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Abstract

The paper examines the environmental impact of artisanal mining of gold with mercury (Hg) in Ghana. In spite of its positive socio-economic contributions, it is well known that artisanal mining of gold contributes in no small measure to land degradation, loss of biodiversity and natural resources, deforestation, water pollution, etc. In Ghana, these environmental problems remain poorly studied. In the case of Hg pollution, caused by gold extraction using the amalgamation process, total Hg levels in different environmental compartments of the gold-mining-impacted Pra River basin in southwestern Ghana were determined using the latest sampling and analytical techniques. Artisanal gold mining activities in the Pra River basin are on the increase and even though Hg levels determined in water, soil, and sediments were below WHO safe guideline values, the current state of affairs poses a serious environmental threat. However, the majority of the populace, particularly those engaged in gold mining, are unaware of the dangers posed by the use of Hg in mining operations. This paper seeks to draw the attention of Ghanaians (as well as their foreign counterparts) to the need to take up the mantle in changing the general patterns of environmental damage caused by the artisanal gold miners. The need to regularize artisanal gold mining is long overdue. A legal regime for mines of every size, leading to a transformation of the artisanal mining sector into a legal, regulated industry, will help minimize the impact on the environment.

Introduction

Artisanal gold mining (AGM) with mercury (Hg) has been a subject of keen interest and intense debate by the public, international agencies and many environmental pressure groups lately, because of Hg's toxicity to living organisms in general. The disaster in Minamata, Japan, where several mass poisonings involving Hg attracted the general attention of the scientific community towards the end of the 1950s, is still fresh in memory. The inhabitants living in fishing communities along Minamata Bay suffered an epidemic of neurological disorders, which were afterward attributed to Hg poisoning from fish consumption from the bay. Subsequent investigations revealed contamination by industrial discharges of Hg into Minamata Bay (Klein & Goldberg, 1970; D'Itri & D'Itri, 1977). Other incidents of Hg poisoning have been reported in Iraq, Pakistan, and Guatemala, with numerous deaths resulting from the eating of Hg-contaminated fish or consumption of foods prepared from seed grain treated with mercurial fungicides (Bakir *et al.*, 1973; Zhrlich, 1990). Presently, this fearful concern of Hg's hazards or toxicity has heightened as observed in the numerous scientific international conferences and publications on Hg as an environmental pollutant.

Mercury is one of the priority toxic elements of global concern. It is a liquid metal at ambient temperatures and pressures. Hg forms salts in two ionic states Hg(I) and Hg(II). Hg(II) or mercuric salts are more prevalent in the environment than Hg(I) or mercurous salts. These salts, when soluble in water, are bio-available and are thought to be toxic. Elemental Hg is quite volatile and only slightly soluble in water. It is dispersed very effectively through the atmosphere with long residence times of about 2 years, and is normally transported from likely sources of emission (Lodenius & Malm, 1998; Boening, 2000). Thus, Hg in the various oxidation states is released into the environment from a variety of anthro-pogenic activities and natural sources. Wet and dry deposition are the only primary mechanisms for transporting this element from the atmosphere to the terrestrial and aquatic systems. Artisanal gold mining (AGM) is one such anthropogenic activity that has resulted in the use of an enormous amount of metallic mercury. The mercury used by the miners is usually discharged in an abusive manner into ecosystems (Pfeiffer & Larceda, 1988; Meech *et al.*, 1998).

Elemental Hg is now known to spread very effectively from diverse sources to both terrestrial and aquatic systems. Sediments function as sinks and potential sources of Hg and, once contaminated, pose a risk to aquatic life for many years. Depending on the environmental conditions present Hg compounds in aquatic systems could be transformed and liberated from sediments to water phase, ingested by aquatic biota, be lost to the atmosphere and dispersed; or be conveyed with sediment particulate matter to new previously uncontaminated locations

(Ullrich *et al.*, 2001). Furthermore, research indicates that the ecological and toxicological effects of Hg strongly depend on the various chemical species present.

Inorganic Hg may be converted by microbial activity in an organic-rich environment to organic forms of Hg, e.g. methyl-Hg (MeHg), which are many times more toxic to organisms (Beijer & Jernelov, 1979). MeHg is a potent neurotoxin, damages the central nervous system and especially toxic to fetus. It is very soluble in lipids and, therefore, crosses biological membranes with ease. Because of its protein binding properties, it readily bio-accumulates and bio-magnifies in aquatic food chains. As a result, it poses a threat to humans and other fish-eating animals (Lodenius & Malm, 1998). The main pathway of human exposure to this toxic metal is through the consumption of Hg contaminated fish as illustrated by the mass Hg poisoning in Minamata Bay and Agano River in Japan (D'Itri & D'Itri, 1977; Takizawa,1979) during the 1950s and 1960s.

Gold mining with mercury

The mining sector has been identified as an important anthropogenic source of Hg emissions (Nriagu & Pacyan, 1988; Lindqvist *et al.*, 1991; Larceda, 1997; Villas Boas *et al.*, 2001). It has been reported that South America, Russia and Asia emit about 450 tonnes of Hg into the environment annually (Larceda, 2003). Today the use of Hg in gold and silver extraction poses a unique problem in mining areas around the world (Filho & Maddock, 1997). The first known usage of amalgamation in gold mining occurred in Spain as early as 700 BC and the process was subsequently used extensively by the Romans around 50 BC. The Spanish also experienced the first documented case of Hg pollution (Lacerda & Salomons, 1998). Despite these, Hg continues to be utilized in artisanal gold mining throughout the world, especially South America, Africa, Asia and North America (Lacerda & Salomons, 1998). Most emissions occur in third world nations (Larceda, 2003).

AGM is a household word in most developing countries where it is practiced and is the economic backbone of some nations today. Presently, it is rapidly spreading throughout the tropics, particularly in Latin America, Asia and Africa where gold is produced on artisanal and small-scale basis (Lacerda Marins, 1997; Villas Boas *et al.*, 2001). Since 1980, artisanal gold mining activities have been increasing steadily. Conspicuously, AGM is believed to account for one-quarter of the world's gold output. The "gold rush" phenomenon in the artisanal gold mining sector with large numbers of miners flooding an area continues to play an important economic role and provides livelihood for a large number of people. However, research findings from the Brazilian Amazon demonstrate that the threatening potential consequence of the modern Amazon "gold rush" is the uncontrolled use of Hg. This has been known to affect the aquatic ecosystem, in addition to other environmental havocs (Cleary & Thorton, 1994). Ultimately, this has culminated in several studies on the potential consequences of Hg use in gold extraction in the South American environment (Larceda & Salmons, 1998; Malm *et al.*, 1990a; Malm, 1998b).

AGM activities in Ghana are on the increase. Some of the river basins in Ghana are rich in alluvial gold and are characterized by a very wide range of habitats and ecosystems with varying degrees of species diversity. Most of the activities of AGM are undertaken in the rivers as well as along the river banks. Amalgamation is the preferred gold recovery method employed by almost all artisanal gold miners because it is a very simple, inexpensive and an easier to use technique. The extensive use of Hg in gold extraction has become a source of anxiety and worry and mass extinction of some biological species including both plants and animals has been experienced lately (Amegbey *et al.*, 1997). The impact of AGM on bio-diversity and development has either been ignored or not thoroughly examined. Obviously, AGM activities in Ghana are rampant and taking a different dimension. Unfortunately, majority of the populace, particularly those engaged in mining activities are, perhaps, unaware of the dangers posed by Hg. In Ghana, the main environmental problems associated with artisanal gold mining activities are Hg pollution from gold processing, ecosystem destruction, and environmental degradation (Amegbey *et al.*, 1997; Hilson, 2002). The improper use and handling of mercury can also lead to potential health hazards for miners as well as inhabitants of the communities who may be exposed to the metal through the food chain (Lacerda & Salomons, 1998).

Ghana has not paid the needed attention to Hg contamination due to AGM activities. Moreover, there are no dependable data to assess the extent of Hg contamination in the various environmental compartments. Literature available on Hg pollution in Ghana deals with survey data on some of the rivers draining the south-western gold belt. Adimado & Baah (2002) have studied Hg concentrations in human blood, urine, hair, nail and fish from Ankobra and Tano river basins in south-western Ghana. Bannerman *et al.* (2003) reported that there was Hg and arsenic (As) contamination in sediment and water in the gold mining regions of the Ankobra river basin. Bonzongo *et al.,* (2003) also examined the extent of Hg contamination in water, sediment and soil from artisanal gold mining-impacted Ghanaian watersheds. Brief studies have also been carried out on Hg in water, sediments and soils of some rivers near Dunkwa-on-Offin (Golow & Mingle, 2003b; Golow & Adzei, 2002a). In addition, Amonoo-Niezer *et al.* (1996) investigated Hg and Arsenic pollution in soils, food crops and fish around Obuasi, a mining town and its environs. In a study supported by UNIDO, Babut *et al.* (2003) studied Hg contamination in water, sediment, soil and food crops in the Apopre river basin at Dumasi, a well-known artisanal gold mining town in Ghana.

Inspite of all the aforementioned studies on Hg pollution in Ghana, there is the need for further studies on the aquatic ecosystem using the recommended state-of-the- art "ultra-clean free-metal sampling protocol" (Gill & Fitzgerald, 1985) in order to predict the potential impacts of Hg poisoning on humans, as well as aquatic life. This is because in studies where ultra-trace methods were not used, published data were characterized by frequent inaccuracies (Fitzgerald *et al.,* 1998). There is also the need for increased understanding of Hg poisoning in the mining communities. In addition, Hg-rich mine tailings remaining in most mining sites later become susceptible to leaching, erosion and volatilization or degassing (Larceda & Salomons, 1998). One can then suspect an intensive Hg dispersion in these tropical systems due to high annual precipitation and transport via fluvial processes. Above all, warm temperatures found the year round and the high organic matter content of most soils and sediments would favour the methylation of dispersed Hg. However, to date, there has not been any in-depth studies to measure the potential rates of methylation and demethylation in the Ghanaian environment.

A survey study on Hg levels in River Pra and its tributaries, based on the "ultra-clean free-metal sampling protocol" was carried out in July 2002, during the rainy season. During the study, the accuracy and precision of the analytical methods used were evaluated using a certified reference material, CRM-580 (obtained from the European Commission). This was done for both total and MeHg digestion/analyses. Recovery of CRM-580 averaged 98 ± 7% and 89 ± 6% for total Hg and MeHg, respectively. Recoveries on matrix spikes ranged from 90–105% for both total and MeHg. The organic carbon content of soil and sediment samples was determined as loss on ignition (LOI) by combustion at 550 ºC for 2 h. The results obtained demonstrated evidence of Hg contamination in analyzed water, sediment, soil and human hair. This paper is based on the data obtained from the study and is intended to stimulate research on Hg biogeochemistry and its potential effects on human health in Ghana.

Brief history of gold mining with mercury in Ghana

Commercial scale gold mining is believed to have commenced in Ghana in the early 19th century by the British. Other records indicate that AGM was practiced as early as the 4th century and the indigenous population of Ghana got more involved when the Europeans arrived in 1471 (Tsikata, 1997; Akabzaa & Dramani, 2001). Amalgamation technique has been used and is still being used to extract gold from the "crude" ores. Despite the promulgation of Mercury law in 1933 banning Ghanaian gold miners from using Hg in their operations, the practice continued (Akabzaa & Dramani, 2001; Hilson, 2001; 2002) till its legalization in May 1989 by the Provisional National Defence Council Law 218, (PNDC Law 218). The legalization of small-scale gold mining has escalated AGM activities, thus providing direct and indirect employment to over one million people and playing a significant role in the economy of Ghana. Currently, AGM contributes about 10% of the total annual tonnage of gold production in Ghana (Adimado & Baah, 2002).

Impact of artisanal mining in Ghana

In artisanal gold mining, gold is extracted mainly from alluvial deposits along rivers, waterways and terrestrial soils. Gold is then processed by crushing and grinding of the gold-bearing ore. The gold is extracted from the concentrate by adding Hg to form gold-amalgam which is normally roasted in open air to obtain "raw gold". The elemental Hg evaporates into the air and is subsequently deposited onto land and surface waters, after undergoing oxidation to ionic Hg (Hg^{2+}) through reactions mediated by ozone, solar energy and water vapour (Larceda & Salomoms, 1998).

Mercury, once exposed to atmospheric, aquatic and terrestrial influence, may undergo a series of transformations, eventually becoming Methyl-mercury which is a neurotoxin and the most toxic form of the metal. Methyl-mercury is easily incorporated in living organisms and accumulates in the food chain. Consequently, fish and other aquatics are contaminated endangering populations consuming the fish (Cleary & Thornton, 1994). In addition, Hg entering the environment is transported downstream of river systems, probably reaching the coastal region in the Gulf of Guinea.

In addition to the afore-mentioned environmental impacts, artisanal gold mining contributes significantly to land degradation, dust production, pollution of soils and agricultural sites, diversion of river courses, exposure of large areas to erosion and subsequent release of other heavy metals into waterways, and complete deforestation and loss of biota. Hg may also disperse to other distant uncontaminated locations, making those habitats vulnerable to Hg poisoning. This may occur through deterioration of air and water quality and subsequent deleterious effects on living organisms as well as humans (Cleary & Thornton, 1994; Addy, 1998; Ogola *et al.*, 2002; Lombe, 2003). In effect, there is loss of biodiversity and conservation of natural resources.

Scientific research on use of Hg in artisanal gold mining in Ghana

Results of the survey study on assessment of Hg levels in water, sediment, soil and human hair samples collected from the Pra river basin and its main tributary, River Offin (Fig. 1), south-western Ghana in July 2002 are discussed. The results are presented in Table 1. These clearly indicate substantial Hg contamination. Water samples collected from areas remote from current gold mining sites (marked "C" in Fig. 1) gave high Hg concentrations reaching values of about 148 ng/L. Total-Hg concentrations in water samples collected from mining impacted sites along the River Offin are in the range 41.6–420 ng/L whereas in the upper and lower River Pra, Hg concentration range from 24–294 ng/L and 28.7–403 ng/L, respectively. These levels of Hg, definitely exceed values of safe limits given by international agencies (e.g. 1.0 ppb and 2.0 ppb set by WHO (1996) and US-EPA *(www.epa.gov*), respectively. Likewise, the mean values for sediment and soil also exceeded the US-EPA (www.epa.gov) value of 200 ppb in the case of River Offin. However, the remaining sites were below that of US-EPA limit. On the other hand, these values were quite high on comparing with other known artisanal mining regions in the world (Table 2). Concentrations of Hg in hair samples from the study area were lower than the WHO (1996) recommended value of 50 p.p.m. These values obtained is a matter of great concern, since most of the rivers in the affected areas empty into the Gulf of Guinea, and any Hg reaching these waters would likely lead to more human exposure via food intake.

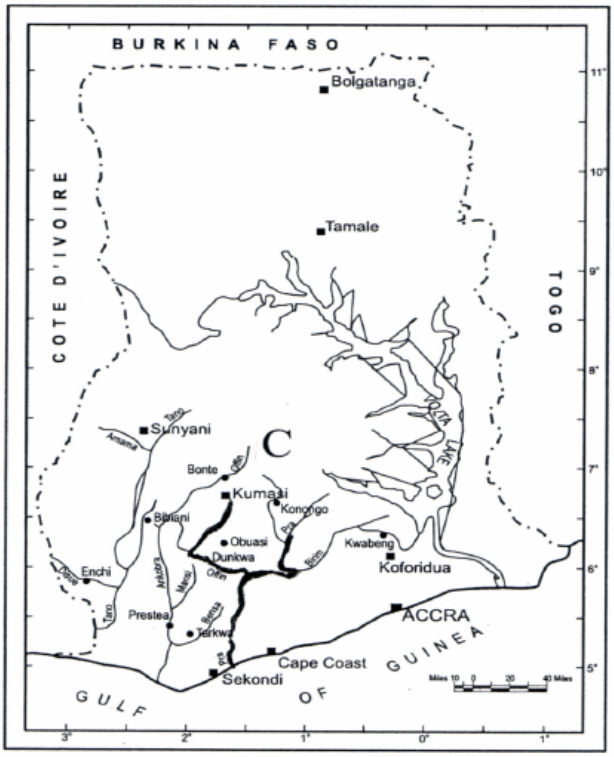

Fig. 1. Map of Ghana showing major rivers where AGM is practiced. The bold river is the river Pra and its tributaries under study.

TABLE 1

Hg concentrations found in River Pra Basin, Ghana

		Lower Pra river basin	*Offin river basin*	*Upper Pra river basin*	*Non-impacted site*
Hg in water (ng/l)	*n*	*8*	*7*	*4*	*1*
	Range	28.70–403.00	41.60–420.00	24.00–294.00	148.92
	average	**144.10**	**205.36**	**150.68**	**148.92**
Hg in sediment (ng/g)	*n*	8	7	4	1
	Range	6.52–57.32	2.73–49.86	13.07–23.22	11.21
	average	**25.89**	**23.00**	**18.09**	**11.21**
Hg in soil (ng/g)	*n*	8	22	4	1
	Range	3.40–202.32	1.56–2146.96	12.09–34.26	4.00
	average	**75.61**	**263.79**	**24.61**	**4.00**
Hg in hair (ng/g)	*n*	24	31	n.d.	n.d.
	Range	374.77–4130.29	582.35–1826.55	n.d.	n.d.
	average	**985.66**	**1185.52**	n.d.	n.d.

n = number of samples; *n.d.* = not determined

Comparison with other known AGM sites in the world

Table 2 gives the comparative data for environmental samples and human hair from Ghana with that of three other famous AGM sites in the world. Hg levels for surface water samples (non-filtered) exceeded WHO Drinking Water Guideline value of 1 ppb (1996) and US-EPA, (*www.epa.gov*), guideline value of 2 ppb for Water Quality Criteria for the Protection of Aquatic Life. Total-Hg concentrations in non-filtered water samples collected from all sites were relatively higher than known sites in Brazil and Indonesia. The Brazilian sites (Madeira and Tapajos rivers) averaged 1.56 and 3.4 ng/L, respectively (Cleary & Thornton, 1994; Malm *et al.*, 1990), whereas the Indonesian site gave 6.03 ng/L of Hg (Aspinall, 2001). The difference in Hg levels between the river basins in Ghana and Brazil and Indonesia, are very significant. However, Hg levels reported for the Philippines (Mindanao Island), averaged 75,400 ng/L (Appeleton *et al.*, 1999; Akagi et al., 2000; Drasch *et al.*, 2001) and far exceed levels recorded in Ghana (Table 2). Such differences could be attributed to the period of sampling, the number of sites sampled and distances from points of collection, as well as the amount of Hg released during amalgamation and roasting of Hg. The mean values for sediment and soil in the Ghanaian river basins were lower compared with those of Brazil, Philippines and Indonesia (Table 2). The difference could probably be due to differences in sampling seasons, location from mining sites, size, volume and flux of waterways and sediment grain size (Larceda & Salomons, 1998).

TABLE 2

AGM and Hg levels in Ghana compared with other nations with active AGM – data sources: Ghana (this study); Brazil (Cleary et al.*, 1994; Malm* et al.*, 1990; Malm, 1998); Philippines (Appeleton* et al.*, 1999; Akagi* et al.*, 2000; Drasch* et al.*, 2001); Indonesia (Aspinall, 2001).*

		Ghana Lower Pra river	*Ghana Offin river*	*Ghana Upper Pra river*	*Brazil Madeira river*	*Brazil Tapajos river*	*Indonesia Talawan area*	*Philippines Mindanao island*
Hg in Water (ng/l)	n	8	7	4	19	28	-	3
	Range	28.70-403.00	41.60-294.00	24.00-20.05	1.17-7.30	1.20-	-	72800.00-78400.00
	Average	**144.10**	**205.36**	**150.68**	**9.09**	**3.40**	**6.03**	**75400.00**
Hg in Sediment (ng/g)	*n*	8	7	4	26	28	-	10
	Range	6.52-57.32	2.73-49.86	13.07-23.22	30.00-350.00	170.00-430.00	-	920.00-66470.00
	Average	**25.89**	**23.00**	**18.09**	**130.00**	**290.00**	**6820.00**	**21030.00**
Hg in Soil (ng/g)	*n*	8	22	4	5	20	-	-
	Range	3.40-202.32	1.56-2146.96	12.09-34.26	270.00-540.00	180.00-360.00	-	-
	Average	**75.61**	**263.79**	**24.61**	**390.00**	**-**	**467.00**	-
Hg in Hair (µg/g)	*n*	24	31	*n.d.*	169	182	*n.d.*	316
	Range	0.37-4.13	0.58-1.83	*n.d.*	0.22-71	1.8-42.7	*n.d.*	0.03-37.76
	Average	**0.99**	**1.18**	*n.d.*	**8.98**	**16.20**	*n.d.*	**4.14**

n = number of samples; *n.d.* = not determined

On the other hand, Hg levels determined in hair samples of both miners and non-miners were below the WHO recommended guideline value of 50 pp m (WHO, 1996). Furthermore, the average Hg values measured in the Ghanaian hair samples were relatively lower than values reported in literature for Brazil and the Philippines, two countries where similar mining conditions prevail. The reasons for the observed trend could be partly due to fish production and consumption patterns in the study area (and by miners). In fact, data in the literature tend to suggest that higher Hg levels in hair are normally observed in months corresponding to the dry season and lower levels in the rainy season (Maurice-Bourgoin *et al.*, 2003; Coquery *et al.*, 2003; Dolbec *et al.*, 2001; Akagi *et al.*, 1995). Also, the difference in mercury levels could be due to exogenous contamination from water, air, or

cosmetic treatment and from endogenous Hg deposition. There is, however, lack of information on the mechanisms and kinetics by which endogenous trace elements are incorporated into the hair. Re-burning operations at the gold buying sites could probably have accounted for the levels of Hg in hair samples.

Consequently and probably, Hg contamination in the Ghanaian environment is yet to be felt compared with nations like Brazil. Research is, therefore, required to ascertain total Hg and methyl-Hg levels, so as to elucidate the ecological fate of the metal in the riverine system. It is hoped to examine the impact of seasonal climatic conditions on these forms of labile Hg.

Conclusion

It is apparent that the effect of gold mining using amalgamation technique has not been thoroughly investigated in Ghana. Specifically, the fate of Hg in the environment is virtually unknown, and the total amount of Hg used for the recovery of gold unascertained. Compared with other active AGM sites in the world, the mean Hg values obtained in the study from the "snap shot" in soil and sediment were lower than those of Brazil, Philippines and Indonesia, with the exception of water. The relatively low absolute Hg values measured in Ghanaian soils and sediments could simply be due to the fact that although the ultimate sink for heavy metals is deposition and burial in soils and sediments, heavy metals often accumulate in the top layer of the soil and, therefore, rain-washed into near-by streams and rivers. Samples were collected during the rainy season. This is supported by the fact that seasonal studies conducted in the Brazilian Amazon and elsewhere in the tropics tend to show variations in Hg levels in environmental compartments, with high values observed in the dry season and low values in the wet season.

On the whole, an urgent attention is definitely needed to curtail and abate Hg distribution, dispersion and transportation to currently uncontaminated sites so as to avoid a major environmental disaster which could arise with continued release of Hg into the ecosystem. The time has, therefore, come for scientists in Ghana to launch intensive studies into the various environmental media so as to establish the levels of mercury in the environment and assess its possible social, economic and human health impacts. It is obvious that scientific information would be needed to aid in designing appropriate sanitary and remedial measures for Hg-impacted areas.

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