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Heavy Metal Concentration in Drinking Water Sources Affected by Dredge Mine Operations of a Gold Mining Company in Ghana

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Abstract: The study assesses concentration of certain heavy metals in water sources affected by the operations of defunct dredged gold mine operations more than a decade to evaluate its quality as a source of drinking water. The concentration of heavy metals were determined from nine (9) surface water sampling points and three (3) boreholes in the Awusu-River basin in comparison with their maximum contaminant levels to assess their suitability as drinking water sources. Results obtained from the analysis of water samples indicated that the concentrations of four heavy metals (Fe, 0.01-14.93 mg/L; Cd, <0.002-0.01 mg/L; As, <0.002-0.003 mg/L and Pb, <0.005-0.05 mg/L) analyzed in surface water samples were above WHO threshold values (Fe 300, Cd 3, As 10 and Pb 10 ug/L) for drinking water and two (Cu, <0.002-0.05 mg/L and Zc, <0.005-0.03 mg/L) were below (Cu 2000 ug/L and Zc 3000 ug/L). Dissolved iron registered the highest concentrations with the Slime Retention Area (SRA) dominating with a mean concentration of 4.979 mg/L. All the sampling points were being used as drinking water sources by the two communities. An integrated approach to management of sources of drinking water quality in the mining areas is needed and should involve not only the mining companies and regulatory agencies but also the local communities to enable the latter understand and appreciate post mining issues of water quality.

Keywords: Concentration, contaminant level, defunct, heavy metal, paddock, persistent

INTRODUCTION

Land use, mineral exploitation and management of drinking water quality are global challenges that affect human survival, development and welfare, peace and security which are related to the provisions of the charter of the United Nations (Okigbo, 1999). The operations and subsequent closure of the dredge mine undertaken by the defunct Gold Mining Company over the Awusu basin may have led to the reduction in access to safe and portable water for the Kwabeng and Akrofufu Communities.

The operations of the Mining Company led to the diversion of Abudusu, Obire-ne-Obeng and Awusu watercourses upstream as well as the excavation of Mining paddocks and conversion of Anikawkaw Swamp (All these constituting the Awusu meshwork) into a Slime Retention Area for the purpose of mining. These streams take their source from the Atewa range, runs through farm lands and the mine out area of the Goldenrae Mining Company before serving as a source of drinking water for these communities.

The decision to undertake the dredge mining underestimated both environmental and the cost imposed by pollution to the quality of drinking water sources (Bush, 2000); because the issue of ethics in water quality control was overshadowed by economic arguments which were based on benefit-cost analysis.

Water resources including drinking water sources in gold mining communities must be managed in such a way that its quality makes it safe for human consumption. But the safety of these sources of drinking water cannot be guaranteed because of the possibility of acid rock drainage from abandoned mine sites which enhances leaching with attendant accumulation of heavy metals on some segments of the ecosystem (Armad and Carboo, 1997; Blay and Adu-Aning, 1997; Sarkodie *et al*., 1997; Carboo and Sarfor-Armah, 1997).

There is no study yet in the Atiwa District on the effect of the defunct Goldenrae Mining Company on the quality of drinking water sources. The socio-economic cost that will result from water quality issues may be passed on as an externality to the community.

Mining accelerates the release of trace metals or heavy metals into water bodies. Trace metals such as mercury, lead, cadmium, iron, arsenic, selenium, nickel and zinc (among others) are highly toxic in concentrations in the parts per billion or million range (Cunningham and

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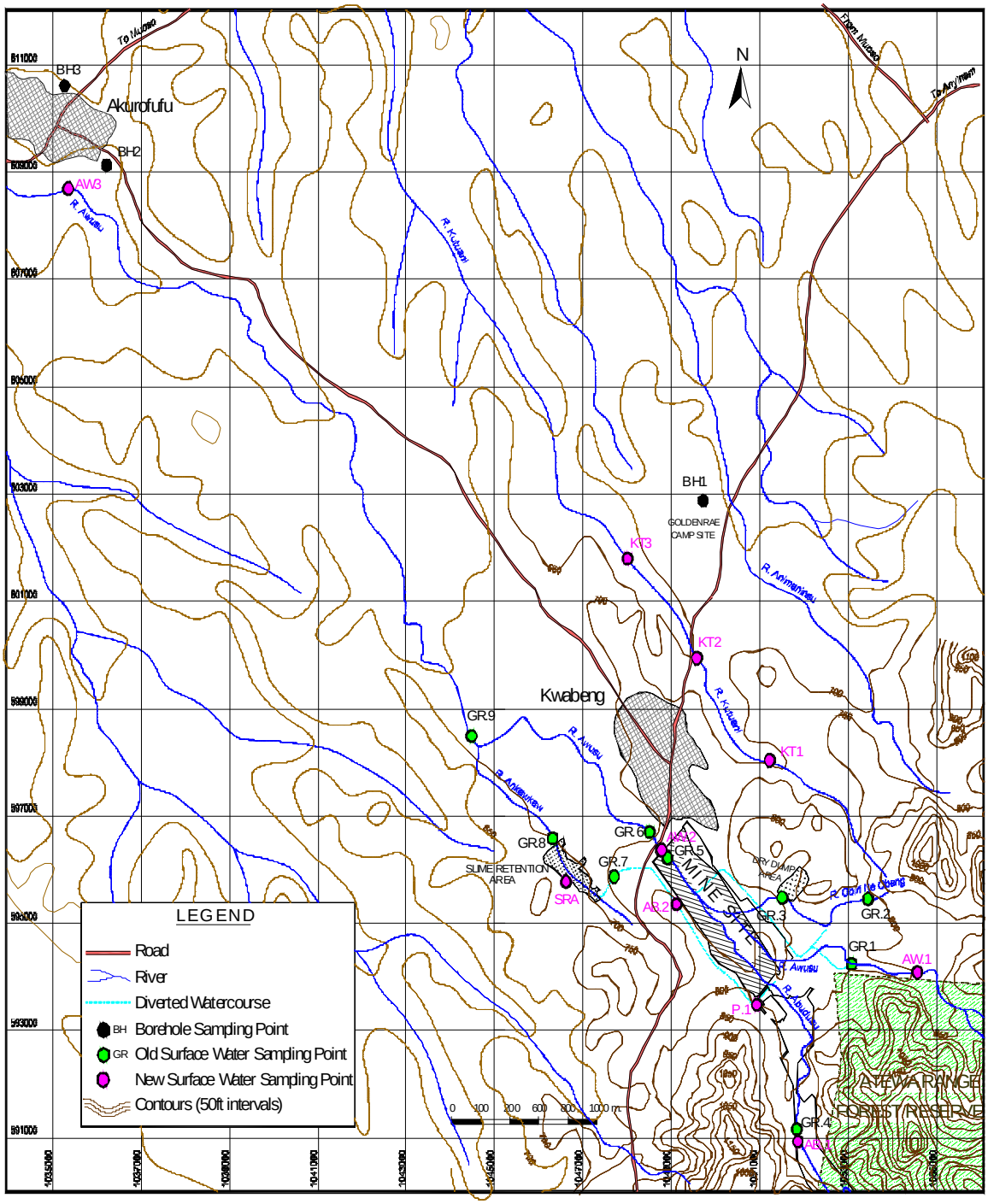

Fig. 1: Map showing the sampling points within the study area Goldenrae Mining Company-Kwabeng (2005)

Saigo, 1999). These metals are highly persistent, accumulate in food chains (or foodstuffs) and have toxicological effects in human and other biological systems (Armad and Carboo, 1997; Sarkodie *et al*., 1997; Baird, 1999).

The objective of the study was to determine the concentration of certain heavy metals in drinking water sources to evaluate its quality as a source of drinking water.

MATERIALS AND METHODS

Sampling site: The major streams draining the north-western end of the Atewa range in the Atiwa District of Ghana (formerly part of the East Akim District) that runs through the mining concession of the defunct Goldenrae Mining Company that ceased operations in October 1990; are Awusu, Kutuani, Animaninsu, Obire-ne-Obeng, Abudusu, Anikawkaw, Asuofu and their tributaries. The streams in this evergreen forest, which presents aesthetic scenery, serve as the source of potable water for domestic use as well as a resource base for the livelihoods of the communities within the concession.

The Atewa range is covered by thick forest, whereas the rest of the concession area is covered by secondary forest, predominantly farmlands belonging to peasant farmers with a variety of flora and fauna, an ecosystem which must have been rich in biodiversity at least before the onset of timber logging and mining. The North-western end of the Atewa range which is the subject of the study is underlain by Birimian system with its rich natural resources (Kesse, 1985; Griffis *et al*., 2002) is the main geological formation with gold mineralization and targets for alluvial, placer or dredge mining.

Twelve sampling points were selected and their coordinates located using a Global Positioning System GARMING 45XLS. Six of the sampling points (AW1, AW2, AW3, AB1, AB2, SRA) were located along the Awusu, Abudusu and Anikawkaw streams impacted by the mine operations, three (KT1, KT2 and KT3) on the Kutuani stream (not affected directly by the mine operations) and three boreholes (BH1, BH2 and BH3) within the community as shown in Fig. 1. These sampling points were quite representative of the drinking water sources in the study area.

A reconnaissance survey of the abandoned mine concession was carried out. The downstream community (Akrofufu) and areas likely to be affected by the abandoned dredge mine operations were identified; observations of likely impacts on the management of water quality at the abandoned mine concession (study area) were also captured. While the most obvious impacts may occur in the immediate vicinity of the mine and waste dumps, ecosystems and communities far distant may be impacted in the case of riverine disposal of mine waste or slurry. These factors were needed to be considered in determining the spatial extent of water quality or environmental disruption.

Collection of samples: Water samples were collected for a period of six months spanning from October 2005 to March 2006. The time at which the sampling was done at each site was recorded. Pre-sterilized 1L polyethylene bottles were used in the collection of water samples. For the collection of surface water from streams, the bottles were held near the base in the hand, plunged neck downward below the surface of water with the neck pointing slightly upward and mouth of bottle directed toward the current.

In the case of the boreholes, samples were collected directly from the source/tap after the mouth and neck of the tap had been thoroughly cleansed with concentrated alcohol (50% by volume), sterilized in an alcohol flame for about three to five minutes and flushed through by substantial amount of water under mounted pressure. Ample space (2.5 cm) was left in the bottles to facilitate mixing by shaking before examination. The collected water samples were placed in a chest containing ice to maintain the temperature at about 4ºC and transported to the laboratory for analysis. Within the period from sampling to analysis, the properties of water may be altered due to the chemical, physical and biological reactions. Sample preservation was therefore necessary to inhibit the reactions in the samples until it was analyzed (Sliwka-Kaszynska *et al*., 2003).

Procedure for trace metal analysis: Water samples were collected into 80 mL polyethylene bottles that had been previously washed with acid (10% HNO_3), rinsed thoroughly with tap water and then with deionized water. The samples were acidified with conc. HNO_3 (pH<2) and kept in an iced chest maintained at a temperature of about 4ºC with ice cubes before transporting to the laboratory. The sampled solutions were aspirated into a flame and atomized. The concentrations of the heavy metals were determined at specified wavelengths by Atomic Absorption Spectrophotometry (AAS) using a calibrated Unicam 969 Atomic Absorption Spectrometer (APHA, AWWA, WEF, 1995).

RESULTS

The concentration of heavy metals determined at the various sites in the study area is presented as Table 1-6. Samples analyzed from the sites indicated that the concentration of dissolved iron was significantly higher than the other trace metals with cadmium recording the least values. The Slime Retention Area (SRA) had the highest concentration of dissolved iron registered in November with Akrofufu-Kwabeng Road Borehole (BH2) registering the least concentration of 0.01 mg/L in December. The overall mean of dissolved iron concentration for the study period was 1.53 mg/L (Table 7). The concentration of copper, lead and zinc

Table 1: Dissolved Iron (mg/L)

Month	AW1	AW2	AW3	AB1	AB2	SRA	KT1	KT2	KT3	BH1	BH2	BH3
Oct	0.077	0623	0.829	0.829	1.342	1.086	0.271	1.107	1.753	0.759	-	-
Nov	0.128	0.413	1.424	0.667	1.454	14.93	1.172	3.093	3.152	2.436	0.902	-
Dec	0.045	0.532	3.915	0.607	0.368	1.203	0.822	1.265	0.964	0.023	0.008	_
Jan	0.113	0.568	1.181	0.649	1.343	8.668	0.609	4.024	1.872	3.623	0.07	1.665
Feb	0.137	0.341	2.399	0.761	1.471	1.303	0.584	1.629	1.599	_	0.654	0.694
Mar	0.076	0.404	1.792	0.612	1.396	2.687	0.739	5.104	_	_	0.931	0.742
Mean	0.096	0.48	1.935	0.688	1.229	4.979	0.699	2.704	1.868	1.71	0.513	1.033
SD	0.036	0.11	1.101	0.089	0.425	5.669	0.298	1.639	0.799	1.627	0.446	0.547

Table 2: Copper (mg/L)

Month	AW1	AW2	AW3	AB1	AB2	SRA	KT1	KT2	KT3	BH1	BH2	BH3
Oct	<0.02	0.038	0.037	<0.02	<0.02	0.054	<0.02	<0.02	0.037	<0.02	_	_
Nov	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.012	_
Dec	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.024	<0.02	<0.02	<0.02	_
Jan	0.004	0.02	0.005	0.02	0.006	0.02	0.008	0.012	0.007	0.017	0.028	0.004
Feb	0.009	0.007	<0.02	0.007	<0.02	<0.002	0.007	0.006	0.002	_	0.016	<0.002
Mar	0.004	0.015	0.003	0.612	0.008	0.014	<0.002	0.018	0.015	_	0.028	0.007
Mean	0.006	0.02	0.015	0.213	0.007	0.029	0.008	0.015	0.015	0.017	0.021	0.006
SD	0.003	0.007		0.346			0	0.008	0.007		0.007	

Table 3: Lead (mg/L)

Month	AW1	AW2	AW3	AB1	AB2	SRA	KT1	KT2	KT3	BH1	BH2	BH3
Oct	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.008	_	_
Nov	0.002	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	<0.005	<0.005	0.014	0.009	_
Dec	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	_
Jan	<0.005	0.04	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.011	<0.005
Feb	<0.005	0.008	0.05	<0.005	<0.005	0.036	<0.005	<0.005	0.042	_	0.004	0.031
Mar	0.001	0.023	0.032	0.047	<0.005	<0.005	0.042	0.018	<0.005	_	0.046	0.041
Mean	0.002	0.024	0.041	0.047		0.036	0.026	0.018	0.042	0.011	0.018	0.036
SD		0.016	0.013		0					0.004	0.023	0.007

Table 4: Zinc (mg/L)

Month	AW1	AW2	AW3	AB1	AB2	SRA	KT1	KT2	KT3	BH1	BH2	BH3
Oct	0.018	<0.005	<0.005	<0.005	<0.005	<0.005	0.002	0.005	0.016	0.022	-	-
Nov	0.003	0.016	0.005	0.005	0.002	0.007	0.004	<0.005	<0.005	0.014	0.006	-
Dec	<0.005	<0.005	0.013	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.012	-
Jan	<0.005	0.007	0.003	<0.005	0.008	0.007	<0.005	<0.005	<0.005	0.032	0.005	0.003
Feb	0.004	0.009	0.006	0.005	0.009	0.004	0.002	0.017	0.008	-	0.005	0.007
Mar	0.002	0.004	0.005	0.006	0.004	0.022	0.004	0.008		-	0.011	0.008
Mean	0.007	0.009	0.006	0.004	0.007	0.01	0.003	0.01	0.012	0.022	0.01	0.006
SD	0.001	0.003	0.004	0.001	0.003	0.01	0.001	0.006			0.004	0.003

Table 5: Arsenic (mg/L)

Month	AW1	AW2	AW3	AB1	AB2	SRA	KT1	KT2	KT3	BH1	BH2	BH3
Oct					0.016	8E-04					-	-
Nov	0.005	0.004	0.003		0.008	0.003	0.006	0.005	0.006	0.008	0.008	-
Dec		0.005	0.005	0.009	0.006	0.004	0.008	0.002	0.003	0.006	0.005	-
Jan		0.003	0.002	0.003	0.005	0.006		0.0012	0.003			0.028
Feb	0.007	0.009	0.006	0.013	0.011	0.008	0.007	0.008		-		0.005
Mar	0.007	0.008	0.006	0.013	0.009	0.0011	0.007	0.008		-		0.005
Mean	0.006	0.006	0.004	0.01	0.009	0.005	0.007	0.007	0.004	0.007	0.006	0.013
SD	0	0.003	0.002	0.005	0.004	0.004	0	0.004	0.002	0.001	0.002	0.013

Table 6: Cadmium (mg/L)

Month	AW1	AW2	AW3	AB1	AB2	SRA	KT1	KT2	KT3	BH1	BH2	BH3
Oct	<0.002	0.004	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	0.003	<0.002	-	-
Nov	<0.002	<0.002	<0.002	<0.002	0.006	<0.002	0.002	0.003	<0.002	<0.002	<0.002	-
Dec	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	-
Jan	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.002	0.003	<0.002
Feb	<0.002	<0.002	0.007	<0.002	0.003	0.006	<0.002	0.01	<0.002	-	0.011	0.004
Mar	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	-	<0.002	<0.002
Mean		0.004	0.007		0.005	0.006	0.002	0.005	0.003	0.002	0.007	0.004
SD	0.003			0.004							0.006	

Table 7: Descriptive statistics of heavy metal concentration

Heavy metal	Units	N statistic	Range statistic	Min statistic	Max statistic	Mean statistic	Std. statistic
Dissolved Iron	mg/L	65.00	14.91	0.01	14.93	1.53	2.19
Copper	mg/L	35.00	0.05	0.00	0.05	0.01	0.01
Lead	mg/L	20.00	0.05	0.00	0.05	0.02	0.02
Zinc	mg/L	46.00	0.03	0.00	0.03	0.01	0.01
Arsenic	mg/L	47.00	0.03	0.00	0.03	0.01	0.00
Cadmium	mg/L	15.00	0.01	0.00	0.01	0.00	0.00

Min: Minimum; Max: Maximum

Table 8: Temporal variation of heavy metal concentrations

Heavy metal	Units	Average value rainy season	Average value dry season
Dissolved Iron	mg/L	1.489	1.511
Copper	mg/L	0.026	0.031
Lead	mg/L	0.006	0.029
Zinc	mg/L	0.011	0.008
Arsenic	mg/L	0.006	0.029
Cadmium	mg/L	0.002	0.003

Bold-faced: Higher average value

ranged from 0.002 to 0.054, 0.0012 to 0.0496 and 0.002 to 0.032 mg/L respectively with overall means of 0.014, 0.02 and 0.0086 m/L.

Arsenic and cadmium recorded higher concentrations of 0.028 and 0.011 mg/L, respectively. The minimum concentration recorded for arsenic was 0.008 mg/L. The minimum value recorded for cadmium was 0.002 mg/L which was just equal to its detection limit. The overall means for arsenic and cadmium over the entire period was 0.00695 and 0.00445 mg/L, respectively. With the exception of zinc, the average concentrations of all the trace metals analysed were higher in the dry season than the rainy season (Table 8).

DISCUSSION

Water quality guidelines are prepared to ensure that water supplies are developed to provide safe water, consistent with the available resources and appropriate technologies; and to furnish a basis for establishing criteria for the design of water supplies and programme planning, including establishing minimum treatment needs and resource allocations for various competing needs and beneficial uses (Ola, 2006).

With the exception of Awusu Upstream (AW1), all the sampling locations do not meet the W.H.O and G.W.C.L guideline of 300 μg/L (0.3 mg/L) of dissolved iron per litre of freshwater samples intended to be used for drinking (W.H.O, 2006; G.W.C.L, 2005). However, it may not give rise to any known health consequence when water from these sampling sites is ingested.

Analysis of water samples over the study period indicated that all the surface water samples qualify as regards their use as a drinking water source with respect to the concentration of copper. They will not pose any public health risk nor give rise to complaints from consumers (W.H.O, 2006).

The mean concentration of lead from Abudusu (AB1) and Awusu Upstream were below W.H.O guideline value 10 μg/L for drinking water (W.H.O, 2006); all the other sampling sites do not qualify as a source of drinking water and may be of significant health risk when water from these sources are ingested.

Water samples from Abudusu Upstream AB1 and Ayigbetowm Community Borehole (BH3) (Table 5) do not meet the W.H.O guideline value of 10 μg/L (0.01 mg/L) for the concentration of arsenic in drinking water. This may have significant health consequences when water from these sources is ingested.

Samples from Kutuani Downstream (KT3) and Ayigbetown Community Borehole (BH3) do not meet the G.W.C.L/W.H.O guideline value of 3 μg (0.003 mg/L) of cadmium per litre of freshwater intended for drinking and there may be significant health consequence when water from these sources are ingested even though they can be used as a source of drinking water for livestock and irrigation water supply.

The concentration of zinc in the water samples from all the sampling sites were below various W.H.O guideline value of 3000 μg/L and as a result all the sampling sites qualify to be used as a source for drinking water. Also the contaminant levels of zinc are not of any health significance neither will it give rise to consumer complaints.

The concentrations of heavy metals around the mined out area (Abudusu Midstream) was below that of the pristine upstream environment of Awusu and Abudusu streams (Table 1-6). This suggests that the disturbance at the mined out area midstream, accelerated the leaching of these trace metals within the area, hence the observed concentration a decade after mine closure. This process might have been enhanced by the poor retentive properties of the parent material of the forest oxysols which are strongly leached (Brian, 1962).

Fuels, exhaust of automobiles, industrial emissions and effluents, leachate from landfill sites and refuse dumps contain a variety of toxic elements including heavy metals (lead, mercury, cadmium, arsenic, zinc, etc), radioactive elements, acids and other toxic substances (Clark, 1992; Ukpebor and Unuigbe, 2003; Ikhuoria and

Uyammadu, 2000; Oyewo and Don-Pedro, 2003). The most important or significant source of heavy metals in freshwater ecosystems in Ghana have been attributed to mining and associated operations not excluding mineral processing (Carboo and Sarfor-Armah, 1997; Armad and Carboo, 1997; Blay and Adu-Anning, 1997; Akabzaa, 2000). These heavy metals accumulate in fish tissues, foodstuffs and irrigated vegetables and are passed on to humans (Sarkodie *et al*., 1997). Also the drinking of water or ingestion of food contaminated with these trace elements at relatively low dosage in the parts per million concentrations (or at instances parts per billion) can lead to brain damage, birth defects and infant mortality among others (Clark, 1992; Cunningham and Saigo, 1999; Baird, 1999). These toxic heavy metals (trace metals) may also be released from weathered rocks/natural soils, carried by storm water runoff into rivers or percolate into groundwater.

The occurrence of heavy metals in various aspects of the environment has also been attributed to the indiscriminate disposal or discharge of industry and mine waste or effluent (Ikhuoria and Uyammadu, 2000). These activities, according to Sarkodie *et al*. (1997) had neither been regularized nor monitored. The situation has led to serious impacts on both the terrestrial and aquatic environment due to the high toxicity and persistence of these metals (Don-Pedro *et al*., 2004).

Mine drainage and leaching of mining wastes are serious sources of metal pollution of water (Cunningham and Saigo, 1999). However, waste piles left from surface gold mining, refuse dumps and abandoned heavy industrial equipment after mine closure remain a visual blight on the landscape. They may contain some amounts of toxic ions, such as lead, arsenic, copper, mercury, cadmium, zinc, dissolved iron and other trace metals, which have low solubility. The abandoned washing plant may not cause appreciable leaching of heavy metals into surface and groundwater where they may contaminate water supplies.

The relatively low concentrations of heavy metals in the sampled media with respect to the maximum contaminant levels for drinking water sources is an indication that the freshwater resources affected by the defunct dredge mine operations is moderately polluted and the quality of freshwater resources including the drinking water sources have been restored by inherent self-purification capacity of the freshwater ecosystem, a decade after mining.

These findings suggest that enforcement of environmental regulations based on periodic environmental audits by regulatory agencies would enhance the inherent self purification capacity of ecosystems to restore quality of freshwater resources affected by dredge mine operations. It is therefore evident that the drinking water sources were not polluted beyond the assimilative capacity with regards to heavy metal concentration, hence the observed resilience a decade after mine closure. However, there is the need for regular monitoring of the concentration of heavy metals in the sources of drinking water (especially swamp retention areas of abandoned dredge mines and also during the dry season when concentrations are relatively high) within the study area affected by the dredge mine to forestall any outbreak of carcinogenic diseases.

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