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Effect of heavy metals and physicochemical parameters on diversity of plants at a gold mine tailings dam in Ghana

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This study focuses on the impact of physicochemical parameters and heavy metals concentrations in soil on abundance, richness and diversity of plants at Marlu tailings dam located near Bogoso, Ghana. The concentrations of heavy metals (mg/kg) in soil at the study area are as follows: Fe (10,528.9 - 7,873.0), Cu (224.9 - 177.4), Zn (51.6 - 42.7), Cd (3.0 - 2.6), As (2.4 - 1.7) and Mn (78.3 - 57.1). Soil nutrient levels (nitrate, phosphate and sulphates) were relatively low with most sites having acidic soils (6.4 - 5.3). A total of 2,055 plants composed of eighteen (18) different species were observed at the study area. *Pennisetum purpureum* was the most abundant plant species (46.8%), and Poaceae and Asteraceae were the predominant families with percentage abundance of 37 and 28.8%, respectively. Diversity of plants measured using Simpson and Shannon indices at sampling sites varied significantly between the different sampling sites but are relatively low compared to other similar sites in Ghana. Species richness and diversity of plants correlated positively with the low nutrient levels and soil acidity. Low plant abundance, species richness and diversity correlated with increased Copper (Cu) levels in soil. Cadmium (Cd) levels were correlated with low abundance of plants belonging to families Asteraceae and Fabaceae. The presence of heavy metals at concentrations above regulatory limits negatively impacted on abundance and diversity of plants at the decommissioned mine tailings dam. Increased concentrations of heavy metals and low nutrient levels in soil could account for reduced plant abundance, species richness and diversity at the mine tailings dam.

Key words: Plant diversity, mine tailings dam, heavy metals, physicochemical parameters.

INTRODUCTION

Gold mining is considered as one of the economic activities known to cause ecological disturbance in spite of its contribution to economic growth of many developing countries (Aboka et al., 2018). The generation of processed mineral wastes known as tailings has become one of the adverse remnants of mining activities due to the difficulty and costly nature of its treatment (Ahmadpour et al., 2012; Ghosh and Singh, 2005). The remediation of gold mine tailings containing heavy metals using conventional methods is an economically

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challenging activity but phytoremediation is a low cost and environmentally friendly alternative and has already been used in many countries including Ghana (Bansah and Addo, 2016; Keller et al., 2003). The aim of the remediation process is to return mined lands to productive status after which they could be released to indigenous communities. Heterogeneous spatial distribution of contaminants and unstable physical composition of mine tailings dams present as formidable challenge for phytoremediation (Huang et al., 2012; Mensah, 2015).

Ineffective remediation of gold mine tailings dams has resulted in erosion and leaching of contaminants into rivers, underground water and farm lands culminating in a reduction of agricultural produce and a rise in the incidence of terminal diseases in humans (Mensah et al., 2020). Heavy metals such as mercury, arsenic and cadmium cause irreversible cellular damage at minimal concentrations when absorbed by plants, and this poses serious health risks to other organisms at higher trophic levels which includes humans (Sarwar et al., 2017). Plants that grow naturally on mine tailings survive the harsh physical and chemical constraints, and establish stable communities are considered to be tolerant and/or able to accumulate these chemical contaminants. Chief among these chemical contaminants are heavy metals or metalloids (arsenic, cadmium, zinc, manganese, copper, mercury, iron and lead) most of which are partially degradable or non-degradable. Plants capable of accumulating high amounts of heavy metals in their tissues are referred to as hyperaccumulators. These plants often grow on soils with naturally high levels of heavy metals and heavy metal contaminated sites such as mine tailings dams than normal soils (Yoon et al., 2006). Changes in abundance and diversity of plant communities in many mining areas have been observed after introduction of heavy metal-rich wastes (Vangronsveld et al., 1996; Mukhopadhyay et al., 2017). Diversity measures such as the Shannon index are used to assess plant community structure, and could be applied to evaluate the impact of mine tailings on plant communities growing on mine tailings dams (Pandey et al., 2014).

The Marlu tailings dam is located near Ghana's mining town of Bogoso which was in operation from the pre-colonial era until 1960 when it closed its mining operations. The concessional area has been operated by other mining companies who have engaged in remediation of the mine tailings dam left by the erstwhile company. This study focuses on the impact of heavy metal concentration and physicochemical parameters on the abundance, richness and diversity at the Marlu tailings dam, Bogoso in the Western Region of Ghana.

MATERIALS AND METHODS

Study area and sampling

The study site is located within coordinates 02°01'20"W – 02°01'32"W and 05°35'04"N - 05°35'14"N in the Forest Zone of Ghana, and forms part of the Ashanti gold belt which is known for its gold deposits (Figure 1).

The study area was used as a tailings dam and has been re-vegetated as part of reclamation efforts since halt of gold mining activities. The study area was divided into five zones using ArcGIS Pro (version 2.0) and a quadrat (1 m × 1 m) was used to randomly sample the established zones at the site. Plant samples were identified using digital and manual resources (Dokosi, 1998). Plant samples were obtained and preserved in a wooden press for further confirmation. The samples were sent to the Department of Theoretical and Applied Biology (KNUST) for further identification to confirm site identification. Furthermore, images of plants were also taken for digital identification using online tools, and manuals. Soil samples surrounding the root of plants were collected into sterile bags and kept at -4°C prior to further analysis.

Plant diversity estimation

Paleontological Statistics (PAST version 3.0) was used to calculate the abundance, species richness, dominance, evenness and diversity of plant species at five samplings plots of the study area.

Species richness (S)

Species richness is the total number of different species sampled and is considered the simplest estimate of biodiversity (Scheiner, 2012). This was estimated as the total number of different plant species observed at the mine tailings dam.

Shannon index (H' or $D_{Shannon}$)

The Shannon index was applied to measure plant diversity, and it incorporates species richness and evenness. It was estimated using the following equation: $D_{shannon} = -\Sigma p_i (\ln p_i)$, where p_i is the proportion of species i relative to the total number of species observed at Marlu mine tailings dams. It assumes that sampling was conducted using the random method and all species were represented.

Simpson's diversity index (D_1)

The Simpson index also measures diversity but emphasizes the dominance of a particular species at mine tailings dam based on its estimates. This index estimates the probability that two individuals selected at random from a mine tailings dam are of the same species. It is calculated as follows: $D_1 = [1 - \Sigma(p_i)^2]$, where pi is the proportion of species i relative to the total number of species at the mine tailings dam.

Simpson's evenness ($E_{Simpson}$)

Evenness is a measure of how individuals are distributed among species at the mine tailings dam. This index facilitates the comparative estimation of how different the numbers of a particular species occur in different sites at the mine tailings dams. In this regard, mine tailings dams or communities with uniform evenness would have the same abundance of different species occurring in at the mine tailings dam.

The equation for estimating Simpson's evenness is as follows:

$E_{Simpson} = Ds/S$, where Ds represents Simpson's dominance index and S the species richness at a mine tailings dam.

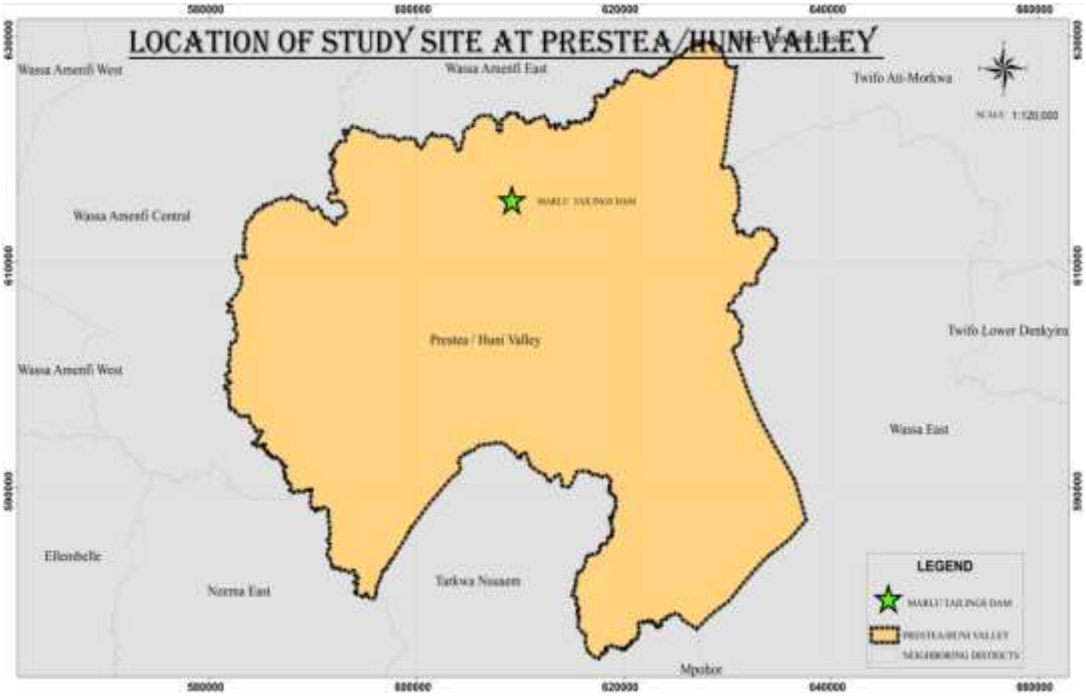

Figure 1. Map of the Marlu gold mine tailings dam in the Prestea-Huni valley district.
Source: Author

Simpson's dominance (D_2)

Dominance is an estimate of how few individuals in a sample or at mine tailings dams dominate in terms of abundance. It is the reciprocal of the original Simpson's index and estimated as follows: Ds = 1 / Σpi^2, where *pi* is the proportion of individuals at mine tailings dam.

Heavy metal and physicochemical analysis

Heavy metal analysis was conducted after acid digestion using flame atomic absorption spectrometry (FAAS, VGP Model 210, Buck Scientific Inc, USA) as described by Bansah and Addo (2016). Soil samples were dried in an oven at 50°C until a uniform weight was obtained. A mixture of perchloric, nitric, and hydrochloric acids (1:2:3) was used to digest soil samples on a hot plate at a 80 to 100°C. The residue is decanted and refilled with deionised water to a volume of 100 ml before heavy metal determination. Physicochemical parameters (pH, conductivity, total dissolved solids) were determined using a bench-top sension-plus probe (HACH, USA). Levels of nitrate-nitrogen, sulphate and available phosphate were measured using Kjeldahl method, Bray No. 1 method and Barium chloride titration method, respectively.

Statistical analysis

Data analysis was conducted using the Statistical Package for Social Sciences (SPSS version 20). Analysis of variance (ANOVA) and post-hoc (Tukey-b) analysis were conducted on replicated measures at 95% confidence interval while t-test was used for non-replicated measures. Spearman correlation was used to determine relationship between heavy metals, physicochemical parameters, plant abundance and diversity measures.

RESULTS

Abundance, species richness (S) and diversity of plants

A total of 2,055 plants comprising 18 plant species and 12 families were identified in this study (Tables 1 and 2). *Pennisetum purpureum*, *Pueraria phaseoloides* and *Mimosa pudica* were the most abundant plants species recording percentage abundance of 46.8, 7.4 and 6.77%, respectively (Figure 2). Poaceae (formerly Graminae) was the most abundant family while species richness varied significantly between sites with S1 (Site 1) being the most diverse (Table 3 and Figure 3). The Simpson and Shannon diversity indices indicated significant variation between the sampling sites in terms of site diversity (Figures 5 and 6). The evenness of plants varied significantly between the sampling sites and ranged from 0.33 to 0.82. The dominance varied significantly between sampling units and ranged from 0.19 to 0.65 (Table 3 and Figure 4). The highest abundance and highest diversity was observed at S1 (Site 1). Asteraceae and Fabaceae are among the six (6) plant families known to hyperaccumulate Cadmium (Cd) found in this study (Reeves et al., 2017). Low evenness and conversely high dominance was observed at S2 and S5 (Figure 7).

Heavy metals levels and physicochemical properties of soil

The concentration of heavy metals in soils at the

Table 1. Abundance of plant species at the Marlu Tailings Dam.

Plant	Site					Abundance	Relative abundance	Percentage abundance
	S1	S2	S3	S4	S5			
Psidium guavaja	54	0	0	3	12	69	0.034	3.36
Chromolaena odorata	95	0	25	0	0	120	0.058	5.84
Cyathea dealbata	75	0	0	0	0	75	0.037	3.65
Pennisetum purpureum	254	28	352	86	242	962	0.468	46.81
Mimosa pudica	114	8	15	0	0	137	0.067	6.67
Justicia flava	75	0	0	18	0	93	0.045	4.53
Scoparia dulcis	61	0	0	0	0	61	0.030	2.97
Pteris vittata	25	15	5	3	5	53	0.026	2.58
Ageratum conyzoides	0	45	0	0	12	57	0.028	2.77
Leucaena leucocephala	0	38	0	0	0	38	0.019	1.85
Pueraria phaseoloides	0	152	0	0	0	152	0.074	7.40
Tridax procumbens	0	16	0	0	5	21	0.010	1.02
Centrosema pubescens	0	0	8	0	0	8	0.004	0.39
Alchornea cordifolia	0	0	24	8	0	32	0.016	1.56
Nephrolepis biserrata	0	0	0	21	0	21	0.010	1.02
Nephrolepis cordifolia	0	0	0	22	0	22	0.011	1.07
Caulophyllum thalictroides	0	0	10	0	0	10	0.005	0.49
Phyllanthus amarus	0	0	0	0	124	124	0.060	6.03

Source: Author

Table 2. Abundance of plant families at the Marlu Tailings Dam.

Plant family	Site					Abundance	Relative abundance	Percentage abundance
	S1	S2	S3	S4	S5			
Acanthaceae	75	0	0	18	0	93	0.036	3.6
Asteraceae	95	611	25	0	17	748	0.288	28.8
Berberidaceae	0	0	10	0	0	10	0.004	0.4
Cyatheaceae	75	0	0	0	0	75	0.029	2.9
Dryopteridaceae	0	0	0	43	0	43	0.017	1.7
Euphorbiaceae	0	0	24	8	0	32	0.012	1.2
Fabaceae	114	192	23	0	0	329	0.127	12.7
Myrtaceae	54	0	0	3	12	69	0.027	2.7
Phyllanthaceae	0	0	0	0	124	124	0.048	4.8
Poaceae	254	28	352	86	242	962	0.370	37.0
Pteridaceae	25	15	5	3	5	53	0.020	2.0
Scrophulariaceae	61	0	0	0	0	61	0.023	2.3

Source: Author

sampling sites and maximum permissible limits of three countries namely United States, United Kingdom and Germany are shown in Table 4. The concentration of Iron (Fe) in soil ranged from 7,873.0 to 10,528.9 mg/kg, and S1 recorded the highest levels of Fe in soil (Table 4). The concentration of Copper (Cu) ranged from 177.4 to 224.9 mg/kg and was greater than permissible levels for agricultural soils in United Kingdom and Germany. The concentration of Zinc (Zn) ranged from 42.7 to 51.6 mg/kg and was lower than permissible levels of all selected countries. Cadmium concentrations were greater than permissible limits in Germany and United Kingdom and ranged from 2.6 to 3.0 mg/kg. The concentration of Arsenic (As) ranged from 1.7 to 2.4 mg/kg and was lower than permissible levels in the United Kingdom. The concentration of Manganese (Mn) ranged from 57.1 to 78.3 mg/kg with S1 recording the highest concentration.

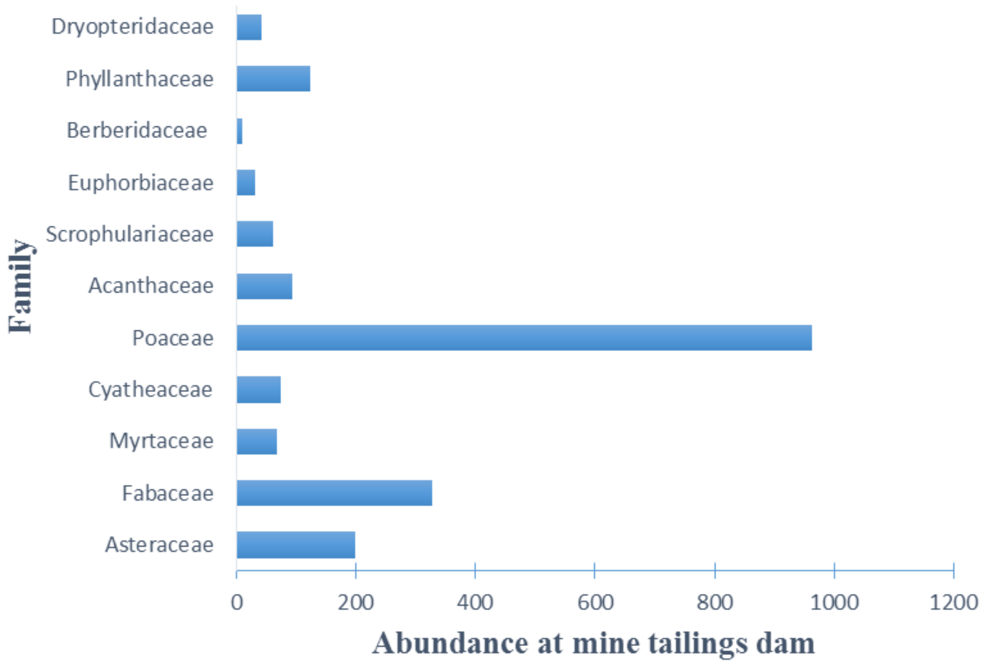

Figure 2. Abundance of plant families at Marlu Tailings dam.
Source: Author

Table 3. Abundance and diversity indices of plant species at the Marlu Tailings Dam.

Parameter	S1	S2	S3	S4	S5
Abundance	753	302	439	161	400
Richness	8.00^a	7.00^b	7.00^b	7.00^b	6.00^c
Shannon	1.88^a	1.51^b	0.83^c	1.42^b	0.99^c
Simpson	0.81^a	0.69^b	0.35^c	0.66^b	0.54^d
Evenness	0.82^a	0.65^b	0.33^c	0.59^b	0.45^d
Dominance	0.19^a	0.31^b	0.65^c	0.34^b	0.46^d

Means in different rows with different alphabets vary significantly ($p < 0.05$).
Source: Author

The physicochemical parameters of soil at the different sampling sites are shown in Table 5. The soil was acidic and had pH values ranging from 5.3 to 6.4. Conductivity of soil ranged from 22.4 to 137.0 µS/cm, and total dissolved solids (TDS) ranged from 11.2 to 68.3. Soil nitrate, phosphate and sulphate levels ranged from 1.2 to 7.6, 0.03 to 0.5 and 3.0 to 48.7 mg/kg, respectively.

Relationship between heavy metals and plant diversity

Impact of heavy metal concentrations on abundance and diversity of plants was assessed using correlation matrix (Table 6). A strong and positive correlation was observed between plant abundance and heavy metals (Fe, Zn and Mn). This observation is associated with their role as micro-nutrients promoting growth and development of plants at low concentrations (Taiz and Zeiger, 2002). Shannon diversity index (H') and species richness (S) had strong and positive correlation with As and Fe concentration, respectively (Table 7). Abundance of grasses (Poaceae) correlated positively with concentrations of Fe, Zn, Cd, As and Mn indicating tolerance of plants in this family to different heavy metals (Table 8 and 9).

DISCUSSION

Abundance of plants growing on mine tailings has been observed to be relatively low and this has been attributed

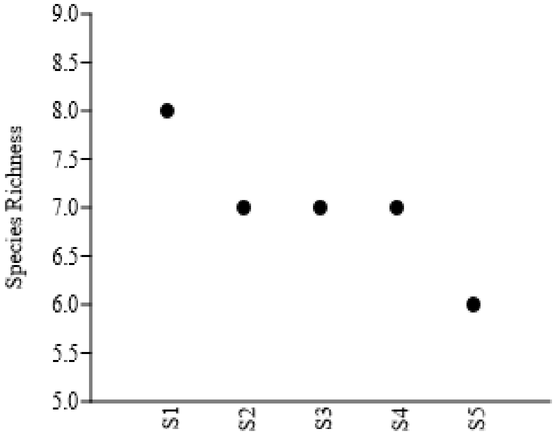

Figure 3. Species richness of plants at the Marlu Tailings Dam.
Source: Author

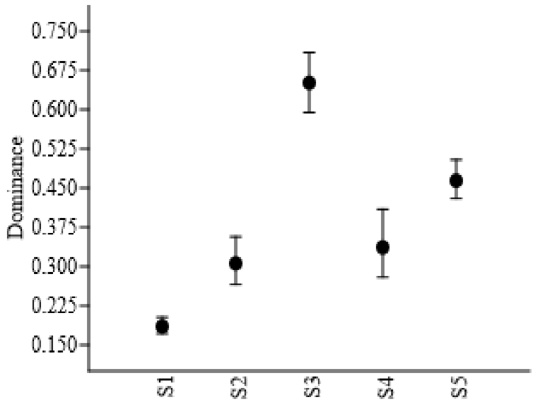

Figure 4. Dominance of plants at the Marlu Tailings Dam.
Source: Author

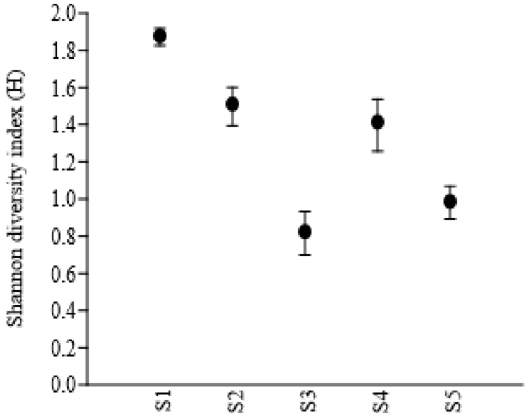

Figure 5. Shannon diversity index of plants at Marlu Tailings Dam.
Source: Author

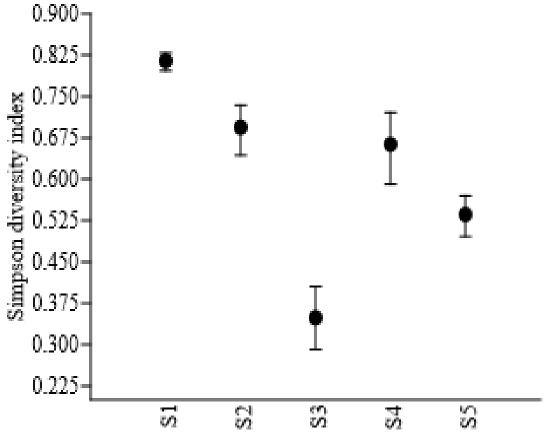

Figure 6. Simpson diversity index of plants at Marlu Tailings dam.
Source: Author

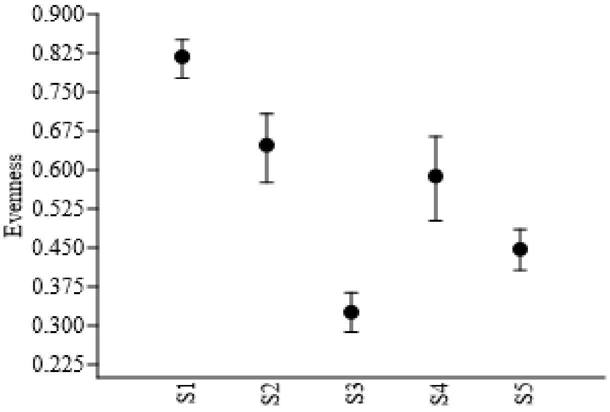

Figure 7. Evenness of plants at Marlu Tailings Dam.
Source: Author

to the 'complex' nature of contaminants and low nutrient levels (Petelka et al., 2019; Nkansah and Belford, 2017; Bansah and Addo, 2016). Although eighteen (18) plants were identified, most sites recorded seven (7) plant species which is comparatively lower compared to other similar studies in Ghana and other parts of the world (Bansah and Addo, 2016; Petelka et al., 2019). Specifically, the plant diversity observed at the Marlu tailings dam is lower than those reports from abandoned tailings dams and ponds in Chile, China, and Spain, and this could partly be associated with semi-arid conditions and high levels of heavy metals in mine tailings (Peng et al., 2007; Hernandez and Pastore, 2008). Consequently, Ginocchio et al. (2017) added that the presence fine soil particles and low nutrient levels in mine tailings are also factors that limit plant colonization of mine tailings. Occurrence of leguminous plants such as *Leucaena leucocephala* known to contribute above the 190 kg of

Table 4. Mean heavy metal concentrations in soil at different sites.

Site	Fe(mg/kg)	Cu(mg/kg)	Zn(mg/kg)	Cd(mg/kg)	As(mg/kg)	Mn (mg/kg)
S1	10528.9^{d}	177.4^{a}	50.1^{c}	3.0^{b}	2.3^{c}	78.3^{d}
S2	8079.7^{b}	217.5^{b}	42.7^{a}	2.6^{a}	2.4^{c}	71.1^{c}
S3	8980.1^{c}	224.9^{c}	45.6^{b}	2.9^{b}	1.7^{a}	67.5^{b}
S4	8059.2^{b}	218.0^{b}	43.4^{a}	3.0^{b}	2.0^{b}	57.1^{a}
S5	7873.0^{a}	215.0^{b}	51.6^{c}	3.0^{b}	2.2^{c}	77.2^{d}
US-EPA	**NA**	**750.0**	**1,400.0**	**20.0**	**NA**	**NA**
Germany	**NA**	**60.0**	**200.0**	**1.5**	**NA**	**NA**
United Kingdom	**NA**	**50.0**	**130.0**	**1.6**	**10.0**	**NA**

Figures in bold font represent maximum allowable concentrations of trace elements in agricultural soil in different countries. Values in the same column with different alphabets differ significantly ($p < 0.05$).
Source: Author

Table 5. Physicochemical parameters of soil at different sites.

Site	pH	Conductivity	TDS	Nitrate	Phosphate	Sulphate
S1	5.5^{a}	22.4^{a}	11.2^{a}	2.1^{bc}	0.40^{c}	6.6^{d}
S2	5.9^{b}	133.6^{d}	66.4^{d}	7.6^{d}	0.50^{d}	7.4^{e}
S3	6.4^{c}	137.0^{e}	68.3^{e}	1.8^{b}	0.03^{a}	4.7^{c}
S4	5.3^{a}	69.0^{c}	34.0^{c}	2.3^{c}	0.50^{d}	4.0^{b}
S5	5.9^{b}	42.0^{b}	20.0^{b}	1.2^{a}	0.32^{b}	3.0^{a}

Values in same columns with different alphabets differ significantly ($p < 0.05$).
Source: Author

Table 6. Correlation between heavy metals in soil, abundance, species richness (S) and Shannon diversity index (H').

Correlation	Fe	Cu	Zn	Cd	As	Mn	Abundance	Species richness (S)	Shannon (H')
Fe	1								
Cu	-0.829	1							
Zn	0.365	-0.527	1						
Cd	0.290	-0.322	0.615	1					
As	0.040	-0.505	0.168	-0.364	1				
Mn	0.424	-0.567	0.763	-0.012	0.523	1			
Abundance	0.896*	-0.821	0.669	0.269	0.199	0.770	1		
Species richness S)	0.848	-0.703	-0.133	0.000	0.127	0.045	0.569	1	
Shannon (H')	0.525	-0.786	-0.039	-0.082	0.688	0.167	0.368	0.748	1

*Correlation is significant at the 0.05 level (2-tailed).
Source: Author

Nitrogen per hectare annually could help improve nutrient levels in mine tailings (Mensah, 2015). More so, high relative abundance of elephant grass (*P. purpureum*) could be due its ability to tolerate low nutrients and heavy metal contaminated soils (Dhar et al., 2018; Singh et al., 2016). However, tolerance of plants to presence of heavy metals in soil may not result in accumulation of heavy metals (Verbruggen et al., 2009). That notwithstanding, Zhang et al. (2014) showed that *P. purpureum* accumulates more heavy metals when cultivated in soils with high metal concentrations suggesting its potential in tolerating and extracting heavy metal contaminants in sediments. Laterally growing herbs such as *C pubescens* and *P. phaseoloides* cover the soil surface preventing direct contact with wind and rainfall thereby reducing rate of erosion, evaporation of soil water and heating of soil (Wang et al., 2018). The metal tolerant and fast growing nature of these plants eliminates other competitors thus

Table 7. Correlation between physicochemical parameters, abundance, species richness (S) and Shannon index (H').

Correlation	pH	Conductivity	TDS	Nitrate	Phosphate	Sulphate	Abundance	Species richness (S)	Shannon index (H')
pH	1								
Conductivity	0.658	1							
TDS	0.656	1.00**	1						
Nitrate	0.041	0.560	0.561	1					
Phosphate	-0.819	-0.334	-0.335	0.483	1				
Sulphate	-0.019	0.292	0.301	0.746	0.293	1			
Abundance	0.073	-0.452	-0.443	-0.284	-0.267	0.346	1		
Species richness (S)	-0.333	-0.132	-0.118	0.122	0.146	0.700	0.569	1	
Shannon index (H')	-0.736	-0.437	-0.429	0.338	0.729	0.655	0.368	0.748	1

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed).
Source: Author

Table 8. Correlation between heavy metal concentration and abundance of four plant families.

Correlation	Fe	Cu	Zn	Cd	As	Mn	Asteraceae	Fabaceae	Phyllanthaceae	Poaceae
Fe	1									
Cu	-0.829	1								
Zn	0.365	-0.527	1							
Cd	0.290	-0.322	0.615	1						
As	0.040	-0.505	0.168	-0.364	1					
Mn	0.424	-0.567	0.763	-0.012	0.523	1				
Asteraceae	-0.187	0.077	-0.493	-0.954*	0.619	0.150	1			
Fabaceae	0.252	-0.331	-0.295	-0.787	0.687	0.351	0.900*	1		
Phyllanthaceae	-0.420	0.131	0.689	0.323	0.161	0.454	-0.285	-0.434	1	
Poaceae	0.489	-0.147	0.609	0.543	0.580	0.366	-0.651	-0.465	0.209	1

*Correlation is significant at the 0.05 level (2-tailed).
Source: Author

occurrence corroborates with other studies which associated the ability of grasses to tolerate heavy metals to their high abundance at mined sites (Zhang et al., 2014; Anoliefo, 2008; Prasad and Freitas, 2003; Gibson and Polard, 1988). The occurrence of plants such as *P. purpureum* and *Pteris vittata* at all sampling sites confirms the ability of these plants to tolerate and accumulate different heavy metals in mine tailings (Hassan et al., 2020; Zhang et al., 2014).

Most sites recorded pH values typical of gold mine tailings (6.0 - 7.5), however acidity associated with mine tailings increases heavy metal bioavailability which favours metal uptake by tolerant plants (Sheoran et al., 2010). Hassan et al. (2020) suggested that alkaline soils support the growth of plants in heavy metal contaminated media thus the acidic condition of mine tailings could limit plant growth. Moreover, Kabas et al. (2017) indicated that under acidic conditions bioavailability of metals increases therefore accentuating their effect in plants. Comparatively, the pH and nutrient levels in soil are lower than other abandoned mine sites in China, Portugal, Poland and Nigeria (Guo et al., 2019; Amadi et al., 2017; Kasowska et al., 2018; Pratas et al., 2005). The low nutrient level at study area is known to impair optimal growth and development of plants (Mensah, 2015). Therefore, low levels of soil nutrients coupled with acidity could partly account for the comparatively low abundance and diversity of plants at the Marlu gold mine tailings dam (Kasowska et al., 2018; Huang et al., 2012).

The levels of iron (Fe) in soil were comparative higher than reports of other gold mine tailings in Ghana (Bansah and Addo, 2016; Bempah et al., 2013) and this could be due to high levels of Fe associated with gold ore (pyrite) in Ghana which is not transformed during mineral extraction. The report of Amadi et al. (2017) indicated higher levels of Fe in abandoned mine tailings compared to Marlu, however the levels at Marlu tailings dam could impair root development. Adverse effects of copper (Cu) have been observed in plants when soil levels exceed 50 mg/kg, however the study area had levels greater of Cu

Table 9. Correlation between physicochemical parameters and abundance of dominant plant families.

Correlation	pH	Conductivity	TDS	Nitrate	Phosphate	Sulphate	Asteraceae	Fabaceae	Phyllanthaceae	Poaceae
pH	1.000									
Conductivity	0.616	1.000								
TDS	0.616	1.000**	1.000							
Nitrate	-0.410	0.200	0.200	1.000						
Phosphate	-0.711	-0.154	-0.154	0.872	1.000					
Sulphate	0.103	0.200	0.200	0.700	0.359	1.000				
Asteraceae	0.205	-0.200	-0.200	0.200	-0.051	0.800	1.000			
Fabaceae	0.237	0.154	0.154	0.564	0.237	0.975**	0.872	1.000		
Phyllanthaceae	0.181	-0.354	-0.354	-0.707	-0.363	-0.707	-0.354	-.0544	1.000	
Poaceae	0.410	0.000	0.000	-0.700	-0.872	-0.200	0.200	-0.154	0.000	1.000

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed).
Source: Author

but plants did not show any signs of toxicity (Mir et al., 2021). This could be viewed as Cu tolerance and hyperaccumulation potential by plants at the Marlu tailings dam. Mossa et al. (2020) indicated levels of zinc (Zn) less than 100 mg/kg in soil facilitate growth and development of plants, implying that the observed soil levels could favour plant growth, and by extrapolation their abundance at the Marlu tailings dam. Compared to other gold mine tailings dams in Ghana, the levels of Zn and Cd in soil at Marlu tailings are low (Petelka et al., 2019). Despite the toxicity of cadmium of very low concentrations in soil (<2 mg/kg), it is worth mentioning the observed range (2.6 - 3.0 mg/kg) could limit plant growth and therefore reduce plant community abundance and diversity at the Marlu tailings dam (Kushwaha et al., 2015). Earlier reports of gold mine tailings dams in Ghana recorded higher levels of As in soils compared to this study (Mensah et al., 2020; Antwi-Agyei et al., 2009). The levels of As observed in soils at Marlu tailings dam is known to impede vital metabolic reactions, and plant species growing in arsenic polluted environments exclude its sequestration to the cell wall components of roots in order to survive its presence (Tripathi et al., 2007).

The concentration of copper (Cu) correlated negatively with plant abundance, diversity and species richness. This perceived reduction in plant abundance, species richness and diversity corroborates with the findings of Yoon et al. (2006) who indicated detrimental impacts of increased Cu concentrations on diversity indices. The low concentrations of arsenic (As) and cadmium (Cd) did not affect abundance of grasses (family Poaceae) indicating the adaptability of the grasses to these heavy metals (Hernandez and Pastore, 2008). This observation is reflected in the notable high relative abundance of *P. purpureum* which is known to possess tolerance to heavy metals (Dhar et al., 2018). Fabaceae includes plants capable of fixing nitrogen in soil and was moderately correlated with nitrogen levels indicating their established contribution towards soil fertility and plant diversity (Sheoran et al., 2010). Pandey et al. (2014) indicated the high abundance of leguminous plants (Fabaceae) growing on mine tailings could be attributed to their rich rhizospheric microbial communities which are responsible for transforming crude metal residues in mine tailings, thus making them thrive in harsh chemical constraints of mine tailings.

Soil acidity correlated negatively with the low plant species richness and diversity indicating adverse impact of acidity on vegetation establishment on gold mine tailings which are usually acidic in nature (Huang et al., 2012). Plants are known to thrive in slightly acidic or neutral-alkaline soil pH which reduces heavy metal bioavailability and toxicity (Huang et al., 2012). Consequently, the impact of soil acidity partly accounts for the reduced abundance and diversity of plants at most mine tailings dams especially those left without adequate plant cover (Petelka et al., 2019; Ginocchio et al., 2017). Nutrient (phosphate and sulphate) concentrations were in tandem with increase in species richness and Shannon index, and this pattern has also been reported in earlier studies (Maiti and Ghose, 2005; Hernandez and Pastore, 2008). However, nitrate levels were negatively correlated with abundance and diversity of plants which could be attributed to the relatively low soil nitrate levels. The importance of improving levels of major nutrients (nitrogen, sulphur and phosphorus) towards the establishment of plant communities has led to the introduction of leguminous plants during phytoremediation attempts on mine tailings dams nevertheless their survival is still challenged by the toxicity of heavy metals (Gagnon et al., 2020).

Conclusion

The findings of this research indicate negative impacts of high concentrations of heavy metals, low nutrient levels and soil acidity on plant diversity (Shannon and species richness) at the Marlu tailings dam. Plant families most affected by concentrations of cadmium in mine tailings were Asteraceae and Fabaceae, however *P. purpureum* (Schumach.) (Poaceae) dominated the study area in terms of species abundance due to its multiple heavy metal tolerance and phytoaccumulation properties. Furthermore, levels of toxic heavy metals such as arsenic and cadmium were associated with the low abundance of plants except *P. purpureum* which confirms its role in phytoremediation of heavy metal contaminated mine tailings. Consequently, the Marlu tailings dam requires regimented remedial efforts for which *P. purpureum*, *P. phaseoloides* and *Leucaena leucocephala* could be employed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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