

Note from the field

## Improving the environmental management of small-scale gold mining in Ghana: a case study of Dumasi

M. Babut <sup>a,\*</sup>, R. Sekyi <sup>b</sup>, A. Rambaud <sup>c</sup>, M. Potin-Gautier <sup>d</sup>, S. Tellier <sup>d</sup>, W. Bannerman <sup>d</sup>,  
C. Beinhoff <sup>e</sup>

<sup>a</sup> Cemagref, Freshwater Biology Research Unit, CP 220, F-69336 Lyon Cedex 9, France

<sup>b</sup> Environmental Protection Agency, PO Box M 326, Accra, Ghana

<sup>c</sup> Université de Montpellier 1, Faculté de Pharmacie, Département des Sciences de l'Environnement et Santé Publique, 15 avenue Ch. Flahault, F-34060 Montpellier Cedex 1, France

<sup>d</sup> Université de Pau, France, Laboratoire de Chimie Analytique Bio-Inorganique et Environnement, UMR 5034 UFR Sciences, avenue de l'Université, F-64000 Pau, France

<sup>e</sup> UNIDO (United Nations Industrial Development Organization), Vienna International Centre, PO Box 300, A-1400 Vienna, Austria

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### Abstract

In April 2000, a UNIDO study was carried out in Dumasi, Ghana, the purpose of which was to determine the environmental impacts of mercury prior to the introduction of (mercury) retorts. The sampling program was intended to identify mercury transfers to rivers, soil systems and groundwater. Results show a diffuse contamination of all environmental media in the village. Although there is no evidence of groundwater contamination, sediments are significantly contaminated, and most fish fillets have mercury contents exceeding the United States Food and Drug Agency (US-FDA) action level, and are therefore unfit for human consumption. Mercury losses mainly occur during amalgamation, and have resulted in widespread pollution of soils and sediments throughout the village. Transparent retorts have been introduced and environmental training is ongoing but these efforts have only partially addressed the mercury problem in Dumasi.

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### 1. Introduction and background

For many years, continuous efforts have been made by the United Nations Industrial Development Organization (UNIDO) to provide assistance to the artisanal gold mining sector. This paper reports on the second part of a study undertaken by this organisation in Dumasi, Ghana. Whereas the first part focused upon the impact of mercury on human health in a gold mining community [1], the present study sought to assess, environmentally, the same “hot spot”. The specific objectives were:

- to collect samples from water, soils, etc. believed to be contaminated with mercury; and
- to evaluate the nature and extent of the mercury pollution in a selected river system and adjacent sites.

As an activity requiring modest investment and minimal technical skills, artisanal gold mining is attracting a growing number of people in Ghana, particularly in the following areas: Bibiani, Dunkwa, Asankragwa, Assin Fosu, Bolgantanga, Akim Oda, Tarkwa. Activities are quintessentially concentrated alongside rivers draining into the Gulf of Guinea. The industry employs an estimated 30,000 people (often reaching 100,000 depending on the season), most of whom are unlicensed [2]. Gold production from the sector amounts to 0.8 ton per year, although it could be as much as 10 times higher, as an undeterminable percentage escapes through illegal channels. More recent figures [e.g. Precious Minerals Market-

\* Corresponding author. Tel.: + 33-4-72-20-87-28; fax: + 33-4-78-47-78-75.

E-mail address: marc.babut@cemagref.fr (M. Babut).

ing Cooperation (PMMC)], however, estimate annual production to be in the range of 4 tons [3].

In Ghana, artisanal gold is produced as follows. First, prospective ore is brought back to villages and crushed either by hand or in mechanical mills. The fine gravel is mixed with water, and then gently washed in ‘sluice boxes’, where gravity concentration occurs on hemp tissues. The resulting concentrate is refined, and then amalgamated with mercury. Mixing of mercury and concentrate is done by hand; because of its high cost, the mercury is added progressively, until the amalgam appears homogeneous. The amalgam is then squeezed, in order to eliminate residual water. Gold is recovered by burning the amalgam in open pans (Fig. 1).

Ghanaian artisanal gold washers are semiskilled chemists capable of conducting sophisticated processes. For example, when engaged in mechanical crushing, washing powder is added to water during the mixing stage to eliminate the grease released by the mill. This grease would otherwise coat particles and thus hinder amalgamation. Moreover, some gold washers in Ghana use magnets for removing iron particles released during the crushing stage.

Up until 50 years ago, mercury was not utilised in artisanal gold extraction. Its use only began some twenty-five years ago when it became too difficult to extract gold from rocks. The optimal mercury to gold ratio (Hg: Au) is about 1 (v/v), but gold washers commonly add greater quantities to ensure that all available gold is amalgamated. In some areas of Brazil, for example, the Hg: Au ratio is estimated to range between 1.32 [4] and 2.0 [5]. Some researchers, however, argue that the official figure of 1.32 is an underestimation,

since field conditions make it difficult to recover the mercury. Many propose that ratios as high as 6.0 or 10.0 are more realistic estimations [6]. The PMMC has estimated the Hg: Au ratio to be approximately 4.0 in Ghana (Precious Minerals Marketing Cooperation, Tarkwa Office).

## 2. A case study of Dumasi

A mercury study was undertaken by UNIDO in the village of Dumasi, which is located in the vicinity of the Bogoso Ltd industrial mine in the Western region of Ghana. Some 2000 people are currently living in this village. According to the Community Register of the Sub-Office of CARE International of Bogoso, as of June 1999, the village was comprised of 1084 males and 984 females. Although few are employed at the Bogoso Mine itself, it is estimated that between 20 and 25% of adults are involved in local artisanal gold production [7]. Two small rivers border Dumasi (about 1 m in width or less at the time of sampling; depth far less than 1 m; no data available for flow): the Apopre (E–W) and the Rora (N–S). Gold processing is known to occur along the banks of these rivers but most of the local processing installations are found on the south side of the village along the Apopre River (Fig. 2). This section of the paper describes the schematics of the UNIDO study, and the important results obtained.

### 2.1. Methodology

Samples were collected in areas where mercury losses were expected to occur. An analysis of the literature revealed that losses occur throughout the amalgamation process as a result of continuous washing and squeezing. Mercury is also released into the atmosphere during roasting, when the amalgam is burned. This atmospheric mercury is often deposited on nearby soils and vegetables, or inhaled directly by people (Fig. 3). It typically reaches rivers, is transformed into a toxic methylated state, and accumulates in fish.

A wide variety of samples—river water, sediments, vegetables, chicken flesh and some fish—was collected in April 2000 to assess the extent of mercury contamination in the river system, determine the general level of contamination, and provide relevant information to resident health assessors. Chemical analysis was accomplished using cold vapour/atomic fluorescence spectrometry (CV–AFS), following either acidification in a strong oxidising medium for water samples or acid digestion for dried samples of sediment, fish and vegetable items. Certified sediment and fish samples were included in the analytical series.

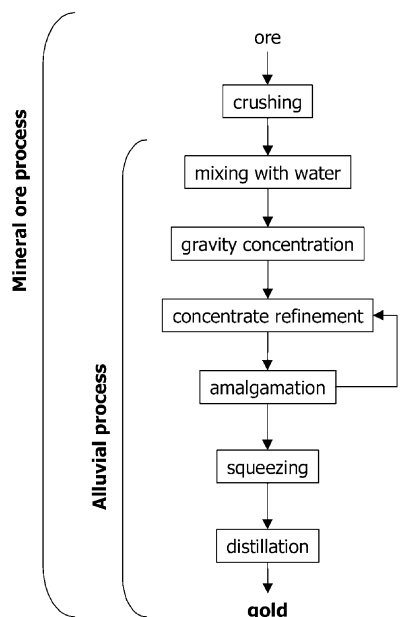


Fig. 1. Typical flow sheet for artisanal gold extraction in Ghana.

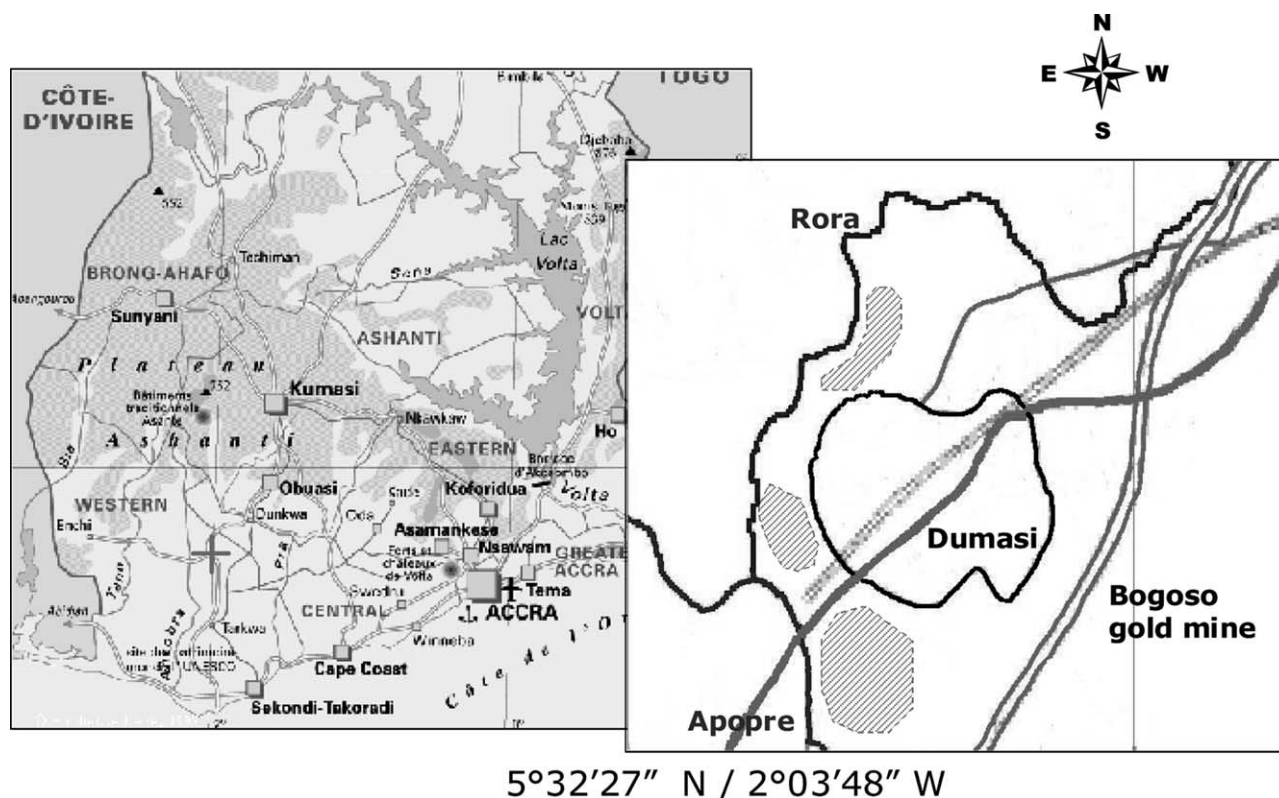


Fig. 2. Location of small-scale gold mining site.

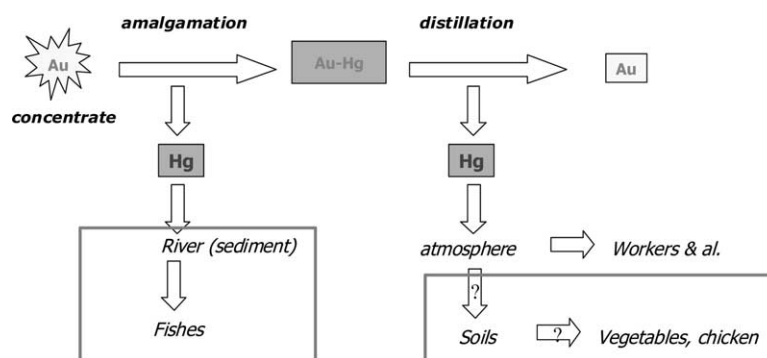


Fig. 3. Mercury releases to ecosystem in small-scale gold mining.

## 2.2. Results and assessment

Mercury concentrations in groundwater (obtained from boreholes) ranged between  $0.12$  and  $0.27 \mu\text{g l}^{-1}$  ( $n = 8$ ); concentrations in river water samples were more variable, ranging between  $0.18$  and  $0.76 \mu\text{g l}^{-1}$  ( $n = 5$ ). Apopre and Rora River sediments contained between  $0.64$  and  $8.5 \mu\text{g g}^{-1}$ , while mercury in “sumps” sediments ranged between  $1.3$  and  $93.1 \mu\text{g g}^{-1}$ . For various reasons (mainly sociological), only one soil sample could be obtained. The mercury fresh weight concentrations of the 15 fish collected in the vicinity of the main gold processing area ranged between  $0.55$  and  $1.59$

$\mu\text{g g}^{-1}$  (fw). Mercury concentrations in vegetables were rather low, except in the only cocoyam sample (about  $0.4 \mu\text{g g}^{-1}$  fw), which was collected close to a crushing mill and in the vicinity of the most active processing area. Moreover, mercury concentrations collected in chicken breast muscle ranged from  $0.031$  and  $0.053 \mu\text{g g}^{-1}$  (fw).

The sediment concentrations measured in this study compare favourably to those determined in comparatively similar studies undertaken in other gold mining regions such as the Amazon tributaries in Brazil ( $<157 \mu\text{g g}^{-1}$ ) [6] and the Agusan River on Mindanao Island in the Philippines ( $<34 \mu\text{g g}^{-1}$ ) [8]. The same con-

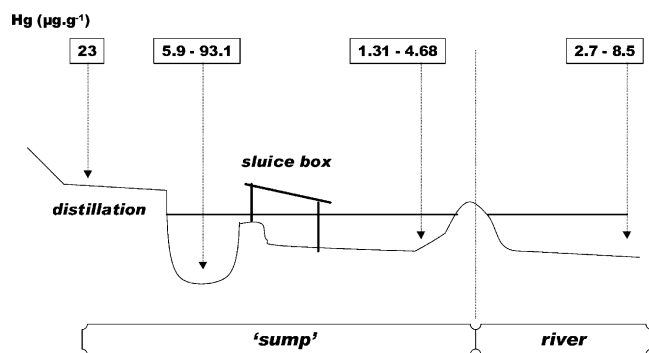


Fig. 4. Longitudinal section of a mercury-contaminated site.

clusion can be drawn for fish contamination: average fish concentration (ww) in our set of data is  $1.03 \mu\text{g g}^{-1}$ , with a maximum of  $1.59 \mu\text{g g}^{-1}$ , comparable to the  $0.88 \mu\text{g g}^{-1}$  concentration determined in a similar French Guyana study [9] and the  $1.08 \mu\text{g g}^{-1}$  value calculated in a Colombian study [10].

Fig. 4 represents a longitudinal section of a “sump”—an artificial wetland connected to the river, where gold washers carry out the extraction processes. Total mercury concentrations found in sump and river sediments are mentioned on this diagram. As expected, the highest concentrations were found where mercury is manipulated, in the open pit at the upper end of the “sluice box”, in places where amalgam is washed, and where amalgam is refined. Furthermore, concentrations in marsh sediments at the lower end of the sluice boxes are similar to those in river sediments. Mercury is also lost during burning, which is commonly conducted near to the sump and throughout the village.

A common means of assessing mercury contamination in aquatic systems is by comparing actual concentrations to “reference” or background ranges. As no regional background values for sediments and fish exist for Ghana or even West Africa, a broad literature survey was conducted to find background ranges in areas located upstream from gold mining areas (fish: [11–13]; sediments: [4,14–17]). The literature indicates that  $0.2 \mu\text{g g}^{-1}$  (wet weight) should be recognised as a cautionary background level for fishes; all of the fish sampled exceed this level of contamination. Moreover, as Fig. 4 indicates, there is a gradient of mercury in Apopre river sediments (left bars corresponding to sampling points 1 = upstream to 3 = downstream); the figure seems less clear for Rora river sediments. As the main sump area is located between point 1 and point 2 on the Apopre River, the fact that the highest mercury concentration is at point 3 implies a transport of contaminated sediments downstream.

It is more difficult to estimate the degree of impact on aquatic or benthic species, as ecotoxicological standards exist only in North America and Europe. Nevertheless,

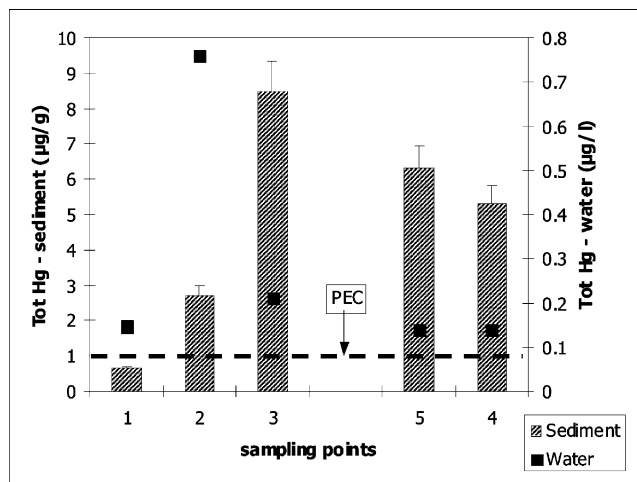


Fig. 5. Mercury concentration in sediments and water around Dumasi.

if using these scales, mercury concentrations in the sampled river water ranges between “chronic” and “acute” classifications [18,19]. For sediments, a comparison with the recently published consensual guidelines [20] indicated that most of these samples could be lethal to benthic species (Fig. 5).

### 3. Discussion: improving environmental management in small-scale gold mining operations in Dumasi

Dumasi residents can expose themselves to mercury by consuming contaminated water or food. Although none of the water samples exceed the World Health Organization (WHO) trigger value of  $1 \mu\text{g l}^{-1}$ , the mercury concentrations of some 60% of sampled fish exceed the current sanitary limit of  $1 \mu\text{g g}^{-1}$  [9]. Moreover, all fish sampled had mercury concentrations in excess of  $0.5 \mu\text{g g}^{-1}$ , considered by WHO as dangerously high for pregnant women and children [21]. The acceptable weekly intake according to the Food and Agriculture Organization (its a publication by a joined committee emanating from both organizations) [22] translates into an average of  $\approx 300 \text{ g}$  of fish, or  $\approx 45 \text{ g}$  per day. Exposure through chicken does not appear to be as serious a concern, as it is rarely consumed and has proven to be much less contaminated than fish. There is, however, merit in monitoring vegetable items more accurately, in particular roots such as cocoyam, which proved to have the highest concentrations of mercury in the vegetables sampled in our study.

At present, small-scale gold mining in Ghana is regulated by several institutions—namely, the Minerals Commission, the PMMC and the Environment Protection Agency (EPA). The EPA was formally established on 30 December 1994 (Act 490) and given the responsi-

bility of regulating the environment and implementing environmental policies. Its objective is to co-manage, protect and enhance the country's environment, as well as to devise regional solutions to generic environment problems. The Minerals Commission was formed in 1984 to promote foreign investment in the country's mining sector. Legislation was later passed in 1989, resulting in the establishment of PMMC, which today purchases some 80% of precious metals produced in the artisanal gold mining industry [23].

Shortly after the passing of this legislation, the Minerals Commission established its Small-Scale Mining (SSM) unit. This unit was charged with the responsibility of implementing a regularisation policy for small-scale mining, and sought to bring the operations of all illegal miners into the mainstream of the economy. Its efforts have helped ensure that gold produced domestically by artisans remains in the country. A liberal licensing, purchasing and tax incentive scheme was also introduced. In addition, seven centres for small-scale miners were established and adequately staffed and equipped. Furthermore the use of mercury in artisanal gold mining was authorised in 1989 (PNDC Law 217). In short, the SSM unit was established to ensure that small-scale mining activities are conducted in an efficient manner. It is important to clarify, however, that up until UNIDO's efforts, the Government had not effectively addressed the mercury issue.

The organisation's environment management efforts are administrative in scope, attempting to supervise the activity through regulations and permits, and by providing gold purchasing services to small-scale miners. Both approaches are traditional tools used by governments [24]. These efforts, however, have failed to effectively control the environmental problems associated with artisanal gold mining.

Following its preliminary assessment of mercury pollution, UNIDO, in cooperation with the Government, initiated an awareness campaign on this toxic metal. A movie was produced and shown on television with impressive pictures of the devastating effect of artisanal mining on the environment, the health hazards associated with mercury, and the possibilities of protecting miners using mercury in gold extraction processes.

For demonstration purposes, a retort<sup>1</sup> was introduced under the UNIDO Project, developed especially to train artisanal gold miners. It was observed in many other countries that retorts constructed from iron were not appreciated by small-scale miners because of a feared



Fig. 6. Retort used for training purposes.

“black box effect”.<sup>2</sup> A new, transparent retort was therefore introduced (Fig. 6; ThermEx® is distributed by Mt Metall-Technic GmbH, Vaterstetten, Germany), consisting of stainless steel (lid, cooler tube, evaporator head and gasket), heat-resistant glass (evaporator vessel and collecting vessel), and a simple jam jar for cooling purposes. Since the change of colour of the amalgam from silver to gold can be observed during heating, this tool proved very suitable for demonstrating the distillation/condensation process to people with no background in science.

The training was accompanied by the distribution of thousands of posters showing people poisoned by mercury and how miners can protect their health by using retorts and recycling mercury. The distribution of retorts to recipients was based on medical findings. The small-scale miners who had participated voluntarily in an earlier medical survey and proved to be contaminated with mercury received the equipment free of charge.

It is important to note that when introducing the retorts, UNIDO mainly focused on technology acceptance rather than economic factors. The equipment was manufactured to be safe and appropriate for training purposes. These models, however, are highly expensive, and it is highly unlikely that miners will be able to purchase them on their own. Micro-financing systems must therefore be introduced to ensure operators can afford the equipment.

It is important to clarify as well that the use of such cleaner technology will not solve the problem completely, as mercury continues to be released into the aquatic environment during the washing/squeezing

<sup>1</sup> A retort is simply a piece of equipment assembled with a closed crucible connected to a condenser, designed so that the mercury from the amalgam evaporates when heated, leaving the gold metal in the crucible (see Fig. 6).

<sup>2</sup> Miners often feel more comfortable “seeing” gold being processed, which reassures them that it does not “disappear” during amalgamation.

stages of the gold production process. As the loss of mercury at this stage is a result of an excess of mercury, the problem can only be resolved with increased training. Moreover, the fact that sump areas are continuously being modified, and sluice boxes are frequently being moved or abandoned, has led to the formation of several mercury “hot spots” in Dumasi. In short, retorting alone will not resolve the mercury problem in Dumasi. Training must be provided to miners, and workers must rationalise the design of “sump” areas, which is key in preventing the formation of new “hot spots”.

#### 4. Conclusions

As expected, we found rather high concentrations of mercury in the sediments and fish collected in Dumasi. It is also highly likely that contaminated sediments have been transported downstream in resident rivers. The contamination of environmental entities inevitably leads to human exposure, which was confirmed during an earlier study.

Although our investigations focused on only one village, the findings nevertheless confirm that mercury emissions from small-scale gold mining operations are a serious environmental threat in Ghana. A nationwide mercury monitoring campaign would therefore be highly beneficial, as it would help to determine the degree to which operators have been affected by mercury. Efforts should be made to sample sediments and fish, as well as humans.

The managerial approach adopted by the Government to facilitate environmental improvement in resident small-scale gold mines has failed to address problems with mercury. As this paper has shown, there is merit in introducing transparent retorts, and providing environmental training to miners, which would undoubtedly decrease exposure to mercury.

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