ANTHROPOGENIC SOURCES OF MERCURY POLLUTION IN THE ANKOBRA RIVER BASIN IN THE SOUTH WESTERN GHANA

T.M. AKABZAA[+], B.K. BANEONG-YAKUBO and T.E.K. ARMAH
Department of Geology University of Ghana, Box LG 58, Legon, Ghana.

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Abstract

The distribution and sources of mercury in the Ankobra River Basin and the Bonsa River Sub-basin in the Wassa West District in south western Ghana is assessed from the results of analyses of samples of water, streambed sediments, soils from areas of active and historic artisanal mining and historic mine spoil from large scale-mining. Eighty-two samples comprising water from streams, boreholes and hand dug wells; sediments from streambeds; and old mine tailings dumps were analysed for their total mercury content. Mercury in water was determined by cold vapour Atomic Fluorescence Spectrometry (CV-AAS). Leachate from sediments and mine spoil were also analysed by CV-AAS, following total nitric acid extraction. The highest mercury concentrations were recorded from historic mine tailings that range from 80 ppb to 2500 ppb. Mercury in water ranged from below detection to 8 ppb. Artisanal gold mining activities and mercury laced historic tailings dumps from large scale mining activities were identified as sources of mercury pollution in the area. Historic tailings dumps at Bondaye and Prestea returned the highest mercury concentrations. These mercury laced dumps together with high mercury concentration in some streams sediments constitute a potential source of major mercury pollution in the area and therefore require major and urgent clean up to mitigate any major health risks.

Key Words: pollution, mercury, old tailings, sediments, water, Tarkwa.

1. Introduction

Mercury is a heavy metal of environmental concern because elevated concentrations are toxic to living organisms. In humans, mercury damages the central nervous system and is especially toxic to the foetus (USEPA, 1997 and Gray *et al*., 2003). Natural and anthropogenic sources account for mercury dispersal in the environment. Naturally, cinnabar (HgS) is practically the only natural source of the metal. Commercial deposits of cinnabar are unknown in Ghana, although prospecting in some stream channels have returned heavy metal concentrates revealing promising mercury dispersion zone in the valley of Tromia in Brong Ahafo region of the country (Kesse, 1985). Apart from this zone, efforts at other areas in the country have so far not indicated mercury concentrations significantly above its crustal abundance of 30ppb (Henderson, 1982), implying that no significant natural sources of the metal are known in Ghana.

However, in recent times elevated mercury concentrations have been reported in streams, sediments, fish, and some plants in the mining districts of Obuasi and Tarkwa (Akabzaa *et al*., 2003; and Babut *et al*., 2003). These recent studies on mercury pollution in these mining areas have focused mainly on its status in water, sediments, fish and some plant species, and have assigned the activities of artisanal miners as the primary source. Between an estimated 30 thousand and 100 thousand legal and illegal artisanal gold miners in Ghana widely use mercury in the extraction of gold, as in many other developing countries. This is because Hg amalgamation requires only limited equipment and can be performed cheaply.

In the not too distant past, the use of mercury in gold ore processing was not limited to artisanal miners alone in Ghana. Large-scale mercury amalgamation mining was the technology of choice in the country until the early 1990s when it was officially prohibited in large-scale mining to be replaced by cyanidation. During the period that mercury was legally used in the large-scale mining sector, over 15 gold mines in the Tarkwa mining district, many of them abandoned today, used mercury for the extraction of gold. Gold ore dressing activities by these large mines have left on their trail scattered mercury-laced tailing dumps. For instance, over hundred years of ore mining in the three underground mines at Prestea, Tuapim and Bondaye, about 45 km from Tarkwa, has generated three vast expands of tailings dumps, covering a total area of about 30 km^2, while similar operations at the Tarkwa underground mine has also generated tailings covering over 16 km^2 of land space.

In this paper, the distribution and sources of mercury in the Ankobra River Basin and the Bonsa River Sub-basin and their mosaic of tributaries are assessed. These basins have poor abundance of fish and invertebrates because of heavy metal pollution (Babut *et al*., 2003). The area has witnessed over 500 and 100 years of artisanal and large-scale gold

+ *corresponding author* (email:takabzaa@ug.edu.gh)

mining respectively (Quashie *et al.*, 1981). Water from streams, boreholes, and hand-dug wells, discharge from mines; stream sediments and active and historic tailing dumps were sampled and analysed for their total mercury content.

2. The Study Area

The two basins are a host to several major mining towns such as Nsuta, Tarkwa, Damang, Abosso, Bogoso and Prestea, all in the Wassa West District of the Western Region of Ghana (Fig. 1). The area consists of low-lying plains with prominent hills and ridges usually less than 200 meters in height. The climate is typically equatorial, generally with high temperatures ranging from 25 °C to 29 °C. Annual rainfall data for the area indicate minimum and maximum values of 1449 mm and 2608 mm respectively with an annual average of about 1874 mm. The vegetation is described as Tropical rain forest, characterized by wet Evergreen and a transition zone between the wet Evergreen and moist tropical Forests

However, a significant portion of the forest has been removed by human activities, such as, timber exploitation, mining, charcoal burning and agricultural practices and has been replaced by secondary forest, scrub and slash-and-burn farmlands. The Ankobra River Basin and the Bonsa River Sub-basin and their mosaic of tributaries (Fig. 2), receive various mine-impacted water from large-scale gold mines at Prestea, Bogoso, Tarkwa and Damang, as well as some small-scale, often illegal mining operations, within the area.

The gold is derived from metasedimentary and metavolcanic rocks of the Birimian System and the paleo-sedimentary rocks of the Tarkwaian System. The Birimian System is dominated by metamorphosed greenstone and slate sequences (Eisenlohr and Hirdes, 1992; Miliesi *et al.*, 1991). In these sequences, the gold occurs in lenses of sulphide-bearing quartz veins, mainly in carbonaceous phyllite, as disseminated sulphides in the metavolcanics, or as oxidised derivatives of the two types. In the Tarkwaian the gold occurs in a conglomeritic horizon called the Banket Formation. The gold in this conglomeritic unit is free milling and very fine (Smith, 2001). It is the oxidised ores and the free milling varieties that are most amenable to dressing with mercury.

3. Materials and Methods

A total of 82 samples comprising water from streams, boreholes and hand dug wells; leachate from mine waste dumps, tailings impoundments, spent heap leach stacks and abandoned mine pit lakes and related drainage; stream sediments from channel-bed alluvium and soil material from old tailings dumps were collected. Samples from stream sediments and tailings dumps were taken from various locations within the same vicinity and combined to produce representative composite samples. All sample locations were recorded with a Global Positioning System (GPS). Details of sampling points are presented on the sample location map in (Fig. 2).

Sample collection, preservation, storage and quality control/quality assurance (QC/QA) protocols followed those outlined by Eppinger *et al.* (1999), APHA (1998), Bloom and Fitzgerald (1988) and Barcelona *et al.* (1985). Temperature, pH and electrical conductivity were measured in the field with WTW-Multiline Universal Meter. Water samples were collected in thoroughly cleaned high-density linear polyethylene 1-bottles. Samples were acidified with pure nitric acid (HNO_3) to pH less than 2 to prevent further reaction of the dissolved species (Appelo and Postma, 1999). Total mercury in water was determined by cold vapour Atomic Fluorescence Spectrometry (CV-AAS) and expressed in parts per billion (ppb) with detection limit of 1ppb.

For streambed sediments and mine spoil sampling, a plastic scoop was used to scoop the material into polyethylene sampling bags and tightly secured. These samples were oven-dried at 40 °C for three days and subsequently sieved to 80 mesh in the laboratory. A total nitric acid extraction was then applied to this fraction to obtain a leachate, which was then analysed for mercury using the same cold vapour Atomic Fluorescence Spectrometry.

Analyses were performed at the Water Research Institute (WRI) of the Council for Scientific Research (CSIR). However duplicates of select samples were analysed at the SGS Commercial laboratory in Tema and the Ecological Laboratory (Ecolab) at the University of Ghana for quality assurance and control purposes.

4. Results

The results of analysis of stream sediments and material from mine spoil are presented in Table 2, while those from water are presented in table 3, while summarised descriptive statistics are presented in Table 1. The samples contain highly variable total mercury concentrations ranging from 33ppb-25000 ppb in old mine tailing dumps; 63ppb to 270 pbb in streambed sediments; and from <1 ppb to 8 ppb for water samples (Table 1).

(a) Mercury in mine spoil and streambed sediments

Mine spoil and stream sediments have mercury concentrations of over 10-100 fold the concentrations in water. The highest mercury concentrations were recorded from historic mine tailings with average concentration of 795 pbb. Samples with the highest mercury values of 2025 ppb and 2500 ppb came from old tailings dumps from the Bondaye and Prestea

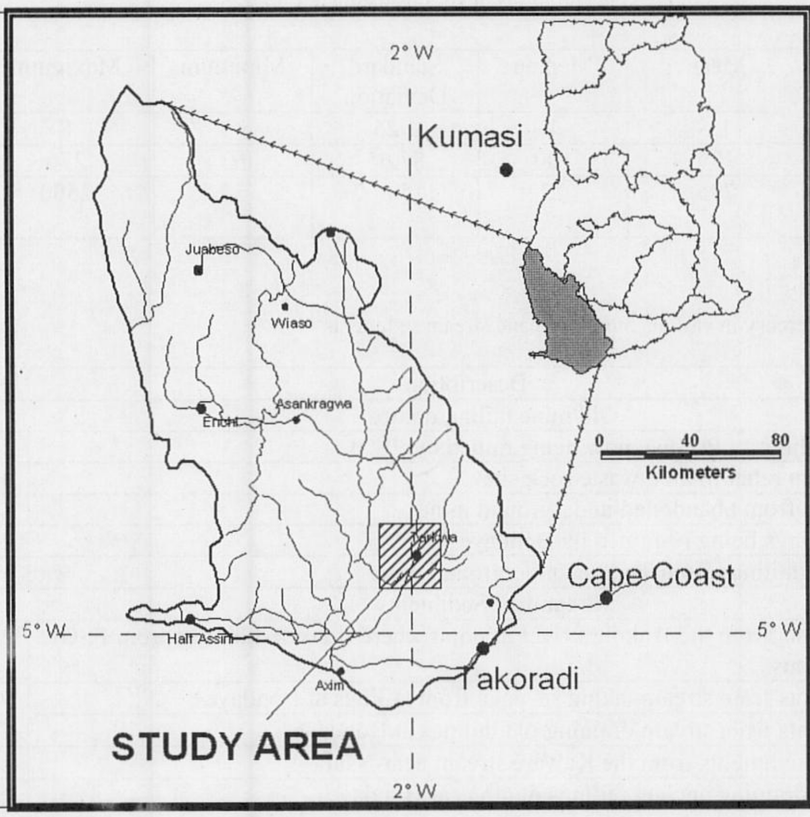

Figure 1: Map showing the Tarkwa area in Ghana

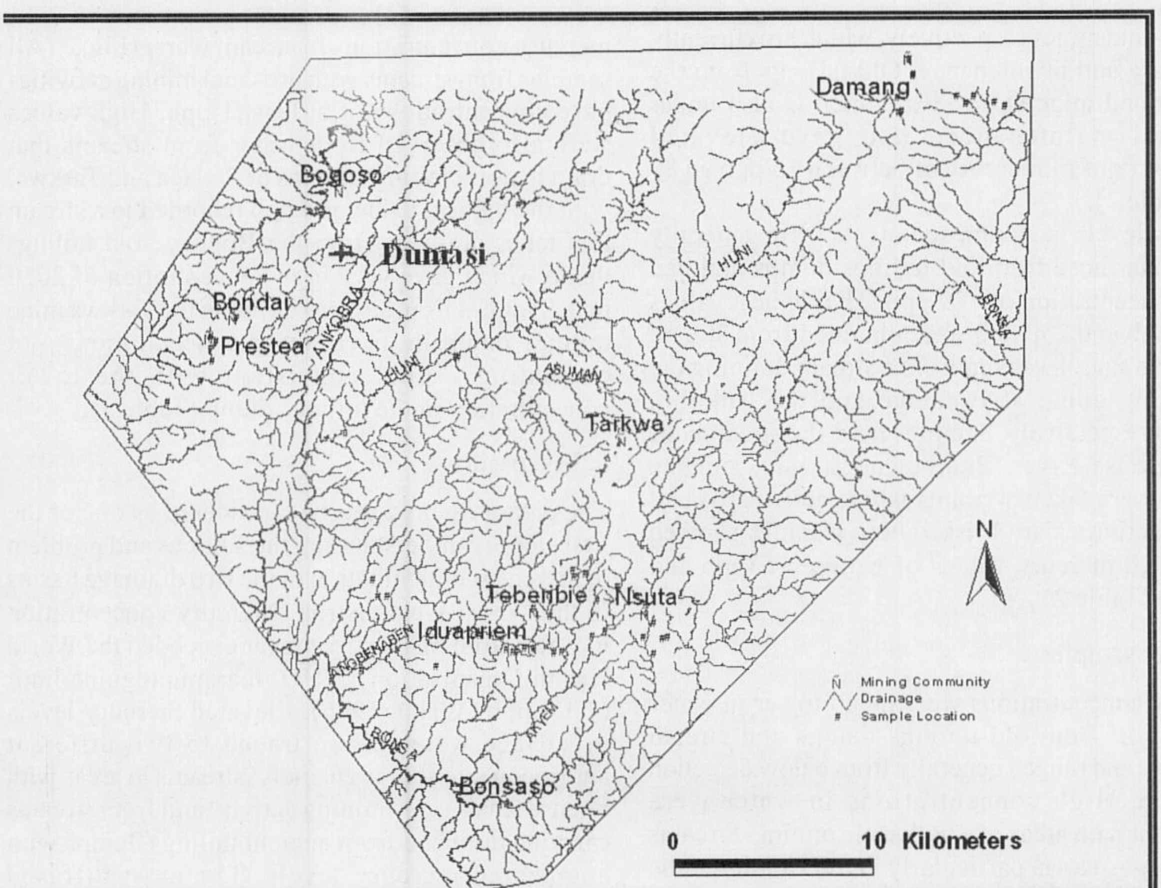

Figure 2: Map showing Drainage and Sampling Points

Table 1 Summary descriptive statistics of Hg concentrations in various media in ppb

Sampling Media	Mean	Median	Standard Deviation	Minimum	Maximum	Count
Water	1.5	1	1.25	<1	8	70
Streambed sediments	139	100	87.65	63	270	6
Old Mine Tailing Dumps	795	72	1154.67	33	2500	6

Table 2: Concentration of mercury in various mine spoil and stream sediments

Sample	Description	Hg (ppb)
	Old mine tailing dumps	
PGRTD01	Old Tailings at Prestea, now being mined by PSGL	2500
SSGFL01	Soil from rehabilitated waste rock site	43
TSGFL01	Tailings from abandoned underground mine	80
PGRTD02	Old tailings being re-mined by Bondaye	2050
TSGFL04	Ancient tailings from Tarkwa underground mine	33
	Streambed Sediments	
SSA01	Sediments from the Ankobra river at point where it takes drainage from PSGL Operations.	230
SSPGRB01	Sediments from stream taking seepage from tailings at Bondaye	97
TSPGRB01	Sediments from stream draining old tailings at Bondaye	270
GMCTS01	Stream sediments from the Kawere stream near Nsuta	103
SSPGRB03	Stream draining ancient tailings dump near Bondaye	63
SS1	Stream sediments from Bonsa Stream	63
SSTGL-6	Stream sediments from Bedibewuo stream near Tarkwa	70

underground mines respectively, which are currently under care and maintenance. Old tailings from the underground mine at Tarkwa, which is also under care and maintenance, also gave elevated concentrations of mercury of between 33 ppb ad 80 ppb (Table 2).

Mercury levels in stream sediments were generally lower than those from old tailings dumps and had mean concentration of 139 ppb. The highest values of 270 ppb and 230 ppb were obtained from stream sediments samples taken from a stream draining the old tailing dump at Bondaye and the Ankobra riverbed respectively. Samples from the streambeds of the Bonsa River, Bedibewuo stream, and the Kawere were taken at points where active artisanal mining activities are brisk. These samples showed augmented mercury values of between 63ppb and 103 ppb (Table 2).

(b) Water samples

Mercury concentrations were much lower in water than in soil from old tailings dumps and stream sediments and ranged generally from below detection to 8 ppb. High concentrations in water were coincident with areas of small-scale mining. Streams in the Bogoso area, particularly in the vicinity of the village of Dumasi and the Ankobra River, where artisanal mining is most intense, contained elevated mercury concentrations in stream water (Fig.3). All samples from streams with artisanal mining activities gave concentrations of at least 1 ppb. High values were also observed from water from streams that drain historic tailings dumps at Prestea and Tarkwa, with the highest value of 8 ppb recorded in a stream that takes drainage from the Bondaye old tailings dump which gave very high concentration of 2050 ppb. Samples from streams draining the Tarkwa mine tailings dumpsite have lower concentrations, not exceeding 1 ppb, consistent with the lower concentration in the tailings dump (Table 3).

5. Discussion

The data presented can be considered as one of the first steps to understanding the sources and problem of mercury contamination in the two drainage basins in the Wassa West district. Mercury concentration in water from many streams far exceeded the World Health Organisátion (WHO) maximum guide limit of 1.0 ppb (WHO, 1996). Elevated mercury levels in surface waters were traced to two different anthropogenic sources namely: streams in areas with intense small-scale mining activity and from streams carrying drainage from ancient tailings dumps with augmented mercury levels. The most diffused contamination of mercury in stream waters generally come from the Ankobra River and a mosaic of

Table 3: Concentration of Mercury in water

Sample No	Description of source	Hg (ppb)
SWS 001	Adieyie stream	<1
SWS 002	Small stream near Adieyie	1.0
SWS003	Angonabeng stream, with active illegal small scale mining activities	2.0
SWS004dn	Tributary of Angonabeng, with active illegal small scale mining activities	3.0
SWS004up	Tributary of Angonabeng, with active illegal small scale mining activities	3.0
SWS005	Tributary of Angonaben, downstream Iduapriem mine.	<1
SWS006	Bonsa River near Akilika Village.	<1
SWS007	Small stream within Neug North Forest Reserve with small scale mining activities.	3.0
SWS008	Stream Within Neug North Forest Reserve.	<1
SWS009	Small stream on the road to GAG staff bungalows.	<1
SWS010	Small stream with illegal small-scale mining.	1.0
SWS011	Lake behind Tailings dump at Iduapriem	<1
SWS012	Stream Behind heap-leach facility of Iduapriem mine with small scale mining workings	2.0
SWS013	Stream draining cyanide leach stacks at the Teberebie mine	<1
SWS014	Leachate from waste rock dump at Iduapriem	1.0
SWS015	Leachate from waste rock dump at Iduapriem	2.0
SWS016	Leachate from waste rock dump at Iduapriem	<1
SWS017	Stream draining waste rock dump at Iduapriem, further down stream.	3.0
SWS018	Bediebewuo Stream, flowing from Teberibie mine site through Teberibie village.	1.0
SWS019	Stream taking leachate from waste rock dump at Iduapriem mine	<1
SWS020	Kanufu Stream, tributary of the Bonsa	1.0
SWS021	Stream taking drainge from the old Teberibie mine.	2.0
SWS022	Bediebewuo stream, further down stream, with brisk illegal artisanal mining.	3.0
SWS023	Chirifan stream, near Akyepim village.	<1
SWS024	Small stream after Akyempim.	1.0
SWS025	Ahweteiso Stream	1.0
SWS026	Bonsa River at Bonsaso.	3.0
SWS027	Small stream close to the Bonsaso bridge, towards Tarkwa.	1.0
SWS028	Chirifan (Upstream), towards Akyem Wassa town	1.0
SWS029	Anikowkow Stream, close to Akyem Wassa Village	3.0
SWS030	Kawere Stream	1.0
SWS031	Small stream very close to Akyem Wassa.	<1
SWS032	Chonchon Stream, taking source from an old mine pit, near Nsuta, at edge of rail line.	<1
SWS033	Old mine pit at Hill A, Nsuta.	<1
SWS034	Mine pit lake at Hill A of the Nsuta. Mine.	<1
SWS035	Stream taking drainage from the manganese washing plant at Nsuta	2.0
SWS036	Stream close to the main entrance to Nsuta mine.	2.0
SWS037	Tamso Stream	<1
SWS038	Bediebewuo with illegal artisanal mining.	1.0
SWS039	Tuapim Stream near Tuapim shaft, Prestea.	2.0
SWS040	Water from Prestea underground mine	<1
SWS041	Stream draining old tailings dump of Prestea Mine now being worked by PSGL	<1
SWS042	Small stream at Bondaye-Nsuta, near Prestea.	1.0
SWS043	Small stream near Tuapim village.	<1
SWS046	Pit lake, from PSGL workings of old tailings dump at Prestea	<1
SWS047	Water pumped from Bondaye shaft.	<1
SWS048	Koroabo Stream with artisanal mining meters upstream	4.0
SWS049	Akobra River, near Prestea.	3.0
SWS050	Drainage from the old tailings dumps behind mill at Prestea	8.0
SWS051	Stream near Yariyaya village.	<1
SWS052	Stream on road to Awudua	<1
SWS053	Punii Stream	<1
SWS054	Small stream taking drainge from Tarkwa mine	1.0
SWS055	Stream carry sediment-loaded drainage from Tarkwa mine.	1.0
SWS057	Small stream taking drainage from the Tarkwa mine	1.0
SWS058	Small stream taking drainage from the Tarkwa mine	1.0
SWS059	Stream at Mile 4 village, downstream operations of GAG with active illegal mining.	3.0
SWS060	Tamann Stream, near Mile 4 village, with illegal mining..	2.0
SWS061	Twinisi Stream, near Tamann Stream, with artisanal mining with over 400 miners in camp called Cocoase.	3.0
SWS062	Tamann Stream (downstream), active artisanal mining activity.	1.0
SWS063	Ben Stream, source of domestic water for old Kyekyewere village.	1.0
SWS064	Anikowkow (downstream) with brisk artisanal mining activities.	5.0
SWS066	Bonsa River, near the Damang mine. It takes water from operational area of the mine	1.0
SWS067	Tamann Stream at New Damang.	2.0
SWS068	Bonsawere Stream at Nsuaem Village.	<1
SWS069	Batinidem Stream	2.0
SWS070	Asunsu Stream	1.0
HDW1	Hand Dug Well at Huniso	<1
HDW2	Hand Dug Well at Damang, near dammed river	<1
SWS045	Pit Lake from old tailings at Tuapim	<1
SWS044	Stream near Bondaye-Nsuta towards Tuapim	<1

tributaries around the Bogoso area where artisanal mining activities are most profound, particularly around the village of Dumasi and its satellite communities (Figure 3). However, the single highest mercury concentration in water came from a stream draining mercury-laced old tailings dump at Bondaye.

These observations are not surprising as mercury is the chemical used in gold extraction by these traditional small miners. All samples taken from streams where these small miners operate gave high mercury values. Some of these miners amalgamate their concentrate right in the streams leading to the spilling of the mercury into the streams (Figure 4).

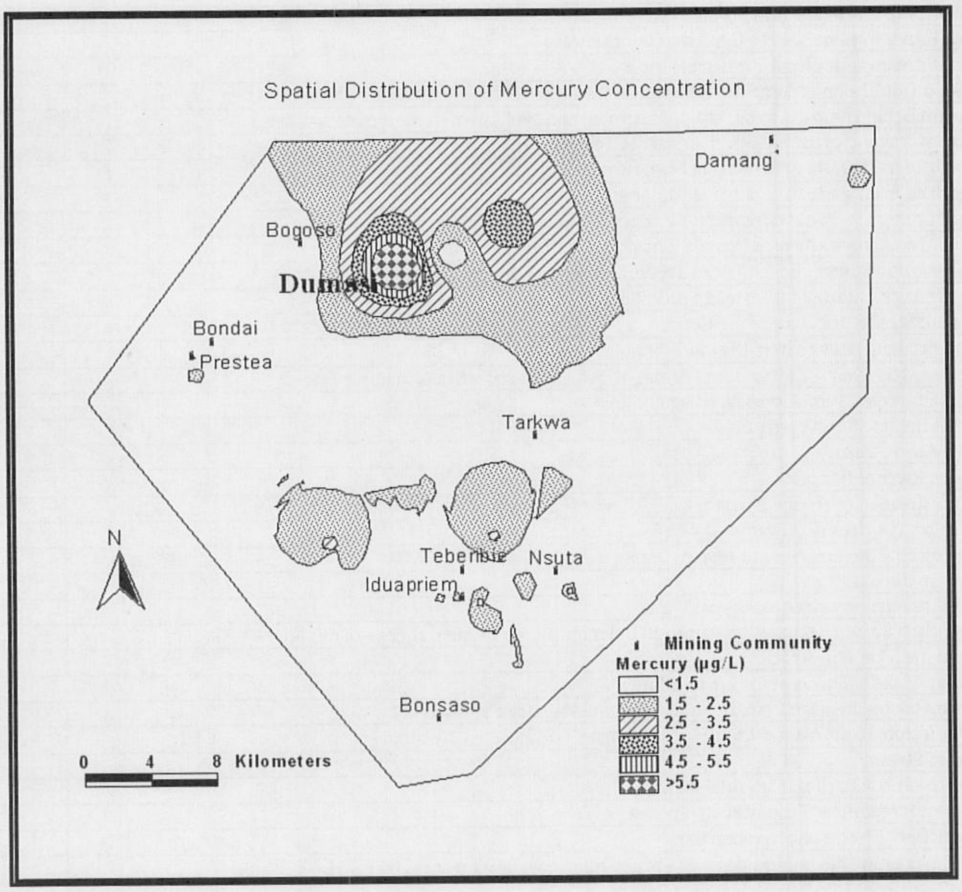

Figure 3: Spatial distribution of Mercury in stream water

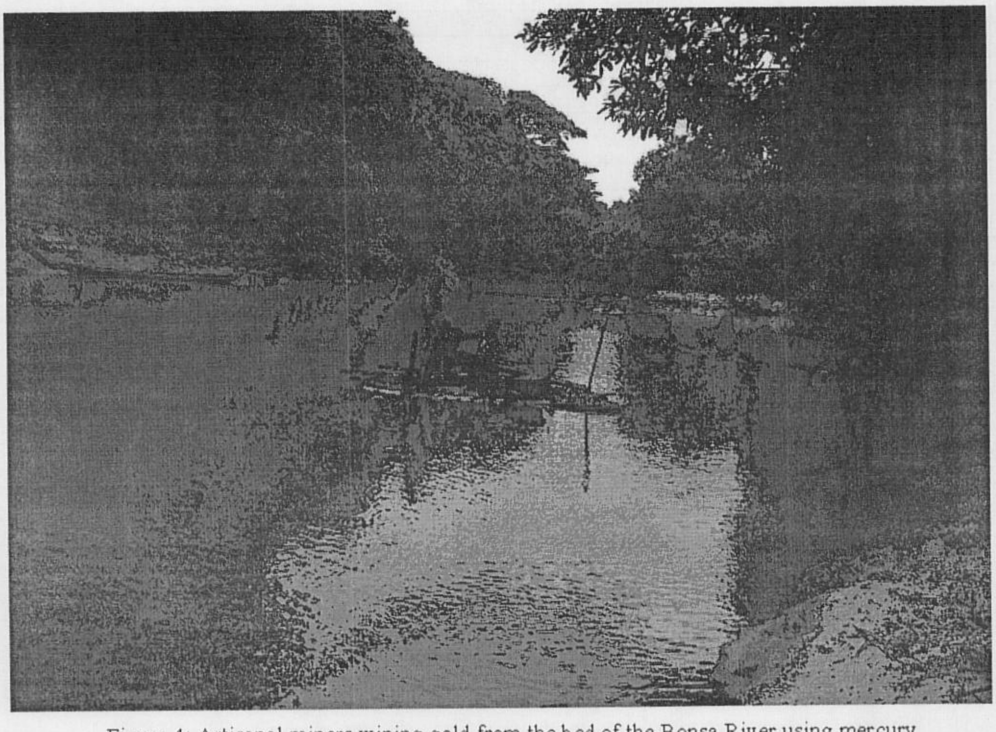

Figure 4: Artisanal miners wining gold from the bed of the Bonsa River using mercury

The relatively low level of mercury in water in these streams despite the high intensity of mercury use by these artisanal miners is not surprising. Hem (1985) has pointed out that mercury in water opened to the atmosphere is likely to be much lower owing to its tendency to escape via vapour. It may also form chloride and hydroxide complexes depending on pH and total chloride concentration.

Figure 4: Artisanal miners wining gold from the bed of the Bonsa River using mercury

Sediments from streams and soils from old tailings dumps have mercury levels of about 5 to more than 500 times in excess of the maximum allowable concentration of 10 ppb in these media that would require immediate remedial action (African Development Bank, 1994). The results demonstrate that mercury use by artisanal miners and mercury in old tailings dumps of large-scale mining activities constitute the two major anthropogenic sources of mercury contamination in the area. The highest mercury concentration in streambed alluvium of 270 ppb and 230 ppb were recorded in the Bondaye stream and Ankobra River intensely worked by both legal and illegal small-scale miners all year round, while the highest values 2025 ppb and 2500 ppb emanate from old tailings at Bondaye and Prestea. The source of mercury in ancient mine spoil in the area stems from historic use of mercury in gold amalgamation in the Prestea and Tarkwa mines up to the late1960s (NRS, 1990).

(a) Threats of wide spread mercury contamination in the area

The relatively low level of mercury concentration in water compared to concentration in sediments and mine tailings is indeed consistent with observation from studies elsewhere, where it has long been recognised that mercury is more efficiently transferred from water to bottom sediments (Koval *et al*, 1999; Varekam *et al.*, 2003; USEPA, 1997). Such rapid transfer is possibly through mechanisms such as sorption on suspended or bed load material, clay and organic material (Jenne, 1997). However, such forms of mercury exhibit weak bonds and can easily be extracted from the sediments under conditions of rainstorms resulting in seasonal flushing of doses of the metal into water (Jenne, 1997). The high concentrations in streambed alluvium and old mine tailings in the area constitute major sources of mercury contamination in surface waters. Varekam *et al.* (2003) have pointed out that such high contaminant sources present serious environmental problems as erosion of soils with high mercury loading brings these mercury bearing particles into the aquatic system.

Earlier studies have indicated augmented mercury concentrations in fish and plant species from the study area (Babut *et al.,* 2003). One possible pathway for fish and plant uptake of mercury would be transfer from sediments through methylation, which ensures a more bioavailable forms of the metal (Kelly, 1999). The dangers posed by high mercury concentrations in sediments have equally been echoed by Hem (1985) who pointed out that mercury ingested from sediments gets concentrated in the successive biological species along aquatic food chains so that fish that live in mildly contaminated environment may contain too much mercury to be used safely for food.

Thus, high mercury sources such as old tailings dumps and stream sediments identified in this study pose real threat to the general environment in the area, as these sources are capable of re-supplying mobile mercury to streams in the area during rainstorms. Currently the old tailings dumps have been evaluated to contain considerable gold resources, and ever since this disclosure, thousands of illegal small-scale miners have besieged these dumps. Their activities are sending considerable tailings into the drainage system. There is the urgent need to put intervention measures in place to clean up the area to prevent widespread mercury pollution.

6. Conclusion

The study has identified the application of mercury in gold ore dressing in small-scale mining and scattered mercury-laced old tailings dumps at Bondaye, Preseta and Tarkwa as the main anthropogenic sources of mercury in water and stream sediments in the Ankobra and Bonsa River Basins. The high concentration of mercury in the identified tailings dumps and streambed alluvium present serious environmental challenges as these serve as reservoirs for the supply of Hg into water bodies through erosion.

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