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Assessment of Water Pollution Status in the Mining Area of Ameka, South Eastern Nigeria Using Metal Pollution Index

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Abstract— *The assessment of water pollution status in the mining areas of Ameka was undertaken to determine the extent to which the hydrological setting of the area have been affected by the mining activities in the area using the World Health Organization Standards as guide. Ten water samples were systematically collected from different sources at interval in thoroughly washed and sterilized plastic container. Physico-chemical analysis was done within 48 hours. The anions were determined by simple flame analysis while Heavy metal analyses was conducted using the Varian AAS 240 Atomic Absorption Spectrophotometer. Metal pollution Index was used to ascertain the level of water pollution in the area. The results show that the surface water in the entire area has been adversely polluted physico-chemically. A pH of 5.7 (average) puts the surface water as acidic. All the heavy metals tested for had pollution indices values far above the threshold. Ten elements that have the highest pollution indices are Cr < Ag < Al < Mn < Pb < Hg < Se < Zn < Cd < As while,* Cl^-, $S0_4^{2-}$, $N0_3^-$, $P0_4^-$, K^+, *Mn, Hg, Mg and Cd had the widest spread each making up to 100, 90 or 80 % spread. Pb, Fe, As, Zn, Ni, Na and Ca where also high making up to 70% appearances in the area. Comparing the above, it is logical to deduce that Hg, Cd and Mn have the most polluting effect followed by As, Zn, Pb, Se, Ag and Cr.*

Keywords— *Ameka, Lead-Zinc mining, Physico-chemical, Water quality, Metal pollution Index.*

I. INTRODUCTION

Ameka is one of the many communities in the Abakaliki area where active mining activities are carried out (Obasi and Akudinibi, 2015). The area lies between latitudes 6^0 09^lN and 6^0 14^lN and longitudes 8^0 05^lE and 8^0 10^lE. The area is endowed with lead- zinc mineralization which has lead to the indiscriminate and illegal mining and dumping of mine waste in the area. Obasi et al., (2015) noted that minig activities generate geochemical products which find their ways into surface water resources. Potable water is the fundamental need of man to sustain life. Water serves as lubricant, regulates the body temperature and provides the basis for the body fluids and metabolism (Staci, 2005). Water is a good solvent and picks up impurities easily and thus changes its taste, colour and odour. It is well-known fact that when water is polluted, its normal functioning and properties are affected (Trivedi *et al.,* 2010). Physico-chemical parameters of water are important to determine the quality of drinking water. According to WHO (1996) the physical parameters that are likely to give rise to complaint from consumers are color, taste, odour and turbidity while low pH causes corrosion and high pH results in taste complaints (Chan *et al.,* 2007).Water of good drinking quality is of basic importance to human physiology and man's continued existence depends on its availability (Lamikaran, 1999).

Heavy metals are among the most common environmental pollutants, and their occurrence in waters and biota indicate the presence of natural or anthropogenic sources (Obasi, 2017). The main natural sources of metals in waters are chemical weathering of minerals and soil leaching. The anthropogenic sources are associated mainly with industrial and domestic effluents, urban storm, water runoff, landfill leachate, mining of coal and ore, atmospheric sources and inputs from rural areas (Zarazua *et al.,* 2006). Water quality and its suitability for drinking purpose can be examined by determining its metal pollution index (Mohan *et al.,* 1996; Prasad and Kumari, 2008). Hence, this research was necessitated sequel to the high anthropogenic activities within the Ameka mining area resulting from the lead-zinc mineralization; to evaluate the degree of pollution or contamination of the surface water bodies within the area.

1.2. Geology and Physiography of the Area

1.2.1 Geology: The area is located within the Abakaliki Anticlinorium in the southern tip of the Benue Trough, South-East Nigeria. The Abakaliki shale Formation of the Asu River Group (Albian) underlies the study area. The Asu River Group consists of Mid-Albian sediments of very fine dark grey marine shale, siltstone and minor limestone lenses. The sediments were described as consisting of rather poorly-bedded sandy limestone lenses (Kogbe, 1986). The shales in some area are highly weathered and show reddish coloration. The reddish brown colour of the (Abakaliki) shales indicate high content of ferric oxide (Fe^{2+}) which is due to high degree of weathering and low grade metamorphism associated with the volcanic activity in the area (Obiora and Charan, 2011). The rocks are extensively fractured, folded and faulted. From field observations, the rocks of the study area consist of variably coloured shale and mudstone that have been intruded

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by lead-zinc vein mineralization, as well as ironstone along the veins (Obasi and Akudinobi, 2015). Lead-zinc mineralization is abundant in the area. The dominant constituent of the vein are galena (PbS) and sphalerite (ZnS) in gangue of siderite ($FeSO_3$) with subordinate chalcopyrite ($CuFeS_2$) and marcasite (FeS_2).On a regional scale, the lead-zinc (Pb-Zn) mineralization in the graben occupies a NE-SW trending, 600m. long belt of dominantly deformed Albian sediments and occurs in different rock types from Ishiagu in the south west tip to Gombe in the North Eastern corner (Obaje, 2009). Olade (1975) and Obaje (2009) noted that largely, mineralization in the area is within fractured or sheared zones which were formed during the deformational episodes.

1.2.2 Climate: This area is characterized by two climatic seasons; the Wet and Dry seasons, also known as the Rainy and Harmattan seasons. The Rainy or Wet season starts in April and last till October with heavy rainfalls recorded in the months of June, July and September. There is usually decline of rainfall in August. This is usually referred to as "August break". The rainy season is usually a period of high humidity, generally low temperatures and low evapo-transpiration.

1.2.3 Soil and Vegetation: The main soil types found in Abakaliki area are silty - hydromorphic soil. This soil has moderate to reddish-brown silty-clay subsoil. This soil has moderate to low drainage properties with a fairly high natural fertility rate. It provides very good yields of crops ranging from vegetables to tubers. The vegetation of the area is mostly characterized by tree shrubs and a variety of other trees such as palm trees. Most of the vegetations are ever-green while some are deciduous.

II. MATERIALS AND METHOD

2.1 Method of Sample Collection

Ten (10) water samples were systematiclly collected from different sources (fig. 1) at interval in thoroughly washed and sterilized plastic bottles. Physico-chemical analysis was done within 48 hour and the samples were stored below room temperature before getting to the laboratory.

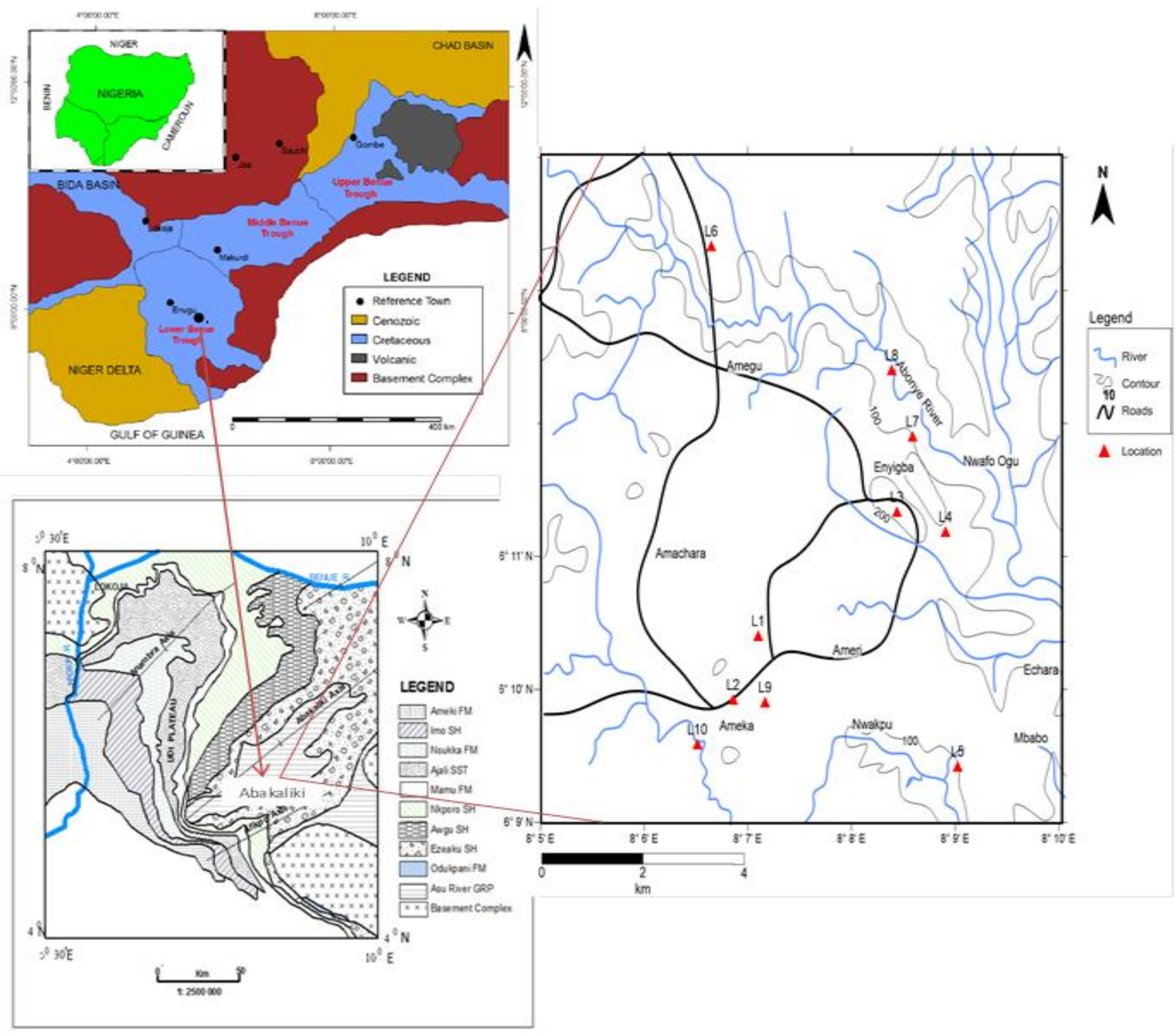

Fig. 1. Sample Location and position of the study area, relative to other formations.

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At the point of collection 2-3 drops of dilute hydrochloric acid were added to reduce hydrolysis, sorption and to further stabilize the samples before getting to the laboratory. In glass thermometer was used to measure the temperature of the water samples, while pH of the water was determined using model DDS 307 pH meter according to the (APHA)2510b guide line (APHA, 1998). The conductivity of water was determined with the help of conductivity meter. Anions were determined by simple flame analysis while, heavy metal analyses were conducted using the Varian AAS 240 Atomic Absorption Spectrophotometer according to the method of APHA, 1995.

2.2 Metal Index/Pollution Index

The index used is the general metal index (MI) for drinking water (Bakan et al., 2010) which takes into account possible additive effect of heavy metals on the human health that help to quickly evaluate the overall quality of drinking waters. Metal pollution Index is given by the expression proposed by (Caeiro *et al.*, 2005).

$$MI = \sum \left| {Ci}/{(MAC)\,i} \right| \quad (1)$$

Where MAC is maximum allowable concentration (here we take account of the WHO maximum permissible limit) and Ci is mean concentration of each metal. The higher the concentration of a metal compared to its respective MAC value the worse the quality of water. MI value > 1 isa threshold of warning (Bakan *et al.*, 2010).

III. Results and Discussion

pH: The pH level in the area ranged from 1.15-9.86. The Ebonyi River and the two Ameka mine sites recoded the lowest pH of 4.06, 1.15 and 4.88 respectively (table I). This high acidity cannot be dissociated from the lead/zinc mining activities in the area. Contrarily, the Enyigba salt lake recorded a pH of 9.87. This high pH is associated to the high concentration of salt in the lake. The average pH levels of 5.7 (table II) puts the surface water in the area as generally acidic. This value falls out the WHO acceptable value range of 6.5-8.5.

Electrical conductivity: The values of the conductivity recorded from the samples were from17.45-388ɥs/m (table I). With these, it implies that about fives samples falls within the WHO permissible range of between 5-50 ɥs/m. however the average value of about 119ɥs/m puts the surface water system of area as having high conductivity.

Turbidity: The Turbidity value recorded in the area ranges from 9-848 NTU (table I). This indicates a generally high turbidity for the area. This relatively high level of turbidity in the area is attributed to the presence of decaying organic matter, clay and silt content of water coupled with other solid particles which are being washed into the surface water and percolate into the hydrological system of the area.

TABLE I. Physico-chemical properties of surface water within the Ameka area.

Sn	Parameters	Unit	L1 Ameka mine	L2 Ameri salt lake	L3 Ameka mine2	L4 Enyigba mine	L5 Onuebonyi river	L6 Akpara river	L7 Ngele river	L8 Enyigba salt lake	L9 Ameka pond	L10 Ameka stream	WHO Std
	Coordinates		**6^{0}09’84N 8^{0}06’65E**	**6^{0}09’84N 8^{0}06’65E**	**6^{0}10’80N 8^{0}08’25E**	**6^{0}11’11N 8^{0}08’53E**	**6^{0}08’85N 8^{0}08’62E**	**6^{0}12’80N 8^{0}06’38E**	**6^{0}11’54N 8^{0}08’34E**	**6^{0}11’84N 8^{0}08’22E**	**6^{0}09’54N 8^{0}06’69E**	**6^{0}09’35N 8^{0}06’30E**	
1	pH		1.15	5.13	4.88	6.47	4.06	6.24	6.20	9.87	6.33	6.69	6.5-8.5
2	Conductivity	ɥs/m	24.4	17.45	18.4	32.7	41.6	120.2	331	137.9	82.7	388	NS
3	Turbidity	NTU	793	703	810	458	107	022	323	433	848	009	50
4	Chlorine	mg/l	1950	45	2800	204	33	42	137.9	40	92	55	250
5	Sulfide	mg/l	65	91	99	45	73	288.1	349.8	246.9	205.8	144.0	250
6	Nitrate	mg/l	0.371	0.386	0.19	1.07	1.09	2.50	2.171	2.653	2.785	2.303	50
7	T.D.S	mg/l	71.5	88.5	70.9	53	70.3	10	8	4	8	2	NS
8	Phosphate	mg/l	72.29	150.9	156.6	199.2	136.3	12.66	9.787	14.12	11.01	10.11	NS
9	Lead	mg/l	0.00	1.73	0.69	0.00	0.02	0.00	0.444	2.728	0.907	1.288	0.01
10	Iron	mg/l	0.00	1.59	0.54	0.37	1.06	0.590	0.00	0.634	6.778	0.00	0.3
11	Copper	mg/l	0.00	0.00	0.004	0.00	0.009	0.028	0.027	0.00	0.00	0.00	2
12	Chromium	mg/l	0.00	0.00	0.19	0.00	0.00	0.796	0.237	0.015	0.861	0.00	0.05
13	Nickel	mg/l	0.00	0.06	0.063	0.003	0.004	0.059	0.108	0.00	0.00	0.149	0.07
14	Manganese	mg/l	0.04	29.44	31.39	9.91	1.043	0.221	0.300	2.059	0.062	10.97	0.4
15	Cadmium	mg/l	0.00	12.08	0.00	0.06	0.046	1.459	0.736	0.618	0.359	2.170	0.003
16	Silver	mg/l	4.24	0.29	0.02	0.07	0.049	0.132	0.00	0.00	0.00	0.00	0.1
17	Cobalt	mg/l	0.00	0.024	0.02	0.07	0.049	0.172	0.145	0.00	0.00	0.00	NS
18	Mercury	mg/l	11	0.4	0.8	1.9	0.00	0.481	0.188	0.101	0.212	0.315	0.006
19	Zinc	mg/l	0.00	10.07	5.88	0.00	0.00	0.032	0.034	0.470	0.228	9.885	0.006
20	Magnesium	mg/l	136	7.77	41.55	25.62	0.00	14.94	0.024	19.23	3.288	18.87	50
21	Potassium	mg/l	2.27	5.24	8.61	8.23	5.87	9.082	0.032	12.85	15.29	15.42	200
22	Sodium	mg/l	4.45	6.03	0.00	1.44	0.00	73.24	0.00	48.95	114.9	96.44	200
23	Calcium	mg/l	0.00	0.00	0.00	5.1	6.4	37.49	4.918	34.95	15.58	51.48	75
24	Arsenic	mg/l	1.22	0.00	0.00	1.88	0.00	22.50	24.72	26.38	26.38	0.757	0.01
25	Selenium	mg/l	0.00	0.00	0.00	0.003	0.00	4.572	10.92	8.949	8.488	3.209	0.01
26	Molybdenum	mg/l	0.00	0.00	0.00	0.003	0.00	0.00	0.00	0.00	0.00	0.00	0.07
27	Aluminum	mg/l	0.00	0.00	0.00	0.001	0.00	1.650	0.596	0.199	0.00	0.00	0.02
28	Vanadium	mg/l	0.00	0.00	0.00	0.004	0.00	0.001	0.00	0.00	0.00	0.00	0.00

*NS implies Not Specified:

TABLE II. Pollution index (Pi) calculated for each element using the metal index (Mi) analysis.

Elements	Mean	WHO	Mi (Pi)	Remark
pH	5.7	6.5-8.5		Acidic
Conductivity	119.4	NS		
Turbidity	450.6	5		High
TDS	38.62	NS		
Chloride	539.9	250	2.2	Moderately polluted
Sulfide	160.8	250	0.64	Practically unpolluted
Nitrate	1.552	50	0.03	Practically unpolluted
Phosphate	77.2	NS		
Lead	0.78	0.01	78	Extremely polluted
Iron	1.156	0.3	3.85	Moderately polluted
Copper	0.007	2	0.004	Practically unpolluted
Chromium	0.210	0.05	4.2	Moderately polluted
Nickel	0.045	0.07	0.642	Practically unpolluted
Manganese	8.537	0.4	21.34	Extremely polluted
Cadmium	1.753	0.003	584.3	Extremely polluted
Silver	0.48	0.1	4.8	Moderately polluted
Cobalt	0.048	NS		
Mercury	1.539	0.006	256.6	Extremely polluted
Zinc	2.660	0.006	443.3	Extremely polluted
Magnesium	26.73	50	0.53	Practically polluted
Potassium	8.289	200	0.041	Practically polluted
Sodium	34.55	200	0.172	Practically polluted
Calcium	15.59	75	0.207	Practically unpolluted
Arsenic	10.38	0.01	1038	Extremely polluted
Selenium	3.614	0.01	361.4	Extremely polluted
Molybdenum	0.0003	0.07	0.004	Practically unpolluted
Aluminum	0.245	0.02	12.23	Extremely polluted
Vanadium	0.0004	NS		

The remarks on table II were made with slight modifications after comparing Water Quality Classification using MI (Lyulko et al., 2001; Caerio et al., 2005)
*NS: Not Specified

TABLE III. The degree of spreading (In %) of the various elements across the study area.

S/No	Element	% Spread
1	Chlorine	100
2	Sulfide	100
3	Nitrate	100
4	Phosphate	100
5	Potassium	100
6	Manganese	100
7	Mercury	90
8	Magnesium	90
9	Cadmium	80
10	Lead	70
11	Iron	70
12	Nickel	70
13	Sodium	70
14	Calcium	70
15	Arsenic	70
16	Zinc	70
17	Silver	60
18	Cobalt	60
19	Selenium	60
20	Chromium	50
21	Aluminum	40
22	Copper	40
23	Molybdenum	10
24	Vanadium	10

The percentages above also illustrate the possibilities/probability of each of the elements occurring in any surface water sample collected within the mapped area.

Turbidity depends on a number of factors such as the size, shape, and refractive index of the clay, colloidal particles and the micro-organisms. The consumption of high turbid water would be a health risk due to microorganism as the probable part in it. Further turbidity can also protect the pathogens from the effects of disinfectants, facilitate their growth and increase the chlorine demand (WHO, 1996).

Chloride: The concentration of chlorine was excessively high in the two mine sites of Ameka, 1950mg/L and 2800 mg/L. This value is against 250 mg/L WHO maximum permissible limit. The high concentration of chloride ion in these two mine

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sites may be due to the leaching of sewage effluents down to the surface water system in the area. It can also come from the dissolution of these ions into the surface water from the abandoned lead-zinc mine. At the other samples, the chlorine levels were quite below the WHO standard. However on the average (539.9 mg/l), the value of chlorine still stood above the WHO maximum permissible limit of 250 mg/l. from the study, chlorine has a 100 % tendency of occurrence in any randomly collected water sample within the area (table III).Chloride ion in excess of 100mg/l impacts a salty taste in water, which may also cause serious health damage (Todd, 1980).

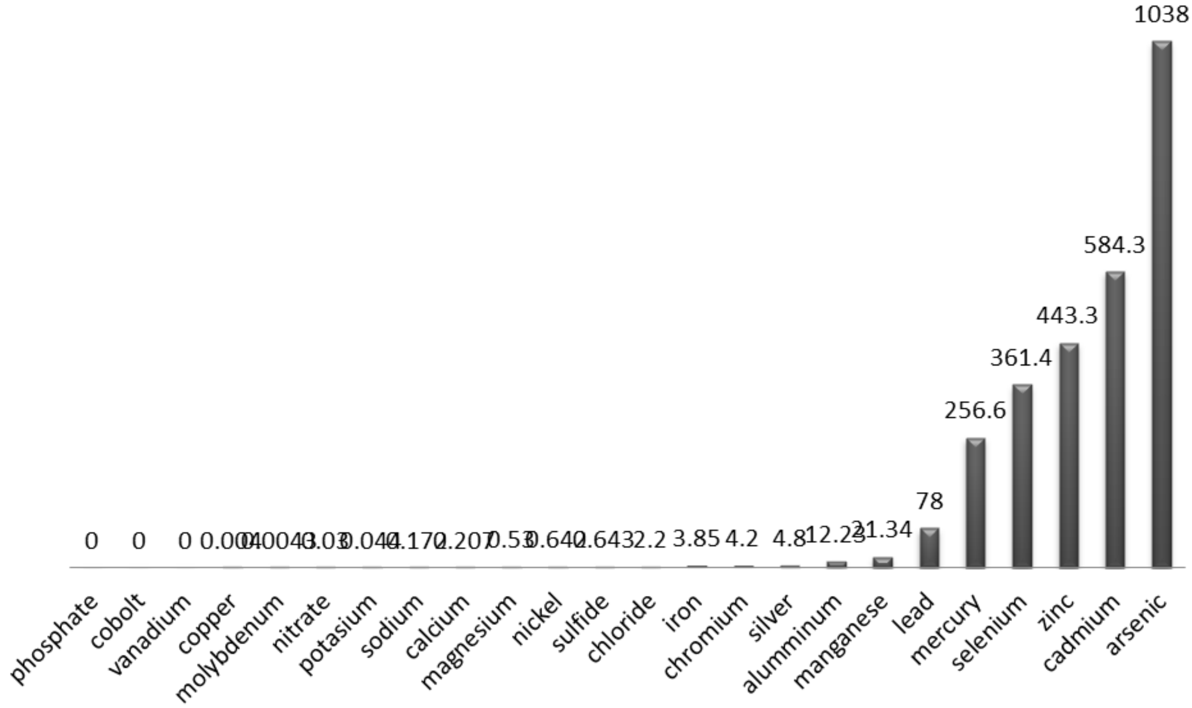

Fig. 2. The trend of the pollution index.

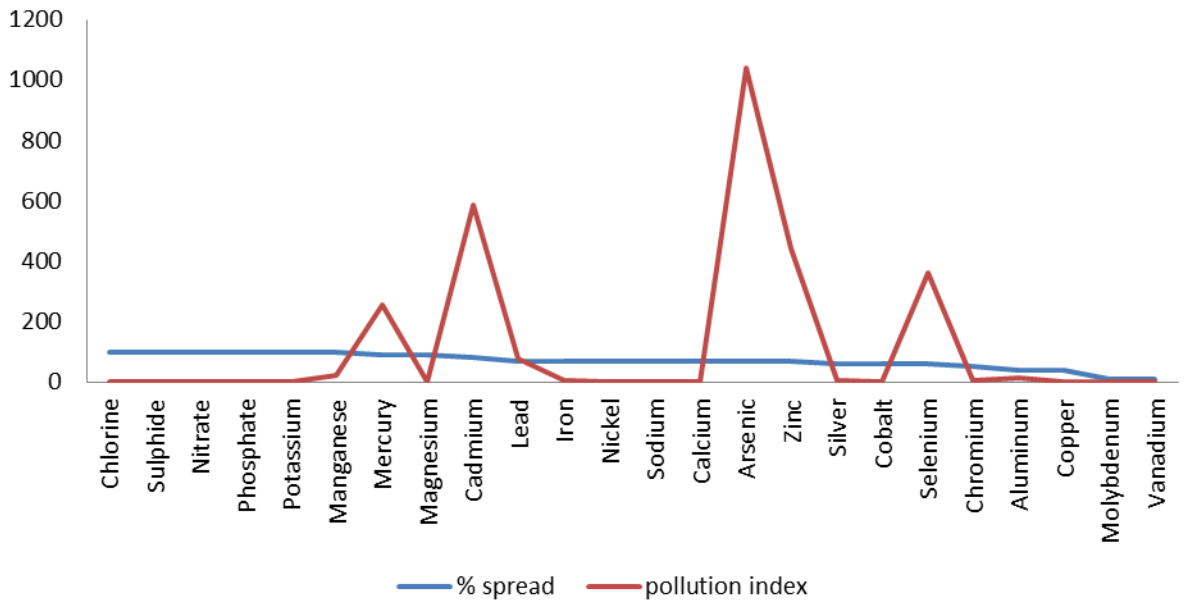

Fig. 3. Comparism of the percentage spread and pollution index.

Sulfide: The values ranges from 45-349.8 mg/l. The lowest (45 mg/L) was recorded in the Enyigba mine. The sulfide concentrations were only high in two samples. The highest concentrations were in the rivers 349.8 mg/l for Ngele river and 288.1 mg/L for Akpara river, this is against 250 mg/L (WHO standard). The source of these sulfide ions in the study area may be attributed to the decomposition of the high sulphide components of the minerals into the hydrological system and also due to the high oxidation of sulfide ores from the mine, these accounts for the 100 % spread or 100 % tendency of occurrence in any randomly collected water sample within the area (table III).

Nitrate: The values of nitrate ranged from 0.19-2.785 mg/L (table 1). These values are very low when compared with the WHO maximum value of 50 mg/L for drinking water. The low concentration of nitrate in the area indicates little or no source of household waste in the area. This implies therefore, that the sources of the nitrate to the surface water environment could be as a result of leachates from dumpsites and farm wastes. Though in little quantities, Nitrate has 100 % tendency of occurrence in any randomly collected water sample within the area (table III). Excessive concentrations of nitrates in drinking water have the potential to harm infant human beings and livestock if consumed on a regular basis (Freeze and Cherry, 1979).

Total dissolved solids (TDS): The TDS values as recorded from the analysis (in table I) gives the value as ranging from 2-88.5 mg/L. The highest values; 88.5, 71.5, 70.9, 70.3 and 53 mg/L were from Ameri salt lake, Ameka mine1, Ameka mine2, Onuebonyi river and Enyigba mine respectively. The lowest concentration of TDS was recorded at the Ameka stream and Enyigba salt lake, their values are 2 and 4 mg/L respectively.

Phosphate: The value for phosphate shows a general low concentration across the area with values ranging from 9.787-199.2 mg/L. The highest (199.2 mg/L) is quite lower than the WHO standard value. Just as in the concentration of Nitrate, though in low quantities, Phosphate has 100 % tendency of occurrence in any randomly collected water sample within the area (table III).

Lead: The Ameka mine1, the Enyigba mine and the Akpara river had zero concentration of lead. The other areas had high concentrations all the values are above the WHO maximum value. The values ranges from 0.02-2.728 mg/L, this is against the 0.01mg/L (WHO standard). The worst affected areas are; the Enyigba salt lake with concentration of 2.728 mg/L, the Ameri salt lake with concentration of 1.73 mg/L and Ameka stream with concentration of 1.288 mg/L. Lead is the sixth most polluting element tested for. This high value is as a result of the dissolution of lead ion into the water system from the abandoned lead-zinc mine in the area. Notwithstanding the fact that Lead is a major element being mined in the area, some water samples still recorded a zero concentration. In general lead has a 70% tendency of occurrence in any randomly collected water sample within the area (table III). This could only be an attribute of a less reactive element. Concentrations of lead to higher extent causes lead poisoning which is dangerous to human health especially infants. It can also cause nervous system depression, nervousness and patty (Nnabo *et al.,* 2011).

Iron: The concentration values for iron ranged from 0.37-6.778 mg/L. Three samples had zero concentration, the samples are Ameka mine1, Ngele river and Ameka stream. The area has an average concentration value of 1.156 mg/L. This is against the WHO value of 0.3 mg/L. The above figure puts the average pollution index to about 3.85 and with about 70 % tendency of occurrence in any sample within the area. This is a very high figure and constitutes a polluting element in the study area.

Copper: Copper was only traced in four samples out of the ten analyzed samples. The values were 0.004, 0.009, 0.028 and 0.027 mg/L for the Ameka mine2, Onu Ebonyi river, Akpara river and Ngele river respectively. These values are below the WHO maximum permissible limit of 2.0 mg/l. Copper can occur naturally in underground water supplies after passing over a zone of mineralization rich in copper minerals (ADWG, 2011). The source of copper ions in the surface water in the study area is from the dissolution of copper ions associated with the lead - zinc mineralization in the area.

Chromium: The values of chromium range from 0.015-0.861mg/L. This represents a generally high value since it is above WHO maximum permissible limit of 0.05 mg/L. The average pollution index for the entire area was 4.2. This very high value as well as the 50 % tendency of occurrence puts chromium as the tenth most polluting element in the area.

Nickel: The concentration of Nickel ranges from 0.003-0.149 mg/L. Its very low concentration in the study area can be linked to the slow dissolution of the chalcopyrite ores in the area. The average concentration of 0.0446mg/L was below the WHO maximum permissible value of 0.07 mg/L. Its inhalation and exposures to a higher degree is the greatest risk of developing health problems such as dermatitis upon contact.

Manganese: The concentration of manganese ranges from 0.04-31.39 mg/L. Minimal values within the WHO maximum permissible limit were 0.04 mg/L from Ameka mine1, 0.221 mg/L from Akpara river, 0.30 mg/L from Ngele river and 0.062 mg/L from Ameka pond. The other areas had values above the WHO maximum permissible limit for drinking water. The average value was 8.5 mg/L as against the WHO value of 0.4 mg/l. These values brings it to an average pollution index of 21.34. This index ranks it as the seventh most polluting element studied. With about 100 % tendency of occurrence in any sample makes it belong to the elements with the most polluting effect.

Cadmium: The value of cadmium ranges from 0.046-12.08 mg/L representing a general pollution threat since the values are above the WHO maximum permissible limit for drinking water. However two samples (Ameka mine 1 and 2) recorded zero concentration. The average concentration is 1.7528 mg/L. This is against the WHO maximum permissible value of 0.003 mg/L. This puts the pollution index to 584.26 representing the second most polluting element studied. This high value of Cadmium in the surface water resources of the Ameka area is from the dissolution of Cadmium ion from the mineralized zone (lead-lead) into the surface water system. This high concentration can result to inflammations of the kidney

Silver: The values of silver ranged from 0.02-4.24 mg/L in six samples (table I) and these values are all above the WHO maximum permissible limit for drinking water. Four samples;

Ngele river, Enyigba salt lake, Ameka pond and Ameka stream had zero values. However, with average concentration of 0.48 mg/L as against 0.1 mg/L (WHO) and a pollution index of 4.8, Silver stood as the ninth most polluting element in the study.

Cobalt: The value for Cobalt ranged from 0.02-0.172 mg/L. This concentration of cobalt in the area is due to the lead-zinc mining activities in the study area where industrial plants can leak cobalt into the environment. This cobalt particles enters the atmosphere, they settle to the ground and enter groundwater and food supplies, thereby serving as a contaminant. Constant exposures to cobalt powders has adverse effect on the sight and hearing ability of humans, liver, pancreas and heart disorders.

Mercury: Mercury had values ranging from 0.101-11 mg/L. These values translate to mean high degree of pollution since the WHO maximum permissible limit for drinking water is 0.006 mg/L. It is only one sample area (Onuebonyi river) that is free from mercury pollution. This high concentration of Mercury in area is due to the dissolution of Mercury from the mine into the hydrological system of the area. With an evaluated pollution index of 256.62, an average concentration value of 1.539mg/L against the 0.006 mg/L WHO maximum permissible value for drinking water, about 90 % tendency of occurrence. Mercury is ranked as the element with the most polluting effect in the study area.

Zinc: Zinc had concentration ranging from 0.032-10.07 mg/L, values of which all exceed the WHO maximum permissible limit for drinking water of 0.006 mg/L. Zinc is ranked the third most polluting element in the area with average concentration of 2.66 mg/L and a pollution index of 443.3. The presence of zinc ions in the hydrological resources of the study area is in no doubt from the dissolution of zinc associated with the sideritic ores in the area, since it is one of the major concentrated metals being minned in the area.

Magnesium: The value of magnesium range ranges from 0.024-136 mg/L of which only two samples; Ameka mine1 (136 mg/l) and Ameka mine2 (41.55 mg/l) has their values above the WHO maximum permissible limit for drinking water. The other eight samples were within the WHO standard of drinking water. The source of these Mg^{2+} in the area is from the weathering of rock containing ferromagnesian minerals and from carbonate rocks. In natural water it can occur in any of the following form such as magnesium carbonate ($MgCo_3$), Magnesium sulfide ($MgSo_4$) and also in some organo-metablic compound and organic matters.

Potassium: The value of potasium ranges from 0.032-15.42 mg/L. The values are very low and within the WHO standard of drinking water. The low concentrations can be linked to the non occurrence of high volcanic rocks in the area. Potassium (K^+) is essential to maintaining the fluid balances in the body. However, more than 50mg/L concentration of this ion (K^+) in water in the presence of suspended matter causes foaming with scales formations.

Sodium: Sodium had values below the 200 mg/L (WHO maximum permissible limit for drinking water) in all the water samples analysed. These concentrations are invariably a result of the lead-zinc mineralization, saline intrusion and the mining activities within the area.

Calcium: The value of calcium ranges from 0.0-51.48 mg/L. These values are all within the WHO standard of drinking water, considering the fact that the WHO maximum permissible limit for drinking water is 75 mg/L. Its presence in the hydrological system of the study area may be due to the intense dissolution and leaching of calcium-rich rocks underlying the area and also from acidic rains.

Arsenic: Three sites (Ameri salt lake, Ameka mine2 and Onuebonyi river) had zero concentration but the other sites has values ranging from 0.757-26.38 mg/L. These values are quite above the WHO maximum permissible limit for drinking water. In this study Arsenic had an average concentration of 10.384 mg/L as against 0.01mg/l WHO maximum permissible limit for drinking water and pollution index of 1038.4 ranking as the most polluting element in the study. This high values of arsenic ions in the study area can be attributed to the dissolution of sulfides from the mine since arsenic readily occurs with sulfide minerals. Its occurrence in the hydrological system in the area can also be from agricultural applications of arsenical based pesticides which most of the farmers use in their rice farms.

Selenium: Four samples (Ameka mine1, Ameri salt lake, Ameka mine2 and Onuebonyiriver) had zero values. The other samples have values ranging from 0.003-10.92 mg/L with an average concentration of 3.614 mg/L.

Aluminum: Aluminum was only traced in four samples Enyigba mine (0.001 mg/l), Akpara river (1.65 mg/l), Ngele river (0.596 mg/L) and Enyigba salt lake (0.199 mg/L), the other samples recorded zero concentration. These four samples gave the area an average concentration of 0.2446 mg/L and this against the WHO maximum permissible limit for drinking water (0.02 mg/L).

IV. SUMMARY

The result shows that the surface water in the entire area has been adversely polluted physico-chemically with heavy metals. A pH of 5.7 (average) puts the surface water as acidic, turbidity of 450.6 NTU is on the high side. All the heavy metals tested for had pollution indices values far above the threshold. The highest pollution indices are Cr < Ag < Al< Mn < Pb < Hg < Se < Zn < Cd < As. This work also shows that Chlorine, Sulfide, Nitrate, Phosphate, Potassium, Manganese, Mercury, Magnesium and Cadmium has the highest spread of between 100 to 80% while, Lead, Iron, Arsenic, Zinc, Nickel, Sodium and Calcium made up to 70% appearances in the study area (table III). Comparing the above, it is logical to deduce that Mercury, Cadmium and Manganese have the most polluting effect followed by Arsenic, Zinc, Lead, Selenium, Silver and Chromium.

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