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Full Length Research Paper

Trace elements contamination of soils around gold mine tailings dams at Obuasi, Ghana

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This study investigated the issue of tailings dams as a potential source of trace elements contamination in soils at the Obuasi gold mine in Ghana. Soil samples taken from depths of up to 12 cm and within a radius of 400 m from the tailings dams (active and decommissioned), were analysed for As, Cu, Pb and Zn using atomic absorption spectrometry. Average concentrations of As, Cu, Pb and Zn in soils around the active tailings dams were respectively 581±130, 39.64 ± 3.02, 24.22 ± 2.62 and 72.64 ± 8.01 mg/kg. Soils in the vicinity of the decommissioned tailings dam registered increased values - 1711 ± 172, 71.44 ± 5.27, 38.67 ± 3.59 and 168.1 ± 36.2 mg/kg for As, Cu, Pb and Zn respectively. Both types of tailings dams impacted adjoining soils with greater concentrations of the trace elements when compared to undisturbed control soils. Arsenic was above the Netherlands intervention value of 55 mg/kg dry weight, even in control soils. The following trend of accumulation was observed in the soils: As>Zn>Cu>Pb. Improved tailings management strategies, among other factors, might have influenced the reduced level of trace elements contamination at the active tailings dams' site.

Key words: Gold mining, tailings dam, trace elements, soil, Obuasi.

INTRODUCTION

Gold mining at Obuasi in Ghana dates back to over a century and remains one of the oldest viable mines on the continent of Africa. This long history of mining at Obuasi has generated huge environmental legacy issues in the area. Perhaps, the most significant of the environmental challenges is that of trace elements contamination. Amonoo-Neizer et al. (1995) found significant distribution of As and Hg in the top soils, plantain, water fern, elephant grass, cassava and mud fish at Obuasi and its environs. Other studies have made various findings regarding presence of trace elements in water sources, soils and foodstuffs at Obuasi and surrounding areas (Amasa, 1975; Bamford et al., 1990; Golow et al., 1995). So far, it appears that As constitutes the major trace element problem in the Obuasi area. This has been linked to the considerable level of naturally occurring arsenic at Obuasi, as well as liberations from arsenic-bearing gold ores during gold extraction (Amonoo-Neizer et al., 1995; Asiam, 1996; Smedley, 1996; Smedley et al., 1996; Ahmad and Carboo, 2000; Kumi-Boateng, 2007).

During mining, a fine grind of the ore is often necessary to release metals and minerals, so the mining industry produces enormous quantities of fine rock particles, in sizes ranging from sand-sized down to as low as a few microns (USEPA, 1994). These fine-grained wastes are known as "tailings". By far, the larger proportion of ore mined in most industry sectors ultimately becomes tailings that must be disposed of. In the gold industry, only a few hundredths of an ounce of gold may be produced for every ton of dry tailings generated (USEPA, 1994). Tailings need to be properly managed because they constitute a major source of release of many trace elements into the environment. Gold mine tailings at Obuasi, for instance, contain very high amount of As, averagely 8305 mg/kg (Ahmad and Carboo, 2000). The preferred approach to tailings management is to pump the tailings, usually in slurry form, into impoundments or dams designed to hold the tailings and perform a number of functions, including treatment functions. More recently however, concerns have been raised about the stability and environmental performance of tailings dams and im-

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poundments. The ability of these impoundments to hold tailings without significant intrusions of pollutants over time into adjoining soils have been questioned (Aucamp and van Schalkwyk, 2003). Inactive tailings impoundments also are receiving more attention due to the long-term effects of windblown dispersal, ground water contamination, and acid drainage (USEPA, 1994; Aucamp and van Schalkwyk, 2003).

This present study investigated the issue of gold mines tailings dams as a potential source of trace elements contamination in adjoining soils at the Obuasi gold mine. The study considered two types of tailings dams - one active and the other decommissioned - and assessed how each type might have impacted on the immediate soil environment with regards to trace element contamination. Some probable factors thought to potentially affect trace element intrusions from gold mines tailings dams in Ghana were also highlighted.

METHODOLOGY

Study area

Obuasi is located between latitude 5.35 and 5.65 N and longitude 6.35 and 6.90 N. It covers a land area of 162.4 km^2. There are 53 communities in the Obuasi Municipality. The Municipality is located in the southern part of the Ashanti Region and has undulating topography. The climate is of the semi-equatorial type with a double rainfall regime. Mean annual rainfall ranges between 125 and 175 mm. Mean average annual temperature is 25.5°C and relative humidity is 75 - 80% in the wet season. The population of the Municipality is estimated at 205,000 using the 2000 Housing and Population Census as a base and applying a 4% annual growth rate. The vegetation is predominantly a degraded and semi-deciduous forest (Obuasi Municipality, 2009).

As a historical mining town that has seen continuous mining operations since the 1890s (AngloGold Ashanti, 2006), mining activity presents the predominant potential source of trace element contamination in the area.

The soil profile of the Obuasi area is made up of an ‘A’ zone of admixture of soil and saprolite, interspersed with organic matter, clay aggregates and voids, quartz fragments and ferro-magnesian oxides. This is followed by lateritic transitional ‘A/B’ zone and ‘B’ zone made up of decomposed rock fragments in massive clay matrix. ‘B/C’, is the pallid zone, made up of oxidised rock fragments in fine matrix of clay, quartz, and Ferro-oxides (Bowell, 1991) (Figure 2).

Experimental design

The study investigated trace elements content of soils around (i) active and (ii) decommissioned gold mine tailings dams (Figure 1), with soil samples from an undisturbed area serving as control. The active tailings dams were built some two decades ago with the decommissioning of the old dam, which was used for several decades. Soil samples were taken from a distance of up to 400 m from the tailings dams and from a depth of up to 12 cm, using plastic scoop and stainless steel cutlass. Thus, samples were taken mainly from within the A and AB range of the soil profile (Figure 2). Nine sampling points were demarcated at each of the experimental sites, around the tailing dams (Figure 1). Samples were taken and composited from depths of 0, 6 and 12 cm at each sampling point. The composited samples were then transported in sandwich bags to the laboratory for analysis.

Laboratory analysis

The samples were dried overnight in an electric oven at a temperature of 30^{0}C. This was done to make homogenisation easier and to express the analytes on a dry weight basis. The dried samples were ground using mortar and pestle to particle size of < 0.5 mm.

The aqua regia procedure put forth by Nieuwenhuize et al. (1991) for trace elements digestion was followed. Dried and powdered soil sample of 1.6 g was digested with aqua regia (3:1 HCl: HNO_3) in 50 ml volumetric flask on a hotplate and diluted to volume with distilled water. Arsenic, Cu, Pb and Zn in the digest were determined using atomic absorption spectrometry. The detection limit of the atomic adsorption spectrophotometer used is 0.01.

Statistical analysis

Concentrations of trace elements were expressed as mean ± SEM (Standard Error of the Mean). One-way ANOVA was used to compare mean among treatments and differences resulting in $p<0.05$ were considered statistically significant. Manitab 15 statistical tool was employed for ANOVA computation.

RESULTS AND DISCUSSION

The concentrations of As, Cu, Pb and Zn in soils around the active and decommissioned gold mine tailings dams, and from undisturbed control sites are shown in Table 1. Comparative levels of the trace elements are represented in Figure 3. The order of abundance of the trace elements was As>Zn>Cu>Pb in both the test and control soil samples (Table 1 and Figure 3). With regards to the site with the highest concentrations of trace elements, the following observation was made: decommissioned tailings dam site > active tailings dam site > control site. The increased trace elements in test soils, beyond that of the controls, were probably a direct consequence of the tailings dams, in view of the fact that the dams constituted the only activity at the test sampling sites. This assumption is consistent with literature, in which gold mine tailings dams were implicated as source of trace elements contamination in adjoining environmental media, including soils, river water and sediments (Wray, 1998; Aucamp and van Schalkwyk, 2003; Kim et al., 2002; Bruce et al., 2003). Potentially, these trace elements could be transported into adjoining soils through moisture movement or wind erosion of dried tailings. We suspect that the high level of trace elements contamination potentially associated with the decommissioned tailings dam in this study could be a function of dust, since the tailings were dried and uncapped, and easily prone to the effect of wind.

Discounting the role normally played by soil profile characteristics in trace element mobility (Altaher, 2001), based on the fact that all the sampling sites bear similar soil characteristics, it was assumed that the observed site differences of trace elements concentrations might probably be due to factors that related more directly to the tailings dams and their management. In this respect, fac-

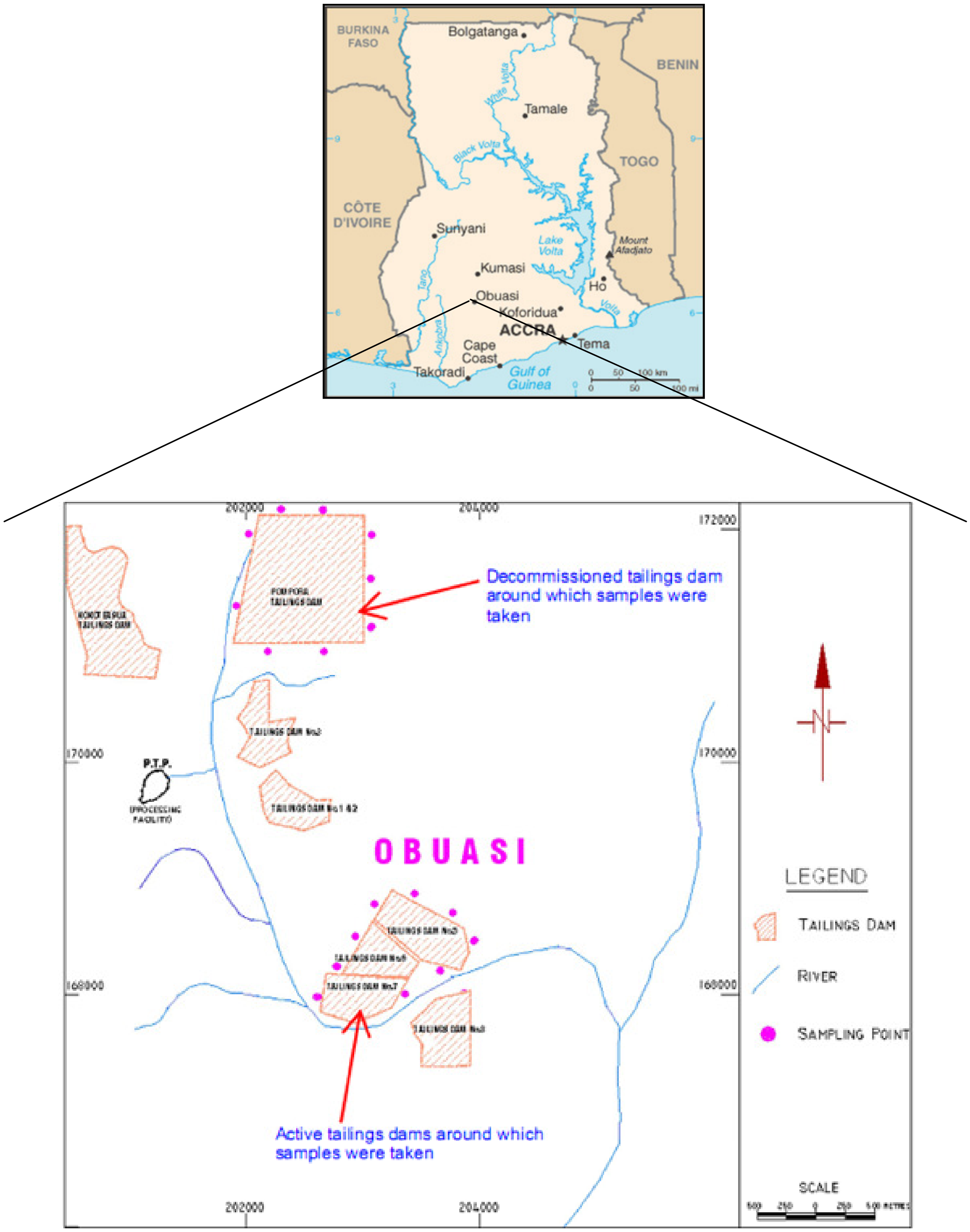

Figure 1. Map of study area showing tailings dams.

factors such as stability of the tailings dams, the amount of tailings they might hold at a particular time, and the regimes and approaches to tailings management were considered as probably contributory to the extent of trace elements contamination around the dams. The active tailings dams, being relatively recent (built in 1991), have benefited from substantial technological improvement over the decommissioned one, which was one of the earliest to be operated at the Obuasi mines. Coupled with recent implementation of an environmental management

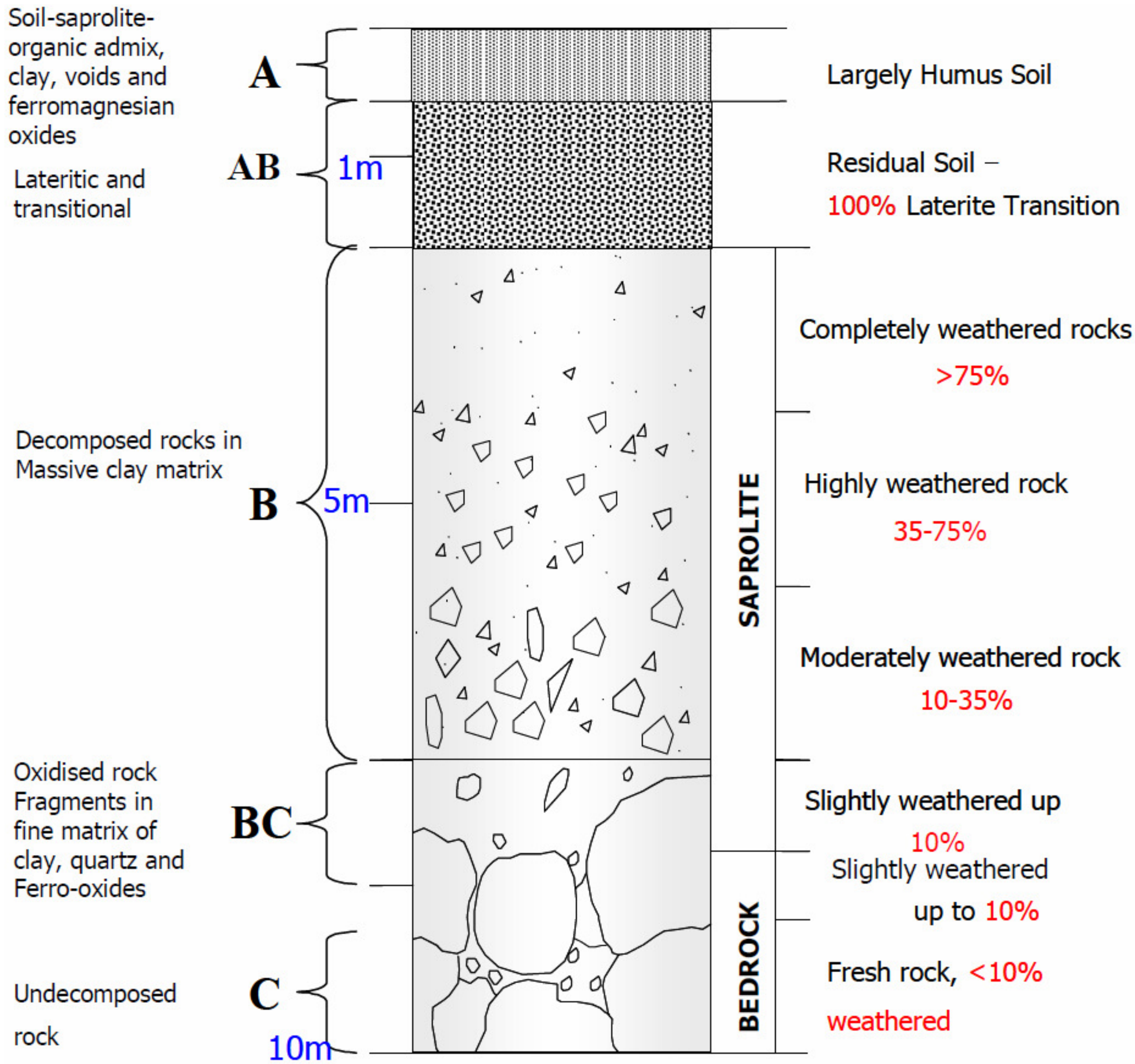

Figure 2. Soil profile of Obuasi (Bowell, 1991) (Profile not drawn to scale).

Table 1. Levels of As, Cu, Pb and Zn in soils around active and decommissioned gold mine tailings dams at Obuasi, Ghana (mg/kg).

Trace element	Tailings dam sites	Total count	Mean	SE mean	St.Dev	Min.	Median	Max.	Range
	Active	9	581	130	389	178	493	1473	1295
As	Decommissioned	9	1711	172	517	700	1885	2430	1730
	Control	9	84.5	13.7	41	36.8	83.3	164	127.3
	Active	9	39.64	3.02	9.07	26.75	39.5	52	25.25
Cu	Decommissioned	9	71.44	5.27	15.8	42	72.5	96.5	54.5
	Control	9	17.75	1.56	4.69	11.25	17.25	25.5	14.25
	Active	9	24.22	2.62	8.46	17.5	20.25	40	22.5
Pb	Decommissioned	9	38.67	3.59	10.76	21.5	38.25	53.5	32
	Control	9	18.28	0.95	2.85	15	18	24.25	9.25
	Active	9	72.64	8.01	24.02	47.75	66	124.75	77
Zn	Decommissioned	9	168.1	36.2	108.7	55	130.2	427.8	372.8
	Control	9	61.8	12.2	36.7	37.3	47	152.8	115.5

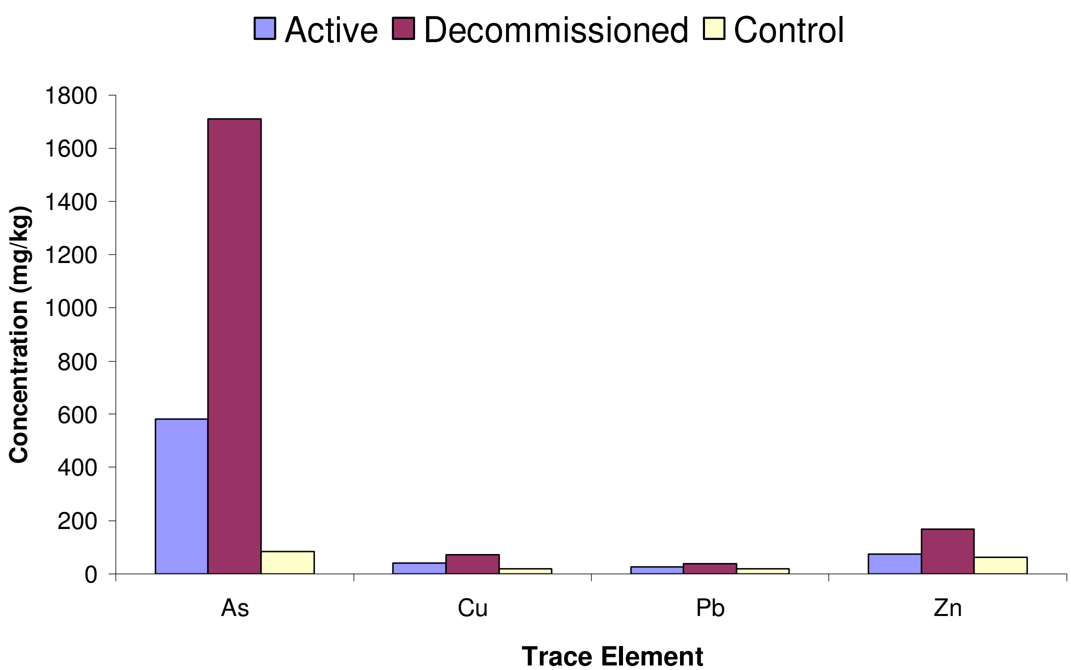

Figure 3. Comparative levels of trace elements in soils around tailings dams at the Obuasi gold mine in Ghana.

system that is ISO 14001 compliant (since December 2006), there has been great institutional commitment to keep contamination from mining operations very low at the Obuasi mines. Regular checks along the lengths of the pipelines that transported tailings to the dams to fix any pipeline wear problems, greatly improved communication between dam operators and tailings treatment plant personnel, and strengthened security around tailings facilities, which prevented vandalization of these facilities, perhaps, constituted a network of management activities that altogether might have worked to ensure the reduced level of contamination around the active tailings dams. Indeed, provision of improved security to protect tailings facilities has substantially reduced deliberate damages to tailings transmitting lines by small-scale artisanal miners, who often seek to obtain and reprocess these tailings. Hitherto, such damages to tailings lines resulted in spillage problems that affected land, vegetation and nearby rivers (Anglogold Ashanti, 2006). The active tailings dams are also presently equipped with facility for draining and re-treatment of effluent, which did not exist during operation of the old decommissioned dam.

Generally, As was found to be in the highest concentration among the four elements studied, which is consistent with previous reports on Obuasi as a severely As contaminated area (Kumi-Boateng, 2007; Smedley et al., 1996; Smedley, 1996). Arsenic levels in the Obuasi region is reportedly among the highest in the world, and has been linked to the principal gold-bearing ore in the region, which is rich in arsenopyrite (FeAsS) mineralization (Amonoo-Neizer et al., 1995; Asiam, 1996; Smedley, 1996; Smedley et al., 1996; Ahmad and Carboo, 2000; Kumi-Boateng, 2007). In this respect, mining at Obuasi has been reported to give rise to substantial airborne As pollution from ore-roasting as well as river-borne As pollution derived from nearby tailings (Asiam, 1996; Smedley, 1996; Smedley et al., 1996, Kumi-Boateng, 2007).

Regarding the divalent metals (Zn, Cu and Pb), it was presumed that their relative abundance in the soils, with respect to contamination from the tailings dams, might be partly dependent on potential intrusions of the elements into soil and their rate of mobility in the soil from the tailings dams. Generally, the selectivity of clay mineral and hydrous oxide absorbents surfaces in soils and sediments for divalent metals follow the order Pb>Cu>Zn (Alloway and Ayres, 1997). In this respect, the rate of mobility of these three metals in such soils would increase in the reverse order (Zn>Cu>Pb), which is consistent with the findings in this study. Overall, the decreasing trend of elements concentration in the soils in this study – As>Zn>Cu>Pb – is contrary to observations by Shumlyanskyy et al. (2005), in which among other metals, As, Zn, Cu and Pb were reported to decrease in soils around a gold-base metal deposit in Ukraine in the order Pb>Zn>As>Cu at a distance of 400 - 700 m from the dump. This disagreement with our study might be attributed to differences in soil properties, considering the two different locations involved.

The mean levels of As in soil samples around the active and decommissioned tailings dams and from the control site were 581.42 ± 129.67, 1711.39 ± 172.41 and 84.53 ± 13.68 mg/kg respectively (Table 1). The mean As level around the active site was significantly different from mean As concentration in control soils ($p = 0.002$). Similarly, As in soils from the decommissioned site was significantly different relative to As in control samples ($p < 0.001$). This suggests that the tailings dams probably introduced considerable amount of As into the surrounding soils beyond background As levels. Arsenic concentrations in soils from the decommissioned tailings dam site also far exceeded that from the active tailings dam sites (p = < 0.001). In relation to the Netherlands soil protection guidelines, As levels in soil beyond 55 mg/kg dry weight requires remediation (VROM, 2000). At this threshold, all the soils tested, especially soils from decommissioned and active tailings dams sites, showed poor quality with respect to As and may pose environmental health concern. Potential intrusions of As from the decommissioned tailings dam was approximately three fold that from the active tailings dams.

The mean concentrations of Cu in soils around the active and decommissioned tailings dams, and in soils from control site were 39.64 ± 3.02, 71.44 ± 5.27 and 17.75 ± 1.56 mg/kg respectively (Table 1). The differences among these three means are statistically significant ($p < 0.001$), which meant that the presence of the tailings dams, both active and decommissioned, probably impacted the surrounding soils with significant amount of Cu. The Cu content in the control soils was within the recommended limit of 36 mg/kg for a typical uncontaminated soil. Though Cu content in soil samples from the active and decommissioned tailings dams sites exceeded this recommended background limit, the values were still within Cu intervention limit of 190 mg/kg for contaminated sites (VROM, 2000).

Mean lead concentrations recorded for active, decommissioned and control sites were 24.22 ± 2.82, 38.67 ± 3.59 and 18.28 ± 0.95 mg/kg respectively (Table 1). Lead content of control soil samples were not statistically different from the active site soil samples ($p = 0.063$), but differed significantly from the decommissioned site soil samples ($p < 0.001$). The difference observed in Pb content between soils around the active and decommissioned tailings dams was also statistically significant ($p < 0.001$). Thus, Pb contamination from the active tailings dams might only be marginal, as the Pb levels were within the range of values for the control soils. We are however not entirely sure what factors might have accounted for the difference in Pb concentrations between soil samples from the two tailings dams sites. But possibly, the poor mobility of Pb in soils might play a part. Lead contamination from the dams via movement through soil might take considerably long time to manifest, probably, a reason why the Pb contamination was more pronounced around the older decommissioned dam compared to the more recent active dams. Another reason might be the susceptibility of old dried tailings of the decommissioned dam to transport by air, in view of the fact that it was not capped. The mean Pb concentrations for all the three sites, though, were within recommended Pb content of 85 mg/kg for a typical uncontaminated soil (VROM, 2000).

Mean Zn content of soils around the active and decommissioned tailings dams and control site were respectively, 72.64 ± 8.01, 168.10 ± 36.20 and 61.80 ± 12.20 mg/kg (Table 1). The control soil samples did not differ significantly in Zn content when compared to soil samples from the active tailings dam ($p = 0.470$). On the other hand, there was significant difference in Zn content between soil sampled from the vicinity of decommissioned tailings dam and control site ($p = 0.013$). Similarly, Zn levels in soils from the active and decommissioned tailing dams differed significantly ($p = 0.02$). These comparisons, as in the case of Pb, seem to give an indication regarding the extent to which Zn might migrate and contaminate adjoining soils from gold mining tailings dams. Zinc levels of soil samples from the decommissioned tailings dam site fell short of recommended background level of 140 mg/kg, but were still within intervention limit of 720 mg/kg (VROM, 2000).

Soils in Obuasi are rich in iron, associated with gold ore deposits principally characterized by sulphide minerals in arsenopyrite form (Osae et al., 1995; Amonoo-Neizer et al., 1995; Asiam, 1996; Smedley, 1996; Smedley et al., 1996; Ahmad and Carboo, 2000; Kumi-Boateng, 2007). Thus, possibly, the heavy metals (Cu, Zn and Pb) could be strongly iron-bound and might not necessarily be bioavailable. In which case, they might not pose direct environmental health threat, considering also the fact that they were all within recommended intervention limits. However, there is the potential that they could remobilise during rainy periods and possibly enter natural waterways to affect aquatic systems.

Conclusion

Considerable amount of trace elements (As, Cu, Zn and Pb) contamination of soils was associated with gold mine tailings dams, irrespective of whether the dam was active or decommissioned. This potential impact was greater for decommissioned tailings dam. It was assumed that factors such as stability of the tailings dams, the amount of tailings they might hold at a particular time, and the regimes and approaches to tailings management probably contributed to the extent of trace elements contamination around the dams.

Arsenic contents of soils from the vicinity of the active and decommissioned tailings dams far exceeded recommended Netherlands intervention value of 55 mg/kg, hence, constituted significant environmental health threat. However, Cu, Zn and Pb contents of soils from all the study sites were within the Netherlands soil protection guideline values and, might not present direct environmental threat, although potentially, they could remobilize (with rainfall) and affect aquatic systems. The study revealed relative concentrations of trace elements in soils at the Obuasi gold mines in the following order: As>Zn>Cu>Pb. The As content of the soils was extremely high, which corroborated past evidence that Obuasi is one of the regions in the world with very high background levels of As. In order to understand the mechanisms of trace elements transport from the tailings dams and associated potential ecological toxicity threats, the following areas were identified for further research: (i) distance profile of the elements from the tailings dams, (ii) the forms of metals to infer mobility, bioavailability and consequent toxicity, and (iii) metal remobilisation potential, especially during rainy seasons.

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