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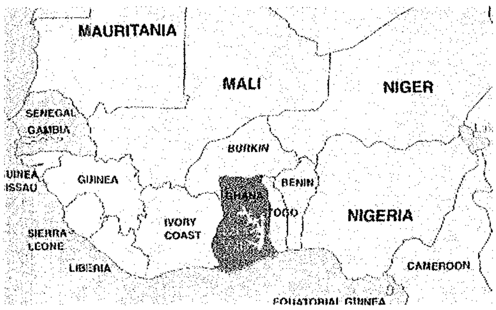
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

# US/GHA/99/128 - Assistance in Assessing and Reducing Mercury Pollution Emanating from Artisanal Gold Mining in Ghana - Phase I

## Part I - General introduction and assessment of human health

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# Contents

## Abbreviations

| | |
|---|---|
| BHC | Bogoso Health Center |
| BGL | Bogoso Goldfields ltd |
| EPA | Environmental Protection Agency |
| FE-SC | French Embassy (Service of Cultural Affairs) |
| MoH | Ministry of Health |
| SMMO | Small Scale Mining Office (Mineral Commission) |
| PMMC | Precious Minerals Marketing Corporation |

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# 1 General introduction

Mercury is one of the most toxic substances in the world, and causes high damages to human health and the environment. These adverse effects have justified regulation enforcement in various countries across North America, Europe and Southeast Asia, along with risk management approaches.

Mercury amalgamation is a virtually ubiquitous method for recovering gold in small-scale production units; due to a worldwide small-scale gold production currently of several hundreds tons, this type of source of mercury to the environment requires a first order control at a global scale.

This report belongs to the first phase of a UNIDO project focusing on the Government's developing target to phase out or at least reduce the use of mercury in artisanal and small scale mining operations. During this phase, an environmental and human health impact assessment should be realised, prior to the introduction of efficient equipment for mineral processing and recycling of mercury. The project will help the Ghanaian government in bridging the technological gap from which the sub-sector is suffering, and in introducing environmental management and cleaner production currently unknown to the rural population. Thus human health and safety should be improved for people involved in this activity. The project should also help to improve the current skill in analytical methodologies.

## 1.1 Specific objectives

According to the project description, the aim of this phase is to assess mercury levels in humans and environment.

Regarding human mercury levels, and related impacts on human health, the specific duties are described as follows:

1. Develop questionnaire on general health condition of members of mining communities and on indications for symptoms of mercury poisoning.
2. Evaluate/estimate the occupational health risk in people directly exposed to mercury through amalgamation activities.
3. Evaluate/estimate the occupational health risk of people living in the vicinity of gold extraction plants and gold melting shops.
4. Check general health condition of directly exposed people and non-directly exposed members of mining population.
5. Take hair, urine, and blood samples according to state of the art in clinical studies.
6. Assess the health condition of people affected by mercury poisoning, for example regarding buccal health, alterations in hand-writing, muscle pain, typical neurological and organic dysfunction etc.

Environmental assessment includes the following detailed tasks:

1. Investigate the situation of the environment on the spot, take samples of waters, sediments, soils, fish, poultry, vegetables ..., where pollution can be assumed.
2. Evaluate the nature and extent of the mercury pollution in a selected river system and adjacent agricultural sites.
3. Introduce and set-up a monitoring system for continuous water quality assessment.
4. Formulate measures for the remediation and possible rehabilitation of hot spots in the river systems and vicinities.

Furthermore, this phase is focused on the village of Dumasi, which is believed to be a highly contaminated area, due to its long history of artisanal gold mining. The human health assessment is presented in this part I report. The environmental assessment will be exposed in part II.

As requested in the project description, the part II report includes recommendations, some of them being addressed to government departments, mining industries and research institutions.

## *1.2 Working organisation*

A team including three French and three Ghanaian scientists and engineers was constituted. These experts performed a single mission to the field together in order to ensure a good coordination of the different tasks. Date: 16th to 28th April 2000. The sample collected during the mission were brought back to France, and analysed in Pau ("Laboratoire de chimie bio-inorganique"). Reports were prepared in France, with electronic exchanges and support from the Ghanaian experts.

***Field mission time schedule***

| | | | |
|---|---|---|---|
| **April, 16th** | Travel from FRANCE to ACCRA | | |
| **17th** 9:00 | UNIDO Office | MM. GARZELLI & KRYGER (UNIDO) Mr. NIAMAKYE (SMMO, Accra) and the six experts* | Meeting with UNIDO representatives, the National Project co-ordinator: Elaboration of the time schedule, organisation and miscellaneous. |
| 11:30 | French Embassy | Mrs. ZWANG-GRAILLOT (FE-SC) MM. GARZELLI & KRUGER (UNIDO) and French experts | General information exchanges |
| 14:30 | Mineral Commisssion | Mr. KRYGER , Mr. NIAMAKYE, Mr. SACKEY, Mr. ANKRAH, Mr. ENSAH, Mrs CASELLAS and Mr. RAMBAUD | Discussion and comments on the ethnosociological report. |
| 15:00 | EPA | M. SEKYI (EPA), M. BABUT | Preparation of the field mission |
| 16:30 | EPA | MM. AQUAH, BOATENG, SEKYI | Environmental policy in mining area |
| **18th** | Road from ACCRA to TARKWA | | |
| 10:30 | SMMO, Tarkwa | MM. NTIBEY & SACKEY (SMMO) and the six experts* | Figures of mercury consumption |
| 13:45 | District Office | Mr. S.K. AMOAH (District Chief Executive Officer) and the six experts* | Presentation of the mission |
| 15:00 | Bogoso Health Centre | Mrs. NKRUMAH (chief nurse) | Preparation of sampling and health questionnaire. |
| 15:45 | Dumasi | Village chief and the six experts* | Presentation of the mission and visit of 'galamseys' households, information about sampling |
| **19th** | Sampling of sediments in the river system and sumps, human health assessment (questionnaires and sampling) | | |
| **20th** | Collection and preparation of fish and vegetables samples; sampling of surface and well water, human health assessment (questionnaires and sampling) | | |
| **21st** | Collection and preparation of chicken samples; sampling of borehole water; Road from TARKWA to ACCRA | | |
| **24th** | Accra | Mr. KRYGER , Mr. BABUT, Mrs. CASELLAS, Mr. RAMBAUD | Debriefing |
| 12:00 | | Mrs. CASELLAS, Mr. RAMBAUD | Road from ACCRA to TARKWA |
| **25th** | Accra | Mr. SEKYI , Mr. BABUT | Data collection, discussions. |
| | | Mr. HALGAND (SDV), Mr. BABUT | Preparation of samples transfer |
| | Dumasi | Dr. SACKEY, Mr. C. SACKEY, Mr. ANKRAH, Mrs. CASELLAS, Mr. RAMBAUD | Human health assessment (questionnaires and sampling). Contacts with Bogoso mining manager for detailed map and GPS. |

***Field mission time schedule (continued)***

| | | | |
|---|---|---|---|
| **26th** | Accra | Mr. SEKYI , Mr. BABUT | Data collection, discussions. |
| | | Mr. DANQUAH (WRI), Mr. BABUT & SEKYI | Fish identification |
| | | Ms. P. LARWEH, Mr. MENSAH (FRI), Mr. BABUT& SEKYI | Reference values of metals concentrations in vegetables |
| | Dumasi | Dr. SACKEY, Mr. C. SACKEY, Mr. ANKRAH, Mrs. CASELLAS, Mr. RAMBAUD | Human health assessment (questionnaires and sampling). Meeting at the Bogoso mining plant of the executive and administrative managers |
| 20:00 | Tarkwa | Mr. AMOAH, Dr. SACKEY, Mr. C. SACKEY, Mr. ANKRAH, Mrs. CASELLAS, Mr. RAMBAUD | Diner : President of the District invitation |
| **27th** | | Mr. SEKYI, Mr. BABUT | Data collection, discussions. |
| | | Mrs. CASELLAS, Mr. RAMBAUD | Road from TARKWA to ACCRA |
| 15:00 | UNIDO office | Mr. NIAMAKYE, Mr. KRYGER and the six experts* | Final meeting, debriefing |
| 20:00 | Departure to France | | |

*The six experts: N. ANKRAH, Dr. S. SACKEY, R. SEKYI, M. BABUT, C. CASELLAS, A. RAMBAUD.

Four nurses from BHC were employed in order to collect human samples properly, and SMMO's expert Mr. C. SACKEY helped the mission in the collection of social and occupational data.

# 2 Background

## *2.1 Geographical context*

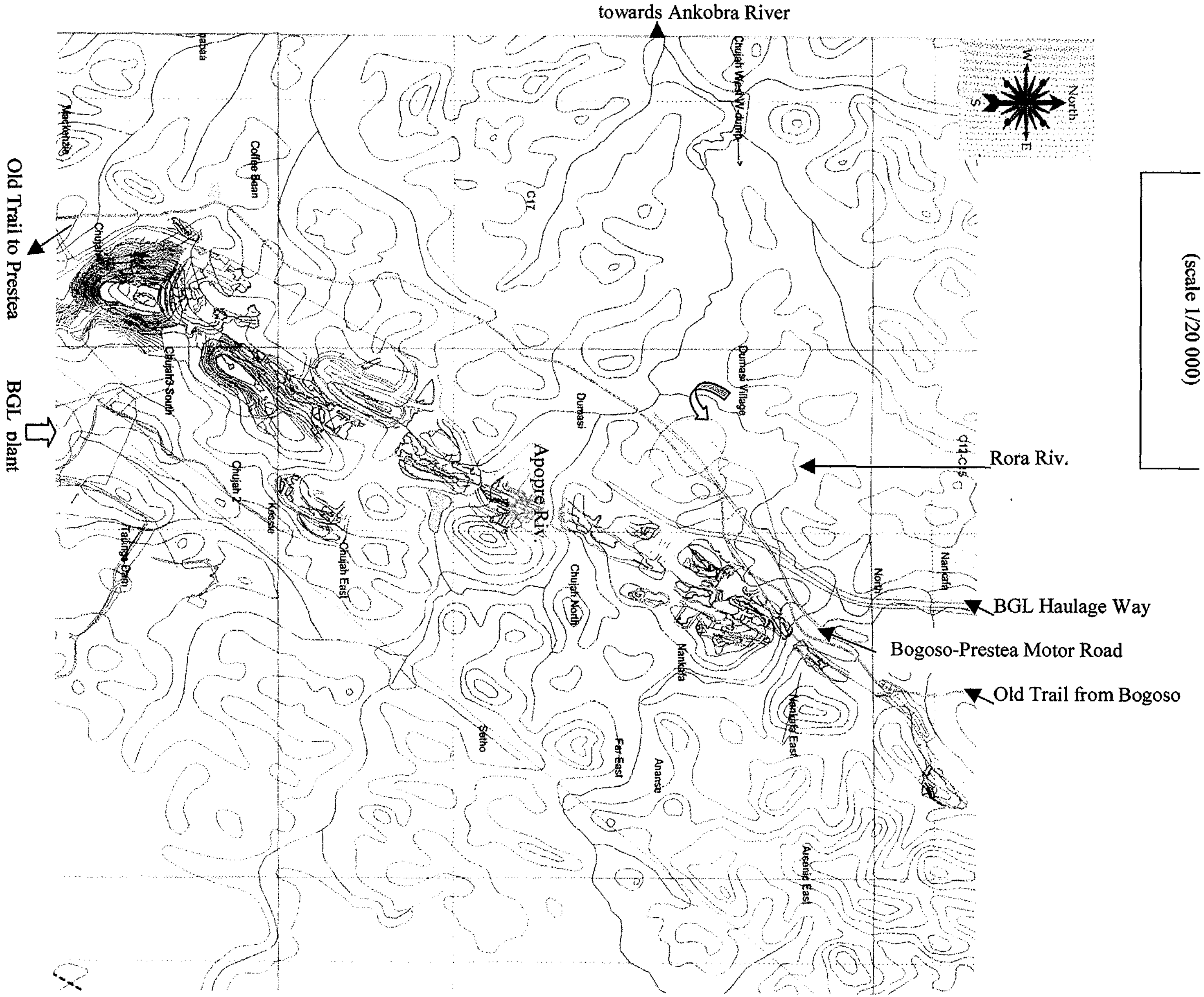
Dumasi is a village located in the Western Region, 5 kilometers from Bogoso on the road from Bogoso to Prestea. It is located close to the Bogoso Gold mine Ltd (BGL) : 5° 32 ' 27" N; 2° 03 ' 48" W. Its community has historically been known to be a small-scale gold mining community and gold mining has been one of their main economic activity.

The village is lined by to rivers, one flowing from East to West and called Apopre river, and one flowing North to South and called Rora river. The confluence of these two rivers is close to the NW corner of the village.

It is estimated that about 2000 people are currently living in Dumasi (**1**), including more men than women.( 1,084 male and 984 female in June 1999, as extracted from the community Register of the Sub-Office of CARE International of Bogoso). Few of them are mine workers. Others are either farmers, shopkeepers, or for most of them involved in clandestine gold production. The latter are called '*galamseys*' in local language. This term is believes to have originated from the phrase " gather and sell" in the days when it requiered very little effort to retrieve gold nuggets and dust from the rock to sell;

The galamsey community is estimated at 20-25% of the total population

**Figure 1- General map of Dumasi area (1/20.000)**: *see next page*


towards Ankobra River
Old Trail to Prestea
BGL plant
(scale 1/20 000)
North
Apopre Riv.
Rora Riv.
BGL Haulage Way
Bogoso-Prestea Motor Road
Old Trail from Bogoso
Coffee Bean
Chujah South
Chujah 2
Chujah East
Chujah North
Dumasi
Dumasi Village
Nankafa
Nankafa East
Far-East
Anansu
Sefwi
Kossie
Tailings Dam
C17

## *2.2 Artisanal gold processing (galamsey activity)*

Galamsey people usually extract gold from alluvial sites, or from abandoned pits in industrial mines, or from river sediments. In Dumasi, the main way of production is to process mineral ores from the neighbouring BGL mine; the steps of this process are as follows:

- crushing the ore
- washing on hemp tissues in sluice boxes (i.e. gravity concentration)
- refine the concentrate in a pan
- addition of mercury in excess
- squeezing the amalgam, which eliminate excess water and mercury to a certain extent
- burning the amalgam

Ore is brought back to the village, then crushed either by hand or by mechanical mills. The resulting fine gravel is mixed with water, then gently washed in 'sluice box', where gravity concentration occurs on hemp tissues. The resulting concentrate is refined by washing it in a pan, 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 homogenous. The amalgam is then squeezed, in order to eliminate residual water[1]. Gold is recovered by burning the amalgam in open pans (Figure 2)

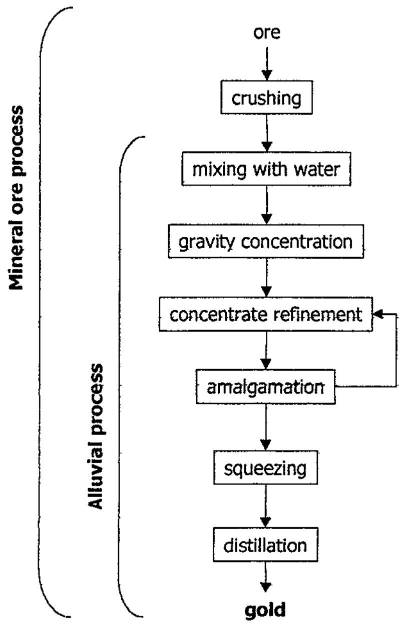



**Figure 2- Flow diagram of 'galamsey' process**

However, as it was considered that a lot of gold had been lost in the sediments of the sumps from the beginning of this activity several decades ago, galamsey people were experimenting to retreat these sediments at the time of the sampling campaign. In this case, the process is similar to that in alluvial sites.

Galamsey people are rather skilled chemists, as they are able to use sophisticated processes. For example, when they use a mechanical crushing mill instead of manpower, they add some washing powder to the water during the mixing stage, in order to eliminate the grease released by the mill. This grease

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[1] Rather than excess mercury, as it is said sometimes

would coat the particles and thus hinder the amalgamation. Moreover, galamsey people use magnets for removing iron particles released during the crushing stage.

The galamsey industry about half a century ago thus did not require mercury in retrieving gold from rocks. The use of mercury began about twenty-five years ago when it became increasingly difficult to extract gold from the rocks.

In Dumasi, the digging and chiseling aspect of the operations is done throughout the week with the exception of Fridays. On Fridays, the operators are only allowed to do crushing and grinding, washing, amalgamation, and burning. Off-operational period for galamsey is during the raining season which runs from June to September. During this period, some galamsey operators take up farming. Initially, women were directly involved in the galamsey operation but since the introduction of crushing mills, the role which was played by women (*sieving of the crushed rocks*) has ceased to exist. The business is now dominated by males and specially by immigrants. There is a Galamsey Committee which is responsible for regulation and representing the activities of all galamsey operators in the community and in front of the Bogoso Gold Mines Limited which has legal title to the land they were mining on. Committee members indicate that they have rules governing the business but the real situation suggests that most operators do their own thing.

## *2.3 Mercury consumption in Dumasi*

According to the process description, losses of mercury may occur at several stages of this process:

- During amalgamation; indeed, some water is added several times at this stage, in order to remove the lightest particles. This water and the associated particles are recycled, e.g. at the gravity concentration stage, thus mercury could be washed out to the sump.
- During burning, because of the high volatility of mercury; then it should either fall back on the surrounding soils, or be inhaled by people.

It can thus be assumed (a) that all the mercury consumed is released to the environment, and (b) that the volume of mercury consumed is somewhat greater than the volume of gold produced:

(a) The main route is through atmospheric transfer, and further deposit on soil. This transfer occur either when the amalgam is broken by roasting, or when the gold is refined by its buyer, in order to remove the residual mercury. To a lesser extent, losses of mercury occur during the preparation of the amalgam, because it is gently washed (several times) before squeezing. Accidental releases may also happen from the bottles used by galamseys for keeping the mercury – fine grains of mercury have been observed at the soil surface of a sump during the sampling campaign in April, 2000 -.

(b) The optimal mercury to gold ratio (Hg:Au) is about 1 (v/v), but galamseys have to add more mercury, in order to be sure that they have amalgamated all the available gold. According to their personal experience, they may waste more or less mercury; however, the high cost of this substance is a powerful incentive to adjust the ratio as close to the optimal one as possible. In some areas of Brazil, the ratio is estimated to be about 1.32 (**2**) to 2.0 or more (**3**). Some researchers argue that the official figure of 1.32 is an underestimation, since field conditions make it difficult to recover the mercury. They mention ratios even up to 6:1 or 10:1 (**4**). There is no evidence that field conditions would be very different in Dumasi area. According to Ghanaian sources, Hg:Au ratio could be about 4:1 (Precious Minerals Marketing Cooperation, Tarkwa Office).

Therefore, assuming an average gold production of 0.5 – 1.0 g *per capita* and per day, it can be estimated that the yearly mercury consumption in Dumasi is on average 270-300 kg (100 – 1500 kg), depending on the ore richness and on the gold to mercury ratio in amalgamation.

# 3 Assessment of Human Health

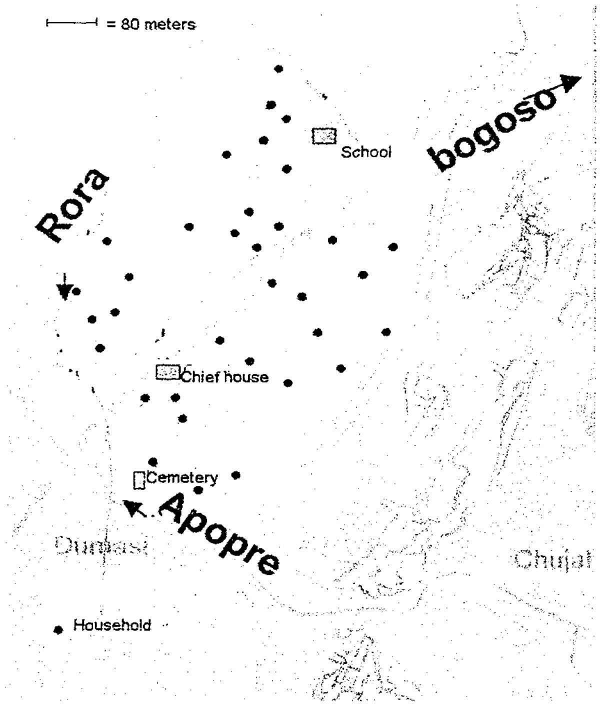
## 3.1 Data collection

### 3.1.1 Social and occupational questionnaire

The questionnaire, and the associated clinical examination procedure, were adapted from a similar study, which was done in Mindanao island (Philippines) under UNIDO auspices (**5**). This strategy was deliberately adopted, to allow a comparison between the two situations. A few modifications were introduced in order to take into account the specificity of the Ghanaian context and culture.

The questioned people were recruited by elders, and have to explicitly consent to participate in the study. Their households were also located on a simplified map of the village (Figure 3) by a number (1 to 45); thus the different parts of the village were almost equally taken into account in the study.

**Figure 3- Dumasi households included in the study**




### 3.1.2 Biological samples collection

Total numbers of samples collected were as follows:

- 181 samples of blood (1 to 3 replicates of 4ml in EDTA-coated vials).
- 120 samples of spontaneous urine (1 to 2 tubes of 50 ml).
- 167 samples of hair: the quantities were very small, according to the "cranium shaved " fashion of the men.
- 179 samples of nails: the quantities were sometimes very small.The urine and blood specimens were cooled after collection, and maintained so until arrival in the laboratory in France.

### 3.1.3 Sample processing and analytical methods

Methods described in this section concern primarily human samples; basically, analytical methods applied to human and environmental samples are identical. Therefore, they will not be presented again in the report section on environment assessment. Conversely, sample processing (i.e. acid digestion) may differ on several details according to the sample type; so process methods will be described in each section.

#### *3.1.3.1 Storage*

The samples, received in their respective containers, were kept under freezing conditions until analyses began. The blood samples were in secured 4ml sterile bottles; the urine samples in 50ml polypropylene centrifuge bottles; the water and sediment samples were respectively in 1 litre polythene bottles; the rest of the samples were in secured sachets.

#### *3.1.3.2 Sample preparation and digestion*

- **Blood**: 300 µL of blood were transferred into polypropylene sample tubes, and transported to the laboratory. 3ml of aqua regia were added and the samples were exposed to ultra sonic waves (BRANSON 2200) for 1 hour. They were then agitated at 420 rpm until complete dissolution. On dilution the solutions became cloudy and this necessitated centrifuging before CV-AFS analysis.
- **Urine**: it was observed after defrosting that the urine samples were not homogeneous. There were some colloidal solids collected at the base of the tubes. Attempts to dissolve the solids, in situ, by pH variations failed.

  Therefore the total volumes of the samples were accurately noted. They were then centrifuged in pre-weighed polypropylene tubes. The solid and liquid portions were separated and treated respectively as follows:

  - Solid: They were dried in an oven at 50°C overnight. 3ml aqua regia were added and agitated on a shaker until complete dissolution. Volumes in the other of 100uL were taken and diluted with the reagent blank for CV-AFS analysis.
  - Liquid: 1 ml of urine was accurately measured and transferred into 25 ml volumetric flasks and diluted to the mark with the reagent blank described in procedure b (see below).

- **Hair and nail**: samples were weighed into polypropylene bottles and 3ml aqua regia added. Care was taken to avoid weight errors introduced by electrostatic forces between the samples and the walls of the containers. The samples were placed on a shaker to agitate overnight. The solutions were diluted with deionised water. Where further dilutions were required to allow the readings in the calibration range these were done with the reagent blank.

#### *3.1.3.3 Total Mercury determination*

Elemental mercury vapour was generated from the digested samples and standards by reduction with tin(II) chloride dihydrate (BAKER) using the continuous flow approach, and was purged from solution by an argon (AGA 4.5) carrier stream at a flow rate of 0.3l/min. The mercury vapour was detected by atomic fluorescence spectrometry using the Merlin PSA 10.023 detector. Measurements were controlled by the Touchstone ® control software.

For purposes of compatibility with pre-treatment reagents two procedures were adopted:

a. The reductant was 2%m/v $SnCl_2$ in 10%v/v HCl (BAKER). For the reagent blank 150ml of 33%v/v HCl and 20ml of 0.1N KBr/KBrO3 were transferred into a litre flask. 0.6ml of 12% m/v OHNH3Cl was added to decolourise and then made to the mark with deionised water.

b. The reductant was 5%m/v $SnCl_2$ in 15%HCl.The reagent blank was a solution of 10% $HNO_3$ and 7%HCl.

Standards were prepared from TITRINORM 1000ppm mercury solution (PROLABO). Working standards were prepared by diluting stock standards with the respective reagent blanks. Calibration ranges were typically 0.0 – 1.0ug/L.

The analytical performance of the procedures employed were assessed for linearity, limit of detection and accuracy and precision of the analytical measurements. The analyses were done in dust-free rooms meant for trace metals.

The water samples were analysed by procedure a. For the soil and sediment samples the microwave-extracted samples were analysed by both procedures a and b while the aqua regia extracts were analysed by procedure b. The urine, blood, nails, hair, vegetables, chicken and fish samples were analysed by procedure b. Anti foaming agents were added to the blood, vegetables, chicken, hair, nail and fish samples before AFS analysis.

The reference materials used for the accuracy assessment include certified NBS SRM 2672a urine, Seronorm trace element 404107y whole blood, IAEA 086 hair, GBW 08205 rice, BCR 464 fish and the BCR 320/678 river sediment samples.

## *3.2 Results & discussion*

### 3.2.1 Social and occupational data

187 adults ([2]) were recruited,, including 117 male and 70 women. 74 men and 23 women declared to be galamseys; 4 of the men galamseys, and 2 of the women claimed they had no contact with mercury, as they only sieved the crushed ore. Most of the women were partial time galamseys, but 2 of them declared they were involved full time. Moreover, 2 traders not involved in galamsey operation acknowledged having contact with mercury.

Non-galamsey population was considered as a possible control, and was well balanced according to gender, as it included 43 men and 47 women. The population is rather young (overall mean age: male 37, female 31.5), but the galamsey group is somewhat younger (mean age: male 33.5, female 28.5) than the non-galamsey group (mean age: male 43, female 31.5) . Figures 4 - 5

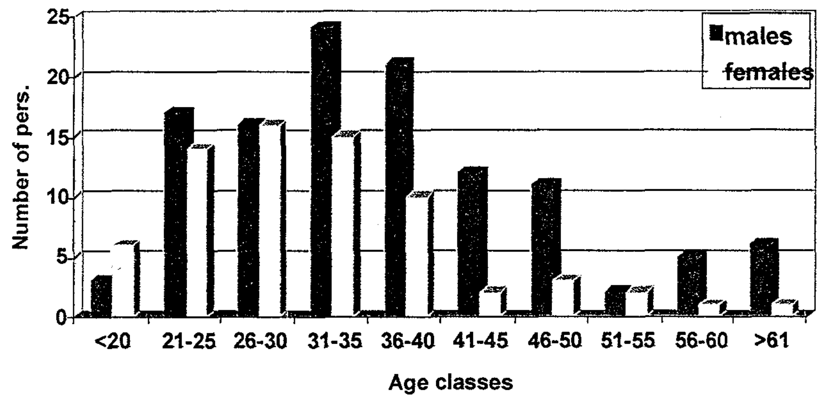



**Figure 4 - General distribution of ages**

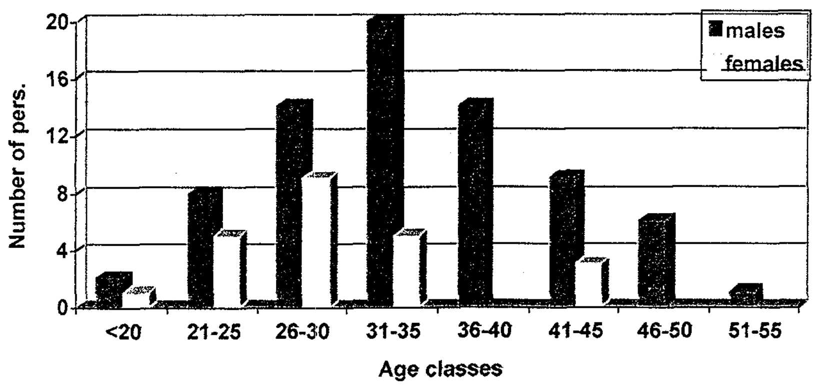



**Figure 5-Galamseys age distribution**

[2] Children (<15 years) were not selected for ethical reasons and difficulties in obtaining parents' consentment

Most of male galamseys (43/64) carry on their activity as full-time occupation; about 55 % of them (35/64) have been galamseys for less than 5 years, and the remaining 45 % between 5 and 20 years. Female galamseys generally do not carry on this occupation more than 5 years, but 30 % of them cannot specify the exact duration. The other galamseys are farmers (n=38), traders (n=11) or other (n=5). The non-galamsey sample is mainly farmer full time (n=35), trader full time (n=11); furthermore 6 are miners working at the BGL mining plant.

The male galamseys population is also rather mobile, as it can be seen on Figure 6; three subsets of this group can be distinguished:

- less than 10 years of activity and less than 10 years of residence, which means they are migrants;
- from 10 to 20 years of activity and less than 10 years of residence: they are therefore also migrants;
- less than 10 years of activity (sometimes even less than 5 years) but from 10 to 30 years of residence; they are late or old galamseys originating mainly from the village.

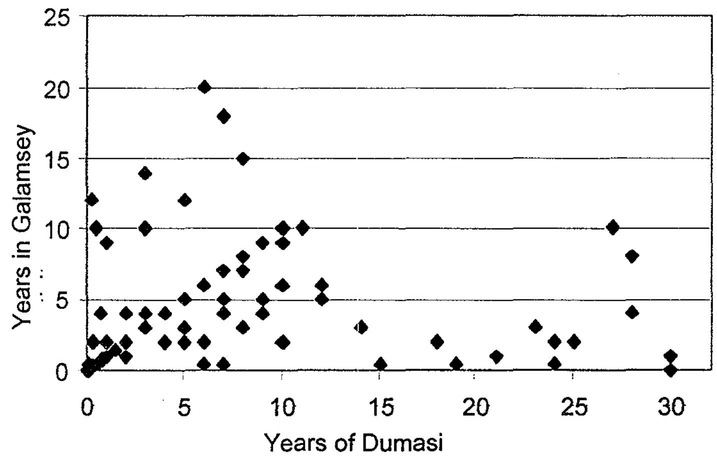



**Figure 6 -Duration of galamsey activity versus residence time in Dumasi**

The overall population is rather poor, and consumes few tobacco and alcohol. The food is mainly composed of tuber, completed by fish (1 time a day); meat and milk are rarely consumed.

The calculation of the ratio between the measured and ideal weight, for a given height, according to Lorentz formula, showed that women are over-weighted, whatever their occupation. Farming activity gives lower Lorentz index values (Figure 7)

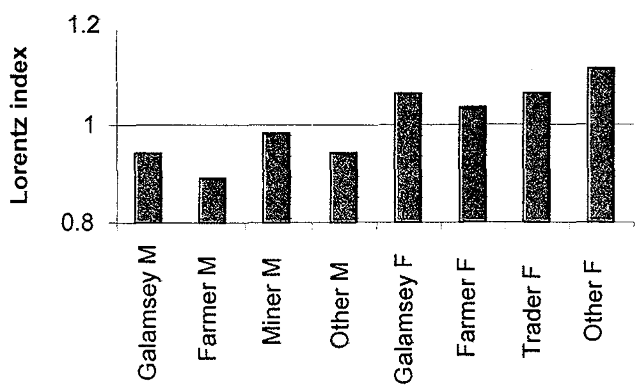



**Figure 7 - Measured weight / calculated weight**

Most of the women are illiterate; this trend is stronger among the galamseys female sub-group; 60% of the men were able to write, e.g. their names, male galamseys not being less educated than non galamseys (Figure 8)

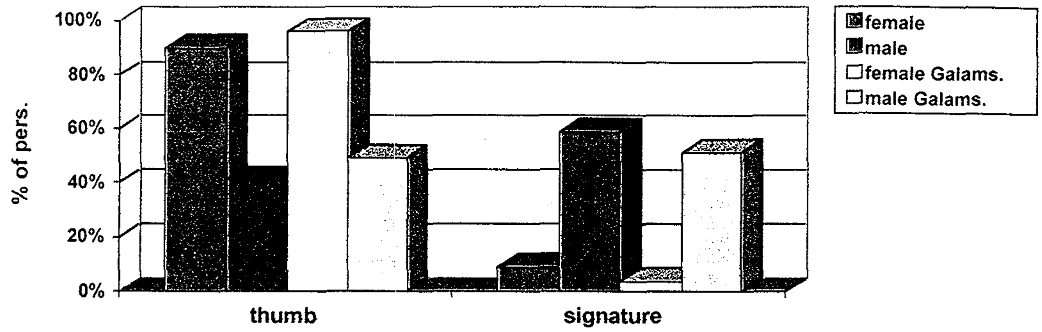



**Figure 8 -Consentment signature**

### 3.2.2 Health perception

40% of male sample – galamseys or not - claimed to have health problems; this ratio was slightly higher in the female sub-group, but in this case galamseys declared more health problems (Figure 9) Most of the declared pathologies were related to the skin area. 90% of the people, being galamsey or not, do not declare or declare slight metallic taste and salivation problems. Nevertheless 20% of the people claimed to have tremors and 65% have sleep disorders.

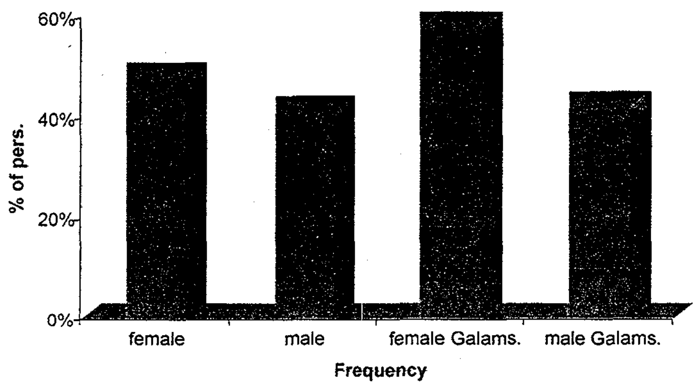



**Figure 9 - Percent of persons declaring health problems**

### 3.2.3 Clinical examination

A special section of the collection of epidemiological data was dedicated to neurological health, as mercury is particularly noxious to the nervous system. The clinical examinations consisted in classical tests relating to walking, standing, sitting, lying, to the reflexes and the memory.

13 people having slight neurological disorders were identified: none of them was concerned with lying, 1 was concerned with reflexes, 5 with standing and 9 with sitting. These 13 people are men with a mean age of 52 years (20 - 67). Furthermore, 5 among these 13 are galamseys,

In the memory test, galamseys generally had a better score than non-galamsey: 65% of galamsey had very good scores (Figure 10) it must be noted that these people are younger than the remaining people examined.

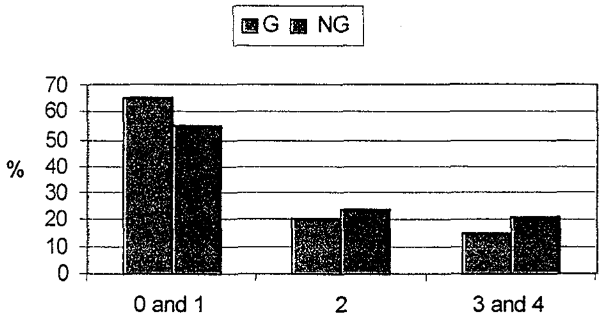



**Figure 10 – Memory scores**

### 3.2.4 Mercury in biological samples

#### 3.2.4.1 *Standards & limit values* (6) (7) (8) (9) (10) (11) (12) (13) (14) (15) (16)

**Blood**: The reference value in the non-exposed general population is < 10 µg/l. The main indices of exposure are occupationally treshold limits:

- BEI (Biological Exposure Index) = 15 $\mu g.l^{-1}$, after working, (ACGIH: American Conference of Governmental Industrial Hygienists) - (France);
- BAT (Biologischer Arbeitsstoff-Toleranz-Wert) = 25 µg/l (DFG: Deutsche Forschungsgemeinshaft). These BAT-values are exclusively valid for healthy adult workers, as these galamsey people (under occupational medical control) and for metallic and inorganic Hg exposure

According to the literature, the first neurotoxic effects would occur in adults, at concentrations higher than 200 $\mu g.l^{-1}$. It is recommended to maintain the blood mercury < 100 $\mu g.l^{-1}$.

**Urine**: The reference value in the nonexposed general population is < 5 $\mu g.g^{-1}$ creatinin. The main indices of exposure are :

- BEI = 35 $\mu g.g^{-1}$ of creatinin, before working
- BAT= 100 $\mu g.l^{-1}$ of urine ( for metallic and in organic Hg)
- WHO = 50 $\mu g.l^{-1}$

The threshold value, for blood and urine, were applied to the whole population, because the objective was to assess the risk from mercury use in Dumasi either for galamseys and non galamseys.

**Hair**: The reference value in the nonexposed general population is < 2 $\mu g.g^{-1}$ . The WHO recommended limit is 10 $\mu g.g^{-1}$.

According to the literature, the first neurotoxic effects would occur in adults at concentrations higher than 50 $\mu g.g^{-1}$ .

**Nails**: the same levels as for hair will be applied, because of the few existing data in the literature.

### *3.2.4.2 Exposure to Mercury in Dumasi*

Detailed results are given in Annex. They can be summarised as shown in Table 1.

| *Hg content in ...* | *Blood ($\mu g.l^{-1}$)* | *Urine ($\mu g.l^{-1}$)* | *Urinary Creatinine ($\mu g.g^{-1}$)* | *Hair ($\mu g.g^{-1}$)* | *Nails ($\mu g.g^{-1}$)* |
|---|---|---|---|---|---|
| Mean- | 24.4 | 23.85 | 15.54 | 3.85 | 3.99 |
| Median | 20 | 11 | 7 | 2.71 | 2.6 |
| Mode | 18 | 3.6 | 5.6 | 2.6 | 2.1 |
| Minimum | 1 | 1.1 | 1 | 0.39 | 0.66 |
| Maximum | 96 | 252.9 | 193 | 44.6 | 55.7 |
| *Stand.deviation* | *16.9* | *40.3* | *25.4* | *4.67* | *5.44* |
| *Number N* | *180* | *102 ** | *102 ** | *148* | *161* |

**Table 1 - Summary of mercury exposure in the investigated population**

**Excessively diluted urinary samples (creatinin < 0,50 $g.l^{-1}$) as well as very concentrated ones (creatinin > 3 $g.l^{-1}$) cannot be used for biological monitoring. In such a case, new samples should normally be taken. The difficulties encountered in taking sufficient quantities of urine, often because of the strong perspiration of the villagers, led us to first check the creatinin contents of the collected samples : of 118 samples of urine, 16 were eliminated because of creatinin values above the limit of 3 $g.l^{-1}$. For the 102 samples selected, the results are expressed in $\mu g$ $Hg.l^{-1}$ of urine and $\mu g$ Hg .$g^{-1}$ of creatinin in the urine.*

For all the biological descriptors, mean are higher than reference values in the non-exposed general population. For blood, the mean and the median are very close to the exposure index (BAT); however, the range is rather large. Variability is also high for urine data, and for hair and nails as well. The maximum values for blood and hair are however lower than the lower bound for neurotoxic effects. For the urine, only 5 samples exceed 50 $\mu g.g^{-1}$ of creatinin.

### *3.2.4.3 Correlations between the various exposure indicators*

The examined biomonitors are weakly correlated one to one (Table 2); the best correlations are obtained for urine and creatinin (S **, p<0.001), then hair and nails (S *; p<0.05). No correlation at all was found between blood mercury concentrations and the other indicators. As mercury concentrations in whole urine and in creatinin appear well correlated, only creatinin was kept for further statistical analysis.

| | Hair | Nails | Blood | Urine | Creatinin |
|---|---|---|---|---|---|
| Hair | 1 | | | | |
| Nails | 0.578 | 1 | | | |
| Blood | 0.086 | 0.079 | 1 | | |
| Urine | 0.257 | 0.311 | 0.285 | 1 | |
| Creatinin | 0.283 | 0.285 | 0.241 | 0.94 | 1 |

**Table 2 - Correlation coefficients between exposure indicators**

### *3.2.4.4 Influence of gender and occupation*

Means and standard deviations ($\sigma$) calculated by sample type (blood, urine etc.) and for various regroupments of the examined population are shown in Table 3.

| Medium | Parameters | TOTAL | | | MALES | | FEMALES | |
|---|---|---|---|---|---|---|---|---|
| | | 187 pers. | G | Non-G | G | Non-G | G | Non-G |
| Blood | Number | 180 | 93 | 87 | 71 | 42 | 22 | 45 |
| | Mean | 24.4 | 27.3 | 21.3 | 27.3 | 22.7 | 27.4 | 19.9 |
| | σ | 16.9 | 17.8 | 15.2 | 17.7 | 19.4 | 18.9 | 9.9 |
| | p | - | **S** | | **NS** | | **S** | |
| Creati-nin | Number | 102 | 66 | 36 | 57 | 20 | 9 | 15 |
| | Mean | 15.54 | 19.4 | 8.5 | 21 | 11.7 | 9.2 | 4.5 |
| | σ | 25.4 | 29.6 | 12.7 | 31.5 | 16.5 | 6.2 | 2.0 |
| | p | - | **S*** | | **S** | | **S** | |
| Hair | Number | 148 | 76 | 72 | 58 | 29 | 18 | 43 |
| | Mean | 3.85 | 4.7 | 3.0 | 5.35 | 3.5 | 2.56 | 2.62 |
| | σ | 4.7 | 6.0 | 2.5 | 6.6 | 2.5 | 1.6 | 2.4 |
| | p | - | **S** | | **S** | | **NS** | |
| Nails | Number | 161 | 81 | 80 | 64 | 37 | 17 | 43 |
| | Mean | 3.99 | 5.2 | 2.8 | 5.8 | 2.5 | 2.6 | 3.1 |
| | σ | 5.44 | 7.2 | 2.0 | 8.0 | 1.5 | 1.6 | 2.3 |
| | p | - | **S*** | | **S*** | | **NS** | |

**Table 3 - Comparison of galamseys and non galamseys exposure with respect to gender**

*NS = non significant ; S = significant (p<0.05); S* = very significant (p<0.01); (G), (Non-G) = galamsey & non-galamsey*

As a whole (columns "TOTAL"), mercury mean concentrations of all indicators differ significantly for galamseys and non galamsey people. Apart for blood in males and hair and nails in females, the same difference between galamseys and non galamseys is found in sub-groups (colums "MALES" and "FEMALES"). Blood mean concentrations are equivalent between male and female subgroups.

### 3.2.5 *Classification of exposures*

#### *3.2.5.1 Class limits*

Three classes were defined for each biomonitor: the first one corresponds to results below the reference value (non-exposed general population), the third one to results above the level indicating an obviously exposed population, while the remaining data correspond to an intermediate situation. The class limits are summarised in Table 4.

| Class | Hg µg.l$^{-1}$ in Blood | Hg µg.g$^{-1}$ in Creatinin | Hg µg.g$^{-1}$ in Hair or Nails |
|---|---|---|---|
| 1 | < 10 | < 5 | < 5 |
| 2 | > 10- <25 | > 5- <35 | > 5- <10 |
| 3 | > 25 | >35 | >10 |

**Table 4 - Class limits for exposure indicators**

#### *3.2.5.2 Classification results*

- The distribution of galamseys and non-galamseys among the 3 classes was studied for each indicator, with distinction by gender – as women are supposed to be less exposed to mercury from artisanal gold mining, because the proportion of galamseys among women is lower, or because they have often several occupations (see § 3.2.1).

**Blood**: people in class 1 (non-exposed) account for only 9 to 14% of the total population (Figure 11);40 to 50% of galamseys people are in class 3, versus 20 to 30 % of non galamseys. This shows that:

- Dumasi population shows generally mercury concentrations in blood higher than 10 $\mu g.l^{-1}$ , which is the reference value for non-exposed populations;
- Among the most exposed people (i.e. class 3), galamseys are much more represented.

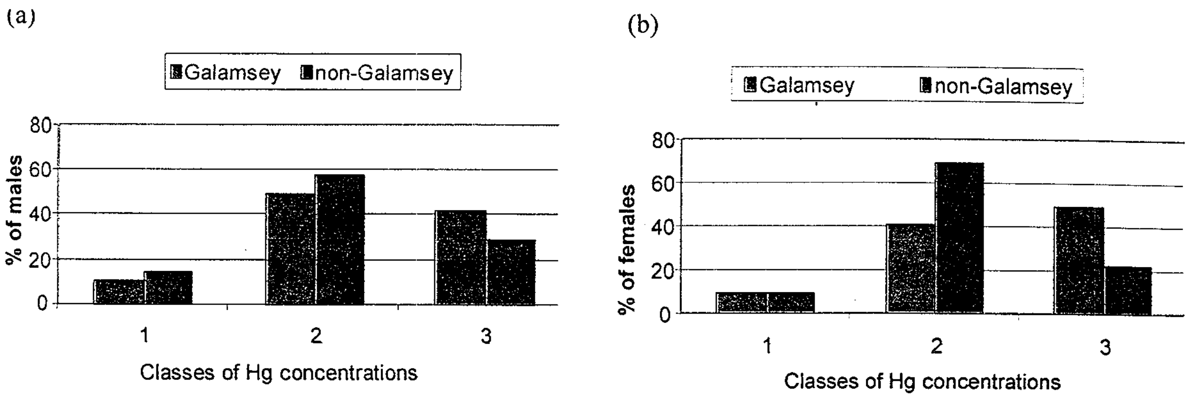



**Figure 11 - Percentage of galamseys and non galamseys people in 3 classes of blood mercury contents : a) – Males ; b) – Females**

**Urine, hair and nails**: proportion of people in classes 2 and 3 are lower than for blood, but again, galamseys proportions in these classes are higher than non galamseys. shows 2 examples for hair (a) and nails (b).

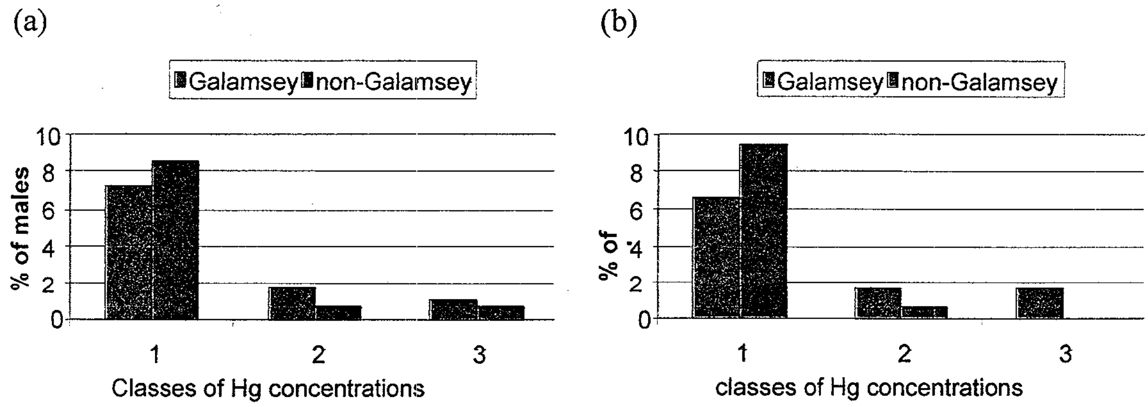



**Figure 12 - Percentage of gamaseys and non galamseys people in 3 classes of mercury contents : a) – in hair; b) – in nails**

Table 5 summarises the distribution of people belonging to class 3 according to their occupation and gender. As a whole, there are 92 people in this class: 74 of them exceed the limit for at least one indicator. Moreover, some people of this group exceed the class 3 limit for more than one indicator: sometimes 2 or 3, even 4. These 74 people are studied in details in the following section.

| Classe 3 | Galamsey operators | | Non-Galamsey operators | | Total |
|---|---|---|---|---|---|
| | Females | Males | Females | Males | |
| Blood | 11 | 29 | 10 | 12 | 62 |
| Creatinin | 0 | 8 | 0 | 1 | 9 |
| Hair | 0 | 6 | 1 | 2 | 9 |
| Nails | 0 | 11 | 1 | 0 | 12 |
| S/total | 11 | 54 | 12 | 15 | |
| Total | 65 | | 27 | | 92 |

**Table 5 - Distribution of people in class 3 according to occupation and gender**

### *3.2.5.3 Observation of most exposed people (class 3)*

About 67% people (among the total of 92) are in class 3 because of their high mercury blood content; this proportion falls to only 10% for creatinin, showing that blood is a more discriminant indicator in this study.

Within the group of male galamseys (N=36), 12 exceed the exposure value for several descriptors (up to 4). This feature is never observed in the non-galamsey group, nor in the female galamsey group, where only one exposure indicator is execeeded at a time (mainly blood, 33 occurences for a total of 38). There is only one exception, a supposed male non-galamsey who shows very high mercury concentrations in blood and urine (93 $\mu g.l^{-1}$ and 78 $\mu g.g^{-1}$ creatinin respectively) and declares having tremor.

The Table 6 displays a statistical summary of exposure indicators for class 3 people, and allows the comparison between 2 groups, i.e. galamseys (male only), and non-galamseys (male and female were grouped, so as to obtain a group of a comparable size). Means in groups A and B are obviously different for all indicators, excepted for blood.

**a)**

| group | Blood Hg $\mu g.l^{-1}$ | | | | Creatinin Hg $\mu g.g^{-1}$ | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Max | min | N | Mean | Max | min | N |
| A | 36.5*(38.1)* | 74*(93)* | 9 | 36 *(37)* | 30.7*(32.2)* | 193 | 1.7 | 30*(31)* |
| B | 37.5*(35.4)* | 96 | 7 | 27*(26)* | 11.9*(6.4)* | 78.3*(16)* | 1.6 | 13*(12)* |

**b)**

| group | Hair Hg $\mu g.g^{-1}$ | | | | Nails Hg $\mu g.g^{-1}$ | | | |
|---|---|---|---|---|---|---|---|---|
| | Mean | Max | min | N | Mean | Max | min | N |
| A | 7.4 | 44.6 | 0.4 | 29 | 8.5 | 55.7 | 1.4 | 32 |
| B | 4.4 | 14.3 | 0.7 | 21 | 3.0 | 12.6 | 0.9 | 24 |

**Table 6 – Statistical summary of mercury exposure for class 3 people**

*A: male only galamseys; B: male and female non galamseys. Values in brackets are obtained after reclassing the non-galamsey man with high blood and urine mercury in the galamsey group, following the assumption that his response to the questionaire was erroneous.*

In conclusion, among 187 investigated people 74 are in class 3 for at least one indicator, i.e. 48 galamseys (on a total of 98) and 26 non galamseys (on a total of 89) . The galamseys are always more exposed than the non galamseys. Moreover, 13 male galamseys among 37 (50% of the overall class 3 number) are classified in this class for several indicators. These 13 men are younger (mean = 30 years) than the class 3 men in general (33 years) or than the overall investigated men (35 years). They are also more illiterate (83%) than the male galamseys group (49%, N=98). This could perhaps mean that educated galamseys are more aware of mercury hazards, and use it with caution. The education of this subgroup could be efficient for reducing their individual risk.

### 3.2.6 Comparison with neurological data obtained during the epidemiological study

Among the 13 people having slight neurological disorders, there were 6 men belonging to class 3 (30 to 38 µg.l$^{-1}$ Hg in blood). Two of them are galamseys, of which one exceeds the limit for 2 biomonitors. One of these 2 exceeds the limit for 2 biomonitors (blood and creatinin, 31 µg.l$^{-1}$ and 39 µg.g$^{-1}$ respectively). The diagnosis for him was "*moderate excess salivation, the person is observed talking and asked to open his mouth and elevate his tongue*". Among the 6 class 3 individuals, there are 3 cases of "moderate tremor", and also 2 of "vision problems", 2 "skin diseases", and 1 asthma.

The fact that so few neurological disorders could be observed is strongly coherent with the biological data, as the symptoms are likely to be observed at concentrations higher than the maximum concentration observed in Dumasi. This does not preclude however a chronic intoxication of the galamseys population, and to a lesser extent of the non galamseys one

### 3.2.7 Brief comparison with the UNIDO study in Mindanao (the Philippines)

As mentioned previously, a recent study was carried out in Mindanao island (the Philippines) by G. Drasch et al. (**17**) among clandestine gold miners. Intentionnally, our approach was similar to Table 7 summarises respective findings of this study and the current one.

| BLOOD | | | URINE | | |
|---|---|---|---|---|---|
| | % of total cases | | | % of total cases | |
| | **1 a** | **2 a** | | **1 b** | **2 b** |
| N | 161 | 180 | N | 161 | 102 |
| range | 2.9-110 | 1.0-96 | range | 0.3-511 | 1.1-253 |
| mean | 17.3 | 24.4 | mean | 32.2 | 23.8 |
| Class limits µg.l$^{-1}$ | | | Class limits µg.l$^{-1}$ | | |
| < 5 | 13.1 | 2.8 | < 7 | 41.6 | 36.2 |
| 5 - 15 | 42.2 | 32.3 | 7-25 | 24.2 | 39.2 |
| > 15 | 44.7 | 78.9 | >25 | 34.2 | 24.5 |
| >25 | 21.1 | 33.3 | >100 | 8.1 | 4.9 |
| *total* | *100%* | *100%* | *total* | *100%* | *100%* |

**1= Mindanao; 2= Dumasi**

**Table 7 - Comparisons of Mindanao and Dumasi results**

Blood samples show comparable range and mean, whereas Mindanao people have higher mercury concentrations in their urine. Several authors have concluded that blood mercury is linked to exposure through food, while urinary mercury would mean occupational exposure to atmospheric (thus mineral) mercury. Therefore people in both contexts display similar food exposure, but Mindanao people seem more exposed through mercury processing.(**18**) (**19**

In Mindanao, 55 (36.7%) out of 150 hair samples exceed 5 µg.g$^{-1}$ and 37 (24.7%) 7 µg.g$^{-1}$ . The range was 8 - 42.2 with a mean of 5.6 µg.g$^{-1}$. In Dumasi, 24 (16%) out of 148 hair samples exceed 5 µg.g$^{-1}$ and 11 (7.5%) 7 µg.g$^{-1}$ and the range was 0.4-44.6 with a mean = 3.9 µg.g$^{-1}$

# 4 Design of a monitoring system for continuous biological sampling & analyses

## *4.1 Objectives*

Two levels of objectives could be identified :

- for Dumasi : continuous monitoring of the group at risk identified by this study must be done after the introduction of retorts,
- for an overall survey in Ghana, extend the assessment of human exposure to mercury in other artisanal gold mining sites : different locations must be studied for their geographical and processing gold specificities ( i.e. alluvial areas).

## *4.2 Strategy*

The group at the risk the most exposed to mercury is male galamseys. Their survey cannot be done extensively.

- for Dumasi, the survey will be based on the group at risk identified. Another sampling campaign will be done to confirm their exposure. Retorts will be distributed to the galamseys of that group. A survey one year later on these users of retorts must be done for the evaluation of this preventive process.
- for other artisanal gold mining sites, we would propose to make the same type of study. The choice of the sites will be done by the Small-Scale Mining Department. Fifty persons will be sampled. The sampling strategy is the following : 30 male galamseys, their spouses and children (20 persons) will be chosen as control group : biological samples preferred will be blood and hair or nails.
- Continuous monitoring of the overall galamseys exposure could be done through the health infrastructure of Ghana : each male galamsey or his spouse and children could be sampled for their hair or nails.

This pilot proposal could be tested, before its extension to all the health centres in Ghana, in Bogoso and another Health Centre in the North of Ghana. If this proposal is feasible we could propose a very simplified protocol for data and samples collection.

# 5 Intermediate conclusions

- There is a strong evidence of mercury exposure among Dumasi population;
- Galamseys are more exposed to mercury than non galamseys;
- Young illiterate galamseys show the strongest exposure (several indicators in class 3). People inhabiting the village for a long time are also among the most exposed people.
- Results are a bit confusing, as blood is the most discriminating indicator; following the literature, urine indicators should be more discriminant for people exposed mainly through their occupation. However, strong perspiration could perhaps explain this situation.
- Many non galamsey people, even less exposed than galamseys, show obviously mercury blood levels higher than reference values, meaning that there is also an exposure through the environment (food).
- Mercury blood levels in Dumasi are comparable to those in Mindanao (the Philippines), whereas urinary mercury is higher in the latter study; this shows that exposure through food is an important route in Dumasi.
- However, it seems difficult to extrapolate this conclusion to the whole Ghanaian auriferous area, as processes may greatly vary (e.g. in alluvium).
- One important goal of the project's second phase should therefore be to reduce mercury transfers to the environment.
- Education is a dramatic issue in this context; young galamseys and women appear of particular concern for that issue.
- A second target should be the introduction of appropriate technology for mercury distillation, as it has been shown that galamseys were more exposed than other people.
- Other prevention measures should also be envisaged, as people are also exposed through their environment.

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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

# US/GHA/99/128 - Assistance in Assessing and Reducing Mercury Pollution Emanating from Artisanal Gold Mining in Ghana - Phase I

## Part II - Conduct of surveys on river systems & overall conclusions


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## Contents

## *Abbreviations*

| | |
|---|---|
| ADI | Acceptable Daily Intake |
| BGL | Bogoso Goldfields Limited, Bogoso, Ghana |
| BHC | Bogoso Health Center |
| CCC | Criterion Continuous Concentration: the highest concentration of a pollutant to which aquatic life can be exposed for an extended period of time (4 days) without deleterious effects |
| CMC | Criterion Maximum Concentration: the highest concentration of a pollutant to which aquatic life can be exposed for a short period of time (1 hour average) without deleterious effects |
| EPA | Environmental Protection Agency, Accra, Ghana |
| ISQG | Interim sediment quality guideline |
| PEC | Probable Effect Concentration: concentration above which toxic effects for benthic organisms are expected (consensus) |
| PEL | Probable effect level: level above which toxic effects for benthic organisms are expected |
| RCQE | Canadian Recommendations for the Quality of the Environment |
| SMMO | Small Scale Mining Office (Mineral Commission) |
| SQG | Sediment Quality Guideline |
| TEC | Threshold effect concentration: concentration below which toxic effect for benthic organisms are not expected (consensus) |
| TEL | Threshold Effect Level: level below which toxic effect for benthic organisms are not expected |
| UP | Pau University, Inorganic analysis laboratory |
| US-FDA | United States Food & Drug Administration |
| WRI | Water Research Institute, Accra, Ghana |

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# 1 Introduction

This report belongs to the US/GHA/99/128 project implemented by the UNIDO and entitled "Assistance in Assessing and Reducing Mercury Pollution Emanating from Artisanal Gold Mining in Ghana (phase 1)". This part II report relates to the environmental assessment of mercury pollution, which includes the following tasks:

1. Investigate the situation of the environment on the spot, take samples from waters and soils where pollution can be assumed.
2. Evaluate the nature and extent of the mercury pollution in a selected river system and adjacent agricultural sites.
3. Introduce and set-up a monitoring system for continuous water quality assessment.
4. Formulate measures for the remediation and possible rehabilitation of hot spots in the river systems and vicinities.
5. Advise on necessary interactions between government departments, mining industry and research institutions.
6. Prepare a concise report on all findings and data including recommendations.

Tasks 5 will be examined along with the findings and conclusions of part I report, which relates more specifically to human health assessment.

# 2 Current situation of the environment

## 2.1 *Global situation in Dumasi area*

The first and obvious environmental issue in the area of concern relates to important modifications of the topography. From 1987 (beginning of the concession) to 1998, about 52 millions of tonnes have been excavated (**1**). 80% of this amount is waste and returned to land.

Hydrography and hydrology should have been modified accordingly, but no quantitative data were made available. Industrial mining, by digging large pits, represents certainly the main impact in this field. Localised impacts linked with artisanal mining occur at a local scale: even though not quantified, the installation of sumps along the Apopre river strongly disturbs the discharge regime. Because of a lower sump density, disturbances are less discernible in the Rora river.

A third issue is erosion, which is particularly visible in the Apopre river upstream Dumasi. The water is orange coloured and completely turbid. Erosion is linked to tailings piles and to digging activities; galamsey activity probably increases turbidity, since many sumps are grouped in a small area, like in the SE part of Dumasi. Either upstream or close to the confluence, the Rora river appears again less affected by turbidity.

The fourth issue is acid rock drainage, which is created by the rainwater drainage of sulfides after they have been oxidised in sulphates, resulting in sulphuric acid formation. Consequently, various metals from ore minerals are then dissolved in pit waters, and may be released into the adjacent rivers (**2**).

BGL mining company sustains a consistent rehabilitation effort with about 68 ha planted with nitrogen fixing tree seedlings and 18 ha with various grass species in 8 months in 1998 (**1**). However, reclamation success is sometimes hampered by the composition of the mineral materials used in this process, which can induce phytotoxicity. This undesirable effect may be due to arsenic, which is widespread in the rocks of this area.

## 2.2 *Mercury releases to the environment*

Assuming an average gold production of 0.5 – 1.0 g *per capita* (see part I), § 2.3), it can be estimated that the yearly mercury consumption in Dumasi is on average 450 kg (100 – 1500 kg), depending on the ore richness and on the gold to mercury ratio in amalgamation.

## 2.3 Water quality

Existing data concerning surface water quality around Dumasi may be obtained from the mine's monitoring program and from the general monitoring program of river quality.

### 2.3.1 Monitoring data from BGL

BGL's monitoring program includes 6 sampling locations (Table 1; Figure 1); measurements include pH, suspended solids (TSS or TDS, according to the period), conductivity, and three trace elements: arsenic, copper, and zinc. Free cyanide is measured in samples from pits (P13, Tailing dams, and P14, Lake Marwood), and from Apopre river (P16).

| Code | Location |
|---|---|
| N01 | Apopre Chujah |
| N02 | Wora Wora Creek |
| P13 | Tailings dams |
| P14 | Lake Marwood |
| P16 | Apopre stream |
| Q04 | Subri above Mansi river |

**Table 1 - BGL's sampling locations**

The tailing dams and Chujah area are drained directly or indirectly by the Apopre river, upstream Dumasi village (Figure 1; cf. part I report, § 1.2). Therefore, the most interesting data are those from N01, N02, P13, P14 and P16 locations, even though the respective contributions of these effluents to Apopre's flow are yet unknown.

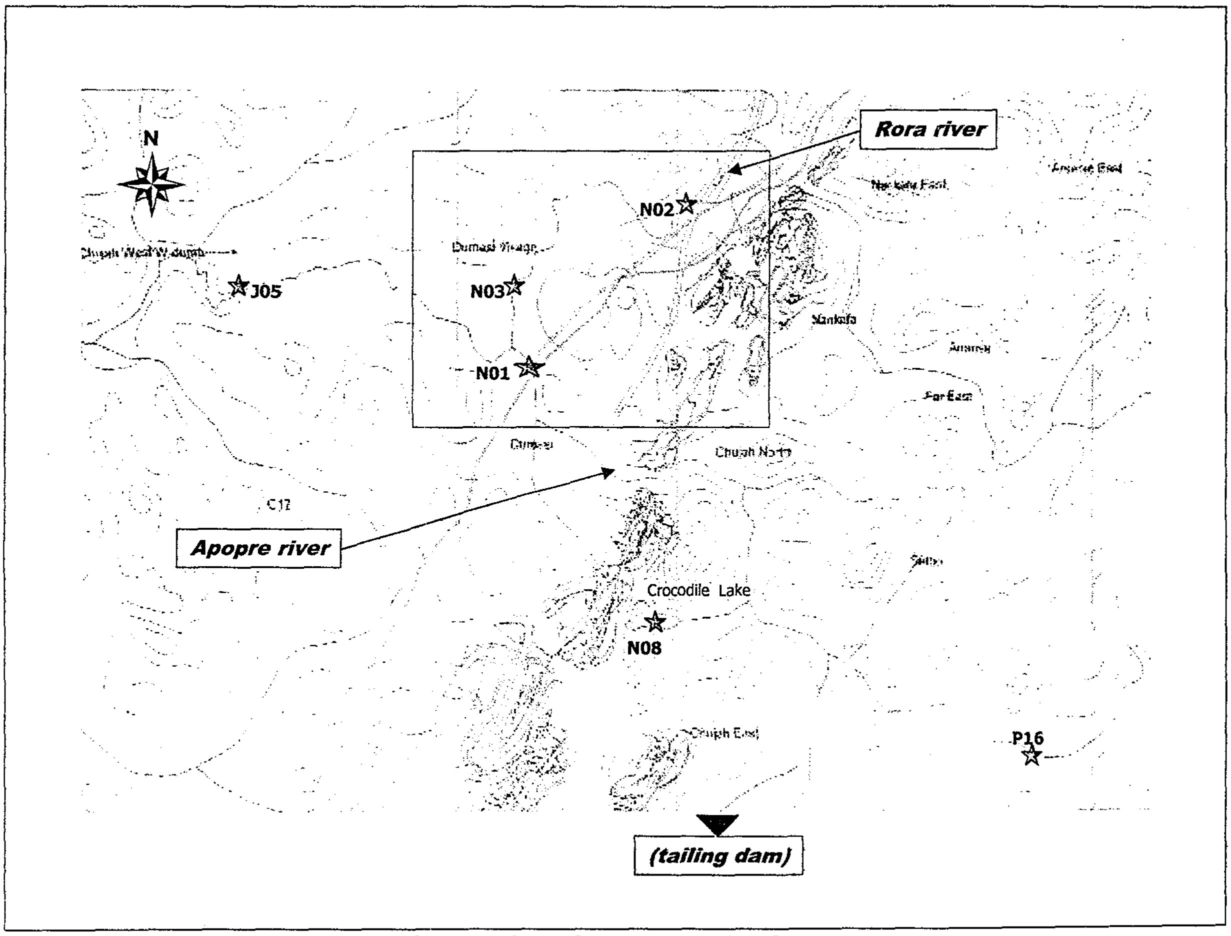


**Figure 1 – Sampling locations for BGL's effluents monitoring**
(the square corresponds to Figure 2)

Monitoring results of BGL's mining effluents for the year 1999 may be summarised as follows:

**N01:** water quality is characterised by pH values close to 7 (mean = 6.79, min = 6.18, max = 7.16), low concentrations of copper (mean = 0.014 $mg.l^{-1}$) and zinc (0.01 $mg.l^{-1}$). With a mean value of 0.054, arsenic concentrations in N01 samples are lower than those from pits or tailing dams (i.e. P13 and P14), but they seem rather variable (max 0.151 $mg.l^{-1}$)[a]. Mean TDS concentration[b] is equal to 68 $mg.l^{-1}$.

**N02:** pH values are slightly lower than the neutrality (mean = 6.56, min = 5.80, max = 6.80, and low copper (mean = 0.014 $mg.l^{-1}$) and zinc. Arsenic concentrations are comparable to those of N01 or P16, and mean TDS is equal to 41 $mg.l^{-1}$.

**P13:** at this sampling point, water is rather alcaline (mean pH = 9.28, min = 8.47, max = 9.8). Mean TDS concentration is equal to 377 $mg.l^{-1}$. Arsenic and copper concentrations are higly variable, but both parameters show rather elevated values, as compared to the other sampling points (mean As = 0.386 $mg.l^{-1}$; mean Cu = 0.347 $mg.l^{-1}$). In contrast, zinc concentrations are low. Free cyanide is measured at this point, with a mean concentration of 0.036 $mg.l^{-1}$ (max 0.060).

**P14:** at this sampling point, water is alcaline too (mean pH = 8.12, min = 6.98, max = 9.16). Mean TDS concentration is equal to 342 $mg.l^{-1}$. Arsenic (mean = 0.368 $mg.l^{-1}$) and copper (mean = 0.058 $mg.l^{-1}$) show an intermediate pattern, when compared to the other sampling points. Free cyanide is also measured at this point, with a mean concentration of 0.034 $mg.l^{-1}$ (max 0.050).

**P16**: pH values are similar to those at N01, but slightly more variable (mean = 6.73, min = 6.38, max = 7.64). Mean TDS concentration is equal to 72 $mg.l^{-1}$, which is close to N01 value; nevertheless, maximum TDS concentration is higher at P16 (188 $mg.l^{-1}$ instead of 115 $mg.l^{-1}$). Copper and zinc mean concentrations are also low (respectively 0.011 and 0.02 $mg.l^{-1}$). Arsenic mean concentration is equal to 0.032 $mg.l^{-1}$; free cyanide mean concentration at this point equals 0.016 $mg.l^{-1}$ (max = 0.03 $mg.l^{-1}$).

EPA has set standards for mine effluents (**3**), which are summarised in Table 2.

| Parameter | EPA's criteria ($mg.l^{-1}$) |
|---|---|
| TSS | 50 |
| TDS | 1000 |
| CN (free) | 0.2 |
| CN (total) | 1.0 |
| As (dissolved) | 0.1 |
| As (total) | 0.5 |

**Table 2 - EPA's limit values for mining effluents**

*From ref. (3)*

According to these standards, BGL's monitoring results appear to violate TSS standards at each points in January and February 1999; results are then lacking until March, where TDS measurements replaced TSS. The TDS standard is never violated in 1999 at BGL's sampling points.

EPA's standard for free cyanide has never been passed in 1999. Conversely, dissolved arsenic standard is often passed at P13 and P14 sampling points; however, it is seldomly passed at Apopre river sampling points (i.e. N01 & P16).

In summary, BGL's discharges to Apopre river are mainly characterised by their loads of suspended solids – even though one of the corresponding mandatory standards is generally respected -, and to a lesser extent their arsenic content. According to the available pH data, acid rock drainage seems less pronounced; however, it may occur in non monitored areas, or at previous stages of the waste management process. This could explain the higher values of As and Cu concentrations in P13 and P14 samples, the effluent acidity being then neutralised. Moreover, these points are located in dams which receive alcaline cyanide residues. So acid rock drainage is certainly a true environmental issue in Dumasi region, even though data are uncomplete.

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[a] In 1999; max concentration from June, 1998 to March, 2000 is 0.198 $mg.l^{-1}$

[b] TDS measurement replaced TSS in Feb., 1999

### 2.3.2 EPA's "GERMP" monitoring program of river water quality

This program includes measurements of temperature, colour, turbidity, suspended matter, dissolved oxygen, ammonia, nitrates and coliforms in selected rivers and reservoirs in all Ghana. There is one sampling location from that program in Prestea (Ankobra river), a few kms away from Dumasi. Unfortunately, data were not retrieved.

## *2.4 Environment perception by Dumasi population*

According to the ethno-sociological report by S. ESSAH (**4**), villagers have expressed some concerns about their environment. These concerns include:

- *Groundwater pollution: metallic taste, brownish coloration of white clothes when washing, black-blue coloration of some vegetables (e.g. plantain) when in contact with the water. Several boreholes within the village show these specific characteristics.*
- *Changes in aire quality.*
- *Changes in surface water quality.*
- *Health problems, linked at least in part to water quality.*
- *Soil degradation, crop failure. None of these allegedly degraded parcels was visited during the field mission.*

# 3 Assessment of the nature & extent of mercury pollution in Dumasi

## *3.1 Strategy*

According to the reference documents (Project description & Job description), the sampling program should help to assess the nature and extent of mercury pollution in the river system around Dumasi, and in adjacent agricultural sites. Sampling locations were thus selected in order to determine the specific influence of *galamseys* activities:

- *Sediment and surface water sampling locations were selected upstream the village on the 2 rivers, and close to the confluence, which is located downstream the village; these locations should allow to determine the global impact on the river system.*
- *Sediment sampling locations were also placed in several processing areas, which are called 'sumps'; these sumps are located all along the two rivers, and are more or less connected to them. The selection of specific locations was done in order to give a view of the various steps of the process.*
- *As it was necessary to rely upon village people to catch fishes, the sampling locations were not determined accurately in advance. They were considered progressively, as people brought some fishes to the team.*
- *Vegetables sampling locations were selected in the vicinity of sumps either active or abandoned, in three different parts of the village.*
- *As for fishes, chicken sampling locations were not determined in advance. It was only asked to villagers to bring some few chickens from different parts of the village.*
- *As far as possible, different kinds of samples were grouped in close locations (e.g. SS6, W6; SS9, W9, V2; SS7 and SB1). All sampling locations are reported in Figure 2; these are in fact approximate locations, because no GPS device was available during the sampling campaign.*

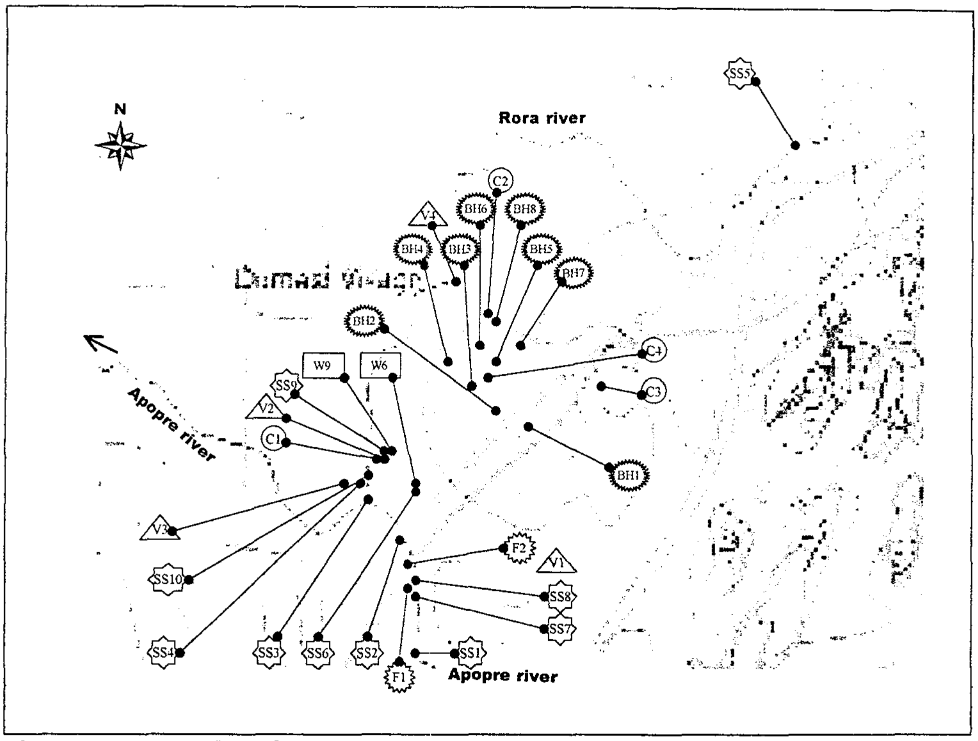


**Figure 2 - Sampling locations (April 2000)**

## *3.2 Sampling protocol*

### 3.2.1 Sediments

Bulk sediment 10 to 20 cm thick were collected in various places (at least 2) of each sampling location with a shovel. Vegetal debris were removed, and sediment was taken from the content of the shovel in various places, with a stainless steel spoon, and added to 500 ml plastic bottles rinsed 2 times with raw water from the location beforehand. These plastic bottles were filled as much as possible, in order to avoid further oxidation.

All the samples were collected during the same afternoon, and frozen at -20°C within a few hours.

10 samples (SS1 to SS10) were collected: 5 were from the river system, and the remaining 5 from the sumps, either active or abandoned. Their identification is summarised in Table 3.

### 3.2.2 Soils

According to the terms of reference, soils samples should have been taken where pollution could have been assumed. Such locations may include places where mercury is sold, or those where it is used, and finally those where amalgam is burnt.

Some of those sites were identified during the campaign, but their owners were very reluctant to accept the sampling, for at least two reasons: (1) they alleged that these soils may contain gold from galamsey operations, and (2) they may have feared that these soils would be used for voodoo. Thus only 1 soil from an amalgam burning place could be obtained (SB1).

Because of the reluctance of the site owner, it was impossible to apply any current sampling protocol. A 40 * 40 cm square was delineated, and a layer of ≈ 1 cm thick was removed. The whole sample was kept, and frozen within a few hours.

### 3.2.3 *Groundwater and surface water*

All the water samples were obtained following the same protocol: 1000 ml plastic bottles rinsed 2 times with freshly pumped water were filled up to the edge. Temperature and oxygen were measured immediately with a portable probe.

There are 9 boreholes in Dumasi village, equipped with manpower pumps of Ghanaian fabrication; one pump was currently out, so 8 samples were collected. The borehole pipe should be emptied by pumping before taking the sample. In fact, these boreholes are almost continuously working throughout the day, so the samples were collected directly. The 8 boreholes samples (BH1 to 8) were collected within 2 hours, and frozen ½ hour later.

There are also some traditional wells in many households. Some of them were dug near sumps, when those could not receive their water directly from the river (e.g. SW sumps). In this case, the water table is very close to the surface (< 1 m), and the distance to the sump is also very short (≤ 1.5 m). 2 of these wells were sampled and quoted W6 and W9, because the corresponding sumps were included in the sediment sampling sub-program and identified as SS6 and SS9.

Surface water samples (SW1 to 5) were collected at the same locations where river sediments (SS1 to 5) had been taken. Well and surface water samples were collected the same morning as the first fish lot, and frozen about 2 hours later.

At the arrival in France, defrost water samples were acidified with 1 ml of strong nitric acid and quickly transferred to the laboratory.

### 3.2.4 Fishes

Fishes were obtained from 2 locations: F1 in the SE sump, and F2 from Apopre river close to the cemetery, i.e. downstream F1. The F1 capture included 5 fishes and 2 crustaceans (cf. Table , F1/1 to F1/8), and the F2 one 10 fishes (F2/1 to F2/10). Captures were obtained during the same day, one lot in the morning and the other in the afternoon. The fishes were kept in water until Bogoso Health Centre (BHC), where they were processed as follows.

As quickly as possible after the fish death, its length was measured. Then some scales of a side , and the corresponding skin, were removed, a piece of fillet of about 5-10 g was taken with a scalpel, and placed in a plastic bag suitable for food freezing. The pieces of fillet were then frozen.

Crustaceans were frozen without sub-sampling.

All this process occurred in a tempered room (≤ 25°C); a Teflon sheet had been installed on the table, and was washed with nitric acid and alcohol between 2 successive samplings. Instruments were also cleaned with alcohol between the samplings.

Fish species were tentatively identified with the help of Water Research Institute technicians from pictures taken before sampling the fillets, and named according to Teugels, Lévêque & al. (**5**,**6**).

### 3.2.5 Chicken

1 chicken was bought from villagers in each part of the village (i.e. 4 chickens, identified as C1 to C4, for SE, SW, NE and NW parts; cf. Figure 2). The chickens were kept alive until their processing at BHC.

Breast feathers were removed, then skin was cut, and a piece of fillet of about 5-10 g was taken with a scalpel, and placed in a plastic bag suitable for food freezing. The pieces of fillet were frozen within 1 hour.

This process was realised under the same conditions than for fish samples (i.e. cleaning the Teflon sheet and instruments).

### 3.2.6 Vegetables

Vegetables were obtained from 4 different locations (V1 to V4). V3-cassava was taken from a remote field beyond SS3/SW3 location, and could therefore be considered as a reference sample. V1 is located near a mechanical crushing mill, but uphill the SE sumps. V2 is located in an household and its associated sump. V4 is located in an abandoned sump.

These vegetables were brought back to BHC and processed in a similar way as fishes and chickens; the skin was removed, and some pieces were taken and placed in plastic bags suitable for food freezing. The Teflon sheet and instruments were cleaned after each vegetable processing. All the samples were frozen within 1 hour.

### 3.2.7 Summary of the April 2000 sampling campaign

**Table 3 - Identification of environmental samples**

| Type | Code | Date | Description / Comment |
|---|---|---|---|
| borehole water | BH1 | 21/04/2000 | |
| | BH2 | 21/04/2000 | ([c]) |
| | BH3 | 21/04/2000 | |
| | BH4 | 21/04/2000 | ([c]) |
| | BH5 | 21/04/2000 | ([c]) |
| | BH6 | 21/04/2000 | ([c]) |
| | BH7 | 21/04/2000 | |
| | BH8 | 21/04/2000 | |
| surface water | SW1 | 20/04/2000 | Same location as SSi |
| | SW2 | 20/04/2000 | |
| | SW3 | 20/04/2000 | |
| | SW4 | 20/04/2000 | |
| | SW5 | 20/04/2000 | |
| well water | W6 | 20/04/2000 | Very close to SS6 sample |
| | W9 | 20/04/2000 | Very close to SS9 sample |
| sediment | SS1 | 19/04/2000 | Apopre river - upstream |
| | SS2 | 19/04/2000 | Apopre river – downstream the SE sumps; corresponds to N02 location of BGL's prog. |
| | SS3 | 19/04/2000 | Apopre river - downstream the SW sumps |
| | SS4 | 19/04/2000 | Rora river – close to the confluence with Apopre |
| | SS5 | 19/04/2000 | Rora river – upstream Dumasi, along haulage road; corresponds to N01 location of BGL's prog. |
| | SS6 | 19/04/2000 | SW sump, under the front of the 'sluice' box |
| | SS7 | 19/04/2000 | SE sumps, under the front of the 'sluice' box |
| | SS8 | 19/04/2000 | SE sumps, output of the sump area |
| | SS9 | 19/04/2000 | SW sump, output of the sump area |
| | SS10 | 19/04/2000 | SE abandoned sump – wet, partially oxygenated sediment |
| soil | SB1 | 20/04/2000 | SE sump, distillation place |
| chicken | C1 | 21/04/2000 | |
| | C2 | 21/04/2000 | |
| | C3 | 21/04/2000 | |
| | C4 | 21/04/2000 | |
| fish | F1/1 | 20/04/2000 | 'mudfish' – *Parachanna obscura* |
| | F1/2 | 20/04/2000 | tilapia – *Tilapia guineensis* |
| | F1/3 | 20/04/2000 | tilapia – *Tilapia guineensis* |
| | F1/4 | 20/04/2000 | tilapia – *Tilapia guineensis* |
| | F1/5 | 20/04/2000 | tilapia – *Hemichromis spp.* |
| | F2/1 | 20/04/2000 | 'mudfish' – *Parachanna obscura* |
| | F2/2 | 20/04/2000 | 'catfish' – *Heterobranchus spp.* |
| | F2/3 | 20/04/2000 | 'catfish' – *Heterobranchus spp.* |
| | F2/4 | 20/04/2000 | 'catfish' – *Heterobranchus spp.* |
| | F2/5 | 20/04/2000 | tilapia – *Tilapia guineensis* |
| | F2/6 | 20/04/2000 | tilapia – *Tilapia guineensis* |
| | F2/7 | 20/04/2000 | tilapia – *Tilapia guineensis* |
| | F2/8 | 20/04/2000 | tilapia – *Tilapia guineensis* |
| | F2/9 | 20/04/2000 | tilapia – *Tilapia guineensis* |
| | F2/10 | 20/04/2000 | tilapia – *Hemichromis spp.* |

[c] *The water turns brownish in contact with air, and purple colored when plantain or cocoyam are dropped in*

| Type | Code | Date | Description |
|---|---|---|---|
| lobster | F1/7 | 20/04/2000 | |
| shrimp | F1/8 | 20/04/2000 | |
| vegetable | V1/1 | 20/04/2000 | cocoyam |
| | V1/2 | 20/04/2000 | plantain |
| | V2/1 | 20/04/2000 | plantain |
| | V2/2 | 20/04/2000 | sugar cane |
| | V3/1 | 20/04/2000 | cassava |
| | V4/1 | 20/04/2000 | cassava |

**Table 3 - Identification of environmental samples (continued)**

## *3.3 Analytical methods used for environmental samples*

Environmental samples were processed and analysed in the "Laboratoire de Chimie bioinorganique & environnement" in Pau University (UP). As the analytical procedure itself is basically the same for all kinds of samples, it will not be described here. Only sample preparation and digestion are presented.

- ***Water:*** *aliquots of 40ml were accurately transferred into 50ml volumetric flasks. 7.5 ml of 33% v/v hydrochloric acid (BAKER Intra-analysed for trace metals) and 1ml 1N KBr/$KBrO_3$ reagents were added and allowed to stand for 1hour. In all cases the yellow coloration due to free bromine persisted. 6.0uL of 12% m/v hydroxylamine hydrochloride (BAKER) was added to each sample. Coloration disappeared. They were diluted to the mark with de-ionised water.*
- ***Soils and sediments:*** *Masses between 50-100g of samples were dried in a clean chamber at ambient temperature (<30°C) for 7-14 days. They were hand ground in porcelain mortar with pestle and preserved in clean water-tight screw-capped polypropylene containers (POLY LABO sterilised). About 0.5 g of the dried sample was weighed into the sample holder of a microwave digester (PROLABO 301) and digested according to the following six-step automated digestion programme using concentrated $HNO_3$, HCl and HF (MERCK Suprapur):*

| STEP | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| REAGENT | HNO3 | HCl | HF | | HCl | WATER |
| SPEED 1/10 | 10 | 10 | 8 | | 10 | 10 |
| VOLUME ml | 6 | 5 | 15 | | 3 | 40 |
| POWER % | 10 | 20 | 20 | 85 | 15 | 35 |
| TIME min. | 5 | 5 | 5 | 20 | 10 | 10 |

The digested solutions were washed and diluted to 100ml with deionised water (Milli-Q). Further dilutions were made with reagent blank prior to the CV-AFS analysis. As an alternative extraction procedure 0.5g of the dried ground samples were treated with 5ml aqua regia and agitated over a shaker overnight.

- ***Fishes:*** *The freeze-dried fish samples were microwave-digested according to the following programme*

| STEP | 1 | 2 | 3 |
|---|---|---|---|
| REAGENT | AQUA REGIA | $H_2O$ | 5% $KMnO_4$ |
| VOLUME ml | 3 | 5 | 2 |
| POWER % | 20 | 0 | 20 |
| TIME min | 5 | 0 | 5 |

Reagent introductions were done manually.

- ***Vegetables and Chicken:*** *vegetables include plantain (peeled), cassava (peeled), sugarcane (without skin nor joints) and cocoyam (peeled). The chicken samples were taken in breast muscles. The chicken and the vegetables were dry-frozen with the exception of the sugarcane. The dry freezing were done in a BIOBLOCK SCIENTIFIC dry freezer at -50°C and 0.055mbar pressure for 24 hours. Percentage humidity content of the samples were determined by weight differences prior and after drying to allow expression of results in both wet and dry weight bases.*

Because consumers swallow only the juice of the sugar cane the juice were mechanically extracted and analysed separately from the fiber. 10-50mg of the dried samples were weighed into polypropylene bottles and 1.5ml of aqua regia added. They were exposed to ultra sonic waves (BRANSON 2200) for 1 hour and diluted to 10ml with deionised water.

Processed samples were all analysed by atomic fluorescence, as explained in part I report.

## *3.4 Results*

### 3.4.1 Total Mercury in water samples

Results are shown in Table 4. With an average concentration of 0.165 $\mu g.l^{-1}$ (± 0.05), water samples from boreholes seem rather homogenous, and far beyond the limit value for drinking water (see § 3.5.1.1). Other types of water samples seem more variable.

| Sample code | Concentration (in $\mu g.l^{-1}$) |
|---|---|
| BH1 | 0.27 |
| BH2 | 0.14 |
| BH3 | 0.15 |
| BH4 | 0.20 |
| BH5 | 0.18 |
| BH6 | 0.13 |
| BH7 | 0.13 |
| BH8 | 0.12 |
| SW1 | 0.15 |
| SW2 | 0.76 |
| SW3 | 0.21 |
| SW4 | 0.14 |
| SW5 | 0.14 |
| W6 | 0.18 |
| W9 | 0.50 |

**Table 4 - Total mercury concentrations in water samples**

### 3.4.2 Total Mercury in soil and sediment samples

Results are given in Table 5. Concentrations are expressed on a dry weight basis (dw). One certified sample was introduced in the series (0.910 – 0.947 $\mu g.g^{-1}$, BCR 320/678 river sediment).

| Sample code | Concentration (in $\mu g.g^{-1}$) |
|---|---|
| SS1 | 0.64 |
| SS2 | 2.7 |
| SS3 | 8.5 |
| SS4 | 5.3 |
| SS5 | 6.3 |
| SS6 | 5.9 |
| SS7 | 93.1 |
| SS8 | 4.65 |
| SS9 | 1.31 |
| SS10 | 6.3 |

**Table 5 - Total mercury concentrations in soil & sediment samples**

### 3.4.3 Total Mercury in fish samples

Results are given in Table 6; one certified sample of tuna fish (BCR CRM 464) was introduced in the series; UP found in it 4.37 and 4.54 $\mu g.g^{-1}$, which is slightly less than the certified value of 5.24 $\mu g.g^{-1}$, but acceptable. The whole series can therefore be accepted.

| Sample code | Common name | Moisture (%) | Tot Hg ( µg.g$^{-1}$) dw | Tot Hg (µg.g$^{-1}$) ww |
|---|---|---|---|---|
| F1.1 | mudfish | 81.80 | 4.19 | 0.76 |
| F1.2 | tilapia | 78.50 | 4.89 | 1.05 |
| F1.3 | tilapia | 78.90 | 5.59 | 1.18 |
| F1.4 | tilapia | 77.20 | 6.41 | 1.46 |
| F1.5 | tilapia (hemichromis) | 76.10 | 2.79 | 0.67 |
| F1.7 | lobster | 71.30 | 0.90 | 0.26 |
| F1.8 | shrimp | 71.10 | 0.46 | 0.13 |
| F2.1 | mudfish | 80.30 | 6.06 | 1.19 |
| F2.2 | catfish | 77.80 | 2.87 | 0.64 |
| F2.3 | catfish | 75.20 | 6.42 | 1.59 |
| F2.4 | catfish | 77.50 | 2.45 | 0.55 |
| F2.5 | tilapia | 78.00 | 3.69 | 0.81 |
| F2.6 | tilapia | 80.30 | 6.07 | 1.20 |
| F2.7 | tilapia | 77.20 | 5.07 | 1.16 |
| F2.8 | tilapia | 76.10 | 4.54 | 1.08 |
| F2.9 | tilapia | 71.50 | 4.90 | 1.40 |
| F2.10 | tilapia (hemichromis) | 76.10 | 3.03 | 0.72 |

**Table 6 – Total mercury in fishes**

### 3.4.4 Total Mercury in vegetable and chicken samples

Table 6 shows mercury concentrations in vegetables as measured by UP laboratory; one certified sample of rice (GBW 08508), containing 38 ng.g$^{-1}$ of mercury was introduced in the series. UP laboratory found 33.71 and 37.08 ng.g$^{-1}$, which is in good agreement with the control sample. Therefore, the whole series can be accepted.

| Sample code | Common name | Moisture (%) | Tot Hg (µg.g$^{-1}$) ww | Tot Hg (µg.g$^{-1}$) dw |
|---|---|---|---|---|
| V1/1 | cocoyam | 64.5 | 0.380 | 1.070 |
| V1/2 | plantain | 63.8 | 0.052 | 0.144 |
| V2/1 | plantain | 66.3 | 0.047 | 0.139 |
| V2/2 | sugar cane | 81.2 | 0.002 | 0.012 |
| V3/1 | cassava | 57.4 | 0.018 | 0.042 |
| V4/1 | cassava | 64.1 | 0.013 | 0.035 |

**Table 7 - Total mercury in vegetables**
(ww: wet weight; dw: dry weight)

Table 8 shows mercury concentrations in chicken samples. As the process before analysis was exactly the same than for fishes, only one certified sample was used (see 3.4.3).

| Sample code | Common name | Moisture (%) | Tot Hg (µg.g$^{-1}$) ww | Tot Hg (µg.g$^{-1}$) dw |
|---|---|---|---|---|
| C1 | chicken | 74.8 | 0.053 | 0.211 |
| C2 | chicken | 76.5 | 0.031 | 0.132 |
| C3 | chicken | 74.05 | 0.057 | 0.218 |
| C4 | chicken | 73.3 | 0.038 | 0.143 |

**Table 8 - Total mercury in chicken samples**
(ww: wet weight; dw: dry weight)

When expressed on a dry weight basis, mercury concentrations in chicken muscles look rather homogenous (average 176 ± 44.8). The range of concentrations encountered in vegetables is much wider. The only cocoyam sample, which was taken close to a crushing mill near NW sumps, shows a high level of total mercury; the two other tuber samples show much lower concentrations, but they were also sampled in remote areas of the village, and not so close to gold processing places than sample V1/1. No mercury could be detected in sugar cane juice.

## 3.5 Discussion

### 3.5.1 Standards and limit values

Environmental concentrations may first be compared with standards, which are currently based on a toxicological approach (e.g. water, fish) or on ecotoxicological or geochemical approaches (e.g. fish and sediment). In the geochemical approach, "background" or "natural" concentrations or ranges of concentrations are proposed. It is considered that concentrations above that natural concentration, or above the upper bound of the background range of concentrations, are due to anthropogenic sources. For mercury, standards are proposed for water, sediment and fish. Moreover, there are some data on background concentrations either in sediments or fishes, in tropical and temperate countries.

#### *3.5.1.1 Water:*

- For drinking water the World Health Organisation (WHO) recommends a limit value of 1 $\mu g.l^{-1}$ (**7**).
- For surface water, a summary of available water quality criteria and guidelines is shown in Table 9; all of them were drawn on an ecotoxicological basis.

| Country | Criteria | Concentration ($\mu g.l^{-1}$) | • | Ref. |
|---|---|---|---|---|
| • *British Columbia* | Freshwater aquatic life | 0.02<br>0.1 | • *30 d. average (total Hg)*<br>• *any time (total Hg)* | (**8**) |
| • *France* | 1-<br>2-<br>3-<br>4- | 0.07<br>0.7<br>3.0<br>21.0 | • *No-effect threshold*<br>• *Lowest 'no observed effect conc.'*<br>• *Lowest acute value*<br>• *Mean of acute values* | (**9**) |
| • *USA* | CMC<br>CCC | 2.1<br>0.012 | • *Criterion Maximum Concentration*<br>• *Criterion Continuous Concentration* | (**10**) |

**Table 9 - Standards for mercury in surface waters**

Variations among these guidelines may be explained by methodological differences, and by the datasets used for deriving the criteria.

#### *3.5.1.2 Fish:*

- *For this medium, standards are set in order to protect human health.*
  - According to WHO, concentrations higher than 0.5 $mg.kg^{-1}$ may be dangerous, in particular for pregnant women or children[d].
  - In the USA, 2 different standards are currently used for fish advisories: the US-EPA's standard is equal to 0.5 $mg.kg^{-1}$; US – FDA action level is 1.0 $mg.kg^{-1}$ (**11**).
  - The French standard varies between 0.5 to 1.0 $mg.kg^{-1}$ (wet weight), depending on the fish species (**12,13**). The 0.5 $mg.kg^{-1}$ value applies to any kind of fish, while the latter 1.0 $mg.kg^{-1}$ applies to predator fishes. These values have no mandatory status and should be considered as guidelines.
  - In other European countries, standards vary between 0.3 $mg.kg^{-1}$ (United Kingdom, Denmark, Norway) to 0.7 $mg.kg^{-1}$ (Italy) or 1.0 $mg.kg^{-1}$ (Germany, the Netherlands, Sweden and Finland); Greece admits a slightly higher value, as the applicable standard is 0.7 $mg.kg^{-1}$ as methyl-mercury (**12**).

[d] These guidelines are usually expressed in $mg.kg^{-1}$, which is strictly equivalent to $\mu g.g^{-1}$; the latter is more commonly used in the scientific literature, so we kept it for the report

Furthermore, Southworth & al. (**14**) tried to determine "background concentrations" in some American fishes, i.e. bluegill (*Lepomis macrochirus*) and redbreast sunfish (*Lepomis auritus*), in small to medium size lowlands streams. They define "background concentrations" as measured concentrations in fishes caught in presumably unimpacted lakes or rivers, or distant from major anthropogenic sources. They found mean values of respectively 0.079 ± 0.004 $\mu g.g^{-1}$ (n=94) and 0.079 ± 0.005 $\mu g.g^{-1}$ (n=89). Mercury concentrations were more variable in the same species from lakes, partly because of important fluctuations of the lake level. Mercury bioconcentration in fishes is a well-known consequence of flooding of terrestrial environments (several ref. quoted by Southworth & al.). This range of concentrations seems more reliable than that mentioned by Bahnick, Sauer & al. (**15**), who found a mean of 0.34 ± 0.40 $\mu g.g^{-1}$ (max. 1.77) for bottom-feeding fishes caught at 21 background sites in the USA. However, they admit that some unknown sources of mercury may be present upstream.

Rose & al. (**16**) examined the assumption stating that this variability may be explained by an ecoregional approach, and by lake trophic status as well as fish feeding behaviour. They found mean background levels of 0.15 $\mu g.g^{-1}$ in brown bullhead (*Ameirus nebulosus*; bottom feeder; range 0.01 – 0.79 $\mu g.g^{-1}$), 0.31 $\mu g.g^{-1}$ in yellow perch (*Perca flavescens*; omnivorous; 0.01 – 0.75 $\mu g.g^{-1}$) and 0.39 $\mu g.g^{-1}$ in largemouth bass (*Micropterus salmoides*; predator; 0.05 – 1.1 $\mu g.g^{-1}$). Their main conclusion is that neither ecoregion nor species have any influence on mercury concentration in background conditions.

Several other studies on mercury contamination mention either control values (concentrations measured in fishes away, but sometimes downstream, from the study area) or background concentrations, but the methodology for determining the latter is seldom explained. These findings are summarised in Table 10.

| Country | Species | Range ($\mu g.\ g^{-1}$) | n | Ref. |
|---|---|---|---|---|
| England (East Anglia) | Roach | 0.014 – 0.045 | 28 | (**17**) |
| Colombia | 9 species (7 carnivorous) | <DL – 0.187 | 30 | (**18**) |
| Brazil (Amazon) | Carnivorous – 11 species | 0.057 – 0.399 | 159 | (**19**) |
| | Non carnivorous – 9 species | <DL – 0.086 | 144 | |
| Brazil (Amazon) | Not mentioned | 0.200[e] (mean) | - | (**20**) |

**Table 10 - Background concentrations or control values for "total Hg" in fishes**

This brief review shows how difficult it is to define accurately an appropriate background level for mercury in fishes. This is due principally to the vagueness of the concept, and accordingly to a lack of a precise methodology. Nevertheless, it seems that 'background' concentrations are currently not expected to exceed 0.2 $\mu g.g^{-1}$ of total mercury.

#### *3.5.1.3 Other food items*

Apparently, there is no published standard for food items other than fish, as fish is usually considered as the main source of mercury through food. However, if necessary, limit values could be calculated by combining the acceptable daily intake with assumptions on the respective proportions of each food item (carbohydrates, vegetables, fruit, proteins etc.) in the ration.

#### *3.5.1.4 Sediment*

Some standards determined on an ecotoxicological basis are compiled in Table 11. In many cases, one standard (or quality guideline) corresponds to the upper limit of the non toxic concentration range for a substance, and a second one corresponds to the lower limit of the toxic concentration range. Concentrations between these benchmarks may correspond either to toxic or to non toxic samples.

[e] wet weight.

| Country - Institution | Type | Value (µg. g$^{-1}$)[f] | Ref. |
|---|---|---|---|
| Canada (RCQE) | ISQG<br>PEL | 0.17<br>0.486 | **(21)** |
| France | Threshold level 1[g]<br>Threshold level 2 | 0.13<br>0.70 | **(22)** |
| Washington, USA - WAC | No-effect level<br>Minor effect level | 0.41<br>0.59 | **(23)** |

**Table 11 – Examples of freshwater sediment quality guidelines for mercury**

Recently, consensus sediment quality guidelines were proposed by Ingersoll, MacDonald & al. (**24**). These consensus guidelines are derived from other existing guidelines by calculating their geometric mean, in each category. They obtain two criteria, called TEC (threshold effect concentration), and PEC (probable effect concentration). Mercury's TEC and PEC values are respectively 0.18 and 1.06 µg.g$^{-1}$.

Background concentrations – which are sometimes "control values" from upstream sites in specific studies – are proposed by various authors and summarised in Table 12.

| River | Catchment or region | Country | Range | Ref. |
|---|---|---|---|---|
| Yare | East Anglia | England | 0.74 – 6.79 | **(25)** |
| Chesapeake Bay | Chesapeake | Maryland, USA | 0.08 – 0.5 | **(26)** |
| - | Chestatee | Georgia, USA | 0.02 – 0.06 | **(27)** |
| La Paz lagoon | Baja California | Mexico | 0.007 – 0.025 | **(28)** |
| Degh Nala | Ravi | Pakistan | 0.048[h] | **(29)** |
| Carmo | Doce | Minas Gerais, Brazil | 0.1 – 0.5 | **(30)** |
| Sepetiba Bay | | Brazil | 0.02 – 0.03 | **(31)** |

**Table 12 - Background concentrations of total Hg in sediments (µg.g$^{-1}$)**

Background values in UK (Yare catchment) appear very high, as compared to other countries. This may be due to non-point sources, which are more common in industrialised areas, or even to unknown sources. Sediment 'background' concentrations are not expected to exceed 0.1 µg.g$^{-1}$.

Methyl-Hg in non contaminated sediments is less commonly assessed; in the Chesapeake Bay context, it was measured in the range 1.0 - 8.5 ng.g$^{-1}$ at reference sites (**26**), in relation with organic carbon concentration. In reference sites in the Yare catchment (UK), methyl-Hg is in the range 0.1 – 26.6 ng.g$^{-1}$ (**25**).

## 3.5.2 *Assessment of environmental contamination by mercury*

### *3.5.2.1 Comparison to standards and background levels*

None of the drinking water samples (BH or W) exceed WHO recommended limit value; only one surface water sample exceeded 0.25 µg.l$^{-1}$, which is the median of the water quality criteria based on chronic toxicity to freshwater organisms (Table 9). In both cases, the temporal variability could not be assessed; groundwater concentrations should not vary greatly in time, at the opposite of surface waters, which are more influenced by galamseys activities and flow discharge.

All sediment samples (SS) exceed both the selected background concentration and the consensus threshold concentration (TEC) of 0.18 µg.g$^{-1}$; most of them exceed also the probable effect concentration (PEC), which means that toxic effects on sediment dwelling organisms may occur. These high concentrations are certainly due to mercury losses during gold processing (see § 3.5.2.4), but also to atmospheric transport and deposition, as upstream samples (SS1 and SS5) show higher levels than background.

[f] expressed on a dry weight basis
[g] identical with a TEL ; threshold level 2 is equivalent to a PEL
[h] control site

All fish samples exceed the background concentration of 0.2 $\mu g.g^{-1}$ and the widely used 0.5 $\mu g.g^{-1}$ health standard; 60% (9 samples) are also higher than US-FDA action level. The lobster and shrimp samples are not included in this count; their total mercury concentrations remain low.

### *3.5.2.2 Comparison to sediment studies in other regions*

Literature data on sediment mercury contamination may be grouped in two categories: concentrations ranges in urban and/or industrialised catchments, and in gold mining areas, particularly small-scale mining. An excerpt of this literature is shown in Table 13. All the sediments sampled in Dumasi show concentrations in the same range as polluted areas over the world; most of them however are in the least contaminated part of the range.

| ***River*** | ***Region, catchment*** | ***Country*** | ***Range ($\mu g.g^{-1}$)*** | ***Ref.*** |
|---|---|---|---|---|
| **Urban / industrialised areas** | | | | |
| various | Ravi | Pakistan | 3.60 - 887 | **(29)** |
| various | various | USA | 0.01 – 14.5 | **(32)** |
| Ebro | Ebro | Spain | 0.05 - 1.46 | **(33)** |
| several tributaries | Sepetiba Bay | Rio de Janeiro, Brazil | 0.036 - 0.197 | **(31)** |
| Yare & tributaries | Yare | England | 1.28 - 14.94 | **(25)** |
| **Gold mining areas (small scale)** | | | | |
| Magdalena | | Colombia | 0.140 - 0.355 | **(18)** |
| Madeira | Amazon | Brazil | up to 157 | **(34)** |
| Agusan | Mindanao | Philipines | up to 34 | **(35)** |
| various | Chestatee | Georgia, USA | 0.04 - 3.90[i] | **(27)** |
| | | | 0.40 - 12.00 | |

**Table 13 - Review of mercury ranges in contaminated sediments**

The high variability of the concentration ranges reported in Table 13 may be explained by the sampling strategy - sampling points may have been spread along downstream gradients -, by differences in the gold extraction process, or by ore richness. For example, Dumasi galamseys extract gold from solid rocks which are rather poor in gold[j]; they spend most of their time in processing this material before amalgamation. Thus they need relatively few mercury along the day. Conversely, people extracting gold from alluvial materials, in Brazilian Amazon or in other parts of Ghana, are working directly with fine particles. They probably will use mercury more often, and in larger quantities; also, when the extraction is carried out on a boat as in the Amazon, more mercury should be released in the river.

The concentrations measured in Dumasi sediments are also in the same range than those measured by Claon in the Aby lagoon in Ivory Coast (**36**); he observed concentrations between 0.54 and 16.54 $\mu g.g^{-1}$ in 13 samples taken in this lagoon, which receives waters from the Tanoe river. The corresponding catchment is adjacent to Ankobra's basin, in which Dumasi is located. The similarity between these two sets of samples gives indirectly an indication of the magnitude of mercury pollution in the whole auriferous region, as sediment transport to the coast or the lagoon is rather slow, and occurs by successive suspension and settling events, which should mix the contaminated sediment with clean particles. Further more, it means that there could be a risk for populations eating fish or shellfish.

### *3.5.2.3 Mercury fate in the river network*

Mercury concentrations in Apopre rivers sediments show a coherent picture, with an enrichment from upstream to downstream. Concentrations in Rora sediments seem higher, apparently without gradient (Figure 3). Mercury concentrations in water, as they are highly variable, are not necessarily in complete coherence with the sediment ones.

[i] historical flood plain sediments (i.e. soils)
[j] and therefore abandoned by the mine company

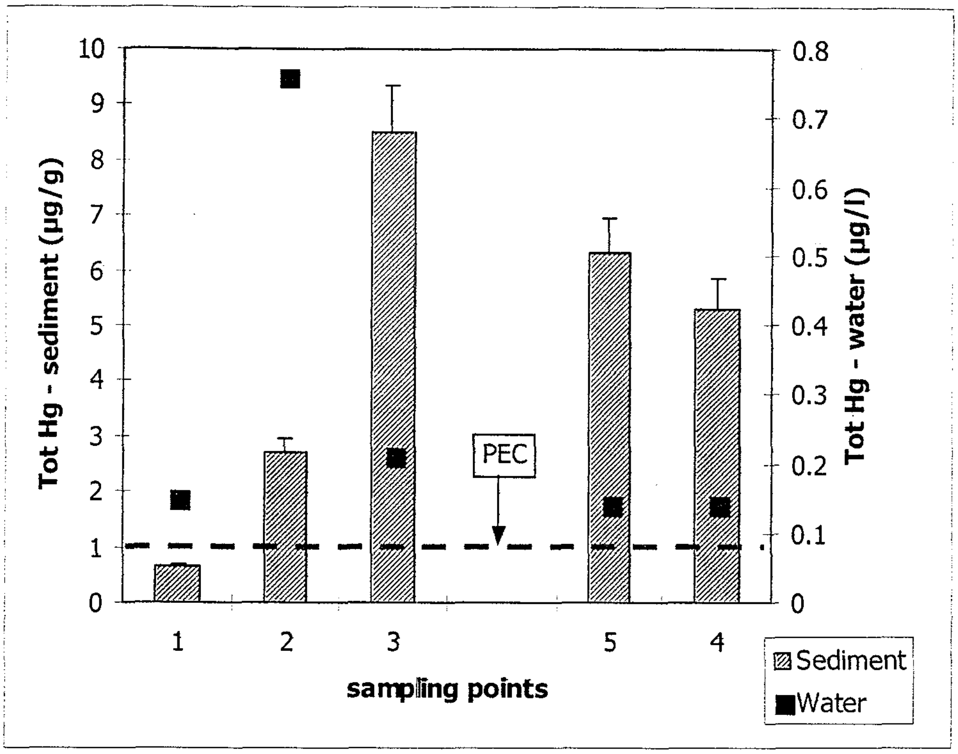


**Figure 3 - Total mercury in Rora and Apopre rivers sediments & waters**
(sampling points, up- to downstream: 1 - 3: Apopre; 5 - 4: Rora)

### *3.5.2.4 Losses of mercury from the gold extraction process*

The concentrations ranges found in soil and sediments at sampling points related to the extraction process are shown in Figure 4. As it could be expected, the highest concentrations have been found in places where mercury is manipulated – dropped into the pans, washed or refined -. Concentrations in marshes sediments at the lower end of sluice boxes are similar to those in the river, and about 10 times lower than that in the pit at the upper end. This probably means that sediment particles are relatively confined in these pits, and are not easily transported downstream; if so, there are probably many contaminated spots in the sumps area, as the sluice boxes and their associated pits and marshes are often displaced and rebuilt. Thus, SS10 sample was taken in an abandoned pit, in the upper layer of sediment of the residual pit; obviously, this sediment was mixed with soil and sand, which means that mercury (6.1 $\mu g.g^{-1}$) was probably diluted. It is completely impossible to locate these spots at the scale of the village.

The unique soil sample (SB1 – 23.3 $\mu g.g^{-1}$) was taken at a burning place, where amalgams are refined; this operation is sometimes done close to the sumps (Figure 4), because placers' owners probably want to control the whole process, but it may also occur close to the houses, or even in other places. The exact spatial extent of the soil contamination around burning places can be assessed, but it can be assumed that it looks like narrow spots, which are therefore distributed all over the village area. Furthermore, as mercury is volatile or can be transported associated with dust particles, these spots are then sources of a more diffuse soil contamination.

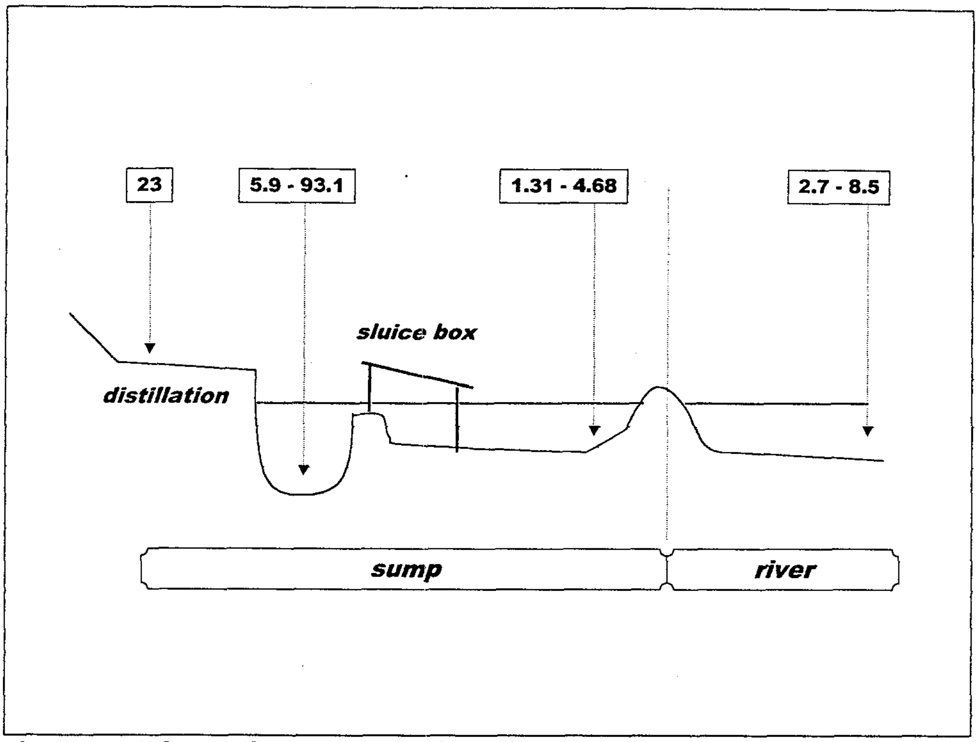


**Figure 4- Schematic representation of mercury losses during gold extraction**

Moreover, there is no evidence that a transfer does occur from sediment to groundwater or not; mercury concentrations in W6 and W9 samples, which are located very close to the upper end of sluice boxes, are lower than the drinking water limit value, but this does not exactly means that there is no transfer from pit sediment to groundwater.

### *3.5.2.5 Impacts on the food webs*

With the exception of cocoyam, vegetables appear as a whole moderately contaminated; concentrations in chicken seem also rather low. Concerning cocoyam, the higher concentration might be due to its nature (tuber), or to a higher soil concentration in the surrounding, as the sample was taken in the vicinity of SE sumps and close to a mechanical crushing mill. These assumptions are even not exclusive.

Literature data concerning vegetables mercury contamination are rare, so it is difficult to make a detailed comparison; Dumasi dataset is also limited in size. In the French Guyana study, which tried to assess very accurately the mercury daily intake from food, only fish and game meat were analysed (**13**). Moreover, in the Philipines study undertaken under UNIDO auspices, it was found that paddy rice mercury concentration range was 0.009 – 0.0580 $\mu g.g^{-1}$ (dry weight) (**37**).

It would be interesting to complete this preliminary assessment by analyses of cocoyam and other tubers, and their leaves, which are used by villagers for cooking various sauces. As corn constitutes also an important proportion of the typical Ghanaian ration, it should be surveyed too.

There are many more studies on fish contamination, as it is considered as the main source of food mercury. An excerpt of this literature is shown in Table 14. It shows that the fishes caught in our study were in same range of concentrations as in other gold mining areas, in Brasil, Tanzania etc.

Moreover, Claon analysed mercury in Aby lagoon fishes, and observed a range of 0.03 – 0.4 $\mu g.g^{-1}$ (**36**), which is lower than concentrations observed in the present work. This seems a bit surprising, as Aby lagoon bottom sediments show a contamination of the same order of magnitude as those sampled around Dumasi. However in Dumasi, only bottom sediments have been sampled; suspended sediments could be more contaminated than bottom ones, as the sampling points were located in the vicinity of the gold extraction process. So, it is possible that only a part of the contaminated particles have settled, thus lowering the apparent contamination. In the meantime, fishes are usually more exposed to suspended particles than directly to bottom sediments. Thus, they could have been exposed to higher concentrations in Apopre river than in Aby lagoon

| *River* | *Basin* | *Country* | *Range* | *Species* | *Ref* |
|---|---|---|---|---|---|
| **Urban / industrialized catchments** | | | | | |
| various | Sepetiba Bay | Rio de Janeiro, Brazil | 12 - 18 | M. fumieri etc. | **(31)** |
| | | | .. – 0.108 | P. brasiliensis | |
| Yare and tributaries | Yare | England | 0.01 - 1.08 | eel | **(25)** |
| | | | 0.028 - 0.47 | roach | |
| | | | 0.08 - 0.77 | pike | |
| Yare and tributaries | Yare | England | <DL - 0.222 | roach | **(17)** |
| 67 sites in 5 regions | | United Kingdom | 0.007 - 0.195 | roach | **(26)** |
| | | | 0.020 - 0.664 | eel | |
| 118 sites | | USA | <DL - 1.40 | bottom-feeding fishes | **(15)** |
| **Gold mining areas (small scale)** | | | | | |
| Magdalena | | Colombia | 0.0074 - 1.084 | various | **(18)** |
| (marshes) | Magdalena, Cauca | Colombia | 0.022 - 1.236 | 10 species | **(38)** |
| Lake Victoria | | Tanzania | 1.8 - 2.4 | tilapia | **(39)** |
| | | | 6.9 - 11.7 | Nile perch | |
| | | | 7.8 - 16.9 | soga | |
| | | | 2.2 | catfish | |
| | | | 5.4 - 8.3 | furu | |
| Maroni | Guyana | France | 0.01 – 0.880 | 44 species | **(13)** |
| Madeira | Amazon | Brazil | 0.165 – 3.920 | 50 species | **(20)** |
| Madeira | | | 0.060 – 3.960 | 22 species | |
| Madeira | | | 0.011 – 0.500 | - | |
| Tapajos | | | 0.025 – 5.960 | 23 species | |
| Tapajos | | | 0.046 – 2.200 | 12 species | |
| Tapajos | | | 0.132 – 1.354 | 19 species | |
| Tapajos | | | 0.120 – 3.580 | 9 species | |
| Negro | | | 0.226 – 4.231 | 18 species | |
| Tucurui res. | | | 0.200 – 5.900 | 8 species | |
| Balbina res. | | | 0.049 – 1.103 | 6 species | |
| Tapajos | Amazon | Brazil | 0.190 – 0.650 | carnivorous species | **(19)** |
| | | | 0.009 – 0.115 | non carn. species | |
| Tapajos | Amazon | Brazil | 0.062 – 0.880 | carnivorous species | **(40)** |
| | | | 0.009 – 0.137 | non carn. species | |
| Cuiaba | Pantanal floodplain | Brazil | 2.33 - 12.31 | 8 species | **(41)** |
| Bento Gomes | | | 2.29 - 13.28 | | |
| Paraguay | | | 1.21 - 1.36 | | |

**Table 14 - Review of fish contamination**

The observed range of mercury fish contamination in Dumasi (0.26 – 1.59 $\mu g.g^{-1}$; Table 6) is comparable to the typical range in gold mining areas; the maximum value is lower than in other regions, but the sample size (n = 15) is also limited.

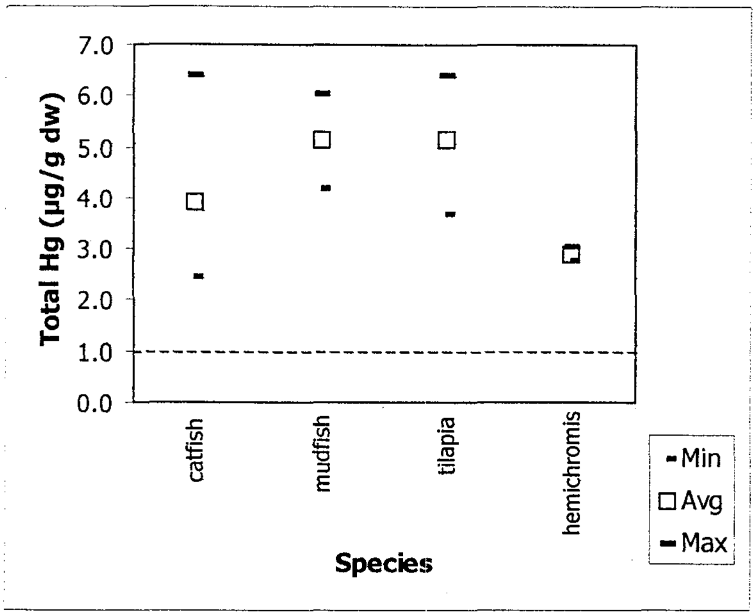


**Figure 5 - Mercury concentrations in different fish species**
(the dotted line corresponds to US-FDA action level)

Many authors have shown consistent differences in mercury bioaccumulation in fishes according to their feeding behaviour (**13, 19, 40**): carnivorous species usually show higher mercury level than other species. In the current dataset, *Hemichromis* spp. and 'mudfishes' (*Parachanna obscura*) are carnivorous; 'true' tilapia (*Tilapia guineensis*) eats macrophytes, while 'catfishes' (*Heterobranchus* spp.) are omnivorous. No obvious difference can be observed in the dataset (Figure 5 ), but the sample size is small, and there are probably confounding variables like fish age.

The typical food ration is unknown to us neither for Dumasi population, nor in Ghana; so, instead of assessing the risk associated to food, we only calculated the quantity of each type of food necessary to obtain the ADI of about 43 µg (recalculated from a weekly intake of 300 µg of total mercury, according to (**42**). According to our data, this amount is obtained either with about 45 g of fish or cocoyam, or 240 g of chicken, or 300 g of plantain. Provided that a more representative assessment would confirm these data, this clearly shows that there is a risk to human health in Dumasi population.

### 3.5.3 Summary of findings

- *Mercury in drinking water remains at a level far lower than the WHO standard; there is no evidence of groundwater contamination, even in shallow groundwaters close to sumps.*
- *Sediments are significantly contaminated, even though less than heavily polluted areas in other parts of the world. They are certainly transported far downstream, and can reach coastal areas. Thus, some mercury was found in Aby lagoon (Ivory Coast) at similar levels as those observed in Dumasi.*
- *Fishes are also significantly contaminated; the concentrations range is comparable to those observed in other gold mining areas. On average, the consumption of only 45 g of Dumasi fish per day is sufficient to exceed WHO's weekly tolerance of 300 µg.*
- *Vegetables show generally low concentrations of mercury, except cocoyam; however, the weekly mercury intake could exceed the acceptable level set by WHO/FAO expert committee for several vegetables. A more complete food survey seems necessary, and should include typical food sources like corn, cocoyam, plantain; mercury distribution in the plants should also be assessed, as leaves are used in cooking .*
- *All environmental media in the village show a somewhat diffuse contamination.*
- *According to the kind of ore processed in the village, the exposure to mercury might probably be higher in other parts of the country.*

- *Spots probably exist, but they cannot be easily identified, as places for gold extraction are rather evolutive. So no proposal for remediation can be done.*

# 4 Design of a monitoring program for water quality assessment

This study of the contamination of the environment by mercury in Dumasi should be viewed as a preliminary study. It allowed to identify the most relevant approaches for a broader assessment of the situation in the auriferous area, and a continuous monitoring process, as recommended by the UNIDO (see § 1).

Monitoring may be viewed as a cycle (Figure 6, from ref. **43**); this representation underlines the fact that all elementary steps of a monitoring process are linked to the others, in a logical way. The starting point of the cycle is the definition of information needs, but nearly all the steps have to be reviewed at the design stage of any monitoring process, before going to the field and collecting samples.

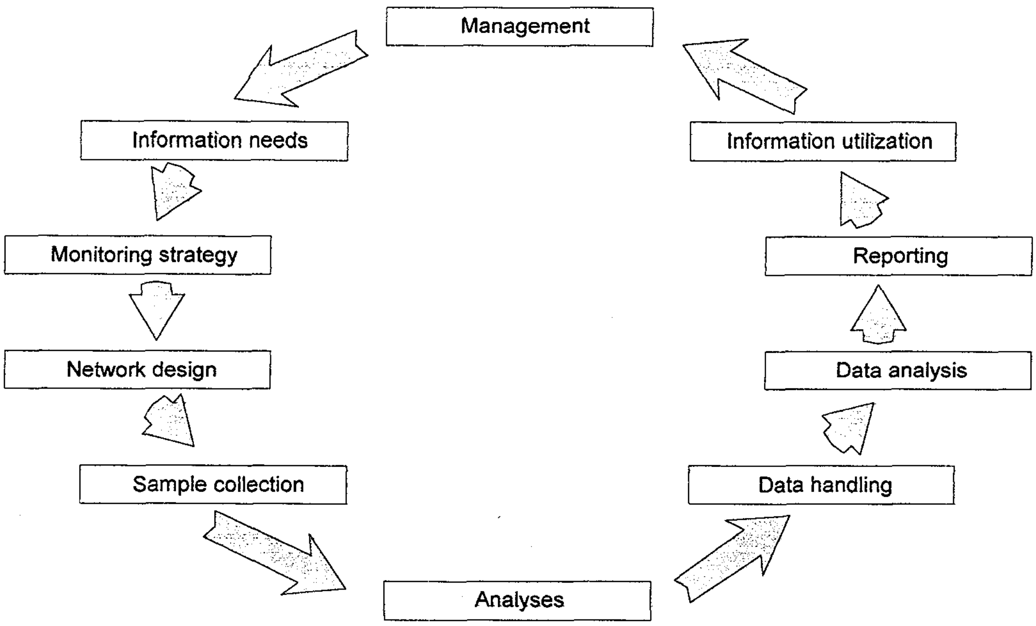


**Figure 6 - Monitoring cycle**

## *4.1 Information needs (objectives)*

Comparing the results obtained in Dumasi samples (e.g. sediments) with published data, it might be concluded that mercury environmental impacts are rather limited. Consequently, human health impacts might also be considered as weak, as it was confirmed by the human health survey (see part 1 of this report). However, are these conclusions valid at a broader scale, and to what extent ? Accordingly, are there geographic and demographic characteristics which could explain the mercury contamination in the region ?

These questions appear critical, because possible responses will justify various strategic choices for Ghanaian authorities. Therefore, relevant objectives for a monitoring process could be:

1. Extend the current evaluation to the whole auriferous area, in order to understand the contamination pattern, and to allow to assess the risks to human health and the environment.
2. Detect trends.

The first objective is related to a better spatial coverage of the mercury issue, while the second one will allow either to show the effects of a preventive policy, if any, or simply show the trends.

## *4.2 Strategy*

*Galamseys'* activities are strongly related to water; therefore, focus should be put on aquatic media, i.e. sediments or fishes. This choice is consistent with the available scientific literature, as most of the papers found and quoted in the present report rely on sediment or fish sampling. Accordingly, total mercury measurements seem appropriate at least for fish, as methyl-mercury represents 90-100 % of total Hg in these organisms (**11**). Methyl-mercury to total mercury ratios in sediments may be more variable (**26,44**); however, sediment methyl-mercury content has limited relevance by itself in the perspective of a risk assessment. Considering that sediment analyses will first allow to identify areas with important mercury inputs to rivers, total mercury analysis in sediments can represent a good compromise. However, as there is apparently no consistent relationship between mercury concentrations in water, sediment and biota (**19**), it will be essential to refine the assessment obtained from sediments with fish monitoring.

Sediment and fish sampling and analysis have different advantages and present different kinds of operational difficulties, which are summarised in Table 15.

| **Criteria** | **Sediment** | **Fish** |
|---|---|---|
| Sample collection | **Relatively easy** (depends on river depth and width) | **Uneasy and uncertain** (fishes are mobile, and must be caught by electrofishing or by fishermen) |
| Handling, processing | **Relatively easy** (conservation at 4°C) | **Difficult** : ideally, samples should be processed and frozen in the field. |
| Analysis | **Difficult** (due to mercury volatility) | **Very difficult** (basically same process than for sediments, but some steps are more tricky) |
| Dosage limit | | |
| Relevance<br>(a) according to the current knowledge | **good** | **high** |
| (b) sensitivity to possible policies | **Uncertain**, depends on the age of the deposit collected, currently not measurable | **Relatively good** (if fishes are analysed separately, and young can be discriminated from older specimens) |

**Table 15 – Comparison of sediment and fish sampling**

According to these elements, it appears clearly that sediment sampling, handling and analysis would be easier, more efficient, in the sense that there would be less uncertain to collect sediments, and probably less expansive. However, the relevance of this approach appears less satisfactory, because the sensitivity to prevention or remediation policies remains uncertain or limited. This uncertainty could be reduced by datation of the deposits[k], through measurements of specific isotopes, but this technique relies upon very specific equipment not currently available, and is rather expansive.

Therefore, it seems reasonable to complete sediment analyses by a limited number of fish analyses, caught in some particularly interesting areas.

Aiming to characterise the contamination pattern, network design should allow to assess the different types of geologic and demographic conditions throughout the region, rather than simply distribute sampling stations on a geographic or hydrogaphic basis. This means that a premiminary step in the monitoring process should be to draw a map of galamseys activities under a GIS system, and match it with the hydrographic network.

If they are judiciously distributed, 25 to 30 sediment sampling stations and 5 sampling stations for fishes (including low and high contamination areas) may allow to achieve the first objective.

According to this first objective (*extend the current evaluation to the whole auriferous area*), a first campaign should occur within a year, e.g. during the low flow period. There is no real need to repeat the

[k] the sampling of surficial sediments aims to assess recent deposits and their pollution; but after a flood, recently deposited sediments have been eroded. Therefore, when sampling occurs within a short while after high flow, it is difficult to ascertain that the sampled sediments are really recent ones.

operation each year; the second objective (*detect trends*) may therefore be achieved by sampling campaigns occurring each three years[1].

These specifications are summarised in Table 16.

| Media | Nb of locations | Additionnal parameters |
|---|---|---|
| sediment | 25 | Grain size, organic carbon; other metals - Arsenic |
| fish | 10 | Species identification - Length, weight, lipid content, moisture |

**Table 16 - Monitoring program summary**

Sampling points selection will allow to monitor the different kinds of ores (rocks, alluvions) processed in Ghana; this implies to first draw a map of artisanal gold mining.

## *4.3 Sample collection*

### 4.3.1 Sediments

Sediment samples collection could be done by EPA field teams in the auriferous region, as a supplementary task of the "GERMP" monitorig program, in order to minimize sampling costs. The needed equipment is very simple, and consists in a shovel, a plastic bucket for mixing subsamples, and 1 L plastic containers. Samples should be stored at 4°C, or frozen, until the laboratory.

The cost estimate of such a sediment sampling program is 2000 US$ (team size 4 people, duration 5 days for 25 sampling points, distance 2000 km).

### 4.3.2 Fishes

Fish samples collection could be done by WRI, with assistance of local fishermen. These people should be paid for catching the fishes. Thus there is no need to hold and maintain an electro-fishing equipment, which is very expensive. The needed equipment just consists in plastic bags and ice boxes. Fish should be kept intact and stored frozen.

The cost estimate of such a sediment sampling program is 1500 US$ (team size 4 people, duration 4 days for 10 sampling points, distance 1600 km).

## *4.4 Analyses*

The analytical protocol will follow the same steps as those applied in the current study: first, a drying / digestion step with aqua regia, then vapor generation from the digested samples by reduction with tin chlorhydrate, purge by a gas carrier like Argon, and finally detection of elemental mercury by atomic fluorescence spectrometry. In order to ensure a good reliability, it is essential to include certified samples in each series. Also, sediment samples should be dried carefully at ≈ 20 °C, while fish samples should be freeze-dried.

According to a comparison on human samples analysis between a Ghanaian laboratory and UP, it was concluded that the current analytical skills in Ghana cannot warrant sufficient precision and accuracy of mercury analysis. Consequently, it should be done out of the country, by a laboratory operating under rigorous QA/QC conditions. This laboratory should be selected under the joined auspices of SMMO and EPA.

However, it must be acknowledged that this approach also generates various drawbacks, in terms of logistics, efficiency (loss of samples), possibly quality of the results (influence of conservation), and transport costs. The overall balance is at the moment clearly in favour of such an organisation, but on the long term disadvantages may exceed the current benefits. It is therefore essential to improve Ghanaian analytical skills within the proposed monitoring program, through a sub-program including parallel analyses of few samples and technical exchanges (and/or assistance), in order to identify the origins and reduce the discrepancies.

Annual analytical costs are estimated to be about 5000 US$ for sediments on the basis of 25 sampling points, icluding duplicate for interlaboratory comparison purposes, or ≥ 150 US$ per sampling point (without interlaboratory work). For fishes, the needed grant would be about 2000 US$. These

[1] Or sampling campaigns may be organised alternatively in 1 third of the area each year, or 1 main catchment, in order to complete the whole network in 3 years and distribute the costs over time.

estimations do not include technical assistance or training, which should be provided if an interlaboratory comparison be carried out. Transport costs to the laboratory are not included.

## 4.5 Data handling

In order to manage properly the monitoring data, and to make them available for assessing the achievement of assigned objectives, it would be absolutely necessary to implement a database. This could be done on the basis of a commercially available program, as it was done for the current study. The proposed structure of this database is included in Figure 7. The database is composed of 3 main tables (sampling stations, samples and results). This simple structure allows to reduce information redundancy. If necessary, the "results" table could be separated in 2 different tables, 1 for sediment data and 1 for fish, depending on the number of expected rows. That is, if only few fish samples are expected, it would be simpler to include the corresponding analytical results in the same tables as sediment data, provided respective samples are well identified.

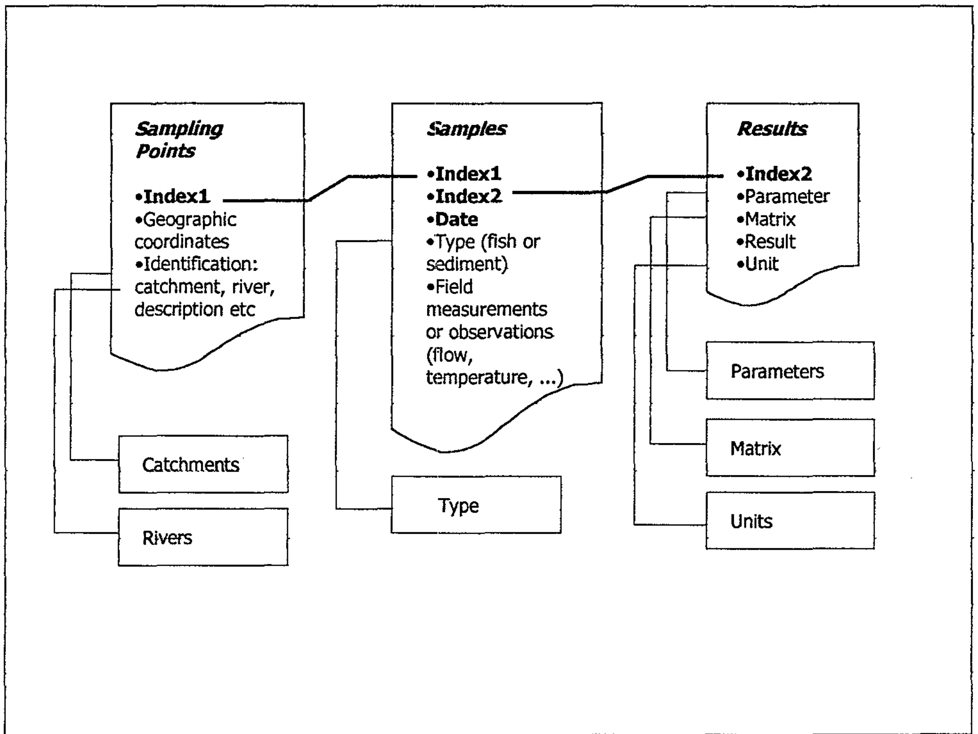


**Figure 7 - Simplified framework of the database**

It is not formally necessary to include a field "parameter" in the "results" table, as the monitoring program is proposed for mercury. However, this simple precaution seems useful, as it will allow to include data for other trace elements, or methyl-mercury, without changing the overall structure of the database. Thus, the database might become 'the' national sediment quality database.

This database should be managed by EPA.

## 4.6 Data analysis & reporting

Data analysis will rely upon similar criteria to those used in the current assessment: TEC and PEC for sediment contamination, WHO and/or US-FDA standards for fish. Reporting should be done through annual summaries, including a short description of the program, the obtained data, simple statistics and maps[m]. A trend analysis could be released every five years.

# 5 Overall Conclusions

This study provided a first outline of environmental exposure to mercury in Ghana's auriferous region; the findings can be summarised as follows:

*Environment*

- Mercury in drinking water remains at a level far lower than the WHO standard; there is no evidence of groundwater contamination, even in shallow groundwaters close to sumps.
- Sediments are significantly contaminated, even though less than heavily polluted areas in other parts of the world. They are certainly transported far downstream, and can reach coastal areas. Thus, some mercury was found in Aby lagoon (Ivory Coast) at similar levels as those observed in Dumasi.
- Fishes are also significantly contaminated; the concentrations range is comparable to those observed in other gold mining areas. On average, the consumption of only 45 g of Dumasi fish per day is sufficient to exceed WHO's weekly tolerance of 300 µg.
- Vegetables show generally low concentrations of mercury, except cocoyam; however, the weekly mercury intake could exceed the acceptable level set by WHO/FAO expert committee for several vegetables. A more complete food survey seems necessary, and should include typical food sources like corn, cocoyam, plantain; mercury distribution in the plants should also be assessed, as leaves are used in cooking .
- All environmental media in the village show a somewhat diffuse contamination.
- According to the kind of ore processed in the village, the exposure to mercury might probably be higher in other parts of the country.
- Spots probably exist, but they cannot be easily identified, as places for gold extraction are rather evolutive. So no proposal for remediation can be done.

*Human health*

The intermediate conclusions (part I, p. 19) are repeated above:

- There is a strong evidence of mercury exposure among Dumasi population;
- Galamseys are more exposed to mercury than non galamseys;
- Young illiterate galamseys show the strongest exposure (several indicators in class 3). People inhabiting the village for a long time are also among the most exposed people.
- Results are a bit confusing, as blood is the most discriminating indicator; following the literature, urine indicators should be more discriminant for people exposed mainly through their occupation. However, strong perspiration could perhaps explain this situation.
- Many non galamsey people, even less exposed than galamseys, show obviously mercury blood levels higher than reference values, meaning that there is also an exposure through the environment (food).
- Mercury blood levels in Dumasi are comparable to those in Mindanao (the Philippines), whereas urinary mercury is higher in the latter study; this shows that exposure through food is an important route in Dumasi.
- However, it seems difficult to extrapolate this conclusion to the whole Ghanaian auriferous area, as processes may greatly vary (e.g. in alluvium).

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[m] E.g. for sediment contamination, sampling points could be represented as coloured dots; 1 colour like green would correspond to concentrations lower than TEC, another colour like yellow would correspond to concentrations between TEC and PEC, and a third colour, e.g. red would correspond to points above PEC

- One important goal of the project's second phase should therefore be to reduce mercury transfers to the environment.
- Education is a dramatic issue in this context; young galamseys and women appear of particular concern for that issue.
- A second target should be the introduction of appropriate technology for mercury distillation, as it has been shown that galamseys were more exposed than other people.

# 6 Recommendations for the implementation of the program

It therefore appears that this work should now be completed, particularly on the following items:

- Impacts of artisanal gold mining in alluvium should be assessed too, as it could be more severe than in solid rocks like in Dumasi; this could be achieved either through a specific study, or through monitoring (see below). The choice of the sirtes to be studied should be driven by the small scale mining department.
- Continuous monitoring of the overall galamseys exposure could be done through the health infrastructure of Ghana. This program should be driven by the Ministry of Health.
- Some research should be carried out on mercury levels in vegetables, in particular cocoyam, plantain and corn, and on the transfers from soils to plants including the leaves. Some attention should also be paid to Arsenic, which is released to the environment in large quantities from mining in general.
- It would also be necessary to implement a monitoring program based on sediment analysis, and completed by fish analysis at sediment hot spots. This would allow to assess more accurately the risk to environment and human beings due to improper mercury use in artisanal gold mining, and later to discern trends. This program should be driven by EPA, with a support from WRI; analyses should be done out of the country at the beginning.
- In parallel, it would be essential to help the Ghanaian institutions in developing a reference analytical method and preparation protocols, through technical assistance. The PHD ongoing in Pau University with a Ghanaian student is a first step in this direction.
- A first essential step for implementing the monitoring program should be to draw a map of artisanal gold mining activities in Ghana.

- *Remediation, policy & coordination*
  - The introduction of retorts, as intended by UNIDO, should help to reduce the overall release of mercury; however, Dumasi is perhaps not the most appropriate place for a pilot operation with retorts or other means for decreasing mercury releases, as exposure to mercury could be less pronounced than in alluvium areas, and because the village could be translocated, following BGL extension.
  - SMMO will assume in Ghana the leadership of this UNIDO project; as this project is interdisciplinary and includes many different aspects, SMMO will constitute a task force including EPA, and MoH representatives. This task force will supervise the project, plan the operation, and control their achievement.

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# ANNEXE

# Model of the Questionnaire

ID Number: ____________________

# UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

## Small-scale gold mining and mineral processing in Mindanao/Philippines

UNIDO

## Questionnaire and Examination

# 1 Personal Data

ID Number: ____________________

## 1.1 Participant

**1.1.1 Surname** ..............................................................................................

**1.1.2 First Name** ..............................................................................................

**1.1.3 Date of Birth** ........................................Age:..........................................

**1.1.4 Sex:**

☐ Male ☐ Female

**1.1.5 Address** ..............................................................................................

..............................................................................................

..............................................................................................

## 1.2 Interviewer

**1.2.1 Date of interview:**..............................................................................................

**1.2.2 Name of the interviewer:**..............................................................................................

# 2 General Questionnaire

## 2.1 Habitat

**2.1.1 How long do you live in this area?** _______ year(s)

**2.1.2 In which distance do you live from the next mineral processing plant?** _______ km

**2.1.3 In which distance do you live from the next gold melting shop?** ________ km

## 2.2 Work Exposure

**2.2.1 Occupation (Detailed description of the job)**

..............................................................................................

..............................................................................................

..............................................................................................

**2.2.2 Do you work in a gold plant or mineral processing plant?**

☐ Yes

If yes: Since how many years? ..............................................................

Name of the plant? ..............................................................................

ID Number: ____________________

*The following questions only have to be answered, if you work in gold plant or mineral processing plant (2.2.3 - 2.2.10)*

### 2.2.3 Do you work with mercury or with mercury polluted tailings?

☐ Yes
☐ No
☐ Uncertain

### 2.2.4 How many times do you burn amalgam in the open (for example in pans)?

☐ At least once a day
☐ At least once a week
☐ At least once a month
☐ Never

### 2.2.5 How many times do you melt gold in the open or with inadequate fume hoods?

☐ At least once a day
☐ At least once a week
☐ At least once a month
☐ Never

### 2.2.6 How do you handle mercury?

☐ Filling mercury into ball or rod mills and emptying the mills after the operation
☐ Separating the amalgam from excess mercury by a washing operation
☐ Squeezing the amalgam through a cloth
☐ Carrying bags filled with tailings
☐ Opening or emptying bags with tailings

### 2.2.7 How many times do you handle mercury in the above mentioned way?

☐ At least once a day
☐ At least once a week
☐ At least once a month
☐ Never

### 2.2.8 Do you store mercury containers or flasks?

☐ At home
☐ At work
☐ Never

### 2.2.9 Do you return with dirty working clothes to your home?

☐ Yes
☐ No

### 2.2.10 Do you keep work clothes at home?

☐ Yes
☐ No

## 2.3 Diet Issues

### 2.3.1 How frequently do you eat fish?

☐ At least once a day
☐ At least once a week
☐ At least once a month
☐ Never

ID Number: ____________________

### 2.3.2 Name the fish most consumed:

..................................................................................................................

### 2.3.3 Carnivorous fish

- ☐ Yes
- ☐ No
- ☐ Uncertain

### 2.3.4 Does the fish consumed by you come from dark water rivers?

- ☐ Yes
- ☐ No
- ☐ Uncertain
- ☐ Unknown

### 2.3.5 Do you consume from local production:

| | | | |
|---|---|---|---|
| Chicken, ducks or eggs? | ☐ Never | ☐ Occasionally | ☐ Often |
| Meat (beef etc.)? | ☐ Never | ☐ Occasionally | ☐ Often |
| Vegetables, Fruits | ☐ Never | ☐ Occasionally | ☐ Often |
| Milk or milk products | ☐ Never | ☐ Occasionally | ☐ Often |

## 2.4 Health Problems

### 2.4.1 Did you ever have malaria?

- ☐ Yes
  - ☐ within the last year?
  - ☐ earlier?
- ☐ No

### 2.4.2 Did you have any serious accidents (did you have to go to hospital)?

- ☐ No
- ☐ Yes

If yes: ..................................................................................................................

### 2.4.3 Did you ever have any major acute or chronic health problems in the past?

| | | | | |
|---|---|---|---|---|
| Kidney diseases | ☐ | Yes | ☐ | No |
| Skin problems (allergies, loss of hair, eczema's) | ☐ | Yes | ☐ | No |
| Problems to get pregnant, become a father (fertility) | ☐ | Yes | ☐ | No |
| Respiratory problems (asthma, pneumonia) | ☐ | Yes | ☐ | No |
| Hepatic disorders (hepatitis) | ☐ | Yes | ☐ | No |
| Major infections, like tuberculosis | ☐ | Yes | ☐ | No |
| Neurological disorders (epilepsy, Parkinson etc.) | ☐ | Yes | ☐ | No |
| Any mental/ nervous disorders? | ☐ | Yes | ☐ | No |
| Other diseases | ☐ | Yes | ☐ | No |

If yes: ..................................................................................................

### 2.4.4 Are you healthy now?

- ☐ Yes
- ☐ No

If no: Which health problems do you have?

..................................................................................................

..................................................................................................

..................................................................................................

### 2.4.5 Has the actual or former health problem worsened since exposure to mercury occurred?

- ☐ Yes
- ☐ No
- ☐ Uncertain
- ☐ No mercury exposure

ID Number: ____________________

### 2.4.6 Do you smoke?

- ☐ Lots (more then 20 cigarettes per day)
- ☐ Medium (10-20 cigarettes per day)
- ☐ Rarely (0-10 cigarettes per day)
- ☐ Never

### 2.4.7 Do you drink alcohol?

- ☐ At least once a day
- ☐ At least once a week
- ☐ At least once a month
- ☐ Never

Added question: 1/2/3 bottles of beer (1/3 l) per day/week or 1/2/3 glasses of tuba-tuba or hard drink

### 2.4.8 Do you have a kind of a metallic taste

- ☐ At least once a day
- ☐ At least once a week
- ☐ At least once a month
- ☐ Never

### 2.4.9 Do you suffer from excessive salivation

- ☐ At least once a day
- ☐ At least once a week
- ☐ At least once a month
- ☐ Never

### 2.4.10 Do you have any problems with tremor (shaking ?) at work?

*(modified Clinical tremor Rating Scale)*

- ☐ 0 I have no tremor or tremor does not interfere with my job
- ☐ 1 I am able to do everything, but with errors; poorer than usual performance because of tremor
- ☐ 2 I am unable to do any outside job; housework very limited

### 2.4.11 Do you have any problems with sleeping at night?

*How do you feel after a usual night of sleep? Which is the most appropriate smiley for you ?*

- ☐ 0 ☺
- ☐ 1 😐
- ☐ 2 ☹

# 3 Only for females: (3.1.- 3.2.)

## 3.1 Pregnancy

### 3.1.1 How many pregnancies did you have? _____

### 3.1.2 How many miscarriages or still-births did you have? _____

## 3.2 Children

### 3.2.1 How many children were born alive? _____

### 3.2.2 How many own children do you have? _____

ID Number: ____________________

### 3.2.3 How many children died in the meantime? _____

### 3.2.4 In which age? Cause of death (if known)?

..........................................................................................................
..........................................................................................................

### 3.2.5 Do you have any children with birth defects?

☐ Yes
☐ No

**Which birth defects?**

..........................................................................................................
..........................................................................................................

# 4 Clinical Examination

## 4.1 Weight and Height

### 4.1.1 Weight: ______ Kg

### 4.1.2 Height: ______ m

## 4.2 Mouth and Teeth:

### 4.2.1 Clinical signs of stomatitis

☐ No
☐ Yes

### 4.2.2 Clinical signs of gingivitis

☐ Yes
☐ No

**Added: signs of bluish discolouration of gums**

☐ Yes, strong
☐ Slight
☐ No

### 4.2.3 How many teeth with dental fillings (Amalgam)?

☐ None
☐ One or more → how many _______

## 4.3 Skin in children:

### 4.3.1 Clinical signs?

*(acrodynie, eczema's, dermographismus)*

☐ Yes
..........................................................................................................
..........................................................................................................
..........................................................................................................
☐ No

# 5 Neurological Examination:

## 5.1 Examiner

ID Number: ____________________

## 5.1.1 Date of examination:..........................................................................................

## 5.1.2 Name of the examiner:.....................................................................................

# 5.2 Walking

## 5.2.1 Rigidity of gait (walking)

*Person is asked to walk into the examining room.*
*Examiner is watching the swing of the arms, general posture and rates (modified Simpson Angus Score)*

- ☐ 0 Normal
- ☐ 1 Obvious diminution in swing suggesting shoulder rigidity
- ☐ 2 Rigid gait with arms slightly pronated

## 5.2.2 Ataxia of gait (walking)

*Examiner is watching for signs of ataxia (modified Klockgether Score)*

- ☐ 0 Absent
- ☐ 1 Moderate (ataxia visible in normal walking)
- ☐ 2 Severe (unable to walk without support; wheelchair bound)

# 5.3 Standing

## 5.3.1 Ataxia of posture (stance, standing position)

*Person is asked to stand still (modified Klockgether Score )*

- ☐ 0 Absent
- ☐ 1 Moderate (moderate swaying; still able to stance with feet together)
- ☐ 2 Severe (unable to stand without support)

## 5.3.2 Tremor with posture holding

*Person is asked to stand still – arms outstrechted, wrist mildly extended, fingers spread apart. Examiner is watching the arms and rates the tremor (modified Clinical Tremor Rating Scale)*

- ☐ 0 None
- ☐ 1 Moderate (amplitude 0,5-1,0 cm); may be intermittent
- ☐ 2 Severe amplitude (> 2 cm)

## 5.3.3 Tremor with posture holding – Romberg

*Person is asked to stand still, legs together– arms outstrechted, wrist mildly extended, fingers spread apart, eyes closed. Examiner is watching the arms and rates the tremor for above 30 sec. (modified Clinical Tremor Rating Scale)*

- ☐ 0 None
- ☐ 1 Moderate (amplitude 0,5-1,0 cm); may be intermittent
- ☐ 2 Severe amplitude (> 2 cm)

## 5.3.4 Tremor – finger to nose

*Person is asked to stand still, legs together– arms outstretched. Eyes closed. Finger tip should touch the nose. Examine watching and rates the* ***tremor*** *(modified Clinical Tremor Rating Scale)*

- ☐ 0 None
- ☐ 1 Moderate (amplitude 0,5-1,0 cm); may be intermittent
- ☐ 2 Severe amplitude (> 2 cm)

## 5.3.5 Tremor – finger to nose

*Person is asked to stand still, legs together– arms outstretched. Eyes closed. Finger tip should touch the nose. Examine watching and rates the* ***co-ordination***

- ☐ 0 Normal
- ☐ 1 Moderate pathologic
- ☐ 2 Severe pathologic

## 5.3.6 Dysdiadochokinesis

*Person is asked to twist hands very quickly (alternating movements of the wrists (modified Klockgether Score)*

- ☐ 0 Absent
- ☐ 1 Moderate (marked slowness of alternating movements)
- ☐ 2 Severe (severe irregularity of alternating movements)

ID Number: ____________________

## 5.4 Sitting

### 5.4.1 Tremor of the tongue

*Person is asked to sit on a chair. Person is asked to open the mouth and stretch out the tongue. Eyes closed. Rate tremor of the tongue (modified Clinical Tremor Rating Scale).*

- ☐ 0 None
- ☐ 1 Moderate (amplitude 0,5-1,0 cm); may be intermittent
- ☐ 2 Severe amplitude (> 2 cm)

### 5.4.2 Salivation

*Person is observed while talking and then asked to open his mouth and elevate his tongue*

- ☐ 0 Normal
- ☐ 1 Moderate excess salivation
- ☐ 2 Severe excess salivation

### 5.4.3 Dysathria

*Rate disturbances of spontaneous speech (modified Klockgether Score)*

- ☐ 0 Absent
- ☐ 1 Moderate (moderate disturbances)
- ☐ 2 Severe (considerable difficulties in understanding)

### 5.4.4 Pouring

*Two firm plastic cups (8 cm tall); one filled with water to 1 cm from the top, the other one empty. Please pour water from or cup to the other. Rate tremor (modified Clinical Tremor Rating Scale).*

- ☐ 0 None
- ☐ 1 Moderate (amplitude 0,5-1,0 cm); may be intermittent
- ☐ 2 Severe amplitude (> 2 cm)

### 5.4.5 Field of vision

*Person is asked to follow the light of the examiners lamp. Rate field of vision*

- ☐ 0 Normal
- ☐ 1 Pathologic

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### 5.4.6 Nystagmus

*Person is asked to follow the light of the examiners lamp. Rate nystagmus*

- ☐ 0 No nystagmus
- ☐ 1 Pathologic

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## 5.5 Lying

### 5.5.1 Lower limb ataxia (heel-to-knee test)

*Person is asked to lie on the examination bench. Person is asked to touch with his heel the knee of the other leg. Eyes closed. Rate ataxia (modified Klockgether Score)*

- ☐ 0 Absent
- ☐ 1 Moderate (hypermetria and slight ataxic performance of heel-to-knee test)
- ☐ 2 Severe (pronounced ataxia in performing heel-to-knee test)

### 5.5.2 Intention tremor

*Rate tremor during heel-to-knee test (modified Klockgether Score)*

- ☐ 0 Absent
- ☐ 1 Moderate (marked terminal tremor)
- ☐ 2 Severe (severe kinetic tremor heavily interfering with everyday life)

## 5.6 Reflex status

### 5.6.1 PSR (quadrizeps reflex)

*Test tendon and cutaneous reflexes. If there is any difference of the reflexes between right and left sight, please note it.*

- ☐ 2 No reflex

ID Number: ____________________

| | | |
|---|---|---|
| ☐ | 1 | Hyporeflexia |
| ☐ | 0 | Normal |
| ☐ | 1 | Slight hyperreflexia |
| ☐ | 2 | Very brisk or reflex zone enlarged or clonus |

### 5.6.2 BSR (bizeps brachii reflex)

| | | |
|---|---|---|
| ☐ | 2 | No reflex |
| ☐ | 1 | Hyporeflexia |
| ☐ | 0 | Normal |
| ☐ | 1 | Slight hyperreflexia |
| ☐ | 2 | Very brisk or reflex zone enlarged or clonus |

### 5.6.3 Babinski reflex

| | | |
|---|---|---|
| ☐ | 0 | Negative |
| ☐ | 1 | Positive |

### 5.6.4 Sucking reflex

| | | |
|---|---|---|
| ☐ | 0 | Negative |
| ☐ | 1 | Positive |

## 5.7 Sensory examination

| | Upper extremity | | | Lower extremity | | |
|---|---|---|---|---|---|---|
| **Brush** | ☐ | 0 | + | ☐ | 0 | + |
| | ☐ | 1 | - | ☐ | 1 | - |
| **Blunt** | ☐ | 0 | + | ☐ | 0 | + |
| | ☐ | 1 | - | ☐ | 1 | - |
| **Joint Position** | ☐ | 0 | + | ☐ | 0 | + |
| | ☐ | 1 | - | ☐ | 1 | - |

*Test sensitivity clinically. If there is any difference between right and left sight, please note it*

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# 6 Specific Tests

### 6.1.1 Memory disturbances: Digit span test (Part of Wechsler Memory Scale)

*Please repeat each column of numbers*

| | Score | Test |
|---|---|---|
| ☐ | 4 | 6-4-3-9 |
| ☐ | 4 | 7-2-8-6 |
| ☐ | 3 | 4-2-7-3-1 |
| ☐ | 3 | 7-5-8-3-6 |
| ☐ | 2 | 6-1-9-4-7-3 |
| ☐ | 2 | 3-9-2-4-8-7 |
| ☐ | 1 | 5-9-1-7-4-2-3 |
| ☐ | 1 | 4-1-7-9-3-8-6 |
| ☐ | 0 | 5-8-1-9-2-6-4-7 |
| ☐ | 0 | 3-8-2-9-5-1-7-4 |

# 7 Specimens

## 7.1 Blood (Hepar.-Lith.-blood 4 ml x 2)

☐ Yes
☐ No

## 7.2 Urine (spontaneous urine sample 50 ml,if it is possibble)

☐ Yes
☐ No

## 7.3 Hair

☐ Yes
☐ No

## 7.4 Nails

☐ Yes
☐ No



I hereby declare that I want to take part in the UNIDO study. I will be questioned about my living circumstances and health problems related to mercury. I will be medically examined including neurological examination. Blood, urine and a small amount of hair nail will be taken.
If I have any questions about the study, I can ask Dr Sackey at any time . The assessment is done respecting the "Recommendation for Conduct of Clinical Research" (WHO Declaration of Helsinki).

______________________________________________

Signature/ Right Thumb print , in case of children signature of parents/guardian