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IMPACT OF MINING ACTIVITIES ON THE QUALITY OF WATER OF LEAD MINING SITES OF ADUDU, NASARAWA STATE NIGERIA

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ABSTRACT

Heavy metals are a potential health risk, especially in mining sites ,where they deteriorate from sulfide-rich ore bodies. Lead, cadmium, arsenic, and mercury are very carcinogenic, while others are toxic. The assessment of the levels of these metals in water resources of the lead mining communities of Adudu, Nasarawa State was carried out, and the potential health risk has been investigated. These areas make up one of the main mining communities of Nasarawa State, where active and abandoned mines are located. One hundred and five (105) water samples were analyzed in two periods using atomic absorption spectrophotometric. Result indicates levels of Pb > Hg > As > Cd > Mn > Ag > Se > Ni > Cr > Cu in water sources. High levels of Mn (61.90 mg/L), Pb (11.92 mg/L), Cr (13.70 mg/L), Ni (13.06), Cd (16.3 mg/L), Ag (7.01 mg/L), Hg (3.30 mg/L), As (4.13 mg/L), Se (3.01 mg/L), Zn (10.10 mg/L) and Co (1.0 mg/L) above the WHO recommended standards for drinking water were observed. Only Cu (1.98 mg/L) recorded safe concentrations in 100% samples analyzed. Levels of associated metals including Pb, As, Hg, Se, and Cd are higher in groundwater, especially in areas close to the active mines; this is due to mineralization in the area. Alternative water supply sources and sensitization on the potential health risk are highly advocated in these communities.

Keywords: Heavy metals · Mining · Water pollution · Mine waste · Health impact

INTRODUCTION

Mining activities negatively affect the environment by causing loss of biodiversity, soil erosion, and contamination of surface water, ground water, and soil. It can also initiate the development of sinkholes. The outflow of chemicals from mining sites can also have harmful effects on the health of the population living at or around the mining site (El Amari *et al.,* 2014). This has usually led to water pollution which is a serious issue facing many developing countries of the world. This is due to the fact that mine wastes generate acid mine drainage (AMD) which contains high amount of sulfide-bearing components and can migrate (Obiora *et al.,* 2018) Sulfide ores, including galena, are composed of heavy metal components especially lead, mercury, copper, manganese, zinc, nickel, cobalt, arsenic, selenium, molybdenum, chromium, silver and vanadium (El Amari *et al.,* 2014; Davies *et al.,* 2005). Some heavy metals are either essential nutrient**s** (cobalt and zinc) or relatively harmless such as silver. However, others like cadmium, mercury and lead are highly poisonous (El Amari *et al.,* 2014; Moye *et al.,* 2017). Other researchers showed that the abandoned pyrrhotite mine in Kettara, Morocco, contains more than 3 million tons of mine wastes deposited in the environment without protection (Hakkou *et al.,* 2008; El Amari *et al.,* 2014). The impact of AMD and geochemical assessment of soil/water in the Kettara mine environment have been described elsewhere (Cidu *et al.,* 2011; Equeenuddin *et al,* 2010; Buzatu *et al.,* 2016; Han *et al.,* 2017). Furthermore, the geochemical and eco-toxicological characteristics of stream water and groundwater of the Kettara mines in Morocco were investigated and the results showed contamination of soils and potable water supply sources with heavy metals and potentially harmful elements such as lead–zinc (Obiora *et al.,*2016).

Heavy metal effluents from the weathering of the mineral deposits may have serious consequences on soil and water quality due to soil–water interaction (Obasi and Akudinobi 2019b). Similarly, 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 (Koki *et al.,* 2015). It is against this background that an investigation on the levels and potential health risk of these metals in the mining areas of Adudu community of Nasarawa State where active and abandoned mines are located. This study is necessary and timely as a social interactive survey in the area indicates that more than 70% of these rural inhabitants depend on impounded water in abandoned mine ponds and unprotected stream channels for their domestic uses. This study will provide valuable information on the levels and associated health risk of these heavy metals in the areas. This may likely constitute a vital planning tool to rural water supply and health safety regulatory agencies.

MATERIALS AND METHODS

The Study Area

The study area is located in Adudu, North Central Nigeria, between latitudes 08˚10'00''N and 08˚19'00''N and longitudes 08˚55'00''E and 09˚6'30" E (Figure 1). It is bounded to the west by Keana, north by Lafia, and to the east by Awe. The area is accessible by the Lafia-Obi roads, minor roads, and footpaths. It is a town under Obi Local Government Area.

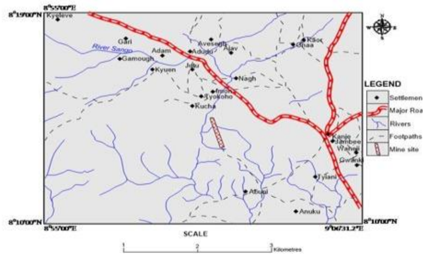

Figure 1: Map showing the location area of the study

Geology and Hydrogeology of the Study Area

Adudu and environ lie within the Awe and Agwu formations (Figure 2) which fall under the Middle Benue Trough of Nigeria and also igneous origin. The study area is underlain by shales (baked and compacted) Basalt and Sandstone, Bluish-grey to dark black carbonaceous shales of Late Albian–Early Cenomanism age predominate the study area. Basalts intruded the black shale forming a hill of about 250 m high, and the common structural features observed are mud cracks, veins, joints.

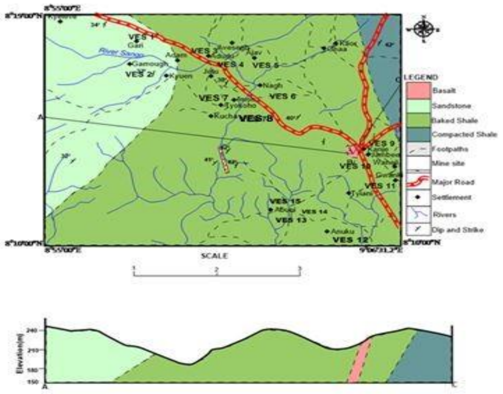

Figure 2: Geology and VES map of Adudu and its environment.

METHODOLOGY

Sample Collection and preparation

A total of one hundred and five (105) water samples comprising sixty-five (65) surface water and forty (40) groundwater were collected systematically on daily basis for the research. Surface water sources considered include active and abandoned mine pits, rivers, streams and lakes, while groundwater sources include shallow wells. These samples were collected from March to May and October to December 2019. The water samples from all observation wells and surface were stored in a plastic 1-liter container for detailed chemical analysis. These containers were washed thoroughly with distilled water and dried before being filled with the water samples.

To obtain a composite sample, they were collected after the well was subjected to agitation with motorized agitator for 5–10 min (for pump wells), while surface waters were cleared of visible wastes before sample collection. Filtration of water samples was done in the field using 0.45 μm diameter disposable filters to ensure the removal of suspended solids before storage in prepared bottles. Acidification of samples was done with 1.0 mL of conc. HNO_3 using new syringes. This is necessary to prevent sorption. The samples were stored in ice-packed containers to maintain the transportation temperature. Accordingly, before the sampling, sample bottles and beakers were washed thoroughly and soaked in distilled water acidified with 1.0 mL of HNO_3 for 3 days. They were also rinsed with dilute HNO_3 and vigorously rinsed at least three times with the water sources at the point of water collection. Samples for analysis were prepared using 2 ppm, 5 ppm and 10 ppm standard solution (Agilent technology) for all the metals.

Laboratory analysis

Laboratory analysis for the concentration of As, Cr, Zn, Ni, Se, Pb, Cu, Hg, Cr, Ni, Cd and Mn was done using Agilent Fast Sequential (FS Varian 2400 AA) atomic absorption spectrophotometer. The Agilent FS2400AA has an accuracy level of 99.8% and a precision of 97.6%. The detection limits of the elements are shown in Tables 1 and 2. All sampling steps and data analysis were performed according to standard methods for water and wastewater (APHA ,1995).

Data analysis

All data obtained were analyzed using SPSS software The results were discussed and compared with the World Health Organization (WHO) standards for water quality with respect to the associated health risk. Student’s *t* test was applied to compare the element means difference between the March to May and October to December 2019.

RESULTS

Results of **the** analysis are presented in Tables 1 and 2 for March to May periods and October to December periods, Also, Table 3 is the summarized result with percentage measures above drinking-water limits and Table 4 shows the average data of the heavy metals analyzed while Table 5 indicates the Levenes' test for variance of homogeneity.

Table 1: Concentration of Heavy Metals in Pre-monsoon (March - May) season

	Sample ID	Se (mg/L)	As (mg/L)	Mn (mg/L)	Ag (mg/L)	Cu(mg/L)	Hg (mg/L)	Pb (mg/L)	Zn (mg/L)	Co (mg/L)	Ni (mg/L)	Cd (mg/L)	Cr (mg/L)
1	ADD/1SS	0.00	1.11	3.05	0.72	0.01	0.00	0.00	0.00	0.04	0.01	0.06	0.00
2	ADD/2AM	0.00	0.00	1.04	0.36	0.01	0.00	0.02	0.00	0.05	0.00	0.05	0.00
3	ADD/3SS	0.00	0.00	4.36	0.27	0.00	0.00	0.00	0.00	0.05	0.00	0.05	0.00
4	ADD/4AM	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00
5	ADD/5AM	0.00	0.00	0.00	0.30	0.00	0.00	0.00	9.98	0.00	0.00	0.00	0.00
6	ADD/6SS	0.00	0.00	2.90	0.35	0.00	2.30	0.02	0.00	0.04	0.00	0.00	0.00
7	ADD/7SS	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.04	0.10	0.00	0.00	0.00
8	ADD/8SS	0.00	0.00	0.02	0.00	0.00	1.00	0.00	0.06	0.00	0.00	0.00	0.01
9	ADD/9SS	0.00	0.00	7.67	0.35	0.02	3.30	3.00	0.00	0.01	0.01	0.00	0.15
10	ADD/10AM	0.00	1.88	9.91	0.24	0.00	1.90	0.00	0.01	0.10	0.00	0.00	0.00
11	ADD/11SS	0.00	1.22	0.00	0.42	0.00	1.10	0.00	0.00	0.00	0.00	0.00	0.00
12	ADD/12AM	0.00	0.52	4.09	0.00	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.00
13	ADD/13SS	0.00	0.00	3.08	0.00	0.00	0.98	0.10	0.00	1.00	0.00	0.00	0.00
14	ADD/14SS	0.00	0.00	4.58	0.25	0.00	0.70	3.91	0.00	0.00	0.00	0.00	0.00
15	ADD/15AM	0.00	0.00	1.29	0.24	0.00	2.00	0.51	0.01	0.00	0.10	0.00	0.00
16	ADD/16SS	0.00	0.00	31.39	1.25	0.00	0.80	0.72	0.00	0.02	0.02	0.20	0.00
17	ADD/17AM	0.00	0.11	0.00	2.55	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
18	ADD/18SS	0.00	0.28	1.70	7.01	0.00	0.30	0.89	0.00	0.00	0.00	0.00	0.00
19	ADD/19SS	0.00	0.00	45.13	0.29	0.00	0.40	1.73	10.07	0.00	0.10	11.00	0.00
20	ADD/20AM	0.00	0.79	2.05	0.46	0.07	0.30	5.42	10.10	0.20	0.20	10.32	0.00
21	ADD/21AM	0.00	0.00	1.26	0.01	0.00	0.60	0.05	0.00	0.20	0.10	0.10	0.00
22	ADD/22SS	0.00	0.00	23.24	0.29	0.03	0.80	1.15	0.99	0.00	0.00	0.01	0.00
23	ADD/23AM	0.00	0.91	12.10	0.79	0.05	0.00	0.60	2.09	0.00	0.00	0.00	0.00
24	ADD/24AM	0.00	0.00	0.21	0.19	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00
25	ADD/25AM	0.00	0.00	0.40	0.17	0.00	0.00	0.01	0.10	0.00	0.00	0.00	0.00
26	ADD/26SS	0.00	0.63	16.67	0.25	0.00	0.00	2.08	0.21	0.00	0.02	0.00	13.70
27	ADD/27AM	0.01	0.10	1.25	0.53	0.34	0.80	6.14	10.10	0.02	0.02	4.05	0.00
28	ADD/28AM	0.00	0.98	23.44	0.34	0.03	0.60	0.12	0.24	0.00	0.02	0.00	0.00
29	ADD/29AM	0.00	0.00	1.65	0.78	0.10	0.00	5.06	1.50	0.01	0.02	0.00	0.00
30	ADD/30AM	0.01	0.00	8.81	2.02	0.01	1.50	0.59	0.24	0.00	0.02	0.04	0.00

31	ADD/31SS	0.00	0.00	2.50	0.35	0.04	0.20	0.08	0.93	0.20	0.02	0.03	0.00
32	ADD/32SS	0.26	2.98	0.00	0.00	0.00	0.24	2.03	0.39	0.10	0.00	0.17	0.00
33	ADD/33SS	0.27	0.26	0.00	0.00	0.00	0.15	2.83	0.40	0.12	0.00	0.31	0.00
34	ADD/34SS	0.82	1.54	0.00	0.00	0.00	0.28	2.00	0.03	0.29	0.02	0.13	0.00
35	ADD/35	1.25	4.01	1.13	0.04	0.00	0.15	3.20	1.72	0.01	0.00	0.24	0.00
36	ADD/36SS	0.17	3.00	0.00	0.00	0.00	0.22	2.63	0.23	0.24	0.00	0.27	0.00
37	ADD/37AM	1.23	3.74	0.00	0.00	0.00	0.07	2.00	0.09	0.17	0.00	0.31	0.00
38	ADD/38SS	0.19	3.55	0.00	0.00	0.03	0.17	3.00	0.01	0.19	0.00	0.09	0.00
39	ADD/39SS	0.20	4.04	0.12	0.00	0.04	0.12	2.87	0.05	0.07	0.00	0.32	0.00
40	ADD/40	0.12	2.68	2.73	0.00	0.08	0.08	3.26	0.68	0.18	0.00	0.19	0.00
41	ADD/41	1.04	3.00	2.15	0.00	0.16	0.18	4.19	0.77	0.21	0.17	0.12	0.00
42	ADD/42	2.00	1.61	0.00	0.00	0.03	0.37	2.73	0.00	0.17	0.00	0.37	0.00
43	ADD/43	2.14	3.48	0.00	0.00	0.00	0.22	2.77	0.04	0.00	0.00	0.26	0.00
44	ADD/44	2.66	2.73	0.00	0.00	0.00	0.37	2.26	0.00	0.21	0.09	0.28	0.00
45	ADD/45	3.01	2.86	0.00	0.00	0.01	0.36	2.43	0.00	0.24	0.08	0.43	0.00
46	ADD/46	2.49	2.94	0.00	0.00	0.02	0.25	2.76	0.00	0.06	0.06	0.45	0.00
47	ADD/47	0.82	1.79	0.00	0.00	0.05	0.45	1.88	0.00	0.22	0.00	0.38	0.00
48	ADD/48	0.83	2.36	0.00	0.00	0.03	0.38	1.66	0.00	0.18	0.00	0.51	0.09
49	ADD/49	1.31	2.02	0.00	0.00	0.05	0.40	1.87	0.04	0.00	0.05	0.16	0.00
50	ADD/50	0.97	1.11	0.00	0.00	0.00	0.33	2.76	0.11	0.05	0.07	0.32	0.00
51	ADD/20AM	0.00	0.79	2.05	0.46	0.07	0.30	5.42	10.53	0.20	0.20	10.32	0.00
52	ADD/21AM	0.00	0.00	1.26	0.01	0.00	0.60	0.05	0.00	0.20	0.10	0.10	0.00
53	ADD/22SS	0.00	0.00	23.24	0.29	0.03	0.80	1.15	0.99	0.00	0.00	0.01	0.00
54	ADD/23AM	0.00	0.91	12.10	0.79	0.05	0.00	0.60	2.09	0.00	0.00	0.00	0.00
55	ADD/24AM	0.00	0.00	0.21	0.19	0.00	0.00	0.00	0.16	0.00	0.00	0.00	0.00
56	ADD/25AM	0.00	0.00	0.40	0.17	0.00	0.00	0.01	0.10	0.00	0.00	0.00	0.00
57	ADD/26SS	0.00	0.63	16.67	0.25	0.00	0.00	2.08	0.21	0.00	0.02	0.00	13.70
58	ADD/27AM	0.01	0.10	1.25	0.53	0.34	0.80	6.14	10.10	0.02	0.02	4.05	0.00
59	ADD/28AM	0.00	0.98	23.44	0.34	0.03	0.60	0.12	0.24	0.00	0.02	0.00	0.00
60	ADD/29AM	0.00	0.00	1.65	0.78	0.10	0.00	5.06	1.50	0.01	0.02	0.00	0.00
Detection limit		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WHO standard limit		0.04	0.01	0.40	0.10	2.00	0.01	0.01	N/A	N/A	0.07	0.00	0.05

AC = Active mine, AM = Abandoned mine, SS = stream Source, SW = Surface water, GW = Ground Water, N/A Not available

Table 2: Concentration of Heavy Metals in Post-monsoon (October - December) season

	Sample ID	Se (mg/L)	As (mg/L)	Mn (mg/L)	Ag (mg/L)	Cu(mg/L)	Hg (mg/L)	Pb (mg/L)	Zn (mg/L)	Co (mg/L)	Ni (mg/L)	Cd (mg/L)	Cr (mg/L)
1	ADD/1SS	0.00	0.40	0.11	1.71	0.03	0.00	0.00	0.00	0.00	0.00	0.08	0.10
2	ADD/2AM	0.00	0.39	0.03	1.47	0.04	0.00	0.00	0.00	0.00	0.00	0.06	0.02
3	ADD/3AC	0.00	0.80	61.90	0.10	0.12	1.01	3.98	10.08	0.56	0.00	12.70	0.20
4	ADD/4SS	0.00	0.22	0.23	0.01	0.22	0.51	0.00	0.02	0.10	0.02	0.15	0.01
5	ADD/5AC	0.00	0.39	0.12	0.00	0.03	0.00	0.00	0.00	0.00	0.02	0.14	0.18
6	ADD/6AC	0.00	0.00	0.99	0.02	0.01	0.00	0.30	0.00	0.05	0.00	0.06	0.07
7	ADD/7AM	0.00	0.44	6.67	0.00	0.00	0.00	0.00	0.18	0.00	0.00	0.05	0.00
8	ADD/8SS	0.00	0.23	31.91	0.00	0.01	0.00	0.00	0.01	0.03	0.02	0.04	0.06
9	ADD/9AM	0.00	0.17	0.97	0.00	0.03	0.00	0.00	0.00	0.11	0.03	0.09	0.00
10	ADD/10SS	0.00	0.00	0.08	0.00	0.03	0.00	0.00	0.00	0.07	0.03	0.04	0.00
11	ADD/11SS	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
12	ADD/12SS	0.00	0.00	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00
13	ADD/13SS	0.00	0.00	0.77	0.12	0.30	0.00	0.21	0.00	0.02	0.00	0.03	0.01
14	ADD/14SS	0.00	0.22	0.14	0.11	0.11	0.00	0.01	0.00	0.00	0.01	0.00	0.00
15	ADD/15SS	0.00	0.20	2.13	2.48	0.06	0.01	0.00	0.01	0.02	0.03	0.61	0.90
16	ADD/16SS	0.00	0.00	1.40	0.11	0.01	0.12	0.02	0.00	0.00	0.06	0.66	0.70
17	ADD/17SS	0.00	0.12	0.12	0.92	0.01	0.00	0.00	0.00	0.00	0.18	0.00	0.00
18	ADD/18SS	0.00	0.34	0.33	0.71	0.02	0.10	0.12	0.01	0.01	0.00	0.10	0.00
19	ADD/19SS	0.00	0.12	4.20	0.00	0.07	0.25	0.03	0.01	0.01	0.17	0.50	0.18
20	ADD/20	0.00	0.47	2.10	2.01	0.13	0.01	0.04	0.05	0.00	0.06	0.13	0.38
21	ADD/21	0.00	0.51	2.08	1.78	0.04	0.40	0.00	1.42	0.04	0.00	0.17	0.12
22	ADD/22	0.00	0.00	1.22	1.33	0.05	0.10	0.00	0.00	0.00	0.01	0.11	0.13
23	ADD/23	0.00	0.56	0.40	1.33	0.04	0.10	0.00	0.00	0.00	0.07	0.09	0.04
24	ADD/24	0.00	0.55	2.59	0.60	0.02	0.00	0.00	0.00	2.10	0.02	3.00	0.13
25	ADD/25	0.00	0.36	0.40	0.90	0.06	0.00	4.01	0.00	0.00	0.01	0.09	0.12
26	ADD/26	0.00	0.90	0.07	0.56	0.08	0.10	0.00	0.20	0.00	0.00	0.10	0.03
27	ADD/27	0.01	0.15	0.30	0.31	0.13	0.00	0.00	0.00	0.00	0.17	0.08	0.00
28	ADD/28	0.00	0.33	0.73	0.19	0.03	0.00	0.29	0.00	0.00	0.05	0.06	0.00
29	ADD/29	0.00	0.45	0.43	0.13	0.01	0.00	0.00	0.00	0.00	0.00	0.03	0.00
30	ADD/30	0.00	0.30	2.40	0.05	0.00	0.00	0.00	0.00	0.10	0.00	0.01	0.00
31	ADD/31	0.00	0.28	0.79	0.00	0.07	0.00	0.00	0.80	0.11	0.19	0.99	0.29
32	ADD/32	0.00	0.63	0.68	0.00	0.02	0.00	0.00	0.38	0.00	0.02	0.21	0.12
33	ADD/33	0.00	0.56	2.64	0.00	0.01	0.00	0.00	0.33	0.10	0.03	0.03	0.04
34	ADD/34	0.00	0.44	0.21	0.00	0.00	0.00	0.00	0.69	0.00	0.03	0.00	0.37
35	ADD/35	0.00	0.45	0.17	0.00	0.00	0.00	0.20	0.66	0.00	0.02	0.00	0.08
36	ADD/36	0.00	0.00	1.50	0.00	0.00	0,001	0.01	0.00	0.01	0.02	0.00	0.02
37	ADD/37	0.00	0.32	0.96	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.00	0.00

38	ADD/38	0.00	0.11	3.07	0.00	0.03	0.00	0.02	0.05	0.04	0.05	0.00	0.11
39	ADD/39	0.00	0.24	0.14	0.00	0.07	0.10	0.00	0.01	0.00	0.02	0.06	0.02
40	ADD/40	0.00	0.66	0.89	0.00	0.12	0.00	0.20	0.22	0.00	0.07	0.01	0.04
41	ADD/41AB	0.98	2.64	2.07	0.00	0.00	0.10	2.70	0.47	0.00	0.00	0.60	0.01
42	ADD/42SS	0.79	2.69	0.06	0.00	0.00	0.22	0.90	0.23	0.00	0.00	0.35	0.97
43	ADD/43SS	0.41	0.89	10.67	0.00	0.00	0.32	1.28	9.77	0.01	0.20	2.17	0.00
44	ADD/44SS	0.68	1.79	0.00	0.00	0.00	0.34	0.80	0.00	0.15	0.10	0.36	0.04
45	ADD/45SS	2.68	2.01	0.12	0.00	0.00	0.24	1.30	0.11	0.06	0.22	0.28	0.00
46	ADD/46SS	1.10	2.87	13.76	0.00	0.06	0.34	2.14	0.47	0.08	0.00	0.26	0.00
47	ADD/47	0.46	1.76	0.59	0.00	0.00	0.39	1.97	0.20	0.50	0.04	0.27	0.00
48	ADD/48	0.83	0.88	0.00	2.07	0.00	0.71	38.00	0.00	0.00	13.06	0.00	10.10
49	ADD/49SS	1.21	0.98	0.05	0.30	0.12	1.60	3.60	0.01	0.00	0.12	0.02	0.00
50	ADD/50SS	0.00	0.00	0.08	0.00	0.03	0.00	0.00	0.00	0.07	0.03	0.04	0.00
51	ADD/51SS	0.00	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
52	ADD/52SS	0.00	0.00	0.15	0.00	0.00	0.00	11.92	0.00	0.00	0.02	0.01	0.00
53	ADD/53SS	0.00	0.00	0.77	0.12	0.30	0.00	0.21	0.00	0.02	0.00	16.3	0.01
54	ADD/54SS	0.00	0.22	0.14	0.11	0.11	0.00	0.01	0.00	0.00	0.01	0.00	0.00
55	ADD/55SS	0.00	0.20	2.13	2.48	0.06	0.01	0.00	0.01	0.02	0.03	0.61	0.90
56	ADD/56SS	0.00	0.00	1.40	0.11	0.01	0.12	0.02	0.00	0.00	0.06	0.66	0.70
57	ADD/57SS	0.00	0.12	0.12	0.92	0.01	0.00	0.00	0.00	0.00	0.18	0.00	0.00
58	ADD/58SS	0.00	0.34	0.33	0.71	0.02	0.10	0.12	0.01	0.01	0.00	0.10	0.00
59	ADD/59SS	0.00	0.12	4.20	0.00	0.07	0.25	0.03	0.01	0.01	0.17	0.50	0.18
60	ADD/60AM	0.00	0.47	2.10	2.01	0.13	0.01	0.04	0.05	0.00	0.06	0.13	0.38
Detection limit		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WHO limit		0.04	0.01	0.40	0.10	2.00	0.01	0.01	N/A	N/A	0.07	0.00	0.05

AC = Active mine, AM = Abandoned mine, SS = stream Source, SW = Surface water, GW = Ground Water, N/A = Not available

Table 3: Summary of the results with percentage above limits of the analyzed samples.

Parameter	WHO Limits	Pre-Monsoon season								Post- Monsoon season							
		Surface Water				Ground Water				Surface Water				Ground Water			
		Min. value	Max. Value	Ave. value	% Above limit	Min. value	Max. Value	Ave. value	% Above limit	Min. value	Max. Value	Ave. value	% Above limit	Min. value	Max. Value	Ave. value	% Above limit
pH	6-8.5	2.05	9.87	5.41	47.98	3.12	7.40	6.26	21.10	4.77	11.07	6.77	50.00	3.82	10.64	6.44	45.00
Pb (mg/L)	0.01	0.00	11.42	1.79	77.98	0.00	4.30	2.15	91.40	0.00	3.98	2.25	40.00	0.00	0.80	0.18	37.00
Cu (mg/L)	2.00	0.00	0.447	0.02	0.00	0.00	1.98	0.13	0.00	0.00	0.37	0.07	0.00	0.00	0.31	0.04	0.00
Cr (mg/L)	0.05	0.00	1.74	0.35	17.60	0.00	10.10	0.43	8.45	0.00	0.92	0.14	50.00	0.00	0.37	0.81	41.00
Ni (mg/L)	0.07	0.00	0.76	0.05	21.60	0.00	1.26	0.07	21.10	0.00	0.17	0.04	10.00	0.00	0.18	0.03	18.00
Mn (mg/L)	0.40	0.00	45.13	6.14	57.40	0.00	12.10	1.37	33.60	0.045	63.62	5.83	50.00	0.00	3.04	1.07	68.00
Cd (mg/L)	0.00	0.00	16.08	1.09	61.56	0.00	0.50	0.24	83.50	0.00	12.71	0.74	78.00	0.00	0.89	0.12	74.00
Ag (mg/L)	0.10	0.00	6.71	0.43	57.43	0.00	2.07	0.13	21.10	0.00	2.51	0.47	50.00	0.00	2.02	0.41	53.00
Co (mg/L)	NA	0.00	0.87	0.73	-	0.00	0.50	0.11	-	0.00	0.67	0.03	-	0.00	0.15	0.04	-
Hg (mg/L)	0.01	0.00	2.56	0.58	74.80	0.00	2.19	0.50	95.60	0.00	1.00	0.11	32.00	0.00	0.41	0.01	24.00
As (mg/L)	0.01	0.00	4.09	0.98	65.98	0.00	3.97	2.10	87.80	0.00	0.79	0.21	63.00	0.00	0.91	0.41	63.00
Se (mg/L)	0.04	0.00	2.29	0.29	42.50	0.00	2.66	0.97	79.21	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.00

Zn (mg/L)	NA	0.00	11.07	1.49	-	0.00	1.69	0.12	-	0.00	10.12	0.60	-	0.00	2.19	0.20	-

Table 4: Average data of the Concentrations of Heavy Metals.

Heavy Metals	Se (mg/L)	As (mg/L)	Mn (mg/L)	Ag (mg/L)	Cu (mg/L)	Hg (mg/L)	Pb (mg/L)	Zn (mg/L)	Co (mg/L)	Ni (mg/L)	Cd (mg/L)	Cr (mg/L)
Pre-Monsoon	0.4567	1.2299	4.5790	0.2988	0.0246	0.4710	1.5979	1.1090	0.0769	0.0213	0.6432	0.2579
Post-Monsoon	0.2198	0.6198	4.0210	0.3499	4.6319	0.2710	1.4988	0.4977	0.0467	0.0300	0.7045	0.2134

t Test result, t calculated -0.4235 and t tabulated = 2.202 at 0.05 and degree of freedom = 11

Table 5: Levenes' test for variance of homogeneity

	Mean	Variance	Standard deviations	Observations	df	T test	F	significance
Var1	0.932547	18.50766	1.690876	12	14	-0.4235	0.704	0.076
Var2	1.120905	26.21877	2.110987	12	14			

DISCUSSION

pH

The pH of water samples of March to May (dry) periods in the area ranges from 2.05 to 9.87, while samples of October to December (rainy) periods ranged from 3.82 to 10.64. March to May periods samples show that the surface waters are more acidic than groundwater. The pH of samples from mine sites, especially the active mines, ranged from 2.05 to 4.77. This indicates that the water is highly acidic, especially in areas where active mining is ongoing. This study also showed that the pH of water samples in the Adudu areas is more acidic. Generally, the pH of water resources in the mining areas is not in line with the WHO guideline for drinking water, especially in rivers and streams closer to the mines where mine wastes have been reportedly discharged into. This acidity in the active mining areas can be attributed to the active chemical activities taking place in the area. This high acidity was observed in March to May periods samples, it is very worrisome because this is the time when the villagers suffer a shortage of water, and are left with no option than the use of acidic water for their domestic purposes. This can be due to the discharge of mine waters from active mines into adjoining streams and river channels in these areas.

Lead

The occurrence and concentrations of lead in drinking water are generally below 5 mg/L, although much higher concentrations (above 100 mg/L) have been measured where lead fittings are present (Howard and Bartram, 2003). Due to the decreasing use of lead-containing additives in petrol, concentrations in air are declining, and intake from drinking water constitutes a greater proportion of total intake of lead (Howard and Bartram 2003). Occupational exposure to inorganic lead occurs in mines and smelters as well as welding of lead painted metal, and in battery plants. Low or moderate exposure may take place in the glass industry. High levels of air emissions may pollute areas near lead mines and smelters. From the analysis, lead concentrations of March to May periods water samples ranges between 0 and 11.4 mg/L, while October to December periods sample ranges from 0 to 4.01 mg/L. This shows very high pollution (about 85%) of lead for the water samples especially in the areas where active mining is ongoing. This result clearly indicates that the gangues and mine wastes of the lead ores (galena) significantly affect the quality of water sources of the area. Apart from the composition of these waste and gangues in the area, the low pH, the salinity and presence of CO_2 in the water sources cause faster dissolution of lead in water (ATSDR 2007). Lead is very mobile in water especially, at low pH. (WHO 2011) proposed a health guideline value of 0.05 mg/L and in 1993 reviewed it to 0.01 mg/L. 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. (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 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 ($CuFeS_2$), chalcocite (Cu_2S), covellite (CuS), cuprite (Cu_2O) and malachite ($CuCO_3 . Cu(OH)_2$) (ATSDR 2007). Staining of laundry and sanitary wares occurs at copper concentrations above 1 mg/L. Gallagher (2001) stated that at levels above 2.5 mg/L copper imparts an unfavorable bitter taste to water; at higher levels, the color of the water is also impacted. The WHO (2011) guidelines derived a provisional health-based guideline value of 2 mg/L for copper. From the analysis, copper values of March to May and October to December periods samples ranged from 0 to 0.447 mg/L. Significant values were recorded at the active mines and surface water sources. The result indicates that the concentration of copper (100%) in the study area is below the WHO (2011) guideline for drinking water. Brikké (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 that reduces the surface area for reactivity.

Copper is essential for good health. However, exposure to higher doses can be harmful. Long-term exposure to copper dust can irritate your nose, mouth and eyes, and cause headaches, dizziness, nausea and diarrhea. If you drink water that contains higher than normal levels of copper, you may experience nausea, vomiting, stomach cramps or diarrhea. High intakes of copper can affect liver and kidney which can lead to death.

Chromium
Chromium is widely distributed in the Earth's crust. It can exist in valences of + 2 to + 6. In general, food appears to be the major source of intake (Jardine *et al.,* 1999). Chromium is highly carcinogenic; therefore, minimal intake has been advocated (WHO 2011). The analysis shows that concentrations of chromium in March to May periods samples ranges between 0 and 1.74 mg/L, while October to December periods range from 0 to 0.92 mg/L. About 80% of the samples show no content for chromium, while the mines and the surrounding rivers around them show values above the WHO guideline of 0.05 mg/L as against 1.74 mg/L. The area is composed of high grade igneous and baked shales; these might be the sources of chromium in the area.

Exposure of extremely high doses of chromium (VI) compounds to humans can result in severe cardiovascular, respiratory, hematological, gastrointestinal, renal, hepatic and neurological effects and possibly death (Engwa *et al.,*2018).

Nickel
Nickel is noted in special cases of release from natural or industrial nickel deposits in the ground. It occurs naturally in water, with concentrations normally less than 0.02 mg/L (WHO, 2011). The analysis shows concentrations of water samples in March to May periods samples ranging from 0 to 0.76 mg/L, while post monsoon periods samples range from 0 to 0.17 mg/L. But water samples within the mining areas are above the (WHO, 2011) guideline value of 0.07 mg/L. This reflects high concentration for nickel. Sources of nickel in mining areas may include effluent water generated from mining.

Nickel has an extensive range of carcinogenic mechanisms which include regulation of transcription factors, controlled expression of certain genes and generation of free radicals. Nickel has been shown to be implicated in regulating the expression of specific long non-coding ribonucleic acids (RNA). It has also been demonstrated that nickel can generate free radicals, which contributes to carcinogenic processes (Engwa *et al.,*2018).

Manganese
Manganese is one of the most abundant metals in the Earth's crust, usually occurring with iron, oxygen, sulfur 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 with industrial pollution particularly in anaerobic or low oxidation conditions are also reported (WHO, 2011). The analysis shows that the concentration of manganese for March to May periods samples ranges from 0 mg/L to 45.13 mg/L, while October to December periods samples ranges from 0.045 to 63.62 mg/L. This result shows that water sources (especially mine pond water and groundwater) have higher values above the (WHO, 2011) guideline value of 0.4 mg/L. This high concentration is attributed to the dissolution of manganese from the chalcopyrite and siderite ores which might be found there.

Cadmium
Cadmium occurs naturally in the environment. Additional releases of cadmium to the environment occur from natural sources and from processes such as the combustion of fossil fuel, incineration of municipal or industrial wastes, or land application of sewage sludge or fertilizer (EPA, 1985). WHO (2008) reveals that smoking is a significant additional source of cadmium exposure in humans. Occurrence levels in drinking water are usually less than 1 mg/L Elinder (1985). From the analysis, cadmium concentration in dry periods samples ranges 0 mg/ to 16.08 mg/L, while rainy periods samples ranges from 0 to 12.71 mg/L. These high levels 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 (acidic).

Silver
Concentration of silver in March to May periods water samples ranged between 0 and 6.71 mg/L, while October to December periods samples ranged from 0 to 2.466 mg/L. Over 50% of samples showed concentrations above the (WHO 2008) guideline of 0.1 mg/L. This high concentration can be attributed to the decomposition of wastes from the dumps. Also, since silver in soils is largely immobilized by precipitation to insoluble salts and by complexation or adsorption by organic matter, the concentration can be localized and silver may be leached into groundwater from the soils. The leaching rate increases with low pH and increases drainage (ATSDR, 1990), Smith and Carson (1977). This can be seen as over 60% of water samples recorded very low pH in the area.

Mercury
From the results, the concentration of mercury in March to May periods samples ranged from 0 to 2.56 mg/L, while post-monsoon periods samples ranged from 0 to 1.00 mg/L. This indicates high level of contamination of mercury in the water sources of which translates to over 60% of the samples are above the WHO (2011) guideline of 0.006 mg/L for drinking water. It was reported that Human activities such as mining and burning of fossil fuels from the beginning of the industrial age, have contributed to the additional release of mercury to the environment Dikinya and Areola (2010). This heavy metal associated with soils can be directly washed into surface waters during rain events. Furthermore, Meili (2013) reported that surface runoff is an important mechanism for transporting mercury from the soil into surface waters, particularly for soils with high humic content. This is pertinent in the area since the soil is rich in humus.

Arsenic
Arsenic contaminations have occurred as a result of both natural geologic processes and the activities of man. Anthropogenic

sources of arsenic include human activities such as mining and processing of ores. The result of the analysis shows the concentration of 0 mg/L to 4.09 mg/L for March to May periods samples, while October to December periods samples ranged from 0 to 0.79 mg/L, with groundwater recording higher concentrations. This result indicates that about 86% of the samples have values above the WHO (2011) guideline of 0.01 mg/L for drinking water. This is high potential health risk to the rural communities. 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/L. However, in waters, particularly ground waters, where there are sulfide mineral deposits and sedimentary deposits deriving from volcanic rocks, the concentrations can be significantly elevated up to 12 mg/L WHO (2011). Arsenic is found in the diet, particularly in fish and shellfish, in which it is found mainly in the less toxic organic form as reported by Garvey *et al.,* (2013). Soluble forms move with the water and may be carried long distances through rivers EPA (1979).

It was reported that, low levels of arsenic exposure can cause nausea and vomiting, reduced production of erythrocytes and leukocytes, abnormal heart beat, pricking sensation in hands and legs, and damage to blood vessels. Long-term exposure can lead to the formation of skin lesions, internal cancers, neurological problems, pulmonary disease, peripheral vascular disease, hypertension and cardiovascular disease and diabetes mellitus (Smith *et al.,* 2000).

Selenium

The result of the analysis shows that the concentration of selenium for March to May periods samples ranges from 0 to 2.29 mg/L, while in October to December periods, samples ranged from 0 to 0.01 mg/L. This indicates a high degree of contamination as about 60% of the samples (especially groundwater) are above the WHO (2011) drinking-water standard of 0.04 mg/L. Selenium is also commonly found in rocks and soils, often in association with sulfur-containing minerals, or with silver, copper, lead and nickel minerals ATSDR (2003). Apart from its dissolution from the sulfur—rich ores and migration from decomposed wastes.

Selenium can cause muscle tenderness, tremors, lightheadedness, facial flushing, blood clotting problems, liver and kidney problems, and other side effects. High doses of selenium can cause significant side effects including nausea, vomiting, nail changes, loss of energy, and irritability.

Zinc

Result**s** of the analysis for the March to May periods water samples ranged from 0.00 to 11.07 mg/L, while October to December periods samples ranged from 0 to 10.12 mg/L. Although WHO (2011) does not state a permissible limit for zinc, **a** concentration between 3 and 5 mg/L is good for healthy living ATSDR (2007). Zinc is abundant in the earth's crust and it is a chalcophile metallic element and forms several minerals, including sphalerite (ZnS), the commonest Zn mineral, smithsonite ($ZnCO_3$), and zincite (ZnO), but is also widely dispersed as a trace element in pyroxene, amphibole, mica, garnet and magnetite Andrews and Sutherland (2004).

Zinc has been shown to exert adverse reproductive biochemical, physiological and behavioral effect**s** on a variety of aquatic organisms as concentrations exceed 20 mg/kg. Toxicity is, however, influenced by many factors such as the temperature, hardness, and pH of the water WHO (2011).

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 shows low concentrations of cobalt in the water samples analyzed. Pre-monsoon period samples ranged from 0 to 0.87 mg/L, while October to December periods ranged from 0 to 0.67 mg/L. Although no permissible limit has been established for cobalt WHO (2011), cobalt is highly radioactive ATSDR (2004), and high concentration can pose serious health risk**s**.

Student's *t* test and Levene's test

The calculated value of *t* (calculated 0.4235) is less than the critical (or tabulated) value of *t* at *df* 11, i.e., 0.4235 < 2.202; hence, the Ho is accepted. There is therefore a significant difference between the means concentration of chemical constituents of the element in the March to May and October to December periods (see Table 4).

Levels of heavy metals and potential health effects

Human activities like mining, to a large extent, upset the natural cycle of heavy metals and help increase their content in the various media to toxic levels. According to FDA (1987), IOM (2002), EPA (2003), the effects of heavy metals on humans depend on ingested dosage and may cause impairment to human health.

The main threats to human health from heavy metals are associated with exposure to lead, cadmium, mercury and arsenic, (Lars, 2003). Some of the heavy metals have no significant physical or biological action except for the toxic effects in relation to inhibiting the actions of certain enzymes Long *et al.,* (1995). If they become excess, they become toxic and can lead to damage to the internal organs, reduce energy levels, mental and central nervous dysfunction, plants and aquatic lives are not left out (Ayandiran and Dahunsi ,2016). The effects of long term exposure may result in slowly progressing physical, muscular and neurological degenerative processes (Gerhat and Blomquist 1992).

Conclusion

From this research, the levels of heavy metals in water resources and the potential health risk have been studied in the mining areas of the Adudu community of Nasarawa State. Sixty (60) water samples were collected and analyzed using Atomic Absorption Spectrophotometric and ultraviolet/visible spectroscopic methods. SPSS Statistical software was used to plot the distribution of the metals in the area to show potentially high-risk areas. Result shows the levels Pb >Hg > As > Cd > Mn > Ag > Se > Ni > Cr > Cu in the area. Acidic to slightly basic waters exist within the mining areas, while the abandoned mines showed considerably lower concentrations than the active mines. Water sources around active mines are polluted and hence considered unfit for many domestic and agricultural uses, especially for drinking and feeding of live stocks. This is because bio-accumulation can occur in the food chain. Lead, cadmium, mercury, and arsenic are highly carcinogenic and can cause serious public health problems. Nickel, manganese, and cobalt cause cells damages and affect carcinogenic processes. Heavy metal toxicity could be acute, while others could be chronic after long-term exposure which may lead to the damage of several organs in the body such as the brain, lungs, liver and kidney causing diseases in the body. Alternative sources of water supply including sitting of boreholes (after accurate geochemical surveys) for potable water for the community dwellers should be facilitated. Meanwhile, sensitization and awareness of the health risk of the consumption of mine tailings affected water sources should be carried out.

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