UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

PROJECT DOCUMENT

Country:	Ghana
Number:	xx/GHA/99/xxx
Title:	Assistance in Assessing and Reducing Mercury Pollution Emanating from Artisanal Gold Mining in Ghana - Phase I
Planned duration:	12 months
Project site:	Artisanal gold mining and processing sites in the vicinity of the village Dumasi (Bogoso area)/Western Region
Total UNIDO budget: (excl. support cost)	US$ 211,504
Total UNIDO budget: (incl. support cost)	US$ 239,000
Counterpart Agency:	Minerals Commission - Small Scale Mining Unit, Environmental Protection Agency
Estimated starting date:	October 1999
Government inputs:	
(in kind):	
(in cash):	

Brief description

The lack of appropriate technology and proper health and safety procedures in the informal gold mining sector in Ghana have led to severe environmental degradation and mercury pollution of river systems and adjacent agricultural sites. In some areas, public health might be endangered because of mercury pollution. Due to a lack of trained personnel and equipment, the extent of the pollution has not yet been assessed. The project is planned to monitor mercury levels in a selected small scale mining community through analyses of surface waters, sediments, soils and human specimens, such as hair, blood and urine. Based on the results proposals will be prepared and people be trained on introduction and promotion of technology which is more efficient in respect to gold recovery and that reduces substantially mercury emissions.

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EXECUTIVE SUMMARY

Mercury is one of the most toxic substances in the world causing significant damage to the environment and to the health of people who handle it. The adverse human and ecotoxical consequences of mercury contamination in terrestrial and aquatic systems have been recognized since the 1950's, when the Minamata poisoning episode in Japan (arising from human exposure to methyl mercury in fish) triggered a tightening of legislative controls on mercury discharges across Europe, North America and parts of South-East Asia.

Mercury amalgamation, a virtually ubiquitous method of gold recovery with particular applicability for the beneficiation of alluvial or free gold, typically requires the use of 2 to 5 tons of mercury per ton of gold recovered. With gold production of small-scale miners worldwide currently of the order of hundreds of tons per year, the mobilization of mercury through such activities now require a first-order control on global scale. Mercury is absorbed by the human organism through drinking water, food or breathed air.

Artisanal and small scale gold mining activities (AGM) are widely practiced in the in the western, central and northern part of Ghana. According to official figures AGM employs an 100,000 people in the country. The number of people directly or indirectly benefiting from this activity through the extended family system and the multiplier effect can be as high as 1,000,000. A great part of the miners are women.

As an activity requiring modest investment and little technical knowledge, AGM is attracting people in growing number, especially in the following areas: Bibiani, Dunkwa, Asankragwa, Assin Fosu, Bolgantanga. Akim Oda, Tarkwa. Small-scale gold mining sites are in the vicinity of rivers draining to the Gulf of Guinea. For every gram of gold recovered, a significant amount of mercury is released into the environment - leaving behind a permanently ruined habitat and often resulting in sickness and even death of men, women and children. The relevant simplicity and effectiveness of the technology, known as amalgamation, mask its dangers. This process can be improved with procedures using inexpensive and highly efficient devices which can be manufactured locally at low cost.

The main objectives of the UNIDO assistance in Phase I of the project are:

- To monitor mercury levels in humans in the selected small scale mining community.

- To conduct a study on the extent of mercury pollution of the surrounding environment, especially of surface water, river sediments, soil, fish, vegetables and fruits.

- To improve human safety through training in new methods for more efficient gravity separation and mercury recycling.

- To train 50 representatives of local offices of the Small-Scale Mining Project (Minerals Commission) in environmental management of small-scale gold mining operations.

Based on the experience gained in UNIDO, approximately US$ 239,000 (incl. support costs) are required for the implementation of the project in Ghana.

PART A: CONTEXT

1. Description of the sub-sector

Since antiquity, the country has been one of the most important gold producers in Africa. Phoenicians and Carthagians may have sailed to West Africa as early as in the 5th or 6th century B.C. By 1000 A.D gold was transported overland to North Africa and then to Europe. Portuguese trade started in the 15th century. By early in the 18th century regular gold shipments to Europe were made from sources in the Ashanti Region which is still the main gold producing area in West Africa. With a today's gold production of approximately 50 tons, the country is Africa's second largest gold producer after South Africa. Ten percent of this quantity originates from the artisanal mining sector.

Artisanal and small scale gold mining activities (AGM) are widely practiced in the in the western, central and northern part of the country. It is estimated that AGM employs between 100,000 and 1,000,000 people in Ghana. The number of people directly or indirectly benefiting from this activity through the extended family system and the multiplier effect can exceeds by far 1,000,000.

As an activity requiring modest investment and little technical knowledge, AGM is attracting people in growing number, especially in the the following areas: Bibiani, Dunkwa, Asankragwa, Assin Fosu, Bolgantanga. Akim Oda, Tarkwa. Small-scale gold mining sites are in the vicinity of rivers draining to the Gulf of Guinea. There are 4 types of resources in Ghana on which small scale miners are working on:

- alluvial;
- hard rock surface;
- hard rock underground;
- tailings from old workings.

During a UNIDO Mission in April/May 1999, mining and mineral processing of alluvial deposits were visited at different places in the Western and Ashanti Region, where operations are characterized by a very low level of mechanization. Methods employed by the small-scale miners include panning, pitting, sluicing and washing to concentrate the ore. The overall gold recovery is estimated to be less than 50 percent.

Excavation of alluvials is done by digging with spades into a depth of 2 m. The loosened material is then transported by women to adjacent water-filled pits where it is pulped and bucketed into the heads of sluice boxes covered with tissues of jute bags. The material caught on the sacks is removed into a bowl of clean water several times a day to separate the concentrate. The miners amalgamate this material with their bare hands by rubbing fresh mercury into the gold bearing material. The resulting amalgam is heated on a spade in an open charcoal fire to vaporize the mercury. The way of handling the amalgam and expelling the mercury shows that people are not aware of the dangers involved in their exposure to the toxic vapor. Exposure of miners occurs through both liquid elemental and gaseous mercury during the vaporizing process and when checking on the progress of the burning-off.

A teaspoon of mercury (approx. 8 g) costs in the field up to 2 US$. For each gram of gold produced, up to two grams of mercury escape into the environment. Since all the artisanal gold is reported to be produced through amalgamation, approximately 10 tons of mercury are likely to be released annually to the environment. The official figure for mercury sales to artisanal miners amount to 0.8 tons only.

Artisanal gold mining activities have led to enormous social and environmental problems emanating from poor gold mining and processing practices associated with amalgamation as the preferred method adopted by artisanal miners to process gold ore. The impact of amalgamation on the environment is twofold. A direct impact is caused by evaporating mercury into the air. A second serious impact is resulting from the mercury discharged to the environment with the residues (tailings) of mining operations. Both types of pollution define the extent of mercury losses.

When the whole ore is amalgamated, mercury losses can be as high as 2 to 5 times the amount of gold produced. When only concentrates are amalgamated, the main source of mercury emission is the burning of amalgam in open pans. This leads to a gold bullion which still has 2 to 5% residual mercury. When gold bullion is melted in gold shops, about 20 g of mercury vapor per kg of gold are released. Studies have shown that the main portion of mercury emitted by gold smelters is deposited near the emission source (i.e. within 1 km), contaminating the urban environment.

Artisanal miners in Ghana apply amalgamation to treat either the run of mine (ore) or concentrates produced by gravity concentration. When gravity concentrates are amalgamated, the mineral portion is separated from amalgam by panning, forming the amalgamation tailing which is usually dumped into the water streams forming "hot spots". Panning takes place either in water boxes, pools excavated in the ground or at creek margins. Excess mercury from amalgams is removed by filtration using a piece of fabric to squeeze by hand. The amalgam obtained, usually with 60% gold content is retorted or simply burnt in pans. Mercury entering the atmosphere can represent as much as 50% of that introduced into the amalgamation process when retorts are not used. However, when amalgamation is conducted properly and retorts are used, far less mercury is lost to the environment (0.05% only).

Part of the mercury emitted by gold miners may be transformed into methyl mercury to be bioaccumulated in the aquatic environment. The high content of organic acids in sediments and waters favors oxidation of metallic mercury dumped by miners into the water streams or precipitated from the atmosphere. Soluble Hg-organic complexes are transformed into methyl mercury and quickly taken up by aquatic biota.

Riparian communities living adjacent to mercury contaminated areas and who have fish as main diet are expected to show high levels of mercury in the blood. Women and children, are the main victims of the lack of information and appreciation about the danger of this pollutant. The future generations will inherit the legacy to cope with this level of pollution. Education is a pre-requisite for a long-term solution of the mercury emission problem. Technical solutions must be rapidly provided to avoid a future epidemic situation.

2. Government strategy to regulate small-scale gold mining operations and to abate pollution

Role of Minerals Commission

Small scale gold mining was legalized in May 1989 with the enactment of PNDC Law 218. In order to manage the problems related to the regularization policy, the Small Scale Mining (SSM) Unit of the Minerals Commission (acting as counterpart in the UNIDO project) was created. The Minerals Commission was charged with the responsibility to implement the regularization policy. The immediate objective was to bring the operations of all illegal miners into the mainstream of economy. This was to ensure that the gold produced by the artisans remained in the country. For this purpose a liberal licencing, purchasing and tax incentive scheme was introduced. In addition 7 centres for small scale miners were established and adequately staffed and equipped a four-wheel drive car, motor bike, office equipment, including computer and fax.

The SSM unit was established to emphasize that small scale mining activities shall be conducted in a manner that it is both pro-people and pro-environment in sustaining wealth creation and an improved quality of life.

Role of Environmental Protection Agency

The Environmental Protection Agency (EPA) was formally established on 30 December 1994 (Act 490) and given the responsibility of regulating the environment and ensuring the implementation of Government policies on the environment.

The Environmental Protection Agency (EPA) seeks to become an Agency dedicated to continuously improving and conserving the country's environment, in particular.

EPA is an Agency recognized for:

- Leadership in environmental protection and the conservation of natural resources.
- Working in effective partnership with all stakeholders and catalyzing change to make environmental protection and sustainable development commonly held values.
- Applying the legal processes in a fair, equitable and efficient manner to ensure responsible environmental behavior in the country.

The objective of EPA is to co-manage, protect and enhance the country's environment, as well as seek common solutions to global environment problems.

3. Related technical assistance projects

Recent investigations on the extent of metal pollution caused by the **industrial gold mining sector** have been carried out by the University of Montpellier/France in collaboration with Ghanaian institutions. The project involves cooperation between University of Montpellier with Ghanaian academic institutions, such as University of Science and Technology, University of Cape Coast, as well as governmental bodies, such as Environmental Protection Agency, Water Research Institute, Ministry of Health, Ministry of Works and Housing. Pollutants under scrutiny are arsenic, lead, selenium, copper, zinc and mercury. Since industrial mining activities pursued in Ghana might cause transboundary pollution in Côte d'Ivoire through river Tano forming a lagoon between Côte d'Ivoire and Ghana, cooperation has started with Ivorian academic institution, too.

The investigations conducted so far have been financed by the French Government with approximately US$100,000.

4. Institutional framework for the sub-sector

The small scale gold mining sub-sector is governed and controlled by the Small Scale Mining Unit (SSM) of Minerals Commission having 7 offices throughout the gold belt. Regarding mercury, SSM tries to discourage its utilization to the extent possible. One way of doing that, is to impose a high rate of duty on mercury. However, SSM refrain from banning it totally, since prohibition would divert the scarce resources by creating a black market. The policy is that mercury should be freely available through licences of authorized dealers by Mines Department. High cost but freely available mercury is thought to reduce waste and make recycling and conservation of the toxic metal attractive for the miners. SSM wants to introduce amalgam retorts as a mandatory tool for the artisans.

EPA as a regulatory body will take over the environmental stewardship of the UNIDO project. The Agency has five main division including one department for mining. The main objectives of this department are:

- Minimization of the potential negative impacts if mining and other industrial developments through such control measures as regulation (standards etc.) on industrial discharges, monitoring of pollution and compliance with commitments made in Environmental Impact Statements (EISs) and Environmental Management Plans (EMPs).
- Development of appropriate standards for emissions and discharges from all industry types and mining operations.

EPA will assist in creating awareness both within and outside the conventional industrial/mining setting through dissemination of information on the nature of operation of these establishments. Furthermore, EPA will advise on effective mechanism for monitoring the activities of small scale gold mining sector.

The UNIDO counterpart and Project owner will be the Small Scale Mining Unit of the Minerals Commission. (vide: Chapter 7 ***'Coordination arrangements'***).

PART B: PROJECT JUSTIFICATION

The gold rush in Ghana which had started some decades ago has involved hundred thousands of people who became artisanal miners to escape complete social marginalization. Their activities have caused a disastrous environmental impact through pollution of their habitat with mercury.

The Government is prepared to move beyond the establishment of legal frameworks for protecting the environment, to assist small-scale miners in introduction of environmentally safe technology and has recognized the constructive possibilities of working closely with local and international organizations such as UNIDO, of expanding the scope for local participation including special attention to educational and gender issues and opportunities and of establishing technical support to the small-scale mining associations.

Government has greatly appreciated UNIDO's programme and efforts in combating mercury pollution on global scale.

1. Problems to be addressed; the present situation

Artisanal and small-scale gold mining is regarded by Government as an enormous environmental threat because of the extensive pollution being caused in different parts of the country. Until now only estimates can be made as regards the pollution emanating from small scale gold mining operations. This is true for the impact of mercury on the environment, but also on occupational and public health. The Project is intended to deliver reliable data on the extent of pollution in a selected small scale gold mining area. Besides the identification and assessment of the mercury problem, train-the-trainer courses will be held for introducing efficient technology that reduces mercury emissions to the environment and eliminating direct exposure to the toxic metal.

2. Expected end-of-project situation

Based on information obtained during the UNIDO mission in April/May 99 and discussions held with Government and various institutions and organizations, including scientists of University of Montpellier (*vide:* 3. Related Technical Assistance Projects), UNIDO proposes the following interventions to address the environmental problems:

- To monitor mercury levels in humans in the selected small scale mining community.
- To conduct a study on the extent of mercury pollution of the surrounding environment, especially of surface water, river sediments, soil, fish, vegetables and fruits.
- To improve human safety through training in new methods for more efficient gravity separation and mercury recycling.
- To train 50 representatives of local offices of the Small-Scale Mining Project (Minerals Commission) in environmental management of small-scale gold mining operations.

The results obtained in Phase I of the project will enable the Government to base all future decisions regarding the development of the small-scale gold mining sector on a scientific assessment of the environmental situation and on high-level technical advice. Moreover, the training in environmental management of key personnel from the local SSM Units will facilitate the introduction of sustainable technology.

3. Target beneficiaries

Target beneficiaries will be SSM and artisanal/small scale gold miners in the selected area exploiting gold in different operations and on different scale from alluvial and primary deposits.

The selected mining community will mainly benefit from training in occupational health issues related to mercury, environmental management, efficient mineral processing methods, and safe mercury recovery technology from amalgam.

4. Project strategy and institutional arrangements

The assessment of the environmental pollution of the most affected areas is considered both by Government and UNIDO as a prerequisite for any further assistance to the sub-sector. The extent of pollution must be fully assessed in the interest of health, and economic development of future rural generations.

Artisanal gold mining has resulted in alarming amounts of mercury lost to the environment. So far, attempts of the Minerals Commission and the EPA have failed in bringing solutions to stop or reduce mercury emissions and provide safe technologies to the miners due to a complex mix of socio-economic and technological problems. The UNIDO Project alerts the miners through educational measures and provide options for handling mercury and will train trainers in environmental management of small-scale mining sites. These measures reach the artisanal miners directly or through their associations. The UNIDO strategy is to convince miners that they are being affected by mercury vapors which cause irreversible health problems for their neighbors, friends and family members.

5. Reasons for assistance

UNIDO has recently established an Integrated Programme for Ghana in which “Mercury Pollution Abatement” forms only one component. When establishing this Integrated Programme it was found that the overall critical problem to be addressed is that Ghana's industrial development is currently not environmentally sustainable because there are few if any controls on the waste and pollution caused by industrial establishments and their products. Within this overall problem, the environmental component of the Integrated Programme is addressing the following specific problems:

- There is little awareness of cleaner production and the benefits it can bring.

- There is a lack of awareness of the hazards posed by mercury emissions from artisanal gold mining and therefore there is little national capacity to monitor and reduce such emissions.
- There is no properly functioning system in place for the management of hazardous industrial waste.

Role of UNIDO to Combat Mercury Pollution

In the international UNIDO Workshop on Ecologically Sustainable Gold Mining and Processing held in Jakarta/Indonesia in November 1995, participants recognized the necessity for provision of advice and technical assistance in order to avoid further mercury pollution. Participants of this Workshop fully endorsed UNIDO's High-Impact Programme entitled "Introducing New Technologies for Global Abatement of Mercury Pollution" and supported the following recommendations:

1. Gold mining on the small and artisanal level should make a valuable contribution to alleviate poverty in developing countries.

2. Since the environmental impacts of this increased activity are considerable, particularly from the widespread use of mercury, a long term strategy for remediation and for regularization of the sector should be developed.

3. The UN system, particularly UNIDO, must play an important role in assisting developing countries in engineering ecologically sustainable development. In the gold mining sector, UNIDO should increase its assistance to developing countries, including policy advice to government, the promotion of low cost, efficient and safer equipment and techniques and the encouragement of support by both miners and the public for solutions to the numerous environmental concerns. The participants endorsed the use of bilateral agreements between developing countries for cooperation in these areas.

4. Legal and financial constraints limit the evolution of the small scale gold mining sector into formal operations. Attention needs to be given to both legalizing this sector and to creating alternative finance assistance, including linkages with the formal sector, the use of development bank finance and appropriate taxation regimes.

5. UNIDO and other donor community agencies, in cooperation with the governments concerned, should continue and increase their support to developing countries, in particular to the least developed countries, for the development of an orderly and ecologically sustainable small scale gold mining sector. Such assistance should be directed at and made in conjunction with the needs of the miners working in the field.

6. Women play a major role in artisanal and small scale gold mining, and special efforts should be made to ensure that they benefit from any assistance given to this sector.

7. Because of the widespread use of child labor in the informal gold mining sector, the relevant governments and agencies should be urged to provide the resources needed to abolish this abuse.

Since the issue of damage caused to the environment and human health by mercury pollution due to artisanal gold mining is multifaceted and complex, education, communication of information and technology transfer can be considered as keys for improving the situation. For achieving this, UNIDO is well prepared and experienced in putting together cross-discipline programmes, covering environmental protection, introduction of new technologies and manufacturing, mineral beneficiation as well as integration of women in industry.

In the latter context, UNIDO will make a special effort to ensure that women participate equally in - and benefit equally from - the introduction of new equipment and processing techniques. UNIDO is also counting on women miners to be the most ardent advocates for the alternative technology because of their traditional care-giver roles.

6. Special considerations

Artisanal gold mining activities occur at several places in Ghana. Because of the impact of the sub-sector on environment and health, the project will be implemented at a place which is said to be very polluted. Access to the selected project site at Dumasi/Western Region is possible from an asphalt road connecting the villages Dominase and Mpoasen. The project area is suffering from poor living, work and safety conditions, pollution, unplanned development, social problems and poor resource utilization.

The Government through its EPA and Minerals Commission provides full support to the Project by enacting transparent legislation and incentives to promote the development of the small-scale gold mining sector through land and mineral rights reforms and the regulated use of mercury (mandatory use of retorts).

7. Co-ordination arrangements

The Minerals Commission with its Small Scale Mining Unit as the agency specifically mandated by law for the management of small scale and artisanal gold mining and responsible for regularizing these activities throughout the country together with the Mining Department of EPA will ensure the overall coordination of the Project. It shall appoint a National Director and an administrative secretary and provide national experts in environmentally related studies as well as experts in the area of mining and supervise the necessary field work. The national coordination and National Director shall be based at SSM Office in Accra.

Moreover, SSM will monitor, during the whole project cycle, introduction of new equipment as well as the progress of training. It will have a lead role in all technology- and environment-related issues. All information and expertise related to the social patters in the country will be made available by SSM and their central and regional offices. This includes the availability to project personnel of reports and studies, both published and unpublished.

UNIDO will be responsible for the overall control of the project and will put together the cross-discipline programme involving coordination of environmentalists, small-scale mining and mineral processing. For the purpose of project management, a Steering Committee will be established comprising SSM, EPA and UNIDO. The Steering Committee will meet every 6 months to review progress.

8. Counterpart support capacity

SSM and its Regional Office for the Western Region have the full administrative supervision over the project and will provide support to the UNIDO project through the existent infrastructure of their headquarter organization and the regional office. SSM will supervise and control the project activities. In the selected artisanal mining fields SSM will in particular ensure:

- free access of UNIDO personnel to conduct project activities, provided such activities do not unduly interfere with the operations of the small scale miners.

Furthermore, SSM will provide assistance to the Project through their head office in Accra, if such services are requested by UNIDO.

PART C: DEVELOPMENT OBJECTIVE

The project is focusing on the Government's developing target to phase out or at least to reduce the use of mercury in artisanal and small scale mining operations by conducting an environmental impact assess and introducing more efficient equipment for mineral processing and recycling of mercury. The project will help the Government in bridging the technological gap from which the sub-sector is suffering and introducing environmental management and cleaner production being unknown to the rural population.

PART D: OBJECTIVES, OUTPUTS AND ACTIVITIES

1. Immediate objective

Assistance in reducing mercury emissions in a highly contaminated artisanal gold mining area in the vicinity of the village Dumasi (Bogoso area)/Western Region.

Output 1:

Assessment of mercury levels in humans and environment.

Activities:

- Develop questionnaire on general health condition of members of mining communities and on indications for symptoms of mercury poisoning.

- Evaluate/estimate the occupational health risk in people directly exposed to mercury through amalgamation activities.

- Evaluate/estimate the occupational health risk of people living in the vicinity of gold extraction plants and gold melting shops.

- Check general health condition of directly exposed people and non-directly exposed members of mining population.

- Take hair, urine, and blood samples according to state of the art in clinical studies.

- 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.

- Draft report summarizing facts and conclusions.

Output 2:

A study on the extent of mercury and related chemical pollution along the polluted surface waters and their neighboring areas.

Activities:

- Evaluation of the nature and extent of mercury pollution of water, sediments, fish and soils.

- Introduce and set up a monitoring system for continuous water quality assessment.

- Summarize facts and conclusions on the assessment of mercury levels in the environment for consideration of concerned agencies/bodies.

- Formulate measures for the remediation and possible rehabilitation of hot spots in the river systems and vicinities.

Output 3:

Improvement of human safety through demonstration of mercury recycling by using maintenance-free retorts and training in their proper utilization.

Activities:

- Purchase of 100 maintenance-free and user-friendly retorts to be made available at the mining sites/processing centers.

- Training of miners in occupational safety aspects related to mercury.

- Training of miners through the local SSM office in proper handling and recycling of mercury at Dumasi.

<u>Output 4:</u>

Some 50 representatives from local SSM offices trained by UNEP in environmental management of small-scale mining operations.

<u>Activities:</u>

Design of training in:

- Environmental Management Strategies.
- Sustainable Development Strategies.
- Regulatory Framework.

Implementation of training in:

- Mining and Environmental Protection Legislation.
- Environmental Impact Assessment.
- Environmental Risk Assessment.
- Environmental Quality Standards and Criteria.
- Enforcement Mechanisms.

<u>Output 6:</u>

A Report on mining policies regarding artisanal and small-scale gold mining including recommendations for policy updating.

<u>Activities:</u>

- Based on experience in other countries, advise the SSM on possible legal and administrative framework to address the various environmental challenges of small-scale gold mining.

- Provide advisory assistance to the SSM in the formulation of policies, taking into consideration the various political, social, and environmental dimensions of small-scale mining activities.

PART E: INPUTS

1. <u>Government inputs</u>

1.1 <u>Personnel and organizational assistance</u>

The Minerals Commission will appoint a National Project Director and a secretary to the project. Furthermore, it will make available all expertise gained, its archives and personnel for research and will assist through its liaison with the local offices of SSM. SSM will monitor the introduction of the new equipment and the progress of the work. The Environmental Protection Agency will have the lead role in all environment-related issues and will supervise the activities for an assessment of the environment in the affected area.

1.2 Office facilities

SSM will provide an adequately equipped office with air-conditioning and telephone to NPD and International Experts.

1.3 Geological information

SSM will make available to project personnel all pertinent geological reports and maps, both published and unpublished, from the archives in Accra and its offices in the field.

1.4 Other SSM support commitments

- Vehicle support in the field.
- Geologists, Chemists, Mining Engineer, Metallurgist as the project might require for consultation.

2. UNIDO inputs

		TOTAL	
Budget Line	**Functional Title**	**m/m**	**US$**
11-01	UNEP Expert on Environmental Management	0.8	9,750
11-02	Environmental Expert on conduct of surveys on river systems	0.8	9,750
11-03	Environmental Expert on conduct of sampling and analyses of biological samples	0.8	9,750
11-04	Toxicologist for assessment of mercury levels in humans	0.8	9,750
15-00	Project travel in the country		8,500
16-00	Other personnel costs including UNIDO staff missions for coordination of project		12,000
17-01	National Expert on conduct of surveys on river systems	2.5	12,500
17-02	National Expert on conduct of sampling and analyses of biological samples	2.5	12,500
17-03	National Expert on Public Health for assessment of mercury levels in humans	1.0	5,000
19-99	**Total Personnel Component**	**9.2**	**89,500**
21-01	**Subcontract on reference analyses**		**8,000**
21-02	**Subcontract on environmental and health assessment**		**67,000**
49-99	**Total Equipment**		**35,500**
59-99	**Total Miscellaneous Component (Operation & Maintenance)**		**11,504**
99-99	**Total Budget excluding 13 % Support Cost**	**9.2**	**211,504**
	+ 13 % Support Cost		27,496
	Total Budget including 13 % Support Cost	**9.2**	**239,000**

PART F: RISKS

Equipment Breakdown

This can be expected in any project operating in remote field areas or countries out of immediate reach of spares or repair facilities. Vehicle breakdown has a particular leverage at shutting the project down for a short while.

PART G: PRIOR OBLIGATIONS AND PREREQUISITES

Prior obligations: none

Prerequisites: SSM Recruitment of National Project Director, assignment of one administrative assistance for preparation of adequate premises for project staff.

SSM Assignment of one extensionist to establish industrial contacts between Accra and the project site in Dumasi.

PART H: PROJECT REVIEWS, REPORTING AND EVALUATION

Succinct progress will be produced every two months throughout the project.

Summary reports by experts on the results of the studies undertaken pursuant to the major outputs will be produced as conclusions become firm.

A project performance evaluation report (PER) will be produced three months prior to the first tripartite review meeting.

A project terminal report will be produced sufficiently in advance of the terminal tripartite review meeting to allow review and technical clearance by the implementing agency.

The project will be subject to evaluation 1 months prior to scheduled termination. The organization, terms of reference, and timing will be decided after consultation among the parties to the project document.

ANNEX 1

JOB DESCRIPTIONS

Post 11-01
Post 11-02
Post 11-03
Post 11-04
Post 17-01
Post 17-02
Post 17-03

JOB DESCRIPTION
xx/GHA/99/xxx/11-01

Post Title: UNEP Expert on environmental management

Duration: 0.8 m/m (breakdown: 0.3 m/m home based work, 0.5 m/m teaching in the field)

Duty station: Accra/Tarkwa/Dumasi

Purpose of project: Assistance in reducing mercury emissions in highly contaminated gold mining areas.

Duties: Under the direction of the National Project Coordinator, and in cooperation with national personnel, the expert will be responsible for the following duties:

1. Prepare and give lectures on:

   * Mining and Environmental Protection Legislation;
   * Methodologies for environmental management;
   * Environmental Impact Assessment;
   * Environmental Risk Management;
   * Environmental Quality Standards and Criteria;
   * Mitigation measures to improve environmental performance;
   * Examples of good practices;
   * Environmental management networks to improve access to information, technologies and solutions.

Qualification: Senior Mining Engineer with experience in environmental management of mining sites.

Background and Justification:

The lack of appropriate technology and proper health and safety procedures in the informal gold mining sector in Ghana have led to severe environmental degradation and mercury pollution of river systems and adjacent agricultural sites. In some areas, public health might be endangered because of mercury pollution. Due to a lack of trained personnel and equipment, the extent of the pollution has not yet been assessed. The project is planned to monitor mercury levels in a selected small scale mining community through analyses of surface waters, sediments, soils and human specimens, such as hair, blood and urine. Based on the results proposals will be prepared on introduction and promotion of technology which is more efficient in respect to gold recovery and that reduces substantially mercury emissions.

JOB DESCRIPTION

xx/GHA/99/xxx/11-02

Post Title: Environmental Expert on conduct of surveys on river systems.

Duration: 0.8 m/ms (breakdown: 0.1 m/m home based work, 0.7 m/m field work)

Duty station: Small scale gold mining area in the vicinity of Dumasi

Purpose of project: Assistance in reducing mercury emissions in highly contaminated gold mining areas.

Duties: Under the direction of the National Project Coordinator, and in cooperation with national personnel, the expert will be responsible for the following duties:

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

Qualification: Senior Chemist/Environmentalist with experience in industrial pollution emanating from mining operation.

Background and Justification:

The lack of appropriate technology and proper health and safety procedures in the informal gold mining sector in Ghana have led to severe environmental degradation and mercury pollution of river systems and adjacent agricultural sites. In some areas, public health might be endangered because of mercury pollution. Due to a lack of trained personnel and equipment, the extent of the pollution has not yet been assessed. The project is planned to monitor mercury levels in a selected small scale mining community through analyses of surface waters, sediments, soils and human specimens, such as hair, blood and urine. Based on the results proposals will be prepared on introduction and promotion of technology which is more efficient in respect to gold recovery and that reduces substantially mercury emissions.

JOB DESCRIPTION
xx/GHA/99/xxx/11-03

Post Title: Environmental Expert on conduct of sampling and analyses of biological samples.

Duration: 0.8 m/m (field work)

Duty station: Small scale gold mining area in the vicinity of Dumasi.

Purpose of project: Assistance in reducing mercury emissions in highly contaminated gold mining areas.

Duties: Under the direction of the National Project Coordinator, and in cooperation with national personnel, the expert will be responsible for the following duties:

1. Meet officials of Government and mining related institutions and discuss present situation of the environment and health in gold mining and processing areas and evaluate existing data of analyses conducted in the past.
2. Investigate the situation of the environment on the spot, take biological samples from agricultural sites where pollution can be assumed from irrigation.
3. Evaluate the nature and extent of the mercury pollution in produce.
4. Introduce and set-up a monitoring system for continuous biological sampling and analyses.
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.

Qualification: Senior Chemist/Environmentalist with experience in biological monitoring, sampling and analysis.

Background and Justification:

The lack of appropriate technology and proper health and safety procedures in the informal gold mining sector in Ghana have led to severe environmental degradation and mercury pollution of river systems and adjacent agricultural sites. In some areas, public health might be endangered because of mercury pollution. Due to a lack of trained personnel and equipment, the extent of the pollution has not yet been assessed. The project is planned to monitor mercury levels in a selected small scale mining community through analyses of surface waters, sediments, soils and human specimens, such as hair, blood and urine. Based on the results proposals will be prepared on introduction and promotion of technology which is more efficient in respect to gold recovery and that reduces substantially mercury emissions.

JOB DESCRIPTION
xx/GHA/99/xxx/11-04

Post Title: Toxicologist for assessment of mercury levels in humans

Duration: 0.8 m/m field work

Duty station: Small scale gold mining area in the vicinity of Dumasi.

Purpose of project: Assistance in reducing mercury emissions in highly contaminated gold mining areas.

Duties: Under the direction of the National Project Coordinator, and in cooperation with national personnel, the expert will be responsible for the following duties:

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.
7. Propose training programs for toxicologists from Department of Health and hospitals.
8. Draft report summarizing facts and conclusions.

Qualification: Senior Toxicologist with experience in Industrial Hygiene and Occupational Health**.**

Background and Justification:

The lack of appropriate technology and proper health and safety procedures in the informal gold mining sector in Ghana have led to severe environmental degradation and mercury pollution of river systems and adjacent agricultural sites. In some areas, public health might be endangered because of mercury pollution. Due to a lack of trained personnel and equipment, the extent of the pollution has not yet been assessed. The project is planned to monitor mercury levels in a selected small scale mining community through analyses of surface waters, sediments, soils and human specimens, such as hair, blood and urine. Based on the results proposals will be prepared on introduction and promotion of technology which is more efficient in respect to gold recovery and that reduces substantially mercury emissions.

JOB DESCRIPTION
xx/GHA/99/xxx/17-01

Post Title: Environmental Expert on conduct of surveys on river systems.

Duration: 2.5 m/m field work

Duty station: Small scale gold mining area in the vicinity of Dumasi.

Purpose of project: Assistance in reducing mercury emissions in highly contaminated gold mining areas.

Duties: Under the direction of the National Project Coordinator, and in cooperation with the International Expert 11-02, the expert will be responsible for the following duties:

1. Assist the International Expert in investigating the situation of the environment on the spot, take samples from waters and soils where pollution can be assumed.

2. Assist the International Expert in evaluating the nature and extent of the mercury pollution in a selected river system and adjacent agricultural sites.

3. Assist the International Expert in introducing and setting-up a monitoring system for continuous water quality assessment.

4. Assist the International Expert in formulating 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 data for Final Report of International Expert.

Qualification: Senior Chemist/Environmentalist with experience in industrial pollution.

Background and Justification:

The lack of appropriate technology and proper health and safety procedures in the informal gold mining sector in Ghana have led to severe environmental degradation and mercury pollution of river systems and adjacent agricultural sites. In some areas, public health might be endangered because of mercury pollution. Due to a lack of trained personnel and equipment, the extent of the pollution has not yet been assessed. The project is planned to monitor mercury levels in a selected small scale mining community through analyses of surface waters, sediments, soils and human specimens, such as hair, blood and urine. Based on the results proposals will be prepared on introduction and promotion of technology which is more efficient in respect to gold recovery and that reduces substantially mercury emissions.

JOB DESCRIPTION
xx/GHA/99/xxx/17-02

Post Title: Environmental Expert on conduct of sampling and analyses of biological samples.

Duration: 2.5 m/m field work

Duty station: Small scale gold mining area in the vicinity of Dumasi.

Purpose of project: Assistance in reducing mercury emissions in highly contaminated gold mining areas.

Duties: Under the direction of the National Project Coordinator, and in cooperation with the International Expert 11-03, the expert will be responsible for the following duties:

1. Assist the International Expert in investigating the situation of the environment on the spot, take biological samples from agricultural sites where pollution can be assumed from irrigation.

2. Assist the International Expert in evaluating the nature and extent of the mercury pollution in produce.

3. Assist the International Expert in introducing and setting-up a monitoring system for continuous biological sampling and analyses.

4. Advise on necessary interactions between Government departments, mining industry and research institutions.

5. Prepare data for Final Report of the International Expert.

Qualification: Senior Chemist/Environmentalist with experience in industrial pollution.

Background and Justification:

The lack of appropriate technology and proper health and safety procedures in the informal gold mining sector in Ghana have led to severe environmental degradation and mercury pollution of river systems and adjacent agricultural sites. In some areas, public health might be endangered because of mercury pollution. Due to a lack of trained personnel and equipment, the extent of the pollution has not yet been assessed. The project is planned to monitor mercury levels in a selected small scale mining community through analyses of surface waters, sediments, soils and human specimens, such as hair, blood and urine. Based on the results proposals will be prepared on introduction and promotion of technology which is more efficient in respect to gold recovery and that reduces substantially mercury emissions.

JOB DESCRIPTION

xx/GHA/99/xxx/17-03

Post Title: Expert on Public Health for assessment of mercury levels in humans.

Duration: 1.0 m/m field work

Duty station: Small scale gold mining area in the vicinity of Dumasi.

Purpose of project: Assistance in reducing mercury emissions in highly contaminated gold mining areas.

Duties: Under the direction of the National Project Coordinator, and in cooperation with the International Expert 11-04, the expert will be responsible for the following duties:

1. Assist the International Expert in taking human specimens and to preserve them for analyses.

2. Assist the International Expert in checking general health condition of directly exposed people and non-directly exposed members of mining population.

3. Take hair, urine, and blood samples according to state of the art in clinical studies.

4. Assist the International Expert in assessing 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.

5. Prepare a concise report on medical data collected from the selected cohort.

Qualification: Senior Health Expert with experience in toxicology, neurology.

Background and Justification:

The lack of appropriate technology and proper health and safety procedures in the informal gold mining sector in Ghana have led to severe environmental degradation and mercury pollution of river systems and adjacent agricultural sites. In some areas, public health might be endangered because of mercury pollution. Due to a lack of trained personnel and equipment, the extent of the pollution has not yet been assessed. The project is planned to monitor mercury levels in a selected small scale mining community through analyses of surface waters, sediments, soils and human specimens, such as hair, blood and urine. Based on the results proposals will be prepared on introduction and promotion of technology which is more efficient in respect to gold recovery and that reduces substantially mercury emissions.

ANNEX 2

TERMS OF REFERENCE OF SUB-CONTRACT

1. Background Information

Mercury is one of the most toxic substances in the world causing significant damage to the environment and to the health of people who handle it. The adverse human and ecotoxical consequences of mercury contamination in terrestrial and aquatic systems have been recognized since the 1950's, when the Minamata poisoning episode in Japan (arising from human exposure to methyl mercury in fish) triggered a tightening of legislative controls on mercury discharges across Europe, North America and parts of South-East Asia.

Mercury amalgamation, a virtually ubiquitous method of gold recovery with particular applicability for the beneficiation of alluvial or free gold, typically requires the use of 2 to 5 tons of mercury per ton of gold recovered. With gold production of small-scale miners worldwide currently of the order of hundreds of tons per year, the mobilization of mercury through such activities now require a first-order control on global scale.

Mercury is absorbed by the human organism through drinking water, food or breathed air. Artisanal and small scale gold mining activities (AGM) are widely practiced in the in the western, central and northern part of the country. According to official figures AGM employs an 100,000 people in Ghana. The number of people directly or indirectly benefiting from this activity through the extended family system and the multiplier effect can be as high as 1,000,000.

As an activity requiring modest investment and little technical knowledge, AGM is attracting people in growing number, especially in the following areas: Bibiani, Dunkwa, Asankragwa, Assin Fosu, Bolgantanga, Akim Oda, Tarkwa. Small-scale gold mining sites are in the vicinity of rivers draining to the Gulf of Guinea. A great proportion of these miners are women. For every gram of gold recovered, a significant amount of mercury is released into the environment - leaving behind a permanently ruined habitat and often resulting in sickness and even alleged death of men, women and children. The relevant simplicity and effectiveness of the technology, known as amalgamation, mask its dangers. This process can be improved with procedures using inexpensive and highly efficient devices which can be manufactured locally at low cost.

The main objectives of the UNIDO assistance in Phase I of the project are:

- To monitor mercury levels in humans in the selected small scale mining community.
- To conduct a study on the extent of mercury pollution of the surrounding environment, especially of surface water, river sediments, soil, fish, vegetables and fruits.
- To improve human safety through training in new methods for more efficient gravity separation and mercury recycling.
- To train 50 representatives of local offices of the Small-Scale Mining Project (Minerals Commission) in environmental management of small-scale gold mining operations.

2. The Scope of Contracting Services

The project requires substantial input, mainly in form of anorganic mercury analyses of water, sediments, soil, biochemical analyses for determining mercury concentrations in fish, food and in human specimens such as blood, urine and hair.

The services of the subcontractor must encompass the following activities:

- To develop together with International Expert 11-06 (Toxicologist) questionnaire on general health condition of members of mining communities and on indications for symptoms of mercury poisoning.

- To advise on best preservation methods for all biological samples and human specimens taken by the International Experts.

- To analyze biological samples and human specimens taken by the International Experts.

- Based on analytical results advise on the risk of general public living near mining operations and gold shops where gold is melted.

- To propose training programme on analyzing mercury in humans for toxicologists working in Department of Health and hospitals.

- To draft report summarizing facts and conclusions on the environmental assessment.

3. Reports

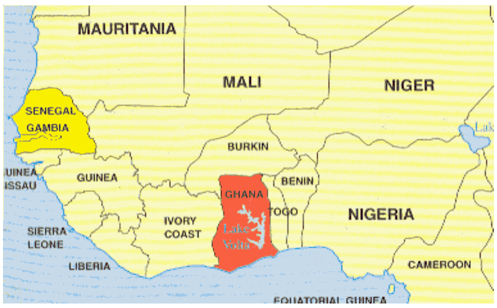
(a) A Draft Final Report, to be submitted to UNIDO/Contract Section in 3 copies, not later than 1 month after receipt of last samples.

(b) A Final Report, in English, in seven (7) copies and a diskette, submission 3 weeks after the Contractor's receipt of UNIDO's comments on the Draft Final Report.

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



André RAMBAUD , Claude CASELLAS (α), Samuel O.SACKEY (β), Nii-Ayi ANKRAH (γ), Martine POTIN-GAUTIER (γ), Sylvaine TELLIER (γ), William BANNERMAN (γ,ε) & Marc BABUT (τ)

(α) Université de Montpellier I, Département Sciences de l'Environnement & Santé publique

(β) Disease Control Unit , Ministry of Health; Accra, GHANA

(γ) Noguchi Memorial Institute for Medical Research ; Accra, GHANA

(δ) Université de Pau & des pays de l'Adour, Laboratoire de Chimie analytique bioinorganique et environnement

(ε) Kwame Nkrumah University of Science & Technology, Chemistry Department, Kumasi, GHANA

(τ) Cemagref, Groupement de Lyon, UR Biologie des Ecosystèmes Aquatiques

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

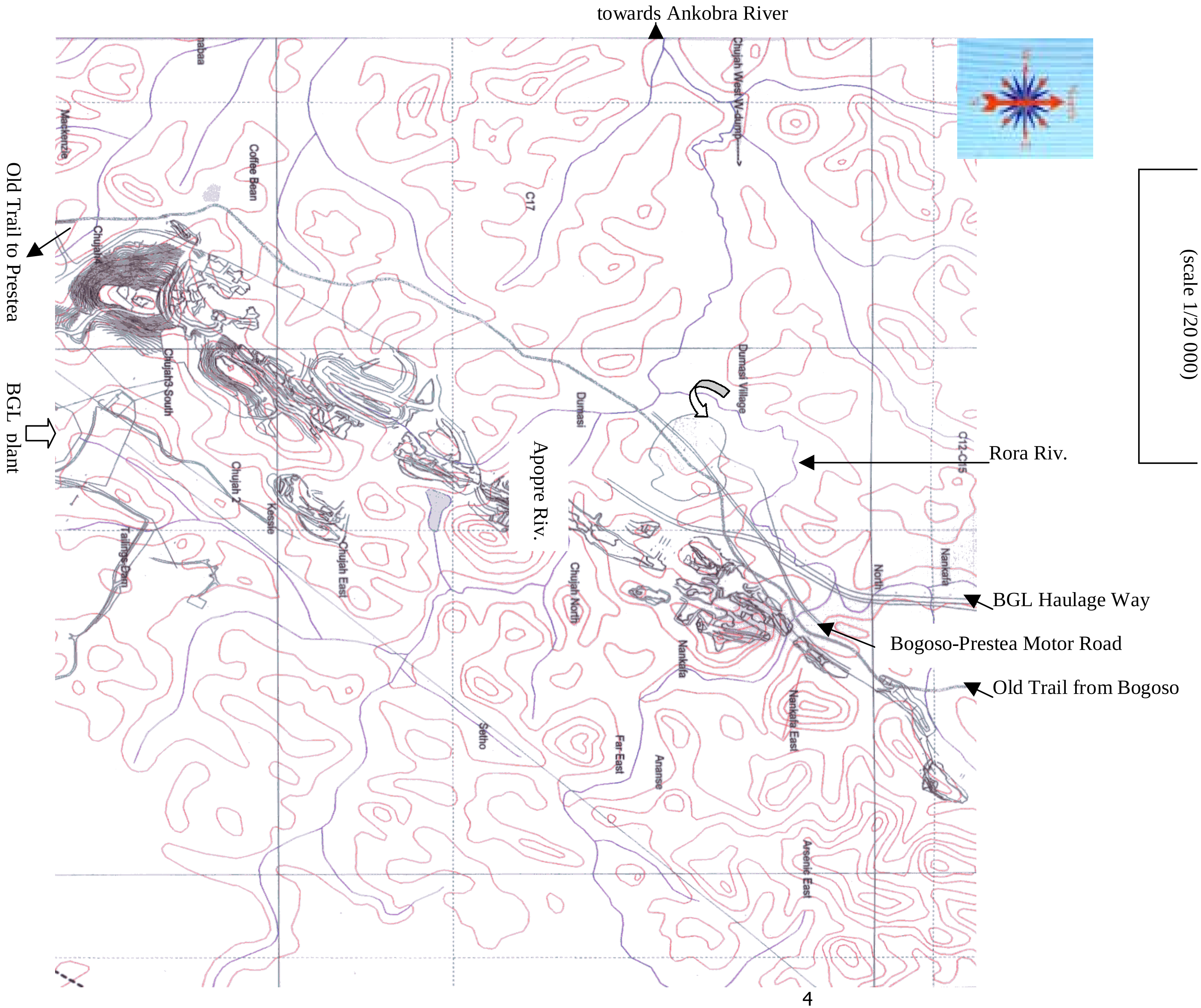
Dumasi is a village located in the Western Region, 5 kilometers from Bogoso on the road from Bogoso to Prestea. It is located close to the Bogoso Gold mine Ltd (BGL) : 5° 32 ′ 27″ N; 2° 03 ‘ 48″ W. Its community has historically been known to be a small-scale gold mining community and gold mining has 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
Apopre Riv.
Rora Riv.
(scale 1/20 000)
BGL Haulage Way
Bogoso-Prestea Motor Road
Old Trail from Bogoso
Chujah West W-dump
Coffee Bean
C17
Dumasi Village
Dumasi
Chujah South
Chujah 2
Kessie
Chujah East
Chujah North
Tailings Dam
Nankafa
Nankafa East
Far-East
Ananse
Sefwo
Arsenic East
North
C12-C15
Makkenzie

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)

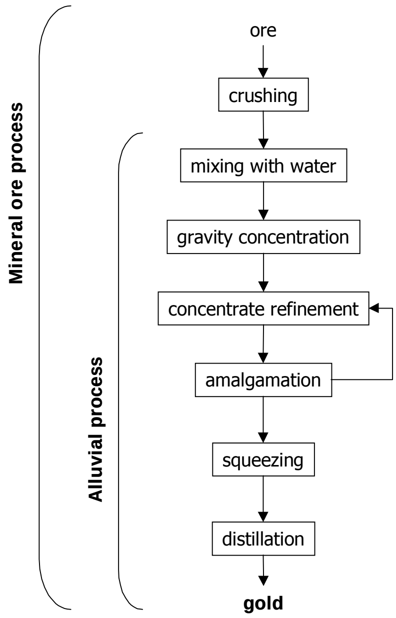


Figure 2- Flow diagram of 'galamsey' process

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

[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

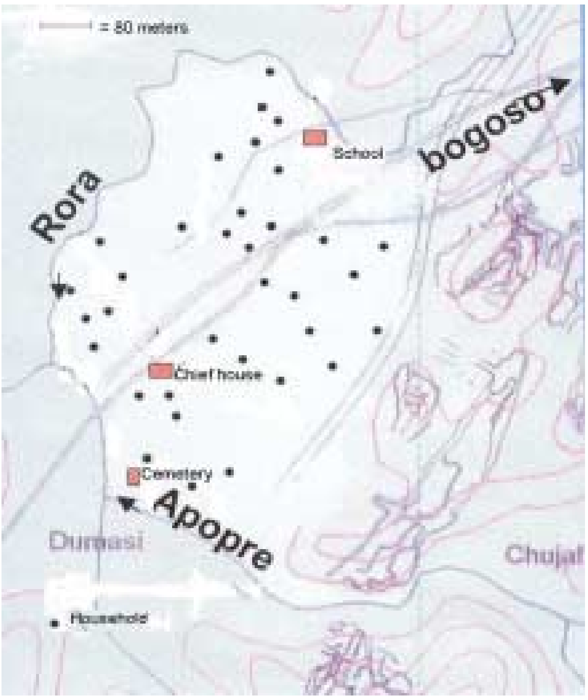
3.1 Data collection

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

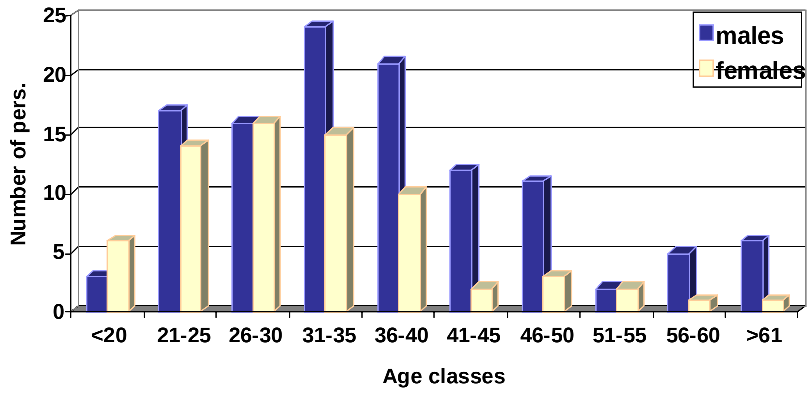


Figure 4 - General distribution of ages

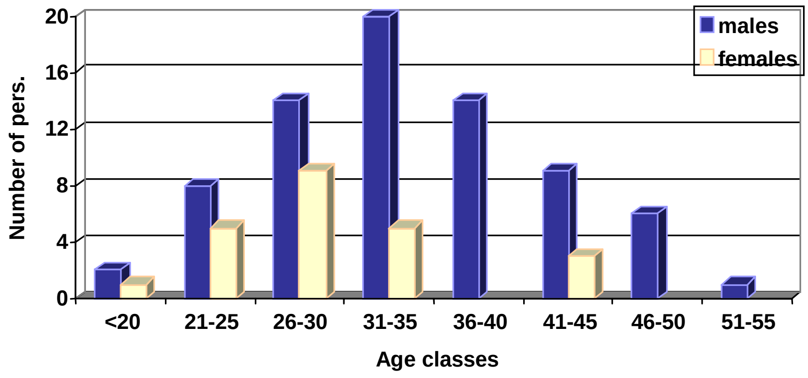


Figure 5-Galamseys age distribution

[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.

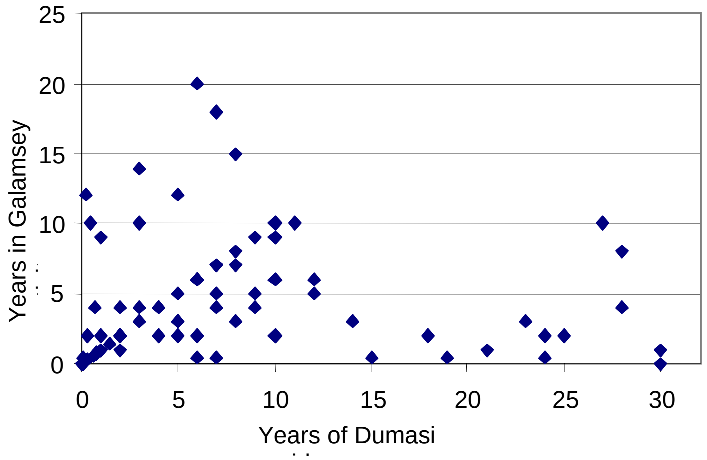


Figure 6 -Duration of galamsey activity versus residence time in Dumasi

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)

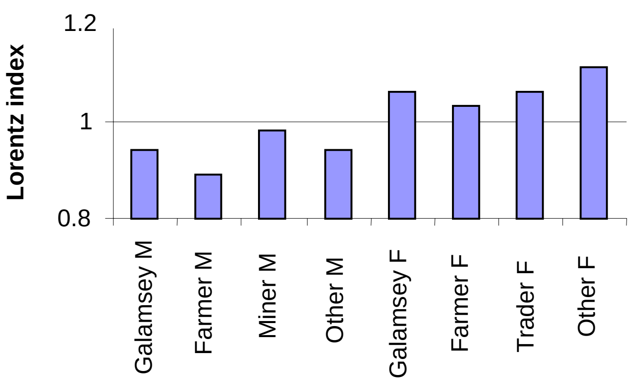


Figure 7 - Measured weight / calculated weight

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)

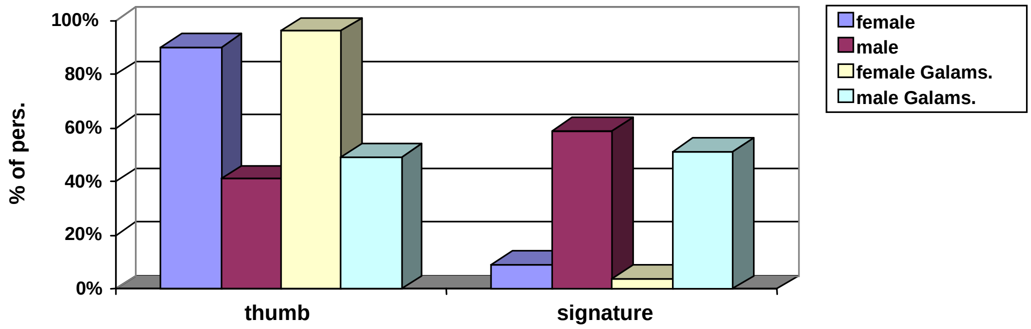


Figure 8 -Consentment signature

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.

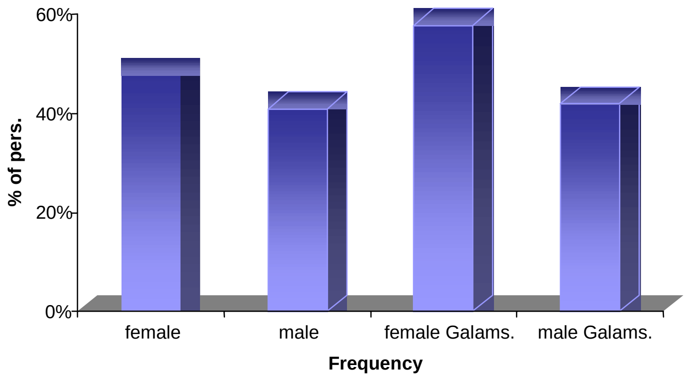


Figure 9 - Percent of persons declaring health problems

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.

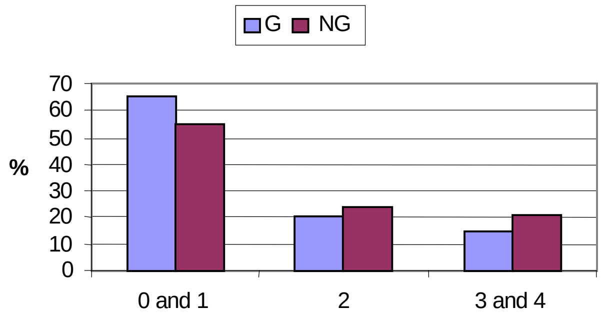


Figure 10 – Memory scores

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 µg.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 µg.l^{-1}. It is recommended to maintain the blood mercury < 100 µg.l^{-1}.

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

- BEI = 35 µg.g^{-1} of creatinin, before working
- BAT= 100 µg.l^{-1} of urine (for metallic and in organic Hg)
- WHO = 50 µg.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 µg.g^{-1} . The WHO recommended limit is 10 µg.g^{-1}.

According to the literature, the first neurotoxic effects would occur in adults at concentrations higher than 50 µg.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 (µg.l^{-1})*	*Urine (µg.l^{-1})*	*Urinary Creatinine (µg.g^{-1})*	*Hair (µg.g^{-1})*	*Nails (µg.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 µg Hg.l^{-1} of urine and µg 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 µg.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 (σ) 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).

<u>Blood</u>: 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 µg.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.

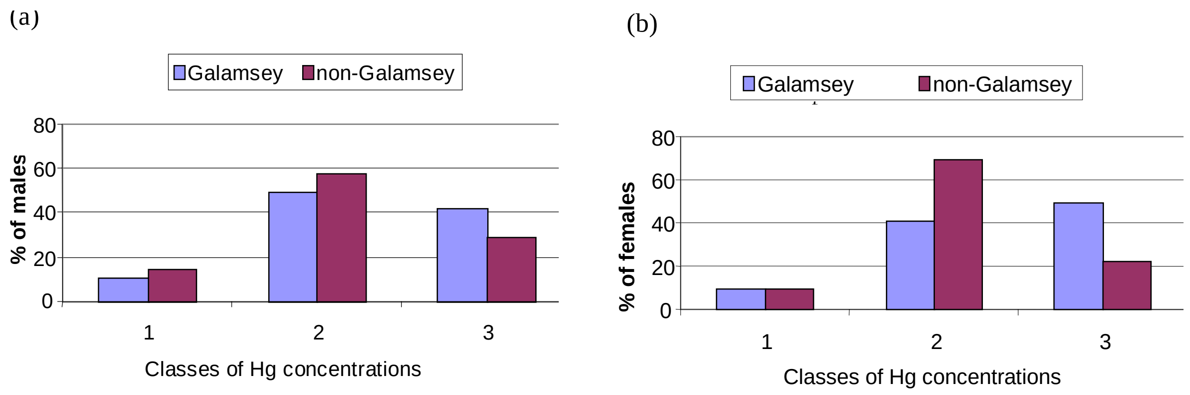


Figure 11 - Percentage of galamseys and non galamseys people in 3 classes of blood mercury contents : a) – Males ; b) – Females

<u>Urine, hair and nails</u>: 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).

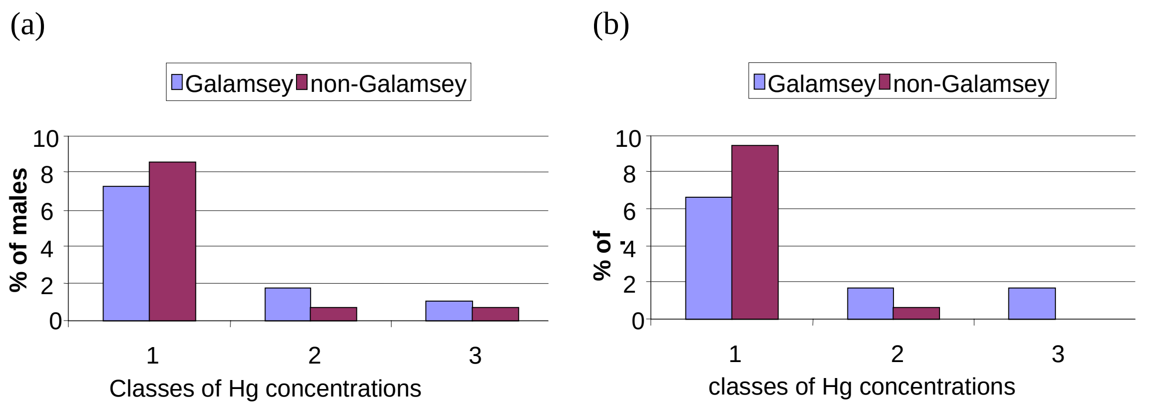


Figure 12 - Percentage of gamaseys and non galamseys people in 3 classes of mercury contents : a) – in hair; b) – in nails

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= <u>Mindanao</u>; 2= <u>Dumasi</u>

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

Marc BABUT (α), Ransford SEKYI (β), Martine POTIN-GAUTIER & Sylvaine TELLIER (γ), William BANNERMAN (δ,γ) Claude CASELLAS & André RAMBAUD (ε)

(α) Cemagref, Groupement de Lyon, UR Biologie des Ecosystèmes Aquatiques
(β) Environmental Protection Agency, GHANA
(γ) Université de Pau & des pays de l'Adour, Laboratoire de Chimie analytique bioinorganique et environnement
(δ) Kwame Nkrumah University of Science & Technology, Chemistry Department, Kumasi, GHANA
(ε) Université de Montpellier I, Département Sciences de l'Environnement & Santé publique

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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.

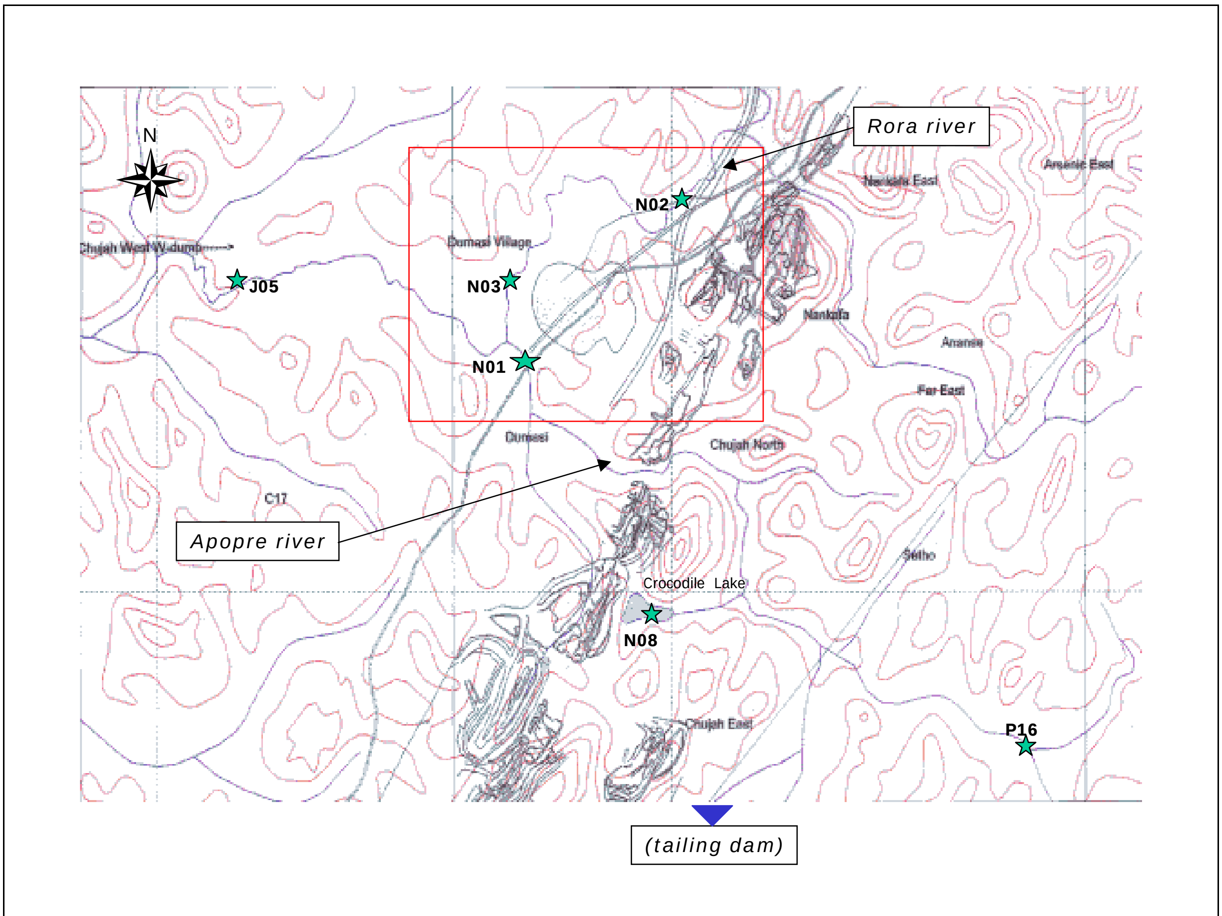

Figure 1 – Sampling locations for BGL's effluents monitoring
(the square corresponds to Figure 2)

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.

[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.*

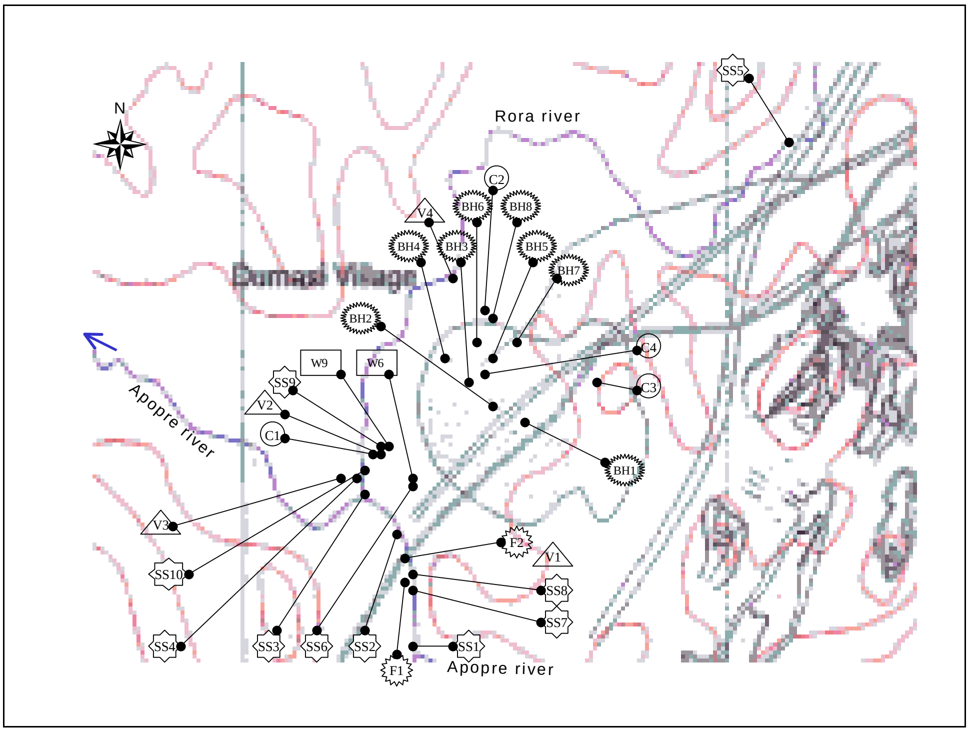

Figure 2 - Sampling locations (April 2000)

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	
	SW2	20/04/2000	
	SW3	20/04/2000	Same location as SSi
	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 µg.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 µg.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 µg.g^{-1}, BCR 320/678 river sediment).

Sample code	Concentration (in µg.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 µg.g^{-1}, which is slightly less than the certified value of 5.24 µg.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 $\pm$ 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 0.1	• *30 d. average (total Hg)* • *any time (total Hg)*	(**8**)
• *France*	1- 2- 3- 4-	0.07 0.7 3.0 21.0	• *No-effect threshold* • *Lowest 'no observed effect conc.'* • *Lowest acute value* • *Mean of acute values*	(**9**)
• *USA*	CMC CCC	2.1 0.012	• *Criterion Maximum Concentration* • *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 PEL	0.17 0.486	(**21**)
France	Threshold level 1[g] Threshold level 2	0.13 0.70	(**22**)
Washington, USA - WAC	No-effect level Minor effect level	0.41 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.

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[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

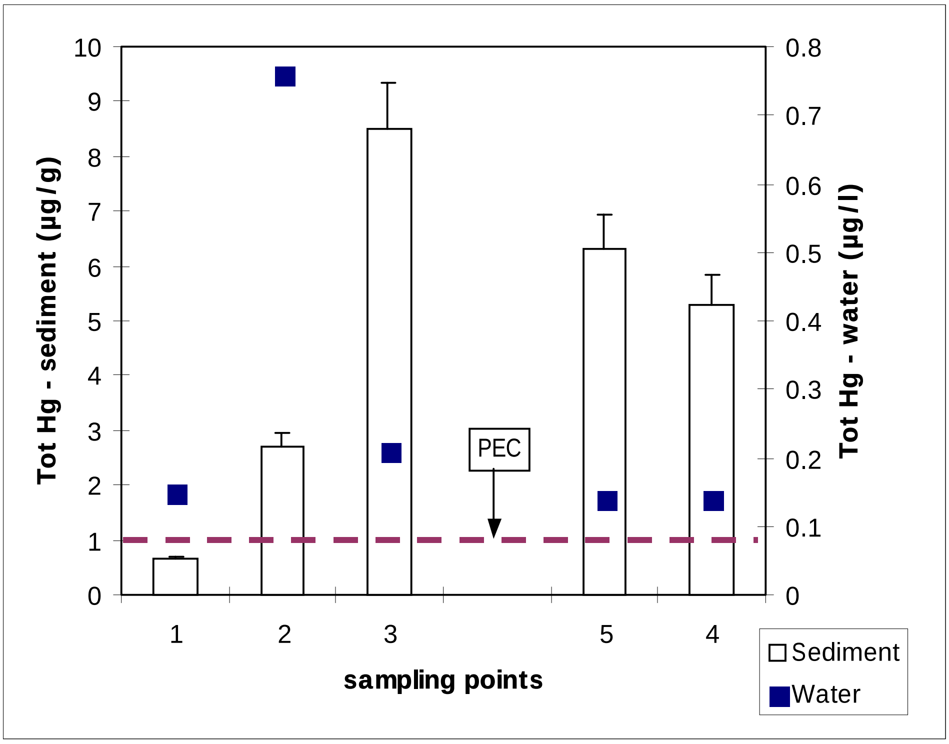

Figure 3 - Total mercury in Rora and Apopre rivers sediments & waters
(sampling points, up- to downstream: 1 - 3: Apopre; 5 - 4: Rora)

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.

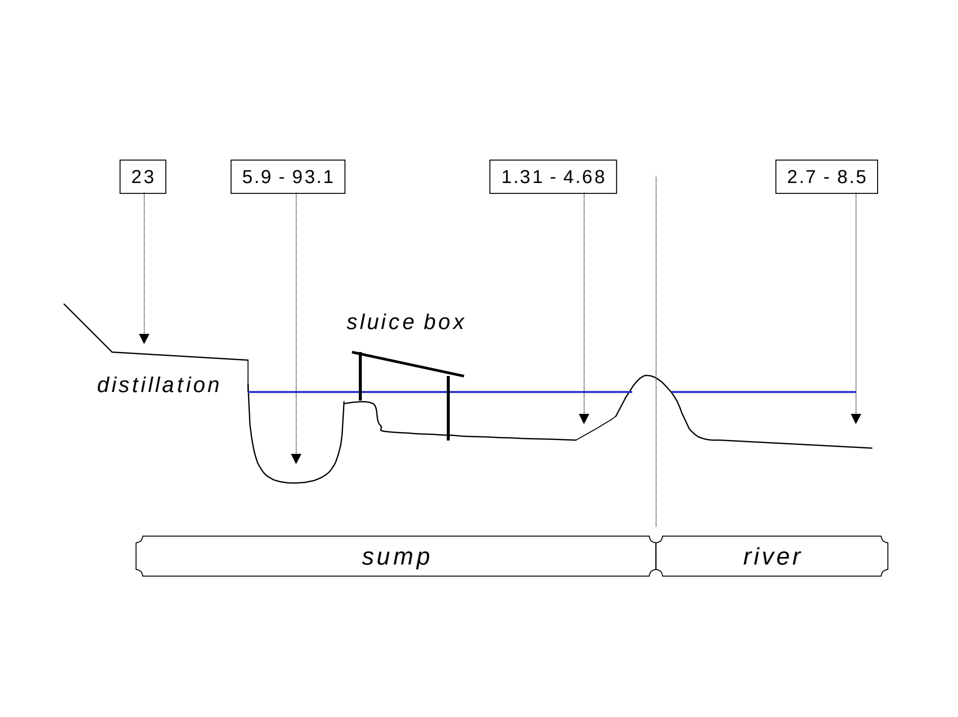

Figure 4- Schematic representation of mercury losses during gold extraction

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.

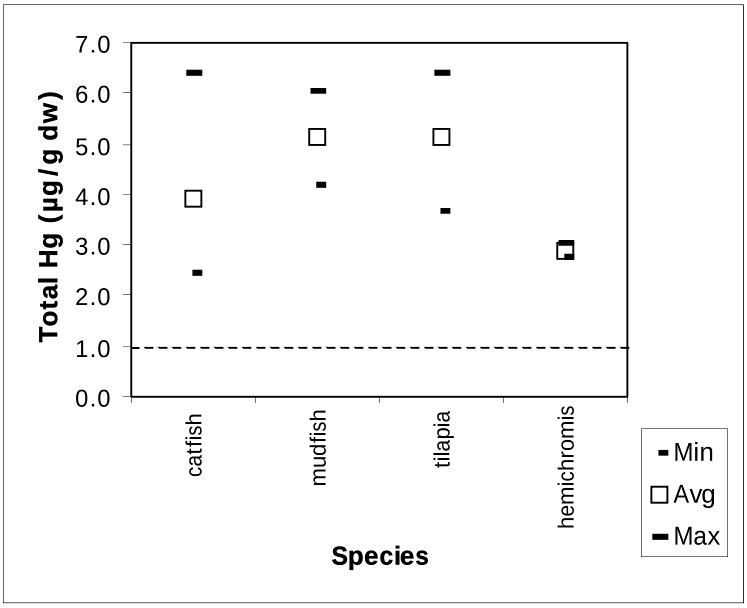

Figure 5 - Mercury concentrations in different fish species
(the dotted line corresponds to US-FDA action level)

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.

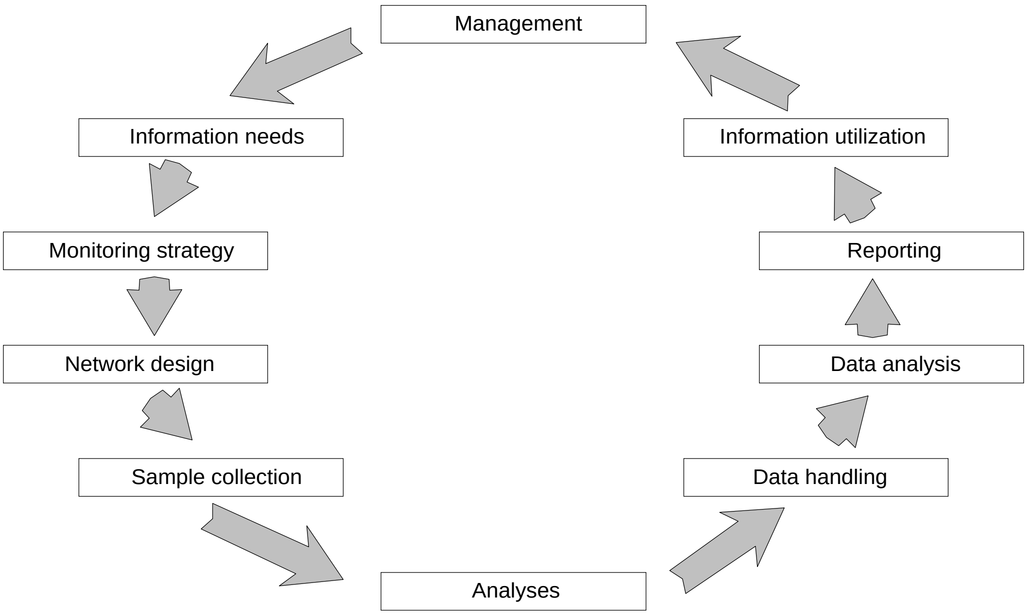

Figure 6 - Monitoring cycle

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 (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[I].

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

[I] 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.

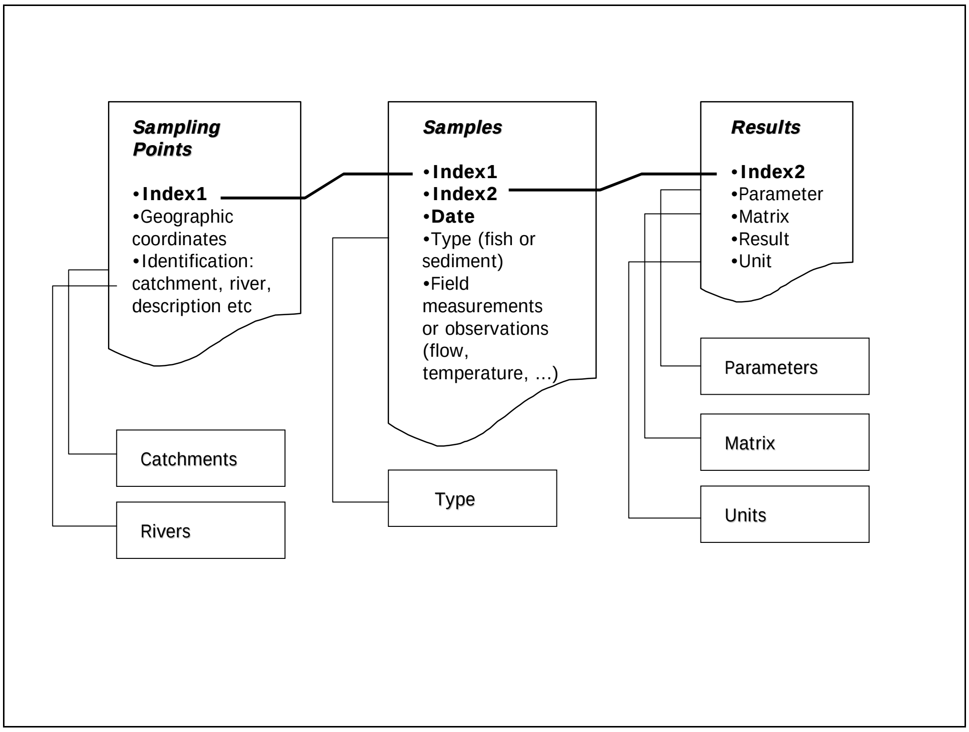

Figure 7 - Simplified framework of the database

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).

[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.
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- *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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