

Heavy Metals Evaluation of Water Resources of Mkpuma Ekwaoku Mining Area, Ebonyi State, Southeast Nigeria.

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ABSTRACT

Heavy metals evaluation of Mkpuma Ekwaoku mining area, Ebonyi State was carried out. The area lies between longitude 6° 29' N - 6° 36' N and latitude 8° 12' E - 8° 20' E. Geologically, the area is underlain by shales and mudstone which belong to the Asu River Group (Albian). Twenty (20) water samples were collected from drinking water sources like abandoned mine ponds, hand dug wells and boreholes and were analyzed using Atomic Absorption Spectrophotometric (AAS). The result of hydrogeochemical analysis reveals basic water resources with concentrations of Mn>As>Zn>Co>Ni>Cr>Pb>Cd>Cu>Hg in the study area. Physical parameters tested includes; pH, TDS, Ec and Turbidity and shows basic water. Concentrations of As, Co, Cr, Pb, Cd and Hg are above the USEPA and WHO, 2011 permissible values for safe domestic water supply. The high concentration is as a result of the dissolution of the ions into groundwater sources from ore bodies and abandoned mines. Proper water resources protection and management is being advocated in the area.

Keywords: Hydrochemical; Heavy metals; Mining; Groundwater; Mkpuma Ekwaoku

INTRODUCTION

Pollution and management of water resources are among the major challenges facing many developing countries of the world (Nidhi et al., 2017). These problems often emanate from both natural and anthropogenic sources. Natural sources may result from the host rocks (depending on the geology of the area), volcanic activities, and chemical evolution of hydrochemical facies, while anthropogenic sources often emanate from the challenges of waste disposal linked to human activities, including urbanization, industrialization, mining, municipal and domestic activities, among others (Obasi and Akudinobi, 2020, 2019a and b; Moreno-Jimenez et al, 2009; Igwe et al., 2022; Martinez –Martinez et al., 2013; Musah et al., 2013; Obiorah et al., 2016, 2018). Lead – zinc mineralization and mining in the Mkpuma Ekwaoku area increases the potential for groundwater pollution. According to Moye et al., (2017), Rubio et al., (2000); and Nieto et al., (2007) pollutant and contaminant transport in the aqueous medium can occur in groundwater basins. Mine waste management and subsequent discharge of water containing high concentrations of dissolved metals into river channels and streams are serious global health and environmental problems (Obasi, 2017; Mgbefurike et al, 2022., Obasi and Akudinobi, 2019b; Moye et al., 2017). Mine wastewater contributes high inputs to Acid Mine Drainage (AMD) as they provide aqueous medium for the transportation of contaminants into other areas (Andriano, 1986). Geochemical and environmental researches of abandoned and active mines in different parts of the world show high threshold and contamination in soils, rivers, sediments and ponds. Bio magnification of metal contaminants in soils and plants has also been indicated. This is deleterious to animals and human species (Mgbefurike, et al., 2022., Obasi, 2020; Obasi and Akudinobi, 2020, 2019a and b; Owor et al., 2007; Khan et al., 2008, 2010; Moreno-Jimenez et al., 2009; Martinez –Martinez et al., 2013; Musah et al., 2013; Obiorah et al., 2016, 2018). Burt et al., (2011) stated that potential contamination of soil and potable water supply can be determined using the studies of trace elements concentration, their bio- availability and transportation mechanism by surface water and groundwater regimes. Acidic waters can deteriorate surface and groundwater (Moye et al., 2017, Rubio et al., 2000; Nieto et al., 2007). Other factors including pH, Ec, hardness, and Total Dissolved Solids (TDS) have effects on the toxicity of trace constituents in soils and water (Munk et al., 2002; Conesa et al., 2008). Heavy metal effluents

from the weathering of the mineral deposits may have adverse consequences on soil and water quality due to soil – water interaction. Apart from the challenges to sustainable water quality, pollutants and contaminants from mining sources constitute a major threat to human health, aquatic lives, land use and agriculture and other aspects of ecosystem imbalance (Igwe et al., 2022; Obasi et al., 2022a and b; Obiora et al., 2018; Obasi and Akudinobi, 2019, 2020). Rural dwellers in various communities commonly depend on water from the abandoned mines and drainage channels for their domestic activities (see plate 1). There is therefore, the need to study the distribution of Pb, Zn, Cu, Cd, Hg, Cr, Ni and As in the water sources of the area. The groundwater interaction with the host rocks and mineral bearing formations and surface water interaction has been investigated. Emphasis has been placed on qualitative assessment of the water sources. Hence, providing valuable information in this regard may likely alleviate the health of the inhabitants of the area and constitute a vital planning tool to healthcare providers and regulatory authorities and rural water supply agencies.

Location, Physiography and Geology

The study area lies between longitudes 8°12'E and 8°20'E and latitudes 6° 29'N and 6° 36' N (fig 1). It extends from Otam in the north to Ojiegbe in the south covering a total area of about 94.2Km². The only major town within the area is Oferekpe, others being rural communities where mining activities have been going on. These communities include Mkpuma Ekwaoku, Edenyaka, Nduoke and Ndiechi, all in Izzi Local Government Area of Ebonyi state, Southeastern Nigeria. The area comprises predominantly of rural populations. The discovery and mining of mineral deposits in the area led to unstable ecological balance (Obasi et al., 2022), this has not only affected the hydrogeochemical attributes of the water resources of the area, soils and vegetation has been implicated. The major river that drains the area is the Ebonyi River and its tributaries; River Abe and Ololo River (fig 1). Both tributaries are perennial and usually overflow their banks at the peak of the raining season. The drainage system of the study area is dendritic in pattern, as a function of lithology control. All these, both the major and minor drainage system flow eastward to join the Cross River somewhere outside the study area. The vegetation is characterized by stunted trees and pockets of dreadlock woodland. The area lies within tropical rain forest of Nigeria, it has two main seasons; the rainy and dry season. Igbozuruike, (1975) described the area as having four dry months in which precipitation is less than 60mm while the total annual rainfall for the study area ranges between 1.87mm and over 2500mm. Rainy season start from May and ends around October. There is a short break of rainy season for dry season known as August break and this is associated with an inversion of tropical maritime air masses which gives the air masses much weight and causes conventional rainfall even when the humidity is high. The mean monthly temperature in the hottest period of February to April is about 330°C. Dry season is experienced in the study area from November to April; it is characterized by the predominance of Northeast trade winds which caused harmattan during the month of December to February.

Regionally, the geologic stratigraphic history started with the deposition of marine shales, with subordinate sandstones and limestones ranging in age from middle – upper Albian. These rocks consist of non-fossiliferous, arkosic, poorly sorted, commonly cross-bedded sandstones and grey to dark fossiliferous shales. Nwabufor-Ene (1976) noted that the Abakaliki Shales of the Asu River Group is middle Albian, while the sediments at Ishiagu and Ndeaboh are early Albian. However, the Albian stage is the first transgressive phase of the Benue Trough. The Abakaliki area has been renowned for its high tectonic activities which occurred in the Santonian orogenic times (Kogbe, 1976). This orogeny, led to the fracturing of the shales, and mineralization in the area. Obasi et al., (2022) and Odoh, et al., (2012) have noted that these fractures now form the basis for groundwater development and solid mineral exploration in the area. The occurrence of volcanic intrusions and pyroclastic rocks is obvious in the area (Olade, 1979). Locally, the lithology consists mainly of well-indurated shales, minor argillaceous sandstones, siltstones and mudstones. Veins and lodes of lead- zinc mineralizations are obvious with lithostratigraphic sections of wells showing mineralization in wells in some places.

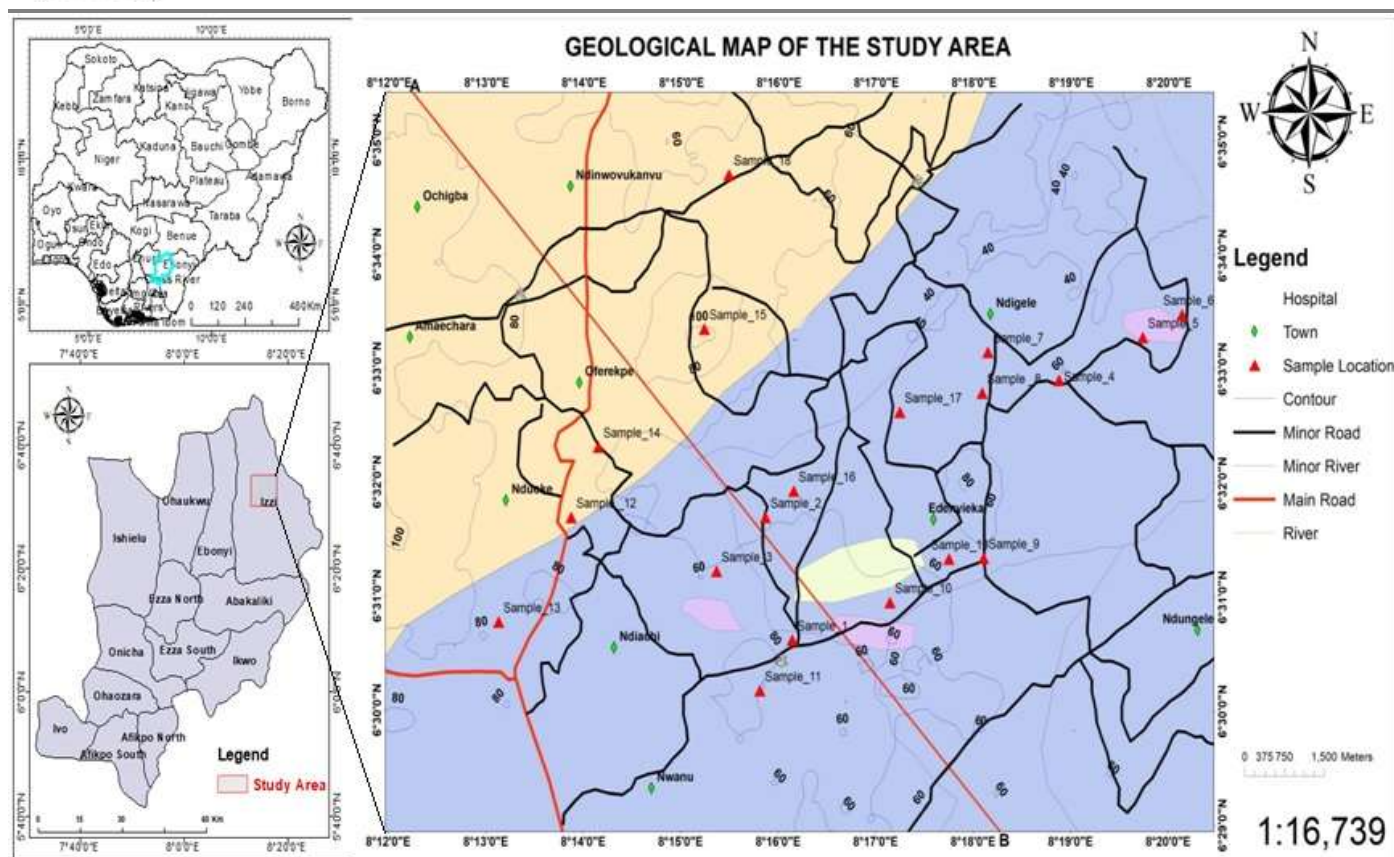


Fig 1: Map of Ebonyi State showing the study area.

METHODOLOGY

Water Sample Collection and analysis

Twenty (20) water samples were collected systematically from different locations from groundwater and surface water sources. Surface water sources considered include active and abandoned mine pits, and ponds while groundwater sources include shallow wells (hand dug wells) and hand pump wells. At each location (see figure 1 for sample locations), observations on the physical aspects of water quality such as colour, taste, odour, pH and electrical conductivity were done using the various kits. The samples were stored in ethylene – free plastic bottles with fitted lids, and preserved in an ice – packed coolers below 4°C prior to laboratory analysis.

Water Laboratory Analysis

The analysis was carried out within forty-eight (48) hours of collection. The samples were analyzed at Doccy Analytical Laboratory and Environmental Services Ltd, Awka, Anambra State. Electrical conductivity and pH were measured in-situ at the points of collection using mercury- in- glass thermometer, electrical conductivity meter (DDS 307 model), and pH meter (Hanna model H1991300) respectively. Laboratory analysis for the heavy metal constituents: As, Cr, Zn, Ni, Pb, Cu, Hg, Cr, Ni, Cd and Mn were analysed using Fast Sequential (FS) (Varian 240 AA) Atomic Absorbtion Spectrophotometer. The results were discussed and compared with the World Health Organization (WHO) standards for water quality.



A: Groundwater sample at Four Corners



B: Groundwater sample at Comm. Sec. Sch. Mkuuma Ndizea



A: Groundwater sample at Four



B: Groundwater sample at Comm. Sec.

Plate 1: Some water sample collection points in the study area

RESULT AND DISCUSSION

The result of hydrochemical analysis is shown in table 3.

Physical Parameters

Physical parameters include pH (H^+ concentration), turbidity; electrical conductivity, and total dissolved solids (TDS).

pH

This is a measure of hydrogen ion (H^+) concentration in the water sample. pH is an important variable in water quality assessment as it controls many activities that take place in the environment. It is an essential parameter in water treatment and supply (Brikke, 2000). The pH of water samples in the study area ranges from 7.36 – 8.01. This indicates that the water resources of the area are basic. Generally, the pH of water resources in the area is with the WHO guideline for drinking water.

Turbidity

Turbidity is a measure of the suspended and colloidal matter (such as clays, silt, organic matter, and microscopic organisms) in water. Finely divided air bubbles can also contribute (WHO, 2017). Turbidity determines the transparency of the water body. The turbidity of the water samples analysed ranges from 0.003 – 0.93 NTU. Considering WHO, 2017 standard for drinking water, turbidity exceeding 1NTU is not good for domestic use. Therefore, the available water sources in the area are considered not turbid.

Electrical Conductivity

Electrical conductivity is the ability of water to conduct electric current. The ability of water to conduct electric current is due to the presence of solids (dissolved solids) in solution. Most dissolved inorganic substances in water are in the ionized form, and contribute to specific conductance. A measure of conductance gives a practical estimate of the variation in the dissolved mineral constituents in a given area (APHA, 2005). The electrical conductivity of water samples ranges from 8.34 – 101.1 μ S cm^{-1} . The groundwater samples showed high conductivity values than the abandoned ponds samples. However, this conductivity does not exceed the WHO, 2017 limit of 1000 μ S cm^{-1} .

Total Dissolved Solid (TDS)

TDS comprise inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water (Lucassen, 2002). TDS in drinking-water originate from natural sources, sewage, urban runoff and industrial wastewater.

However, the presence of high levels of TDS in drinking-water (greater than 1200 mg/litre) may be objectionable to consumers (WHO, 2017). Water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste. From the analysis, the TDS of water samples analysed ranges from 11.37 – 285.17 mg/l. This value is below the WHO limit of 1000mg/l for drinking water.

Table 3: Result of hydrochemical analysis

S/N	pH	EC mS cm ⁻¹	TDS mg/L	TUR B NTU	Pb mg/L	As mg/L	Hg mg/L	Cd mg/L	Mn mg/L	Zn mg/L	Ni mg/L	Co mg/L	Cu mg/L	Cr mg/L
1	7.47	70.14	19.72	0.8	0.049	0.105	0.027	0.086	0.377	0.255	0.049	0.068	0.039	0.022
2	7.36	41.28	58.48	4	0.055	0.117	0.013	0.062	0.246	0.217	0.045	0.072	0.074	0.013
3	7.53	31.74	44.88	0.4	0.033	0.122	0.015	0.034	0.253	0.122	0.038	0.044	0.023	0.028
4	7.62	35.28	49.98	7	0.044	0.105	0.022	0.083	0.152	0.245	0.601	0.091	0.014	0.018
5	7.51	8.34	11.373	2	0.083	0.224	0.027	0.048	0.273	0.224	0.044	0.075	0.093	0.045
6	7.38	48.36	68.51	3	0.073	0.232	0.013	0.045	0.433	0.132	0.067	0.056	0.048	0.022
7	7.5	72.12	19.72	0.93	0.079	0.115	0.025	0.034	0.366	0.215	0.052	0.076	0.019	0.014
8	7.75	84	77.18	0.2	0.067	0.209	0.022	0.039	0.26	0.029	0.031	0.06	0.027	0.022
9	7.41	54.36	77.18	0.3	0.034	0.2	0.022	0.052	0.143	0.02	0.027	0.059	0.034	0.017
10	7.74	82.14	143.65	0.2	0.043	0.217	0.018	0.039	0.044	0.021	0.036	0.079	0.043	0.019
11	7.53	101.1	102.17	0.2	0.038	0.118	0.017	0.022	0.368	0.218	0.038	0.08	0.038	0.118
12	7.66	59.46	285.17	0.3	0.053	0.228	0.018	0.037	0.255	0.228	0.028	0.061	0.053	0.228
13	7.65	84	119	0.4	0.022	0.247	0.019	0.046	0.134	0.147	0.03	0.057	0.022	0.247
14	7.68	26.41	270.01	0.21	0.056	0.128	0.017	0.076	0.126	0.126	0.031	0.02	0.011	0.021

15	7.76	32.44	10.87	0.2	0.042	0.152	0.022	0.061	0.306	0.306	0.039	0.073	0.013	0.019
16	8.01	36.52	201.19	0.4	0.039	0.166	0.019	0.043	0.219	0.219	0.052	0.052	0.021	0.008
17	7.52	29.12	66.44	0.2	0.028	0.201	0.02	0.038	0.0401	0.204	0.028	0.056	0.042	0.109
18	7.88	81.21	43.98	0.4	0.059	0.217	0.014	0.014	0.216	0.123	0.062	0.07	0.026	0.061
19	7.92	36.81	256.28	0.3	0.064	0.194	0.016	0.033	0.281	0.021	0.021	0.061	0.031	0.125
20	7.5	10.44	12.13	2	0.092	0.221	0.039	0.049	0.292	0.226	0.036	0.703	0.098	0.029
WH O LIMI T	6.5 - 8.5	1000	1000	1NT U	0.01	0.01	0.006	0.003	0.4	5	0.07	0.05	2	0.05
AVE.	7.61 9	51.26 35	96.895 65	1.17 2	0.052 65	0.175 9	0.020 25	0.047 05	0.2392 05	0.164 9	0.067 75	0.095 65	0.038 45	0.059 25
MA X	8.01	101.1	285.17	7	0.092	0.247	0.039	0.086	0.433	0.306	0.601	0.703	0.098	0.247
MIN	7.36	8.34	10.87	0.2	0.022	0.105	0.013	0.014	0.0401	0.02	0.021	0.02	0.011	0.008

Heavy Metal Elements

Freeze and Cherry (1979) classified those inorganic elements that are less than 0.1mg/l in water as trace constituent and those that are between 0.01-10.0mg/l in concentration in water as minor constituents. For the purpose of this research, they are termed heavy metal elements. These elements form a very broad base of this research as most of them are associated with lead – zinc mineralizations in the Mkpuma Ekwoku area. These include Arsenic, Cadmium, Chromium, Cobalt, Copper, Lead, Manganese, Zinc, Mercury and Nickel.

Lead

The concentration of lead in drinking-water is generally below 5 mg/l, although much higher concentrations (above 100 mg/litre) have been measured where lead fittings are present (Howard and Batram, 2003). WHO, (2017) noted that lead is rarely present in tap water as a result of its dissolution from natural sources; rather, its presence is primarily from household plumbing systems containing lead in pipes, solder, fittings or the service connections to homes. The amount of lead in water depends on several factors, including pH, temperature, water hardness and standing time of the water (WHO, 2008). WHO (1984) proposed a health guideline value of 0.05 mg/l and in 1993 reviewed it to 0.01mg. This review was necessary on the basis that lead is a cumulative poison and that there should be no accumulation of body burden of lead. The analysis revealed that the concentrations of lead in the water samples range between 0.022mg/l to 0.092mg/l. This is above the WHO (2017) guidelines for drinking water. This result clearly indicates that the interaction of the water sources with the lead ores (galena) significantly affect the quality of water sources of the area. Apart from the composition of the mineralization in the area, the low pH, the salinity and presence of CO₂ in the water sources causes faster dissolution of lead in water (ATSDR, 2007). Davies et al, 2005 opined that the high concentration of lead in water of mining sites can be attributed to the high immobility of lead.

Copper

Copper is both an essential nutrient and a drinking-water contaminant. Food and water are the primary sources of copper exposure in developed countries. Ores of copper are Chalcopyrite (CuFeS₂), Chalcocite (Cu₂S), Covellite (CuS), Cuprite (Cu₂O) and Malachite (CuCO₃ · Cu (OH)₂) (ATSDR, 2007). Gallagher et al., (2001) stated that at levels above 2.5 mg/lcopper imparts an undesirable bitter taste to water; at higher levels, the colour of water is also impacted. The WHO 2011, guidelines derived a provisional health-based guideline value of 2mg/litre for copper. From the analysis, copper values of the samples ranged from 0.011mg/l – 0.098 mg/l. Significant values were recorded at the abandoned mine ponds at Olua, Mkpuma Ekwaoku. The result indicates that the concentration of copper in the study area is below the WHO (2017) guideline of 2.0mg/L for drinking

water. Brikke (2000) noted that Chalcopyrite (which is endowed in the area), breaks down into copper and pyrite but copper has low mobility and reacts slowly with water. This can be attributed to the low concentration of copper in the area. Nriagu and Pacyna, (1988), also stated that copper, on exposure to air and water forms a thin protective metallic shield which reduces the surface area for reactivity.

Chromium

Chromium is widely distributed in the Earth's crust. It is highly carcinogenic, therefore, minimal intake has been advocated (WHO, 2011). Sources of chromium in the area include the rocks and soils of the area. The analysis shows that concentrations of Chromium in the water samples ranges between 0.105mg/l – 0.247mg/l. 100% of the samples show values of Chromium above the WHO guideline of 0.05mg/l in the area.

Nickel

Nickel occurs naturally in water. The concentration in drinking-water is normally less than 0.02 mg/l, although nickel released from taps and fittings may contribute up to 1 mg/l (WHO, 2011).

The analysis shows concentrations of water samples ranged from 0.021mg/l to 0.061mg/l. This imply that all water samples analysed are below the WHO (2017) guideline value of 0.07 mg/l for drinking water. ATSDR (2005) stated that effluent water generated from mining and smelting operations, runoff from tailing piles, or from utility water used for mine operations can lead to higher concentrations of nickel in mining areas.

Manganese

Manganese is one of the most abundant metals in the Earth's crust, usually occurring with iron, oxygen, sulphur and chlorine (ATSDR, 2012). It is an essential element for humans and other animals and occurs naturally in food and water sources. Occurrence levels in fresh water typically range from 1 to 200 mg/l, although levels as high as 10 mg/l in acidic groundwater have been reported; higher levels in aerobic waters usually associated within dustrial pollution particularly in anaerobic or low oxidation conditions, and this is the most important source for drinking-water (WHO, 2011).

The analysis shows that the concentration of Manganese ranges from 0.0401mg/l to 0.377mg/l. Although, these concentrations are within the WHO, (2017) guideline value of 0.4 mg/l for drinking water, higher values were recorded in the abandoned mine pond and groundwater sources. This is attributed to the dissolution of manganese from the chalcopyrite and siderite ores which underlie the area. This is controlled by the solubility, pH, Eh (oxidation-reduction potential), and the characteristics of the available anions in water (Clewel, et al., 2003).

Cadmium

Cadmium occurs naturally in the environment. Additional releases of cadmium to the environment occur from natural sources and from processes such as combustion of fossil fuel, incineration of municipal or industrial wastes, or land application of sewage sludge or fertilizer (EPA 1985a). From the analysis, cadmium concentration ranges between 0.014mg/l to 0.086 mg/l. This indicates high values in the area. 100% of the samples are above the WHO (2017) guideline value of 0.003 mg/l for drinking water. This is acute contamination. These high concentrations can be linked to the weathering and subsequent dissolution of the chalcopyrite and pyrite ores in the area. Cadmium's mobility in water depends on several factors including the pH and the availability of organic matter. Generally, cadmium will bind strongly to organic matter and this will, for the most part, immobilize cadmium (Autier and White, 2004). Cadmium in water tends to be more available when the pH is low (Elinder, 1992). In surface water and groundwater, cadmium can exist as the hydrated ion or as ionic complexes with other inorganic or organic substances. While soluble forms may migrate in water, cadmium is relatively nonmobile in insoluble complexes or adsorbed to sediments, which may leach into water (Elinder 1985a; EPA 1979d).

Mercury

Mercury is present in the inorganic form in surface water and groundwater at concentrations usually below 0.5 mg/litre, although local mineral deposits may produce higher levels in groundwater. From the analysis, concentration of mercury ranged from 0.013mg/L – 0.039mg/l. These values are above the WHO, 2017 guideline of 0.006mg/l for drinking water. This high concentration can be linked the normal breakdown of minerals in rocks and soil from exposure to wind and water, and from volcanic activity (ATSDR, 2009). This indicates acute contamination of mercury in the water sources of the area. UNEP, (2002) noted that human activities since the start of the industrial age (e.g., mining, burning of fossil fuels) have resulted in additional release of mercury to the environment. Mercury associated with soils can be directly washed into surface waters during rain events. Surface runoff is an important mechanism for transporting mercury from soil into surface waters, particularly for soils with high humic content (Meili, 2013). The most common organic form of mercury, methylmercury, is soluble, mobile, and quickly enters water by dissolution. Sulfur-reducing bacteria are responsible for most of the mercury methylation in the environment (Gilmour and Henry, 1991). Low pH and high mercury sediment concentrations favor the formation of methylmercury, which has greater bioavailability potential for aquatic organisms than inorganic mercury compounds (WHO, 2011).

Arsenic

Arsenic is found widely in the earth's crust often as sulfides or metal arsenides or arsenates. In water, it is mostly present as arsenate, but in anaerobic conditions, it is likely to be present as arsenite (Almela et al., 2002). It is usually present in natural waters at concentrations of less than 1–2 mg/litre. However, in waters, particularly groundwaters, where there are sulfide mineral deposits and sedimentary deposits deriving from volcanic rocks, the concentrations can be significantly elevated upto 12mg/l (WHO, 2017).

The result shows concentration of 0.105 mg/l to 0.247mg/l for the samples. This result shows that 100% of the samples have values above the WHO (2017) guideline of 0.01mg/l for drinking water. This is acute contamination. Arsenic is associated with ores containing metals, such as copper and lead, volcanic eruptions are another source of arsenic (ATSDR, 2007). Transport and partitioning of arsenic in water depends upon the chemical form (oxidation state and counter ion) of the arsenic and on interactions with other materials present. Soluble forms move with the water, and may be carried long distances through rivers (EPA, 1979). Barton et al., 1992 noted that some arsenic compounds can stick to particles in the water or sediment on the bottom of lakes or rivers, and some will be carried along by the water. However, arsenic may be adsorbed from water onto sediments or soils, especially clays, iron oxides, aluminum hydroxides, manganese compounds, and organic material (EPA, 1982b; Welch et al., 1988).

Zinc

Zinc is abundant in the earth's crust. It is a chalcophile metallic element and forms several minerals, including Sphalerite (ZnS), the commonest Zn mineral, Smithsonite (ZnCO₃) and Zincite (ZnO), but is also widely dispersed as a trace element in pyroxene, amphibole, mica, garnet and magnetite (Andrews and Sutherland, 2004). It is released to the environment from both natural and anthropogenic sources; however, releases from anthropogenic sources are greater than those from natural sources (Barbera, et al., 1991).

Result of the analysis for the water samples ranged from 0.020mg/L to 0.255 mg/L. Although, WHO, 2017 does not state a permissible limit for zinc, concentration between 3- 5mg/l is good for healthy living (ATSDR, 2007). This result indicates low concentrations of zinc in the area. Apart from the dissolution of zinc in water, which increases with acidity, zinc is immobile in water (Gundersen and Steinnes, 2003). In most waters, zinc exists primarily as the hydrated form of the divalent cation. However, the metal often forms complexes with a variety of organic and inorganic ligands (EPA, 1984b, 1987c). The transport of zinc in water is controlled by anion species. In natural waters, complexing agents, such as humic acid, can bind zinc (Barcelous, 1999). Divalent zinc ion, often replaces magnesium in silicate mineral of igneous rocks; consequently, weathering of this zinc containing bedrock gives rise to Zn⁺² in solution (EPA 1979d).

Cobalt

Cobalt is a naturally-occurring element that has properties similar to those of iron and nickel. Small amounts of cobalt are naturally found in most rocks, soil, water, plants, and animals, typically in small amounts. Cobalt is also found in meteorites (Barceloux, 1999). However, cobalt is usually found in the environment combined with other elements such as oxygen, sulfur, and arsenic. The result showed that the concentration of cobalt ranged from 0.044mg/L to 0.091mg/L. This is slightly above the WHO (2017) limit of 0.005mg/L for drinking water in some places. Cobalt is highly radioactive (ATSDR, 2004), and high concentration can pose serious health risk. This can be linked to mining and weathering of volcanic rocks in the area. Cobalt may enter air and water, and settle onland from windblown dust, seawater spray, volcanic eruptions, and forest fires and may additionally get into surface water from runoff and leaching when rainwater washes through soil and rock containing cobalt (Mahara and Kudo, 2001).

CONCLUSION

Heavy metal evaluation of water resources of the Mkpuma Ekwaoku, mining area of Ebonyi State, Nigeria has been carried out. The area is endowed with hydrothermal enrichment of minerals. Hydrochemical analysis using AAS shows that concentrations of As, Co, Cr, Pb, Cd and Hg are above the WHO, 2017 permissible guidelines for drinking water. This implies that water sources in the area are not suitable for drinking as biomagnification can occur in the food chain.

REFERENCES

1. Adelekan, A & Abegunde, K (2011). Heavy metals contamination of soil and groundwater at automobile mechanic villages in Ibadan, Nigerian. *International Journal of the Physical Sciences* Vol. 6(5), pp. 1045-1058.
2. Agbugui, M. O. and Deekae, S.N. (2013). Assessment of the Physico-chemical Parameters and Quality of Water of the New Calabar-Bonny River, Porthacourt, Nigeria. *Cancer Biology*, 4(1):1 – 9
3. Almela, C., Algora, S. and Benito, V., (2002), Heavy metal, total arsenic, and inorganic arsenic contents of algae food products. *J Agric Food Chem* 50:918-923.
4. APHA. (2005) Standard methods for the examination of water and wastewater, 20th edn. American Public Health Association, Washington DC
5. Amadi, A. N., Nwankwoala, H. O., Olasehinde, P. I., Okoye, N. O., Okunlola, I. A. and Alkali, Y. B. (2012) Investigation of Aquifer Quality in Bonny Island, Eastern Niger Delta, Nigeria using Geophysical and Geochemical Techniques. *Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS)* 3 (1): 180-184.
6. American Public Health Association (APHA), (1998), Direct Air- Acetylene flame method, standard method of water and wastewater 20th edition
7. Andrews S. and Sutherland R. A. (2004), Cu, Pb and Zn contamination in Nuuanu watershed, Oahu, Hawaii. *Sci Total Environ* 324(1-3):173-182.
8. Autier, V., White, D. (2004). Examination of cadmium sorption characteristics for aboreal soil near Fairbanks, Alaska. *Journal of Hazard Material*, 106B:149-155.
9. Aremu, D.A, Olawuyi, J, and Meshitsuka, S. (2002), Heavy metal analysis of groundwater from Warri, Nigeria. *Int J Environ Health Res* 12:261-267.
10. Barbera, R., Farre, R. and Mesado, D. (1991). Determination of cadmium, cobalt, copper, iron, lead, manganese, nickel and zinc in diets: Development of a method. *Nahrung* 35(7):683-687.
11. Barceloux, D. G. (1999), Zinc. *Clin Toxicol* 37(2):279-292.
12. Barton, E. N., Gilbert, D. T, and Raju, K. (1992). Arsenic: The forgotten poison? *West Indian Medical Journal* 41(1):36-38.
13. Benkheilil, J. (1989), Cretaceous Deformation, Magmatism and Metamorphism in the Lower Benue Trough. Nigeria in *African Geology Reviews* (Peter Bowden and Judith Kinnaird, ed). Geol. John Wiley and Sons Ltd. Benue Rift (Aulacogen): A re-interpretation. *Journal Mining*. 20(10): 56-90.

14. Brikké, F. (2000). Operation and maintenance of rural water supply and sanitation systems: a training package for managers and planners. Delft, IRC International Water and Sanitation Centre; and Geneva, World Health Organization.
15. Boske, L., Sobczynski, O. and Kowalski, A. (2004), Distribution of mercury and other heavy metals in bottom sediments of the middle Odra River (Germany/ Poland). Polish jour of envi. Studies. 13(5): 495-502pp.
16. Bullard, E·C; Everrtt, J·E·, smith A·G; (1965), Fit of the Continents around the Atlantic philosophical Transactions of the Royal society London A· 258· 41-51·
17. Burt, R., Weber, T., Park, S., Yochum, S., Fergusson, R. (2011).Trace element concentration and speciation in selected mining- contaminated soils and water in Willow Creek flood plain , Colorado. Applied Environmental Soil Science. <http://doi.org/10.1155/2011/237071>
18. Burke, K.C., Dessawvagia, R. F. J., and Whiteman, A. W. (1972), Geology History of the Benue Valley and Adjacent Area, Africa Geology, University of Ibadan Press. Geology.10(5): 187-206.
19. Clewell, H. J., Lawrence, G. A., Calne, D. B; (2003), Determination of an occupational exposure guideline for manganese using the benchmark method. Risk Anal 23(5):1031-1046
20. Conesa, H. M., Robinson, B. H., Schulin, R., Nowack, B. (2008). Metal extractability in acidic and neutral mine tailings from the Cartagena- La Union Mining district (SE Spain). Applied Geochemistry, 23:1232 – 1240
21. Davies, B. E., Bowman, C., Davies, T. C. and Sellinus, O., (2005), Medical Geology: Perspectives and Prospects. Essent.Med. Geol., Elsevier Inc., pp.1-14.
22. Dimashki M., Lim L.H., Harrison R.M., and Harrad, S. (2001) Temporal trends, temperature dependence, and relativereactivity of atmospheric polycyclic aromatic hydrocarbons. Environ. Sci. Technol. 35 (11), 2264.
23. Dalton, M.B. and Upchurch, S.B., (1978) Interpretation of Hydrochemical facies by factor analysis. Groundwater Journal, volume 16, Number 4, pp. 228-223.
24. Edet, A.,Ukpong, A.,andNganje, T. (2013) Hydrochemical studies of Cross River Basin (southeastern) river systems using cross plots, statistics and water quality index. Environ. Earth Sci. 70 (7). 3043-3056.
25. Edet, A., Nganje, T. N., Ukpong, A. J., Ekwere, A. S. (2011). Groundwater Chemistry and Quality of Nigeria: A Status Review. African Journal of Environmental Science and Technology, 5(13), pp. 1152 – 1169. DOI: 10.5897/AJESTX11.011
26. Egboka, B. C. E, Anike, L.O., and Olushola, I. (1993), Potentials for Environmental Pollution/Contamination of Lead-Zinc Areas of Nigeria. Journal Mining Geology workshop, pp. 17
27. El Amari, K., Valera, P., Hibti, M., Pretti, S., Marcello, A., Essarraj, S. (2014). Impact of mine tailings on surrounding soils and ground water: case of Kettara old mine, Morocco. Journal of African Earth Science, 100, 437e449.
28. Elinder, C. G. (1985). Cadmium: Uses, occurrence and intake. In: Friberg, L., Elinder, C. G., Kjellström, T., eds. Cadmium and health: A toxicological and epidemiological appraisal. Vol. I. Exposure, dose, and metabolism.Effects and response. Boca Raton, FL: CRC Press, 23-64.
29. Elinder, C. G. (1992), Cadmium as an environmental hazard. IARC SciPubl 118:123-132.
30. Environmental Protection Agency(EPA).(1982), Exposure and risk assessment for arsenic. Washington, DC: U.S. Environmental Protection Agency, Office of Water Regulations and Standards. PB85221711.(EPA)440485005. 1.14.68.
31. Eyankware, M. O., Obasi, P. N. (2021). A holistic review of heavy metals in water and soil in Ebonyi SE. Nigeria; with emphasis on its effects on human, aquatic organisms and plants. World News of Natural Science,38; 1-19.
32. Ezeh, H. N., Anike, O. L. and Egboka, B. C. E., (2007), The Distribution of some Heavy Metals in Soil in areas around the Derelict Enyigba Mines and its Environmental Implication.Journ. Min. Geol. Vol. 2(2) pp. 99-106.
33. Garvey, G. J., Hahn, G. and Lee, R. V., (2013), Heavy metal hazards of Asian traditional remedies. Int J Environ Health Res 11(1):63-71.
34. Gilmour, C. C and Henry, E. A. (1991), Mercury methylation in aquatic systems affected by acid deposition.Environmental Pollution 71(2-4):131-169.

35. Gundersen, P., Steinnes, E. (2003). Influence of pH and TOC concentration on Cu, Zn, Cd, and Al speciation in rivers. *Water Resources*, 37:307-318.
36. Gerhat, J. M., Blomquist, J. D. (1992). Selected Trace Elements and Organic Contaminant in Stream Bed Sediments of the Potomac River Basin. U.S. Geological Survey, Water Resources Investigation Report 95 – 4267, 1-12.
37. Guiraud, R. and Bellion, Y., (1995), Late Carboniferous to Recent geodynamic evolution of the west Gondwanian, Cratonic, Tethyan margins. *The ocean Basins and Margins* vol 8. Pp 101- 124.
38. Howard, G., Bartram, J. (2003). Domestic water quantity, service level and health World Health Organization, Geneva.
39. Hulme. (1997) mean annual rainfall for Nigeria for 1951- 1995.
40. Hutton M, Symon C (1986). The quantities of cadmium, lead, mercury and arsenic entering the U.K. environment from human activities. *Sci Total Environ.* 1;57:129-50
41. Hoque, M. (1977) Petrographic differentiation of tectonically controlled Cretaceous sedimentary cycles, southeastern Nigeria. *Journal of Sedimentary Geology*, vol.17, pp 235 245.
42. Hoque, M; and Nwajide, C.S. (1985), Tectonic Sedimentological evolution of an elongate Intracratonic basin (aulacogen). The case of the Benue Trough of Nig. *Journal of Mining and Geology* 21, pp. 19-26.
43. Igbozulike, M.U. (1975) : Vegetation Types . In Ofomata, G. (ed). *Nigeria Map of Eastern States*. Ethiope Publishers Ltd ; Benin, pp. 30- 32.
44. Igwe, O., Ngwoke, M., Ukah, B. U., and Ubido, O. E. (2021) Assessment of the physicochemical qualities of groundwater and soils around oil-producing communities in Afam, area of Porthacourt, Niger Delta Nigeria. **Applied Water Science**; [Vol. 11, Iss. 4](#), DOI:10.1007/s13201-021-01393-6
45. Igwe, O., Adepehin, E.J., Iwuanyanwu, C., and Una, C.O. (2014). Risks associated with the mining of Pb – Zn minerals in some parts of the Southern Benue Trough, Nigeria. *Environmental Monitoring and Assessment*. 186: 3755- 3765.
46. Igwe E. O, Ede C. O, Eyankware M.O, Nwachukwu C.M, Williams O.B (2022) Assessment of potentially toxic metals from mine tailings and waste rocks around mining areas of Oshiri-Ishiagu region, Southeastern Nigeria. *Earth Syst Environ*. [https:// doi. org/ 10. 1007/ s41748- 022- 00306-0](https://doi.org/10.1007/s41748-022-00306-0)
47. Khan, S., Rehman, S., Khan, A. Z., Khan, M. A., Shah, M. T. (2010). Soils and vegetables enrichment with heavy metals from geological sources in Gilgit, Northern Pakistan. *Ecotoxicology Environmental safety*, 73:1820- 1827
48. Khan, M.A and Ghouri, A.M (2011). Environmental Pollution: Its Effects on Life and Its Remedies. *Journal of Arts, Science & Commerce*, Vol. 2, No. 2, pp. 276-285.
49. Kribek, B. (2013). Recommendations for the collection and processing of samples when assessing the degree and extent of contamination of surface and ground waters, stream sediments, soils, and vegetation in areas affected by mining and mineral processing in countries of Sub – Saharan Africa. Unpublished Report. SIDA Project planning Meeting, 2013. Prague, Czech Republic, pp16
50. Kogbe, C. A. (1986), The Cretaceous and Paleogene sediments of Southern Nigeria. In Kogbe C. A (ed), *Geology of Nig*. Elizabeth Publishers Lagos Pp275-281.
51. Kogbe, C. A. (1976). Paleogeographic History of Nigeria from Albian times. In Kogbe C. A (ed) *Geology of Nig*. Elizabeth Publishers Lagos Pp237-252.
52. Lu, Z., Yu, X., Huang, Q. (2014). Effect of mining waste water on drinking water quality and tumor mortality of villagers. *Journal of Environmental Health*, 21 (5), 303e304.
53. Lucassen, E., Smolders, A. J. P., Roelofs, J. G. M. (2002). Potential sensitivity of mines to drought, acidification and mobilization of heavy metals: The sediment S/Ca +Mg) ratio as diagnostic tool. *Environmental Pollution*, 120:635-646.
54. Mahara, Y. and Kudo, A. (2001), Interaction and mobility of cobalt-60 between water and sediments in marine environments possible effects by acid rain. *Water Res* 15(4):413-419.
55. Martinez- Martinez. S, Acosta, J.A, Fascano, A, Carnoma D.M., Zornoza, R, Cerda, C. (2013). Assessment of the lead and zinc content in natural soils and tailing ponds from the Cartagena – La Union mining district SE Spain. *Journal of Geochemical Exploration*, 124:166 – 175
56. Meili, M. (2013). The coupling of mercury and organic matter in the biogeochemical cycle - towards a mechanistic model for the boreal forest zone. *Water Air Soil Pollution*, 56:333-347.

57. Mendoza, C. A., Cortes, G. and Munoz, D. (1996), Heavy metal pollution in soils and sediments of ruraldeveloping district 063, Mexico. *Environ Toxicol Water Qual* 11:327-333.
58. Moreno- Jimenez, E., Penalosa, J. M., Manzano, R., Carpena- Riuz, R. O., Gamarra R, Esteban, E. (2009). Heavy metals distribution in soils surrounding an abandoned mine in NW Madrid Spain and their transference to wideflora. *Journal of Hazard Material*, 162:854- 859.
59. Moya J, Picard-Lesteven, T., Zouhri, L., El Amari, K., Hibti, M., Benkaddour,A. (2017).Groundwater assessment and environmental impact in the abandoned mine of Kettara (Morocco). *Environmental Pollution* , 231(Pt 1):899-907
60. Murat, R.C. (1972). Stratigraphy and paleogeography of the Cretaceous and Lower Tertiary in Southeastern Nigeria. In: T.F.J., Dessauvage and A.A, Whiteman (eds) *African Geology*. University of Ibadan press, Ibadan, Nigeria, 251-2761
61. Musah, S. N., Maxiwe, A., Boateng, A. (2013). Health risks of heavy metals in selected crops cultivated in small-scale- gold- mining areas in Wassa- Amenfi- west district of Ghana. *Journal of National Science research*, 3(5):2224-3186
62. Nidhi, G., Pankaj, P. ,Jakir, H. (2017). Effect of physicochemical and biological parameters on the qualityof river water of Narmada, Madhya Pradesh, India. *Water Science*, 31 (2017) 11–23.
63. Nieto, J. M., Sarmiento, A. M, Olfas M. Canovas, CR, Riba I. Kalman J. Delvalls T. A. (2007). Acid mine Drainage pollution in the Tinto and Odiel rivers (Iberian pyrite belt, SW Spain) and bioavailability of the transported metals to theHuelva estuary. *EnvironmentInternational*, 33:445- 456.
64. Ngah, A. ,Braide, S. and Dike, C. (2017) Physico-Chemistry of Elechi Creek in the Upper Bonny Estuary, Rivers State, Nigeria. *Journal of Geoscience and Environment Protection*, 5, 181-197.
[doi: 10.4236/gep.2017.58015](https://doi.org/10.4236/gep.2017.58015).
65. Nnabo, P. N., Ezech, H. N. and Chima, K. I., (2009), The preliminary assessment of the level of some heavy metals in the stream sediments of Eka-Awoke watershed, SE of Abakaliki, SE Nigeria. *Journal of Applied & Natural Sciences (JANS)*4 (1), 70-78.
66. Nriagu, J. O., Pacyna, J. M. (1988).Quantitative assessment of worldwide contamination of air, water and soils by trace metals. *Nature*, 333:134-139.
67. Nwachukwu, S.O., (1972), The Tectonic Evolution of the Southern Portion of the Benue Trough, Nigeria. *Geol. Mag*:**109**(30): 411-419.
68. Nwankwoala, H. O., Ngah, S. A., Ushie, F. A., and Amadi, A. N. (2014). Statistical characterization of groundwater quality I Port Harcourt, Southern Nigeria. *Science Africian Journal of Scientific Issues,Research and Essays*, 2(8), 338–341.
69. Obasi, P. N., Akudinobi, B. E. B. (2015).Geochemical Assessment of Heavy Metal Distribution and Pollution Status in Soil/Stream Sediment in the Ameka Mining Area of Ebonyi State, Nigeria.*African Journal of Geo-Science Research*, 3(4): 01-07
70. Obasi, P. N. (2017). Hydrogeological and Geochemical Assessment of the Lead – Zinc Mining Areas of Abakaliki Ebonyi State, Southeastern Nigeria.Unpublished Ph. D Thesis.NnamdiAzikiwe University, Awka, Nigeria.
71. Obasi, P. N and Akudinobi, B. E. B (2020) Potential Health Risk and Levels of Heavy Metals in Water Resources of Lead- zinc Mining Communities of Abakaliki, Southeast Nigeria. Springer- Applied Water Science [https://doi.org/ 10.1007/s13201-020-01233-](https://doi.org/10.1007/s13201-020-01233-)
72. Obasi, P. N. (2020), Occurrence and Distribution of Heavy Metals in Arable Soils Around Lead- Zinc Mining Sites of Abakaliki, Southeast Nigeria. Springer – Modelling Earth Systems and Environment. <https://doi.org/10.1007/s40808-020-00800-2>
73. Obasi, P. N., and Akudinobi, B. E. B., (2019b), Heavy Metals Occurrence, Assessment and Distribution in Water Resources in the Lead- Zinc Mining Areas of Abakaliki, Southeastern Nigeria. Springer - International jour. of Envi science and technology. <https://doi.org/10.1007/s13762-019-02489-y>
74. Obasi, P. N., and Akudinobi, B. E. B., (2019a), Pollution Status of arable Soil and Stream Sediment in the Mining Areas of Abakaliki, Lower Benue Trough. Springer - International jour. of Envi science and technology. <https://doi.org/10.1007/s13762-019-02337-z>
75. Obasi, P.N., Eyankware, M.O., Akudinobi, B.E.B. (2021).Characterization and evaluation of the effects of mine discharges on surface water resources for irrigation: a case study of the Enyigba Mining District, Southeast Nigeria. *Applied Water Science*, <https://doi.org/10.1007/s13201-021-01400-w>.

76. Obasi, P. N., Eyankware, M. O., Edene, E. N (2022b). Contamination of potable water supply sources in the lead–zinc mining communities of Mkpuma Akpatakpa, Southeastern Nigeria International Journal of Energy and Water Resources <https://doi.org/10.1007/s42108-022-00199-9>
77. Obasi, P.N. ; Akakuru, O.C. , Nweke, O.M. and Okolo C.M. (2022a) Groundwater Assessment and Contaminant Migration in Fractured Shale Aquifers of Abakaliki Mining Areas, Southeast Nigeria. Journal of Mining and Geology Vol. 58(1) 2022. pp. 211 - 227
78. Obiorah, S. C., Chukwu, A., Toteu, S. F., Davies, T. C.(2016). Assessment of Heavy metals Contamination in soils around Pb- Zn mining Areas in Enyigba, Southeastern Nigeria. Journal of Geological Society of India, 87 453- 462.
79. Obiorah, S. C., Chukwu, A., Toteu, S. F., Davies, T. C. (2018). Contamination of the potable water supply sources in the Lead – Zinc mining Communities of Enyigba, Southeastern Nigeria. Mine Water and the environment <http://doi.org/10.1007/s10230-018-0550-0>.
80. Obinwanne, C. O. (2015) Assessment of physico-chemical property of water samples from Port Harcourt, Bonny and Opobo coastal areas for sustainable coastal tourism development In Rivers State, Nigeria. International Journal of Scientific & Technology Research volume 4, Issue 12. 257-261.
81. Ofoegbu, C.O and Onuoha, K.M. (1991).A review of geological investigations in the Benue Trough. Journal of Africa earth science. Vol3. pp283-291.
82. Ogbonna, D. N., Ngah, S. A., Youdeowei, P. O., and Origbe, M. E. (2021). Physico- Chemistry of Surface Water Impacted by Crude Oil Spills in Bodo/Bonny Rivers, Nigeria. Journal of Applied Life Sciences International, 24(5), 1-18. <https://doi.org/10.9734/jalsi/2021/v24i530234>
83. Olade, M.A. (1976). Evolution of Nigeria’s Benue Trough (aulacogen): a tectonic model Geology magazine, 112: 575-583
84. Owor M, Hartwig, T., Muwanga, A., Zachmann, D., Pohl, W. (2007). Impact of tailings from the Kilembe copper mining district on lake George, Uganda. Environmental Geology, 51:1065 1075
85. Oyeku, O and Eludoyin, A (2010) Heavy metal contamination of groundwater resources in a Nigerian urban settlement. African Journal of Environmental Science and Technology. Vol 4, No 4 (2010).
86. Peters, S.W. (1978), Stratigraphic Evolution of the Benue Trough and its implications for Paleogeography of West Africa. Journal of Geology Volume 86, pp 311-322.
87. Reyment, R. A. (1965b), Aspects of the Geology of Nigeria, University of Ibadan Press, p 144.
88. Sawyer, R., Simpson-Hébert, M., Wood, S. (1998), PHAST step-by-step guide: A participatory approach for the control of diarrhoeal disease. Geneva, World Health Organization (WHO/EOS/98.3).
89. Short. K. C. and Stauble, A. I. (1967), Outline of the Geology of Nigeria Delta. Hull AAPG **54**: 761-779.
90. Todd, D. K. (1980), Groundwater Hydrology, 2nd edition. John Willey and sons, New York.
91. Udom, G. J., Nwankwoala, H. O., Daniel, T. E. (2018). Physico-Chemical Evaluation Groundwater in Ogbia, Bayelsa State, Nigeria. International Journal of Weather, Climate Change and Conservation, 4(1), pp. 19 -32.
92. Welch, A. H., Lico, M. S, and Hughes, J. L. (1988), Arsenic in groundwater of the western United States. Ground Water 26(3):333-347.
93. World Health Organization (WHO). (2011), Guidelines for Drinking water quality Third edition Geneva
94. World Health Organization (WHO). (2017), Guidelines for Drinking water quality Third edition Geneva
95. Zhang, Y., Wu, J., and Xu, B. (2018). Human health risk assessment of groundwater nitrogen pollution in Jinghui canal irrigation area of the loess region, northwest China. Environment and Earth Science, 77(7), 273. <https://doi.org/10.1007/s12665-018-7456-9>.