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Levels of zinc, copper, iron and manganese in soils of abandoned mine pits around the Tarkwa gold mining area of Ghana

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ABSTRACT

Abandoned mine pits have been a health threat to the inhabitants of many mining communities in Ghana. In this paper, the concentrations of copper (Cu), zinc (Zn), iron (Fe) and manganese (Mn) in sand and clay soil samples from seven of such abandoned open mine pits in the Tarkwa gold mining district of Ghana, were examined. The mean Cu concentrations in the sand soil samples ranged from 6.5±0.50 µg/g to 56.17±1.61 µg/g. Abandoned mine pits 5, 6 and 7 recorded mean Cu concentrations slightly higher than the background concentrations. However the mean Cu concentrations in the clay soil samples were all less than the background levels. The mean Zn concentrations in the sand soil samples were between 4.17±1.23 µg/g and 43.17±4.75 µg/g. Similar pattern of this metal was registered in the clay soil samples. The mean Fe levels in the sand soil samples ranged between 8133±292 µg/g and 119166±135 µg/g. sampling site 5, 6 and 7 recorded mean Fe concentrations higher than the background levels. These elevated Fe concentrations in the sand soil samples may be due to the mining activities which took place in these pits. The mean Mn concentrations in the sand soil samples ranged between 26.67±1.44 µg/g and 1595±157.16 µg/g. These high levels may also be attributed to the mining activities in the area. The results of the quantification of the metal contamination of the soil samples using contamination factors and pollution load index (PLI) indicated that some of the studied pits are significantly polluted with Cu, Fe and Mn.

Keywords: Pollution, Pollution Load Index, One-Way ANOVA, Anthropogenic activities, Bioremediation.

INTRODUCTION

Ghana is an important gold-producing country with mining operations since the late 19^{th} century [1, 2]. Ghana produces about one third of the world's yearly gold production [2, 3]. About 40 %

of gross foreign exchange earnings of the country come from the mining sector. It has been reported by Aryee [4] that the mining sector in Ghana generates about 5.7% of gross domestic product (GDP).

In recent times, a lot of attention has been drawn to the mining industry and its adverse impacts on the environment. In spite of the socio-economic benefits of gold mining to the local communities and the country as a whole, a considerable stress has been put on the environment and basic life support systems, thus posing potential threat to the health of the people [5]. In Ghana, some studies have been conducted on metals pollution in some mining towns or areas [5, 6, 7, 8]. Most of these studies have indicated that some potentially toxic metals are high in environmental samples collected from these mining areas. Serfor-Armah et al. [7] reported high levels of arsenic and antimony in some streams of Prestea, a gold mining town in the western part of Ghana. According to a research conducted by Kumi-Boateng [2], soil and sediment samples from Obuasi (a major gold mining town in Ghana) contained high arsenic concentrations. Nyarko et al. [5] reported high levels of some heavy metals in the atmosphere of Obuasi and its surrounding villages.

Mining activities have been found to cause considerable changes to the environment, particularly the soil [9]. One of such effects is the making of minute potentially toxic metals to become abundant in agricultural and non-agricultural lands. Mining operations such as milling, concentrating ores and tailings disposal provide sources of metal contamination in the environment [10, 11]. When mine wastes become incorporated into the soil, their metals contents may be absorbed by plants and subsequently into the food chain in significantly quantities [9, 12].

Heavy metals (such as Zn and Fe) are classified among the most dangerous groups of environmental pollutants due to their toxicity and persistence in the environment [7, 13, 14]. Researches carried out by some environmental scientists have revealed that the occurrence and geographical distribution of certain diseases could be correlated with the presence of toxic elements in the geologic environment [11]. In view of that, it is critical to continually assess and monitor the levels of metals species in soils due to mining activities, for the evaluation of human exposure and for sustainable environment.

The rationale behind the selection of Tarkwa for this study is that, it has historically been known to be a gold mining town, and mining of gold by large and small scale miners (including illegal *galamsey* operators) is currently on the increase. However, knowledge of the levels of copper, zinc, iron and manganese concentrations in soils on which these mining activities occur and surrounding areas is fairly limited. Data on the background levels of metals in soils at gold mining communities are important for policy makers and the general public. Consequently, this paper assesses the levels of Cu, Zn, Fe and Mn in soils (sand and clay) from seven abundant mine pits in Tarkwa.

MATERIALS AND METHODS

Sample collection and preparation

Sand and clay soil samples were collected from seven abandoned mine pits in the Tarkwa gold mining area of the Western Region of Ghana during November 2009–January 2010. Samples were collected once every month from all designated seven sampling sites. The soil samples collected at a depth of about 10-20cm using hand trowel [21]. The soil samples were kept in a polyethylene bags which had been rinsed with 1M HCl and transported into the laboratory.

The samples were disaggregated, dried in an oven for 3 hours. The samples were sieved using <40 mesh, homogenized and packed in polyethylene bags and stored in the laboratory until analysis. Three replicate sub-samples were prepared for each sample. The samples were then digested using the procedure described by Essumang et al. [15].

One gram of soil was each weighed into 100mL beakers. About 20mL of concentrated HNO_3 were added, thoroughly mixed, and set on a hot plate in a fume chamber. The mixture was heated for 30 minutes, cooled and filtered through Whatman No.1 filter paper, and stored for analysis. A blank sample was also prepared for the analysis. The **ICP** atomic absorption spectrophotometer was used for the analysis of all the studied metals. The analytical method was validated using the standard STD BM 160. The precision was calculated as a percentage relative standard deviation (%RSD) of six replicate samples of the prepared standard, and was found to be less than 5%.

Quantification of soil pollution

The amount of metal contamination in the examined sand and clay soil samples was quantified using pollution load index (PLI). A brief description of the applied index is given below:

The contamination factor (CF) is the ratio obtained by dividing the concentration of each studied metal in the soil samples by the baseline or background value (concentration in unpolluted soil):

$$CF = \frac{\text{Concentration of metal in sample}}{\text{Concentration of metal in background}}$$

The contamination levels of the metals may be classified based on their intensities on a scale ranging from 1 to 6 (0= none, 1= none to medium, 2= moderate, 3= moderately to strong, 4= strongly polluted, 5=strong to very strong, 6=very strong) [16, 17]. The CF value of 6 indicates that the metal concentration is 100 times greater than what would be expected in the world average shale as reported by Turakian and Wedepohl [18].

According to Tomlinson et al. 1980, pollution load index (PLI) is an empirical index which provides a simple, comparative means for assessing the level of metal pollution. Pollution load index was therefore used to find out the mutual pollution effect of the studied metals on each of the monitored mine pits. The PLI values were calculated as the nth root of the product of the n CF [19, 20, 21]:

$$PLI = \sqrt[n]{CF\ (Cu) X CF (Zn) X CF\ (Fe) X CF\ (Mn)}$$

Statistical analysis

The pollution Load Indices (PLIs) were computed using Microsoft Excel 2007. The mean elemental concentrations, standard deviations and charts were executed for the soil data using

SPSS version 16 software. One Way analysis of variance (ANOVA) was used to compare the mean concentrations of metals in sand and clay soils at a significant level of 0.05.

RESULTS AND DISCUSSION

Metal levels in soil samples

The results of the determination of the Cu, Zn, Fe and Mn concentration in the sand and clay soils are presented on Table 1. The variation of the studied metals in the sampled soils is also depicted by figures 1-4.

The mean Cu concentrations in the sand soil samples ranged from 6.5±0.50 µg/g to 56.17±1.61 µg/g. Abandoned mine pits 5, 6 and 7 recorded mean Cu concentrations slightly higher than the world average shale value (45 µg/g) as reported by Turekian and Wedepohl [18]. The results from this study agreed with the range of Cu levels in soil samples studied by Boamponsem [22] in the study area. However the mean Cu concentrations in the clay soil samples were all less than the world average values. This might be due to the depths of the soil profile from which the samples were taken.

The mean Zn concentrations in the sand soil samples were between 4.17±1.23 µg/g and 43.17±4.75 µg/g. Similar pattern of this metal was registered in the clay soil samples. These levels are lower than the world average value of 95 µg/g. The mean Fe levels in the sand soil samples ranged between 8133±292 µg/g and 119166±135 µg/g. Sampling site 5, 6 and 7 recorded mean Fe concentrations higher than the world average shale values. These elevated Fe concentrations in the sand soil samples may be due to the mining activities which took place in these pits. Mean Fe concentrations in the clay soil samples were very high and above the world average values. This may be due to the higher retention capacity of the clay soil texture.

The mean Mn concentrations in the sand soil samples ranged between 26.67±1.44 µg/g and 1595±157.16 µg/g. These values were higher than the levels recorded in the clay soil samples and that reported by Boamponsem [22]. This may also be attributed to the mining activities in the area.

Table 1. Mean (±Standard deviation) metals concentration (µg/g)

Sample	Metal	PIT 1	PIT 2	PIT 3	PIT 4	PIT 5	PIT 6	PIT 7
Sand	Cu	11.50±2.59	6.5±0.50	12.00±0.01	7.17±0.29	56.17±1.61	55.83±1.60	54.33±1.26
	Zn	17.17±15.69	9.67±3.75	4.17±1.23	8.33±3.62	41.00±2.65	37.00±1.32	43.17±4.75
	Fe	14500±1322.87	8133.33±292.97	11666.66±104.08	6633.33±104.10	112500±108.00	119166.7±135.33	99500±781.25
	Mn	61.67±3.33	26.67±1.44	1015±65.38	605.0±26.46	1773.3±150.02	1595±157.16	1203.53±101.0
Clay	Cu	21.83±1.44	19.17±1.52	21.17±3.55	21.00±0.50	9.33±0.57	9.34±0.51	9.17±0.76
	Zn	15.0±9.09	14.33±4.19	18.0±2.65	23.67±8.09	19.67±1.04	17.33±2.52	27.67±2.02
	Fe	106833.33±2254.62	81666.66±2081.66	312500±407032.24	67000±500	134833.3±3752.77	109833.3±8519.58	152000±7399.3
	Mn	41.16±4.19	36.16±3.21	147.3±11.25	130.5±7.37	59.33±4.91	56.67±1.15	58.0±1.32

In general, one-way ANOVA revealed that the concentrations of the four studied metals in the sand soil samples were not statistically significantly different from the concentrations recorded in the clay soil samples ($F=3.594$, $df=1$, P-value=0.06).

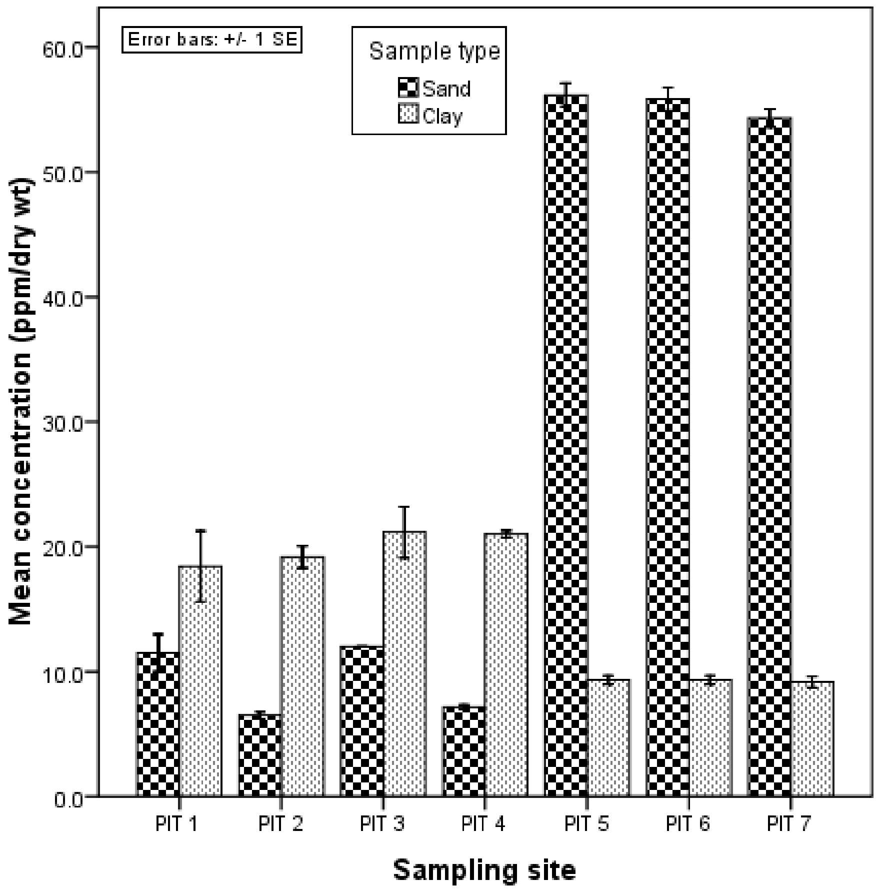

Figure 1. Comparison of Copper concentration in sand and clay soil samples

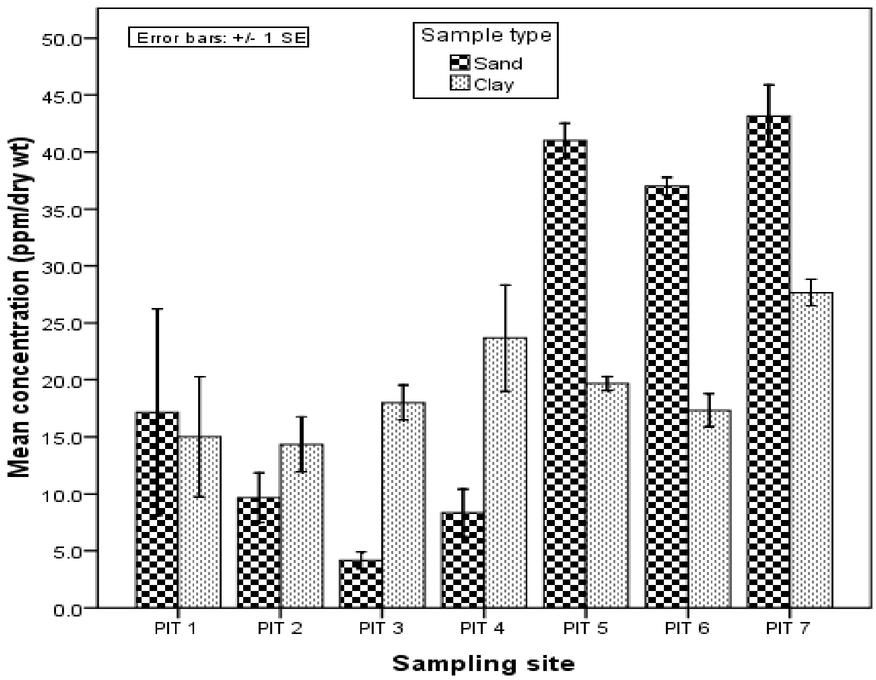

Figure 2. Comparison of zinc concentration in sand and clay soil samples

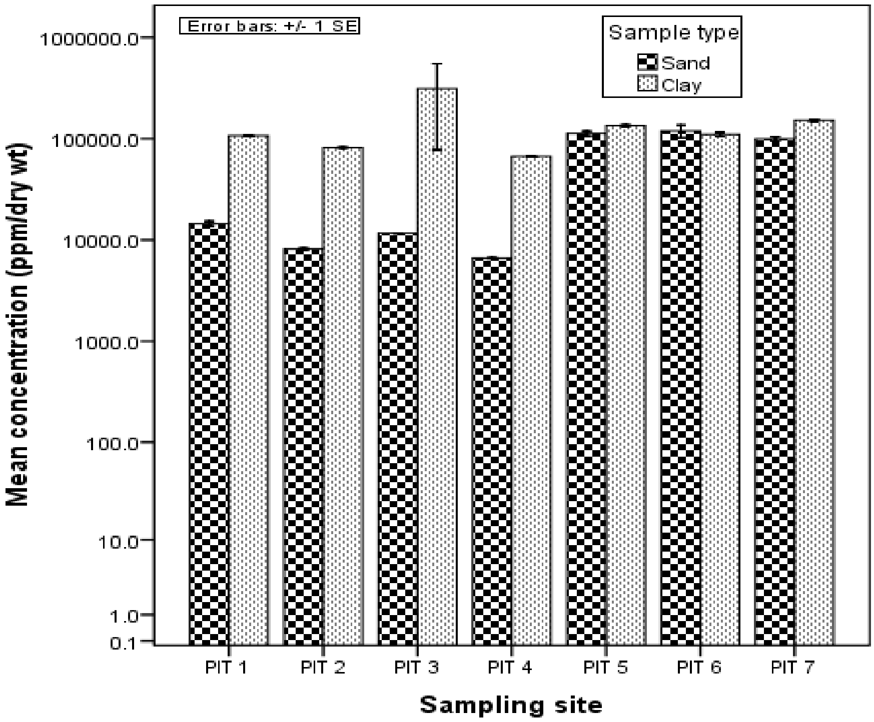

Figure 3. Comparison of iron concentration in sand and clay soil samples

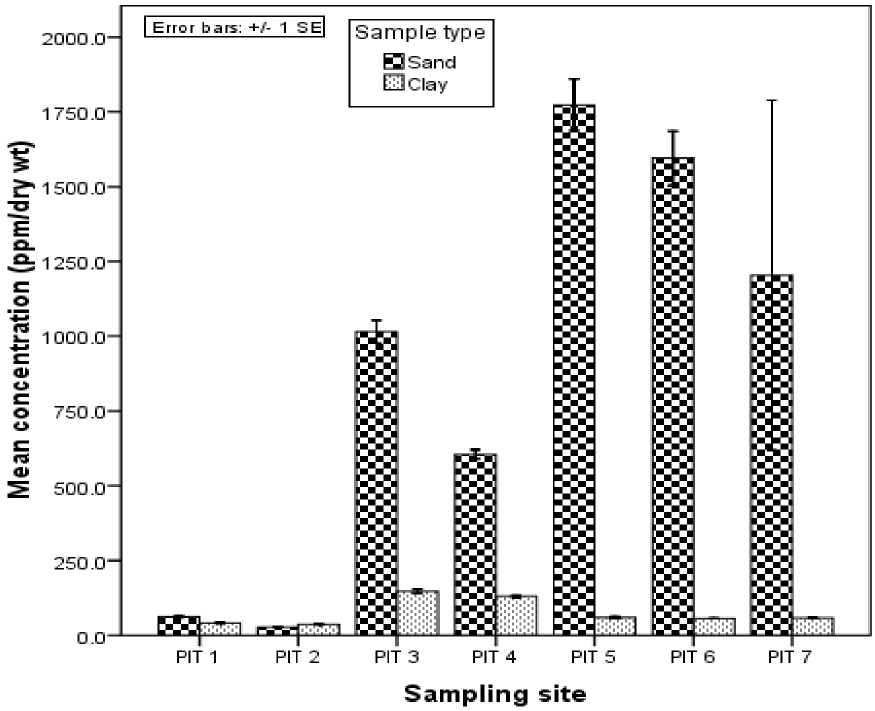

Figure 4. Comparison of manganese concentration in sand and clay soil samples

Pollution quantification

The results of the quantification of the metal contamination of the soil samples using contamination factors and pollution load indices are shown by Table 2. The pictorial impression of the trend in the mutual pollution effect of the studied metals on the sampled abandoned mine pits is presented by Figure 5. As revealed by Table 2, some of the sampling points (e.g. PITS 5, 6 and 7) had Cu, Fe and Mn contamination factors (CFs) above unity. This implies that these sites are polluted with Cu, Fe and Mn. The likely sources may be mainly anthropogenic activities such as the mining operations.

Table 2. Contamination factor (CF) and pollution load index (PLI) of sampling sites

Sample type	Samplig site	CF_{Cu}	CF_{Zn}	CF_{Fe}	CF_{Mn}	PLI
	PIT 1	0.256	0.382	0.307	0.073	0.216
	PIT 2	0.144	0.102	0.172	0.043	0.102
Sand	PIT 3	0.267	0.093	0.247	1.194	0.292
	PIT 4	0.159	0.088	0.141	0.712	0.193
	PIT 5	1.248	0.432	2.383	2.086	1.279
	PIT 6	1.241	0.389	2.525	1.876	1.230
	PIT 7	1.207	0.454	2.108	1.416	1.131
	PIT 1	0.485	0.158	2.263	0.048	0.303
	PIT 2	0.426	0.151	1.730	0.043	0.262
Clay	PIT 3	0.470	0.189	6.621	0.154	0.549
	PIT 4	0.467	0.249	1.419	0.154	0.399
	PIT 5	0.207	0.207	2.857	0.070	0.304
	PIT 6	0.208	0.182	2.327	0.067	0.277
	PIT 7	0.204	0.291	3.220	0.068	0.338

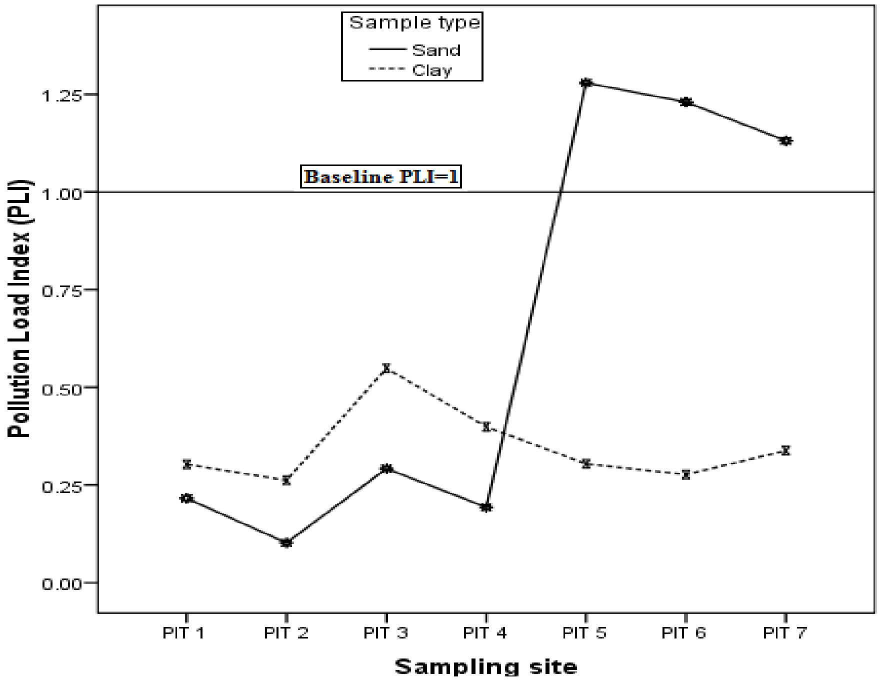

Figure 5. Variations of PLI in sand and clay soil samples across abandoned mine pits

CONCLUSION

This study have revealed that metal pollution from abandoned mine pits is a threat to the health of the inhabitants of the study area. It is therefore important for policy makers and opinion leaders to advocate for possible remedial actions which will safeguard the environment. A further study is recommended on the possibility of using bioremediation techniques such as bioleaching of these metals from abandoned mine pits and metallurgical wastes.

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