RESEARCH

3(11), July - September, 2017

ISSN 2394-3750
EISSN 2394-3769

Science & Technology

Surface water contamination by heavy metals from Enyigba Pb-Zn mine district, southeastern Nigeria using metal enrichment and pollution indices

Paulinus N Nnabo[1]☼, Jimoh Ajadi[2]

1.Department of Geology, Ebonyi State University, Abakaliki, Nigeria; E-mail: paulinusnnabo@gmail.com; Phone: +2348036780952
2.Department of Geology and Mineral Sciences, Kwara State University, Malete, Nigeria; E-mail: jimohajadi@gmail.com; Phone: +2348136436333

Article History
Received: 16 June 2017
Accepted: 29 July 2017
Published: July - September 2017

Citation
Paulinus N Nnabo, Jimoh Ajadi. Surface water contamination by heavy metals from Enyigba Pb-Zn mine district, southeastern Nigeria using metal enrichment and pollution indices. *Science & Technology,* 2017, 3(11), 146-157

Publication License
This work is licensed under a Creative Commons Attribution 4.0 International License.

General Note
Article is recommended to print as color digital version in recycled paper.

ABSTRACT

A total of twelve (12) surface water samples were collected from the Enyigba Pb/Zn mining district to assess the contamination of the water sources by heavy metals as a result of mining of lead and zinc minerals in the area. The samples were acidified to stabilize the metals for periods more than four days without the use of refrigeration. The acidified surface water samples were analysed by a commercial laboratory at Projects Development Institute (PRODA), Enugu using Atomic Absorption Spectroscopy (AAS). The elements analysed for are lead (Pb), zinc (Zn), copper (Cu), arsenic (As), cadmium (Cd), nickel (Ni), manganese (Mn) and cobalt (Co). The result and analysis based on metal enrichment and pollution indices (MEI and MPI) indicate that the MEI of As, Cd, Pb and Ni are very high in the surface water and all contributed to very slight pollution of the surface water based on metal pollution index.

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS

Key word: heavy metal contamination, surface water, metal enrichment/pollution indices, Lead-Zinc Mine, Enyigba

1. INTRODUCTION

The study area (Figure 1), 14 km southeast of Abakaliki, covered the Pb-Zn mining district of Enyigba and its surrounding villages of Ameka, Ameri and Ohankwu all in Ebonyi State, southeastern Nigeria. The deposit of Pb-Zn sulphides (galena and sphalerite) in Nigeria have been known for a long time but have only been exploited in the past on a very small scale. The lead-zinc field covers over 48,000 sq km in extent with lead-zinc mineralization at many centres. The deposits are localized in the Cretaceous sediments along 600 km long belt within the Benue Trough, a sediment filled intracratonic basin extending from Ishiagu (South of Abakaliki) north-eastwards to Gombe (Farrington 1952, Orazulike 1994). The occurrence of lead–zinc in the Benue valley has attracted a lot of attention. Mining of the ore has been carried out for a long time by both the natives, for local uses as cosmetics, and foreign companies, for export. Production of the ore started in the year 1925 (Offodile, 1989) but commercial production started in 1947 (Kogbe, 1989).

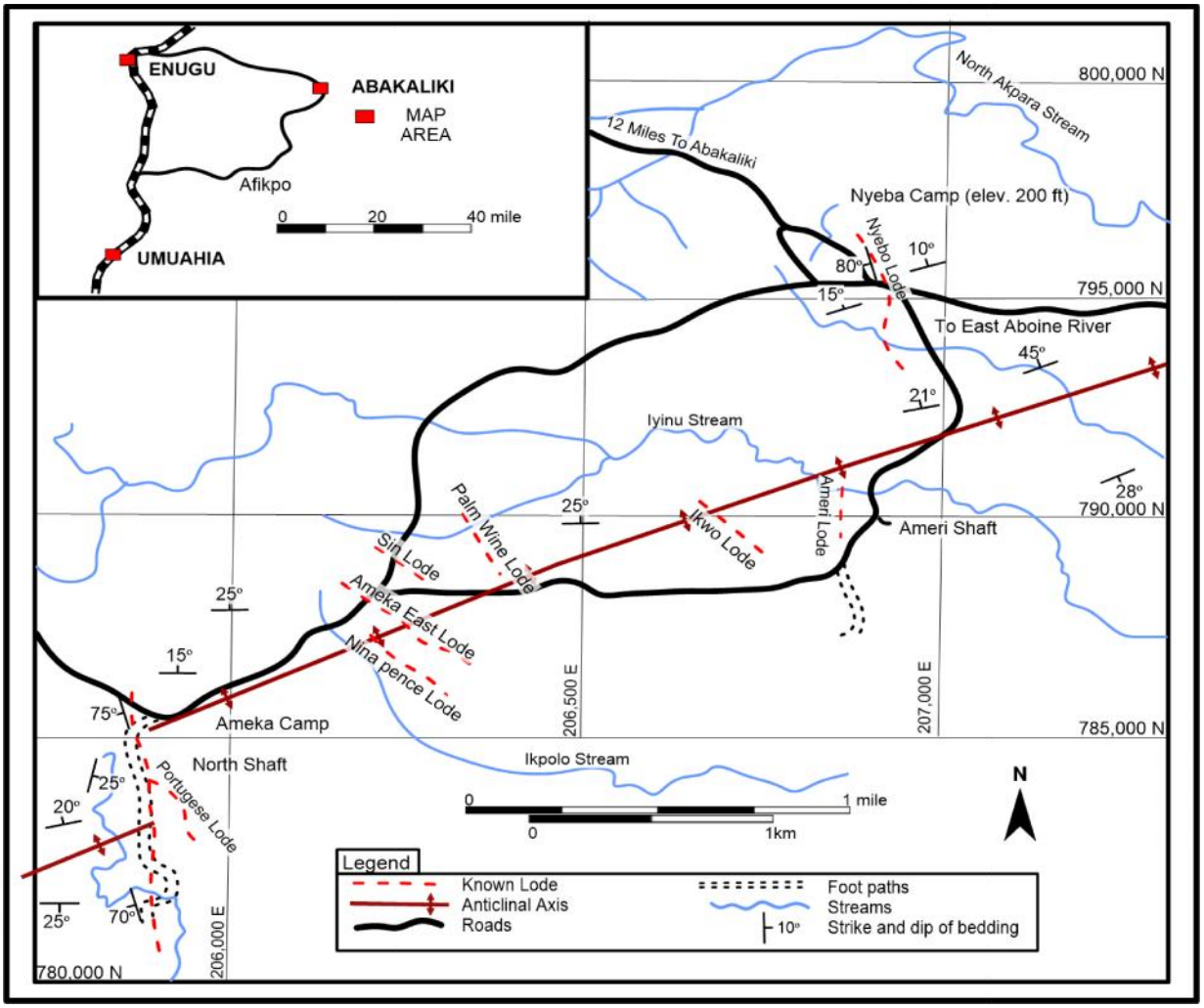


Figure 1 Geological map of lead-zinc deposits of Enyigba district, near Abakaliki, Lower Benue Trough. The area is underlain by Abakaliki shales (Modified from Orajaka, 1965).

Since the discovery of and mining of Pb-Zn deposits in Abakaliki and its environs in the early 1900s, data existing on the impact of their mining on the environment are very rare.

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS

Metal contamination that occurs as a result of mining characterized by elevated toxic metal concentrations and acid rock and mine drainage, continue several years after the cessation of mining activities. Heavy metal effluents from the weathering of the mineral deposits and mine dumps affect both the surface and underground water quality and soil. These levels of contamination in the area lead to low agricultural production, and adversely affect the ecosystem if present at anomalously high level. This study is to assess the levels of heavy metals contamination of the surface and underground water as may have resulted from the lead-zinc mining in the area.

2. LITERATURE REVIEW

In the study area, the topography is undulating plain alternating with running of ridges and hills from east to west. The plains are underlain by shale and some mudstones. The Enyigba, Ameri and Ameka are marked by undulating range of shale outcrops, which serve as the host for Pb-Zn mineral ore bodies. The whole area formed the "Abakaliki anticlinorium" and generally underlain by shales. The area had about 60m as its highest elevation and 30m as its lowest elevation above sea level. The area falls within the tropical rainforest belt of South East Nigeria, and characterized by an average rainfall of 1750-2000 mm per annum. The highlands are characterized by drought resistance grasses, along stream and rivers. Among the vegetation includes economic mangoes trees, orange trees, and palm and coconut trees. The drainage system of the area is dendritic in pattern, which is a function of the lithology. The area is majorly drained by Ebonyi River. All the drainage systems flow eastward to join the Cross River somewhere outside the area.

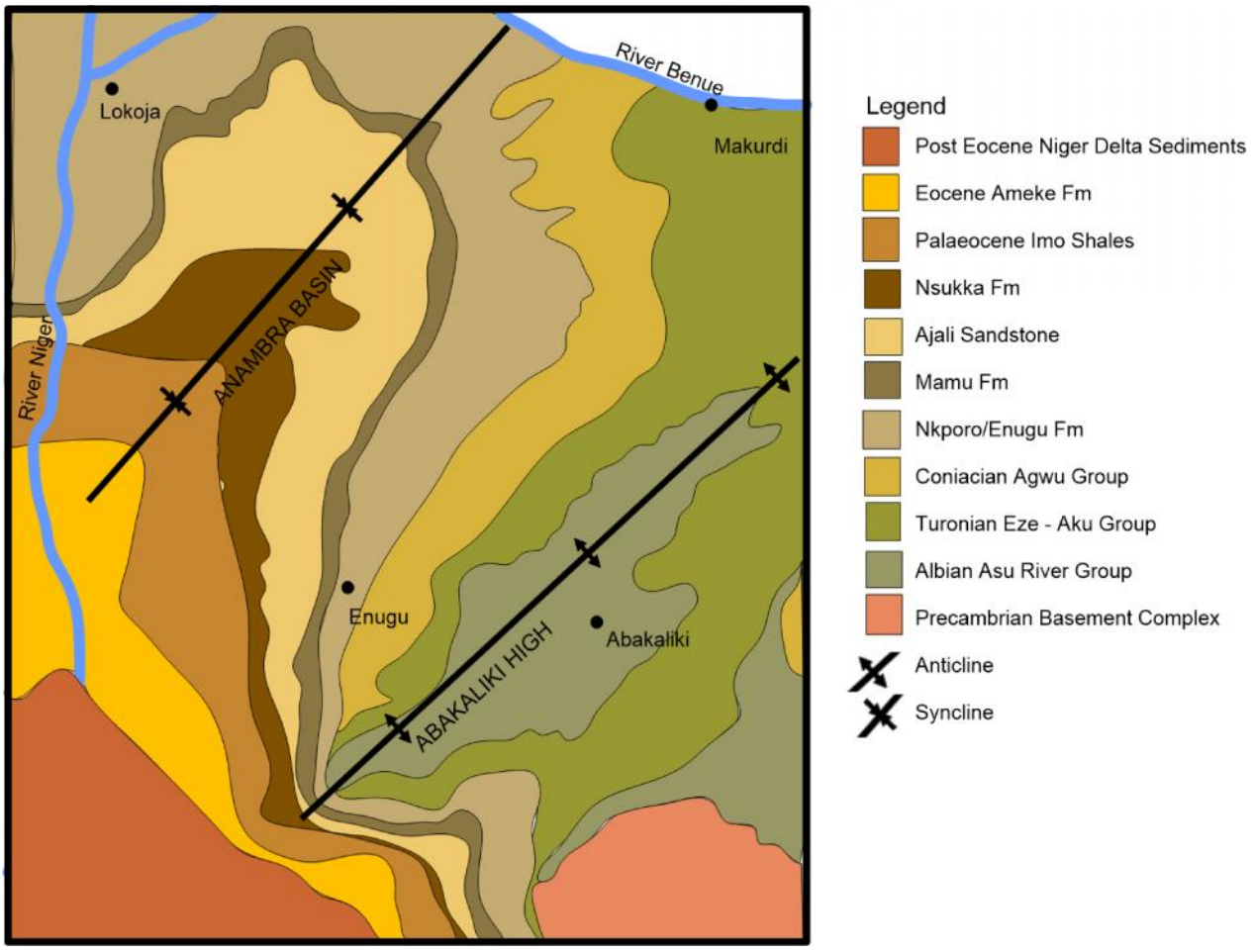


Figure 2 General geologic map of Southeastern Nigeria showing Abakaliki basin in the Lower Benue Trough (Modified after Nwajide, 1990).

The Abakaliki shale of lower Cretaceous age is exposed in the area. The sedimentary rocks are predominantly black calcareous (calcite-cemented) shale with occasional intercalation of siltstone (Figure 2). The shale formation belongs to the Asu-River Group of

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS

the Albian Cretaceous sediments. The Asu River group which consists of alternating sequence of shales, mudstone and siltstone with some occurrence of sandstone and limestone lenses in some places and attains an estimated thickness of 1500 meters (Agumanu 1989, Farrington, 1952). Kogbe (1989) described the sediments as consisting of rather poorly-bedded sandy limestone lenses. The shales in some places are highly weathered and ferrugenized. The rocks are extensively fractured folded and faulted. From field observations, the rocks of the area consist of variably coloured shale and mudstone that has been imbedded by lead – zinc vein mineralization, baked intrusive shale as well as ironstone along veins. The ironstone occur as inter-beds within the shale and as vein filling. The vein mineralization is hosted within the dark shale (Nnabo et al. 2011). The geology and mineral resources are the major factors responsible for availability of the heavy metals in the area. While the sulphide mineralization have high concentration of these metals, the shale host are capable of retaining them from ancient sea (Nnabo et al. 2011).

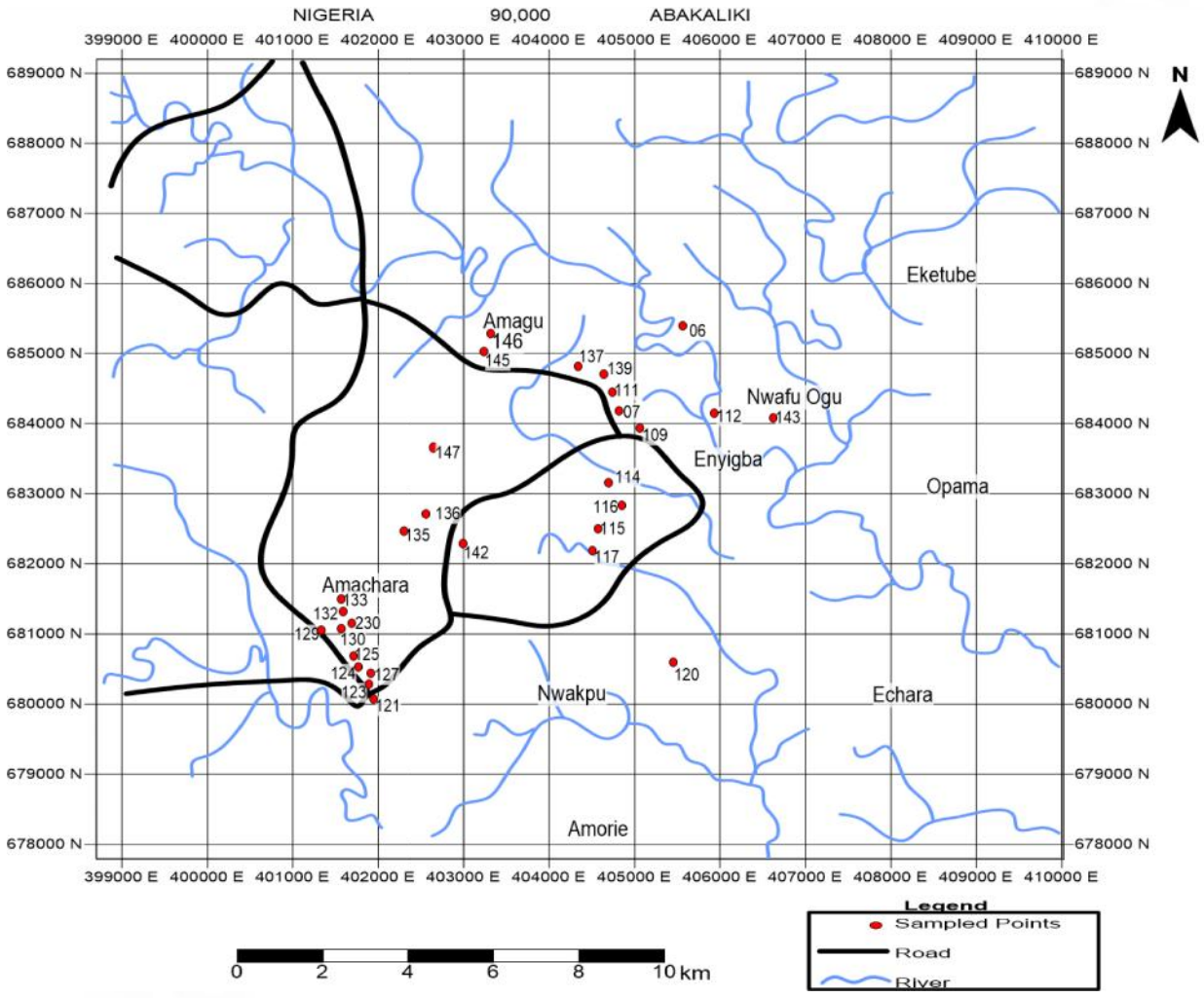


Figure 3 Location of Water Samples collected from Enyigba and its Environs

3. METHODS

Water sampling was carried out in the months of August and September. Sample locations (Figure 3) were located on 1:90,000 scale topographic map and recorded on site with a conventional global positioning system (GPS) instrument. Water samples for analyses were collected from surface (stagnant) and ground sources including mine pits, seeping from mine dumps and streams found in and around the area of the mining activities. Notes were taken on the nature of any mineral coatings related to the water, if any, because these are often indicators of degraded water quality. Water samples were collected from sources where the water was deemed to be representative of a geological or mine setting and would yield information on the mobility of metals in that environment. Flow rate (for moving sources) and water characteristics (colour, suspended material, bed colours or mineralogy) are recorded and pH was measured using portable pH metre– HANNA pHep Hi 98127. The pH meter (HANNA pHep Hi 98127) with built–in temperature

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS

electrode was a calibrated based on standards solution. The field standards were buffered solutions of pH 4.0, 7.0 and 10.0. The measurement of pH carries an uncertainty of about ±0.05 standard unit. The water samples for analyses was collected with disposable 60 ml bottles. The disposable polyethylene bottle was rinsed three times in the sampled water prior to collection. The sample was acidified at the site with three drops of ultrapure 1:1 HNO_3.

The acid stabilized metals for periods more than four days without the use of refrigeration. Laboratory and field blank tests were carried out using deionized water. The acidified water samples were analysed by a commercial laboratory at Projects Development Institute (PRODA), Enugu using Atomic Absorption Spectroscopy (AAS). The elements determined by this method are lead (Pb), zinc (Zn), copper (Cu), arsenic (As), cadmium (Cd), nickel (Ni), manganese (Mn) and cobalt (Co).

4. RESULTS

The results of the analysis of surface water samples for their contamination by heavy metals are shown in Table 1. The table also contains the statistical data for each metal. The concentrations of each metal that are above the World Health Organization (WHO, 2011) established maximum limits of heavy metals permissible in water are highlighted.. The content of As, Cd, Ni and Pb in many of the samples are above the WHO maximum permissible limits for drinking water. The distributions of As, Cd and Pb in all the sampled sites are plotted in Figures 4 to 6.

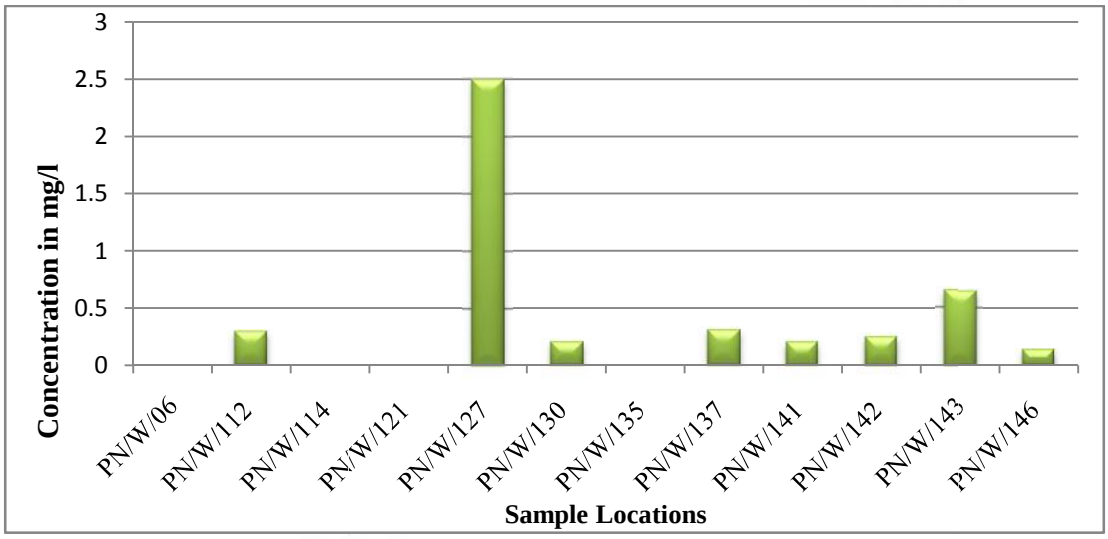


Figure 4 Concentration of arsenic in surface water from Enyigba Pb-Zn mine district

Table 1

Concentration of heavy metals in surface water (in mg/l) and its assessment with the maximum limits established by the World Health Organization (WHO, 2011) (NL = No limit)

Sample No	Location	pH	As	Cd	Co	Cu	Mn	Ni	Pb	Zn
PN/W/06	Enyigba Stream 1	7.0	Nil	**3.20**	4.20	0.17	**0.42**	**1.49**	**0.70**	0.56
PN/W/112	Enyigba stream 2	6.6	**0.30**	**6.00**	1.26	0.08	0.06	**1.43**	Nil	0.54
PN/W/114	Ameri stream	6.7	Nil	**1.40**	1.71	0.06	0.11	Nil	**0.20**	0.09
PN/W/121	Ohankwu stream 1	6.2	Nil	**1.30**	0.60	0.05	0.02	**0.88**	**0.20**	0.01
PN/W/127	Ohankwu stream 2	5.5	**2.50**	**13.50**	Nil	0.02	0.21	**0.97**	Nil	Nil
PN/W/130	Ameka stream 1	5.8	**0.20**	**12.30**	Nil	Nil	0.07	**0.42**	**0.30**	0.15
PN/W/135	Ameka stream 2	5.6	Nil	Nil	0.97	0.02	0.04	Nil	**0.20**	0.27
PN/W/137	Enyigba villa pond	6.0	**0.30**	Nil	4.60	0.06	0.20	**2.07**	**0.20**	Nil
PN/W/141	Enyigba villa stream	6.8	**0.20**	Nil	2.39	0.03	0.26	**1.58**	**0.10**	**9.70**

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS

	1									
PN/W/142	Ameka villa stream	6.6	**0.25**	Nil	5.06	0.08	0.01	**0.52**	**0.20**	**6.40**
PN/W/143	Ebonyi River, Enyigba	7.0	**0.65**	Nil	3.90	0.04	0.20	Nil	**0.10**	**10.1**
PN/W/146	Enyigba villa stream 2	7.2	**0.13**	Nil	1.00	0.01	0.07	**0.63**	**0.10**	**7.50**
TOTAL		77	**4.53**	37.70	25.69	0.62	1.67	**9.99**	**2.30**	**35.32**
MEAN		6.42	**0.57**	6.28	2.57	0.06	0.14	**1.11**	**0.23**	**3.53**
MAX		7.20	**2.50**	13.50	5.06	0.17	0.42	**2.07**	**0.70**	**10.10**
MIN		5.50	**0.13**	1.30	0.60	0.01	0.01	**0.42**	**0.10**	**0.01**
STD. DEV		0.56	**0.75**	4.94	1.62	0.04	0.12	**0.53**	**0.17**	**4.11**
WHO (2011) Max. Limit (mg/l)			.01	.003	NL	2	0.4	0.07	0.01	3

High contents of As in water were recorded in a stream from Ohankwu area (PN/W/127) (Table 1; Figure 4). PN/W/127 is a stream that took its source from a mining hill at Ohankwu area.

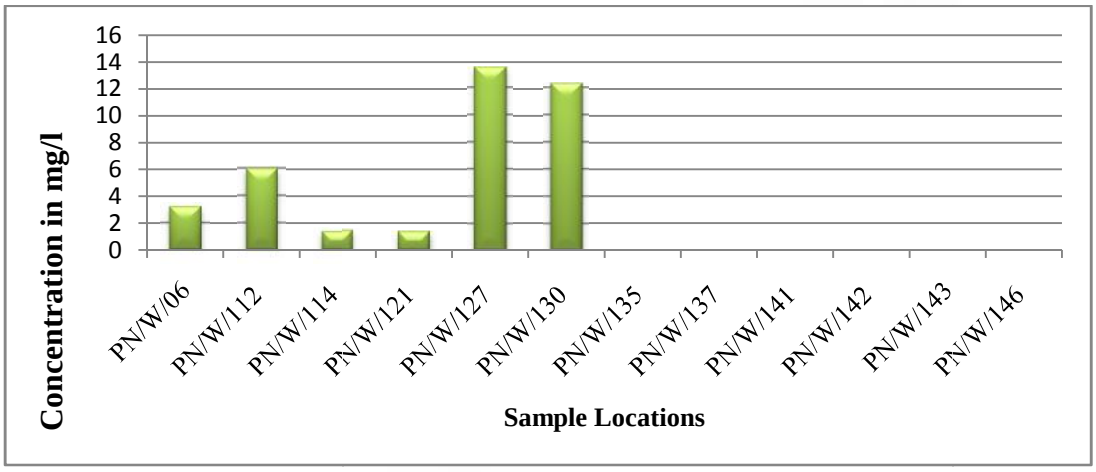


Figure 5 Concentration of cadmium in surface water from Enyigba Pb-Zn mine district.

Very high concentration of Cd in surface water samples were recorded in two streams from Ohankwu (PN/W/127) and Ameka (PN/W/130) areas (Table 1; Figure 5). PN/W/127 and PN/W/130 are streams that drain the mining areas at Ohankwu and Ameka.

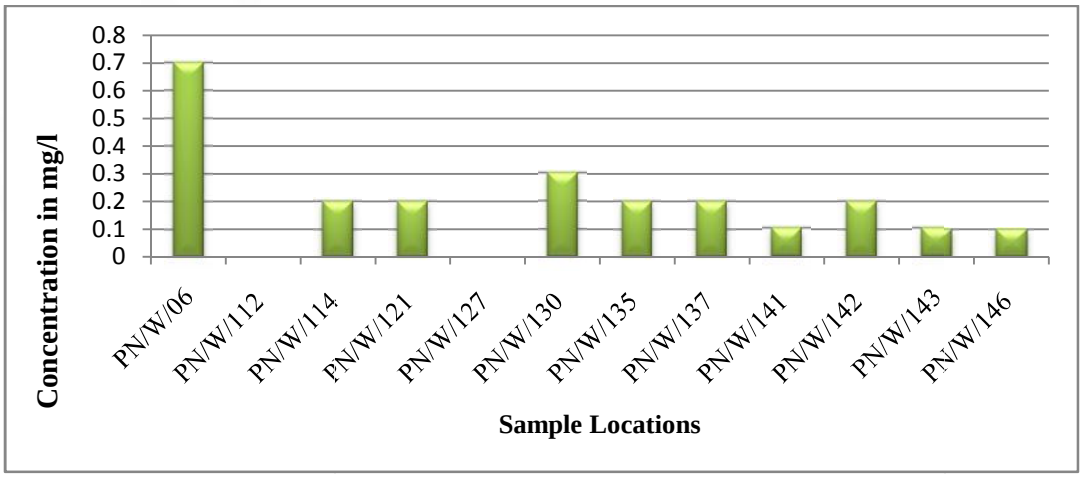


Figure 6 Concentration of lead in surface water from Enyigba Pb-Zn mine district.

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS

High values of Pb in water were concentrated in mine ponds from Ohankwu and Ameka areas. The contents of Pb in the surface and underground water samples were very low with a maximum value of 0.7 mg/l obtained from one stream at Enyigba area (PN/W/06) (Table 1; Figure 6).

Metal Enrichment Index (*MEI*)

Metal enrichment index (*MEI*) of heavy metals in the surface water samples were calculated using the formula:

Metal Enrichment Index $MEI = \frac{C_i - C_o}{C_o}$

Where C_i is the total concentration of each metal *i* measured in the water samples; C_o is the heavy metal background established for the system studied. The WHO maximum permissible limits of metals in water (see Table 2) were used as the background value for the metals.

Table 3

Metal enrichment indices of heavy metals in surface water from Enyigba and Environs.

Sample No	Location	pH	As	Cd	Cu	Mn	Ni	Pb	Zn
PN/W/06	Enyigba Stream 1	7.0	Nil	**3.20**	0.17	**0.42**	**1.49**	**0.70**	0.56
PN/W/112	Enyigba stream 2	6.6	**0.30**	**6.00**	0.08	0.06	**1.43**	Nil	0.54
PN/W/114	Ameri stream	6.7	Nil	**1.40**	0.06	0.11	Nil	**0.20**	0.09
PN/W/121	Ohankwu stream 1	6.2	Nil	**1.30**	0.05	0.02	**0.88**	**0.20**	0.01
PN/W/127	Ohankwu stream 2	5.5	**2.50**	**13.50**	0.02	0.21	**0.97**	Nil	Nil
PN/W/130	Ameka stream 1	5.8	**0.20**	**12.30**	Nil	0.07	**0.42**	**0.30**	0.15
PN/W/135	Ameka stream 2	5.6	Nil	Nil	0.02	0.04	Nil	**0.20**	0.27
PN/W/137	Enyigba villa pond	6.0	**0.30**	Nil	0.06	0.20	**2.07**	**0.20**	Nil
PN/W/141	Enyigba villa stream 1	6.8	**0.20**	Nil	0.03	0.26	**1.58**	**0.10**	**9.70**
PN/W/142	Ameka villa stream	6.6	**0.25**	Nil	0.08	0.01	**0.52**	**0.20**	**6.40**
PN/W/143	Ebonyi River, Enyigba	7.0	**0.65**	Nil	0.04	0.20	Nil	**0.10**	**10.1**
PN/W/146	Enyigba villa stream 2	7.2	**0.13**	Nil	0.01	0.07	**0.63**	**0.10**	**7.50**
TOTAL			**4.53**	37.70	0.62	1.67	**9.99**	**2.30**	**35.32**
MEI			**452**	**12566**	**-0.69**	**3.18**	**141.71**	**229**	**10.77**
WHO (2011) Max. Limit (mg/l)			**0.01**	**0.003**	**2**	**0.4**	**0.07**	**0.01**	**3**

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS

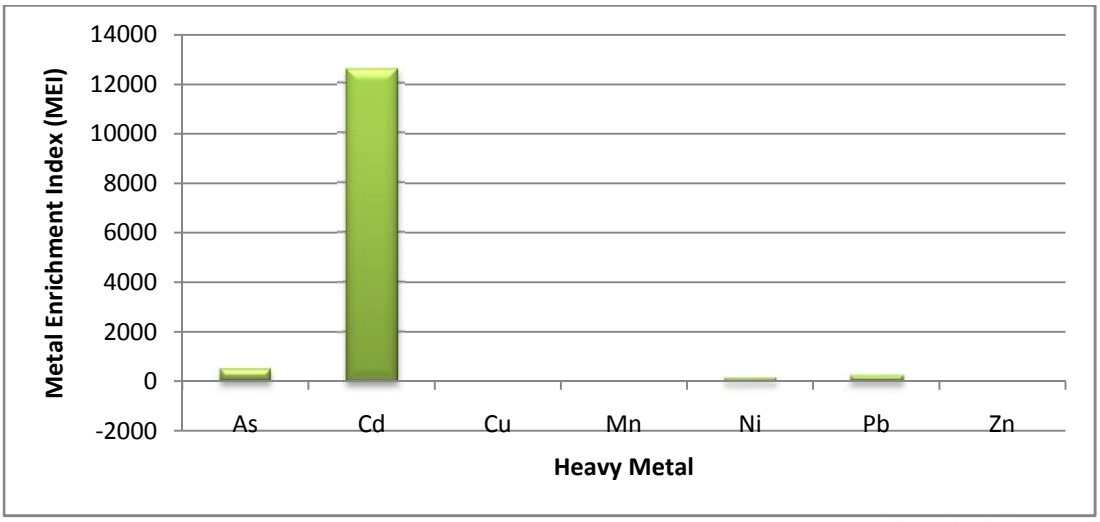


Figure 7 Metal enrichment index of heavy metals in surface water from Enyigba Pb-Zn mine district.

Figure 7 shows that in the surface water samples, Cd had the highest metal enrichment value of 12566 followed by As, Pb and Ni with values of 452, 229 and 141.71 respectively.

Metal Pollution Index (*MPI*).

Metal pollution index (*MPI*) is calculated using the formula (Caeiro et al 2005):

$$MPI = \sqrt[n]{M1 \text{ X } M2 \text{ X } M3 \text{ X } \ldots\ldots Mn}$$

Where M*n* is the concentration of metal *n* in the water samples expressed in mg/l. This is simple but does not compare the contaminant concentration with any baseline value. The calculated metal pollution index of the heavy metals in the surface water samples of the area are shown on Table 4 and plotted in Figure 8. The values of the calculated metal pollution index (MPI) in surface water were all very low (Table 4 and Figure 8).

Table 4

Metal Pollution Index (*MPI*) of heavy metals in Water from Enyigba and Environs

Sample No	Location	Sample type	Ph	As	Cd	Co	Cu	Mn	Ni	Pb	Zn	MPI
PN/W/06	Enyigba Stream 1	Surface	7.0	Nil	3.2	4.2	0.17	0.42	1.49	0.7	0.56	**0.92**
PN/W/112	Enyigba stream 2	Surface	6.6	0.3	6.0	1.26	0.08	0.06	1.43	Nil	0.54	**0.52**
PN/W/114	Ameri stream	Surface	6.7	Nil	1.40	1.71	0.06	0.11	Nil	0.2	0.09	**0.26**
PN/W/121	Ohankwu stream 1	Surface	6.2	Nil	1.30	0.60	0.05	0.02	0.88	0.20	0.01	**0.15**
PN/W/127	Ohankwu stream 2	Surface	5.5	2.50	13.5	Nil	0.02	0.21	0.97	Nil	Nil	**0.67**
PN/W/130	Ameka stream 1	Surface	5.8	0.20	12.3	Nil	Nil	0.07	0.42	0.30	0.15	**0.38**
PN/W/135	Ameka stream 2	Surface	5.6	Nil	Nil	0.97	0.02	0.04	Nil	0.20	0.27	**0.13**
PN/W/137	Enyigba villa pond	Surface	6.0	0.30	Nil	4.60	0.06	0.20	2.07	0.20	Nil	**0.46**
PN/W/141	Enyigba villa stream 1	Surface	6.8	0.20	Nil	2.39	0.03	0.26	1.58	0.10	9.70	**0.52**
PN/W/142	Ameka villa stream	Surface	6.6	0.25	Nil	5.06	0.08	0.01	0.52	0.20	6.40	**0.35**
PN/W/143	Ebonyi River,	Surface	7.0	0.65	Nil	3.90	0.04	0.197	Nil	0.10	10.1	**0.52**

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS

	Enyigba											
PN/W/146	Enyigba villa stream 2	Surface	7.2	0.13	Nil	1.0	0.01	0.07	0.63	0.10	7.50	**0.19**

≤ 1	1 – 5	5 – 20	20 – 40	➢ 40
Practically unpolluted	Slightly polluted	Moderately polluted	Strongly polluted	Very strongly polluted

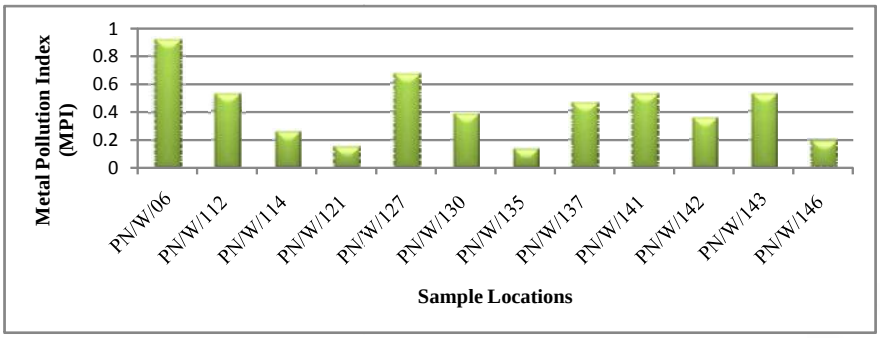


Figure 8 Metal Pollution Index of heavy metals in Water from Enyigba and Environs

5. DISCUSSION

The concentration of arsenic in surface water from the Enyigba and Environs varied from 0.13 to 2.5 mg/l with an average value of 0.57 mg/l with very high contents in water recorded in stream from Ohankwu area and mine ponds from Ameka and Ohankwu areas. These samples were collected at sites where active local mining of Pb/Zn are still taking place. Uncontrolled local mining activities has led to generation of heavy metal pollutants with negative influences on the nearby environment (Onyedika and Nwosu, 2008; Johnston et al. 2008; Antunes et al. 2008). Mining and related operations are the most important anthropogenic sources of heavy metals to the environment (Boussen et al. 2008). Waters nearby the mine wastes generated from mining of Ba-Pb-Zn quartz veins at Segura area, central Portugal, was reported to have high contents of As and Mn (Antunes et al. 2008).

The concentration of *As* in many locations (eight surface water samples), were above the WHO (2011) maximum permissible limit for water quality. These high values may have been the consequence of Pb-Zn mining activities in Enyigba area. In Simav area (Turkey), As-rich mine wastes of an abandoned Cu-Pb-Zn mine have been the potential sources of As in the aquifer (Gunduz and Simsek, 2008). High As in surface and subsurface water was mainly related to the occurrence of arsenopyrite in the area.

In surface water, high concentration of As was recorded from Ohankwu Stream, Ebonyi River at Enyigba, Enyigba Stream and Village pond with concentrations of 2.5, 0.65, 0.3 and 0.3 mg/l respectively. These values are 250, 65, 30 and 30 times above the WHO (2011) maximum permissible limit of 0.01 mg/l for water quality. The total concentration of As in surface water (4.53 mg/l) is 453 times the WHO standard and contributed significantly to the pollution index of heavy metals in surface water. The average content of 0.57 mg/l of As in surface water is 57 times above the WHO (2011) limit for water quality (Table 5). These may have been associated with the Pb/Zn veins and mining activities in the area.

The dissolved concentrations of As persist at relatively high levels in the area due to additional inputs contributed by contaminated waters that drain the old mine workings and mine dumps. This is supported by the As contents of the rocks, mine dumps and the soils, and moderately mobility of As in neutral to alkaline conditions (Plant and Raiswell, 1983). It is difficult to pinpoint the exact concentration of As in drinking water that can lead to a particular health problems as the effects from exposure to As in drinking water typically takes many years to develop. The best way to find out if one is being exposed to excessive amount of As is to test the source of water one drinks from. The majority of exposure to environmental As occurs by taking As that is present in water, soil, dust and food. Drinking water that contains As at high concentrations for many years may be linked to a variety of health problems.

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS

In surface water, elevated concentration of Cd was recorded from Ohankwu, Ameka and Enyigba streams with concentrations of 13.5, 12.3 and 6 mg/l respectively. These values are 4500, 4100 and 2000 times the WHO (2011) maximum permissible limit of 0.003 mg/l for water quality. The total concentration of Cd in surface water (37.7 mg/l) is 12567 times the WHO standard and contributed very significantly to the pollution index of heavy metals in surface water. The average content of 6.28 mg/l of Cd in surface water is above the WHO (2011) limit for water quality (Table 2). Cadmium is a natural, usually minor constituent of surface and groundwater. It enters aquatic systems through weathering and erosion of bedrocks and soils. Much of the cadmium entering fresh waters may be rapidly adsorbed by sediments which are significant sinks for cadmium emitted to the aquatic environment (WHO, 2011).

The dissolved concentrations of Cd persist at relatively high levels in the area due to additional inputs of contaminated waters that drain the old mine workings and mine dumps (Nnabo, 2015, Igwe et al. 2012). This is supported by the Cd contents of the rocks, mine dumps and the soils (Onyeobi and Imeokparia, 2014). The mine wastes close to the mining area, are also the source of this metal. Cadmium is a priority hazardous metal and most failures to achieve its quality standard in fresh water are in base metal mining areas (Johnston et al. 2008). These localized high concentrations of Cd in the streams of Enyigba area may be related to the vicinity of the highly oxidized ore zones (Bolucek, 2007), and its moderate mobility under neutral to alkaline environments (Plant and Raiswell, 1983).

In surface water, elevated concentrations of Pb were recorded from Enyigba and Ameka streams with concentrations of 0.7 and 0.3 mg/l and respectively 70 and 30 times above the WHO (2011) maximum permissible limit of 0.01 mg/l for water quality. The total concentration of Pb in surface water (2.3 mg/l) is 230 times the WHO standard and contributed to the significant pollution index of heavy metals in surface water (Table 2). The average content of 0.23 mg/l of Pb in surface water is 23 times above the WHO (2011) limit for water quality (Table 2). Pb, perhaps due to its insoluble nature, decreased rapidly with distances away from the mineralization zones (Bolucek, 2007) coupled with fact that Pb, if it is in solution phase, would be highly attenuated through adsorption reactions by organic substances thereby restricting its mobility and with higher Pb in such environment (Plant and Raiswell, 1983). Lead concentration ranges from 0.1 to 0.7 mg/l.

The dissolved concentrations of Pb persist at relatively high levels in the area due to additional inputs of contaminated waters that drain the old mine workings and mine dumps. This is supported by the Pb contents of the rocks, mine dumps and the soils ((Onyeobi and Imeokparia, 2014, Nnabo, 2015, Igwe et al. 2012). The mine wastes close to the mining area, are also the source of this metal. This water dissolves many heavy metals including Pb at high concentrations (Byrne et al. 2009; Johnston et al. 2008). Pb concentrations of up to 100 times greater than the allowable levels were also reported by Byrne et al. (2009). The stream water around Pb-Zn-Cu deposits in Guryong mines (South Korea) showed highest concentrations of Pb, Cu, Zn, Mn, Co and Ni (Kim et al. 2007). In Baia Mare Mining Basin (NW Romania), characterized by Cu-Pb-Zn sulphide ores, heavy metals such as Cu, Zn, Cd, As and Pb leached from mine wastes caused severe contamination of surface and ground waters (Bolucek, 2007), and that the concentrations of Cu, Pb, Zn and Cd were found in higher levels in water courses due to mining and ore processing activities in the area. Despite the reduction in mining activities, the improper mines closure and poor mine wastes management still generated significant heavy metals pollution of surface waters in many areas such as Baia Mare (Bolucek, 2007), and Malluni region in Bolivia (Savarredy-Arangureen et al. 2008) Water from mine dumps are the main sources of the toxic metals and their subsequent mobilization into surface and groundwater is probably the most significant environmental impact associated with metallic sulphide mining Nash, 2002). Lead is known to fulfil no essential function in the body as it is merely harmful after uptake from food, air or water. It is a particularly dangerous metal, as it can accumulate in individual organisms and also in entire food chains, causing several health effects.

In surface water, elevated concentration of Ni was recorded from surface pond and streams at Enyigba and Ohankwu with concentrations as high as 2.07 mg/l which is up to 30 times above the WHO (2011) maximum permissible limit of 0.07 mg/l for water quality (Table 2). The total concentration of Ni in surface water (9.99 mg/l) is 143 times the WHO standard and contributed to the pollution index of heavy metals in surface water (Table 2). The average content of 1.11 mg/l of Ni in surface water is 16 times above the WHO (2011) limit for water quality (Table 2). High Ni in surface waters can inhibits the growth of algae.

In surface water, elevated concentration of Zn was recorded from Ebonyi River and streams from Enyigba and Ameka with concentrations as high as 10.1 mg/l and up to 3 times above the WHO (2011) maximum permissible limit of 3 mg/l for water quality (Table 2). The total concentration of Zn in surface water (35.32 mg/l) is 11.77 times the WHO standard and contributed to the pollution index of heavy metals in surface water (Table 3). The average content of 3.53 mg/l of Zn in surface water is only 1.18 times above the WHO (2011) limit for water quality (Table 2). The concentration of mobile Zn in the area will present some health effects in surface and underground water in the affected areas, where deposits of sphalerite and its mining may contribute to the high concentrations. The great mobility of Zn is exhibited here by a long dispersal pattern downstream from the mineralization zones (Bolucek, 2007).

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS

Metal Enrichment Index (MEI) and Metal Pollution Index (MPI)

The metal enrichment index of As in the water from the area was high in surface water (Figure 7) and indicates high contamination but more in mine ponds followed by surface water.

The metal enrichment index of Cd in the water samples were high in surface water (Figure 7), and again indicates high contamination but more in surface water and mine ponds followed by the underground water. As and Cd were possibly adsorbed on to soil particles.

The metal enrichment index of Ni in the surface water samples was high (Figure 7), also indicating high contamination in surface water and mine ponds and moderate pollution in underground water. This may be due to low very low mobility of Ni in neutral to alkaline conditions (Plant and Raiswell, 1983). The metal enrichment index of Cu is negative in surface water (Figure 7).

The metal enrichment index of Pb was high in surface water (Figure 7) and indicating high contamination but more in mine ponds followed by surface water. This may be due to low very low mobility of Pb in neutral to alkaline conditions (Plant and Raiswell, 1983).

The metal enrichment index of Zn in surface and mine pond water was very low (Figures 7) which indicated low to no pollution in surface and mine ponds water. The metal enrichment index of Mn in all the water samples was very low.

The values of the calculated metal pollution index (MPI) in surface water were all very low (Table 4 and Figure 8).

6. CONCLUSION

The MEI of As was very high in surface water (452) and and indicating high contamination by As. Based on MPI, As made contribution to the slight pollution in Ohankwu surface water sources. The MEI of Cd was high in surface water and indicating high degree of contamination. Based on MPI, Cd made contribution to the slight pollution in Ohankwu surface water sources. The MEI of Pb was high in surface water and indicates varying degrees high contamination. The high level of contamination expressed by the concentrations of As, Cd and Pb were related to the Pb/Zn occurrence and mining in the study area. This is also shown by the positive correlation between Pb, Cu and Zn which indicates the effects of man's activities on the source environment of the metals. Based on MPI, Pb made contribution to the slight pollution in the surface water of the area. The MEI of Ni in surface water was also high, which indicates high contamination in surface and mine pond water. It also contributed to the slight pollution of the surface water sources in the area based on MPI.

REFERENCE

1. Agumanu, A. E. (1989). The Abakaliki and Ebonyi Formations: sub-divisions of the Albian Asu River Group in the the southern Benue trough, Nigeria. Journal of African Earth Sciences. Vol. 9, No 1, pp. 195-207.
2. Antunes, I. M., Neiva, a. and Silva, M. (2008). Environmental contamination associated with some abandoned mines in Central Portugal. Retrieved from: www.imwa.info/docs/imwa-2008/IMWA 2008_078. Antunes.pdf.
3. Boussen, S., Soubrand,-Colin, M., Ouerfelli, K., Abdeljaouad, S. and Bril, H. (2008). Release of Pb and Zn from mine tailings, Tunisia. Retrieved from: www.gises.ensg.inpl-nancy.fr/User files/file/PM-2008/PM 08%20 Actes/Boussen.pdf. 7p
4. Bölücek, C. (2007). Environmental contamination in the Keban mining district, eastern Turkey. *Arabian Journal of Science and Engineering* 32 (1A), 3-18.
5. Byrne, P., Reid, I. and Wood, P. J. (2009). Sedimentary geochemistry of streams draining abandoned lead/zinc mines in central Wales – the Afon Twymyn. Geophysical Research Abstracts, Volume II, EGU 2009 – 8470.
6. Caeiro, S., Costa, M. H., Ramos, T. B., Fernandes, F., Silveira, N., Coimbra, A., Medeiros, G. and Painho, M. (2005). Assessing heavy metal contamination in Sado estuary sediment: an index analysis approach. *Ecological Indicators* 5, 151-169.
7. (6).
8. Farrington, J. L. (1952). A Preliminary Description of the Nigerian lead-zinc field. Econ. Geol 47 (6), 583-608.
9. Gajowiec, B. and Witkowski, A. (1993). Impact of lead/zinc mining on groundwater quality in Trzebionka mine (Southern Poland), *Mine Water and Environment* 12, 1-10.
10. Gunduz, O. and Simsek, C. (2008). Mechanisms of arsenic contamination of a surfacial aquifer in Turkey. Proceedings 6th International Groundwater Quality Conference, Fremantle, Western Australia, 2-7 December 2008. IAHS Publication No. XXX.
11. Igwe, O., Adepehin, E. I. and Iwuanyanwu, C. (2012). Environmental effects of the mining of lead-zinc minerals in Enyigba and its suburbs, southern Bebue Trough, Nigeria. Nigeria Journal of Education, Heath and Technology Research, 3 (2): 30-44.

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS

12. Johnston, D., Potter, H., Jones, C., Rolley, C., Watson, I. and Pritchard, J. (2008). Abandoned mines and the water environment. Science Project Report SC030136-41. Environment Agency, Bristol. 31p.
13. Kar, D., Sur, P., Mandal, S. K., Saha, T. and Kole, R. K. (2008). Assessment of heavy metals pollution in surface water. *International Journal of Environmental Science and Technology* 5(1), 119-124.
14. Kim, J. G., Ko, K., Kim, T. H., Lee, G. H., Song, Y., Chon, C. and Lee, J. (2007). Effect of mining and geology on the chemistry of stream water and sediment in a small watershed. Geosciences Journal 11 (2), 175-183.
15. Kogbe, C. A. (1989). The Cretaceous and Paleogene sediments of Southern Nigeria, In Geology of Nigeria, C. A. Kogbe
16. (ed). Rock View Nigeria Limited, Jos. pp. 325-334.
17. Kumar, S. P. and Edward, J. K. P. (2009). Assessment of metal concentration in the sediment cores of Manakudy estuary, south west coast of India. *Indian Journal of Marine Science* 38 (2), 235-248.
18. Mattigod, S. V. and Page, A. L. (1983). Assessment of metal pollution in soils. *In:* Thornton, I. (ed) Applied Environmental Geochemistry, Academic Press, London, 355-393.
19. Nash, J. T. (2002). Hydrogeochemical investigations of historic mining districts, Central Western Slope of Colorado, including influence on surface water quality. USGS Digital Data Series, DDS-73. 168p.
20. Nash, J. T. (2003). Historic mills and mill tailings as potential sources of contamination in and near the Humboldt River Basin, Northern Nevada, USGS Bulletin 2210 – D, 36p.
21. Nimick, D. A., Church, S. E., Cleasby, T. E., Fey, D. L., Kimball, B. A., Leib, K. J., Mast, M. A. and Wright, W. G. (1999). Characterization of metals in water and bed sediment in two watersheds affected by historical mining in Montana and Colorado. Retrieved from: http://toxics.usgs.gov/pubs/wri99-4018/vol1/sectionA/1201-Nimick/pdf/Nimick.pdf.
22. Nnabo, P. N. (2011). Environmental impacts of lead/zinc mining in Enyigba area, SE of Abakaliki, SE Nigeria. Ph.D Thesis, Ebonyi State University, Abakaliki, Nigeria. 322p.
23. Nnabo, P. N. (2015). Assessment of heavy metal distribution in rocks from Enyigba Pb-Zn district, southeastern Nigeria. International Journal of Innovation and Scientific Research, 17 (1): 175-185.
24. Nnabo, P. N., Orazulike, D. M. and Offor, C. O. (2011). The preliminary assessment of the level of heavy Elements contaminations in stream bed sediments of Enyigba and environs, south eastern Nigeria Journal of Basic Physical Research, Vol. 2, No.2, pp. 43 – 52.
25. Nwajide, C.S., 1990. Eocene tidal sedimentation in the Anambra Basin, Southern Nigeria. Sedimentary Geology, 25, 189-207.
26. Onyedika, G. O. and Nwosu, G. U. (2008). Lead, zinc and cadmium in root crops from mineralized galena-sphalerite mining areas, and environment. *Pakistan Journal of Nutrition* 7 (3), 418-420.
27. Onyeobi, T. U. S. and Imeokparia, E. G. (2014). Heavy metal contamination and distribution in soils around Pb-Zn mines of Abakaliki district, southeastern Nigeria. Frontiers in Geosciences, 2 (2): 30-40.
28. Orajaka, S. (1965). The Geology of Enyigba, Ameri and Ameka Lead-Zinc lodes Abakaliki; South-eastern Nigeria. A reconnaissance. J. Min. Geol. 2, 65-69.
29. Plant, J. A. and Raiswell, R. (1983). Principles of environmental geochemistry. *In:* Thornton, I. (ed) Applied Environmental Geochemistry, Academic Press, London, 1-39
30. World Health Organization (2011). Guidelines for drinking-water quality [electronic resource]: incorporating 1st and 2nd addenda. Vol. 1, Recommendations, 5th edition. Geneva. 668p.

© 2017 Discovery Publication. All Rights Reserved. www.discoveryjournals.com | OPEN ACCESS