ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Heavy Metal Pollution: The Environmental Impact of Artisanal Gold Mining on Bagega Village of Zamfara State, Nigeria.

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ABSTRACT

Following the recent incident of lead poisoning in Zamfara State of Nigeria, interest in the levels of heavy metals in environmental samples from the affected areas has increased. In this regard, we collected and analysed water and soil/sediment samples of Bagega artisanal gold mining region using flame Atomic Absorption Spectrometry (AAS) to assess the levels of heavy metals. Samples were obtained from different water sources (wells, boreholes and surface pond) and soil/sediment of Bagega where environmental contamination was expected to be high due to artisanal gold mining activities. Samples were also collected in Anka, a non-artisanal gold mining environment, for comparison. It was observed that the water samples of the study area were contaminated with Pb and Ni, but Hg contamination was only observed in the water samples of Bagega. Surprisingly, higher contamination levels of Pb and Ni were recorded in reference water samples (Anka) compared to the water samples of Bagega. Very high contamination of all soil/sediment samples by Pb was also observed in the study area. High Hg contamination level was only recorded in the soil samples at the sedimentation zone (Bagega ore-processing site). In general, the water and soil/sediment samples of Bagega vicinity were far more contaminated compared to samples from Anka. This might not be unconnected with the anthropogenic activities, i.e. artisanal gold mining, on-going in Bagega.

Keywords: artisanal gold mining, pollution, sedimentation zone, milling zone, heavy metals.

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ISSN: 0975-8585

INTRODUCTION

Environmental implication of toxic heavy metals does not only elicit concern in cosmopolitan and metropolitan cities but also in remote and rural communities where anthropogenic activities, such as mining, are taking place. Gold mining and processing have been the main sources of heavy metal contamination in the environment [1-4]. During the processing of the ores for gold, poisonous substances such as oxides and sulphides of heavy metal pollutants are released into the environment [3].

Several scientific literatures have reported a series of environmental and biological problems associated with artisanal mining. For example, Heavy metal contaminations and poisoning due to artisanal gold mining activities are widely reported in Ghana, Ecuador, Tanzania (Geita Gold mine) and Brazilian Amazon [5-8]. In addition, studies of small-scale gold mining sites in the Migori gold belt (Kenya) have demonstrated lead, mercury, and arsenic pollution due to gold processing [9, 10]. High levels of mercury pollution were also found on gold mining and processing sites of Philippines [5]. Recently, there have been several reports on acute lead (Pb) poisoning outbreak among the dwellers of some remote villages of Zamfara State, Nigeria. This has been linked to the illegal mining operations by the people of remote communities who mostly live on less than half a dollar per day [11].

Investigation of heavy metals (in both soil and water) is very essential since slight changes in their concentrations above the acceptable levels, whether due to natural or anthropogenic factors, can result in serious environmental and subsequent health problems [12]. Therefore, the impact of heavy metals contamination on the environment should be of great concern. Since there is little or no investigation on the heavy metals pollution in the environmental samples (e.g. water and soil samples) of the study area (Bagega), it became imperative to assess the level of heavy metals contamination in both water and soil samples of the study area. This work would go a long way in making available data that can be used in remediation policy for environmental contamination caused by Pb and some other heavy metals. In this work the concentration level of selected heavy metals in both water and soil/sediment samples of Bagega (artisanal gold mining vicinity) would be quantitatively determined and results obtained would be compared to values obtained for Anka, a non-artisanal gold mining area in order to ascertain the extent of contamination resulting from artisanal gold mining.

MATERIALS AND METHODS

All experiments were performed with analytical grade chemicals (Sigma-Aldrich) and deionised water was used throughout the entire analysis. Measurements were made using Varian model-AA240FS Atomic Absorption Spectrophotometer (AAS) equipped with a hollow cathode lamp each for respective heavy metals analysed.

Study area

Bagega is a remote village in Zamfara State, Nigeria. It is one of the regions where active artisanal gold mining is on-going. It is a regional hub for ore processing and centre for informal gold trade. Geographically, it lies on the coordinates of 11^{o} 51' 47" N, 6^{o} 0' 15" E. Anka was chosen as a reference site because there was no record of artisanal gold mining in the locality. It lies on the geographical coordinates of latitude 12^{o} 6' 35" N and longitude 5^{o} 55' 46" E.

Collection and preservation of water samples

Water samples were obtained on 21^{ist} of April 2013. Ten (10) ground water samples each were collected randomly from different Boreholes and domestic wells (i.e. 5 well waters and 5 borehole waters) of Bagega village and Anka (reference site). Also Five (5) surface water samples were collected at different points of Bagega dam (previously used for ore processing before the outbreak of Pb poisoning). This was the only surface water available in the study area during the period of sampling. Therefore, there was no reference for surface water. Collection of all water samples was done according to APHA standard method of water sampling [13]. Pre-cleaned 2 litre polyethylene sampling bottles were used for sampling. At each sampling point, the bottles were rinsed 3 times with the water before collection of the sample. The samples were preserved by acidifying with 2cm^{3} of concentrated HNO_3 in order to achieve a pH of 2. All the samples were returned to the laboratory and the analysis was carried out immediately.

Collection of soil/ sediments samples

A total of seventy two (69) soil / sediment samples were collected on 20th April 2013 from five (5) sampling sites (Reference site "Anka" inclusive) as shown in Table 1.

Each soil/sediment sample collected was transferred into labelled double clean polythene bags. All the samples were transported to the laboratory where on arrival, analytical procedure commenced in earnest.

Pre-treatment of water samples

Water samples were digested according to APHA procedure [13]. Briefly, 1000cm^3 of well mixed, acid preserved sample was transferred into a beaker. Exactly, 50cm^3 of conc. HNO_3 was added and heated to boiling. This was then evaporated on a hot plate to 20cm^3. Heating and addition of concentrated HNO_3 continued until digestion was completed as indicated by a light colour, clear solution. The content was then transferred to 100cm^3 plastic bottles, cooled and diluted to mark. Portions of this solution were used for heavy metals determination.

Pre-treatment of soil samples

The digestion of soil samples were carried out following published methodology [14]. Exactly 5 g of dried and sieved soil/sediment sample was taken in a beaker. 10 cm^3 of nitric/perchloric acid (2:1) was added to the sample. This sample was then digested at 105°C. This was followed by the addition of HCl and distilled water (1:1) to the digested sample and the mixture was transferred to the digester again for 30 min. The digestate was then removed from the digester and allowed to cool to room temperature. The content was filtered using Whiteman filter paper No. 1, then transferred into 100 cm^3 plastic bottles and diluted to mark. Portions of this solution were used for heavy metals determination.

Quantitative determination of heavy metals

Flame Atomic absorption spectrophotometer (Varian model-AA240FS) equipped with a hollow cathode lamp (each for respective heavy metal), was used for quantitative determination of heavy metals in the samples (water and soil/sediment).

Assessment heavy metal pollution

Contamination factor (CF) for each heavy metal was calculated using the ratio of concentration of the metal in sample to the background concentration of the metal [3]**.** In this study, the WHO [15] guidelines values for drinking water quality were selected as background level for the calculation of contamination factors of the water samples. For soil/sediment samples, however, the world shale value [16, 17] was used as baseline or background metal levels. The contamination factor may be classified based on their intensities on a scale ranging from <1 to >6. This is given as Cf< 1, 1<Cf<3, 3< Cf <6, and Cf >6 for low, moderate, considerable and very high contamination factor respectively [18]. Degree of contamination (C_d) of overall heavy metals in water samples was calculated as reported by Ata *et al*. [18], and pollution load index (PLI) was calculated as reported by Bhupander *et al*. [17]. According to Ong *et al* [19] PLI value > 1 indicates pollution whereas PLI value < 1 indicates no pollution.

RESULTS AND DISCUSSION

Heavy metal contents of water samples

The concentrations of heavy metals in water samples of the study area (both Bagega and Anka) are shown in Fig. 1 and Fig. 2. The concentration of Zn, Cd, Cu and Fe in all the water samples analysed in the study area were found to be below the WHO [15] maximum permissible limits of 5.0 ppm, 0.03 ppm, 1.0 ppm and 1.0 ppm for Zn, Cd, Cu and Fe respectively. However, the concentrations of Pb and Ni in the water samples were above the 0.01 ppm and 0.02 ppm maximum permissible limits for Pb and Ni respectively. Mercury (Hg) was only found in the water samples of Bagega village. The concentration of Hg in these samples was above WHO [15] 0.001 ppm maximum permissible limits. Hg was not detected in water samples of Anka (reference site).

Heavy metal contents in soil/sediment samples

The level of heavy metals in all the soil/sediment samples of the study area is shown in Fig.3-7. It was observed that the concentration of heavy metals was highest at the top soil, but did not show a regular trend on moving down the depth of the soil profile. The concentrations of some heavy metal (Zn, Cd, Ni and Fe) for all soil/sediments sample analysed in the study area were below the background world shale value [16]. But the concentration of Pb and Cu observed in all the soil/sediment samples were above the background world shale value. Hg was only detected in the soil sample of sedimentation zone (Bagega ore-processing site) and its values were above the background world shale value.

Assessment of heavy metal pollution in water and soil/sediment samples

The calculated heavy metals contamination factors (C.F) and their contamination degrees (C_d) of water samples are shown in Table 2. It was revealed that all water samples analysed had very high contamination (C.F > 6) for Pb and Ni. Also the water samples of Bagega revealed a far higher contamination (C.F >> 6) for Hg. In the present investigation, the ground water samples of Anka (non-artisanal mining area) were more contaminated with Ni, Cd and Fe compared to the groundwater samples of Bagega (artisanal gold mining area). Further analysis (contamination degree) revealed that the surface water sample (Bagega Dam) recorded the highest value of overall heavy metals contribution. Also the ground water of Bagega recorded a very high value of heavy metal contribution as compared to very low contamination degree of heavy metal in ground water samples of Anka (Reference site). This might be due to high contamination with Hg coupled with the proximity of Bagega water samples to active artisanal gold mining activities in the study area.

Heavy metals contamination factors (C.F) of soil/sediment samples and their pollution load indices (PLI) are shown in Table 3. Generally, there was a low contamination with Zn, Cd, Ni, Cu, and Fe in all the soil/sediment samples. There was a very high contamination (CF>>6) of Pb in all soil/sediment samples. The highest contamination with Pb was observed at sedimentation zone (Bagega ore-processing site), while the soil samples of reference site (Anka) recorded the least contamination with Pb. Also high contamination (CF>6) was recorded for Hg in the soil samples of sedimentation zone (Bagega ore-processing site). This might be due to the use of this metal by artisanal miners during ore-processing of gold at the processing site. The abnormal high contamination level of Pb was expected in Bagega vicinity due to the report that the gold bearing deposits in this region (Zamfara State) usually contained extremely high levels of Pb [11]. PLI value calculated for all the analysed heavy metals was less than 1. This indicates that there was no serious overall load of heavy metal contamination in the entire soil sampling site, even though lead (Pb) showed severe contamination in all the study areas including the reference site “Anka”. However, the PLI value of soil samples of Bagega were higher compared to PLI value obtained for soil samples of Anka (reference site). This was attributed to the artisanal gold mining activities taking place in Bagega.

Table 1: Schedule for soil/sediments sampling

S/N	Sampling Site	Soil/sediment Source	Number of samples
1	Sedimentation zone (ore processing site, Bagega)	0-5cm 10-15cm 20-30cm	5 5 5
2	Milling zone (ore processing site, Bagega)	0-5cm 10-15cm 20-30cm	5 5 5
3	Dam (Bagega)	Sediment(centre) Bank sediment 1 Bank sediment 2	3 3 3
4	Bagega village	0-5cm 10-15cm 20-30cm	5 5 5
5	Anka (Ref)	0-5cm 10-15cm 20-30cm	5 5 5

ISSN: 0975-8585

Table 2: Heavy metals contamination factors (C.F) and Contamination degrees (C_d) of water samples

Location/ Site	Source	Contamination factor (CF)							C_d
		Zn	Pb	Cd	Ni	Cu	Hg	Fe	
Bagega	Well	0.048	7.4*	0.40	10.8*	0.079	1640**	0.9	237.1
	Borehole	0.031	7.6*	0.43	10.2*	0.121	888**	0.78	129.6
	Surface water	0.054	73.5*	0.40	10.9*	0.212	3301**	32.7*	488.4
Anka (Ref. site)	Well	0.025	17.0*	0.72	19.8*	0.203	---	1.11	6.48
	Borehole	0.029	17.2*	0.73	17.4*	0.183	---	1.53	6.18

* = very high contamination (C.F > 6), ** (C.F >>6)

Table 3: Heavy metals contamination factors (C.F) and pollution load indices (PLI)

Location/ Site	Contamination factor (CF)							PLI
	Zn	Pb	Cd	Ni	Cu	Hg	Fe	
S. zone								
0-5cm	0.019	140.1*	0.51	0.010	4.38	42.8*	0.030	0.692
10-15cm	0.016	61.15*	0.18	0.014	1.59	1.40	0.019	0.270
20-30cm	0.009	50.62*	0.10	0.015	1.02	---	0.018	0.152
Average	0.014	83.95*	0.26	0.013	2.33	14.7*	0.022	0 .436
M. zone								
0-5cm	0.010	91.09*	0.197	0.0093	2.74	---	0.017	0.206
10-15cm	0.017	57.72*	0.070	0.0097	1.12	---	0.012	0.144
20-30cm	0.005	40.67*	0.070	0.0097	1.14	---	0.012	0.110
Average	0.011	63.16*	0.110	0.0096	1.66	---	0.014	0.160
Bagega								
0-5cm	0.068	15.09*	0.183	0.022	0.77	---	0.029	0.212
10-15cm	0.074	15.52*	0.070	0.026	0.92	---	0.038	0.204
20-30cm	0.062	15.18*	0.060	0.026	0.97	---	0.028	0.184
Average	0.068	15.26*	0.103	0.025	0.89	---	0.032	0.205
Bagega Dam								
Bank sed. 1	0.017	14.44*	0.057	0.026	1.21	---	0.039	0.160
Bank sed. 2	0.030	17.23*	0.050	0.043	1.30	---	0.055	0.207
Centre sed.	0.030	23.86*	0.063	0.037	1.43	---	0.055	0.225
Average	0.025	18.51*	0.057	0.035	1.31	---	0.050	0.197
Anka (Ref.)								
0-5cm	0.049	9.62*	0.080	0.014	1.44	---	0.020	0.157
10-15cm	0.038	9.49*	0.087	0.016	1.47	---	0.017	0.152
20-30cm	0.031	8.90*	0.090	0.015	1.54	---	0.014	0.141
Average	0.039	9.34*	0.087	0.015	1.48	---	0.017	0.151

* = very high contamination (C.F > 6)

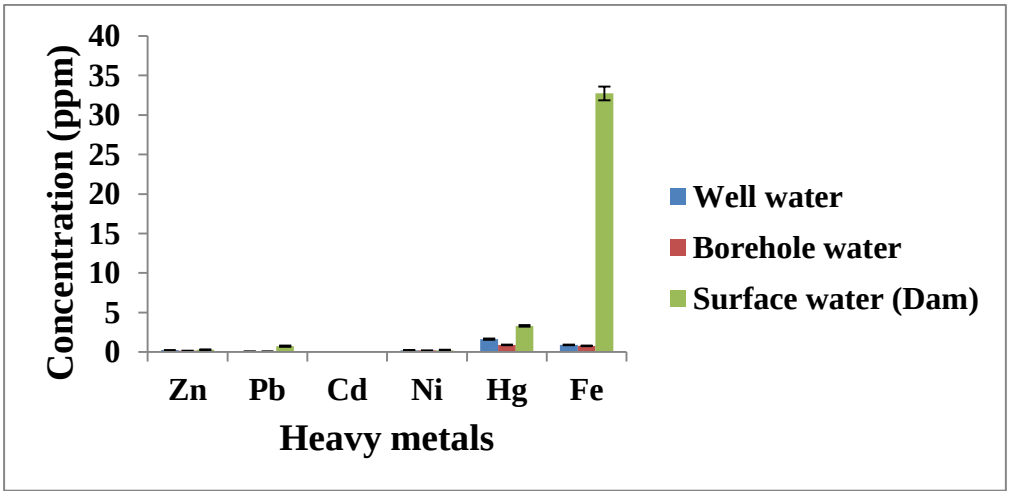

Fig. 1: Concentration of heavy metals in water samples of Bagega village in Zamfara State, Nigeria. Each bar represents mean ± standard deviation of five (5) different samples.

ISSN: 0975-8585

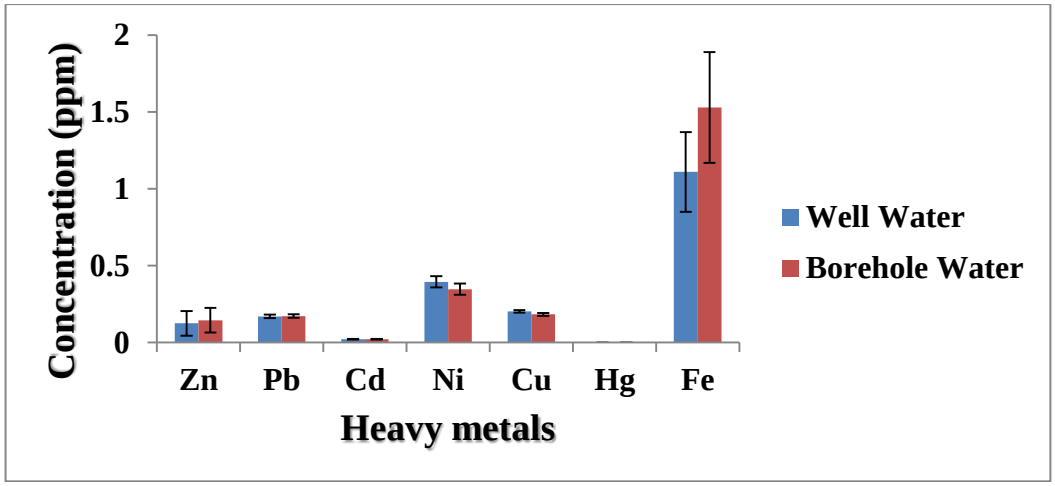

Fig. 2: Concentration of heavy metals in water samples of Anka (reference site) village of Zamfara State, Nigeria. Each bar represents mean ± standard deviation of five (5) different samples.

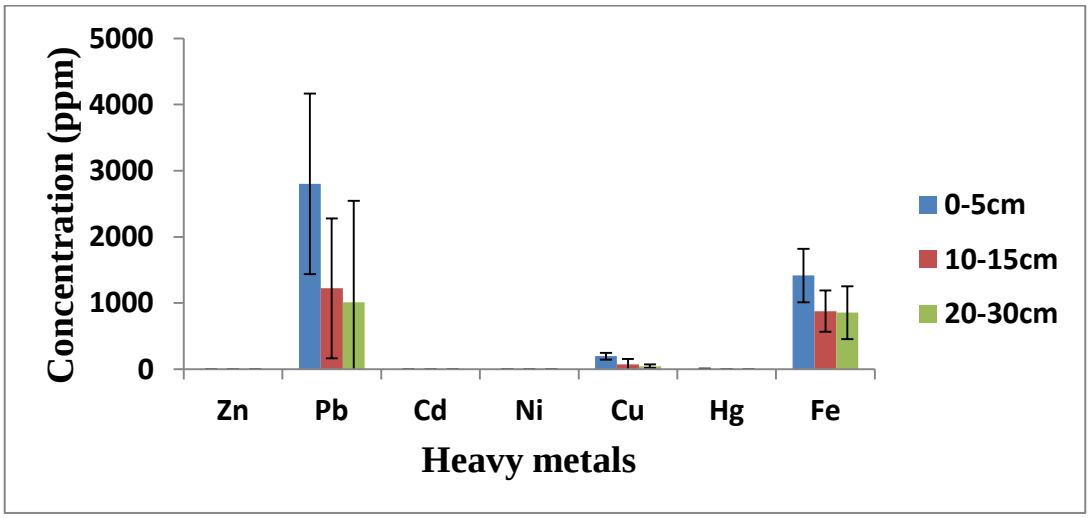

Fig. 3: Concentration of heavy metals in soil samples of sedimentation zone (Bagega ore- processing site), Zamfara State, Nigeria. Each bar represents mean ± standard deviation of five (5) different samples

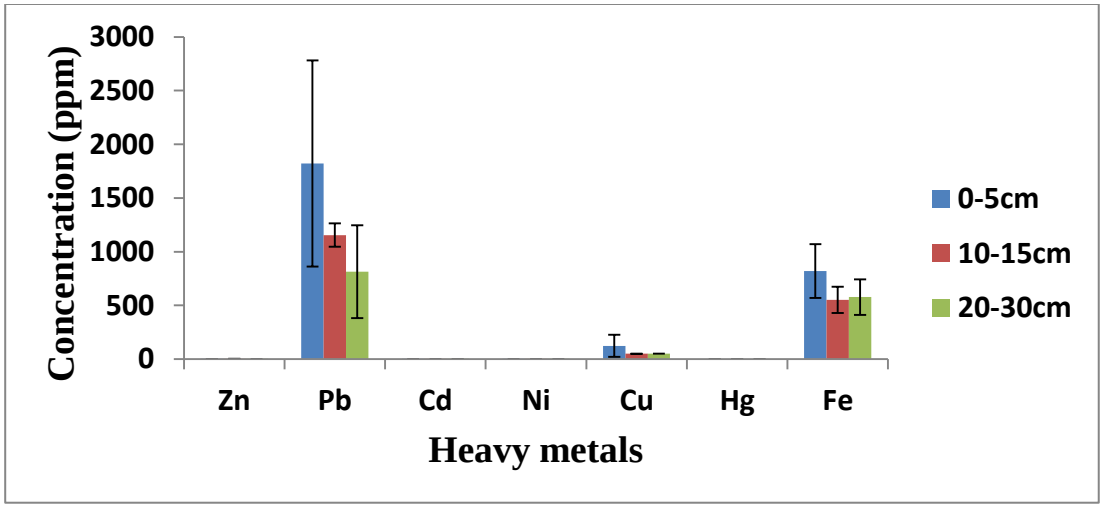

Fig. 4: concentration of heavy metals in Soil samples of milling zone (Bagega ore-processing site), Zamfara State, Nigeria. Each bar represents mean ± standard deviation of five (5) different samples.

ISSN: 0975-8585

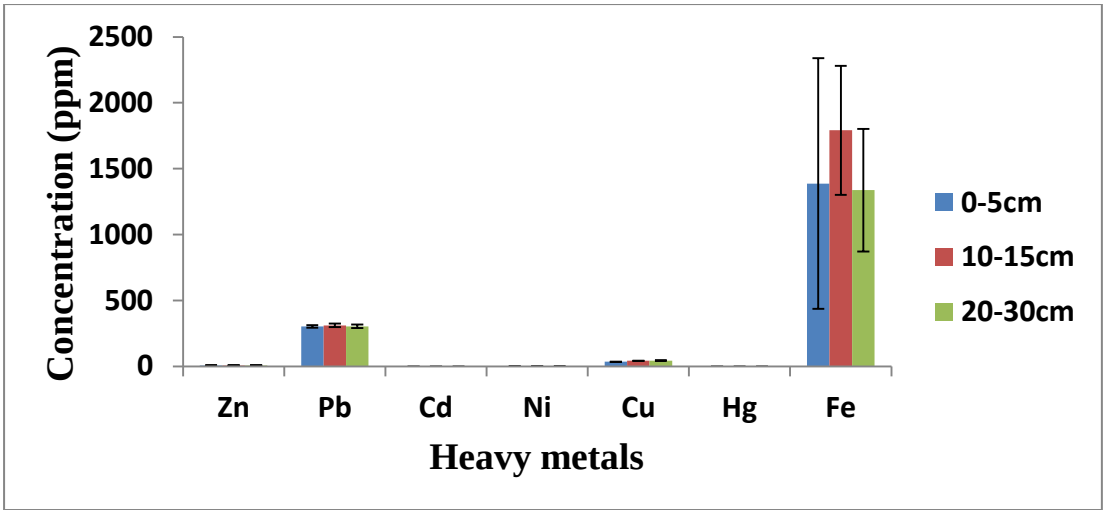

Fig. 5: Concentration of heavy metals in Soil samples of Bagega village, Zamfara State, Nigeria. Each bar represents mean ± standard deviation of five (5) different samples.

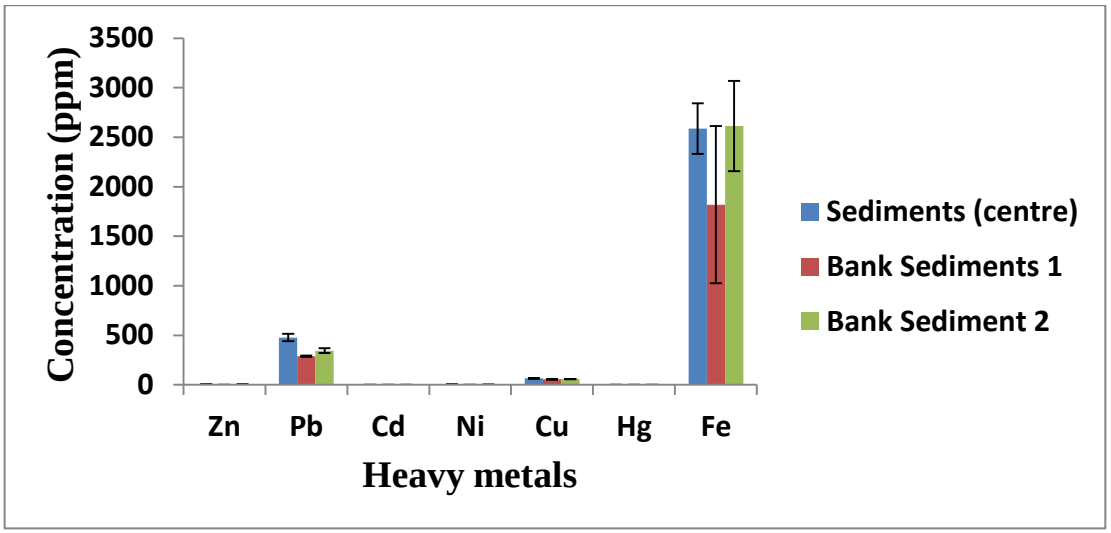

Fig.6: Concentration of heavy metals in Soil samples of sediment samples (Bagega dam), Zamfara State, Nigeria. Each bar represents mean ± standard deviation of three (3) different samples.

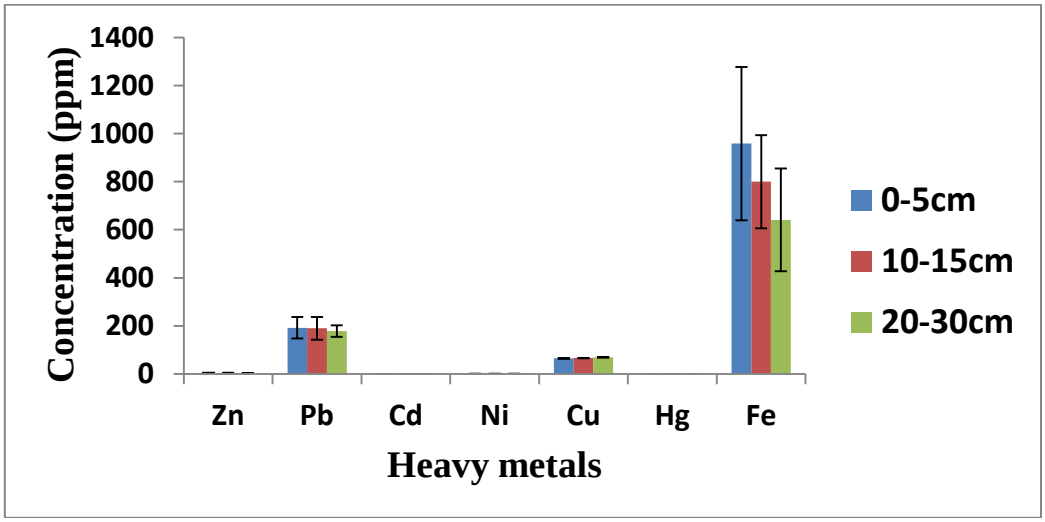

Fig. 7: Concentration of heavy metals in Soil samples of Anka (reference site) village, Anka local Govt. area of Zamfara State, Nigeria. Each bar represents mean ± standard deviation of five (5) different samples.

CONCLUSIONS

In this investigation, it was evident that the water samples of both Bagega and Anka (reference site) were contaminated with Pb and Ni. It was even surprising that a higher contamination level of Pb and Ni were recorded in water samples of Anka (non-artisanal gold mining area) compared to the water samples of Bagega (artisanal gold mining area). Therefore, the presence of these metals (Pb and Ni) in water samples might be due to natural deposits in the soil of studied area, which eventually leached into the water system used by the inhabitants. Very high Hg contamination level was only recorded for water samples of Bagega. However, there was a very high contamination of Pb in all soil/sediment of the study area. High Hg contamination level was only recorded in the soil samples of sedimentation zone (Bagega ore-processing site). In general, the analyses carried out revealed that the water and soil/sediment samples of Bagega vicinity were far more contaminated compared to values obtained for Anka (non-artisanal mining area). This might be due to the contribution of anthropogenic activities, i.e. artisanal gold mining, to the pollution load of Bagega.

ACKNOWLEDGMENT

Mr. M.H. Majiya is grateful to Ahmadu Bello University, Zaria for giving him the opportunity to study for his M.Sc. degree.

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