

## Geochemical Assessment of the Impact of Mine Tailings Reclamation on the Quality of Soils at AngloGold Concession, Obuasi, Ghana

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**Abstract:** This study assessed the geochemical impact of mine tailings reclamation on the quality of soils from the AngloGold Concession, Obuasi, Ghana. Soil samples from mine tailings reclamation sites were evaluated for the concentrations of plant nutrients and trace metals. Contaminations of trace metals, using geochemical pollution indices were used to assess possible effects on agriculture and livelihoods. The average pH ranges from 7.6 to 8.4 at the ex-tailing sites while the control site is 6.0. Organic carbon and nitrogen levels at the ex-tailings site are low due to topsoil loss. Average available P and K levels were low or very low; i.e., <20 and <40 mg/kg, respectively at both ex-tailing and control sites. Average EC values as well as individual values of all the soils were less than 2 dS/m, while average ESP and individual soil values were less than 15%, indicating that the soils are non saline. Average ECEC levels, contributed by Ca and Mg, are medium at the ex-tailing sites but low at the control sites. The concentrations of arsenic (As), copper (Cu), lead (Pb) and zinc (Zn) were compared to their respective background concentrations to calculate their contamination factors and geo-accumulation indices at all the examined areas. Average concentration values for As are consistently high; presenting the highest value of 426.67 mg/kg at Area 3 and the least of 72.03 mg/kg at the control site, above the Netherlands soil/sediment intervention guideline value of 55 mg/kg for remediation. Furthermore, estimates from the geochemical evaluations indicated that As contamination was very high and therefore poses a threat to agricultural land use as well as general environmental quality.

**Key words:** Contamination factor, geo-accumulation index, heavy metals, mine tailings, mined soils, pollution load index

### INTRODUCTION

The metal content in soil is a sum of metals originating from natural processes and human activity. It is estimated that the contribution of metals from anthropogenic sources in soil is higher than the contribution from natural ones (Nriagu and Pacyna, 1988). Anthropogenic activities such as mining and smelting of metal ores have increased the prevalence and occurrence of heavy/trace metal contamination at the earth's surface.

Open cast mining, which generates large amounts of sulfide-rich tailings (Bhattacharya *et al.*, 2006) has a serious environmental impact on the quality of soils and surface water due to pollution. In general, mined soils are mechanically, physically, chemically and biologically deficient (Vega *et al.*, 2006), characterized by instability and limited cohesion, with low contents of nutrients and organic matter and high levels of heavy metals (He *et al.*,

2005). Apart from the local disturbance of the physical properties, toxic metals can cause a more widespread contamination of soil, sediments and food crops leading eventually to a loss of biodiversity and a potential health risk to residents in the vicinity of the mining area (Verner and Ramsey, 1996; Lee *et al.*, 2001; Zhang *et al.*, 2002; Galan *et al.*, 2003).

Studies on heavy metal pollution in various environments within mining communities in Ghana have been undertaken during the last few decades (Amasa, 1975; Carboo and Serfo-Armah, 1997; Hilson, 2002; Adimado and Amegbey, 2003; Golow and Adzei, 2002; Manu *et al.*, 2004; Essumang *et al.*, 2007; Obiri, 2007; Yidana *et al.*, 2008; Armah *et al.*, 2010; Nude *et al.*, 2011). However, information on the impact of mining operations on contamination of soil environments, which serve as the main sink of pollutants are very limited (Golow and Adzei, 2002; Dorgbetor, 2010).

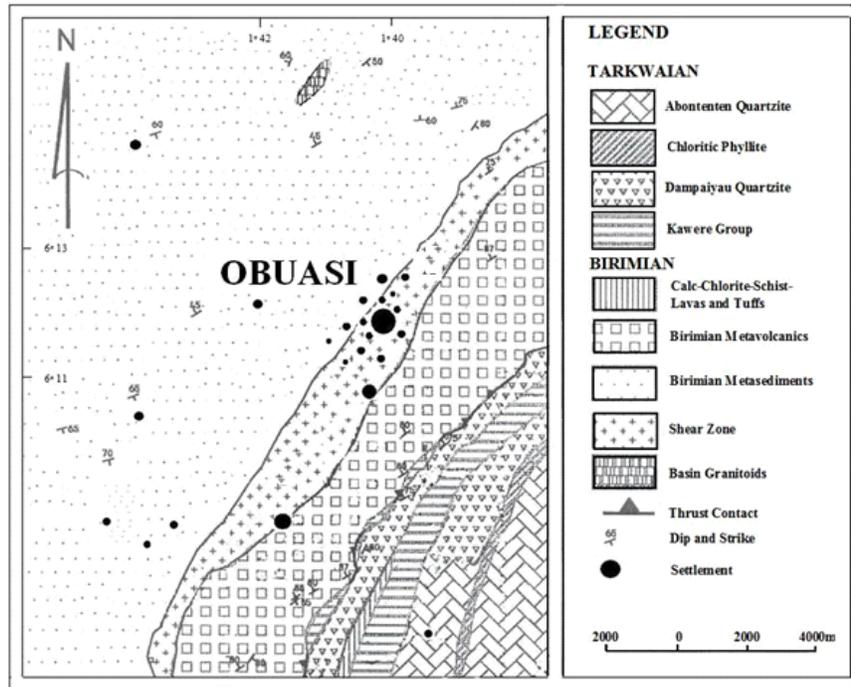


Fig. 1: Geological sketch map of the study area (Kesse, 1985; Foli *et al.*, 2011)

Interest in assessing the geochemical impact of heavy metals on soil quality has been stimulated by increasing awareness that soil is a critically important component of the earth's biosphere, functioning not only in the production of food and fiber but also in the maintenance of local, regional and global environmental quality. Soil is also the basis of agricultural and of natural plant communities. Thus, the thin layer of soil covering the surface of the earth represents the difference between survival and extinction for most land-based life (Doran and Parkin, 1996).

Geochemical assessment of the impact of contaminants on stream sediments in the Obuasi mining area was recently evaluated using relevant evaluating indices (Nude *et al.*, 2011). Use of this approach in evaluating the quality of mined soils has received little attention. The levels of plant nutrients and other heavy or trace metals that might have leached from the tailings into the soil to adversely affect quality of the soil are real. The objective of this study was, therefore, to assess the effect of mine tailings reclamation on the quality of soils using geochemical indices.

## MATERIALS AND METHODS

**Environmental characteristics:** The study was conducted at the AngloGold concession at Obuasi area, Ghana. Obuasi is located between latitude 5.35 and

5.65°N and longitude 6.35 and 6.90°W (Fig. 1) within the semi-deciduous ecological zone of Ghana. The climate is of the semi-equatorial type with a double rainfall regime. Total annual rainfall is about 1700 mm. Mean average annual temperature is 25.5°C and relative humidity is 75-80% in the wet season.

The area is underlain by metavolcanic, pyroclastic and metasedimentary rocks (Fig. 1). The metavolcanic rocks are of basaltic and gabbroic in compositions whereas the metasedimentary rocks are mainly tuffaceous and carbonaceous phyllites, tuff, cherts and manganese sediments. These two units are contemporaneous and separated by a major shear zone. Intruding the metavolcanic and metasedimentary rocks are magmatic bodies and porphyritic granitoids consisting of hornblende-rich varieties that are closely associated with the volcanic rocks, and mica-rich varieties which are found in the metasediment units (Kesse, 1985). The Birimian is overlain by the Tarkwaian rocks made up of sedimentary units and also recent alluvial deposits. Gold ores contain high sulphide minerals, made up mainly of arsenopyrite and pyrite (Osae *et al.*, 1995).

The top 30-80 m of the subsurface is made up of porous rocks that mark the water table in the area (Foli and Nude, 2012). Rock porosity ranges from 1.0-5.0  $\times 10^{-7}$  m/s (Kumapley, 1993). These rocks have undergone some degree of weathering and consist mainly of clay deposits which have subsequently been hardened and

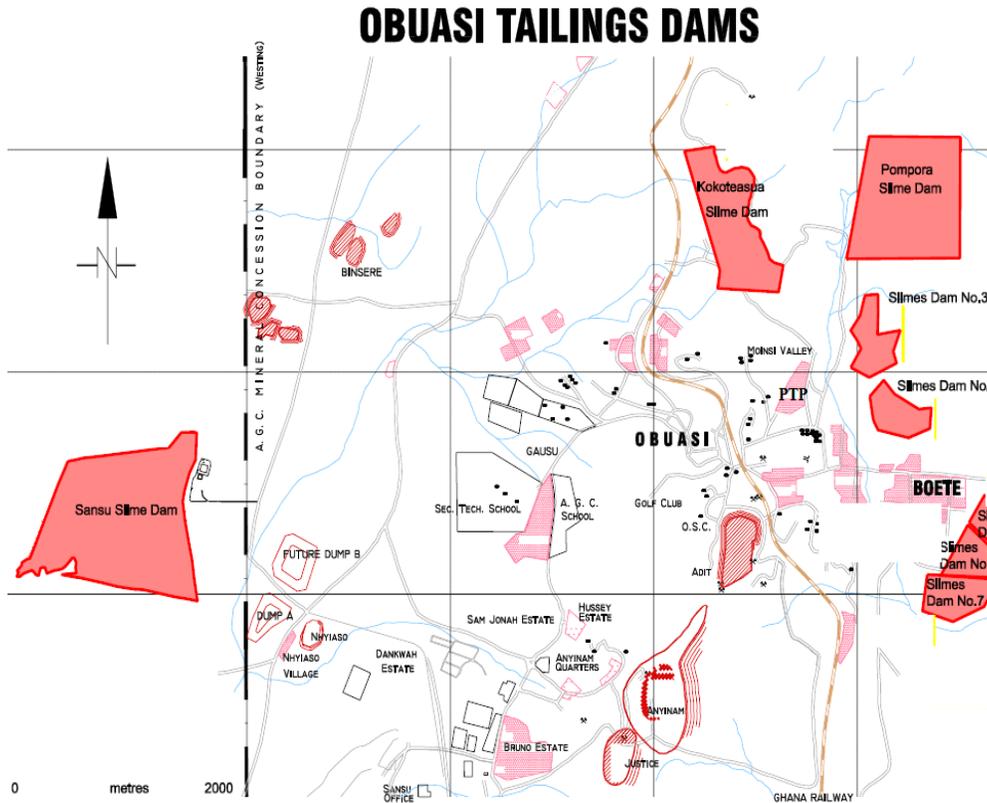


Fig. 2: Sketch map of Obuasi area showing tailing dams and sampling sites

altered. A cross section of the hills along the roads reveals the presence of an uneven distribution of quartz veins injected into the phyllites which break up on weathering to give rise to pisolithic and gravelly pebbles. The topography of Obuasi and its environs varies from gently undulating to hilly. There are moderately high-elevated lands with lowlands and valleys between them. The highlands trend in different directions; they have flat and plateau tops and are generally amorphous in their shapes.

**Soils, sites and sampling:** The dominant soils within the study area are the Bekwai-Nzima-Kokofu compound association. On a typical toposequence, Bekwai and Nzima series (Ferric Acrisols) occupy the summit and upper slope sites followed by Kokofu series (Haplic Acrisol) at middle to lower slope sites. Both the Bekwai and Nzima series are developed from in-situ weathered phyllite parent material and are well drained with few angular quartz gravel and common manganese dioxide concretions below the top soil. The two soils have strong brown to yellowish brown top soil grading into dark red to red for Bekwai series and yellowish brown to yellowish red for Nzima series in the sub soil. The Kokofu series, developed from colluvial material, are also very deep,

imperfectly drained, yellowish brown top soil over strong brown to brownish yellow sub soil free from gravel and concretions.

Six sampling sites namely, Dams 1, 2, 3, 4 and 5 and a control (uncontaminated site) were selected for this study (Fig. 2). These six sites have been reclassified for this study to facilitate easy evaluation of pollution indices. Area 1 (Dams 1 and 2 or sites 1 and 2) contained tailings that were generated from crude methods of metal beneficiation (period of little environmental concern). Area 2 (Kokoteasua slime Dam or site 3) contained tailings generated from improved technological methods of metallurgical activities (period of major environmental concern). Area 3 (PTP or site 4) contained materials from active ore treatment processes (period of little environmental concern). Area 4 (Dam No. 5 or site 5) contained tailings generated mostly from reworked tailings from Area 3. The Control site constitutes the last area and is at about 16.1 km away from the perceived pollution hotspot, which is the former PTP area. All the sites are located on the Bekwai series (Ferric Acrisols). Ten spots were selected randomly at each study site for sampling using soil auger and chisel hoe. Mini pits were dug at selected points, the soils were identified by the series name and sampled at two depths of 0-20 and 20-50 cm.

**Laboratory analyses:** Laboratory analyses were carried on selected soil properties. Particle size distribution was determined using the modified Bouyoucos hydrometer (Day, 1965). Soil pH and Electrical Conductivity (EC) were determined by glass electrode in a soil-water ratio of 1:2.5. Soil organic carbon was measured by the dry combustion method involving the use of the Carbon Analyzer. Total nitrogen was determined by the acid digestion Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was determined by the method of Bray and Kurtz (1945). Exchangeable bases were determined by extraction with 1 M ammonium acetate (NH<sub>4</sub>OAc, pH 7) followed by analyses for Ca and Mg by Atomic Absorption Spectrometry and Na and K by flame photometry. Exchange acidity was determined using the KCl extraction method (Thomas, 1982). Heavy/trace metals in the soil samples were extracted using nitric acid digestion and their concentration determined using Atomic Absorption Spectrometry. Cyanide concentration was determined using ion selective electrode.

**Geochemical calculations:** With the development of ecological geochemistry survey and exploration geochemistry survey, a great deal of data related to heavy metal concentration in soils and aquatic sediments have been measured which can be used to assess the quality of ecological and geochemical environments. Many calculation methods have been presented to assess the environmental quality; one of such important methods is the pollution index (Qingjie *et al.*, 2008), which is used to assess the level or degree of contamination in soils and sediments. The PLI outlined by Kumar and Edward (2009) and Mohiuddin *et al.* (2010) is given by the equation:

$$PLI_{for\ site} = \sqrt[n]{CF \times CF \dots CF_n} \quad (1)$$

where CF Eq. (2) is the contamination factor and *n* is the number of contamination factor and sites, respectively.

$$CF = \frac{C_n}{B_n}; (I_{geo}) = \log_2 \frac{C_n}{1.5 \cdot B_n} \quad (\text{Mohiuddin } et\ al., 2010) \quad (2)$$

where *C<sub>n</sub>* is the measured concentration of element *n* in the soil, *B<sub>n</sub>* is the geochemical background for the element *n*, which is often cited from published data (Mohiuddin *et al.*, 2010) and *I<sub>geo</sub>* is geo-accumulation index, which is defined as:

$$I_{geo} = \log_2 \frac{C_i}{1.5 C_{ri}} \quad (3)$$

where *C<sub>i</sub>* is the measured concentration of the examined metal *i* in the sediment, and *C<sub>ri</sub>* is the geochemical

Table 1: Particle size distribution (mean of three samples) and texture of the soils

| Area       | Depth (cm) | Particle size distribution (%) |      |      | Texture         |
|------------|------------|--------------------------------|------|------|-----------------|
|            |            | Sand                           | Silt | Clay |                 |
| 1 (site 1) | 0-20       | 28                             | 53   | 19   | silty loam      |
|            | 20-50      | 20                             | 21   | 59   | clay            |
| 1 (site 2) | 0-20       | 15                             | 68   | 17   | silty loam      |
|            | 20-50      | 20                             | 29   | 51   | clay            |
| 2 (site 3) | 0-20       | 12                             | 56   | 32   | silty clay loam |
|            | 20-50      | 15                             | 33   | 62   | clay            |
| 3 (site 4) | 0-20       | 30                             | 20   | 50   | clay            |
|            | 20-50      | 24                             | 21   | 55   | clay            |
| 4 (site 5) | 0-20       | 9                              | 21   | 70   | clay            |
|            | 20-50      | 7                              | 16   | 77   | clay            |
| Control    | 0-20       | 27                             | 32   | 41   | silty clay loam |
|            | 20-50      | 23                             | 22   | 55   | silty clay      |

background concentration or reference value of the metal *i*. The factor or constant 1.5 allows for the analysis of possible variations in background values for a given metal in the environment as well as very small anthropogenic influences (Loska *et al.*, 2004; Qingjie *et al.*, 2008).

## RESULTS AND DISCUSSION

**General soil properties:** Data on particle size distribution are presented in Table 1. The texture of soils at the Control site is silty clay loam in the surface and silty clay in the subsurface. Due to disturbance, the texture of soils at the five tailing sites did not reflect that of the control. The average pH ranges from 7.6 to 8.4 at the ex-tailing sites while the control site is 6.0 (Table 2a, b). However, at one of the spots in Area 1 (sites 1 and 2), the pH value recorded was 4.8 and 5.1 (very strongly acidic) for the sub and top soils, respectively. Within pH range of 5.8-6.5, acidity is present (apparently from hydroxyl-Al and organic functional groups, ordinarily hydronium, in amounts sufficient to affect acid-sensitive crops (Buol *et al.*, 2003). For pH at 6.5-8.0 the soil is essentially fully base saturated, with large amounts of exchangeable Ca and Mg. Organic carbon and nitrogen contents are very low at ex-tailing sites but are moderate at the control site suggesting loss of carbon as a result of removal of soil material during mining operations.

Average available P levels were low i.e., less than 20 mg/kg soil at both ex-tailing and control sites. Similarly, available K levels were very low (<40 mg/kg soil) at both ex-tailing and control site. Electrical conductivity measurements are used as indicators of total quantities of soluble salts in soils. The EC values together with Exchangeable Sodium Percentage (ESP) values are used to determine the salinity or sodicity of soils. Average EC values as well as individual values of all the soils were less than 2 dS/m. Also average ESP and individual soil values were less than 15%. The inference is that the soils are non saline. Average ECEC levels are medium at ex-tailing sites but low at control sites. Much of the ECEC have been contributed by Ca and Mg rather than Na, K or Exchangeable Acidity (Al +H).

Table 2a: Analytical data of selected chemical properties

| Area          | pH      | EC (dS/m) | (g/kg)   |          | (mg/kg)    |            |
|---------------|---------|-----------|----------|----------|------------|------------|
|               |         |           | Total N  | Org. C   | Avail. P   | Avail. K   |
| 1 (sites 1&2) | 7.1±0.3 | 0.88±0.06 | 0.3±0.02 | 3.6±0.3  | 6.96±0.16  | 18.40±0.78 |
| 2 (site 3)    | 7.2±0.3 | 0.61±0.10 | 0.2±0.02 | 2.5±0.2  | 14.30±0.27 | 25.30±1.02 |
| 3 (site 4)    | 8.1±0.4 | 0.28±0.06 | 0.2±0.02 | 5.9±0.3  | 8.60±0.19  | 18.40±0.98 |
| 4 (site 5)    | 7.9±0.4 | 1.06±0.08 | 0.6±0.03 | 4.5±0.3  | 9.76±0.21  | 21.47±1.05 |
| Control       | 6.0±0.3 | 0.18±0.05 | 1.3±0.07 | 16.0±0.6 | 7.40±0.19  | 11.50±0.89 |

‡: Data represent means (and standard) of 10 samples per site

Table 2b: Analytical data of selected chemical properties†

| Area          | Exchangeable bases |           |           |            | cmol/kg    |           |            |
|---------------|--------------------|-----------|-----------|------------|------------|-----------|------------|
|               | Ca                 | Mg        | K         | Na         | TEB        | EA        | ECEC       |
| 1 (sites 1&2) | 7.26±0.98          | 2.77±0.32 | 0.18±0.02 | 0.48 ±0.05 | 10.67±0.35 | 0.92±0.08 | 17.00±0.22 |
| 2 (site 3)    | 6.56±0.87          | 4.43±0.31 | 0.23±0.03 | 0.17±0.03  | 11.39±0.31 | 0.57±0.06 | 11.96±0.19 |
| 3 (site 4)    | 7.30±1.01          | 3.53±0.29 | 0.21±0.02 | 0.16±0.02  | 11.20±0.34 | 0.78±0.04 | 11.98±0.19 |
| 4 (site 5)    | 9.37±0.99          | 4.81±0.45 | 0.19±0.01 | 0.19±0.03  | 14.56±0.37 | 0.96±0.05 | 15.52±0.21 |
| Control       | 6.56±0.78          | 4.43±0.36 | 0.23±0.03 | 0.17±0.03  | 11.39±0.30 | 0.57±0.03 | 11.96±0.17 |

‡: Data represent means (and standard) of 10 samples per site

Table 3: Concentration of heavy metals in the soils (0-50 cm depth)

| Area          | (mg/kg)        |                |                 |                |        |
|---------------|----------------|----------------|-----------------|----------------|--------|
|               | Pb             | Cu             | As              | Zn             | CN     |
| 1 (sites 1&2) | 56.24<br>±1.98 | 71.38<br>±1.85 | 305.52<br>±5.30 | 75.17<br>±1.38 | <0.001 |
| 2 (site 3)    | 29.91<br>±1.25 | 65.32<br>±1.65 | 360.17<br>±4.86 | 48.00<br>±1.87 | <0.001 |
| 3 (site 4)    | 30.08<br>±1.67 | 75.85<br>±2.01 | 426.67<br>±3.52 | 79.48<br>±1.39 | <0.001 |
| 4 (site 5)    | 42.28<br>±1.87 | 55.17<br>±1.36 | 217.98<br>±2.89 | 63.90<br>±1.94 | <0.001 |
| Control       | 11.52<br>±1.92 | 25.19<br>±1.42 | 72.03<br>±2.20  | 32.23<br>±1.46 | <0.001 |

‡: Data represent means (and standard) of 10 samples per site

**Concentration of trace metals:** Results of concentration of heavy/trace metals namely, lead, copper, arsenic, zinc and cyanide for ex-tailing sites and the control area are presented in Table 3. The mean lead values range from 11.52 mg/kg (control) to 56.24 mg/kg at the ex-tailing sites. For agricultural land use, the maximum acceptable concentration of lead is 70 mg/kg; commercial land use is 260 mg/kg and industrial land use is 600 mg/kg. Lead concentration in the soils is therefore within acceptable limits for all three land use systems.

The average range of copper concentration is between 25.19 and 71.38 mg/kg. Copper concentration is above the level for agricultural land use at sites 1-4 but below that for commercial and industrial land use. The Control site has Cu concentration below the maximum acceptable level for agricultural, commercial and industrial land use. The mean Arsenic concentration ranged from 25.19 mg/kg (Control area) to 426 mg/kg, and is far above the maximum acceptable limit for agricultural, industrial and commercial land use. Average

zinc concentration ranged from 72.03 to 103.37 mg/kg. This concentration is far below the maximum acceptable level for agricultural, commercial and industrial land use.

Throughout the areas investigated (including control sites), mean As values are consistently above the Netherlands soil/sediment intervention guideline value of 55 mg/kg for remediation. Guideline values for remediation for the other metals determined are 720 mg/kg for Zn; 85 mg/kg for Pb and 190 mg/kg for Cu (VROM, 2000). Cyanide concentrations are in trace amounts.

Time factor and closeness (isolation) of the specific environment appear to be key to the trends in the concentrations of the elements at the various sites. A close assessment of analytical data of the soils studied (Table 1 and 2a, b) coupled with field observations shows that variations of trace element concentrations may have been influenced by the textural characteristics. Clay-rich soils are known to have the capacity to retain metals by adsorption.

The texture of Area 1 is silt loam (0-20 cm) and clay (20-50 cm). From Fig. 3a, all the elements are higher within the 20-50 cm horizon than the 0-20 cm horizon, probably for two reasons. First, the site was the first to be reclaimed and so the remnant elements from the tailings had enough time to drain to lower levels and second, the lower zone being dominantly clay has the capacity to retain the metals.

Area 2 has silty clay loam (0-20 cm) and dominantly clay at 20-50 cm. The Pb, Cu and Zn concentrations show the converse trend of what pertains at Area 1 (Fig. 3b), while As conformed to the trend. Reclamation activity here was undertaken after that at Area 1, consequently, there was not enough time for the metals to leach to lower horizons as would be expected in a closed system. The

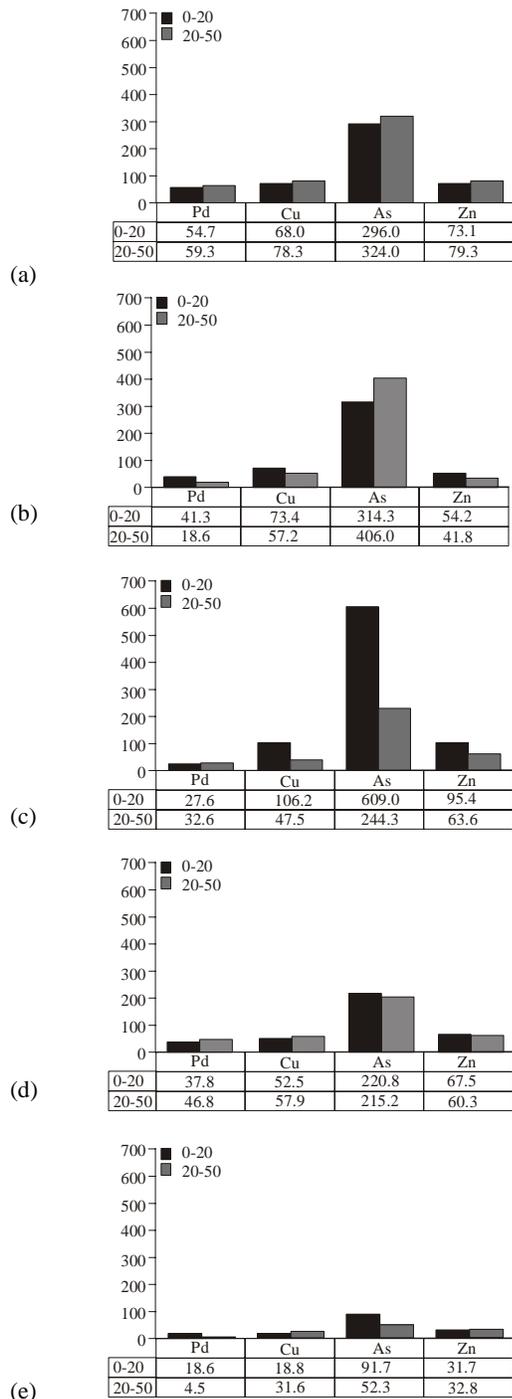


Fig. 3(a-e): Histograms showing raw concentrations of all trace elements at separate elevations per area

converse pattern shown in the concentration of As is likely due to the rapid decomposition of arsenopyrite to release the As under reducing conditions (Smedley *et al.*, 1996) and probably mobilization of the metal from the hyporheic zone.

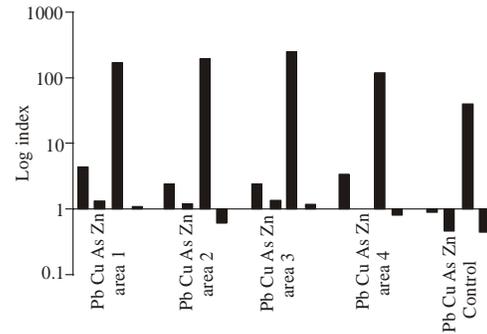


Fig. 4: Contamination Factor (CF) values evaluated from the mean trace metal concentrations at areas 1, 2, 3, 4 and the control site

At Area 3, the surface soil (0-20 cm) texture is dominantly clay with minor silty loam whereas the subsurface is also clayey with small amounts of clay loam. The concentration pattern (Fig. 3c) depicts recent beneficiation activities during the closing stages of the ore processing plant. These activities included the introduction of ore material, both from primary sources as well as secondary sources such as tailings reclamation activities. Texture at Area 4 is uniform (clayey) and tends to conform to the trend in concentration of the elements (Fig. 3d). It is apparent that this fairly stable trend may be attributed to the involvement of refined (retreated) tailings as well as being distal to areas of direct impact from mining and processing activities. The Control site, situated at Manpamhwe is at about 16.1 km away from the perceived pollution hotspot which is the former PTP area, and so had relatively low metal contents in the environment.

It should be noted that Areas 1, 2 and 3 are in close proximity to the main Ashanti shear zone that stretches through the Pompora valley, and also constantly received gaseous effluents, which contain high levels of  $AsO_3$  discharges from the PTP and deposited directly into the soils. Fluctuating groundwater levels within the active hyporheic/vadose zone may, therefore, over time mobilize the As and probably the other metals from the shear zone and the contaminated sources, which are effluent discharges into the Kwabrafo stream draining the area and in turn runs through the Boete tailings site. This explains why the concentration of As and Cu, which have been shown to have strong mining source relationship (Foli and Nude, 2012), is much lower at the Area 4 (Boete site) than the other areas.

**Evaluation of contaminations:** Evaluated data on pollution indices calculated using Eq. (1), (2) and (3) are presented in Table 4. Continental crust/background values ( $B_n$ ) for measured parameters (Table 5) are As (1.8 mg/kg), Cu (55 mg/kg), Pb (12.5 mg/kg) and Zn (70 mg/kg), respectively, while evaluation methods and interpretation of contamination levels of the pollution

Table 4: Evaluated pollution indices at the study areas

| Area          | Pb   |           | Cu   |           | As     |           | Zn   |           |
|---------------|------|-----------|------|-----------|--------|-----------|------|-----------|
|               | CF   | $I_{geo}$ | CF   | $I_{geo}$ | CF     | $I_{geo}$ | CF   | $I_{geo}$ |
| 1 (sites 1&2) | 4.50 | 1.58      | 1.30 | -0.21     | 169.73 | 6.82      | 1.07 | -0.48     |
| 2 (site 3)    | 2.39 | 0.67      | 1.19 | -0.34     | 200.09 | 7.06      | 0.69 | -1.13     |
| 3 (site 4)    | 2.41 | 0.68      | 1.40 | -0.10     | 237.04 | 7.30      | 1.14 | -0.40     |
| 4 (site 5)    | 3.38 | 1.17      | 1.00 | -0.58     | 121.10 | 6.34      | 0.91 | -0.72     |
| Control       | 0.92 | -0.70     | 0.46 | -1.71     | 40.02  | 4.72      | 0.46 | -1.70     |

†: CF = Contamination factor;  $I_{geo}$  = Geo-accumulation index

Table 5: Mean concentration of heavy metals in the soils (0-50 cm depth) and calculated background metals (Bn)

|                               | (mg/kg) |       |        |       |
|-------------------------------|---------|-------|--------|-------|
|                               | Pb      | Cu    | As     | Zn    |
| <b>Area 1 (sites 1 and 2)</b> |         |       |        |       |
| Mean                          | 56.24   | 71.38 | 305.52 | 75.17 |
| Bn                            | 12.50   | 55.00 | 1.80   | 70.00 |
| <b>Area 2 (site 3)</b>        |         |       |        |       |
| Mean                          | 29.91   | 65.32 | 360.17 | 48.00 |
| Bn                            | 12.50   | 55.00 | 1.80   | 70.00 |
| <b>Area 3 (site 4)</b>        |         |       |        |       |
| Mean                          | 30.08   | 75.85 | 426.67 | 79.48 |
| Bn                            | 12.50   | 55.00 | 1.80   | 70.00 |
| <b>Area 4 (site 5)</b>        |         |       |        |       |
| Mean                          | 42.28   | 55.17 | 217.98 | 63.90 |
| Bn                            | 12.50   | 55.00 | 1.80   | 70.00 |
| <b>Control</b>                |         |       |        |       |
| Mean                          | 11.52   | 25.19 | 72.03  | 32.23 |
| Bn                            | 12.50   | 55.00 | 1.80   | 70.00 |

Table 6a: The four categories of contamination based on the contamination factor

| Contamination factor | Description of contamination level |
|----------------------|------------------------------------|
| CF<1                 | Low                                |
| 1≤CF<3               | Moderate                           |
| 3≤CF<6               | Considerable                       |
| 6≤CF                 | Very high                          |

Table 6b: Classes of geo-accumulation index

| Class | Range             | Interpretation (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 very heavily (extremely) contaminated |
| 6     | $I_{geo} \geq 5$  | Very heavily (extremely) contaminated            |

indices are outlined in Mohiuddin *et al.* (2010) and Nude *et al.* (2011).

Figure 4 illustrates the Contamination Factor (CF) values evaluated from the mean trace metal concentrations at Area 1, 2, 3, 4 and the Control site. From the standard interpretations (Table 6a, b) of the pollution indices evaluated, the concentration of As from all the four areas are established to be very highly or very heavily/extremely contaminated; apparently due to the mining activity (anthropogenesis) where the metal occurs as a vital component in arsenopyrite present in the gold ores being mined in the area (Oberthur *et al.*, 1994). The pattern of geoaccumulation index ( $I_{geo}$ ) values evaluated from the mean trace metal concentrations at Area 1, 2, 3, 4 and Control site are shown in Fig. 5. Copper and Zn

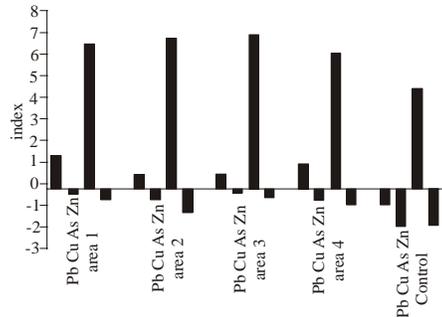


Fig. 5: Geoaccumulation index ( $I_{geo}$ ) values evaluated from the mean trace metal concentrations at areas 1, 2, 3, 4 and the control site

contamination in the environment are low, clearly indicated by the geo-accumulation data (Fig. 5), while Pb is moderately enriched in the area. The order of enrichment is  $As > Pb > Cu > Zn$ ; a trend that conformed to that established by Nude *et al.* (2011) for stream sediments from the area. Arsenic contamination is highest at Area 3 and least at Area 4; while Pb is highest at Area 1 and least at Area 3. The Control site had the least pollution indices, which can be attributed to the relatively low concentrations of the heavy metals.

The areas are generally mine tailings reclaimed sites, suggesting that contaminations from the metals should have drastically reduced over time as evidenced in the relatively low pollution indices for Pd, Cu and Zn; this was however not in the case for As. Clay contents and also the occurrence of Fe, evident by the mottled reddish coloration of the clay within the soil profile (Bowell, 1991; Kumapley, 1993) may have contributed to the retention of As in the soils. Clay surfaces are known to highly adsorb trace metals under suitable geochemical conditions, and also with high concentration of Fe in the medium. Iron just like As occurs highly in the sulphide ores mined in the area (Oberthur *et al.*, 1994). Amonoo-Neizer and Busari (1980) identified the Fe-As combination as one of the most dominant iron fraction in Ghanaian soils and at the Obuasi area, iron was responsible for the sorption of arsenic in soils at low pH values, which were found to range from 3.1 to 3.4 around smelters. Bowell (1991) determined soil pH in the Obuasi area to be about 5.8.

## CONCLUSION AND RECOMMENDATIONS

Soil samples from some tailings reclaimed sites within the Obuasi environment indicate a fairly balanced distribution of chemical constituents that seems to suggest that soil quality has been restored, except for the levels in As concentrations. The concentrations seem to be highest in areas closest to the former PTP area and decrease further away towards control site. To this end, the contamination has rendered the reclaimed sites not yet favourable for the cultivation of food crops, but may rather be used for other horticultural activities, up to such a time that the concentration of As reduces to acceptable limits, probably through natural attenuation. Any form of vegetation cover will inhibit soil erosion, thereby limiting pollution of the adjoining water and air environment with particulate matter, rich in As.

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