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EFFECTS OF LEAD-ZINC MINING ACTIVITIES ON WATER AND SOIL QUALITY IN AMEKA MINING AREA OF EZZA SOUTH, EBONYI STATE, NIGERIA

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ABSTRACT

This study assessed the effects of lead-zinc mining on water and soil quality in Ameka mining area of Ezza South, Ebonyi State, Nigeria using standard protocols. The results of physcochemical properties of water and soil showed anthropegenic pollution with values significantly exceeding ($P < 0.05$) that of the control and permissible threshold limits set by World Health Organization (WHO), United State Environmental Protection Agency (USEPA), Federal Ministry of Environment (FME) among other standard organization. Different heavy metals were dectected at varying levels in the water and soil samples at levels significantly above ($P < 0.05$) those of the control and the standand set by regulatory agencies (WHO, USEPA, FME among others). The results showed that Pb, Zn, Fe, and Cu were detected in the water samples from all the studied boreholes and surface waters in both the rainy and dry seasons, Cd and Mn only were detected in Akpara stream, Amajim pit lake and Akpara Okpo stream in both season, Cr only was detected in Akpara stream and Amajim pit lake only while Ni only was detected in Amajim pit lake only The results also indicated that all the metals studied were present in the soil samples from the different farmlands studied in the mining community. The microbial profile of the water samples showed anthropogenic pollution with wide range of clinical isolates (Bacillus subtilis, Salmonela spp., Streptococcus faecalis, Escherichia coli, Pseudomonas aeruginosa, Staphylococcus spp Morganella morgenii, Yersinia enterolitica, Clostridium xerosis, and Mucor) of pathological

importance. Routine assessment of the effects of mining activites on the inhabitants of these host communities is advocated to ensure maintenance of health especially in those that are most vulnerable. There is urgent need to make policies that will guide and regulate mining activities especially artisan mining in this area.

Key Words: Mining, Ameka, Heavy metals, Clinical isolates, Toxicity

Introduction

Mining industry, as with other extractive industries is an economically viable enterprise, enhancing employment opportunities, lubricating livelihoods and among others, supporting national income. Many countries have taken to mining as a means of expanding their economic bases. Nigerian Government recognized the economic importance of mining activities when it set up a new mineral policy, the mineral and mining act of 2007, with the ultimate aim of orderly and sustainable development of the solid mineral sector, (NMMA 2007).

In Ebonyi State, Southeast Nigeria, solid mineral mining is next to agricultural sector in her economies. Ever since the discovery of solid mineral deposit in the old Abakaliki division of the old Eastern Nigeria, in the forties and the subsequent mining concession by the Federal Government of Nigeria to the mines Development Syndicate (WA) limited, by the mining lease (188 Mining Property) of 1954 (operated by its subsidiary-Nigeria Lead-Zinc Mining Company Limited (NLZM), the Abakaliki lead-zinc mining areas have witnessed continued presence of different forms of mining activities. In a culture characterized by poor economic background, high level of illiteracy, inadequate knowledge of primary hygiene, fragile ecosystem, and dispersed demography, the impacts of indiscriminate mining activities are disastrous.

The principal mineral of interest in this area is lead-zinc, though there are handouts of other elements such as copper and quartz in some locations. The total lead mine area is about 21.8sq.km, consisting of three Local Government Areas Enyigba in Abakaliki LGA, Ameka in Ezza South LGA, and Ameri in Ikwo LGA area and is generally referred to as Abakaliki lead mining area, Ebonyi State (EBMCI, 2003).

Ameka lead-zinc mine sites often look like moonscapes filled with broken rocks and dirts. The mining process involves mass earthmoving which usually releases harmful constituents and great cloud of dust, thus compromising air quality in the surrounding area. Excavations are carried out with pail loaders, simple tools and sometimes bare hands. Sometimes, toxic

chemicals such as cyanide and sulphuric acids in addition to dynamite are used to blast the rock veins to aid excavation of the mine sites. Noise pollution resulting from the constant blasts affects wide life and generates acoustic pollution to humans around the site. Vibration associated with blasts also distorts the soil ecology, mechanics and geomorphology, while structural defects are characteristic feature of buildings within the mine environment. Geological structures according to Ezeh *et al*. (2008) are affected as a result of mining activities giving room for cracks and where existing, widened. Also geological fault lines many distances away from the blast sites are amplified, enhancing the possibilities of earthquakes and cave-ins. Globally, mine sites are known to be contaminated by heavy metals, containing a mixture of non-renewable mineral and aggregate resources in quantifiable amounts, which are exhaustible with time (Lombi *et al*., 2001) Mining operations according Ofomata (2003) are being recognized as important source of heavy metals in the environment and are considered an environmental degrading venture. Although, anthropogenic-induced metal pollution is traceable to a lot of industrial activities such as petroleum exploration, exploitation and utilization, fertilizer application to agricultural soil and battery industries, mining and smelting of mataliferous ores remain probably the major source of environmental metallization (Algbedion and Iyayi 2007). The situation is exacerbated when the mining operations are carried out in crude manner by unskilled artisanal miners resulting in the improper disposal of mining wastes (Nwaugo *et al*., 2007). This is the case with the Ameka lead-zinc mining where the mining operations are carried out in crude manner by unskilled artisanal miners.

Artisanal mining has negative impacts on the surrounding environment. It exposes both ores and host rocks to atmospheric influences, resulting in the creation of artificial ponds and pits which form source of drinking water for the inhabitants of the area. These open pits are sometimes deeper than the water table level and may be filled with water to form artificial lakes. The integrity of the surface and ground water in this area may be threatened as poisonous heavy metals may leach into water supplies below and above the ground causing gross contamination and aquatic life loss. The soil being the major reservoir of effluent discharges from industrial activity is also at risk of pollution from the mining activities.

Ameka lead-zinc mining activities is characterized by the indiscriminate dumping of mine tailings, which appear sometimes as elongate ridge trailing parallel to mined out veins. These tailings contain ore and gangue, which like the mineral veins, on weathering release the composing metals to the environment. Metals such as lead (Pb), zinc (Zn), copper (Cu), nickel (Ni) and arsenic (As) which are also associated with lead-zinc (Pb-Zn) mineralization

can be released into the terrestrial environment by intensive weathering and podzolisation, polluting soils, surface and underground waters and sediments (Ezeh and Anike 2009).

Mining activities have been reported to among others affect soil fertility and introduce heavy metals to the environment at levels exceeding their threshold limit (Aremu *et al*., 2010). These metals may bio-accumulated by edible food plants and as such may pose health risks to flora and fauna in the ecosystem (Obasi *et al*., 2013). Reports have shown that mining activities significantly contribute to the increase in lead and other potential harmful elements in surrounding environment, these activities coupled with prolonged human exposure and ingestion of the contaminated edible food plants have effects on the people living within the vicinity of the mines (Ezeh, 2010; Oti and Nwabue, 2012).

There are numerous reports on the effects of lead-zinc mining activities on health and environment (Aremu *et al*., 2008). Currently, the activities of artisan mining in the Ameka lead-zinc mines are on the increase. Despite the effects of such activities on the environment of host communities, there is little or none data on these effects the soil and water qualities of the host community. Therefore, this work is designed to evaluate and generate base-line data on soil and water quality in order to determine their potential health and environmental effects. It is hoped to equip appropriate authorities properly in making policies on issues of public health and safety, as it relates to mining and the environment.

Materials and Methods

Study Area

Ameka is an autonomous community in Ezza South Local Government Area of Ebonyi State located approximately in $7^0$25'N and $7^0$18'E. The area experiences the wet and dry season's climate regimes. The rainy season is experienced between April to October while the dry season becomes evident from October to March. Maximum temperature of 32^0C is experienced in March with a minimum of 24^0C in July. Population of the area was estimated to be 28918 people by 2006 (NPC Ebonyi State Office, 20011) .Socio-economically the people of Ameka are mainly farmers. The crops cultivated include yams, cassava and rice. Cassava and yam are commercially produced and therefore form the economic base of the area. Recently, most of the dwellers are artisan miners. The mineral assemblage and associations in the area comprise both primary and secondary mineralization (Offordile 2001). Geologically, the Ameka lead-zinc deposits form part of the Abakaliki lead-zinc field (BESL, 2004). This field occurs within a substantial part of the largest cretaceous sedimentary basins in Nigeria known as the Benue trough. The primary metalliferons

deposits in the area include galena, sphalerite, chaleopyrite, marcasite cerrurite and pyromorphite while the gangue minerals associated with the metallic ores include siderite, calcite, fluorite, barite and quartz (BESL, 2004).

Field Reconnaissance

Several field recognizance visits were done from year 2012 through year 2013 by the researcher. The research Areas of interest in the study community were clearly mapped out and technical delineated for proper assessment. A Pentax Espio 738 S regular zoom camera with colour films and a Hewiett Packard photosmart 850 digital camera with memory card were used to take photographs of the different mapped sites for the research. A Global positioning system (GPS), Garmin GPS 7211 with its accessories and a Silva compass with clinometer aided in navigation and location of geographic coordinates.

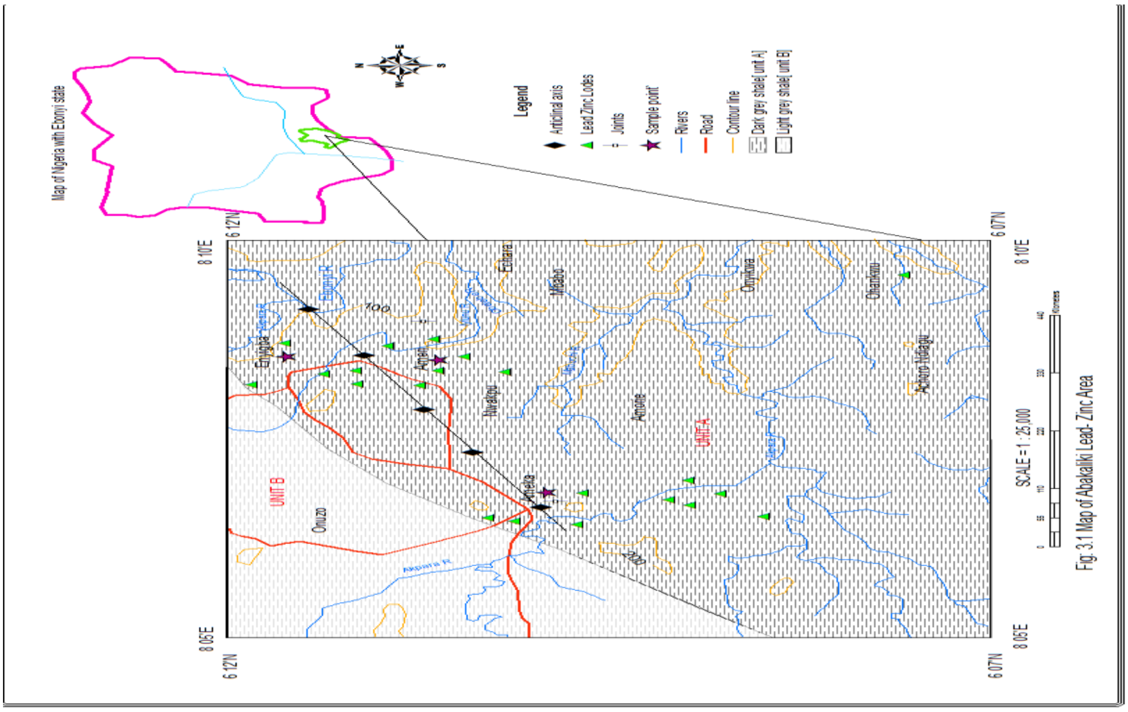

Fig 1: Map of Abakaliki Lead-Zinc Area showing Lead-Zinc Lodes and Sample Point (Ameka)

Source: Nigerian Geographical Regions (2010)

Water Quality

The assessment of water quality in the study involved sampling from eight sources namely: Amajim borehole I, Alegu borehole, Amajim borehole II, Control borehole, Akpara stream,

Amajim Pit Lake, Akpara okpo stream and Control stream. The control borehole and stream samples were obtained from Onueke community in Ezza South with no mining activities.

Physicochemical and Heavy Metals Analyses

The physicochemical properties of the water samples were determined according to standard methods.

Determination of pH: The pH was carried out in-situ at the site of sample collection using the Hanna microprocessor pH meter. It was standardized with a buffer solution of pH range between 4-9.

Measurement of temperature: This was carried out in-situ at the site of sample collection using a mobile thermometer. This was done by dipping the thermometer into the sample and recording the stable reading.

Determination of conductivity: This was done using a Jenway conductivity meter (4510 model). The probe was dipped into the container of the samples until a stable reading was obtained and recorded.

Determination of acidity: Following the procedure in the American Society for Testing and Materials (1982), acidity was determined by titration. Exactly 50ml of the sample was pipetted into a clean 250ml conical flask. Two drops of phenolphthalein indicator were then added and the solution titrated against a standard 0.01M NaOH solution to a pink end-point.

Calculation

Acidity (mg/l) = V x M x 100,000/ ml of sample used

Where V = volume of NaOH used

M = molarity of NaOH used

Determination of Alkalinity: Exactly 50ml of the sample was pipetted into a clean 250ml conical flask. Two drops of methyl red indicator were then added and the solution titrated against a standard 0.01M HCl solution to a pink end-point. (American Society for Testing and Materials, 1982).

Calculation

Total alkalinity (mg/l) = V x M x 100,000 / ml of sample used

Where V = volume of HCl used

M = Molarity of HCl used

Determination of Turbidity: This was determined using a standardized Hanna H198703 Turbidimeter. The samples were poured into the measuring bottle and the surface or the bottle was wiped with silicon oil. The bottle was then inserted into the turbidimeter and the reading was obtained.

Determination of total solids (TS) by gravimetric Method: Exactly 10ml of the samples were measured into a pre-weighed evaporating dish which was then dried in an oven at a temperature of 103 to 105^0C for two and half hours. The dish was transferred into a desiccators and allowed cool to room temperature and was weighed. The total solid was represented by the increase in the weight of the evaporating dish.

Calculation

Total solids (mg/l) = (W2-W1) mg x 1000/ ml of sample used

Where W1 = initial weight of evaporating dish

W2 = Final weight of the dish (evaporating dish + residue)

Determination of total dissolved solids (TDS) by Gravimetric Method: A portion of water was filtered out and 10ml of the filtrate measured into a pre-weighed evaporating dish. Following the procedure for the determination of total solids above, the total dissolved solids content of the water was calculated.

Calculation

Total dissolved solids (mg/l) = (W2-W1) mg x 1000/ ml of filtrate used.

Where W1 = initial weight of evaporating dish

W2 = Final weight of the dish (evaporating dish + residue).

Determination of total suspended solids (TSS)

The total suspended solids were easily obtained by simple calculation, i.e.

Calculation

Total suspended solids = total solid - total dissolved solids.

Determination of Total Hardness: Exactly 25ml of the samples was placed in different clean 250ml conical flasks. To this were added 3ml of ammonium chloride in concentrated ammonia buffer and 2 drops of Eriochrome Black T indicator. This was titrated against 0.01M EDTA solution until there was a colour change from violet to blue.

Calculation:

Hardness in mg/l $CaCO_3$ = [V x M x 1000] / ml of sample used

Where M = Molarity of EDTA Used

V =Volume of EDTA used.

Determination of nitrate: A photometric method was used for the determination, NO_3^-. Analytical water test tablets prescribed for Palintest® Photometer 5000 (Wagtech, Thatcham. Berkshire, UK) series were used.

Heavy metal determination: The sample water were digested using concentrated nitric acid HNO_3 and concentration of lead (Pb), zinc (Zn), iron (Fe), copper (Cu), Cadmium (Cd), Manganese (Mn), nickel (Ni), Cobalt (Co) and Chromium (Cr) measured with Perkin-Elmer atomic absorption spectrophotometer (model 403) (Williams *et al.*, 2007; Essien *et al.*, 2006; Adekoya *et al.*, 2006). The essence of the digestion before analysis was to reduce organic matter interference and convert metal to a form that can be analyzed by AAS.

Determination of Microbial Profile of Water Samples

Collection of Samples

Seventeen water samples from borehole, artificial lakes, and streams were collected for Microbial analysis. The sampling bottles were soaked overnight with hydrogen peroxide and then rinsed with distled water. The cap of the sampling bottle was removed while the bottle was submerged into the water for surface water bodies, while the tap of the borehole was cleaned with a cotton wool soaked in 70% alcohol, flamed with spirit lamp and the water allowed to run for a 60s before collecting in a 500 ml sterile bottle which was carefully covered with its screw cap. All samples collected from all sources were taken to the laboratory for analysis within six hours after collection. Each of the sample bottles was labelled with sample code number and they were thoroughly mixed, before testing.

Determination of microbial load

All glasswares used for this study were sterilized in a hot box oven at 160^0C for one hour. Nine milliliters of sterile water was transferred into 5 sterile tubes labeled 10^{-1} to 10^{-5}. One milliliter of the sample aseptically transferred into the first test tube (10^{-1}) with a sterile pipette and mixed. From the first test tube, one millimeter was equally transferred to the test tube labeled 10^{-2} and mixed using fresh pipette. This was repeated until the test tube labeled 10^{-5}. The Pour Plate Technique was used and the culture medium was Nutrient Agar. One milliliter of the sample from 10^{-2} test tube was aseptically transferred into sterile Petri dishes using sterile pipette. The Nutrient Agar was prepared according to the manufacturer‟s instruction and allowed to cool to 45^0C. Twenty milliliters of the culture medium was poured into the Petri dish and properly mixed with the sample. This was done in triplicates. A control was equally prepared, but without adding the sample. The plates were labeled, allowed to solidify, inverted and finally incubated at 37^0C for 24-48 hours. The plates were observed for development of bacterial colonies. Statistical tables were then used to derive the concentration of organisms in the original sample.

Soil Quality

Soil samples were collected at depths of 0-20cm using the mineral veins from farmlands in Amajim, Alegu and Akpara within the vicinity of mining pits. Samples from each of the locations were composed to form homogenous mixture and labeled as Amajim Farmland, Alegu Farmland, and Akpara Farmland respectively. Control sample was obtained from a farmland in Onueke, Ezza South with no mining activites.

Soil pH was determined (1:2.5w/v) using digital pH meter according to the method described by Bates (1954), soil electrical conductivity was determined (1:2.5 w/v) using conductivity meter according to the method outlined by Godson *et al*. (2002), moisture content was determined by the method of Shrivastava and Banerjee (2004), total organic carbon and total organic matter were determined according to the method outlined by Osuji and Adesiyan (2005), Total nitrogen was determined by the Semi kjeldhal method (Yeomans and Bremmer, 1991), SO_4^{2-} was quantified by the turbidimetric method outlined by Butters and Chenery (1959) while PO_4^{3-} was determined by Braig No. 1 method (Olsen and Somners, 1982).

Soil samples were air dried, ground to fine dust, sieved to pass through a 2mm sieve one gram of the sieved soil sampled was weighed into a conical flask and digested with 10ml of 50% hydrochloric acid on a hot plate until 2-3ml of acid was left. The content was the filtered into a 50ml volumetric flask and rinse to make up to the mark with deionized water. The concentrations of heavy metals in all the samples were determined using the Perkin-Elmer atomic absorption spectrophotometer (model 403).

Results

Results of Water Physicochemical Quality

The results of physicochemical properties of water samples collected from boreholes and surface water from the Ameka community in rainy and dry seasons are shown in Tables 1 and 2 respectively. The results showed that the temperature of the borehole water were generally higher than surface water at both seasons and significantly ($P < 0.05$) varied among the sources with a range from 27.1^{o}C in Amajim lake to 28.1^{o}C in Amajim borehole I for rainy season and from 26.2^{o}C in Akpara Okpo stream to 27.6^{o}C in Amajim borehole II. The pH of the water samples were shown to be generally low with a range from 6.5 to 7.5 and significantly ($P < 0.05$) differed from one water source to another. The total dissolved solids (TSS) and total acidity (TA) of borehole and surface water from the different sources in the mining community were significantly ($P < 0.05$) higher than those from the control sites and varied significantly ($P < 0.05$) from one site to another site with borehole water having higher values compared to surface water. The results (Table 1 and 2) also indicated that the electrical

conductivity (EC), total suspended solids, (TSS), total solids (TS), turbidity, total alkalinity (TAL), nitrate (NO_3^-) and total hardness (TH) of borehole and surface water from the different sources in the mining community were significantly ($P < 0.05$) higher than those from the control sites and varied significantly ($P < 0.05$) from one site to another site with surface water having higher values compared to borehole water.

The results of heavy metal content of water samples collected from boreholes and surface water from the different sources in the mining community in rainy and dry seasons are shown in tables 3 and 4. The results showed that Pb, Zn, Fe and Cu were present in varying degrees while Cd, Mn, Ni, Co and Cr were below detectable limits in both the borehole and the surface water. The Pb, Zn, Fe and Cu content of borehole and surface water from the different sources in the mining community were significantly ($P < 0.05$) higher than those from the control site in both seasons and varied significantly ($P < 0.05$) from one site to another site with surface water having higher values compared to borehole water.

Table 1: Physicochemical Properties of Water Samples Collected during Rainy Season

Location		**Amajim**	**Alegu**	**Amajim**	**Control**	**Akpara**	**Amajim pit**	**Akpara Okpo**	**Control**
Parameters	**WHO(2008)**	**Borehole 1**	**Borehole**	**Borehole II**	**Borehole**	**Stream**	**Lake**	**Surface**	**Surface**
Temp (^{0}C)	25^0C	$28.1^{d} \pm 0.02$	$27.9^{d} \pm 0.11$	$27.6^{c} \pm 0.05$	$27.4^{b} \pm 0.05$	$27.2^{a} \pm 0.03$	$27.1^{a} \pm 0.04$	$27.4^{b} \pm 0.01$	$27.1^{a} \pm 0.03$
pH	6.5-8.5	$6.5^{a} \pm 0.01$	$6.8^{b} \pm 0.05$	$6.6^{a} \pm 0.01$	$6.8^{b} \pm 0.05$	$7.2^{c} \pm 0.02$	$7.5^{d} \pm 0.01$	$7.4^{d} \pm 0.02$	$6.9^{b} \pm 0.02$
EC (µS/cm)	1400	$252.0^{d} \pm 0.03$	$263.3^{e} \pm 0.13$	$245.0^{c} \pm 1.03$	$80.0^{a} \pm 1.15$	$380.0^{f} \pm 0.07$	$461.7^{h} \pm 0.11$	$424.6^{g} \pm 0.12$	$87.0^{b} \pm 0.12$
TDS (mg/l)	1000	$66.7^{c} \pm 0.06$	$122.5^{d} \pm 0.14$	$132.7^{f} \pm 1.21$	$32.2^{a} \pm 0.50$	$148.5^{g} \pm 1.05$	$207.0^{h} \pm 1.11$	$128.5^{e} \pm 0.03$	$41.5^{b} \pm 1.01$
TSS (mg/l)	-	$6.8^{b} \pm 0.05$	$7.6^{c} \pm 0.18$	$9.5^{d} \pm 1.12$	$3.8^{a} \pm 0.11$	$152.6^{f} \pm 0.62$	$167.4^{g} \pm 1.13$	$139.5^{e} \pm 0.15$	$7.6^{c} \pm 0.27$
TS (mg/l)	-	$73.5^{c} \pm 0.37$	$130.1^{d} \pm 0.62$	$142.2^{e} \pm 0.31$	$36.0^{a} \pm 1.31$	$301.1^{g} \pm 0.97$	$374.4^{h} \pm 1.25$	$268.0^{f} \pm 0.55$	$49.1^{b} \pm 0.33$
Turbidity (NTU)	5	$3.7^{b} \pm 0.13$	$3.6^{f} \pm 0.12$	$4.9^{c} \pm 0.15$	$2.8^{a} \pm 0.50$	$4.6^{c} \pm 0.14$	$6.3^{e} \pm 0.22$	$5.1^{cd} \pm 0.25$	$3.4^{b} \pm 0.42$
TAL (mg/l)	-	$15.2^{d} \pm 0.25$	$21.3^{g} \pm 0.31$	$23.0^{h} \pm 1.12$	$13.8^{b} \pm 1.05$	$18.6^{f} \pm 0.85$	$17.5^{e} \pm 0.67$	$14.9^{c} \pm 0.77$	$11.2^{a} \pm 1.23$
TA (mg/l)	-	$13.2^{b} \pm 0.14$	$12.5^{a} \pm 0.76$	$15.2^{e} \pm 1.28$	$18.3^{f} \pm 0.45$	$14.5^{d} \pm 0.42$	$18.2^{f} \pm 0.55$	$13.8^{c} \pm 0.11$	$12.4^{a} \pm 1.15$
NO_3^- (mg/l)	50	$7.7^{d} \pm 0.41$	$5.4^{b} \pm 0.25$	$5.1^{b} \pm 0.17$	$3.2^{a} \pm 1.05$	$9.4^{e} \pm 0.65$	$12.6^{f} \pm 0.93$	$5.9^{c} \pm 0.14$	$3.1^{a} \pm 0.21$
TH (mg/l)		$104.5^{c} \pm 0.32$	$125.4^{e} \pm 0.27$	$115.0^{d} \pm 0.15$	$102.5^{b} \pm 0.18$	$124.6^{e} \pm 1.33$	$175.4^{g} \pm 0.47$	$135.5^{f} \pm 0.12$	$101.6^{a} \pm 0.42$

LEGEND: - EC= Electrical Conductivity = µS/cm, TDS = Total Dissolved Solids = mg/l, TSS = Total Suspended Solid = mg/l, TS = Total Solids = mg/l, Turbidity = NTU, TAL =Titratable Alkalinity = mg/l, TA = Titratable Acidity = mg/l, Nitrate = mg/l, TH = Total Hardness = mg/l. Figures by the same alphabets along the row are not significantly different at $P < 0.05$ using Ducan Multiple Range Test (DMRT)

Source: Authors field work

Table 2: Physicochemical Properties of Water Samples Collected during Dry Season

Location		Amajim	Alegu	Amajim	Control	Akpara	Amajim pit	Akpara Okpo	Control
Parameters	**WHO(2008)**	**Borehole I**	**Borehole**	**Borehole II**	**Borehole**	**Surface**	**Surface**	**Surface**	**Surface**
Temp (^{0}C)	25^{0}C	27.2^{c} ± 0.03	27.5^{d} ± 0.11	27.6^{e} ± 0.13	26.0 ^{a} ± 0.07	26.5^{b} ± 0.05	26.8^{b} ± 0.02	26.2^{a} ± 0.01	26.3 ^{a} ± 0.45
pH	6.5-8.5	6.6^{a} ± 0.02	6.8^{ab} ± 0.01	6.7^{a} ± 0.05	6.8^{ab} ± 0.01	6.9^{b} ± 0.03	7.3^{c} ± 0.05	6.8^{ab} ± 0.01	6.7^{b} ± 0.02
EC (µS/m)	1400	316.5^{b} ± 0.11	328.0^{c} ± 0.15	333.9^{e} ± 0.51	82.5^{a} ± 0.10	365.8^{f} ± 0.35	370.6^{g} ± 0.15	330.0^{d} ± 1.21	92.5^{b} ± 0.23
TDS (mg/l)	1000	165.0^{d} ± 0.12	135.0^{c} ± 1.21	174.7^{e} ± 0.93	76.7^{b} ± 0.23	286.8^{h} ± 0.82	265.3^{f} ± 0.31	272.1^{g} ± 0.11	72.3^{a} ± 0.15
TSS (mg/l)	-	5.1^{b} ± 0.11	8.3^{d} ± 0.52	6.5^{c} ± 0.21	4.6^{a} ± 0.13	112.6^{f} ± 0.12	158.7^{h} ± 1.11	136.5^{g} ± 0.15	17.0^{e} ± 1.05
TS (mg/l)	-	170.1^{d} ± 0.13	143.3^{c} ± 0.51	181.2^{e} ± 1.03	81.3^{a} ± 0.19	399.4^{f} ± 0.33	424.0^{h} ± 1.11	408.6^{g} ± 0.22	89.3^{b} ± 1.17
Turbidity (NTU)	5	3.7^{b} ± 0.22	4.5^{c} ± 0.19	5.3^{d} ± 0.25	2.4^{a} ± 0.18	8.3^{e} ± 0.21	13.2^{g} ± 0.41	11.2^{f} ± 0.31	2.3^{a} ± 0.11
TAL (mg/l)	-	198.3^{d} ± 1.23	168.7^{c} ± 0.19	198.6^{de} ± 0.45	105.0^{b} ± 0.33	216.5^{f} ± 0.20	198.0^{d} ± 0.92	219.5^{h} ± 1.05	102.4^{a} ± 0.55
TA (mg/l)	-	18.2^{g} ± 0.35	16.7^{f} ± 0.17	13.6^{c} ± 0.24	8.2^{b} ± 0.22	15.2^{e} ± 0.41	14.7^{d} ± 0.55	16.4^{f} ± 0.38	7.6^{a} ± 0.24
NO_3^- (mg/l)	50	5.2^{c} ± 0.71	4.1^{b} ± 0.21	5.3^{c} ± 0.19	2.5^{a} ± 0.13	7.8^{d} ± 0.17	14.1^{f} ± 0.41	8.2^{e} ± 0.22	2.7^{a} ± 0.15
TH (mg/l)		138.9^{c} ± 0.31	143.5^{d} ± 0.15	156.5^{e} ± 0.17	108.6^{a} ± 0.16	163.2^{f} ± 0.51	213.5^{h} ± 0.55	202.0^{g} ± 0.35	115.0^{b} ± 0.12

LEGEND: - EC= Electrical Conductivity = µS/cm, TDS = Total Dissolved Solids = mg/l, TSS = Total Suspended Solid = mg/l, TS = Total Solids = mg/l, Turbidity = NTU, TAL =Titratable Alkalinity = mg/l, TA = Titratable Acidity = mg/l, Nitrate = mg/l, TH = Total Hardness = mg/l.

Figures by the same alphabets along the row are not significantly different at $P < 0.05$ using Ducan Multiple Range Test (DMRT)

Source: Authors field work

Table 3: Heavy Metal Contents (mg/l) of Water Samples Collected during Rainy Season

Location			Amajim	Alegu	Amajim	Control	Akpara	Amajim pit	Akpara Okpo	Control
Parameters	WHO (2011) mg/l	USEPA (2002) mg/l	Borehole	Borehole	Borehole	Borehole	Surface	Surface	Surface	Surface
Pb	0.01	0.01	$0.15^{d} \pm 0.01$	$0.09^{b} \pm 0.05$	$0.11^{c} \pm 0.02$	$0.01^{a} \pm 0.03$	$0.14^{d} \pm 0.02$	$0.18^{e} \pm 0.05$	$0.12^{c} \pm 0.02$	$0.01^{a} \pm 0.01$
Zn	5	3	$0.23^{e} \pm 0.03$	$0.15^{d} \pm 0.05$	$0.12^{c} \pm 0.04$	$0.03^{b} \pm 0.01$	$0.28^{g} \pm 0.01$	$0.30^{h} \pm 0.02$	$0.25^{f} \pm 0.05$	$0.01^{a} \pm 0.02$
Fe	-	0.3	$0.16^{c} \pm 0.01$	$0.10^{b} \pm 0.01$	$0.02^{a} \pm 0.10$	$0.01^{a} \pm 0.01$	$0.23^{d} \pm 0.05$	$0.42^{e} \pm 0.03$	$0.25^{d} \pm 0.02$	$0.01^{a} \pm 0.01$
Cu	0.05	0.05	$0.03^{ab} \pm 0.02$	$0.02^{a} \pm 0.01$	$0.04^{b} \pm 0.03$	BDL	$0.05^{b} \pm 0.01$	$0.02^{a} \pm 0.01$	$0.02^{a} \pm 0.03$	BDL
Cd	0.0	0.002	BDL	BDL	BDL	BDL	$0.02^{a} \pm 0.01$	$0.05^{b} \pm 0.01$	$0.03^{a} \pm 0.02$	BDL
Mn	-	0.5	BDL	BDL	BDL	BDL	$0.01^{a} \pm 0.01$	$0.08^{b} \pm 0.02$	$0.02^{a} \pm 0.01$	BDL
Ni	-	-	BDL	BDL	BDL	BDL	BDL	$0.02^{a} \pm 0.01$	BDL	BDL
Co	-	-	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cr	0.05	0.10	BDL	BDL	BDL	BDL	BDL	$0.02^{a} \pm 0.01$	BDL	BDL

BDL = Below Detectable Limit. Figures followed by the same alphabets along the row are not significantly different at $P < 0.05$ using Ducan Multiple Range Test (DMRT)

Source: Authors field work

Table 4: Heavy Metal Contents (mg/l) of Water Samples Collected during Dry Season

Location			Amajim	Alegu	Amajim	Control	Akpara	Amajim pit	Akpara Okpo	Control
Parameters	WHO (2011) mg/l	USEPA (2002) mg/l	Borehole	Borehole	Borehole	Borehole	Surface	Surface	Surface	Surface
Pb	0.01	0.01	$0.16^{d} \pm 0.01$	$0.11^{b} \pm 0.02$	$0.15^{c} \pm 0.02$	$0.01^{a} \pm 0.05$	$0.18^{e} \pm 0.02$	$0.22^{f} \pm 0.11$	$0.17^{de} \pm 0.03$	$0.01^{a} \pm 0.01$
Zn	5	3	$0.25^{d} \pm 0.03$	$0.18^{c} \pm 0.05$	$0.13^{b} \pm 0.04$	$0.02^{a} \pm 0.01$	$0.34^{f} \pm 0.01$	$0.37^{g} \pm 0.02$	$0.31^{e} \pm 0.05$	$0.01^{a} \pm 0.02$
Fe	-	0.1	$0.15^{d} \pm 0.01$	$0.12^{c} \pm 0.05$	$0.08^{b} \pm 0.02$	$0.01^{a} \pm 0.01$	$0.29^{f} \pm 0.03$	$0.48^{g} \pm 0.07$	$0.24^{e} \pm 0.05$	$0.01^{a} \pm 0.01$
Cu	0.05	0.05	$0.02^{ab} \pm 0.02$	$0.01^{a} \pm 0.01$	$0.03^{b} \pm 0.05$	BDL	$0.06^{c} \pm 0.02$	$0.16^{e} \pm 0.05$	$0.07^{cd} \pm 0.03$	BDL
Cd	0.0	0.002	BDL	BDL	BDL	BDL	$0.03^{ab} \pm 0.01$	$0.07^{c} \pm 0.01$	$0.02^{a} \pm 0.02$	BDL
Mn	-	0.5	BDL	BDL	BDL	BDL	$0.01^{a} \pm 0.01$	$0.11^{c} \pm 0.02$	$0.02^{ab} \pm 0.01$	BDL
Ni	-	-	BDL	BDL	BDL	BDL	BDL	$0.05^{a} \pm 0.02$	BDL	BDL
Co	-	-	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cr	0.05	0.10	BDL	BDL	BDL	BDL	$0.01^{a} \pm 0.02$	$0.03^{b} \pm 0.01$	BDL	BDL

BDL = Below Detectable Limit. Figures followed by the same alphabets along the row are not significantly different at $P < 0.05$ using Ducan Multiple Range Test (DMRT)

Source: Authors field work

Results of Water Microbial Profile (Bioload)

The microbial profile of the water samples from borehole and surface water in the rainy and dry season are shown in Tables 5 and 6 respectively. The results showed that the mean microbial bio-load were generally higher in surface water than borehole water for the entire sites studied during the seasons and the mean microbial bio-load for each of the different sources in the mining community was higher than that of the control site. The mean microbial bio-load for surface and borehole water was highest at Amajim pit lake and lowest at Alegu borehole for both the rainy and dry seasons. The results also indicated fifteen (15) clinical isolates in the studied site: *Klebsiella spp., Shigella spp., Bacillus subtilis, Serretia marcescenes, Staphylococcus spp., Sarcina, Salmonela spp., Streptococcus faecalis, Escherichia coli, Pseudomonas aeruginosa, Morganella morgenii, Yersinia enterolitica, Clostridium xerosis, Mucor,* and *Aspergillus spp* with variations from one site to another. The results also revealed that the clinical isolates found in the rainy season were also found in the dry season. The result revealed a slight decrease in the mean microbial bioload in the dry season compared to rainy season.

TABLE 5: Microbial profile of Water Samples Obtained during Rainy Season in the Studied Sites

Source	**Mean Bio-Load**	**Clinical Isolates**
Amajim Borehole 1	2.11×10^4	*Klebsiella spp., Shigella spp., Bacillus subtilis, Serretia marcescenes, Staphylococcus spp., Sarcina Pseudomonas aeruginosa*
Alegu Borehole	1.55×10^4	*Klebsiella spp., Shigella spp., Bacillus subtilis, Serretia marcescenes, Pseudomonas aeruginosa., Sarcina*
Amajim Borehole II	2.82×10^4	*Klebsiella spp., Shigella spp., Bacillus subtilis, Serretia marcescenes, Staphylococcus spp., Sarcina Pseudomonas aeruginosa*
Control Borehole	1.31×10^2	*Bacillus subtilis, Pseudomonas aeruginosa, Escherichia coli*
Akpara Stream	4.57×10^5	*Bacillus subtilis, Salmonela spp., Streptococcus faecalis, Escherichia coli, Pseudomonas aeruginosa, Staphylococcus spp*
Amajim Pit Lake	6.11×10^5	*Bacillus subtilis, Salmonela spp., Streptococcus faecalis, Escherichia coli, Pseudomonas aeruginosa, Staphylococcus spp., Morganella morgenii, Yersinia enterolitica, Clostridium xerosis, Mucor*
Akpara Okpo	3.42×10^5	*Bacillus subtilis, Salmonela spp., Streptococcus faecalis, Escherichia coli, Pseudomonas aeruginosa, Staphylococcus*

Stream		*spp*
Control Surface	2.68×10^2	*Bacillus subtilis, Pseudomonas aeruginosa, Escherichia coli, Staphylococcus spp., Sarcina*

Source: Authors field work

TABLE 6: Microbial Analysis of Dry Season Water Samples in the Study Area

Source	Mean Bio-Load	Clinical Isolates
Amajim Borehole 1	3.26×10^3	*Klebsiella spp., Shigella spp., Bacillus subtilis, Serretia marcescenes, Staphylococcus spp., Sarcina Pseudomonas aeruginosa*
Alegu Borehole	1.14×10^3	*Klebsiella spp., Shigella spp., Bacillus subtilis, Serretia marcescenes, Pseudomonas aeruginosa., Sarcina*
Amajim Borehole II	2.41×10^3	*Klebsiella spp., Shigella spp., Bacillus subtilis, Serretia marcescenes, Staphylococcus spp., Sarcina Pseudomonas aeruginosa*
Control Borehole	1.03×10^2	*Bacillus subtilis, Pseudomonas aeruginosa, Escherichia coli, Staphylococcus spp.*
Akpara Stream	3.29×10^4	*Bacillus subtilis, Salmonela spp., Streptococcus faecalis, Escherichia coli, Pseudomonas aeruginosa, Staphylococcus spp*
Amajim Pit Lake	5.18×10^4	*Bacillus subtilis, Salmonela spp., Streptococcus faecalis, Escherichia coli, Pseudomonas aeruginosa, Staphylococcus spp Morganella morgenii, Yersinia enterolitica, Clostridium xerosis, Mucor*
Akpara Okpo Stream	3.77×10^4	*Bacillus subtilis, Salmonela spp., Streptococcus faecalis, Escherichia coli, Pseudomonas aeruginosa, Staphylococcus spp*
Control Surface	1.53×10^2	*Bacillus subtilis, Pseudomonas aeruginosa, Escherichia coli, Staphylococcus spp., Sarcina*

Source: Authors field work.

Results of Soil Quality

Table 7 shows the results of physicochemical properties of soil samples collected from different locations in the mining community in rainy and dry seasons respectively. The results showed that the pH of the samples were low and ranged from 6.5 in Amajim Farmland to 6.7 in Alegu Farmland during the rainy season and from 6.4 in Amajim Farmland to 6.6 in Alegu Farmland during the dry season. The pH was generally lower in dry season than in the rainy season and varied from one site to another. The electrical conductivity, cation exchange capacity, total organic carbon and total organic matter of the soil from the different sources in

the mining community were significantly ($P < 0.05$) higher than those from the control sites and varied significantly ($P < 0.05$) from one site to another for both seasons. The results also showed that the percentage of clay and silt were significantly ($P < 0.05$) higher in the soil from the different sources in the mining community compared to the control site for both seasons. They were however significant ($P < 0.05$) variations in all the physicochemical parameters from one site to another.

The results of the heavy metal content of soil samples collected from the different sources in the mining community in rainy and dry seasons are shown in Table 8. The results showed that Pb, Zn, Fe, Cu, Cd, Mn, Ni, Co and Cr were all present at varying levels and were all significantly ($P < 0.05$) higher in the soil from the different sources in the mining community compared to the control site for both seasons.

Table 7: Physicochemical Properties of Soil Samples Collected during Rainy and Dry Seasons

Location	Rainy Season				Dry Season			
Parameters	Amajim Farm	Alegu Farm	Akpara Farm	Control Farm	Amajim Farm	Alegu Farm	Akpara Farm	Control Farm
pH	$6.5^{b} \pm 0.02$	$6.7^{d} \pm 0.05$	$6.6^{c} \pm 0.05$	$6.9^{f} \pm 0.05$	$6.4^{a} \pm 0.05$	$6.6^{c} \pm 0.13$	$6.5^{b} \pm 0.02$	$6.8^{e} \pm 0.11$
EC (mS/m)	$3.62^{f} \pm 0.17$	$2.98^{c} \pm 0.97$	$3.53^{e} \pm 1.05$	$1.15^{a} \pm 1.05$	$3.34^{g} \pm 0.33$	$3.45^{d} \pm 0.21$	$3.54^{e} \pm 0.13$	$1.35^{b} \pm 0.15$
CEC (Cmol/kg)	$40.55^{a} \pm 1.01$	$53.58^{c} \pm 0.18$	$53.92^{c} \pm 0.72$	$78.42^{f} \pm 0.42$	$46.31^{b} \pm 0.23$	$59.12^{e} \pm 0.34$	$58.49^{d} \pm 0.27$	$79.37^{g} \pm 0.27$
TOC (%)	$0.85^{a} \pm 0.37$	$1.35^{f} \pm 0.21$	$0.93^{c} \pm 0.34$	$1.85^{h} \pm 0.21$	$0.96^{d} \pm 0.93$	$1.24^{e} \pm 0.11$	$0.90^{b} \pm 0.50$	$1.76^{g} \pm 0.41$
TOM (%)	$1.47^{a} \pm 0.19$	$2.33^{f} \pm 0.72$	$1.60^{c} \pm 0.32$	$3.19^{h} \pm 0.72$	$1.66^{d} \pm 0.15$	$2.14^{e} \pm 0.36$	$1.55^{b} \pm 0.85$	$3.03^{g} \pm 0.15$
Clay (%)	$6.21^{b} \pm 0.12$	$8.00^{c} \pm 0.33$	$8.02^{c} \pm 0.18$	$1.40^{a} \pm 0.14$	$8.44^{d} \pm 0.35$	$7.96^{c} \pm 0.16$	$7.57^{b} \pm 0.22$	$0.92^{a} \pm 0.72$
Silt (%)	$2.26^{b} \pm 0.16$	$2.49^{c} \pm 0.53$	$2.67^{d} \pm 0.51$	$0.35^{a} \pm 0.25$	$4.20^{d} \pm 0.50$	$2.15^{b} \pm 0.15$	$2.96^{c} \pm 0.23$	$0.28^{a} \pm 0.44$
Sand (%)	$91.53^{b} \pm 0.53$	$89.51^{a} \pm 0.82$	$89.31^{a} \pm 0.25$	$98.25^{c} \pm 0.47$	$87.36^{a} \pm 0.28$	$89.89^{b} \pm 0.31$	$89.47^{b} \pm 0.23$	$98.80^{c} \pm 0.19$

EC = Electrical conductivity, CEC = Cation exchange capacity, TOC = Total organic carbon, TOM = Total organic matter. Figures followed by the same alphabets along the row are not significantly different at $P < 0.05$ using Ducan Multiple Range Test (DMRT)

Source: Authors field work

Table 8: Heavy Metal Contents (mg/kg) of Soil Samples Collected during Rainy and Dry Seasons

Location / Parameters	Rainy Season				Dry Season			
	Amajim Farm	**Alegu Farm**	**Akpara Farm**	**Control Farm**	**Amajim Farm**	**Alegu Farm**	**Akpara Farm**	**Control Farm**
Pb	$1953.32^{d} \pm 1.12$	$514.76^{b} \pm 0.17$	$633.44^{c} \pm 0.91$	$23.14^{a} \pm 0.34$	$2315.24^{b} \pm 0.18$	$618.05^{c} \pm 0.42$	$858.54^{d} \pm 0.41$	$21.95^{a} \pm 0.15$
Zn	$1260.50^{b} \pm 1.72$	$466.24^{c} \pm 0.75$	$713.87^{b} \pm 0.11$	$12.50^{a} \pm 0.62$	$1575.60^{b} \pm 0.52$	$679.07^{c} \pm 0.92$	$904.52^{b} \pm 0.24$	$9.40^{a} \pm 0.25$
Fe	2047.50^{b} ± 3.17	1240.65^{c} ± 5.12	1490.54 ± 2.74	108.82^{a} ± 0.17	2865.00^{b} ± 2.11	1545.92^{d} ± 1.18	1967.32^{c} ± 0.93	112.05^{a} ± 0.31
Cu	$118.11^{c} \pm 0.37$	$125.70^{b} \pm 0.18$	$94.40^{b} \pm 0.16$	$9.42^{a} \pm 0.35$	$97.50^{d} \pm 0.41$	$107.68^{c} \pm 0.35$	$91.45^{b} \pm 0.12$	$6.44^{a} \pm 0.27$
Cd	$14.55^{c} \pm 0.91$	$9.33^{b} \pm 0.55$	$8.86^{b} \pm 22$	$0.25^{a} \pm 0.31$	$18.22^{d} \pm 0.72$	$11.54^{c} \pm 0.23$	$10.03^{b} \pm 0.32$	$0.30^{a} \pm 0.31$
Mn	221.09^{b} ± 2.11	123.11^{c} ± 1.37	121.21^{d} ± 0.96	5.96^{a} ± 0.22	283.52^{b} ± 1.44	186.45^{c} ± 2.13	162.50^{d} ± 1.64	6.91^{a} ± 0.75
Ni	$138.24^{b} \pm 0.31$	$172.77^{d} \pm 0.14$	$84.85^{c} \pm 0.33$	$2.60^{a} \pm 0.27$	$91.45^{b} \pm 0.12$	$126.75^{d} \pm 0.24$	$66.39^{c} \pm 0.35$	$2.50^{a} \pm 0.18$
Co	$65.23^{c} \pm 0.42$	$48.46^{b} \pm 0.32$	$39.25^{c} \pm 0.26$	$0.8.03^{a} \pm 0.23$	$54.58^{c} \pm 0.30$	$41.44^{b} \pm 0.45$	$36.40^{d} \pm 0.36$	$1.02^{a} \pm 0.11$
Cr	$116.52^{d} \pm 0.13$	$167.50^{c} \pm 0.47$	$96.70^{b} \pm 1.01$	$2.45^{a} \pm 0.26$	$104.35^{d} \pm 0.71$	$134.67^{c} \pm 0.21$	$84.55^{b} \pm 0.23$	$1.58^{a} \pm 0.60$

Figures followed by the same alphabets along the row are not significantly different at $P < 0.05$ using Ducan Multiple Range Test (DMRT).

Source: Authors field work

Discussion

Water physicochemical Quality

The acceptability and use of potable water for recreational, industrial and other domestic needs are influenced by physicochemical parameters such as pH, total dissolved solids and conductivity (Chinedu *et al*., 2011). The temperature of the sampled borehole and surface waters in both seasons ranged between 27.1 to 28.1°C (Tables 1 and 2) and lie within the range of < 32^{o}C for safe drinking water (WHO, 2011). These values obtained are similar to those reported by numerous researchers (Onwughara *et al*., 2013; Chukwu, 2008; Obi and Okocha, 2007). Cool waters has been reported to be generally more potable for drinking purposes, since high temperatured water enhances the growth of micro-organisms and as such could influence the taste, odour, colour, and possibly increase corrosion problem (Okoye and Okoye, 2008). Thus, the temperature range observed in this work may not impact negatively on the taste and odour of the water (Ayoko *et al*., 2007).

The pH of water is very importantbecause changes in pH values affect water quality (Okonko *et al*., 2008). The pH of the sampled borehole and surface water for both seasons (Tables 1 and 2) fell within the Nigerian Standard for Drinking Water (NSDW) range acceptable for normal consumption and within the normal WHO acceptable range (6.5-8.5) for portable water (WHO, 2011). These results compared favourably with those reported by other independent researchers in other parts of Nigeria (Oko *et al*., 2014; Agbalagba *et al*., 2011; Adefemi *et al*., 2007; Asaolu *et al*., 1997). This near neutrality of most of the waters examined in this study poses no health risk to consumers who may use the water for cooking, washing, drinking, bathing and for other domestic purposes. Slight acidic pH observed in some of the samples may be attributed to the contamination of the borehole and surface water by household waste and sewage and high presence of CO_2 and SO_2 due to mining activities in the area. Reports have shown that consumption of such acidic water could have adverse effects on the digestive and lymphatic systems of human (Orewole *et al*., 2007).

The values of electrical conductivity obtained (Tables 1 and 2) were within the WHO recommended standard of 500 mS/cm (WHO, 2011). The observed electrical conductivity (EC) values for all samples were high compared to those reported by others (Okereke *et al*., 2014; Agwu *et al*., 2013; Onwughara *et al*., 2013; Adindu *et al*., 2012). EC is an indicator of water quality and soil salinity. The relatively high values observed in this study show high salinity ie high dissolved salts in the water implicating more inorganic constituents within the

aquiferous materials. Thus, the water may not be very suitable for domestic and agricultural use.

Total dissolved solids (TDS) comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water (WHO, 2011). It was observed in this work that the electrical conductivity of samples increased with increasing TDS results. The TDS values obtained in this work is within the WHO standard of 1000 mg/l for drinking water. The values obtained were however higher than those reported by Adindu *et al*. (2012) and Agwu *et al*. (2013). This result indicates high impurities in the drinking water. The total suspended solids (TSS) values were generally below WHO permissible limit 30mg/l for all the borehole water but fairly high and above WHO permissible limit 30mg/l for surface waters (Table 1 and 2). This indicated that the surface waters were generally exposed to debris and the high values of TS and TSS can affect the organisms living in water bodies as these can influence the level of dissolved oxygen.

The turbidity (Tables 1 and 2) observed for all borehole waters fell within the acceptable limit of the World Health Organisation (WHO) standard for drinking water but not for the surface waters in this study. Similar results have been reported by Udom *et al*. (1998) and Okonko *et al*. (2008). The observed high turbidity in the surface waters may be attributed to minig activites which generally release particules to the water. The alkalinity and toal acidity values of all the sampled waters were within the stipulated limit range of 30 to 500mg/L by WHO (Tables 1 and 2). These results were higher than those repoted by Agbalagba *et al*. (2011) and Onwughara *et al*. (2013) and as such implicate slight neutrality of the waters. Nitrate values observed in this study (Tables 1 and 2) fell within the WHO recommended limit of 10.0 mg/l with the exception of Amajim pit lake which had nitrate value greater than recommended limit for both the rainy and dry seasons. This implies anthropogenic imput of nitrate which may have arised from agricultural activities. Pollution of water with nitrate may cause methemoglobinemia when converted to nitrite in the intestines (Adeyemo *et al*., 2002) or blue baby syndrome (WHO, 2011).

Hard water is water with high mineral content mostly calcium, and magnesium ions. The World Health Organization (WHO) International Standard for Drinking Water (1998) classified water with a total hardness of $CaCO_3$ < 50 mg/L as soft water, 50 to 150 mg/l as moderately hard water and water hardness above 150 mg/l as hard CaCO3 (Onwughara *et al*., 2013). The observed values for the total hardness of water (Table 1 and 2) indicated that all the samples were moderately hard water in the rainy and dry season with the exception of

Amajim pit lake and Akpara Okpo stream in dry season only. Thus, the waters are suitable for domestic use in terms of hardness especially during rainy season.

Lead ion (Pb) was detected at boreholes and surface water for both the rainy and dry season in the study area (Tables 3 and 4). This result portends some health hazard as accumulative effect may possibly lead to lead (Pb) poisoning (Ademoriti, 1996). The observed average level of zinc, copper and iron in the water samples (Tables 3 and 4) were within the WHO standard of 0.30mg/l, 1.00mg/l and 0.3 mg/l respectively (WHO, 2011). Copper (Cu) was detected in all the samples and this may be associated with application of insecticides in nearby farmlands.

The borehole and surface waters at Amajim pit lake all had traces of varying concentrations of Cd, Mn, Ni, and Cr. These results show that water from Amajim pit lake is polluted with these heavy metals and as such need to be treated to avert heavy metal toxicities associated with the heavy metals. These results compared favourably with the reports of other independent researchers (Okereke *et al*., 2014; Agbalagba *et al*., 2011; Itah and Akpan, 2005). Ishola and Amuda (2014) reported similar results in surface waters of mining communities in Zamfara State. Nigeria. Similarly, Smolders (2003) reported that mining activities greatly affect heavy metal concentration in water, sediments and macro invertebrates in different reaches of the Pilcomayo River from the Potosi mines. These observed values were within the FEPA and WHO permissible guideline and compares favourably with the report of Mattew- Amune *et al* (2012) in in Okehi mining area of Kogi state, Nigeria.

The results (Table 3 and 4) also showed that seasonal variation plays a role in the distribution of heavy metals in the study area with higher level of heavy metals observed in water bodies during the dry season period. The variation in the heavy metals distribution in the seasons showed the effect dry season and water evaporation on concentration of heavy metals in water. Similar reports have been documented (Saeed *et al.,* 2014; Islam *et al*., 2012; Ahmed *et al*., 2010). The high level of these heavy metals observed in the water bodies in the dry season may have also been because of the presence of metals in the geologic distribution of the area (Jung 2008) and the incessant mining activities going on in these area which results in indiscriminate discharge of tailing into water bodies.

Microbial Profile of Water

Bacteria are natural components of underground waters. Drinking water supply channels, like borehole water storage tanks, must provide the consumer with potable water of quality standards almost identical to that of the water leaving the treatment plant. However, drinking

water generally reaches consumer with lower level of microbiological quality than that achieved at the outlet of the treatment plant (Sadik, 2009). A wide variety of bacteria were observed to survive and grow in the borehole and surface waters at the study period. During the period of study, bacteria belonging to the genera *Staphylococcus, Escherichia, Pseudomonas, Enterobacter, Bacillus, Klebsiella, Shigella and Streptococcus* were found (Tables 5 and 6).

The isolation of *Escherichia coli, Streptococcus spp., Enterobacter spp.*, and *Klebsiella species* from most of the samples show pollution of the water by human activities. These organisms are capable of surviving in the aquatic environment after introduction. The total coliform values recorded are on high side considering the WHO standard limit of 0.00 cfu/ml for drinking water. Most of the samples had more than three coliform organisms present in them. The results compared favourably with that reported for borehole waters in Aba (Okereke *et al*., 2014; Agwu *et al*., 2013). Similarly, Anyanwu and Okoli (2012) isolated *Enterobacter* species, *Esherichia coli,* and *Klebsiella* species from borehole water, and recorded higher total coliform levels in Nsukka, Southern Nigeria. Nwachukwu and Ume (2013) also isolated *Pseudomonas aeruginosa, Escherichia coli, Klebsiella* species, *Enterobacter aerogenes, Proteus* species, *Staphylococcus* species, *Aeromonas* species and *Vibrio cholera* from borehole drinking water sources in some other parts of eastern Nigeria.

The presence of faecal coliform like *E. coli* and *Klebsiella* in some samples is an indication of recent pollution by sewage. The high coliforms level recorded in this work could be attributed to poor refuse and sewage disposal system, mainly open air disposal method practiced in the study area. Groundwater may have been contaminated through leaching from surface dumps into the water during rainfall, as well as by household sewage and domestic waste. The presence of these organisms may indicate inadequate water treatment or fresh contamination. Coliforms in distribution systems and stored water supplies can reveal re-growth and possible biofilm formation or contamination through ingress of foreign material, including soil or plants. These waterborne bacterial pathogens are causative agents of many human diseases and their presence poses a potential threat to the human health. *Klebsiella species* poses health risk to patients with impaired immune systems, such as the elderly or very young, patients with burns or excessive wounds, and those undergoing immunosuppressive therapy. Pathogenic *E. coli* causes diarrhea and haemorrhagic colitis which usually develop into potentially fatal haemolytic uraemic syndrome in children, and is characterized by acute renal failure and haemolytic anaemia (WHO, 2011).

Although *Staphylococcus aureus* is a common member of the human micro flora, it can produce disease through two different mechanisms. One is based on the ability of the organisms to multiply and spread widely in tissues, and the other is based on the ability of the organisms to produce extracellular polysaccharides and toxins. Multiplication in tissues can result in manifestations such as boils, skin sepsis, post-operative wound infections, enteric infections, septicaemia, endocarditis, osteomyelitis and pneumonia (WHO, 2011). Gastrointestinal disease (enterocolitis or food poisoning) is caused by a heat-stable staphylococcal enterotoxin and characterized by projectile vomiting, diarrhoea, fever, abdominal cramps, electrolyte imbalance and loss of fluids. *Pseudomonas aeruginosa* is a recognized cause of hospital-acquired infections with potentially serious complications and has been isolated from a range of moist environments such as sinks, water baths, hot water systems, showers and pools (De Victorica and Galván, 2001). *Pseudomonas* observed in some of the boreholes in this work may be associated with complaints about taste, odour and turbidity.

The presence of *Shigella species* may be implicated in a number of large waterborne outbreaks of shigellosis that may have been recorded in the study area. As the organisms are not particularly stable in water environments, their presence in drinking water indicates recent human faecal pollution. *Shigella* species are enteric pathogens predominantly transmitted by the faecal-oral route through person-to-person contact, contaminated food and water. Flies have also been identified as a transmission vector from contaminated faecal waste. The presence of *Shigella* species in high values observed in most samples in this work predisposes consumers to serious intestinal diseases, including bacillary dysentery. *Vibrio* species was not identified in all the water samples and so the pathogenicity associated with the species may not be common in the study area

Soil Quality

The pH of soil or more precisely the pH of the soil solution is very important because soil solution carries in it nutrients such as nitrogen, potassium, and phosphorus that plants need in specific amounts to grow, thrive, and fight off diseases (Brady and Weil, 1999). The pH values of soil obtained from the different sources in the mining community varied. However, in all cases, the pH of the soils was found to be slightly low (Table 7) and as such implicated the soils to be slightly acidic. Soil pH has been widely reported as exerting a controlling influence on the availability of micro-nutrients to plants and a pH range of 6.5 to 7.5 is reported to be optimal for plant nutrient availability (Arias *et al*., 2005; Sanders, 1982). If the soil solution is too acidic plants cannot utilize N, P, K and other nutrients they need. In acidic

soils, plants are more likely to take up toxic metals and some plants eventually die of toxicity (WHO, 2007).

Electrical conductivity (EC) is the common measure of soil salinity and is indicative of the ability of the soil in an aqueous solution to carry an electric current. The rock composition determines the chemistry of the soil and ultimately affects electrical conductivity. Results obtained from the study showed that the EC of the soils from the various sites varied greatly and that in all cases, the EC values obtained for site soils were higher than those obtained for the control sites (Table 7). The EC values obtained from the various sites (Tables 7) were higher than the recommended ideal soil EC level (0.2-1.2 $mScm^{-1}$) accepted for optimum plants performance (Arias *et al*., 2005). The high EC value of the site soils may be attributed to the presence of metal deposits which is one of the constituents of the mineral resources found in the studied farmlands in the mining community. These results implicate the sites soils as high saline soils i.e. contain more soluble salts (Karaca, 2004; Singer and Munns, 1999). High electrical conductivity has also been reported to occur as a result of contamination from anthropogenic sources such as application of chemicals, industrial wastes, poor irrigation and excessive use of fertilizer and these reports have also shown that high EC drastically affects seed germination, plant growth and soil water balance (Arias *et al*., 2005; Singer and Munns, 1999).

Cation exchange capacity (CEC) is a measure of the sum total of the exchangeable cations that the soil can absorb per unit weight of dry soil and as such plays important role in soil fertility. The CEC values obtained in this study were relatively higher in the mining sites soil samples compared to the control site soils (Tables 7). The higher value of CEC obtained for the soils around mine sites compared to the control sites showed again that mining could affect the properties of soils in close proximity to them. The high CEC of the sites may be attributed to the decomposition of organic wastes, which yield more of the exchangeable bases thereby raising the fertility status of the sites. CEC is directly related to the capacity of absorbing heavy metals since the absorption behaviour depends on combination of the soil properties and the specific characteristics of the element (Barry *et al*., 1995). Thus, the high CEC values obtained in this study implicates that the sites soils will contain high concentrations of heavy metals.

Organic carbon is an index of dump materials productivity and the amount of carbon broken down from plants and animals stored in soil (Dekka *et al*., 2008). Thus, total organic carbon/organic matter are the reservoir of essential and non-essential elements for plant growth and development and as such increased organic carbon/ organic matter may lead to

increased soil productivity (Anikwe and Nwobodo, 2002). The total organic carbon/organic matter content of the soils in the study sites were found to be lower than that of the control sites (Tables 7). Organic carbon levels greater than 0.8% is rated as good quality in soil or dump and less than 0.4% is rated as low quality in dump (Ghosh and Singh 1983). This present study showed percentage of organic carbon ranging from 0.85% to 1.24% indicating presence of medium to high organic carbon, hence high productive value of the samples. The values of organic carbon/organic matter obtained in this study (Table 7) was low when compared to those reported by Obasi *et al.* (2012), Ogbonna *et al.* (2009) and Uba *et al.* (2008) for dumpsites. This moderate organic carbon content of the studied site may be due to the accumulation of leaf litter and their decomposition to form humus and vice versa. As the amount of organic matter present in a soil increase, the number of stable aggregates also increases. While soil organic carbon is not a requirement for plant growth, the levels of organic matter in soils influence a number of soil chemical and physical processes and it is an important indicator of the soil as a rooting environment (Okalebo *et al*., 1993).

Heavy metals are elements having some atomic weight between 63.54 and above and a specific gravity greater than 4 (Kennish, 1992). Although trace amount of some heavy metals are required by living organisms, any excess amount of these metals can be detrimental to the organisms (Khan *et al*., 2002; Itanna, 2002; Berti and Jacobs, 1996). Metals also have high affinity for humic acids, organic clays, and oxides coated with organic matter (Kabata-Pendias, 2004; Elliot *et al*., 1986). The solubility of metals in soils and groundwater is predominantly controlled by pH (Henry, 2000; Mc Neil and Waring, 1992; Baker and Walker, 1990), amount of metal and cation exchange capacity (Martinez and Motto, 2000), organic carbon content (Elliot *et al*., 1986) and the oxidation state of mineral components as well as the redox potential of the system (Connell and Miller, 1984).

The study showed that lead (Pb) concentrations in the sites during the seasons fell outside the USEPA (1986) allowed limits of 30-300mgkg^{-1} for agricultural lands (Table 8). Similar results have been reported (Uba *et al*., 2008; Obasi *et al*., 2012). The Zinc (Zn) contents of the sites were higher than the permissible limits of 300mgkg^{-1} for agricultural lands set by USEPA (1986) and CEC (1986) (Table 8). Similar results have been reported earlier (Walter and Cuevas, 1999; During *et al*., 2003; Kansalainen and Yli-Halla, 2003; Su and Wong, 2003) on their seprate studies on the sorption and bioavailability of heavy metals in soils. Zinc (Zn) has been shown to be potential mobile and bioavailable due to its association with the reducible fraction (bound to Fe-Mn oxides) and residual fraction (bound to silicates and detrital materials) (Obasi *et al*., 2014:2012; Walter and Cuevas, 1999; Ma and Rao, 1997).

The concentration levels of iron (Fe) in the studied sites were high and that may have contributed to the reddish brown colour of the soils. These results compare favourably with those reported by others (Ogbonna *et al*., 2009; Uwah *et al*., 2009; Uba *et al*., 2008). Reports have shown that there is high level of Fe in the exchangeable phase of Fe fractions and as such implicate the metal as a potentially toxic metal if not regulated due to their high mobility (Obasi *et al*., 2014:2012; Walter and Cuevas, 1999; Slims and Kline, 1991).

Results of the level of Cu (Table 8) indicated that the metals concentrations in all the sites studied were all below the toxic limit of 250mgkg^{-1} set by USEPA (1986) and CEC (1986) for agricultural lands. Cu has been reported to be mostly found in the residual phase (i.e. bound to silicates and detrital materials) (Obasi *et al*., 2014; 2012; Ikhuoria *et al*., 2010). Results of Cd level (Table 8) are above the critical permissible limit of 3.0mgkg^{-1} for agricultural soils (MAFF, 1992; USEPA, 1986). The high concentration of Cd obtained in this result may be attributed to the dumping of Cd containing substances like Cd batteries and metals from residence and industries to these sites. The results obtained in this study were in agreement with the observations of several others (Ikhuoria *et al*., 2010; Uba *et al*., 2008; Gupta and Sinha, 2006; Kuo *et al*., 1983).

The results of the level of manganese (Mn) obtained from this study (Tables 8) showed that the concentrations of Mn in all the site samples were within the tolerable limits (100-300mgkg^{-1}) set by USEPA (1986) for agricultural lands. Similar results were reported by Uba *et al*. (2008) and Albores *et al*. (2000). The results of the concentration of Nickel (Ni) in the studied sites (Table 8) showed that all the sites had Ni concentration from 26.24-72.28mgkg^{-1} which fell below the permissible limit of 150mgkg^{-1} for residential and agricultural lands (CCME, 1991). Similar results have been reported by several authors (Karaca, 2004; Su and Wong, 2003). The results of Cobalt (Co) in the samples were below 750mgkg^{-1} limit permissible for domestic gardens, residential and agricultural areas (Visser, 1993; CCME, 1991). Chronium (Cr) was found to be above the permissible value of 750mg/kg limit (Visser, 1993; CCME, 1991) in all the sites. Reports have shown that Cr is strongly associated with the residual and oxidizable fractions (Ikhuoria *et al*., 2010; Alvarez *et al*., 2002; Tokalioglu *et al*., 2000).

The results of heavy metals concentrations obtained in this study (Table 8) showed that the soils can be considered highly polluted, since the concentration of the metals in most of the sites were above the critical permissible for agricultural, and residential soils (MAFF, 1992; FEPA, 1991; USEPA, 1986; Visser, 1993; CCME, 1991). Similar results have been reported by several other workers for polluted and waste soils near industries and dumpsites (Ayari *et*

al., 2010; Ebong *et al*., 2007:2008; Uba *et al*., 2008; Okoronkwo and Ano 2006). The seepage of these heavy metals through the soils can infiltrate directly through unsaturated zones to cause severe water pollution problems. Their presence in groundwater can cause a long term health risks to humans through the food chain (Obasi *et al*., 2014:2012; Ogbonna *et al*., 2009; Erah *et al*., 2002). Although metals are essential, at higher concentrations, they become toxic and present different problems to soil microorganisms, because they cause oxidative stress by formation of free radicals (Azevedo and Azevedo, 2006; Oliveira and Pampulha, 2006; McGrath *et al*., 1995; Brookes, 1995). High concentrations of heavy metals in the soil when absorbed by plants can replace essential metals in pigments or enzymes, thus disrupting their function (John *et al*., 2009; Henry, 2000), and may render the land unsuitable for plant growth and destroy the biodiversity (Obute *et al*., 2010).

Conclusion

This study revealed that mining activities in Ameka community in Ezza South, Ebonyi State, Nigeria impact negatively on the environment through introduction of heavy metals above the threshold limit to the soil and water thereby causing severe pollution of the water and soil. There is urgent need to make policies that will guide and regulate mining activities especially artisan mining in this area in order to avoid multiple poisoning effects of these metals as the transverse the ecosystem. Further studies are needed to evaluate the speciation, mobility and bioavailability of theses metals in plants and the associated health problems of the mining activities to the inhabitants of the host community.

Author's Contributions

All the authors made valuable contributions; in the field work and in the facilitation of the development of analytical method, sampling, analysis and in scripting and editing of the study report.

Ethics

The authors' wish to declare that the data reported here in this study, is a part result of a section of a holistic study on the environmental status of a Pb-Zn mining activities in Ameka Community, Ezza South, Ebonyi State of Nigeria and has not been reported previously in any other scientific journal.

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