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## Assessment of the quality of revegetated soil near an active goldmine in southwestern Ghana

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### ABSTRACT

This study presents an assessment of soil quality of revegetated locations within the catchment of a goldmine, using the index of geo-accumulation, enrichment factor and multivariate statistics. Fourteen composite soil samples were analysed for the following parameters: Mn, Cd, Pb, Fe As, pH, organic C, organic matter, available K and P, total N, total exchangeable base, exchangeable acidity, effective cation exchange capacity and base saturation. The results indicate that all locations except one were practically uncontaminated with Fe. Three locations were practically uncontaminated with Mn, whereas all other locations were uncontaminated to moderately-contaminated. Principal component and cluster analyses indicate that most members form one cluster suggesting uniformity in the degree of impacts on the soils with regard to the parameters analyzed; and further signifying that the impacts possibly originate from a common source. 93% of the locations recorded low to very low levels of N (0.04-0.14mg/kg). 15% of the soils show medium levels of available P (8.45-9.81mg/kg) while the other locations (85%) show very low levels (0.01-1.59mg/kg), an indication that most of the soils are phosphorous deficient. The mean ECEC was 8.5meq/100g and ranged from 3.66meq/100g to 17.12meq/100g. 28% of locations recorded less than 5meq/100g CEC, which is the minimum level for adequate exchange capacity according to the Ghana Soil Fertility Capacity Classification. Though the heavy metal concentrations in the soil do not pose any significant risks to agronomic activities, the nutrient / fertility status is low to medium. There will therefore be the need to fertilize to correct the various nutrient deficiencies prior to the commencement of agronomic activities.

**Keywords:** heavy metal, geo-accumulation, enrichment factor, principal component, cluster analysis, nutrient status, reclaimed land

### 1. Introduction

Understanding the spatial variability of soil heavy metals is an important precondition for suitably monitoring and evaluating eco-environment quality in a primary mining production zone. Trace metal contamination of soil is a common problem encountered at many hazardous waste sites. Mining activities generate a large amount of waste rocks and tailing, which get deposited at the surface. In these conditions, chromium, cadmium, copper, nickel, arsenic, vanadium and lead are among the most frequently observed metal contaminants (Bueno et. al. 2009). Trace metals that contaminate soil ecosystems have negative impacts on trophic chains and subsequently human health (Cowen and Silver 1984). Processes of remediation still remain a challenge because of lack of comprehensive understanding on the behaviour of these metals in relation to certain biological activities in this type of system (Warren and Haak 2001). Metals can exist in various forms in soils, however, not all of them are equally toxic, mobile or bioavailable (Warren and Haak 2001). Metal associations may be dynamic and reversible, reflecting the variations in physical-chemical conditions in the water-

soil medium or interface (Fonseca et al 2009). Metal enrichment of sediment is best understood, if the various types of element associations in the samples are identified. Four types of association occur and these include adsorption by carbonates, co-precipitation by hydrous Fe and Mn oxides, complexation by organic molecules and incorporation into crystalline mineral lattices (Gibbs 1977). The behaviour of metals particularly in mining areas and their biogeochemical controls in aquatic environment show complex linkages to the biota. This is mainly bacterially driven along geochemical processes such metal cycling at the microscopic and macroscopic levels (Fonseca et. al. 2009). Monitoring the bioavailability, toxicity and risk relationships arising from trace element contaminants in ecosystems requires the determination of their concentrations in soil, water, microorganisms, plants and animals. It is however, essential to note that primarily, the effect of any substance on a living system is always dependent on the concentration of it available to cells. Accordingly, there are no substances that are always toxic. What we need to evaluate toxicity are dose–response data; i.e. quantitative dose–response relationships. Secondly, a number of metal ions are crucial to the metabolism of cells at low concentrations but are toxic at high concentrations, resulting in bell-shaped dose–response relationships (Marschner 1995).

Previous research works on heavy metal contamination in mining environments in Ghana have focused on water, sediment and biota (Armah et al. 2010a; Armah et al. 2010b). It appears that not much has been done on characterisation and quantification of heavy metal contaminants in revegetated soils in mining environments. Consequently, there are knowledge gaps regarding the variability of these metals in soils over space and time. In this study, we characterised and quantified heavy metal accumulation in revegetated soils within the catchment of a gold mine and examined the spatial variability of heavy metal deposition regarding this soil system that may be indicative of the mode of metal transport. This work will inform relevant agencies and stakeholders of the fundamental spatial distribution of soil physicochemical properties and heavy metals within this operational mining zone. The work can also serve as a preliminary land suitability analysis on agronomic use of the revegetated soils within the catchment of the mine.

## **2. Materials and Methods**

### **2.1 Sample Collection and Handling**

A total of at least 1–1.5 kg of soil was collected at each site. Each sample was deposited into a transparent 3.6-L plastic container with a sealed lid. A center point for each sampling location was identified using a handheld GPS unit. From the center point, five sub-samples were collected; one at the center point and one each at 50 m north, south, east, and west of the center point. Each sub-sample was collected about 0–20 cm in depth using a flat-bladed auger, and then combined at the center point and thoroughly mixed prior to storage. The soil samples were placed in the containers and kept intact at 5°C until they were prepared for analysis. A total of 14 composite soil samples were generated and transported for laboratory analysis. Concentrations of four heavy metals namely Mn, Cd, Pd, Fe and one metalloid (As) were determined by flame atomic absorption spectrometry (Shimadzu model 6401F, Japan) after preparation of appropriate calibration standards. All samples were digested and analyzed in replicate. In addition, other soil parameters including pH, organic C, organic matter, available K and P; total N, total exchangeable base (TEB), exchangeable acidity, effective cation exchange capacity (ECEC), and base saturation were also analysed.

## **2.2 Soil Analysis**

Prior to the test, a pre-treatment was made from each sample. At first, soil intrusions (such as plant residual root, insect cadavers, stone blocks, etc.) and new growth (such as ferromanganese nodules and lime nodules, etc.) were picked out from the samples, air-dried, and then sieved through 100 $\mu$ m mesh. The samples were digested using *aqua regia* (HCl/HNO<sub>3</sub>, 3:1 solution)-HClO<sub>4</sub>, and the concentrations of total As, Cd, Pd, Fe and Mn were measured by atomic absorption spectroscopy (Shimadzu model 6401F, Japan). Duplicates were made for all samples and results accepted when the coefficients of variation was within 5%. Two blanks were included in each batch of analyses for quality control of heavy metal measurements.

## **2.3 Data Analysis**

### **2.3.1 Descriptive statistics**

The descriptive statistics for soil quality data was performed with SPSS version 16.0 for windows (SPSS Inc., Chicago, IL, USA). The distribution of the data was tested for normality by Kolmogorov–Smirnov (K–S) test. The data was not severely skewed; consequently natural logarithmic transformations were not applied. Relationships between soil properties and metal concentrations were established by using correlation analysis. Principal component analysis (PCA) was employed to separate the element groupings inherent in the structure of the correlation matrix (Tao 1998) and to identify their common distribution patterns.

### **2.3.2 Enrichment factor calculation**

The value of the enrichment factor (EF) was calculated using the formula  $EF = C_n/B_n$ ; where  $C_n$  (sample) is the content of the examined element in the examined environment and  $B_n$  (background) is the content of the examined element in the environment (geochemical background value). In our calculation of EF,  $B_n$  is the background content taken from the literature. According to Sutherland (2000), five contamination categories are generally recognized on the basis of the enrichment factor:

$EF < 2$ , depletion to mineral enrichment;

$2 \leq EF < 5$ , moderate enrichment;

$5 \leq EF < 20$ , significant enrichment;

$20 \leq EF < 40$ , very high enrichment;

And  $EF > 40$ , extremely high enrichment

### **2.3.3 Index of geo-accumulation**

The geo-accumulation index (I<sub>geo</sub>) has been used for the past 40 years as an index of trace metal contamination in mining and non-mining areas worldwide. Originally used for bottom sediments (Muller 1969), it has been successfully applied to the measurement of soil contamination at different levels (Loska et. al. 2003). The geo-accumulation index consists of 7 grades or classes (Ji et. al. 2008) as shown in Table 1. Class 6 is an open class and comprises all values of the index higher than Class 5. The elemental concentrations in Class 6 may be hundredfold greater than the geochemical background value (Teng et al. 2002).

Mathematically,

$$I_{geo} = \ln \frac{C_n}{1.5B_n}$$

Where,  $C_n$  is the measured concentration of the element in soil,  $B_n$  is the geochemical background value. The constant, 1.5, allows us to analyze natural fluctuations in the content of a given substance in the environment and to detect very small anthropogenic influences. The factor 1.5 is introduced to include possible differences in the background values due to lithological variations (Ji et. al. 2008).

**Table 1:** Classes of geo-accumulation index

Class	Value	Sediment quality
0	$I_{geo} \leq 0$	Practically uncontaminated
1	$0 < I_{geo} < 1$	Uncontaminated to moderately contaminated
2	$1 < I_{geo} < 2$	Moderately contaminated
3	$2 < I_{geo} < 3$	Moderately to heavily contaminated
4	$3 < I_{geo} < 4$	Heavily contaminated
5	$4 < I_{geo} < 5$	Heavily to extremely contaminated
6	$5 < I_{geo}$	Extremely contaminated

### 3. Results and Discussion

Soils from different locations (sampling sites) near the gold mine differ much in texture, pH, and organic matter content (Table 2). Huamin et. al. (1999), Ashraf et. al. (2008) and Eze and Chukwu (2011) have shown that soils near mining-related industries are contaminated by heavy metals. The present study confirms the findings of these previous research works.

However, the concentrations of As, Pd and Cd do not appear to be potentially phytotoxic. Mn levels in this study are relatively higher than the results obtained by Ashraf et al. (2008). Levels of As are much lower in this study compared to the findings of Ashraf et al. (2008) whereas the levels of Fe in contrast, are much higher in the present study. The concentration of Zn in the present study contradicts the findings of Eze and Chukwu (2011). Unlike Eze and Chukwu (2011), low levels of As, Cd and Pd were obtained in the present study. The concentrations of Zn and Cd are comparable to the results of Jung (2008).

**Table 1:** Soil properties and heavy metal concentrations

(a) Soil properties

Location	E.C.E.C m.e 100g <sup>-1</sup>	% Base Sat.	Mechanical Analysis			Texture
			Sand	Silt	Clay	
SWWB	5.08	84.25	45.74	36.26	18	Loam
CB	4.39	72.67	39.64	28.36	32	Clay loam
ULB	6.03	80.1	31.66	18.34	50	Clay
SWPA	4.66	84.98	48.18	37.82	14	Loam
SEB	11.61	95.26	45.3	32.7	22	Loam
ULA	3.66	59.02	19.46	52.54	28	Silty Clay loam
CDB	10.15	93.6	46.02	35.98	18	Loam
CA	2.73	54.21	44.74	33.26	22	Loam
SEA	15.08	95.36	34.36	39.64	26	Silt loam
SWDB	11.08	92.78	32.74	43.26	24	Loam
SWWA	11.86	99.16	49.38	36.62	14	Loam
SWPB	5.5	81.82	42.98	39.02	18	Loam
SWDA	10.02	89.52	32.76	45.24	22	Loam
CDA	17.12	97.08	47.52	34.48	18	Loam

(b) Heavy metal concentrations

Location	Mg/kg Element / dry matter				
	Fe	Mn	As	Pd	Cd
SWWB	70.56	89.4	1.292	5.717	0.111
CB	26.64	12.6	0.008	1.635	0.045
ULB	80.28	79.8	0.767	2.543	0.093
SWPA	40.2	47.4	0.008	2.567	0.069
SEB	64.38	154.56	0.008	2.288	0.153
ULA	119.52	22.8	0.344	2.159	0.072
CDB	55.8	115.8	0.008	1.475	0.105
CA	13.32	6.6	0.008	0.932	0.039
SEA	64.14	197.4	0.041	2.06	0.129
SWDB	67.08	163.8	0.008	1.937	0.129
SWWA	155.52	64.2	5.201	10.049	0.231
SWPB	42.66	68.4	0.008	2.519	0.093
SWDA	97.56	228	0.008	2.894	0.111
CDA	49.44	115.2	0.008	1.406	0.129

Note: South West Dump B (SWWB); Central Dump Oil Palm B (CB); Bar Hill Side Down A (SWPA); South East B (SEB); Central Dump forest B (CDB); Central Dump Oil Palm A (CA); South East A (SEA); South Waste Dump B (SWDB); Bar Hill Side Down B (SWPB); South-West Dump A (SWWA) ; South Waste Dump A (SWDA); Central Dump forest A (CDA)

### 3.1 Descriptive statistics

The descriptive statistics of the soil properties and heavy metal concentrations are given in Tables 3 and 4 below.

**Table 3:** Descriptive statistics of heavy metal concentrations and soil properties

	<i>ECEC</i>	<i>Base Sat</i>	<i>Fe</i>	<i>Mn</i>	<i>As</i>	<i>Pd</i>	<i>Cd</i>
N	14	14	14	14	14	14	14
Mean	8.497	84.272	67.6500	97.568	.5512	2.8701	.1078
Median	8.020	87.250	64.2600	84.600	.0080	2.2235	.1080
Mode	2.73 <sup>a</sup>	54.21 <sup>a</sup>	13.32 <sup>a</sup>	6.60 <sup>a</sup>	.01	.93 <sup>a</sup>	.13
Std. Dev	4.518	1.394E	3.7190E	6.867E	1.3915	2.3486	.0484
Variance	20.41	193.55	1.383E3	4.708E3	1.937	5.516	.002
Skewness	.493	-1.175	1.000	.479	3.309	2.605	1.033
Kurtosis	-.877	.605	1.296	-.644	11.451	7.213	2.322
Range	14.39	44.95	142.20	221.40	5.19	9.12	.19
Minimum	2.73	54.21	13.32	6.60	.01	.93	.04
Maximum	17.12	99.16	155.52	228.00	5.20	10.05	.23

**Table 4:** Descriptive statistics of soil properties

	<i>pH</i>	<i>Organic Carbon</i>	<i>Organic Matter</i>	<i>Avail P</i>	<i>Avail K</i>	<i>Total N</i>	<i>TEB</i>	<i>Exc Acidity</i>
N	14	14	14	14	14	14	14	14
Mean	5.042	1.2457	2.1586	.1143	2.224	.1143	47.228	.8571
Median	5.200	1.1950	2.0600	.1150	1.160	.1150	46.870	.8000
Mode	4.20 <sup>a</sup>	1.09	1.88	.10 <sup>a</sup>	.01 <sup>a</sup>	.10 <sup>a</sup>	46.87	.70 <sup>a</sup>
Std. Deviation	.8121	.43650	.78579	.0438	3.057	.0438	1.2616E	.36735
Variance	.660	.191	.617	.002	9.350	.002	159.128	.135
Skewness	-.053	.830	1.034	1.104	1.983	1.104	1.685	-.197
Kurtosis	-.276	2.539	3.067	3.353	3.031	3.353	3.830	.063
Range	3.00	1.88	3.40	.19	9.80	.19	48.54	1.40
Minimum	3.60	.46	.80	.04	.01	.04	33.48	.10
Maximum	6.60	2.34	4.20	.23	9.81	.23	82.02	1.50

a. Multiple modes exist. The smallest value is shown

The skew measures how the observations are distributed about the mean. If the histogram is fairly symmetric, then the skew is 0 or close to 0. If there are a few or several large values to the right of the mean (greater than the mean) but not to the left of the mean, the skew is positive and the histogram is said to be *right skewed* or *positively skewed*. If there are a few or several small values to the left of the mean (less than the mean) but not to the right of the mean, the skew is negative and the histogram is said to be *left skewed* or *negatively skewed*.

Because environmental data usually involve measures of chemical concentrations, and concentrations cannot fall below 0, environmental data often tend to be positively skewed. As expected, all the soil data is positively skewed except the following parameters: pH, exchangeable acidity, and base saturation (Tables 3 and 4).

The kurtosis measures how peaked the histogram is relative to an idealized bell-shaped histogram. This idealized bell-shaped histogram is based on the normal (Gaussian) distribution, which has a kurtosis of 3. If the histogram has too many observations in the tails compared to the idealized histogram then the kurtosis is larger than 3 (as in the cases of organic matter, available P, available K, total N, total exchangeable base, and Pd). If the histogram has short tails and most of the observations are tightly clustered around the mean, then the kurtosis is less than 3 (as is the case for all other measured parameters).

The correlation between two random variables is unitless and always lies between -1 and 1. The correlation between a variable and itself is 1. Correlation is a measure of the *linear* association between two random variables. A small absolute value of correlation does not imply two random variables are unrelated; two random variables may be strongly related in a curvilinear way and have a low level of correlation. Correlation does not imply cause. In some instances, two variables are correlated because one variable directly affects the other. High absolute values of correlation suggest strong linear associations. From Table 6 strong linear associations exist between pH and TEB ( $r=0.612$ ,  $p=0.01$ ); exchangeable acidity ( $r=-0.995$ ,  $p=0.01$ ); ECEC; base saturation; and Cd ( $r=0.815$ ,  $p=0.01$ ). This trend is not unexpected as the concentration of hydrogen ions in the soil is known to influence these parameters. Likewise, organic C is strongly correlated with organic matter, total N and Fe (Table 6). Again, this trend is not unexpected as organic carbon is a function of organic matter. TEB is similarly strongly correlated with As and Pd while As is correlated with Pd and Cd.

### **3.2 Principal component analysis**

Principal component analysis is a multivariate technique for transforming a set of related (correlated) variables into a set of unrelated (uncorrelated) variables that account for decreasing proportions of the variation of the original observations. The rationale behind the method is an attempt to reduce the complexity of the data by decreasing the number of variables that need to be considered. If the first few of the derived variables (the principal components) among them account for a large proportion of the total variance of the observed variables, they can be used both to provide a convenient summary of the data and to simplify subsequent analyses. Tables 4 and 6 display the results of the principal component analysis of the soil dataset.

From Table 5, the first principal component (scaled eigenvector), by definition the one that explains the largest part of the total variance, has a variance (Eigen value) of approximately 6.308; this amounts to 42.0% of the total variance. The "Cumulative %" column of Table 5 tell us how much of the total variance can be accounted for by the first k components together. Consequently, to simplify matters, it can be assumed that a three-component solution is adequate in this case. From the component matrix (Table 7), the first component has a high positive correlation with each of the soil parameters except available K and exchangeable acidity; and is simply a weighted average of the heavy metal contamination rates and so provides a measure of the overall level of heavy metal pollution in the soils. The second component is the levels of nutrients in the soil.

**Table 5:** Total variance explained by the three components

Total Variance Explained						
Component	Initial Eigen values			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.308	42.052	42.052	6.308	42.052	42.052
2	4.668	31.119	73.172	4.668	31.119	73.172
3	2.524	16.829	90.000	2.524	16.829	90.000
4	.558	3.723	93.724			
5	.480	3.201	96.924			
6	.253	1.688	98.613			
7	.095	.634	99.246			
8	.050	.334	99.580			
9	.034	.225	99.806			
10	.020	.134	99.939			
11	.006	.038	99.977			
12	.003	.017	99.994			
13	.001	.006	100.000			
14	-1.3E-17	-8.66E-17	100.000			
15	-2.2E-16	-1.47E-15	100.000			

Extraction Method: Principal Component Analysis.



**Table 6:** Correlation matrix of soil properties and heavy metals

Correlations															
	pH	Organic Carbon	Organic Matter	Avail P	Avail K	Total N	TEB	Exc Acidity	ECEC	Base Sat	Fe	Mn	As	Pd	Cd
pH	1	-.088	-.110	-.101	-.326	-.101	.612*	-.995**	.701**	.868**	.248	.380	.488	.525	.815**
Org. Carbon		1	.999**	.992**	.418	.992**	.017	.083	.151	.067	.716**	.132	.210	.185	.320
Org. Matter			1	.994**	.433	.994**	.001	.105	.130	.037	.709**	.113	.198	.172	.297
AvailP				1	.474	1.00**	.008	.098	.121	.027	.669**	.092	.171	.150	.283
AvailK					1	.474	.089	.325	-.522	-.405	.272	-.389	.147	.258	-.181
TotalN						1	-.008	.098	.121	.027	.669**	.092	.171	.150	.283
TEB							1	-.655*	.318	.427	.545*	-.033	.848**	.823**	.684**
ExcAcidity								1	-.698**	-.847**	-.267	-.340	-.532	-.551*	-.825**
ECEC									1	.821**	.229	.710**	.120	.092	.696**
BaseSat										1	.272	.693**	.262	.340	.774**
Fe											1	.189	.724**	.722**	.685**
Mn												1	-.176	-.058	.454
As													1	.951**	.709**
Pd														1	.718**
Cd															1

\*. Correlation is significant at the 0.05 level (2-tailed).

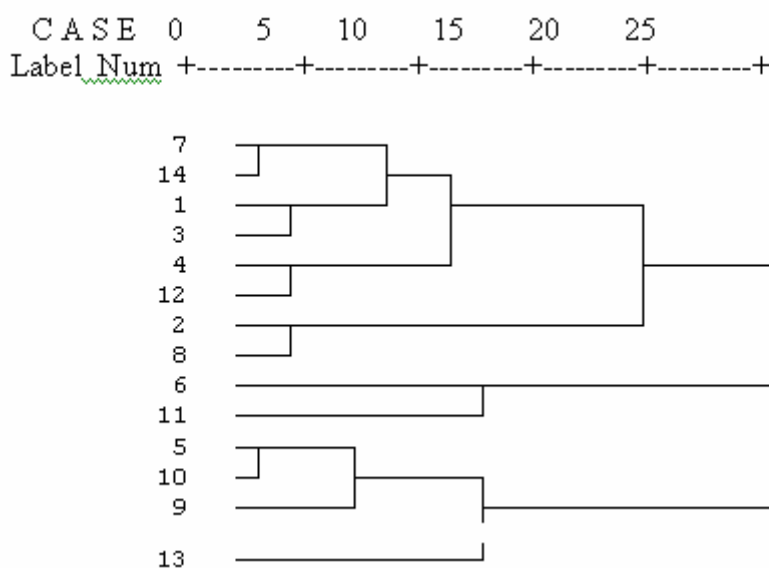
\*\*. Correlation is significant at the 0.01 level (2-tailed).

**Table 7:** Component matrix of soil parameters

Component Matrix <sup>a</sup>			
Parameter	Component		
	1	2	3
pH	.748	-.577	.037
OrganicCarbon	.497	.824	.250
OrganicMatter	.476	.840	.243
AvailP	.461	.844	.242
AvailK	-.004	.681	-.430
TotalN	.461	.844	.242
TEB	.714	-.244	-.538
ExcAcidity	-.761	.570	.005
ECEC	.645	-.383	.573
BaseSat	.732	-.479	.379
Fe	.798	.450	-.163
Mn	.396	-.249	.722
As	.734	-.007	-.637
Pd	.746	-.026	-.619
Cd	.958	-.192	.024

### 3.3 Cluster analysis

Dendrogram using Complete Linkage  
Rescaled Distance Cluster Combine



**Figure 1:** Dendrogram of soil parameters

The hierarchical cluster analysis (agglomerative bottom-up approach), which was used to identify the spatial similarity between the sampling sites based on the levels of chemical concentration, grouped 14 sampling sites into three statistically significant clusters as depicted by the dendrogram (Figure 1). The cluster membership shows that strong associations exist among the sites. Of the 14 sites grouped into three clusters, 8 of the samples belong to cluster 1, while cluster 2 had two members. Clusters 3 had four members. This high number of members in cluster 1 suggests uniformity in the degree of impacts on the samples with regard to the parameters analyzed; and further suggests that the impacts possibly originate from a common source. The clustering situation also confirms the low variability observed in the data.

### 3.4 Enrichment factor of heavy metals

The elemental enrichment factors for the various locations are given in Table 8 below.

**Table 8:** Elemental enrichment factors for various soil locations

Location (profile ID)	Enrichment Factors				
	Fe	Mn	As	Pd	Cd
SWWB	0.706306	1.74269	2.325833	2.431731	1.345455
CB	0.266667	0.245614	0.014401	0.695449	0.545455
SWPA	0.402402	0.923977	0.014401	1.091876	0.836364
SEB	0.644444	3.012865	0.014401	0.973203	1.854545
CDB	0.558559	2.25731	0.014401	0.627393	1.272727
CA	0.133333	0.128655	0.014401	0.396427	0.472727
SEA	0.642042	3.847953	0.073807	0.876223	1.563636
SWDB	0.671471	3.192982	0.014401	0.823905	1.563636
SWWA	1.556757	1.251462	9.362736	4.274351	2.8
SWPB	0.427027	1.333333	0.014401	1.071459	1.127273
SWDA	0.976577	4.444444	0.014401	1.230966	1.345455
CDA	0.494895	2.245614	0.014401	0.598043	1.563636

An enrichment factor close to 1 would indicate a crustal origin, while those with factors greater than 10 are considered to have non-crustal sources such as the weathering of rocks and leaching of soils which are responsible for a portion of the concentrations of heavy metals in the soils. It is clear from Table 8 that Mn, Cd, Fe and Pd EF values were close to unity and may therefore be considered to be predominantly terrigenous in origin and not impacted seriously by an anthropogenic activity. However, the EF value of As at South West Dump A is relatively high and suggests anthropogenic impact.

### 3.5 Geo-accumulation Index of heavy metals

The geo-accumulation indices of the various locations are presented in Table 9 below.

**Table 9:** Geo-accumulation indices for various soil locations

Location (profile ID)	Geo-accumulation Indices				
	Fe	Mn	As	Pd	Cd
SWWD	-0.75317	0.149965	0.438613	0.483138	-0.1083
CB	-1.72722	-1.80946	-4.64592	-0.76866	-1.0116
SWPA	-1.31577	-0.48453	-4.64592	-0.31757	-0.58416
SEB	-0.84483	0.697426	-4.64592	-0.43263	0.21217
CDB	-0.98786	0.408709	-4.64592	-0.87165	-0.1643
CA	-2.42037	-2.45609	-4.64592	-1.33073	-1.1547
SEA	-0.84857	0.942076	-3.01177	-0.5376	0.04154
SWDB	-0.80375	0.75549	-4.64592	-0.59917	0.04154
SWWA	0.03714	-0.18115	1.831272	1.047167	0.62415
SWPB	-1.25637	-0.11778	-4.64592	-0.33644	-0.28566
SWDA	-0.42917	1.08619	-4.64592	-0.19767	-0.10873
CDA	-1.10887	0.403514	-4.64592	-0.91956	0.041549

All locations are practically uncontaminated (class 0) with Fe except South West Dump A which is uncontaminated to moderately contaminated (Table 9). The following locations are practically uncontaminated with Mn; Central Dump Oil Palm B, Bar Hill Side Down A, Central Dump Oil Palm A, South-West Dump A, and Bar Hill Side Down B. However, South-West Dump B, South East B, Central Dump Forest B, South East A, South Waste Dump B, and Central Dump Forest A are uncontaminated to moderately contaminated while South Waste Dump A is moderately contaminated. All locations are practically uncontaminated with As, except South West Dumps A and B. While the former is uncontaminated to moderately-contaminated, the latter is moderately contaminated. This result is identical to the result obtained in the case of Pd. Regarding Cd, five locations namely South East A and B; South Waste Dump B, South West Dump A and Central Dump Forest A are uncontaminated to moderately contaminated whereas the rest of the locations are practically uncontaminated. None of the soils were found to be moderately to heavily contaminated, heavily contaminated, heavily to extremely contaminated or extremely contaminated.

### 3.6 Soil Fertility Analysis

Results of the analysis of selected edaphic factors are presented in Table 10.

**Table 10:** Fertility analysis of soils

Location	pH - H <sub>2</sub> O (1:1)	Rating	% Org. C	% Org. M	Rating	% total N	Rating
SWWB	5.2	strongly acidic	1.13	1.95	low	0.11	low
CB	4.2	very strongly acidic	0.8	1.35	low	0.07	very low
ULB	4.2	very strongly acidic	1.6	2.75	medium	0.14	low
SWPA	5.4	moderately acidic	0.92	1.59	low	0.08	very low
SEB	5.7	moderately acidic	1.34	2.32	medium	0.13	low
ULA	3.6	very strongly acidic	2.34	4.2	high	0.23	medium
CDB	5.6	moderately acidic	1.26	2.17	medium	0.12	low
CA	4.1	very strongly acidic	0.46	0.8	very low	0.04	very low
SEA	5.4	strongly acidic	1.53	2.64	medium	0.14	low
SWDB	5.2	strongly acidic	1.32	2.28	medium	0.12	low
SWWA	6.6	neutral	1.47	2.53	medium	0.13	low
SWPB	4.9	very strongly acidic	1.09	1.88	low	0.1	low
SWDA	4.7	very strongly acidic	1.09	1.88	low	0.09	very low
CDA	5.8	moderately acidic	1.09	1.88	low	0.1	low

Location	C/N Ratio	Rating	Avail P	Rating	% Base Sat.	E.C.E.C
SWWB	10.27	good quality	9.81	medium	84.25	5.08
CB	11.43	good quality	1.04	very low	72.67	4.39
ULB	11.43	good quality	2.79	very low	80.1	6.03
SWPA	11.5	good quality	2.47	very low	84.98	4.66
SEB	10.31	good quality	0.88	very low	95.26	11.61
ULA	10.17	good quality	8.45	medium	59.02	3.66
CDB	10.5	good quality	1.28	very low	93.6	10.15
CA	11.5	good quality	1.04	very low	54.21	2.73
SEA	10.93	good quality	0.24	very low	95.36	15.08
SWDB	11	good quality	0.01	very low	92.78	11.08
SWWA	11.31	good quality	1.44	very low	99.16	11.86
SWPB	10.9	good quality	1.59	very low	81.82	5.5
SWDA	12.11	good quality	0.01	very low	89.52	10.02

The pH varied considerably among sample sites, ranging from 3.6 to 6.6. Considering a soil pH between 5.0 and 5.5 as strongly acidic and below 5.0 very strongly acidic, 21% of the samples were in the strongly acidic group and 43 % in the very strongly acidic group. 28.5% fell in the moderately acidic category while 7.5% representing one location (South West A) was neutral. The lowest pH recorded was 3.6 (undisturbed land A; a forest location). This result is not unexpected as forest soils are generally acidic due to organic matter decomposition and extensive leaching of basic cations as a result of high rainfall intensity. However, from an agronomic point of view, these soils are likely to cause Al and Mn toxicity (Crejan, 1980; Mahoney et.al., 1981; Brady and Weil 2002) especially if planted to acid sensitive species such as soyabean, or will cause Ca and Mg deficiency. Low pH can also affect the availability of certain nutrients. If pH is lower than 6, P may form insoluble compounds with iron (Fe) and aluminium (Al) and if it is higher than 7.5 it forms insoluble compounds with calcium (Ca). A liming regime must be put in place if agronomic practices are to take place on these soils for certain acid sensitive crops and also to maintain optimum balance of nutrients.

Soil organic matter ranged from 0.8% to 4.2%. About 43% of the samples (six locations) had low levels of organic matter with another 43% of the samples recording medium levels of organic matter (Table 10). One location, ULB had high organic matter content while the lowest level of organic matter was recorded at location CA. Ninety-three percent of the locations had low to very low levels of total nitrogen while 7% (one location, ULB) recorded medium levels of nitrogen. The Carbon-nitrogen ratio also ranged from 10.2-12.1, and based on the fertility parameter ratings, the soils are of good quality. However, for agronomic performance it is advised that fertiliser or manure should be applied to increase especially the nitrogen content. On the other hand, leguminous crops or plants should be planted to fix nitrogen in the soil. About 15% of the locations show medium levels of available phosphorus while the rest (85%) show very low levels of available phosphorus. This indicates possible phosphorus deficiency in the soils. Percentage base saturation ranged from 54.21 (CA) to 99.16 (SWWA). With the exception of ULA (59.02) and CA (54.21) which showed medium base saturation, all other locations were high or highly saturated.

The mean ECEC was 8.5 meq/100g and ranged from 3.66 meq/100g to 17.12 meq/100g. Twenty-eight percent of the samples had less than 5 meq/100g, the minimum level for adequate exchange capacity according to the Ghana Soil Fertility Capability Classification system (SRI, 1986). In general, these soils have between low and medium fertility capability. Agronomic activities can however be carried out provided fertiliser and lime applications are undertaken. Shallow rooted crops should be encouraged as the depth of the organic layer is shallow in most of these soils.

#### **4. Conclusions**

Based on the analysis of the soil samples from the various locations, it can be concluded that the heavy metal concentrations in the soils do not pose any significant risk to agronomic activities. However, the nutrient/fertility analysis indicates that the soils have low to medium fertility status. Though, crop production can be carried out on these soils, there is the need for the application of lime to control the low pH and subsequent fertilizer application to correct the various nutrient deficiencies identified so as to support crop cultivation.

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