		
	DS	WS	PWS	DS	WS	PWS	DS	WS	PWS
HPI	641.03	1076.07	1167.66	593.55	978.11	1203.36	593.55	901.49	905.67

Note: DS=dry season, WS=inception of wet season, PWS=Peak wet season.

The mean heavy metal pollution index (HPI) tested for pond, stream, and borehole water sources at the inception of the wet season are 1076.07, 978.11 and 901.49 respectively. The values of the HPI at the inception of wet season for all the sources exceeds the critical value of 100 (Milivojević, 2016). Hence, the water is said to be contaminated by heavy metals and are rendered not portable for consumption according to Mohan et al. (1996). The mean pollution index of the pond during the peak wet season was 1167.66. While the mean pollution index of borehole water increased to 905.67 probably due the presence of more Fe.

With respect to sampling points along the stream, the mean pollution index of 664.77, 593.55 and 624.40 were obtained for upstream, downstream and discharge point respectively. All these values exceeded the critical value of 100, indicating pollution. At the inception of the wet season, the stream recorded the following heavy metal pollution index (HPI); 790.65, 978.11 and 1035.61 at the upstream point of discharge, point of discharge and at the downstream point of discharge respectively.

During the Peak wet season, more heavy metals were detected, thereby, increasing the mean pollution index for all sample points except for the downstream point of pollution. The upstream point recorded a mean pollution index of 1330.34, while the point of discharge had 1203.36 and the downstream point had a value of 811.269. The values showed that the stream is probably being polluted from another source upstream, therefore coal mining in this area may not be said to be responsible for the stream pollution entirely.

Based on the findings of this research, it was observed that cadmium is the dominant pollutant in this community. A situation which may be due to the presence of huge coal deposit beneath the community soil.Cadmiummostlyoccurs in association with zinc, which explains why traces of zinc was found in most of the water samples where cadmium was dominant. Nassef et al.(2006) observed that the main sources of cadmium are mining and industrial activities. They further observed that at higher concentrations, Cd is known to have a toxic potential.Adriano (2001) also observed that cadmium interferes with metabolic processes in plants and can bioaccumulate in aquatic organisms and enter the food chain.

Generally, the metallic levels of the studied metals were relatively low in all the water samples during the dry season with copper, chromium, manganese, cobalt, iron, lead and nickel not being detected which could be due to low waste entrance into this water bodies in this season.However, a reasonable increase during the wet seasons but heavy metals like copper, chromium, cobalt and nickel were still not detected, this increase in metallic presence during the wet season could be attributed to AMD, according to Lawson (2011), and the acidity of a water body influences the concentration of metals by altering their availability and toxicity. Also, run off during this season could carry wastes that are potential carriers of this heavy metals.

The pollution degrees of all the sampled water descended in the order; pond > river > borehole for dry season, pond > river > borehole at the inception of the rainy season and pond > river > borehole during the peak rainy season.

4. Conclusion

The coal tailing of Odagbo is of the silico-aluminium nature which places it in the semi-acidic group, thereby, making the tailings potential environment for AMD. The water from the different sources considered are generally low in pH, indicating high levels of acidity. All pyhsico-chemical parameters measured except turbidity and hardness were within acceptable limits. In same vain, the sampled water sources were fairly polluted however, the source of pollution for all the water soucres may not be tied to mining activities only. The pollution degrees of all the sampled water descended in the order; pond > river > borehole indicating that borehole water was least polluted and therefore the best option for the community consumption after lime treatment to correct its acidity level.The metallic concentrations of the metals considered were generally within acceptable limits in all the water sources during the sampling period.

Though high levels of Mn, Cd, Fe, Pb and Ni were noticed in some cases especially during the wet seasons. The low metallic levels observed during the dry season could be due to the low level of contaminants entering the water sources. The higher metallic levels observed during the wet seasons could be due to AMD because over 50% of the chemical composition of the tailings obtained from Odagbo belong to the group of Semi-Acidic oxides which are potential sources of AMD.

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