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Soil Analysis of a Mined-out Area at Afiesa, Ghana

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This study investigated some physical and chemical properties of composite soil samples obtained from a mined-out area at Afiesa near, Kyebi-Apapam in the Eastern region of Ghana. Soil samples were collected and analysed for total Arsenic (As), Copper (Cu) and Lead (Pb) concentrations using an Agilent 4210 MP AE Spectrophotometer. Physical and chemical properties including porosity, pH, soil organic matter (SOM), total nitrogen, texture and particle size of soil samples were measured. Contamination factor (CF) and degree of contamination (C_{degree}) were also determined. The mined-out soil sample had a loamy silt texture, was acidic (pH 6.00), with a relatively high porosity (40.50% ± 0.10) and particle size (2.00 mm) compared to the reference soil which had a loamy texture, (pH 6.53), with porosity of (35.3% ±0.10) and smaller particle size (0.42 mm). The SOM and total nitrogen of the mined-out soil were found to be quite low (4.71±0.11g/kg, 0.24±0.20g/kg) compared to the reference soil. The degree of contamination of the mined-out soil was found to be 5.839 showing that the mined-out soil was moderately contaminated. Levels of both As and Cu in the mined soil were below the WHO (2001) recommended values (20 ppm and 100 ppm respectively). However, the level of Pb in the mined-out soil was above the background value (11.33 ppm) but below the WHO (2001) recommended standard (50 ppm) making the mined-out soil less hazardous.

Keywords; Mined-out soil, physicochemical properties, heavy metals and metalloids

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INTRODUCTION

Soil is one of the most important resources that sustains living organisms. However, various anthropogenic activities have led to the degradation of this vital resource. Mining processes, whether small-scale or large-scale generate a lot of waste consisting of overburdens and tailings. The processing of the mineral ore which involves milling and separation procedures generates small particles to release the mineral such as gold as well as other metals that may be present in the mineral-bearing ore. This creates huge volumes of tiny rock particles, with sizes that range from sand-sized to a few microns (USEPA, 1994).

Mined-out areas include soils/lands that have undergone mining and have been re-filled, reclaimed/revegetated or left unfilled. These areas are usually characterized by mined soils consisting of a mixture of tailings, overburdens and dumps with varying rock content, soil texture, bulk density or compaction, varied pH and heavy metals levels. Most mined soils consist of coarse fragments which are soil particles that are bigger than 2 mm. These coarse fragments reduce the water holding capacity of the mined soils which is necessary for plants growth (Mensah, 2015). Mined soils also have particle size distribution obtained from their parent rocks which were broken down through weathering to produce soil particles present in mined-out areas. In contrast, unmined soils have top soil that have reduced rock content and hence lower rock particle sizes, giving the soil better water-holding capacity (Moreno-de las Heras *et al*., 2008). Moreover, mined-out soils are usually characterized by variable soil texture. The soil texture depends largely on the relative quantities of sand (2.0 mm – 0.05 mm), silt (0.05 – 0.002 mm) and clay (less than 0.002 mm) particles (Sheoran *et al.*, 2010). Mined soils which have sandy textures are deficient in nutrients with reduced water-holding ability compared to loam and silt soils. While some mined areas have silt soil with fine texture and elevated levels of soluble salts, the majority of mined-out soils have silt loam texture which is dominated by siltstones. Most mined soils have a very high sand content (66%) and little clay content (8.6%) (Ghose, 2005), making them easily compacted.

Mined waste such as tailings available in mined-out soils, serves as a prominent supply point for heavy metals, that pollute both soil and water resources (Matanzas *et al.*, 2021). These heavy metals with fairly high densities, atomic weights and atomic numbers are not degradable and usually stay in the environment for a long period (Kosakivska *et al.*, 2020). They include Chromium (Cr), Cadmium (Cd), Nickel (Ni), Cobalt (Co), Zinc (Zn), Iron (Fe), Arsenic (As), Silver (Ag), Lead (Pb) as well as Platinum (Pt) (Nagajyoti *et al*., 2010). Heavy metals in mined soils consist of metals that have no redox capacity such as Zn, Hg, Pd, and Cd and those that possess redox capability such as Fe and Cu (Kosakivska *et al.*, 2020). Also, heavy metals in mined soil can be grouped as essential heavy metals (Zn, Cu and Fe), which play a crucial role in plants and non-essential heavy metals including Pb and Cd which do not play any important role in plants but are dangerous to cell metabolism. In most soils, copper in the form of copper ion (Cu^{2+}) is bound to clay minerals as well as organic matter. Copper bioavailability is influenced by organic matter and the pH of the mined soil. Increased levels of soil organic matter decrease the bioavailability of copper. Also, at high soil pH, both organic matter and clay particles bind copper thereby reducing copper availability. Copper phytotoxicity for plants, depending on the phenotype and soil pH, occurs above 50 mg kg^{-1} (Taariq-Sidibe *et al.*, 2020). Lead contamination occurs in the environment in an insoluble form. Since Pb^{2+} is not biodegradable, it remains in contaminated mined soil for a long time. Lead accumulates in the topsoil with little mobility due to its binding by soil organic matter (Abubakar, 2015). Study by Kabata-Pendias (2011), demonstrated that both soil organic matter and clay minerals are involved in lead (Pb) adsorption in both mined and unmined soils. Also, lead (Pb) mobility is increased by soil factors such as high acidity and the formation of lead–soil organic matter complexes. Arsenic (As) in soils usually forms both organic and inorganic arsenic compounds by combining with other elements (National Groundwater Association, 2001). Arsenic concentration in soil ranges between 0.1 – 40 mg kg^{-1}, however, the overall mean value for various soil is projected as 6.83 mg kg^{-1} (Kabata-Pendias, 2011). Though arsenic which usually exists as an anion, is very soluble in water, it is less mobile due to strong binding by clay, hydroxides and soil organic matter (Kabata-Pendias, 2011). The bioavailability of arsenic, an environmental contaminant with high toxicity to humans and other living organisms, is increased by high soil pH (Sadiq *et al*., 1983). It has been documented that, phytotoxic levels of arsenic (As) in soil occur between 15 – 315 mgkg^{-1} (Kabata – Pendias, 1992). These heavy metals obtained from the crushed bedrock become available for plant absorption, after mineral processing and dissolution in rainwater. Water soluble salts and ions in the soil indicate the electrical conductivity of mined soil and available mineral nutrients in the soil for plant uptake. Afiesa, a neighbouring town of Kyebi-Apapam, is located in the Abuakwa South Municipal Assembly and lies at a longitude and latitude of 6º09’36.6” N, 0º35’51.0” W respectively. The Municipal Assembly is demarcated by five districts including Abuakwa North, Ayensuano, New Juaben North, Suhum and Atiwa West. (www.asmagov.gh). Afiesa, found in a western semi-equatorial area, has a vegetation of moist semi-deciduous forests with dual rainfall peaks in June and October. It receives 125 – 175 mm of rainfall on average yearly. The region experiences mostly constant temperatures, which vary from 26°C to 30°C in August to March respectively. The percentage of moisture in the air is often high year-round, ranging from 70% to 80% throughout the dry season and from 70% to 85% during the wet season (www.asmagov.gh). This study site was chosen because mining activities are rife in the area. The presence of community mining as well as an illegal small-scale mining (*galamsey*) which has a high possibility of polluting the soil makes it a suitable area for identifying plants for phytoremediation.

For soil to sustain plant growth important plant nutrients and physico-chemical properties of the soil must be optimal. However, mined-out soil has been shown to lack vital plant nutrients and possess both physical and chemical properties that exceed or are below WHO recommended standard values. Additionally, high levels of heavy metals have been identified in mined soil and mined-out areas, which makes it a threat to both plants and animals. Hence there is the need to assess these degraded soils for their quality for plant growth and if possible, remediate the soil. This study is aimed at analysing mined-out soil in the eastern region of Ghana for selected physical and chemical properties.

MATERIALS AND METHODS

Location of the Study Site

Figure 1: Akyem Abuakwa South Municipal in Ghana

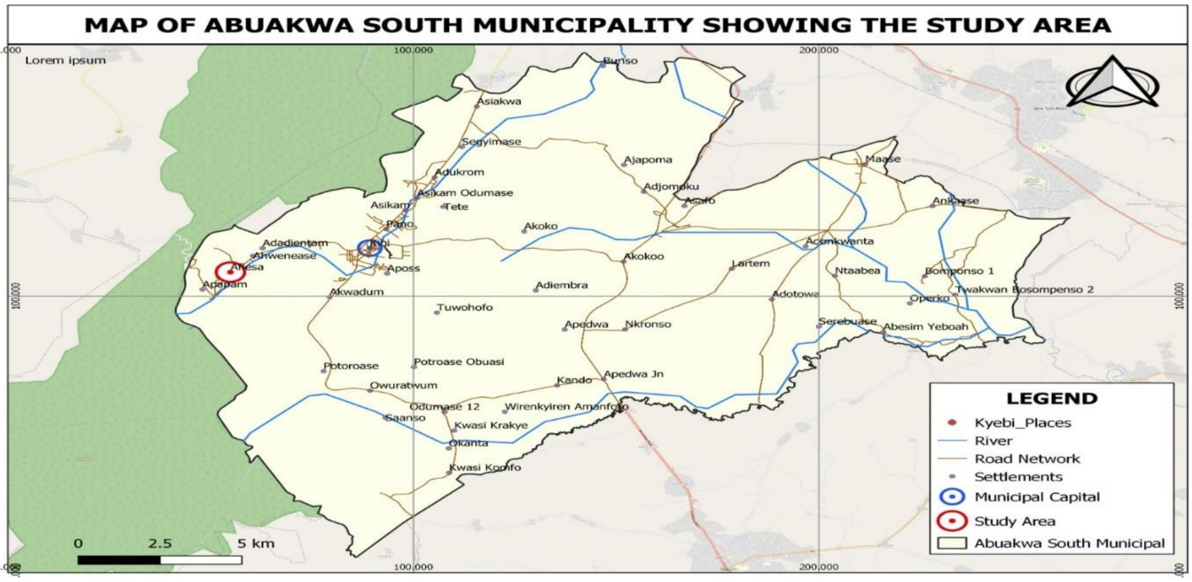

Figure 2: Afiesa, in the Municipal Area

Sample Collection

The sampling was carried out on different points of five plots each covering an area of 25 m^2 within a mined-out area. Mined soil samples within a depth of 15 – 30 cm were collected into polyethylene bags. Soil samples from an undisturbed/reference area were also collected similarly (Petelka *et al.*, 2019).

Sample Preparation

The reference and mined soil samples were separately air-dried for a week and then homogenized using the hands to remove unwanted plant materials present in them. The homogenized soil samples were then oven-dried to a constant of weight 60 º C for 72 hours. A 250 g each of the oven-dried samples were pulverized using mortar and pestle after which the pulverized samples were sieved using a 2 mm fine mesh to eliminate coarse particles (Nkansah & Belford, 2017).

Soil pH Determination

A suspension of soil to water in the ratio 1:2.5 was prepared for the determination of the soil pH as adopted by Nkansah and Belford (2017). The suspension was shaken manually for 60 min at 10-minute intervals to permit the dissolution of soluble salt and subsequent exchange between ions to attain equilibrium before pH was measured using the pH meter (HQ 440d multi-parameter meter).

Soil Particle Size and Soil Texture

The Bouyoucos hydrometer method was used to determine the distribution of particle sizes for texture evaluation. First, 40 g of soil that had passed through a 2 mm sieve was carefully weighed and put into an extraction bottle. Next, 100 ml of a 5% solution of Calgon (sodium hexametaphosphate) was added to the bottle. The mixture was then subjected to mechanical agitation for a duration of 30 minutes. Following this, the resulting suspension was transferred to a graduated sedimentation cylinder with a capacity of 1 litre. To reach the 1-liter mark, distilled water was added to the suspension. A plunger was then inserted into the cylinder to vigorously stir the suspension continually by moving it up and down for about 30 oscillations. Hydrometer readings were recorded initially at 45 minutes, followed by another reading after 5 minutes (to determine silt content), and finally at 5 hours (for clay content). The sand fraction was separated by sieving the suspension through a 0.2 mm sieve. The collected material on the sieve was rinsed with potable water, and the remaining portion was oven-dried at 105°C for a duration of 24 hrs. After oven drying, the samples were retrieved, allowed to cool in desiccators, and subsequently weighed. The proportions of sand, silt, and clay in the soil were then determined using the following equations:

$$\textbf{Silt (\%) + clay (\%)} = \frac{\textbf{corrected hydrometer reading at 5 minutes} \times \textbf{100}}{\textbf{Sample weight (g)}} \text{(Equation 1)}$$

$$\textbf{Clay (\%)} = \frac{\textbf{corrected hydrometer reading at 5 hours} \times \textbf{100}}{\textbf{Sample weight (g)}}$$

………………….. (Equation 2)

$$\textbf{Silt (\%)} = \frac{\textbf{corrected hydrometer reading at 5 minutes} \times \textbf{100}}{\textbf{Sample weight (g)}} - \frac{\textbf{corrected hydrometer reading at 5 hours} \times \textbf{100}}{\textbf{Sample weight (g)}}$$

…(Equation 3)

$$\textbf{Sand (\%)} = \textbf{100} - \frac{\textbf{corrected hydrometer reading at 5 minutes} \times \textbf{100}}{\textbf{Sample weight (g)}}$$

…………………….. (Equation 4)

The soil texture was determined from the textural triangle (USDA) using the percentages of sand, clay and silt (Oyibo, 2013).

Soil Porosity

To obtain the soil porosity, the bulk density was first determined. Soil samples were obtained using the core sampler. The core sampler was driven into the soil and the soil sample was obtained for the different samples aggregated. The aggregated sample was air-dried and weighed. The bulk density was then calculated using; BD = $\frac{Ms}{Vt}$ where Ms = mass of dried soil sample and Vt = total volume of the core sampler. The porosity of the soil sample was determined as the inverse of the bulk density. It was arrived at using the formula; $P\% = [1 - (\frac{BD}{PD})\ x\ 100]$ where P = porosity, BD = Bulk density and PD = particle density (Normal particle density = 2.65).

Total Nitrogen

Determination of total nitrogen was carried out using the method adopted by Abubakar (2015). A 0.5 g dried and pulverized soil sample was weighed into a 100 ml Kjedahl flask. A quantity of 2 g Kjedahl catalyst consisting of Selenium, Copper (II) sulphate and sodium sulphate in the ratio of 1:10:100 respectively was added followed by 5 ml of conc H_2SO_4. After digesting the mixture, a clear and colourless solution was obtained which was cooled and then decanted into a 100 ml volumetric flask. This was diluted up to the 100 ml mark with distilled water. A volume of this digestate was pipetted into a Kjedahl distillation apparatus and 10 ml NaOH was added. The mixture was distilled over boric acid and about 75 ml of the distillate was collected. The distillate was titrated with 0.02 N HCl till the initial blue colour was discharged to grey and then to pink. Digestion blanks were prepared, and the total nitrogen was calculated as follows

$\boldsymbol{N} = \frac{(\boldsymbol{S}-\boldsymbol{B}) \times \boldsymbol{solution\ volume}}{\boldsymbol{102} \times \boldsymbol{aliquot} \times \boldsymbol{sample\ weight}}$, where **S** = titre value of sample and **B** = titre value of blank.

Total Carbon and Soil Organic Matter

Total carbon and soil organic matter were carried out using a procedure adapted by Oyibo (2013). 0.5 g of dried soil sample was sieved into a 250 ml flask containing 10 ml of dichromate solution. To this mixture, 20 ml of conc H_2SO_4 was added, swirled and allowed to stand for 30 min. A volume of 200 ml of distilled water was added to this mixture, followed by 10 ml of orthophosphoric acid. A barium diphenylamine indicator was added, and the mixture was titrated with Fe $(NH4)_2(SO4)_2$ solution from blue to green endpoint. The percentage of carbon was determined using the titre value as follows;

$\boldsymbol{\%\ C} = \frac{[\ \boldsymbol{10} - (\boldsymbol{XN})\ \boldsymbol{x}\ \boldsymbol{0.3}]}{\boldsymbol{W}}$,

where 10 = dichromate volume, **X** = ml of Fe $(NH4)_2(SO4)_2$ solution and **N** = normality of soil sample in grams. The soil organic matter was determined using the formula;

% Soil organic matter = %C x 1.724, where 1.724 is the conversion factor.

Electrical Conductivity Determination (EC)

The EC of soil was measured by preparing a soil/water suspension ratio of 1:2. A quantity of 15 g air-dried and sieved soil sample was weighed and mixed with 30 ml of distilled water in a beaker. A 25-minute stirring of the mixture was done and then left to stand for a further 10 minutes for it to settle. An HQ440d multi-parameter electrical conductivity meter was calibrated at 25° C. The cell of the meter was lowered into the mixture and moved up and down devoid of any disruption of the settled sediments. The readings were noted after the electrical conductivity meter had stabilized (Oyibo, 2013).

Soil Heavy Metal Analysis

Soil samples for digestion and subsequent analysis of total Pb, As and Cu were first ashed in an oven at 65° C for 1½ hours. The dried soil sample was crushed using a mortar and pestle and sieved through a 200 mm metallic mesh sieve. For heavy metal determination, 1 g of the sieved soil sample was weighed into a beaker and 3:1 ratio aqua regia (3 ml of HCl and 1 ml of concentrated HNO_3) was added. The mixture was heated on a hot plate at 100° C for 10 minutes and then cooled at room temperature. The samples were diluted with 50 ml deionized water, filtered with a Whatman filter paper (Grade No. 41) and then analysed for total Pb, As and Co using an Agilent 4210 MP AES Spectrophotometer (Nkansah & Belford, 2017).

Statistical Evaluation

A Pearson correlation matrix was used to determine the mean difference between heavy metals and soil properties using Microsoft Excel (2019). A p-value less than 0.05 was seen as statistically significant.

RESULTS AND DISCUSSION

Soil Properties

The composite mined-out soil sample was found to be a little acidic with a pH value of 6.00 ± 0.01 compared to the reference soil which was less acidic with a pH of 6.53 ± 0.05 (Table 1). The mean difference between the composite soil pH and the pH of the reference soil was found to be significant (T-test score = 11.0192, $p < 0.05$, df = 4) with a difference of 0.53. The available soil organic matter (SOM) and total nitrogen were low (4.71 ± 0.11 g/kg and 0.24 ± 0.20 g/kg respectively) for the mined-out soil as compared to 7.32 ± 0.01 g/kg and 1.15 ± 0.20 g/kg respectively for the reference/control soil (Table 1). The composite mined-out sample was characterized by a loamy silt soil texture compared to the reference soil sample which has a loamy soil texture. Additionally, the composite mined-out soil sample was highly porous with larger particle size (40.0 % ± 0.10%, 2.00 mm respectively) compared to the reference/control soil (35.3% ± 0.10%, 0.42 mm respectively). Also, the electrical conductivities (EC) were both low though the reference soil had a relatively higher EC (36.9 mS/m) than the composite soil (12.88 mS/m).

Table 1: Physicochemical properties of reference and composite soil samples.

Parameters	Composite mined-out soil	Reference soil
pH	6.00 ± 0.01	6.53± 0.01
Soil texture	Loamy silt	Loamy
Porosity	40.50 ± 0.10 %	35.3 ± 0.10 %
Total soil organic matter	4.71 ± 0.11 gkg^{-1}	7.32 ± 0.01 gkg^{-1}
Total nitrogen	0.24 ± 0.01 gkg^{-1}	1.15 ± 0.20 gkg^{-1}
Soil particle size	2.00 mm	0.42 mm
Electrical conductivity (EC)	12.88 mSm^{-1}	36.90 mSm^{-1}

The pH value of 6.0 for the composite mined-out soil was lower than that of the reference/control soil (pH 6.53). This was consistent with pH values (5.11 - 7.12) obtained for mined soil /tailings by Bansah and Addo (2016). However, it was lower when compared with the reported pH values of 7.08 by Nkansah and Belford (2017) and 6.12 – 7.85 by Bempah *et al.* (2013) as well as the pH standard suggested for plant growth. Whiles a study by Mkumbo *et al.* (2012) found much lower pH values ranging from 3.5 to 7.3 in a gold mine located in Tanzania, the pH of the reference soil on the other hand was comparable to the Agricultural standard pH value of 6.0 – 8.0. The pH of the mined soil indicates the quality of the soil. As a result, mined soils containing pyrites undergo oxidation to produce sulphuric acids which lowers the pH of the mined soil. When the pH falls below 5.5, plant nutrients reduce while heavy metal becomes available thereby reducing plant growth (Sheoran *et al.*, 2010). According to Clemente *et* al, (2003), soil pH is a key factor that determines the movement and bioavailability of heavy metals in soil. This proposal is evident in the results obtained for the composite mined-out soil. The mined-out composite soil with a lower pH (<6.5) gave relatively higher concentrations of heavy metals indicating moderate levels and movement of bioavailable heavy metals whereas the reference soil with higher pH (> 6.5) indicating low movement and availability of heavy metals in the soil for plant absorption.

Mined soils which are characterized by sandy texture cannot hold much water and nutrients (Ghose, 2005). Sandy soils have high porosity compared to fine-textured soils like loam and silts. The composite mined-out soil was identified to be silt loamy with a porosity of 40.50% ± 0.10 compared to the reference soil which is loamy with a porosity of 35.30 % ± 0.10 (Table 1). The silt loamy soil with finer texture usually contains high levels of soluble salts. Silt loamy soils are predominant in mined soils having a lot of siltstones (Ghose, 2005).

Soil organic matter (SOM) has been identified to greatly influence the physical and chemical characteristics of soil by binding to metals and metalloids in the soil and hence controls their retention in the soil (Liu *et al.*, 2014). The composite mined-out soil had less SOM compared to the reference soil (Table 2). Mined soils are usually degraded with little SOM, consequently, the metal/metalloids are usually available in the soil for plant uptake compared to reference soil with relatively high SOM (Table 1). However, as vegetation increases in the mined-out soils with increased biological activities, the SOM begins to increase (Mkumbo *et al.*, 2012) hence the observed value of 4.71 ± 0.11g/kg (Table 1).

The mined-out soil in the study showed a low level of nitrogen compared to the undisturbed /reference soil with values of 0.24 ± 0.20gkg^{-1} and 1.15 ± 0.20gkg^{-1} respectively (Table 1). The low levels of nitrogen in the mined soil could be attributed to the destruction of vegetation as well as nitrogen-fixing microorganisms. Revegetation of these mined soils results in a gradual increase in nitrogen as nitrogen-fixing microbes become available. SOM also serves as a source of nitrogen in the soil (Sheoran *et al*., 2010), as a result, the low level in the mined soil could be attributed to the low SOM of the mined soil. The mined soil had low salinity (low EC) indicating poor fertility as a result of soil degradation from the mining activities.

Total Heavy Metal Concentration in Soil

Concentrations of As, Cu and Pb measured in the reference soil and composite mined-out soil samples are presented in Table 2. Total Arsenic, Copper and Lead concentrations in the composite mined-out soil exceeded that of the reference soil. The total Lead concentration in the composite mined-out soil was found to be 1.233 times greater than in the reference soil. The contamination factor for each of the metals was greater than 1. Also, the degree of contamination of the mined-out soil was found to be 5.839.

Table 2: Concentration of selected heavy metal/metalloid in composite mined-out soil and reference sample

Sample	**Concentration in ppm**			**Degree of contamination (C_{degree})**
	As	**Cu**	**Pb**	
Composite mined-out soil	11.84 ±1.01	36.42 ± 3.24	13.97 ±1.00	5.839
Reference soil	8.39 ± 0.25	11.40 ± 0.99	11.33 ±1.10	
WHO/FAO (2001)	**20**	**100**	**50**	
Contamination factor (C_f)	1.411	3.195	1.233	

The concentrations of heavy metal analysed (As, Cu and Pb) were all higher than the recorded values for the baseline/reference soil (Table 2). Copper (Cu) was found to be the major pollutant among the heavy metals analysed with a contamination factor of 3.195. The Lead concentration in the mined soil (13.97 mg/kg) exceeded the reference soil concentration but was lower than the WHO/FAO (2001) permissible value of 50 mg/kg for soils. The background/baseline value of 11.33 mg/kg indicates a lower level of the metal in the unmined or revegetated soil in the area when compared to the WHO/FAO (2001) recommended value of 50 mg/kg. The observed level of Pb in both reference and mined soils may stem from the fact that, the natural mineral form of lead, lead (II) sulphide (PbS), in the soil is usually obtained in association with gold ore (Petelka *et al*., 2019). The concentration of Lead in the present study was lower than the range of 24-39 mg/kg reported by Antwi-Agyei *et al.* (2009). It has been shown that, Lead occurs in higher concentration in the topsoil of most contaminated soil with reduced mobility. However, low pH increases the mobility of the Lead in the mined soil (Abubakar, 2015) which is consistent with the result obtained. High Lead concentration in soil poses serious health concerns as Lead is a poisonous metal even in low concentrations. The copper concentration obtained was below the WHO/FAO (2001) permissible limits of 100 mg/kg, though higher than reference soil Cu levels (Table 2). Mined gold ores are usually associated with copper as an impurity hence its presence in the mined soils (Fashola *et al*., 2016). High copper concentrations in mined soils have been reported in Ghana by Antwi-Agyei *et al*. (2009) at 39.46 – 71.44 mg/kg and by Bempah *et al*. (2013) at 92.17 mg/kg. The arsenic concentration recorded for this study (11.839 mg/kg) was lower than the WHO/FAO (2001) recommended limit of 20 mg/kg but higher than the baseline/reference value (Table 2). Arsenic is present in the form of arsenopyrite which is mined along with gold ore. This is then released into the environment when the gold ore is processed for gold (Petelka *et al*., 2019). The arsenic levels obtained in the study were much lower compared to a reported value of 1752 mg/kg by Bempah *et al*. (2013). All three heavy metals analysed gave a contamination factor greater than 1 showing that the mined-out soil was medially contaminated by each metal (Muller, 1969). Moreover, the degree of contamination of the mined-out soil (5.839) indicated the soil under investigation was less contaminated (Hakanson, 1980).

Analysis of Correlation for Composite Soil

Table 3 presents the results of the Pearson correlation coefficient matrix generated for the composite soil sample's heavy metals (As, Cu, and Pb), soil organic matter (SOM), total nitrogen (TN), pH, and electrical conductivity (EC). SOM positively and substantially correlates with total nitrogen, As and Cu (r = 0.8781, 0.9959 and 0.8785 respectively), according to the statistical results of the correlation analysis. Additionally, total nitrogen, showed a strong positive connection with As and Cu (r = 0.9176 and 0.9999 respectively). There was a negative correlation between Pb, As and Cu, but a positive and robust relation between Cu and As. An insignificant and inverse connection (r = - 0.1321) was found between Pb and EC. There was a negative and weak link between pH, As and SOM but a strong inverse relationship with regard to Cu and TN. A slight positive relation was also seen between pH and Pb. Except for pH, there was an inverse relationship between EC and SOM, TN, As, Cu and Pb.

Table 3: Pearson correlation matrix for composite mined soil properties

	pH	SOM	T N	As	Cu	Pb	EC
pH	1						
SOM	-0.2409	1					
TN	-0.6758	0.8781*	1				
As	-0.3273	0.9959*	0.9176*	1			
Cu	-0.6751	0.8785*	0.9999*	0.9180*	1		
Pb	-0.3170	-0.8441	-0.4847	-0.7924	-0.4855	1	
EC	0.9819*	-0.4199	-0.8029	-0.5000	-0.8024	-0.1321	1

The correlation is significant at 0.05.

Heavy metal availability and mobility in soil are influenced by several factors, including pH, SOM, soil texture (Liu *et al.,* 2014). From this study, there is a strong and positive correlation between heavy metals (As, Cu, and Pb), soil organic matter (SOM) and total nitrogen (TN). As soil microbes break down SOM, high levels of nitrogen are obtained, hence high SOM has a positive relationship with total nitrogen. Additionally, the strong binding of SOM to the heavy metals may be the cause of the positive connection with some heavy metals (As and Cu), as this binding lowers the bioavailability and mobility of the heavy metals in the soil. Given that the current study identified the total heavy metal, it is plausible that the high SOM was associated with the high heavy metal concentration in the soil under investigation. The relationships between pH and SOM, EC, As, Cu, Pb and total nitrogen were all negative. It is well known that topsoil has greater SOM, which breaks down to reduce pH. The reason for the inverse relationship between pH, As and Cu could be that when pH rises, the solubility of As and Cu minerals decreases and vice versa. Cu and As had a strong positive association with one another. This suggests that the source of the two heavy metals may be identical to each other since they are both associated to gold ores. Furthermore, the same environmental conditions that influence these heavy metals' bioavailability are present. While there was a positive link with pH, EC exhibited a negative relationship with pH, SOM, Cu, Pb and As. Furthermore, EC and SOM have an inverse relationship. Low EC causes less soil breakdown, which lessens the amount of humus that builds up in the soil.

CONCLUSION

The results of this study showed that the mine-out soil, which was characterized by loamy silt soil texture with high porosity and elevated level of Pb, had low EC, As, Cu and reduced total nitrogen soil organic matter (SOM). This implies that the mined soil is greatly impacted. The concentration of both As and Cu in the mined soil is not alarming as they are both below the WHO/FAO (2001) recommended values of 20 ppm, 100 ppm and 50 ppm for As, Cu and Pb respectively. Although, the concentration of Pb is above the background/reference value (11.33ppm) it is below the WHO/FAO (2001) recommended standards of 50 ppm, hence it does not pose an environmental or health hazard. The study showed that the mined-out soil is not overly degraded and can be used for crop production with little soil remediation to reduce the levels of lead which may poses environmental hazards at high levels. Thus, the findings of this study will aid decision making on how the soil in the adjoining environment can be remediated to improve its use for agriculture.

DECLARATION

1. **Ethical Approval**
   Not applicable
2. **Consent to Publish**
   All authors have given their approval for the article to be published.
3. **Authors contributions**
   Conceptualization and design of the study were done by both authors. Material preparation, data collection and analysis were performed by Patrick Andrews Okoh. The first draft of the manuscript was written by Patrick Andrews Okoh. Review and editing were done by Hilary Domakyaara Zakpaa. All authors read and approved the final manuscript.

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