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Removal of barriers to the introduction of cleaner artisanal gold mining and extraction technologies in the Ingessana Hills, Blue Nile State, Sudan.

Part A : Environmental assessment

Draft Report

BRGM/RC-53589-FR
March, 2005

DRAFT REPORT

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Study carried out as part of
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Activity code: 420C51

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Executive summary

Introduction

This survey is part of a larger UNIDO program (EG/GLO/01/G34) funded by the Global Environment Facility (GEF) and titled "Removal of Barriers to the Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies". The long-term objective of the UNIDO / GEF program is to assist a pilot suite of developing countries, located in several key trans-boundary river/lake basins, in assessing the extent of pollution from current artisanal mining activities. It is also to introduce cleaner gold mining and extraction technology which minimises or eliminates mercury releases, and develop capacity and regulatory mechanisms that will enable the sector to minimise negative environmental impacts.

In response to a request from the Government of Sudan and as part of the overall UNIDO project, a contract was signed in July 2003 between the United Nations Industrial Development Organization (UNIDO) and the BRGM, in order to carry out environmental and health surveys and assessments in selected Gold Mining Areas in Sudan. The operation was carried out between French teams (BRGM, University of Montpellier and University of Bordeaux) and Sudanese teams (Geological Research Authority of Sudan and University of Nileen). BRGM in cooperation with the Geological Research Authorities of the Sudan (GRAS) were in charge of the coordination of the environmental assessment and the University of Montpellier headed the health assessment survey. The sampling campaign and health survey took place from March 29th to April 18th, 2004 during the hot dry summer before rainy season and the main mining season.

The aim of this study was to collect environmental and health data in the Gugub and Khor Gidad villages of the Bau district in the Ingessana Hills (Blue Nile State of Sudan) previously selected by UNIDO (EG/GLO/1/G34 – BTOMR *of C. Beinhoff and L. Bernaudat, UNIDO)* to undertake the environmental and health survey of the communities living in the surroundings. The ultimate goal of this project is to formulate recommendations on the gold mining practice in order to avoid significant local and regional pollution. A previous report (Récoché *et al.*, 2004) details the information collected in the field and the sampling methodology.

Mining practice and use of mercury

Use of mercury in the area is quite recent and depends on the type of mining activities. Artisanal Small Scale Mining (ASM) in the Ingessana Hills varies somewhat between villages, with some identifying an active participation in the activity and others a decline depending on season and gold-bearing quartz vein discoveries.

Artisanal gold mining activities in the Ingessana Hills started in 1996. Intensive use of mercury in the area is quite recent (around 3 years and may be less) and mainly developed in Gugub area where gold was first discovered and in Khor Gidad after a gold rush in September 2003. During our mission those two sites were the only ones in activity. At the present time, the village of Khor Gidad is a gold-bearing quartz vein extraction and processing sites and the village of Gugub is a processing site only. The other sites mentioned in the sociological reports carried out in the district by Pr. Khalil A. Al Medani (2003) (i.e. Turda, Khor Neiwi) are alluvial types, without mercury use and presently abandoned.

Miners pan alluvial and elluvial gold when the local stream is flowing during rainy season between July and December. In those sites miners do not use mercury and recover only visible gold during the rainy season. Results of Hg analyses carried out in this study confirm this allegation: soils, tailing and sediments sampled around alluvial panning area are not contaminated by Hg.

During the dry season, due to shortage of water in pit sites, only primary gold associated with quartz vein are mined. The procedures used by local people are representative of very poor people using simple and traditional practices. Mercury is used only to recover gold from this primary ore.

Artisanal gold mining in Gugub is practised by both Dawala and Ingessana tribesmen without legal titles. Most people mine and process in small groups which is basically a family affair. Most of these activities were performed by women (13-35 years old), including the hard tasks of digging and excavation. Men are only involved in mining at deeper depths and in roasting phases. There is no major flowing river close to the mining and processing areas, only seasonal drainage and in summer small pools along main wadis. There is no use of Hg on the mining site. The selected ore is transported to the village for crushing, manually milling and panning in the yard of enclosed family unit.

Mining of gold-bearing quartz vein was the only type we observed during the field mission. The extraction of ore is performed mainly by women in a rather muddled way without mechanical tools. Men are only involved in mining at deeper depths. Miners do not use explosives. The material is manually hoisted and sorted out at sight in a empirical way in order to try to concentrate the most probable gold-bearing material. Artisanal primary gold mining entails visual selection of mineralized rock pieces. At this stage, the selected ore is than transported to the village. Crushing, manually milling and panning are done by women in the yard of «family unit» collecting several hut of the same family. Panning is conducted manually in excavated pools using traditional wooden pans. The tailings are disposed around the huts out of the «family unit». Efficiency of panning using the traditional wooden pan is ~50 %. Apparently, all fine gold grains falls down with the fine fraction of the tailings. Panning test on waste heap performed during the mission indicated frequent gold specks. After crushing and/or milling, the pan concentrate is shipped off at home or to the gold merchant shops for amalgamation and roasting. Mercury is used to extract the fine gold particles from the last panned concentrate. The way of handling mercury in gold amalgamation is unsophisticated. After a last panning performed in the yard, Hg is poured onto the concentrate with water and is mixed with bare fingers to make the amalgam. After thorough mixing, the amalgam is squeezed through a piece of cloth and the excess Hg is recovered for reuse. The miners collect the amalgam by hand, without any precautions. After that, the remaining amalgam is transferred to an open plate or frying pan for roasting. In the private yard there is no specific place for amalgamation and roasting. The gold amalgam is roasted in mobile bonfires outside or inside the huts. It is especially the men who practise the roasting. Daily, they roast the amalgam freely without taking any precautions. The roasting operation can occur in the village close to the dealer shop where they buy mercury; in the yard of the «family unit» or in the huts (usually the ones dedicated for cooking). The diameter of amalgam burned during the demonstration carried out during our visit range from 3 to 8 mm. We expect that the duration of the burns (~ 10 minutes) is too short and temperatures produced by the bonfire are too low to burn all the mercury. Roasting tends to be incomplete and at least 15 - 25 % of the *"doré"* selled to the dealers contains residual mercury.

Gold production estimates based on two independent sources (workers production and dealers) gave similar results: the quantity of gold produced from quartz vein in the 2 studied villages is 75-300 g Au/day and 22.5-90 kg Au/year. Workers and dealer probably underestimated their own production and that actual values may be higher.

We demonstrate that to produce such quantities (100-300 g Au/day) from the Gugub sites workers involved must be 800 to 1000 and gold grade 30 to 72 g/t respectively. According to the data available and observations made (average gold grades measured by GRAS of less than 5 g/t and 300 families living on the sites) works in Gugub can not produce the quantity of gold mentionned before from the quartz vein mining alone. A large part of the gold sell during the dry season (probably 50 %) probably comes from alluvial production and also from gold reserves made by workers during rainy season. According to our field observations and the estimations performed, the use of mercury in the Gugub district is between 250 and 500 g Hg per household of artisanal miners. Taking into account these information, the Hg lost/Au produced ratio is probably higher than 3 in the Gugub area.

Analysis of the system and sampling strategy

The sampling strategy was orientated following a risk assessment approach, considering the various sources of mercury, its transfer and pathways and the potential targets.

The artisanal gold miner families (~300) and the (10-15) local gold merchant shops in Gugub and in Khor Gidad constitute the same broad mercury hotspots. Potential risks to the ecosystem were considered to be minor in that process. The main targets identified are local people practising gold concentration processes at home. The shops and surroundings represent also a particular hotspot. We identified 4 sources of loss of mercury in the environment:

- Wrong manipulation of mercury at the shop or at home;
- Loss of Hg on the ground or in the tailings during the amalgamation phase;
- Evaporation during roasting phase
- Occasional panning of tailing in the pools

	Items Considered	Level of occurence
SOURCES	• Shops Hg storage	✱✱
	• Accidental Hg spill during amalgamation (huts & shops)	✱✱✱
	• Amalgam roasting in the hut	✱✱✱
	• Wastes dispersed	✱✱
	• Contamination of sediments during panning on residues in Gugub	✱
TRANSFER & PATHWAYS	• Household dust contamination	✱✱
	• Hg vapor dissemination contaminating the house and its environment	✱✱✱
	• Soil contamination in the vicinity of contaminated huts	✱✱✱
	• Sediment transportation	✱
	• Transfer to the biological chain (fishes)	✱
HUMANS TARGETS	• Hg inhalation during roasting	✱✱✱
	• Household dust and soil ingestion (mostly children in huts or yards)	✱✱✱
	• Contaminated dry Corn and sorghum consumption	✱✱
	• Fish consumption (rare)	✱
	• *Contaminated poultry consumption*	not considered in that study

In the Gugub and Khor Gidad villages, sampling was focussed on medias potentially submitted to ingestion by local people, (mostly children and poultry): household dust: as amalgam roasting occurs sometimes in the hut, soils around the huts of artisanal gold miners, in the yard of "family unit" which collect several huts and in the main square of the village; tailing and residues of process withdraw around "enclosures dwelling" and in garden where vegetables are being grown. Hg contents in atmosphere (air monitoring) was also performed outdoor and indoor (huts) under different conditions.

Based on information from the sociological survey, reference houses were identified in each village: school and mosque yard in Gugub and recent "enclosures dwelling" out of mining area in Khor Gidad. The selection criteria was based on the lack of artisanal mining activity for the concerned household

The objective of the sediment sampling was oriented to control Hg mobility in the drainage pattern around the two villages *Gugub* and *Khor Gidad* and in the main collector *Wadi Maganza*. The strategy was adapted to the field conditions; sediments were taken along narrow streams where possible; we collected both sands (stream) and silty black sediments (banks). We had particularly unfavorable sampling condition in the Gugub and Khor Gidad sites; the Wad Maganza and its tributaries had dried up completely making it impossible to catch any fish in this area. The sociological study also indicated that fish are consumed only occasionally and mainly dried. Fishing is an occasional occupation mainly practised by the younger generation. According to the local people and the Sudanese participants, the Roseires reservoir was the only site where we could find fish of different species and size, as requested by the protocol.

Due to the lack of fish elsewhere in the selected area, fish sampling was mainly carried out in the Roseires reservoir about 50 km to the east of Gugub (to test contamination of the Nile at this location, but not to interpret Hg mobilisation from the Gugub area) and in a wadi between Gugub and Khor Gidad sites which contained a small water hole but was not directly connected with the gold washing zone and the village of Gugub.

Solid samples were analysed by the LUMEX RA915 at BRGM in France. Air monitoring was also performed on site using the LUMEX. Fish samples were analysed by CV-AAS and the University of Bordeaux (LEESA) and vegetables by atomic fluorescence (BRGM laboratory).

Contamination due to amalgamation practices

According to the analysis of the process, the most probable contamination of soil is supposed to be related to solid deposition of mercury during the amalgamation process or to atmospheric deposition of mercury during the roasting and of the dissemination of household dust in the vicinity of artisanal miner huts.

The soils in the yards are contaminated by Hg. The average geochemical Hg content in the village of Gugub and Khor Gidad are around ten times higher (medians ranging from 640 to 1,213 ng g^{-1}) than the local background (100 to 150 ng g^{-1}). The contamination is punctual with probable nugget effects. Higher value in the 2 villages (up to 10^6 ng g^{-1} in KHOR Gidad and up to 27,626 ng g^{-1} in Gugub) are related to zone of amalgamation where Hg droplet were sometimes visible after panning. The indicated zones of last panning and amalgamation showing values several times higher than others places where values are close to local background are principal hotspots.

School yard in Gugub show background Hg contents (106 ng g^{-1}).

Contamination due to roasting of amalgams

It was rather difficult to identify what was the main place of roasting. In Khor Gidad, roasting outdoor seems to be the main way of roasting. It is seem that the proportion is approximately 50 % outdoor and 50 % indoor in Gugub village. It is especially the men who practise the roasting.

Average contents show also significant contamination of domestic dust in some huts and yards of artisanal miners (500 - 2,760 ng g^{-1} in Gugub and 123 - 840,000 ng g^{-1} in KHOR Gidad). It is clearly demonstrated that indoor amalgam roasting may significantly contaminate the dust of the huts but there are no big differences between the Hg contents in soils compared to Hg contents in dusts on all village and no significant difference according to the dust location (hut with or without roasting). It was impossible, at this stage of investigation, to appreciate the ratio between contamination of soil by amalgamation process and by roasting. The information supplied by the inhabitants can be indistinct but these results show at least that the contamination is rather general and homogeneous at the scale of household and of the village.

The monitoring of air quality carried out inside and outside huts showed that Hg concentrations may reach relatively elevated concentrations (around or above 25,000 ng m^{-3}). However, in the worse case, the exposure of the artisanal miners (around 10 to 15 mn per day) was relatively short compared to the exposure limits for professional workers (25,000 ng m^{-3} for 8 h exposure). However as roasting is sometimes performed in huts, we should also consider the possible exposure of children.

The roasting of amalgams generates usually two peaks of Hg above 24,000 ng m^{-3}. The first peak appears when Hg is evaporating from the amalgam, the second one, occurring few minutes later, is probably due to a late recondensation of mercury aerosols emitted during roasting. This condensation phase indicates that a large part of mercury emitted in the hut remains inside and therefore could accumulate in dusts on the floor, on walls, on vegetables hanging at the top of the hut. The second point is that this condensation phase could concern the entire hut unlike the period of roasting (local evaporation near the fire). All the people present in the hut at this moment could therefore breathe this mercury vapor. The condensation effect is lower in huts allowing rather good evacuation of smoke due to openings at the junction of walls and roof. During roasting outdoor the duration of the period of elevated mercury concentration is shorter than in a hut (around 100 s compared to 500 s in a hut) and the second peak of probable condensation of mercury vapor is absent.

Remobilization of Hg in the stream sediment

The remobilisation of Hg from processing zone to local streams seems very low. The Hg contents of wadi and khor flowing from the villages of Gugub and KHOR Gidad are similar (median under 200 ng g^{-1}) with higher contents near the zones of amalgamation (villages) and than a rapid decrease of Hg contents some hundreds meters downstream the villages of miners. The Hg concentrations in sediments of the main collector wadi Maganza are also relatively low (ranging from 42 to 148 ng g^{-1} on a dry weight basis) and do not show important levels of contamination with regard to the usual guideline values for sediment management in Europe or in the North America. It is not possible to compare the results obtained on dry samples from the villages of Gugub and Khor Gidad with samples taken somewhere else in flowing rivers. The conditions of sampling (focussed on dry samples with organic matter) explain certainly partially the high values encountered. The Hg contamination of sediments exist in this villages where amalgamation and roasting took places but it seems restricted to a narrow zone of few hundreds of meters around, and, at the present time, without apparent contamination downstream through the Wadi Maganza.

Contamination of tailings and impact on stream

The phases of grinding, amalgamation and roasting generate heaps of mixed tailings, residues, ash or waste, sometimes several cubic meters in size, often thrown on the ground near the zones of operation, in or around enclosures dwelling or even gardens. Hg analyses carried out on this tailings show a heterogeneous contamination depending on their composition which can be sometimes important (62,300 and 72,500 ng g^{-1} in KHOR Gidad). Their number and location in gardens or within the “enclosed family unit” is a problem to be taken into account in the future operations of environmental management of the area.

Workers indicated that during rainy season part of this tailings and residues are sometime panned in pools located in the *Khor Alyas, at* south of Gugub. The highest Hg contents in sediment (ranging from 1,066 to 1,649 ng g^{-1}) are located along this *Khor Alyas* where aquatic life is unknown but where a water well supplying village with drinking water is known downstream. Control analyses of the water well should be carried out in priority.

Consumption of fishes and vegetables

The other risk of exposure, on a minor level, is related to the consumption of fishes and vegetables (sorghum and corn).

There is a poor representativity of mercury contamination levels in fish species in relation to artisanal gold mining owing to the poor sampling conditions. The levels of contamination in fish muscle samples (15 species - 108 individuals) is very low and there is no fish above the WHO safety limit of 2.5 µgHg/g, on the dry weight basis – the general mean Hg concentration was 0.246 ± 0.048 µg/g and 0.49 ± 0.10 µg/g for the carnivorous species. Compared with Zimbabwe, for fish of a similar size, the mean Hg concentrations were about ten times lower. Analysis of the results relating to the level of mercury contamination in the fish must necessarily bear in mind the constraints imposed by the sampling conditions and lack of any direct relationship with the gold mining site and the village of Gugub. The occasional consumption of fishes in that area , (only 2 % of the people report eating fish occasionally) do not seem to constitute a major risk of exposure. The data from rivers directly affected by gold mining sites using amalgamation procedures must be considered insufficient to produce conclusions relating to fish advisory, or health related matters for this area of Sudan

Sorghum and corn are the main consumed vegetable, at least during the dry season. The average contents in soil of garden (cultivation of sorghum and corn) around the «family unit» ranging from 130 to 280 ng g^{-1} in Khor Gidad and Gugub respectively are close to the background level and below UK and Canadian standard of permissible concentration of Hg in agricultural soil ranging from 1,000 to 8,000 ng g^{-1}. This indicates low mercury remobilization probably due to Fe-rich laterite acting as natural barriers and attenuating the dispersion of Hg. The Hg content of the analysed sorghum and corn is very low and do not present any specific risk, but significant quantities of mercury are present in the dust deposited on the vegetables hanging on the roofs of huts were roasting is performed. This mercury is eliminated with a simple cleaning with water. These results on sorghum and corn should be controlled in a further step as apparently they may contribute to the evaluation of the daily intake of mercury for the local population.

Recommendations

This study was conducted on a short period and do not allow precise conclusions in term of impact assessment, particularly some aspects would require further control.

- In the wadis and khor, the sampling of fishes and sediments should be extended during rainy season and all along wadi Maganza to evaluate the real level of contamination in the river system. The first results indicate that the risk of high contamination of fishes is low.
- The environmental assessment concerned only the environment of artisanal miners. Contamination of gold shops and surroundings was proved in the 2 villages studied. We also expect that roasting tends to be incomplete and at least 15 - 25 % of the *"doré"* contains residual mercury. To complete this assessment particular attention should be pay on the more exposed population that constitute dealers, merchants and their families.
- Results on sorghum and corn should be controlled in a further step as apparently they may contribute to the evaluation of the daily intake of mercury by the local population. The washing of hands and vegetables should be a priority even if sometimes water is restricted in use.

As the practice of local artisanal miners is quite recent, very traditional and with a limited use of mercury, there is no strong need to propose an important program to develop alternative technologies, on a short term basis. However we strongly recommend that some habits in the artisanal mining practices to be changed. Change in local mining practices would require a raising awareness campaign with education of population and specially women, mainly involved, on the risks they face themselves and theirs children. The action should focus on the amalgamation and the roasting procedure in order to promote a safer procedure.

- The main objective being a change of the location to roast the amalgams. Outside roasting must be strongly recommended and exposure to mercury vapours could be avoidable with the application of simple technological improvements such as retorts. Roasting the amalgam does not seem to be a private and confidential activity. It is frequently carried out in the street or at the shops. This fact can help to work in collaboration with the local artisanal miners to found appropriate spots, distant from the village and dedicated to the roasting. This place should be designed to avoid dispersion of Hg in the environment. Presence of children and pregnant women should be avoided during roasting.
- Authorities needs to insure that all amalgamation is carried out in cemented places and that all tailing from the amalgamation are stored in appropriate cemented

storage area that prevent dispersal of Hg contamination onto adjacent land and into water drainage.

- Carefull clean up of contaminated huts should be recommended in order to decrease the hg content of domestic dust.
- Amalgamation zone located in the “enclosed family unit” must be marked and fenced in order to prevent children or animal ingestion.

As use of mercury is recent, the most urgent requirement is to prevent any new Hg input to the river sediment by stopping or at least strictly controlling panning of contaminated tailings in the pools during rainy season.

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Authors are indebted to the help of Ariab Mining Company management who helped us during the preparation of the field camp in Khartoum.

The GRAS delegated Mohamed Ibrahim Suleiman (Head of the chemistry laboratory, ACFP), Adel Osman El Rashid and Said Abdallah Salih (geologists), Shams El Din El Dao and Mohamed El Hassan (Drivers) to participate in all field work. Authors are grateful for their efficient support to collect data, their local knowledge and their advice concerning local practices.

Dr. Khalil. A. El medani, Head of Department of Sociology at the El-Nileen University (Khartoum) joined the team at the middle of field work. The authors are very grateful for his support on knowledge on local communities notably acquired during its sociological study in the area.

Special thanks to Ibrahim Mohamed Toum, GRAS representative in Ad Damazin, who greatly facilitated the contact with local authorities and assisted us during the preparation of the field mission.

BRGM is grateful to the commissioner of Bau district and the Ingessana Tribal chief (Omda) for their consents before approaching artisanal mining community in Gugub and the surroundings.

In Gugub, people committee representative and Pr. Zu Lkifle Yahia, school teacher, were the key persons of the community. Environmental & Health Assessment survey efforts would not have been possible without their consents and daily assistance.

Special thanks to Suleiman Yaya Mohamed and Mohamed Djakalo, the two local workers from Gugub, hired on the site to help in the sediment and soil sampling.

Authors are grateful to Dr Christian LEVEQUE (CNRS, Meudon, France) who determined the species names and the food regimes of the fish collected during the mission to Sudan and to Ph. Freyssinet and V. Laperche (BRGM) who agreed to review and comment this draft report.

Contents

List of illustrations

List of appendices

1. Introduction

This survey is part of a larger UNIDO program (EG/GLO/01/G34) funded by the Global Environment Facility (GEF) and titled "Removal of Barriers to the Introduction of Cleaner Artisanal Gold Mining and Extraction Technologies". The long-term objective of the UNIDO / GEF program is to assist a pilot suite of developing countries, located in several key trans-boundary river/lake basins, in assessing the extent of pollution from current artisanal mining activities. It is also to introduce cleaner gold mining and extraction technology which minimises or eliminates mercury releases, and develop capacity and regulatory mechanisms that will enable the sector to minimise negative environmental impacts.

In response to a request from the Government of Sudan and as part of the overall UNIDO project, a contract was signed in July 2003 between the United Nations Industrial Development Organization (UNIDO) and the BRGM, in order to carry out environmental and health surveys and assessments in selected Gold Mining Areas in Sudan.

The village of Gugub located in the Ingessana Hills (Blue Nile State) was selected by UNIDO (EG/GLO/1/G34 – BTOMR *of C. Beinhoff and L. Bernaudat, UNIDO) to* undertake the environmental and health survey of the communities living in the surroundings. Since 1997 gold was discovered in the central part of Ingessana Hills and the recent discovery of gold around Gugub village has attracted massive population especially those displaced by civil war in the southern parts of the region. Now the Ingessana district is characterised by the presence of about 800 multi-ethnic individuals practising alluvial and primary types' artisanal gold mining and working with mercury under very poor conditions to recover gold. At the moment, the area is characterised by the presence of two main villages, Gugub and Khor Gidad, of artisanal gold miners processing alluvial and primary quartz vein type's ores. The ultimate goal of this project is to formulate recommendations on the gold mining practice in order to avoid significant local and regional pollution.

In accordance with UNIDO and GRAS representatives, the BRGM planned to survey in March, 2004 before the rainy season. The sampling campaign and health survey took place from March 29th to April 18th, 2004.

A previous report (Récoché *et al.*, 2004) details the information collected in the field and the sampling methodology.

This final report summarises the methodological aspects as a well as the field information and presents the analytical results of the environmental survey. The report concludes with an evaluation of Hg contamination in various media.

2. Aims and objectives

The aim of this study was to collect environmental and health data in the Gugub and Khor Gidad villages of the Bau district to assess the level of mercury exposure in the local communities and potential impact in the environment. This district is located in the Ingessana Hills, in the Blue Nile State of Sudan where the practice of artisanal gold mining has been identified. Another small village, Taga was added as a reference village (i.e. a village without a mining history).

The data will also be used to identify appropriate technologies or good practices to reduce the risk of mercury exposure to the humans and mercury contamination in the environment.

Specific study objectives of the environmental assessment are outlined below:

- To identify and evaluate the possible means of exposure of villagers to mercury released by small-scale artisanal gold mining following a risk assessment methodology.
- To sample various environmental media. Different media were sampled according to the protocols recommended by UNIDO (Veiga and Baker, 2003).
- To characterise the source of the pollution and its potential dissemination in the environment.

The environmental assessment was closely coordinated with the health survey in order to support the interpretation of the health data and to evaluate the level of exposure of local population to mercury.

3. Organization and planning

Most of the technical and planning are detailed in the field report (Récoché *et al.*, 2004). The following section summarises some key steps of the project.

3.1. PROJECT TEAM OF THE ENVIRONMENTAL SURVEY

3.1.1. Members of the project team

The members of the project team for the duration of this field mission were as resumed in Illustration 1.

NAMES	OCCUPATION	COUNTRY	ORGANISATION	E-mail
Environmental Team				
RECOCHE Gilles	Geologist Team Leader and Head of Environmental Team	FRANCE	Brgm	g.recoche@brgm.fr
IBRAHIM Mohamed Suleiman	Geologist Assistant CFP	SUDAN	GRAS	Gras@sudanmail.net
GHESTEM Jean-Philippe	Geochemist	FRANCE	Brgm	jp.ghestem@brgm.fr
ROQUES-DUFLO Véronique	Biologist	FRANCE	LEESA University of Bordeaux 1	v.roques-duflo@epoc.u-bordeaux1.fr
Health Team				
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EL BASHIER Abdul Hadi Mohamed	Surgeon	SUDAN	Singer Hospital Sinnar State	
LALOT Marie-Odile	Medicine Doctor	FRANCE		mo.lalot@brgm.fr
EL MEDANI Khalil Abdalla	Sociologist	SUDAN	University. of Nileen	Khalidabdalla@hotmail.com
FENET Hélène	Epidemiologist	FRANCE	University of Montpellier 1	hfenet@iup.pharma.univ-montp1.fr

Illustration 1 - Members of the project team involved on the field mission

3.1.2. Local assistance

The GRAS delegated Mohamed Ibrahim Suleiman (Head of the chemistry laboratory, ACFP), Adel Osman El Rashid and Said Abdallah Salih (geologists), Shams El Din El Dao and Mohamed El Hassan (Drivers) to participate in all field work.

Two local workers from Gugub were hired on the site to help in the sediment and soil sampling and in the panning operation.

Dr. Khalil A. El medani, Head of Department of Sociology at the El-Nileen University (Khartoum), hired by UNIDO, joined the team when field work was ongoing to support Health assessment.

The Commissioner of Bau village arranged the participation of two nurses of the Bau hospital in the Health assessment field work.

The employment of a cook and an electrician was also necessary at the base camp located at Bau.

3.2. PLANNING

The main steps of the projects are summarised as follows:

- Signature of the contract: July 7th, 2004.
- Field campaign in Sudan: March 29th to April 18th, 2004. The details of the tasks performed in the field are described in the Field Report (Récoché *et al.*, 2004).
- Analysis and data processing: from June to September, 2004.
- Final Report: March, 2005.

4. Description of field conditions

4.1. GENERAL CONTEXT

4.1.1. Location

The Gugub artisanal gold mining site selected by UNIDO lies in the middle of Ingessana Hills, some 80 km to the south-west of Ad Damazin town, the capital of the Blue Nile State. The area bounded by latitudes 10° 00'-12° 00'N and longitude 33° 45' eastwards to the Sudan-Ethiopia boarder is geographically referred to as southern Blue Nile region (Illustration 2).

Blue Nile State is administratively divided in four districts: El Damazin, Roseires, Kurmuk, and Bau. Bau and Roseires districts are the main areas where artisanal gold mining is now practiced. Ingessana Hills district comprises major artisanal gold mining sites in Bau Locality. The artisanal sites are scattered around Gugub village, which lies ~10 km north-west of Bau town; the administrative center of the Ingessana Hills district.

According to 1993 latest national census, the total population of the region was 413,694. Bau locality, where all the targeted artisanal gold mining communities live, has a population of ~100,000 (Khalil A. Al Medani, 2003).

The region is full of economic and natural resources. Rain-fed macro and micro-scale farming, wood cutting, charcoal producing, artisanal gold mining, and commercial fishing are the major economic activities in the southern Blue Nile region. The region has more than one million Fedans of arable land and grazing area (1 Fedan = 4,200 m^2). Food crops grown include sorghum, maize, sesame, sunflower, vegetables, and fruits (Khalil A. Al Medani, 2003).

This area is not covered by toposheet except for one that was provided by GRAS edited in 1975 at scale 1/250,000. However, this toposheet is not usable

4.1.2. Topography and climate

Southern Blue Nile region is characterized by both flat clay plains and a hilly topography in the south and the south-west, with gentle slopes towards the north and south-east. There are pediments that are gently sloping and with drainage flow connected to the Blue Nile River system. Ingessana district is characterized by a range of hills rising from 800 to 1000 feet above sea level and expanding in a semi-circular form with a diameter of around 40 kilometers

Blue Nile River is the major drainage landmark in southern Blue Nile region. The prominent seasonal tributaries (Wadi/ Khor) that emerge from the Ingessana massif in

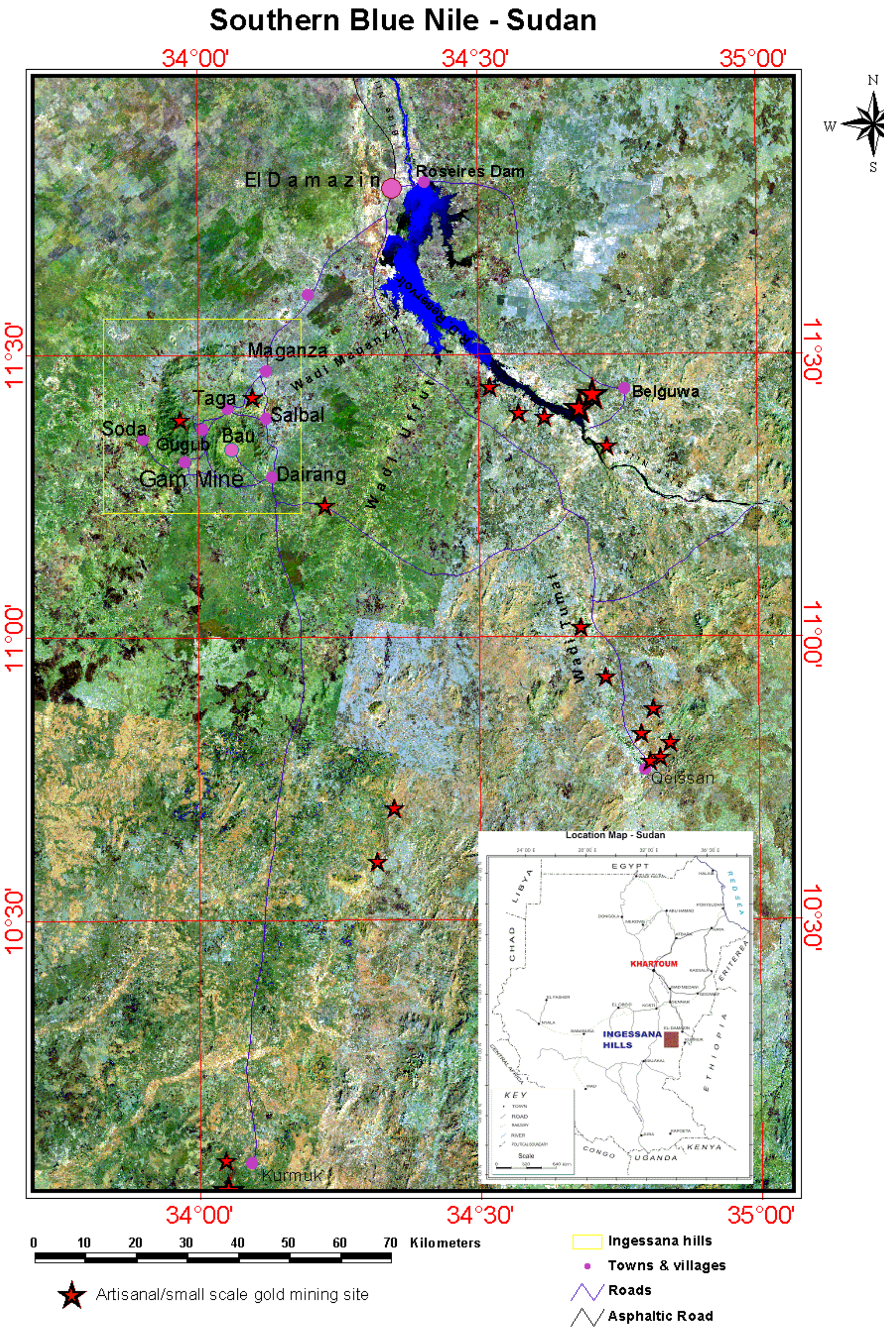

Illustration 2 - Location of the Ingessana Hills area.

radial pattern are Wadis Timsah, Maganza, Ferri, and El Dom. Among these, Wadi Maganza virtually drains all north-eastern parts of the Ingessana Hills where most artisanal gold mining sites are located. Its seasonal waters end up into the western banks of Roseires Dam reservoir at a point lies some 20 km south of Ad Damazin town (Illustration 2). No water flowing was observed during this mission, although there were small pools along main wadis (Illustration 21).

The region lies within the Savannah Zone with annual precipitation ranging between 600 and 800 mm. Dense bush and tall grass cover the hillside and the stream banks as well. Climatic seasons are defined by the hot dry summer (March-June), hot wet autumn (July-October), mild dry winter (November-February), and a very short spring (early March). Mean daily temperature ranges from 43 ºC in mid summer (April-May) to 20 ºC in mid winter (December-January).

The mission took place during the hot dry summer before rainy season. From June to November the area is known as very difficult to reach.

The Gugub and Khor Gidad villages are located within small valley and huts are built on slopes on both sides (Illustration 3 & 4). There is no major flowing river close to the mining and processing areas, only seasonal drainage. All the streams, khors and wadis were dry during our mission and there was no panners (Illustration 5).

In dry season dominant wind direction is North-South; this reversed during rainy season.

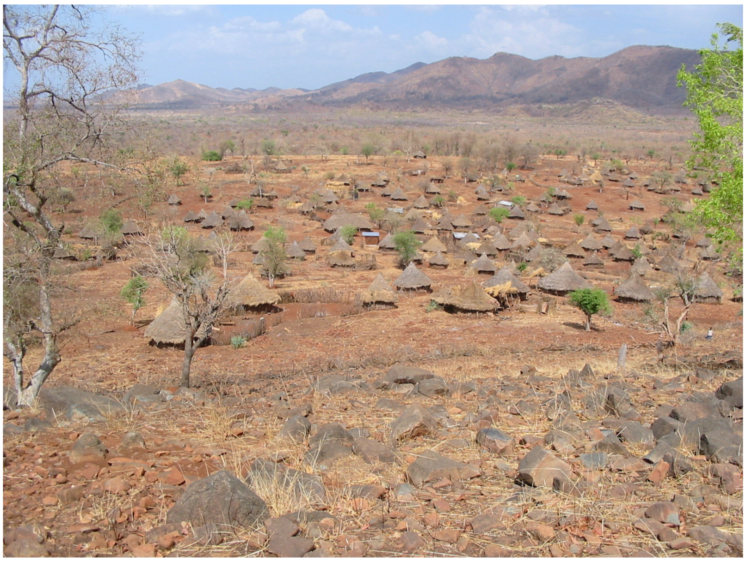

Illustration 3 - View from the NW of the central part of Gugub village.

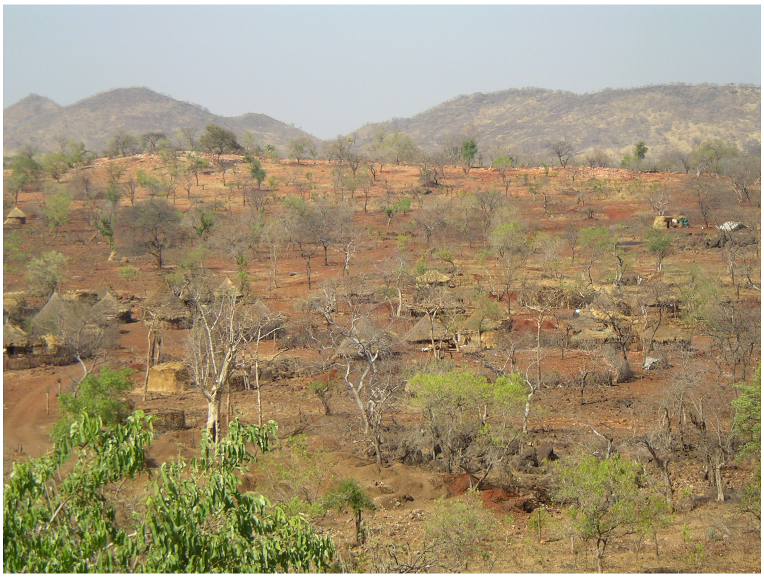

Illustration 4 - View from the SW of the central part of Khor Gidad mining area (gold-bearing quartz vein located on the top of the small hill behind).

4.1.3. Geological information

In Gugub and Khor Gidad, primary ore exploited by artisanal miners is vein-related gold mineralization type. These auriferous bodies are hosted by micro gabbro and associated altered rocks. The gold mineralization is associated with NE-directed shear zones (name Khor Feri Shear zone) sub-parallel to the western contact between Bau granite and adjacent ophiolitic ultrabasic rocks (Elnour K. Mohamed *et al.*, 2002). The quartz veins occurs as bodies of varying lengths of 150-250 meters and width varying from few centimeters to two meters, dipping 30 to 45°NE, in an echelon arrays boudinage and as lenticular pods. Fresh galena and arsenopyrite are the main mineralization observed on quartz samples. Visible gold appears associated with iron oxide within sulphide boxworks.

A chip-sampling campaign carried out by GRAS in 2002 on eight auriferous quartz veins sites of the Gugub area indicated Au low-grades[1] at the surface (Elnour K. Mohamed *et al.*, 2002).

During rainy season gold is panned from alluvial and colluvial deposits that formed terrace along main khors and wadis (Illustration 5).

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[1] Values are given in chapter 4.2.3 (p.31)

Illustration 5 - (a) Alluvial Panning area on Khor Shareban (Gugub) and (b) colluvions working area (Gidad).

4.1.4. Sociological aspects

The information given in the following paragraph are mainly extracted from the sociological survey carried out in the district by Pr. Khalil A. Al Medani (2003) with complements collected during the field mission.

Ingessana are the indigenous Nilotic ethnic group who possibly inhabit the Ingessana hills since the 16th century. The second ethnic group is the Dawala who are war displaced. Historically Ingessana depended on livestock and on minor shifting cultivation in the low lands beyond their mountains. Since 1997, Ingessana district attracted massive people looking for gold. The first to come and live with the Ingessana are Dawala people from Kurmuk ~100 km to the south. About 185 families built their huts in the Gugub village. Artisanal gold miners in the Ingessana Hills concentrate in Gugub, Taga, and Salbal villages. Gugub village of ~1,000 inhabitants is the major center of activities. Artisanal gold miners are scattered in 3 sites at present. The biggest cluster of activities known as khor Gidad is located ~7 km (driving distance) North of Gugub village. There are ~800 individuals who currently practise artisanal alluvial gold pitting mainly along stream terraces. Within the circle of Gugub artisanal gold mining community, Dawala account for ~80 % of the ~185 households (~1,000 heads). The rest are Ingessana groups living at the fringes of the village or as isolated households at hill slopes. The bigger concentrations of sedentary Ingessana artisanal gold miners are found in Taga village ~5 km east of Gugub (~200) and Khor Gam–Rumailik ~7 km northwest of Gugub (~100).

The age of members of the Gugub artisanal gold mining community ranges from 15 to 50 years. The majority of male miner’s ages are in the 15-50 years range while most women miners and water providers at Khor Gidad site are in the 15-35 years old. A few old men and women (> 60 years) practise alluvial gold mining in shallow pits. Children at gold pitting sites are quite visible (10- 15 %). Girls in the 10 to 13 years age range constitute the majority of participating children.

Both Ingessana and Dawala families live in straw and thatch conical huts. Ingessana people build their huts either at the fringes of the mentioned villages or as isolated households on hillsides. Dawalla families, on the other hand, live in groups. Excluding some of the shops, all dwellings, school class rooms, and mosque in Gugub are built of straw and wood even though some Dawalla men are affluent enough to build stone or brick bungalows. In the premises, there is no hut or place reserved for gold processing. The same hut is used for sleeping, cooking food, rock ore grinding, and amalgam burning. The huts of the same family are grouped together and surrounded by a wooden fence. This group of huts is called "family unit" or "enclosed family unit" in this report (Illustration 17). In last August 2003, 53% of artisanal gold miners at Khor Gidad site live half a kilometer from the mining pits, 10 % live three kilometers away, and 37 % live in Gugub ~4 km (walking distance) to the pits (Illustration 3, Illustration 4).

Being located ~50 km away from the Blue Nile western banks; the community of Gugub and the surroundings have no frequent access to fresh fish supply. In the survey, only 2 % of the people report eating fish occasionally. However, dry fish is available in Gugub market.

4.1.5. Sites selected

Most of the data on the artisanal gold mining and processing in the Ingessana Hills area may be found in the UNIDO reports entitled "Information about Ingessana Hills artisanal gold mining sites chosen for the Environmental & Health assessment" by Mohamed S. Ibrahim (November, 2003) and "Socio-economic sample study of the Ingessana hills artisanal gold mining community, Blue Nile State, Sudan" by Prof. Khalil A. Al Medani, University of Nileen, Khartoum, (December, 2003).

During our short orientation survey, and according to the mission objectives, the visits focused primarily on the sites where mercury is used and on the area where the sociological study was made, in order to be able to correlate the environmental and the health assessments subsequently.

Sociological reports, advise from their authors and a short orientation survey carried out during the first days of the field mission, allowed us to select 3 main targets to be studied[2]: the two main artisanal gold mining sites of Gugub and Khor Gidad and the Taga village as a control site (main activity of this populated village of Ingessana was farming and mercury has never been used).

[2] Details are given in the following chapter 4.2

4.2. LOCAL MINING PRACTICES AND USE OF MERCURY

4.2.1. Types and location of mining activities

Artisanal gold mining activities in the Ingessana Hills started in 1996 when a displaced Dawala ethnic group of Kurmuk district, also skilled artisanal gold miners, discovered gold in quartz veins around Gugub village. They first started artisanal gold mining along the stream terraces and later on quartz vein slopes.

In the Gugub district, there are two seasonal types of mining activities:

- Miners pan alluvial and elluvial gold when the local stream is flowing during rainy season between July and December. Ancient or inactive panning sites are visible all around Gugub and Khor Gidad villages along one to several meter wide wadi and Khor (Khor Alyas, Khor Abu Djal, Khor Shareban, Khor Gidad) (Illustration 5). In those sites miners do not use mercury and recover only visible gold during rainy season. No activity of this type was observed during our field mission which took place during the dry season.

- During dry season, due to shortage of water in pit sites, only primary gold associated with quartz vein and colluvions are mined. Miners indicated that mercury is used only to recover gold from primary ore and that primary ore exploitation is more recent than alluvial one.

Sociological study mentioned that, nowadays a gram of gold produced from alluvium through panning only has a higher price in the local market (US$9-9.5) as compared with a gram of gold extracted from hard rocks through amalgamation (US$ 6- 6.5).

Artisanal Small Scale Mining (ASM) in the Ingessana Hills varies somewhat between villages, with some identifying an active participation in the activity and others a decline depending on season and gold-bearing quartz vein discoveries.

Near around Gugub village, activities on primary ore were suspended after spectacular gold discovery of small gold-rich quartz vein last September 2003 in Khor Gidad located 7 km to the north. GRAS geologists report that ~500 miners (officials said 6,000) rushed chaotically into the area from Gugub and elsewhere extracted ~56 kilograms of gold in a week time.

According to our interviews and observations it appears that intensive use of mercury in the area is quite recent (around 3 years and may be less) and mainly developed in Gugub where gold was first discover and in Khor Gidad after the gold rush. The other sites mentioned in the sociological reports (i.e. Turda, Khor Neiwi) are alluvial types, without mercury use and presently abandoned.

During our mission those two sites were the only ones in activity. Khor Gidad has an extraction and processing sites and Gugub has only a processing site. However a few isolated women continue to work occasionally on ancient quartz overburden and tailing around Gugub (Abu Djal quartz veins).

The village of Gugub is the most important one with around 170 households (Illustration 3). Primary ore is usually transported to Gugub where families of miners are living and where merchant propose mercury in their shops. The Khor Gidad mining site is located too far from Gugub (around 7 km by track) to allow daily ore transportation by hand and families from Gugub have started to build up new huts in Khor Gidad (around 70 household) (Illustration 4). Seven shops selling mercury were identified in each site.

4.2.2. Mining practices

Mining practices are described in the sociological survey (Khalil. A. El Medani, 2003 and Ibrahim, 2003).

Artisanal gold mining in Gugub is practiced by both Dawala and Ingessana tribesmen without legal titles. Most people mine and process in small groups which is basically a family affair. The procedures used by local people are representative of very poor people using simple and traditional practices. During our stay, most of the activities were performed by women (13-35 years old), including the hard tasks of digging and excavation. The women represent more than 50 % of the labor force; in the rainy season this can reach as much as 90 %, as men go planting (Ibrahim, or. com.).

The miners do not comply with the provisions provided in the Mines and Quarries Act (1972). Given the adverse situation created by the civil strife around Kurmuk and Queissan boarder areas in 1996, and in an effort to develop the sub-sector in a sustainable way, the Government tried to legalize the gold mining in southern Blue Nile and elsewhere by granting special licenses. A few mill owners introduced hammer mills into the area in 1997-1998 but authorities soon drove them out. Although the known gold occurrences in the Ingessana are relatively small and scattered, back in 1999, a private investor obtained an exclusive prospecting license for gold exploration and mining in a 10 km^2 area around Gugub from the Ministry of Energy and Mining but for the adverse reasons surrendered the area. A condition imposed by Government in such deals is the strict compliance of the artisanal gold miners with mining alluvial gold only.

Now the area is open for licensing without any restrictions on the artisanal gold mining activities. The only restriction imposed by Government is the introduction of rock mills into the area (Ibrahim, 2003).

In the area two different types of gold mining are present: mining of alluvium and colluvium and mining of gold-bearing quartz veins.

Mining of alluvium and colluvium

The description of the exploitation of alluvial ores will not be detailed in this report as far as:

- it is made without use of mercury;
- it is already described in the sociological report;

- no exploitation of this type was observed during our mission.

Mining is done during rainy season only. Ore excavation in alluvium terrace of different Khor and wadi takes place in the vicinity of the villages and implies only small groups of 10-20 peoples. The estimated average daily amount of alluvium extracted from pit by a male miner is about 0.5 ton.

The process involves the following steps:

- Site preparation and removal of the overburden;
- Digging of the excavation pit for mobilisation of the alluvium;
- Panning of the ore;
- Hand recovery of gold specks and nuggets from heavy mineral concentrate.

Alluvial-type gold produced in the area goes directly to the market without further purification (Ibrahim, 2003).

Mining of gold-bearing quartz vein

Mining of gold-bearing quartz vein was the only type we observed during the field mission.

(1) Ore extraction, digging and ore selection on the site

Miners noticed that ore is richer at the footwall of the gold-bearing quartz lenses and consequently the quartz is frequently totally extracted. Miners also work with elluvial material and altered wall rock. In the first meters, the extraction is done mainly by women in a rather muddled way without mechanical tools (Illustration 6). Men are only involved in mining at deeper depths. Wildcat digging and excavation are common. Digging tools include the rudimentary axe, pick, and shovel. Sledge hammer and chisel are used mainly in hard rock excavation (Illustration 6). Miners do not use explosives.

The shafts are up to 15-20 meters deep, dug every 3-4 metres, interconnected and barely timbered.

The material is manually hoisted and sorted out at sight in an empirical way in order to try to concentrate the most probable gold-bearing material. Artisanal primary gold mining entails visual selection of mineralized rock pieces (Illustration 6). The big pieces of quartz are burnt overnight to facilitate the hand-crushing and manual milling.

The estimated average daily amount of gold-bearing quartz rock extracted from pit by a male miner is about 20-30 kilograms.

At this stage, the selected ore (Illustration 6) is than transported to the «family unit» at Khor Gidad or more frequently at Gugub.

Illustration 6 - Women mining activities at Khor Gidad quartz veins area.

(2) Crushing, milling and panning at home

Crushing, manually milling and panning are done by women in the yard of family unit at the shadow of huts or awning. Rock grinding is performed by grindstone or steel mortar (Illustration 7). The semi-final quartz + gold powder (200-500 microns) are panned by women.

The grinding capacity (to < 0.074mm) is less than 5 kg/day/individual. Miners can crush and grind more elluvial material and host altered rock than quartz.

Illustration 7 - Grinding with steel mortar (a) and grindstone (b).

Panning is conducted manually in excavated pools using traditional wooden pans. The tailings are disposed around the huts out of the «family unit» (Illustration 8). Efficiency of panning using the traditional wooden pan is ~50 %. Apparently, all fine gold grains falls down with the light fraction of the tailings. Panning test on waste heap performed during the mission indicated frequent gold specks.

No one mentioned practices of quartz powder storage. Panning and then amalgamation are performed in one daily sequence.

Illustration 8 - Panning area in Khor Gidad producing an important quantity of tailings around the huts and the "family units".

(3) Amalgamation at home or at the shops

After crushing and/or milling, the pan concentrate is shipped off at home or to the shops for amalgamation. In Gugub artisanal gold mining sites, mercury is used in extraction of fine gold particles from the panned concentrate.

The way of handling mercury in gold amalgamation is unsophisticated (Illustration 9 & Illustration 10). After a last panning performed in the enclosure (Illustration 9a), Hg is poured onto the concentrate with water and mixed with bare fingers to make the amalgam (Illustration 9b).

Illustration 9 - Gold recovery process phases (a) panning (b) amalgamation by hand (c) squeezing with piece of cloth (d) roasting on frying pan.

After thorough mixing, the amalgam is squeezed through a piece of cloth and the excess Hg is recovered for reuse (Illustration 9c). The miners collect the amalgam by hand, taking no precautions at all. After that, the remaining amalgam is transferred to an open plate or frying pan for roasting (Illustration 9d). In the private yard there is no specific place for amalgamation. Frequently, owners indicated to us 2 or 3 differents places located along fences or at the shadows of awnings (Illustration 10).

Illustration 10 - Amalgamation performed without precautions in the «family unit».

(4) Roasting at home or at the shop

The gold amalgam is roasted in mobile bonfires which facilitate the movements outside or inside huts. It is especially the men who practise the roasting.

Daily, they roast the amalgam freely without taking any precautions. The roasting operation can occur (Illustration 17):

- in the village close to the dealer shop where they buy mercury;
- in the yard of the «family unit»;
- in the huts (usually the ones dedicated for cooking).

The miners place the gold amalgam on a steel plate and burn it in a bonfire until they consider by visual experience that the *"doré*" is ready (Illustration 11 & Illustration 34). The diameter of amalgam burned during the demonstration carried out during our visit range from 3 to 8 mm. We expect that the duration of the burns (~ 10 minutes) is too short and temperature produce by the bonfire are too low to burn all the mercury. Roasting tends to be incomplete and at least 15 - 25 % of the *"doré"* contains residual mercury (Illustration 11). The *"doré"* also contain other metals accompanying gold in the ore (lead, iron, copper).

Illustration 11 - Exemple of amalgam before roasting (left) and “doré” (right) after roasting.

(5) Recycling of waste and tailing in pools

The phases of grinding, amalgamation and roasting generate tailings, residues or waste often thrown on the ground near the zones of operation. We find frequently in or around enclosures or even gardens, heaps of waste sometime several cubic meters in size. Panning made on this type of material or in grounds near working zones showed the presence as well of gold specks as sometimes drops of mercury especially in Gugub.

Workers indicated that during rainy season part of these tailings and residues are sometime panned in pools located in the *Khor Alyas* close to the southern entrance of Gugub village. Heavy mineral concentrate are then amalgamated and roasted again at home. Tailing recycling could be done many times in order to recover residual gold.

(6) Water supply

One of the main local problems is the lack of water in mid summer. Water is provided and bought by Ingessana women and children that bring the water from about 2 km away (Ibrahim, 2003). They carry a pair of 4-gallon plastic containers on their shoulder with the aid of a stick for making balance or on their heads (Illustration 12). The eight gallons of water cost S.D.50 (US$ 0.2).

Illustration 12 - Water supply from wells assumed by women and children.

4.2.3. Gold production and use of mercury

Gold production from quartz vein mining

It was very difficult to evaluate the quantity of gold produced from alluvium without use of mercury and from quartz vein with mercury amalgamation.

We only estimated the production of gold from the exploitation of the gold-bearing quartz veins which only led to the use of mercury.

Quartz extraction is a dangerous and difficult work compare to alluvium extraction. In a shear zone gold repartition could be erratic and frequently need detailed geological and mineralogical studies to be well understood. Part of the miners discover this new artisanal mining and appeared sometime disappointed. They do not have important skill and experience to exploit quartz lenses and the mining field is a succession of old and new wildcat holes with quartz overburden all around.

Different parameters indicated that it is possible that only 30 to 50 % of the gold contained in the ore is recovered during the complete process and therefore by the miner:

- Large amount of quartz abandoned on site;
- Visual selection of the best sample on site without lenses;
- Uncompleted manual grinding;

- Loss of gold during panning;
- Amalgamation process.

Sociological study and interviews carried out during our mission give some indicative data to try to evaluate the quantity of gold produced and mercury used during artisanal gold mining processes in the Gugub sites:

- The workers said that one worker produces 0.5 to 1 g Au/day. The production is organised by family and the production of one worker must be considered as the production of one family. Sociological studies indicated that adults in age to work are around 350 in the 2 villages. We considered that there were 200 to 300 families working for about 300 days per year. Taking into account this information, the quantity of gold produced ranged from 100-300 g Au/day and 30-90 kg Au/year.
- The dealers said that they buy 5-10 g Au/day. The number of dealers identified in the area ranges from 15 to 20. Taking into account this information, the quantity of gold produced is 75-200 g Au/day and 22.5-60 kg Au/year.

  These estimates were based on two independent sources that gave similar results. Workers and dealer probably underestimated their production and that actual values may be higher.
- Extraction capacity does not exceeds 20-25 kg/day/workers and the manual grinding capacity is probably less than 5 kg/day/workers. All the adults in age to work cannot produce at the same time 25 kg of ore from their mining activity and grind 5 kg of it. Persons for separated tasks are needed. In this case, Illustration 14 indicated that to produce 100 g Au/day from the Gugub sites workers involved must be 800 and gold grade 30 g/t and to produce 300 g Au/day workers involved must be 1,000 and gold grade 72 g/t. Gold analyses carried out by GRAS on Gugub quartz vein (Elnour K. Mohamed *and al.*, 2002) indicated that such average grade are unrealistic. The gold analyses carried out on 53 quartz chip samples ranges between 0 and 14.8 g/t with only 7 values exceeding 1 g/t (1.10; 1.45; 1.72; 1.90; 2.3; 4.04; 14.8).

Annual artisanal gold production estimates in Gugub sites for the period 1997–2002 is 450 kg Au/year (Ibrahim, 2003). But we demonstrated that the 350 individuals that works in Gugub can not produce the quantity of gold indicated:

- Hypothesis 1: a large part of the gold sell during dry season (probably 50 %) comes from alluvial production;
- Hypothesis 2: a large part of the gold sell during dry season (probably 50 %) comes from gold reserves made by workers during rainy season.
- Hypothesis 3: the amount of miners working in the area is underestimated;
- Hypothesis 4: gold production estimation given is more historical then actual.

The Illustration 13 shot during our mission (dry season) militate for hypothesis 1 or 2 : the hand of the gold dealer is full of alluvial gold nuggets instead of "*doré*" pellets coming from roasting.

Illustration 13 - Gold "reserve" shown by a dealer.

A	B	C	D	E	F
Daily Production of gold (Au g/day)	Gold Grades (Au g/t)	Daily quantity of ore extracted needed (kg)	Number of Miners needed (production = 25 kg/day/workers)	Number of Workers involved in Crushing needed (production = 5 kg/day/worker)	Total number of workers needed
		(A/B) * 1000	C/25	C/5	D+E
100	1	100000	4000	20000	24000
	5	20000	800	4000	4800
	10	10000	400	2000	2400
	15	6667	267	1333	1600
	20	5000	200	1000	1200
	25	4000	160	800	960
	30	**3333**	**133**	**667**	**800**
	50	2000	80	400	480
	70	1429	57	286	343
300	1	300000	12000	60000	72000
	5	60000	2400	12000	14400
	10	30000	1200	6000	7200
	15	20000	800	4000	4800
	20	15000	600	3000	3600
	25	12000	480	2400	2880
	30	10000	400	2000	2400
	50	6000	240	1200	1440
	72	**4167**	**167**	**833**	**1000**

Illustration 14 - Estimates of number of workers and Au-grades necessary to produce 100 to 300 g of gold in a day from gold-bearing quartz vein in Gugub area.

Mercury consumption

Sociological study and interviews carried out during our mission give some indicative data to try to evaluate the amount of mercury consumption during artisanal gold mining processes in the Gugub sites:

- Mercury is only used to recover gold from primary ore. We demonstrate that gold produced from primary ore is probably 100-150 g/day and 30-45 kg/year. The ratio of Hg lost per Au produced is usually estimated to be 1.5. Following this ratio, the quantity of Hg lost per year is 45 to 67 kg. In this figure the use of mercury is around 250 g Hg per household of artisanal miners per year.
- The dealers said that they sell 2-4 g Hg/day/workers. On the basis of 200-300 families involved, the quantity of Hg sell per year is 200-360 kg released in the environment. In this figure, the use of mercury is around 1000 g Hg per household of artisanal miners
- Taking into account this information, the Hg lost/Au produced ratio is probably higher than 3 in Gugub area. Following this ratios and an annual gold production from quartz-bearing quartz vein of 30 to 45 kg Au, the quantity of Hg used per year is 90 to 135 kg. In this figure, the use of mercury is around 450 g Hg per household of artisanal miners

According to Ibrahim (2003) the mercury lost to the environment annually was 675 kg but his estimate was based on the wrong consideration that all the annual gold production (overestimated 500 kg per year) is coming from quartz vein mining. We demonstrated previously that this is apparently not the case in Gugub district.

We identified 3 possible sources of loss of mercury:

- Wrong manipulation of mercury at the shop or at home;
- Lost of Hg on the ground or in the tailings during the amalgamation phase;
- Evaporation during the roasting phase

According to our field observations and the estimations performed, the annual use of mercury in the Gugub district ranges between 250 and 500 g Hg per household of artisanal miners.

5. Methodology

5.1. SAMPLING STRATEGY

After the orientation survey, covering the area selected, the following points were analysed:

- Where are the main sources of mercury pollution in the artisanal gold mining of the area, taking into account that the sites visited are representative of this activity in this area?
- What are the main pollution vectors that are likely to transfer the mercury towards a target?
- What are the main target(s) exposed to the direct or indirect effects of mercury ?

This analysis enabled us to classify the sites we visited according to their specific features and their ability to represent the main local and regional risks arising from artisanal activity in this area.

The artisanal gold miner families and the (10-15) local gold merchant shops in Gugub and in Khor Gidad constitute the same broad mercury hotspots. There is no plan of the villages of Gugub and Khor Gidad. The location of the "family unit" of the miners is not exactly known.

As in Zimbabwe (Billaud and Laperche, 2003) and Lao PDR (Freyssinet *et al.,* 2004) the sampling strategy was orientated following a risk assessment approach, considering the various sources of pollutants, their transfer and pathways and the potential targets. The following table summarises the field observations (Illustration 15).

	Items Considered	Level of occurrence
SOURCES	• Shops Hg storage	✱✱
	• Accidental Hg spill during amalgamation (huts & shops)	✱✱✱
	• Amalgam roasting in the hut	✱✱✱
	• Wastes dispersed	✱✱
	• Contamination of sediments during panning on residues in Gugub	✱
TRANSFER & PATHWAYS	• Household dust contamination	✱✱
	• Hg vapor dissemination contaminating the house and its environment	✱✱✱
	• Soil contamination in the vicinity of contaminated huts	✱✱✱
	• Sediment transportation	✱
	• Transfer to the biological chain (fishes)	✱
HUMANS TARGETS	• Hg inhalation during roasting	✱✱✱
	• Household dust and soil ingestion (mostly children in huts or yards)	✱✱✱
	• Contaminated dry Corn and sorghum consumption	✱✱
	• Fish consumption (rare)	✱
	• *Contaminated poultry consumption*	not considered in that study

Illustration 15 - Main components of the risk analysis.

The analysis of the system lead to reinforce the sampling in the villages and particularly in and around the huts of artisanal gold miners and more generally in and around the " enclosed family units " which grouped several huts of the same family. <u>The main target identified are local people. Potential risks to the ecosystem were considered to be minor in that process</u>.

It was then decided to focus the sampling on the following medias (Illustration 17):

In the Gugub and Khor Gidad villages

- Top soils: potentially submitted to ingestion by local people, mostly children and poultry. Sampling was focussed around the huts of artisanal gold miners, in the yard of "family units" which collect several huts and in the main square of the village (school, mosque).

- Composite grab samples were taken from tailing hills around "enclosures dwelling" and in garden where vegetables are being grown.

- Some *Termites hills* located in amalgamation zone, in garden or inside huts were tested in order to check if termites can concentrate Hg during hill building.

Location Type	Number	GUGUB				K. GIDAD				TAGA			
		Total	Yard	Hut	Shop	**Total**	Yard	Hut	Shop	**Total**	Yard	Hut	Garden
Family unit (miners)	Spot	10	9	8		7	7	4					
	Samples	35	21	14		25	20	5					
Shops and family unit associated	Spot	2	2	2	2	5	5	3	2				
	Samples	13	7	4	2	21	16	3	2				
Garden	Spot	6				3							
	Samples	11				3							
Mining Area	Spot	2				5							
	Samples	3				6							
Reference	Spot	2				3				1	1	1	1
	Samples	4				3				4	2	1	1
TOTAL	Spot	15	11	10	2	17	12	7	2	1	1	1	1
	Samples	66	28	18	2	58	36	8	2	4	2	1	1

Illustration 16 - Distribution of samples (soil, dust, termite hill, tailing) by spots and type of location in the 3 villages.

- Household dust: as amalgam roasting occurs sometimes in the hut, dust was sampled in some selected huts.

- Air monitoring: Hg contents in atmosphere was performed outdoor for background evaluation and indoor (huts) under different conditions (see below).

- Wadi and Khor stream sediments: the first objective of the sediment sampling was oriented to control Hg mobility in the drainage pattern around the villages and further in the main collector wadi Maganza. The strategy was adapted to the field conditions; sediments were taken mainly along the narrow streams as possible; we collected both sands (stream) and silty black sediments (banks).

Fifteen soil and seventeen dust sampling spots were respectively selected in Gugub and Khor Gidad villages. Details are given in the Illustration 16.

The spots sampled for the environmental study are identified on the sketch maps of each village (Illustration 18 and Illustration 19).

Based on information from the sociological survey, reference houses were identified in each village: school and mosque yard in Gugub and recent “enclosures dwelling” out of mining area in Khor Gidad. The selection criteria were based on the lack of artisanal mining activity for the concerned household.

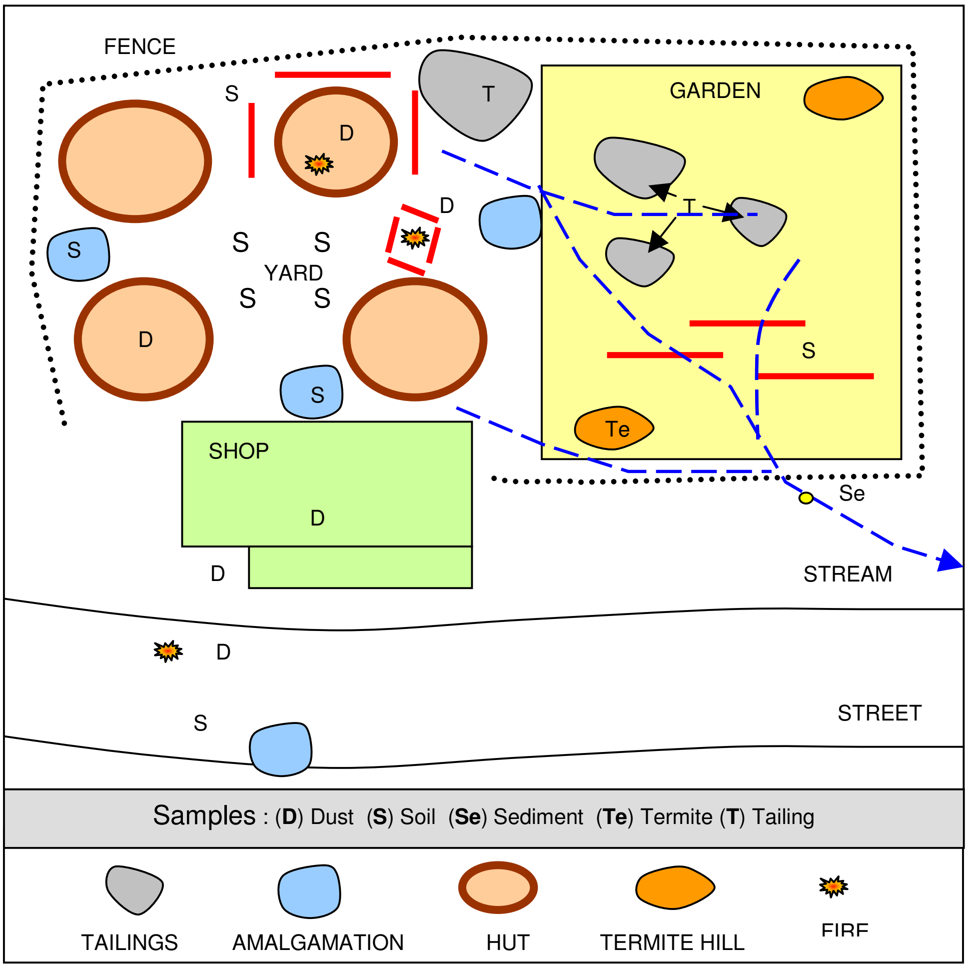


Illustration 17 - Sketch map of the sampling strategy applied in the villages.

- ***River system***

  - **Stream sediment**

As mentioned by Suleiman (2003), the extend of mercury pollution from artisanal gold amalgamation in Gugub and Khor Gidad villages could be controlled by the surface run-off. The villages are located on a high relief and rugged hillside with steep dendritic drainage system. As a result, high energy soil erosion characterizes the area during rainy season (600-800 mm). Although the general drainage pattern of the Ingessana Hills is radial, steep ravines draining Gugub and the surrounding artisanal gold mining sites coalesce on the north-east direction to join Wadi Maganza stream, which drains the north-eastern parts of the Ingessana Hills into the Blue Nile some ~45 km to the north-east (Illustration 20 & Illustration 22).

Wadi Maganza waters contain the artisanal gold mining waste/tailings washed off from Gugub as well as from the mining sites. Among these products, mercury is expected to move ahead with Wadi-fill (clay, silt, sand, gravel) along Wadi Maganza path up to the Roseries dam reservoir at a point ~20 km south of Ad Damazin (Illustration 2).

The objective of the sediment sampling was oriented to control Hg mobility in the drainage pattern around the two villages *Gugub* and *Khor Gidad* and in the main collector *Wadi Maganza*. (Illustration 18, Illustration 19, Illustration 23)

The strategy was adapted to the field conditions; sediments were taken along narrow streams where possible; we collected both sands (stream) and silty black sediments (banks).

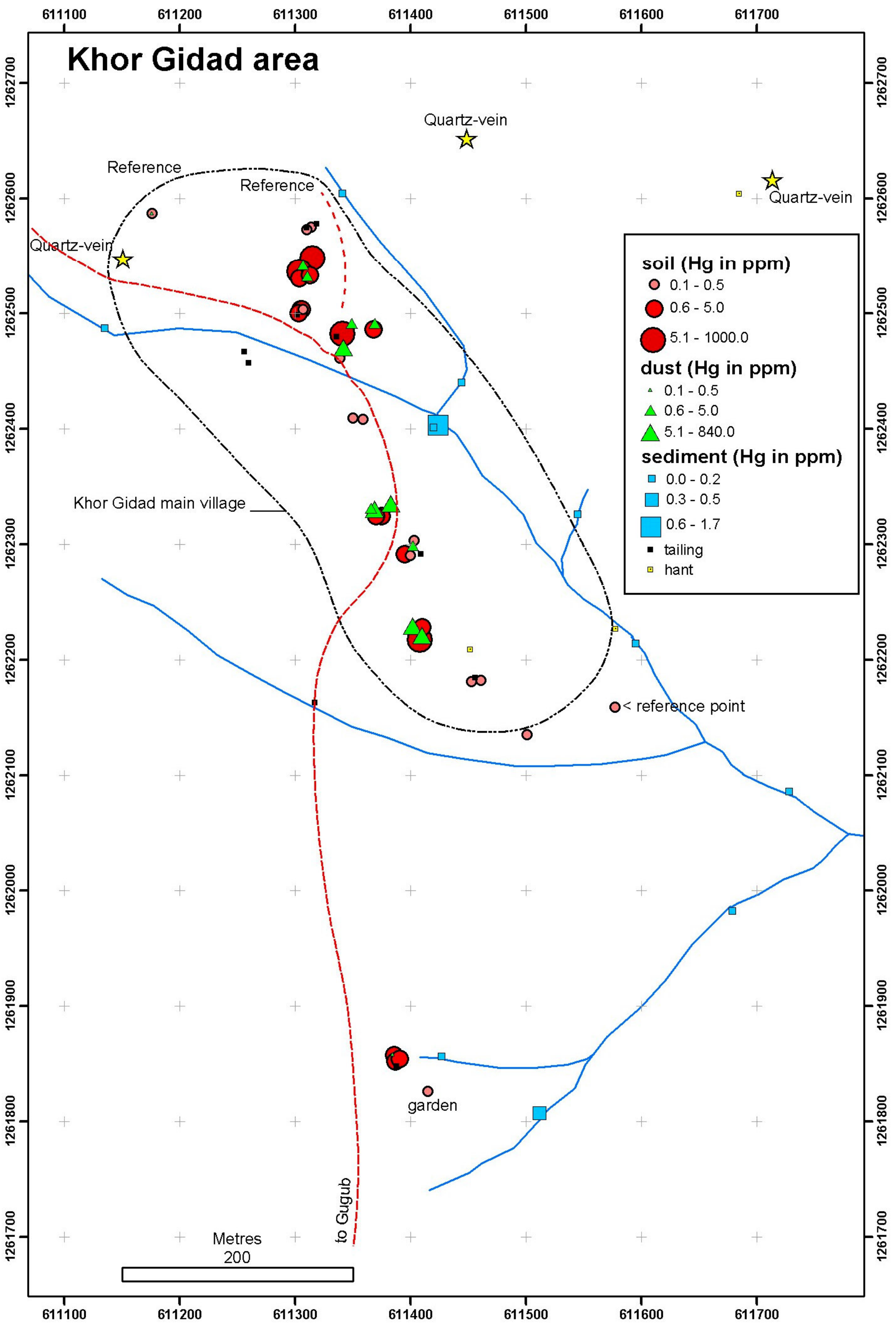


Illustration 18 - Sketch map of Khor Gidad area with location of samples and results of Hg analyses (Nota : "hant" = "termite hill").

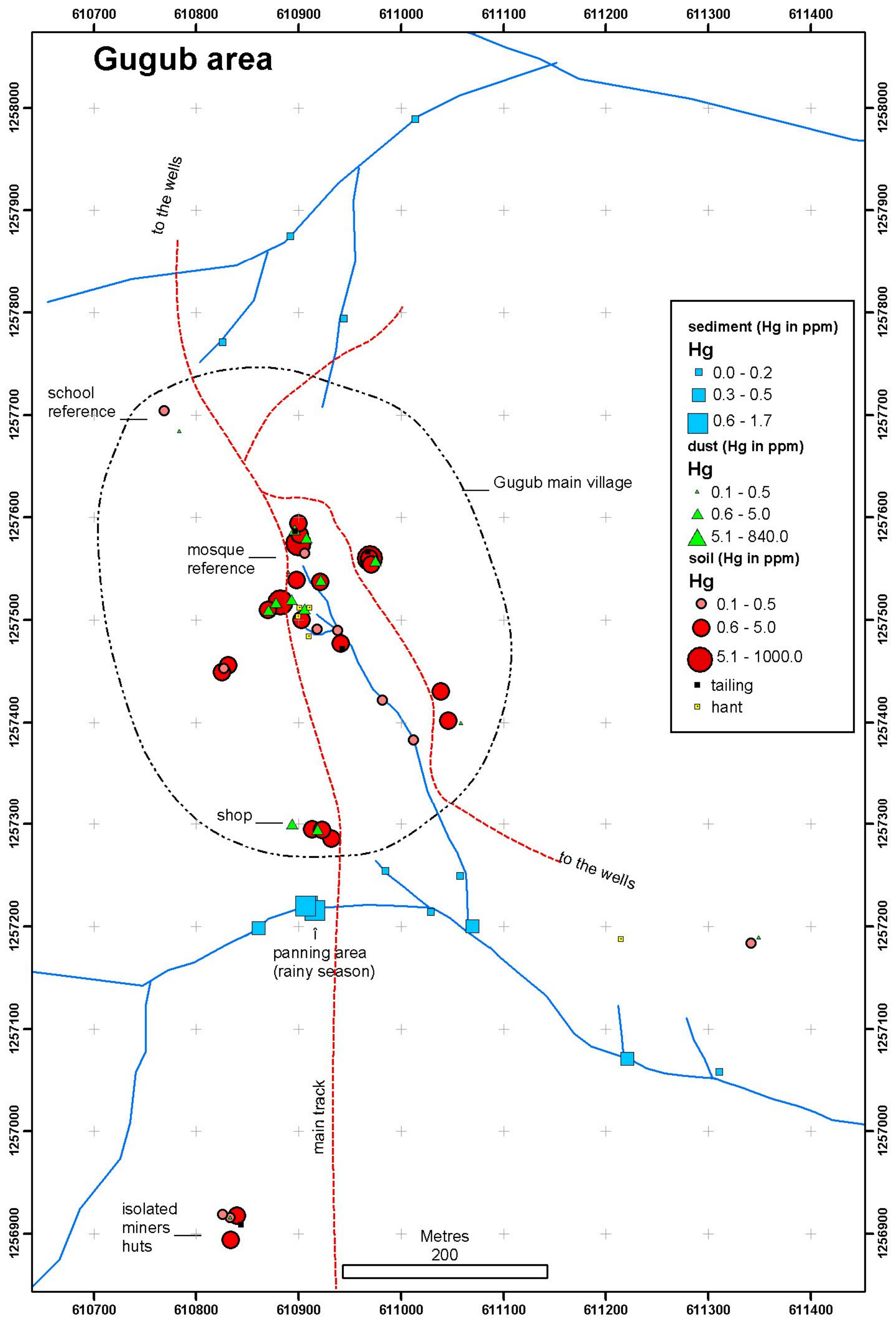


Illustration 19 - Sketch map of Gugub area with location of samples and results of Hg analyses (Nota : "hant" = "termite hill").

- **Fish**

According to the Protocols for Environmental & Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners (ASM) (UNIDO, 2003), the fish sampling strategy was carried out as follows:

- Identify the target species based on interviews with local people, fishermen, fish markets and, if possible, in consultation with local or regional experts.
- Identify areas for fish sampling, including both upstream and downstream of mining activities and, if possible, reference areas.
- Identify sampling areas that coincide with geographic areas identified as "environmental hot spots".

We had particularly unfavorable sampling condition in the Gugub and Khor Gidad sites; the Wad Maganza and its tributaries had dried up completely making it impossible to catch any fish in this area.

The sociological study also indicated that fish are consumed only occasionally and mainly dried. Fishing is an occasional occupation mainly practised by the younger generation. According to the local people and the Sudanese participants, the Roseires reservoir was the only site where we could find fish of different species and size, as requested by the protocol.

Fish sampling was carried out in the Roseires reservoir due to the lack of fish elsewhere in the selected area. The aim was to test contamination of the Nile at this location, but not to interpret Hg release issued from the Gugub area.

Despite this situation, we managed to take some samples from two sites:

- (i) in the Roseires reservoir (fishing spots 1, 2 and 3), about 50 km to the east of Gugub: the reservoir is fed by water from several watersheds, some of which were affected by gold mining activities which predated those at the site originally selected and which were probably on a larger scale, such as ~12 km east of the Blue Nile bank at Belguwa-Sakatna, sites ~80 km southeast of Ad Damazin. Mercury input may also come from other artisanal gold mining sites within the river catchment as far as Qeissan some 150 km to the south.This reservoir was built in 1965 and covers a total area of about 400 km^2. A large number of fishermen catch fish here, mainly using nets, especially in the part furthest from the dam. Most of the fishes are sold outside the fishing zone (supplying the city of Khartoum). The dried fish consumed in the Gugub area is mainly brought from Ad Damazin and the Roseires reservoir.

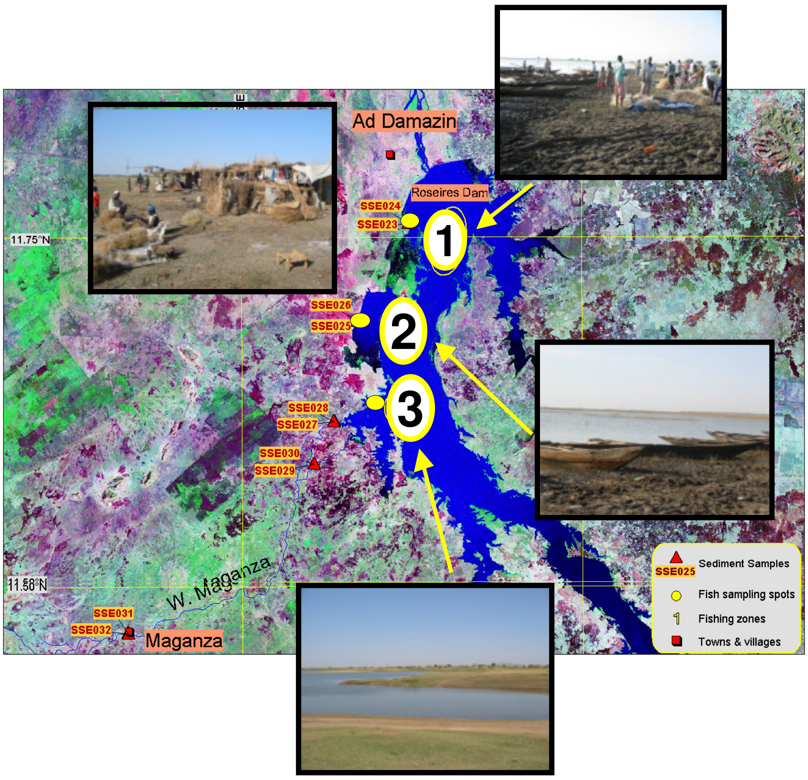


Illustration 20 - Location of the three fish sampling spots on the Roseires reservoir.

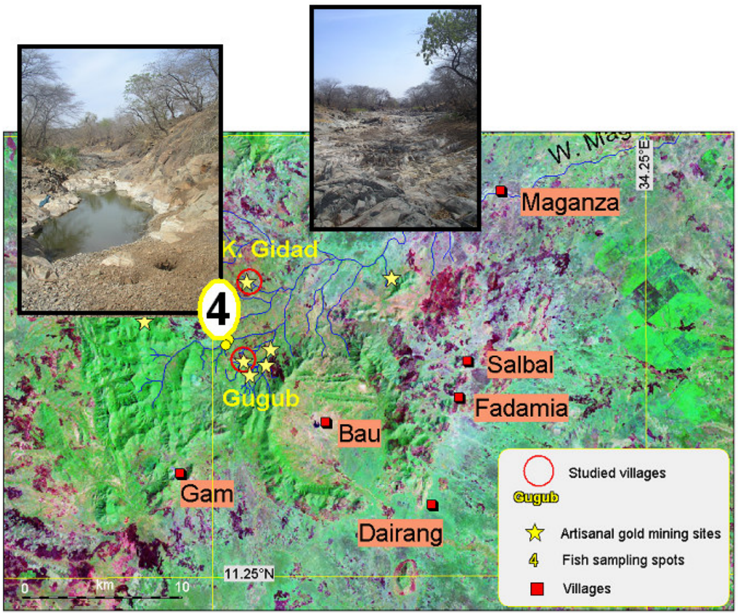


Illustration 21 - Location of the fish sampling spot N°4 in a hole in a small dried river, in the North of Gugub.

- (ii) in a part of the river which contained a small water hole (fishing spot 4 – Illustration 21) we carried out a fishing campaign and were able to catch several species of fish. Once again, this site was not directly connected to the gold washing zone and the village of Gugub.

Analysis of the results relating to the level of mercury contamination in the fish must necessarily bear in mind the constraints imposed by the sampling conditions and the absence of any direct relationship with the gold mining site and the village of Gugub. Nevertheless, they will show the current state of mercury contamination in the fish in this region of Sudan, especially around the dam, which is located downstream of several gold mining sites.

At the four fish sampling spots, catches were made by local fishermen, using nets.

Fifteen different species were collected, with a total of 108 individuals (Illustration 22). The 15 fish species collected are shown in Appendix 5.

	reservoir			**river**	**TOTAL**
sampling spot	**1**	**2**	**3**	**4**	
species number	**8**	**3**	**7**	**4**	**15**
fish number	**37**	**15**	**23**	**33**	**108**

Illustration 22 – Summary of the fish collected in the reservoir and the river.

5.2. SAMPLING PROCEDURES

Sampling procedures are described in detail in the field report (see Récoché *et al.*, 2004). The following table illustrates the distribution of samples per village and locations (Illustration 23).

Location	Gugub	K. Gidad	Taga	Maganza	Roseires	Total
Soil	32	31	3			**66**
Termite	5	3				**8**
Tailings	6	11				**17**
Dust	16	13	1			**30**
Air Monitoring	4	1				**5**
Sediment	26	13		6	4	**49**
Fishes		33			75	**108**
Vegetables	6		2			**8**

Illustration 23 - Distribution of samples by media.

5.3. ANALYSIS OF SAMPLES

5.3.1. Analysis of solid samples

The LUMEX RA-915$^+$ analyzer equipped with the RP 91C attachment (Illustration 24) is intended for measuring the mercury in solid samples. The RA-915$^+$ analyzer operation is based on differential Zeeman atomic absorption spectrometry using high frequency modulation of light polarization.

A radiation source (mercury lamp) is put in a permanent magnetic field. The mercury resonance line λ = 254 nm is split into three polarized Zeeman components (π, σ- and σ+). When radiation propagates along the direction of the magnetic field, a photodetector detects only the radiation of the σ- component, one of those falling within the absorption line profile another one lying outside. When mercury vapor is absent in the analytical cell, the radiation intensities of both σ components are equal. When absorbing atoms appear in the cell, the difference between the intensities of the σ components increase as the mercury vapor concentration grows.

The principle of the RP-91C attachment is based on the thermal destruction (at approximately 800 °C) of a sample matrix and the reduction of the bound mercury in the sample followed by a volatilisation and a determination of the amount of elemental mercury formed by the RA-915$^+$ analyzer.

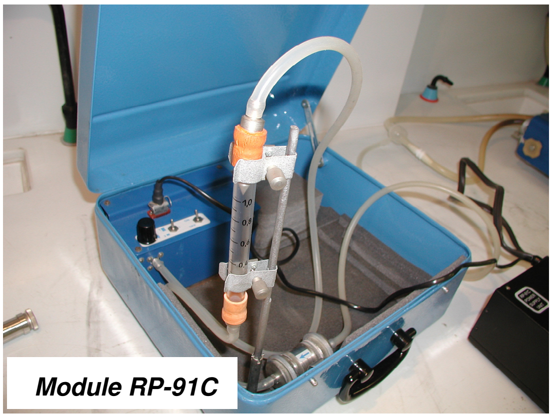


Illustration 24 - The LUMEX RA-915+ analyzer equipped with the RP 91C attachment.

The quantification limit is 0.01 mg kg^{-1}. For concentrations above 20-30 mg kg^{-1} a specific single-path cell is used in place of the multiple-path cell. After stabilization of the lamp of the RA-915+ and of the pyrolysis attachment (about 40 minutes), the equipment was calibrated with two reference material (NIST 2711 and CANMET STSD1). A sample (20 mg to 300 mg) is placed into a quartz spoon and inserted in the oven. The signal acquisition is automatically collected through a monitoring software on a laptop linked to the LUMEX RA-915+. The RA-915+ analyzer does not differentiate between mercury forms; it yields a total mercury concentration. Accuracy of the method was checked every ten samples by analysing a reference material (NIST 2709). 10% of samples were analysed twice with the LUMEX. 10% of results were confirmed by analysis with a reference method.

Before analysis, samples were dried (40 °C) and then ground at 80 µm. Results are given in mg kg^{-1} dry weight.

Quality control procedures are summarized in appendix 7.

5.3.2. Air monitoring

The LUMEX RA-915+ analyzer without the pyrolysis attachment (Illustration 24) is intended for measuring the mercury vapor concentration of ambient air, both in a stationary and continuous mode.

After switch-on, it takes about 20 minutes to stabilize the light source. When the measurement mode is started, a zero adjustment is first carried out automatically. Then the analyzer measures and continuously indicates the measured mercury concentration of the gas as both a numerical value and a graphic chart.

The detection limit and the flow rate are respectively given by the manufacturer at 2 ng m^{-3} and 20 L mn^{-1}. The multi-path cell should not be operated for too long in rooms with high mercury vapour concentrations (higher than 10,000 ng m^{-3}).

Currently, there is no easily available methodology for measuring levels of mercury in ambient air. The RA-915^{+} analyzer (Lumex) should need external calibration for precise validation of air mercury analysis. This calibration has not been possible before this mission. Absolute value given by the Lumex for mercury air concentration should therefore be considered cautiously.

5.3.3. Analysis of fishes

Before sampling the fish flesh, standard length[3] and body weight were measured on each individual and each was photographed. A small piece of dorsal skeletal muscle (1.5 x 1.5 cm) was cut out and kept in a formalin solution (10 % in deionised water) in 50 mL plastic bottles. Caps were tightly screwed and covered with Parafilm. Preliminary experiments in our Laboratory have shown no significant differences between total Hg concentrations, expressed on the dry weight basis, in muscle samples obtained by this procedure and in frozen samples[4].

All analyses were performed in the “Laboratoire d'Ecophysiologie et Ecotoxicologie des Systèmes Aquatiques” (LEESA), CNRS and University of Bordeaux, France.

Total Hg concentrations in the fish muscle samples were determined by flameless atomic absorption spectrometry. Analyses were carried out automatically after drying by thermal decomposition at 750 °C, under an oxygen flow (AMA 254, Leco-France). The validity of the analytical method was checked during each series of measurements against three standard biological reference materials (TORT-2, lobster hepato-pancreas; DORM-2, dogfish muscle; and DOLT-2, dogfish liver, from NRCC-CNRC, Ottawa, Canada). Hg values were consistently within the certified ranges (Illustration 25).

Detection limit (DL) for total Hg was based on three standard deviations from blank measurement: DL on a dry weight basis was 1.4 ng g^{-1}. Method precision (relative standard deviation, % RSD) of total Hg determinations, estimated from 5 replicates of fish muscle samples, was 5 %.

All fish muscle concentrations were reported on a dry weight basis (40 °C over 2 days).

[3] Standard length: from the nose to the caudal fin basis.

[4] This preservation procedure was set up during the first stage of the "Mercury in French Guiana" research program, since in most of the sites studied there was no electricity supply and biological samples could not be frozen on site. A comparative study was done over a 4-month period, using fish muscle samples collected from one individual (N=60) and stored at – 20°C or in diluted formalin, at room temperature and at + 35°C. Replicates were collected after 1, 2, 4, 8 and 16 weeks. No significant differences were observed between Hg total concentrations ($P<0.05$), expressed on the dry weight basis, for the different storage conditions.

		TORT-2	DORM-2	DOLT-2
Total Hg	certified value	0.27 ± 0.06	4.64 ± 0.26	2.14 ± 0.28
(µg g^{-1})	measured value	0.27 ± 0.04	4.78 ± 0.33	2.08 ± 0.12

Illustration 25 - Comparison of measured and certified values of total mercury concentrations using three standard biological reference materials.

5.3.4. Analysis of vegetables

Vegetables samples have been cleaned several times with ultrapure water to remove solid particles. Samples were dried at 40°C during 3 days and then ground to less than 2 mm. Between 0.1 and 0.2 g of dried samples were digested at 90 °C during 24 h in closed teflon bottles with 6ml aqua regia. The samples were then diluted to 50ml with ultrapure water.

Total mercury was analysed by atomic fluorescence after reduction with tin chloride. The system used is the analyser Merlin from PSA which is composed of a continuous flow system, a gaz –liquid separator purged with argon and an atomic fluorescence detector. Measurements were controlled by the PSA software.The reductant solution was 5% m/v $SnCl_2$ in 15% HCl. The standards were prepared from 1000 ppm mercury solution (MERCK). Working standards were prepared by diluting stock standards. The matrix of working standards is adapted to the matrix of digested samples. Typical calibration was in the range 0-500 ng L^{-1}.

Accuracy of calibration is checked with a different stock solution (PANREAC). Spiking of samples before digestion controlled the whole analysis. Samples have been diluted 10 times before analysis.

In order to evaluate mercury deposition on vegetables hanging in huts where roasting take place, the first few milliliter of water used to clean vegetables was kept for analyse. The volume of solution used was approximately 40-50 mL. The solutions were digested and then analysed following European standard EN13506 (water analysis by atomic fluorescence).

6. Results and interpretations

6.1. SOILS

According to the analysis of the process, the most probable contamination of soil is supposed to be related to:

- atmospheric deposition of mercury during the roasting and of the dissemination of household dust in the vicinity of artisanal miner huts. We sampled the top soil from 0 to 2 cm depth, about 2 m away from the hut's walls. Samples were taken along a 3-4 m lines (Illustration 26). Thus, soils around the hut were sampled on different side of the hut in order to evaluate the level of contamination in the vicinity of artisanal miner hut.
- solid deposition of mercury during the amalgamation process. We collected composite surface soil samples (0 to 2 cm depth) in the yards of "family unit", around usual amalgamation sites or roasting bonfires sites. The procedure (Illustration 26 & Illustration 17) consists of taking three to six samples, thoroughly mixing them to form one composite sample and to perform the laboratory analyses on a subsample of the composite as for the exterior hut samples.
- Composite top soil samples were collected in the school yard, in the mosque yard of Gugub village and in recent "family unit" out of mining area in Khor Gidad considered as reference point to evaluate the geochemical content at longer distance of the source of emissions.
- Composite surface soil samples (0 to 2 cm depth) were also collected for evaluation of Hg contamination in different garden close to amalgamation zone. Samples were taken along a 3-4 m lines cross-cutting superficial drainage (Illustration 17).

Illustration 26 - Soil sampling phases – (a) digging along line or point (b) sieving (c) division (d) collection in bottles.

Results of Hg analyses are reported in Appendix 6.

The Illustration 27 & Illustration 28 below show the distribution of Hg contents in soil in term of the villages and illustrates the average level of Hg content in the different location in each village:

- The “natural” geochemical background given by analyses in Taga village and in other reference location spots in Gugub ranged from 100 to 150 ng g^{-1}.
- The average geochemical content in the village of Gugub and Khor Gidad are around ten times higher than the local background. Medians range from 1213 in Gugub to 640 ng g^{-1} in Khor Gidad.
- Higher values in the 2 villages (up to 10^6 ng g^{-1} in Khor Gidad and up to 27,626 ng g^{-1} in Gugub) are related to zone of amalgamation where Hg droplet were visible after panning (Récoché *et al.,* 2004). The zones of amalgamation show values several times higher than in others places where values are close to the local background.
- The average contents in the garden range between 130 to 280 ng g^{-1} in Khor Gidad and Gugub respectively and are close to the background level. However, value in

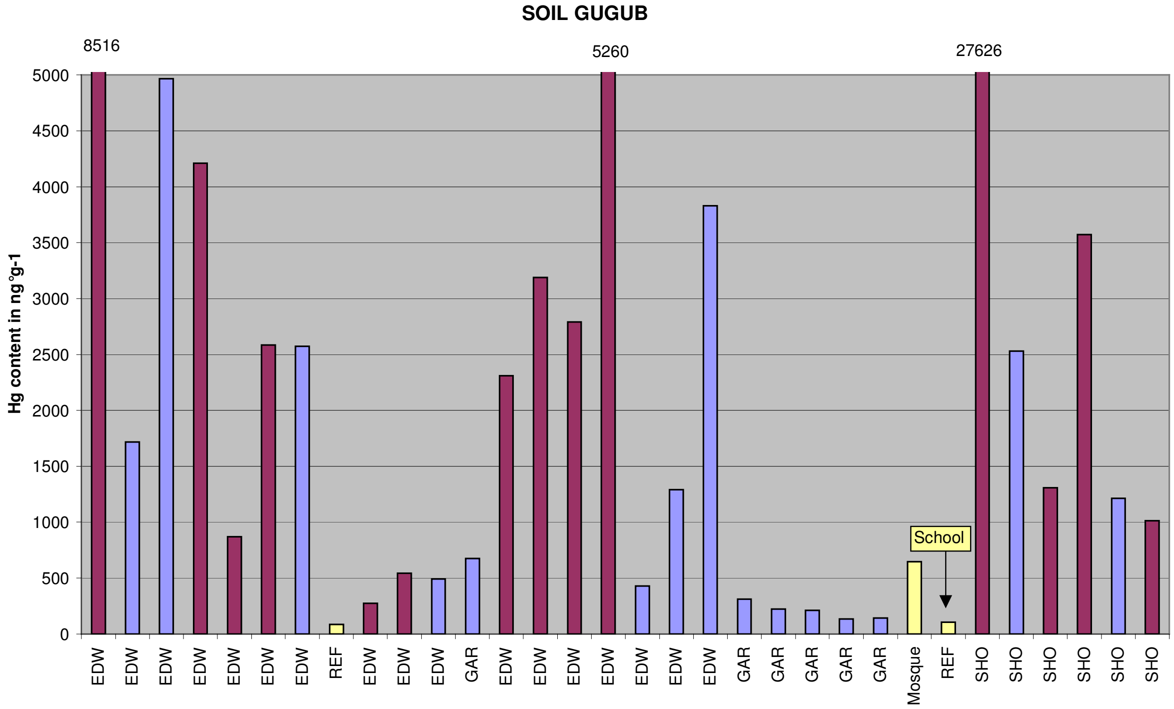
Gugub are higher than in Khor Gidad which could be considered as a quite new mining area.

- The point values are higher in Khor Gidad than in Gugub but the average background is higher in Gugub.
- School yard show background Hg contents (106 ng g^{-1}) higher than soils sampled around houses of artisanal miners (Illustration 28).
- In Khor Gidad the higher contents are related to the soil around the shops where amalgamation could be frequent and quickly performed without precautions and around the huts of dealers. In Gugub practices look different with high content in shops but also and mainly in the yard around huts of miners.

Location	Village	N	Min.	Max.	Med.	Mean	SD
Amalgamation place	GUGUB	13	275	27,626	2,585	4,273	6,894
	K. GIDAD	14	283	1,000,000	1,740	85,442	257,295
Garden	GUGUB	6	133	675	217	283	185
	K. GIDAD	2	114	151	133	133	19
Reference	GUGUB	3	83	648	106	279	261
	K. GIDAD	3	100	1,345	602	682	511
	TAGA	3	90	148	110	106	12
Yard	GUGUB	9	430	4,966	1,716	2,116	1,437
	K. GIDAD	11	100	3,328	240	763	1,000
Total	GUGUB	31	83	27,626	1,213	2,488	4,830
	K. GIDAD	30	100	1,000,000	640	40,230	180,784

Illustration 27 - Average Hg content in soil (in ng g^{-1}) (N: number of samples; Min.: minimum value; Max.: maximum value; Med.: median; SD: Standard Deviation).

Near the mining site (Khor Gidad), the miners make the last panning and the amalgamation close to the mercury dealer shop. We measured high Hg values near these places. In the village of Gugub, the final panning and the amalgamation are performed more frequently in the “enclosed family unit” and mostly in the yard between the hut where we note high values in soils.



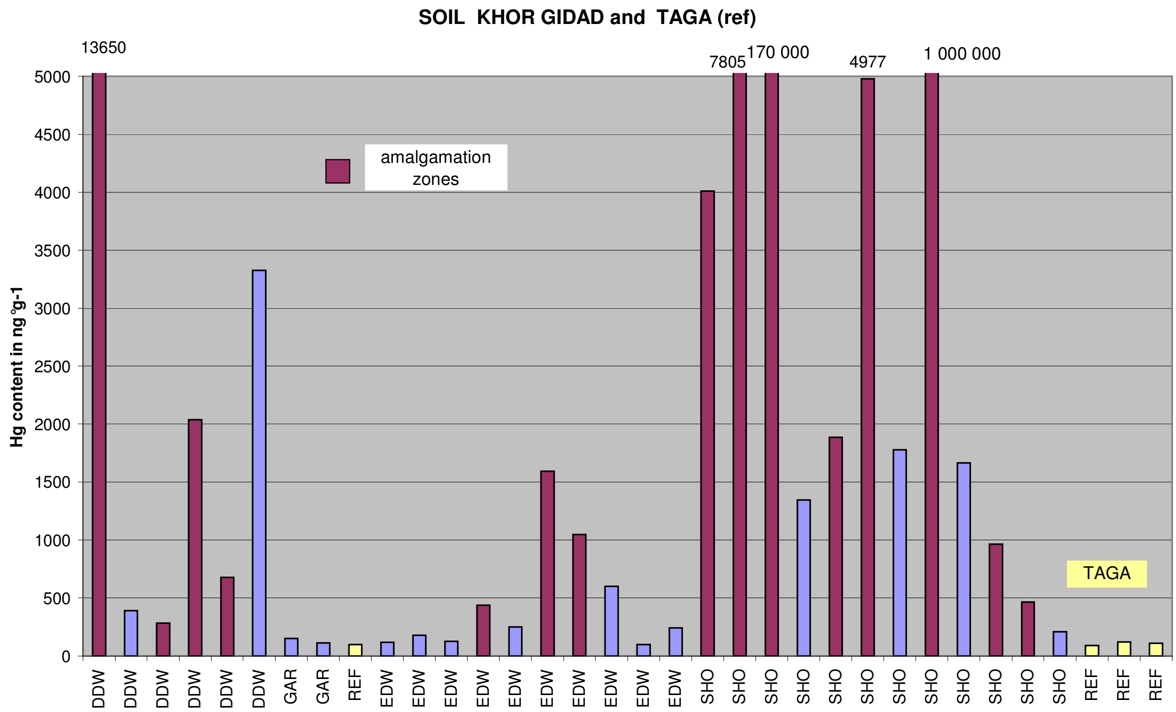


Illustration 28 - Average Hg content (in ng g^{-1}) in soils in Gugub, Khor Gidad and Taga villages [yard of reference (REF), "family unit" of dealer (DDW), "family units" of miners (EDW), shops and family unit associated (SHO), and garden (GAR)].

Several spots that were initially considered as reference in the Gugub and Khor Gidad villages, present higher Hg values than the background recorded at the reference village, Taga. These values show means that are too high for reference sites in the table of illustration 27. At Khor Gidad it is a soil sampled in a miner's hut (SSO052) and in a shop's backyard (SSO029). These site were said not to have been the object of amalgamation or roasting phases. Hg contents of the two samples are respectively 600 and 1,345 ng g^{-1}. These results show indirect ground contaminations from the surrounding processing places.

At Gugub, Hg content of the soil sampled in the school yard (106 ng $g^{-1)}$ is equivalent to the background. The soil sampled at the mosque’s entry where there have been normally no amalgamation or processing operation show, on the contrary, a Hg contamination (648 ng g^{-1}) *(ill.* 28). The school is located at the north extremity of the village, whereas the mosque lies at the village centre, in the middle of huts and in front of a shop, which could also explain and underline an indirect ground contamination around the gold recovery centres.

6.2. DUST SAMPLES

Depending on the information given by owner, dust sampling was carried out in different places:

- Inside the hut where roasting was performed frequently;
- Inside huts that never been used for roasting in the same “family unit”;
- Inside huts in Taga for control;
- Inside shops where frequent mercury exchanges and amalgamation are performed;
- Outside huts in the yard where families and specially children stay around roasting or close to amalgamation spots.

By asking questions it was rather difficult to identify what was the main place of roasting. In Khor Gidad, roasting outdoor seems to be the main way of roasting. It is seem that the proportion is approximately 50 % outdoor and 50 % indoor in Gugub.

The grounds of each hut were brushed to collect dust (Illustration 29). As a control, we collected sometimes 2 bulk dust samples per enclosure in different huts. After division the grab sample were collected in a 150 mL double-capped plastic bottle. Domestic dust samples were sieved at the laboratory at 500 µm (to eliminate pieces of charcoal, wood, hairs…) and analyzed with the LUMEX RA915^{+}.

Illustration 29 - Dust sampling in a hut.

Results are summarised in the following Illustration 30 & 33 and in Appendix 6.

	Total	GUGUB	KHOR GIDAD	TAGA
Number	29	15	13	1
Minimum	52	52	123	183
Maximum	840,000	2,751	840,000	183
Median	1,433	1,219	3,177	183
Mean	46,860	1,236	103,094	183

Illustration 30 - Average Hg content in dust per location type (in ng g^{-1}).

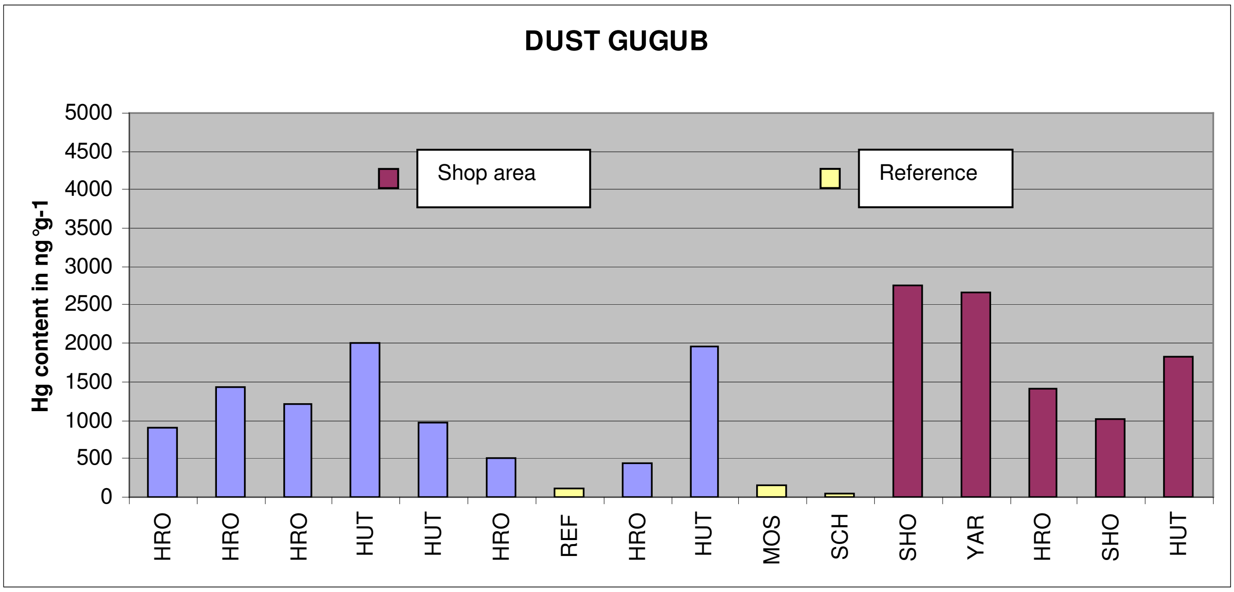
In the reference spots (REF) the Hg contents are low and range between 52 (school of Gugub) and 183 ng g^{-1} (hut in Taga). The contents are the same than those of the soils taken there (110 ng g^{-1} in Taga). This homogeneity shows that domestic dust is not particularly enriched in regard to natural soil.

In the village of Gugub the Hg contents in dusts taken in various places are rather homogeneous. It ranges between 500 and 2,760 ng g^{-1}, these values are several times higher than the background of reference spots. The values do not depend particularly on the samples location (inside of a hut with or without roasting, yard between several huts, and ground of dealer's shop). The Hg contents in dusts of hut where roasting takes place are close to those of huts having never been the object of roasting.

The Hg contents in dusts of Khor Gidad range between 123 and 840,000 ng g^{-1} and are higher than those of Gugub (lower than 2,760 ng g^{-1}). The strongest Hg contents come from dusts taken on the ground of trade shops (465,000 and 840,000 ng g^{-1}). Effects of nuggets are possible.

As in Gugub, except in the shops, there is no preferential distribution of the high values according to the samples location. The information supplied by the inhabitants can be indistinct but these results show that the contamination is rather general and homogeneous at the scale of the villages. Average contents show significant contamination of domestic dust in some hut and yard of artisanal miners. It is clearly demonstrated that indoor amalgam roasting may significantly contaminate the dust of the huts but there are no big differences between the Hg contents in soils compared to Hg contents in dusts on all village.

It is not surprising to find higher values in Khor Gidad where during, our mission the mining activity was more important and essentially concentrated on the mining of the quartz vein, contrary to Gugub where the activity is, at present, less intense and mainly without use of mercury. This contamination may be a long lasting effect as in Gugub, where artisanal mining is less performed by local peoples and where dust contamination is still present.



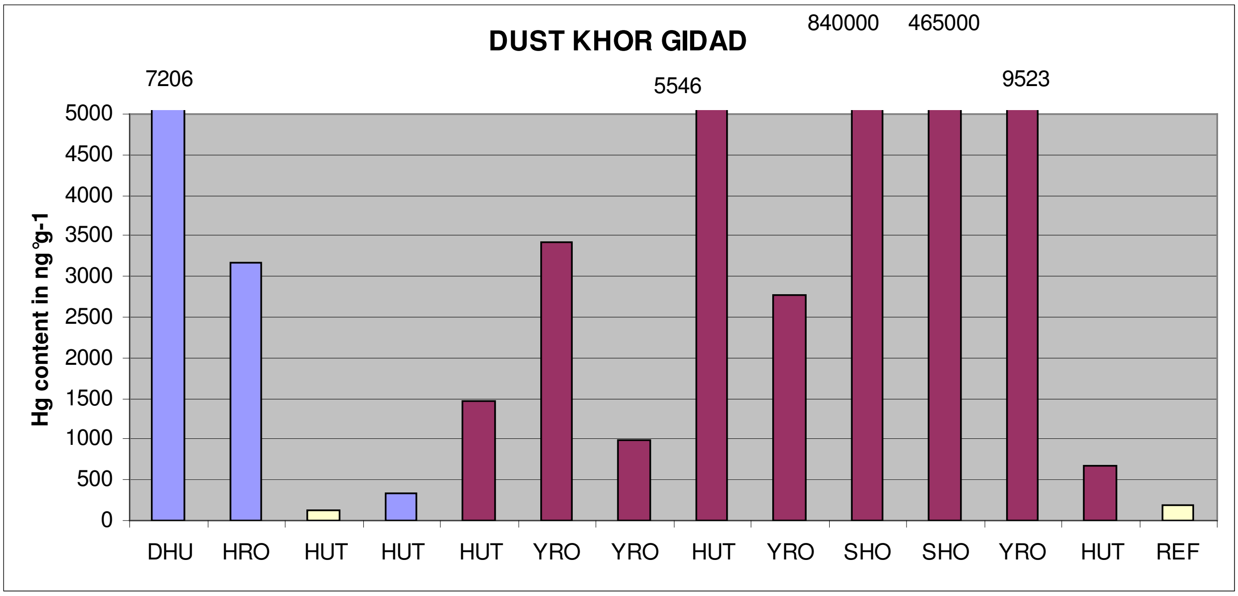


Illustration 31 - Average Hg contents (in ng g^{-1}) in domestic dust per village in (HUT) Hut; (HRO) Hut with roasting; (YRO) Yard with roasting; (MOS) Mosque; (SCH) School; (SHO) Shop; (REF) Reference spot; (DHU) Hut of Dealer.

6.3. OTHER SOLID SAMPLES

6.3.1. Tailings and residues

Composite grab samples were taken from tailing hills around enclosures. Sampling protocol was the same as for soils: sieving to pass 2 mm, division, collected in a 150 mL double-capped plastic bottle.

Illustration 32 - Sampling of tailings (left) and termite hills (right) around mining areas and villages.

In both villages of Gugub and Khor Gidad the Hg contents in the tailing are divided in 2 populations (Illustration 33):

- a main population with value close to the local background and
- a population presenting Hg contamination higher (from 1,550 to 2,630 ng g^{-1} in Gugub) and sometime very high (62,300 and 72,500 ng g^{-1} in Khor Gidad).

In the 2 areas, the tailings sampled on mining sites closed to pits and trenches (STA004, STA005, and ST014 to STA016) presented the lowest values and confirmed that there was no mercury used on the mining sites. In the village of Gugub, the highest values corresponded to tailings located in gardens (STA003 and STA017). In Khor Gidad the sample STA007 (62,300 ng g^{-1}) is a tailing constituted by ash and residues of amalgamation at the border of the main road and the sample STA013 (72,500 ng g-1) is a tailing also constituted by ash and residues of amalgamation located in the yard of a group of hut (“family unit”).

The difference between these two populations could be related to the proportion of residues of amalgams or ash content in the tailing. The high values measured in Khor Gidad tailings could correspond to recent tailings where no phenomenon of superficial washing took place. The ancient tailings of Gugub were able to undergo this washing what would explain their lower Hg content and their homogeneity.

These results show a contamination of these tailings which can be sometimes important. Their number and location in gardens or within the "enclosed family units" is a problem to be taken into account in the future operations of environmental management in the area.

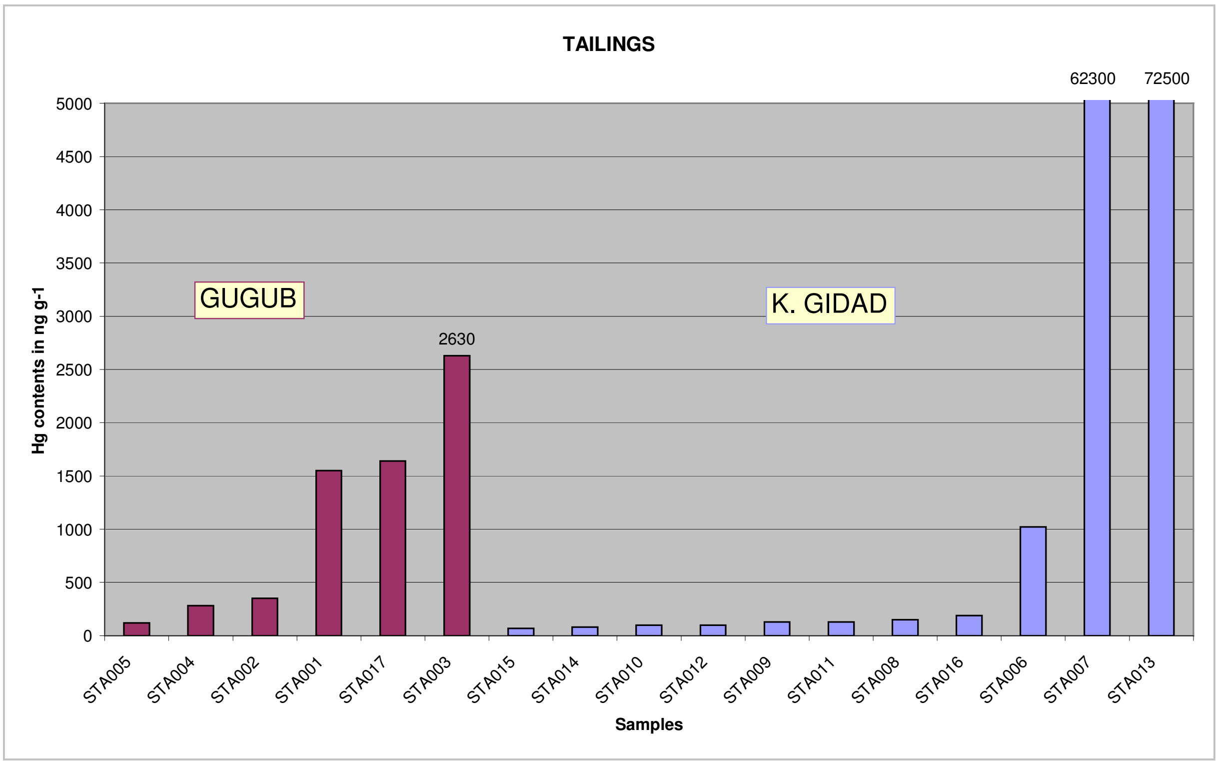


Illustration 33 - Hg contents in tailings in the villages of Gugub and Khor Gidad (in ng g^{-1}).

6.3.2. Termites mounts

Big Termites hills are scattered in the area. Some are located in amalgamation zone, in garden or inside huts. We selected 8 of them as test in order to compare results from soils sample in the same area and check if termites can concentrate Hg during mount building. Sampling protocol was the same as for soils grab sampling (Illustration 32).

The Hg contents are homogeneous and ranged from 28 to 315 ng g^{-1} (Appendix 3 & Appendix 6). The values are closed to the background value and indicate that there is no concentration effect associated in termite mounts. Termite mounts sampled in the vicinity of soils contaminated by mercury show relatively low Hg contents than in the soils.

6.4. AIR MONITORING

6.4.1. Methodology

The two sites studied during this mission have been Gugub which is the main village of the area and Khor Gidad rather considered as a working place. The way of using mercury is the same in the two villages: people are doing amalgamation near the huts and then, roasting takes place outside or inside the hut depending on the families. When roasting is done inside, the same fire is used for cooking.

Due to the great possibility of mercury contamination for people during this phase, the roasting phase has been chosen as the most interesting phase for air monitoring. Moreover, Gugub was chosen for most of the monitorings because it was easier to ask for specific demonstration of roasting to the habitants. During the mission, we never saw any roasting phase without asking for a demonstration. Most of these demonstrations were done by men.

We present monitorings recorded during roasting demonstration in two typical huts in Gugub and one monitoring during roasting demonstration outside (Illustration 34). In the two huts, dusts, soils and sometimes vegetables have been also sampled.

Illustration 34 - Monitoring during roasting (a) inside a hut in Gubub and (b) outside at Khor Gidad.

The hut named A is a typical one : circular room of 3-4 meters of diameter, very little aeration and a fire place for roasting and cooking near the wall. The other one named B is a more organised hut with a very well delimited place for the roasting fire. The structure of the hut allowed a better evacuation of the smoke due to openings at the junction between the walls and the roof. This second type of hut is very rare compared to the first one.

In the typical hut (Type A) the Hg content in dust sampled on the ground is 2,751 ng g^{-1} and in the more organised hut (type B) it is less : 434 ng g^{-1}.

The monitoring sequences were performed to estimate the air quality breathed by the population. For this, the intake hose of the RA-915$^+$ analyzer was installed approximately at nose height of the persons involved. During the amalgam roasting phase, the intake hose was placed at the same distance of the fire than the person performing the roasting.

6.4.2. Description of results

Roasting in a typical Hut (Type A)

There are four steps during the air monitoring of the amalgam roasting shown in Illustration 35: the background situation before roasting, the roasting phase, a step of high mercury concentration after the roasting and the return to the initial situation.

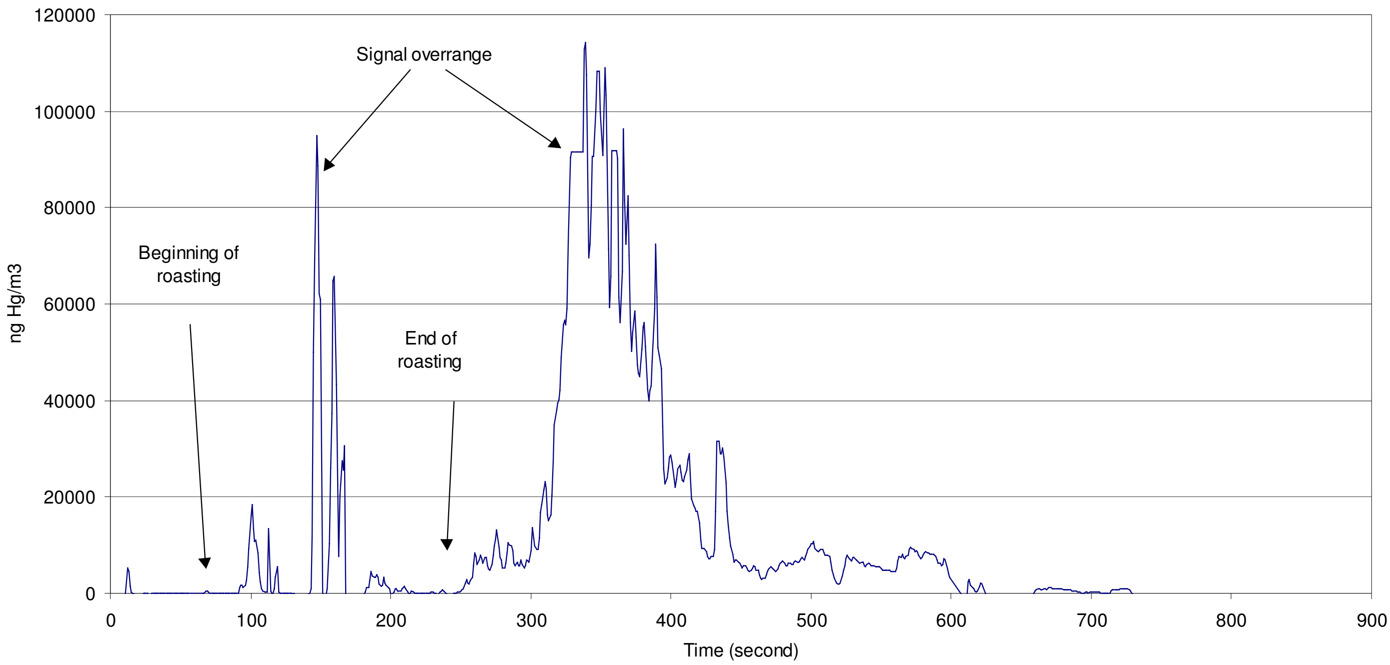


Illustration 35 - Air monitoring in a typical hut in Gugub (type A) before, during and after the roasting of an amalgam.

During the first step (0-70 s) the fire was already lighted for the cooking. The mercury concentration was rather stable (less than around 200-300 ng m^{-3}). When the roasting starts, the mercury concentration increases very rapidly with a few maximum peak values up to 70-90,000 ng m^{-3} (qualitative value because the Lumex indicated overrange signal). This step lasted 3 minutes (as the roasting operation in this case) with a period for maximum peaks of less than 30 s. After three minutes the mercury concentration was back to the initial level. The third step occurred after the roasting was stopped. This step is characterized by a rapid increase of mercury level in air with maximum values up to 80-100,000 ng m^{-3}. This second period of high levels is longer than the first one (6 mn) and the average mercury concentration is higher than during roasting. The final step is a stable background level.

Two important observations about the monitoring of roasting in huts:

- The exposure limit for workers exposed to mercury is 25 µg m^{-3} (average air concentration for an 8 hour shift, WHO, 1994). The period during which high mercury concentrations (around or above 25,000 ng m^{-3}) have been detected is 10 mn which is far below the recommendations of WHO.

- The second peak of mercury concentration is unexpected and is more intense than the peak observed during the roasting phase. The first peak is attributed to the volatilisation of the mercury from the amalgam and the second peak is probably due to a late recondensation of mercury aerosols emitted during roasting. The same phenomenon has been observed in air monitoring in Lao PDR (see Freyssinet *et al*, 2004). This condensation phase indicates that a large part of mercury emitted in the hut remains inside and therefore could accumulate in dusts on the floor, on walls, on vegetables hanged in the hut ... The second point is that this condensation phase concerned all the hut unlike the period of roasting (local evaporation near the fire). All the people present in the hut at this moment could therefore breathe this mercury vapor (not only the person near the fire).

Roasting in hut type B

The four same steps during the roasting in this type of hut (Illustration 36) can be observed as in Illustration 35. The main differences are:

- A more agitated period (more mercury peaks) during evaporation of the amalgam because of an active agitation of fire by the man who is burning the amalgam. This period is longer than in Illustration 35 (around 5 mn from 60 to 360 s). The peak values have the same magnitude (70-90,000 ng m^{-3}) and are very rapid. Nevertheless, the precedent conclusion concerning the average mercury concentrations regarding the recommandations of WHO remains unchanged.

- The second peak that we have identified as a possible condensation of mercury aerosols (between 360 and 550 s) is less intense (shorter and lower maximum values) than in hut A. This seems a direct consequence of the good evacuation of smoke in this hut. The problem of contamination of dust, floor, walls ... inside this type of hut could then be less important.

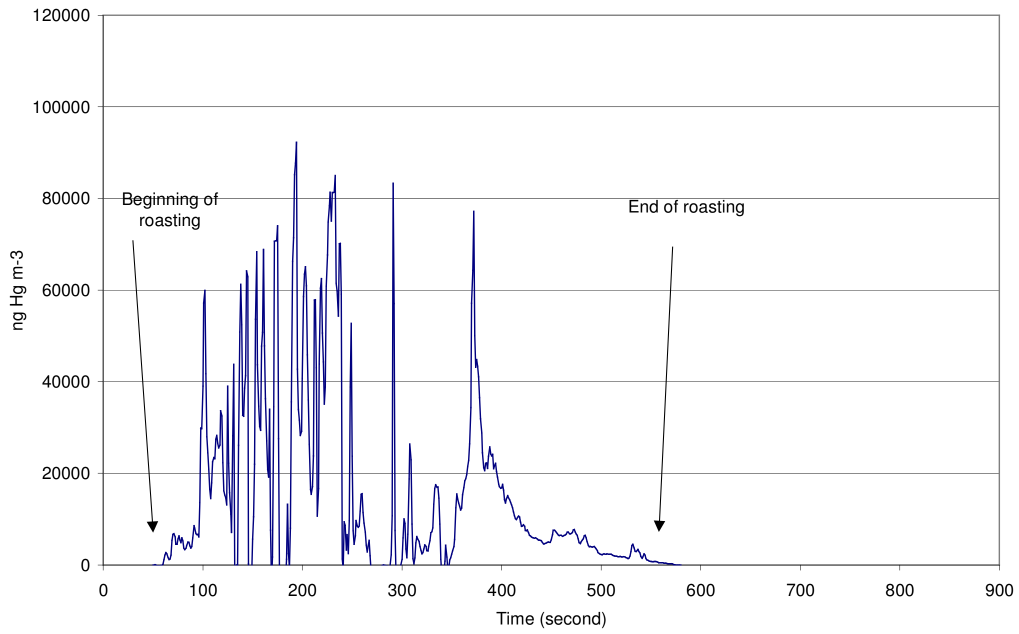


Illustration 36 - Air monitoring in a typical hut in Gugub (type B) before, during and after the roasting of an amalgam.

Roasting in an open place

A few roasting operations which are difficult to evaluate by asking people, took place outside the huts. According to us, around half of the roasting operation is performed outside. A typical monitoring is presented in Illustration 37. The following five observations can be done:

- The period of squeezing (30-130 s) showed little elevated mercury concentration compared with period of roasting (less than about 500 ng m^{-3}).
- As in the hut, during the roasting step the mercury concentration showed a rapid increase up to 80-90000 ng m^{-3} (indicative value). The maximum value is approximately the same as in the hut but the average concentration is lower.
- The duration with high mercury concentration is shorter than in the hut (around 100 s compared to 500 s in a hut).
- The second peak of probable condensation of mercury vapor observed in the hut is absent in this monitoring.

A re-activation of fire at the end of the roasting showed a residual evaporation of mercury.

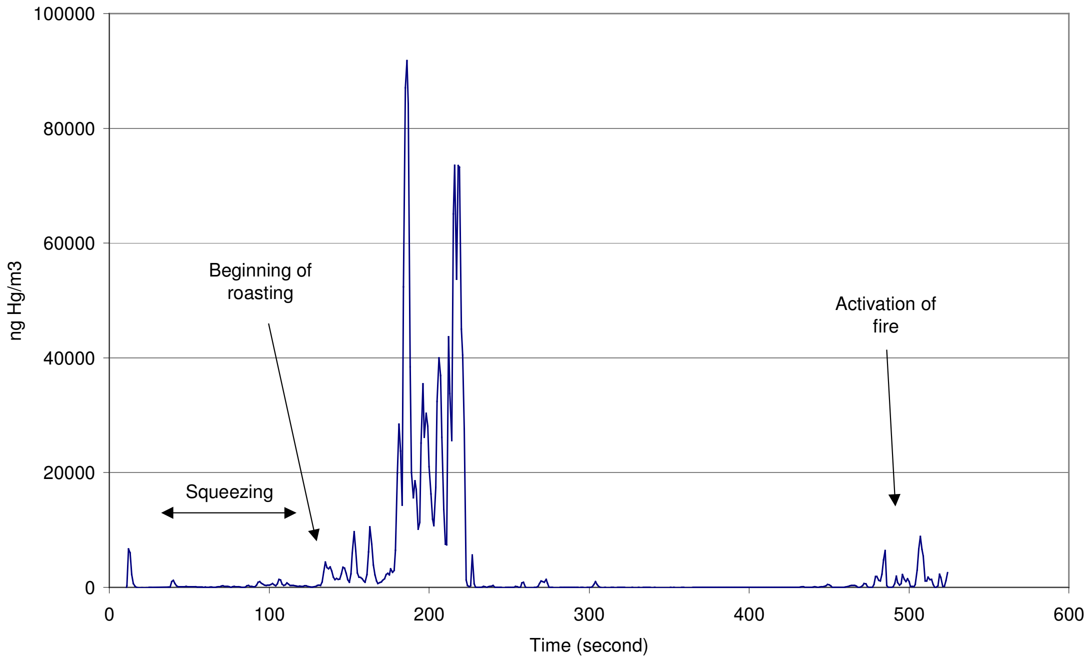


Illustration 37 - Air monitoring in an open place during squeezing, and during the roasting of an amalgam.

6.5. SEDIMENTS

6.5.1. Sampling strategy

Sampling in Gugub, Khor Gidad and Wadi Maganza

Dry stream sediments were collected in the seasonal tributaries (Wadi/ Khor) around Gugub and Khor Gidad (Illustration 20). We tried to collect samples from nearest mercury hot spots (upstream) to main collectors (downstream). The samples were collected in the stream with shovels, smoothly mixed, sieved to pass 2 mm, divided an kept in 150 mL double-capped plastic bottles. The position was determined with a GPS system and the nature of the sample (from gravel to silt) was noticed.

Humid organic matter-rich grab samples were collected, without sieving and division, in the pools of fishing in Gugub and in a poll located in wadi Maganza close to the connection with the Roseires Reservoir.

Sampling in Roseires reservoir

Wet samples were collected on 2 fishing sites of Roseires Reservoir (Illustration 20). Black organic matter-rich silty sediment were collected with shovel on the banks and kept in 150 mL double capped plastic bottles.

49 sediment samples were collected: 26 in Gugub tributaries, 13 in Khor Gidad, 6 in Wadi Maganza and 4 on Roseires reservoirs banks.

The main informations on sediment samples are given in Illustration 38. The complete list is given in Appendix 4

SEDIMENTS		**GUGUB**	**GIDAD**	**ROSEIRES**	**MAGANZA**	**TOTAL**
Number of Sample		26	13	4	6	**49**
Number of Spot		20	11	2	3	36
Sample location	Stream	24	10	0	3	37
	Bank	2	3	4	3	12
Area Types	Panning area	8	5	0	0	13
	Fishing area	2	0	4	0	6
	Mining area	2	0	0	0	2

Illustration 38 - Main informations on sediment sampling.

6.5.2. Description of results

In the mining area, mercury contents ranged from 42 to 1,649 ng g^{-1} on a dry weight (dw) basis in Gugub stream sediments, and between 48 to 886 ng g^{-1} (dw) in the Khor Gidad stream. In wadi Maganza and Roseires Dam, where water flows, values are lowers: mercury contents ranged from 42 to 148 ng g^{-1} on a dry weight (dw) basis in Wadi Maganza and between 157 to 386 ng g^{-1} in the Roseires dam. Most of the samples displayed concentrations below 400 ng g^{-1} in Gugub and Khor Gidad as summarised in Illustration 39.

The respective distributions are presented in Illustration 40.

Sediments	Gugub Streams	K. Gidad Streams	Wadi Maganza	Roseires Dam
Number	25	13	6	4
mean	308	196	75	250
median	160	118	66	228
standard deviation	416	220	35	88
Maximum value	1649	886	148	386
Minimum value	42	48	42	157

Illustration 39 - Summary of the Concentrations observed in Gugub, Khor Gidad, W. Maganza and Roseires dam sediments (in ng g^{-1}, dry weight).

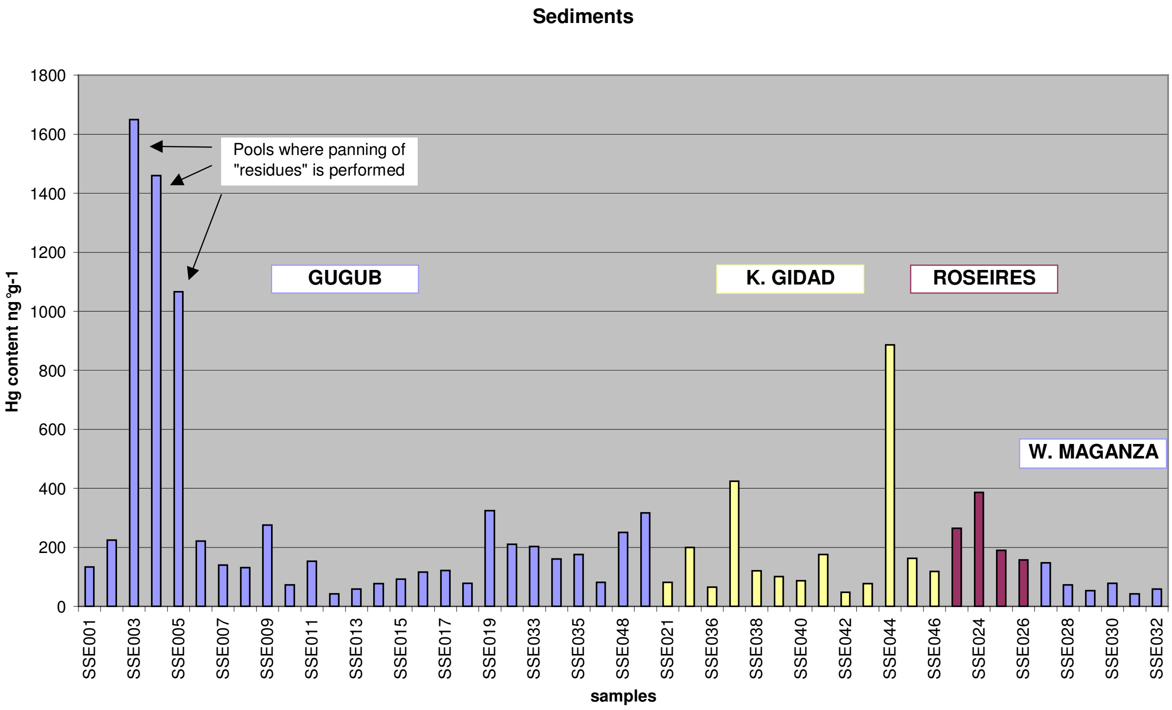


Illustration 40 - Distribution of mercury concentrations in Gugub, Khor Gidad, Wadi Maganza and Roseires dam sediments.

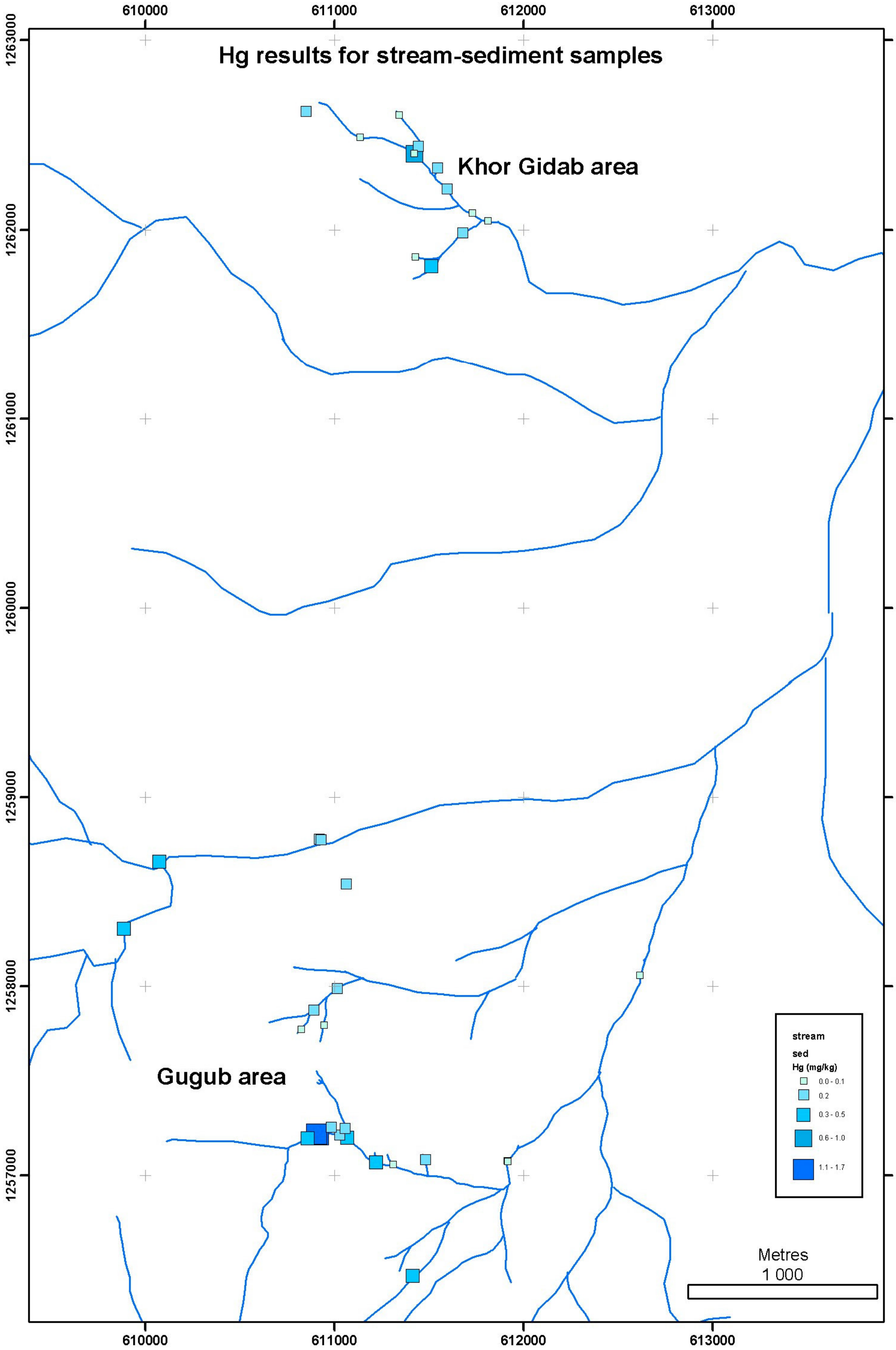


Illustration 41 - Location of Hg analyses results for sediment samples in Gugub and Khor Gidad area.

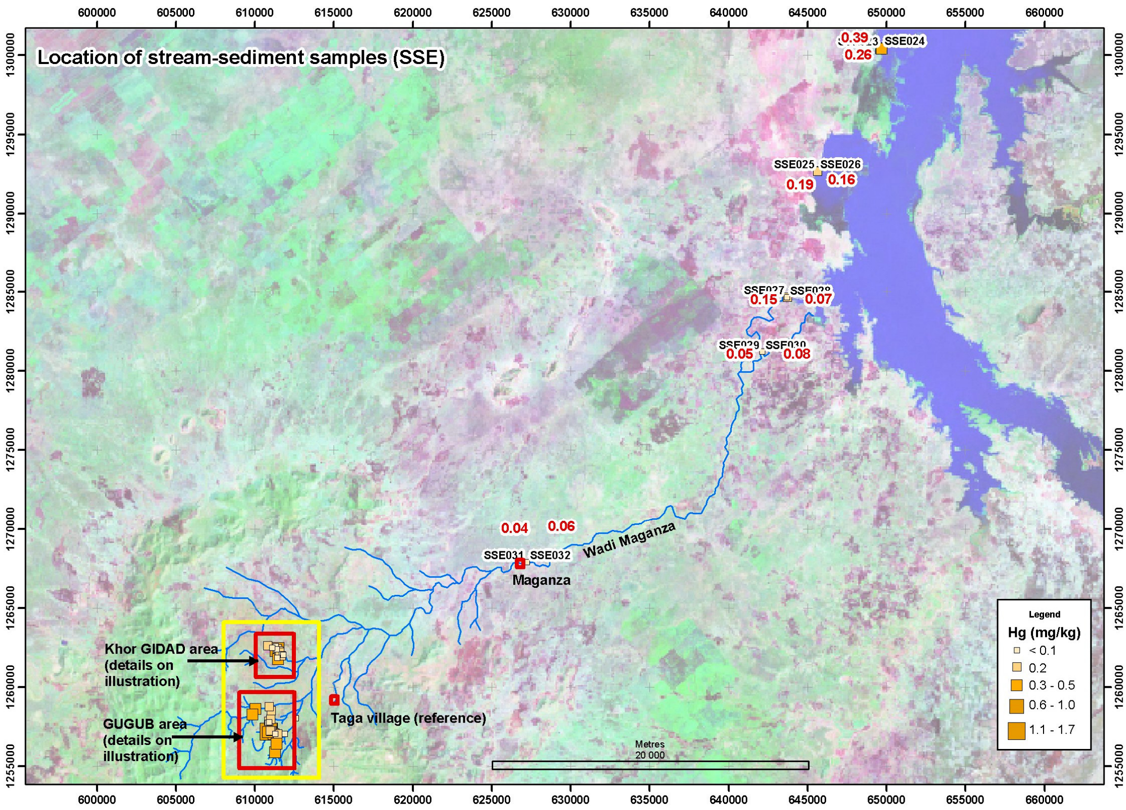


Illustration 42 - Location of stream sediment samples along wadi Maganza and at Roseires Dam.

- The Hg contents in sediments of wadi and khor flowing from the villages of Gugub and Khor Gidad are similar with higher contents near the zones of amalgamation (villages) and than a rapid decrease of Hg contents some hundreds meters downstream the villages of miners (Illustration 18, Illustration 19, Illustration 40).

- <u>The Hg contents in sediments of wadi Maganza are relatively low and do not show important levels of contamination in regard to the usual guideline values for sediment management in Europe or America</u> (Illustration 51).

- In the village of Gugub, the high values correspond to sediments taken in the South network draining the major part of the superficial water of the village where the amalgamation took place. The highest values (ranging from 1,066 to 1,649 ng g^{-1})) are located along the *Khor Alyas* where during rainy season part of the tailings and residues are sometime panned in pools (see 4.2.2, Illustration 19 & 40). Downstream there is a water well supplying village with drinking water. In the North of the village, the network drains only the area of the school and sediments do not show significant Hg contamination.

- In the village of Khor Gidad, Hg contents are mainly below 200 ng g^{-1} (Illustration 40) with 2 values above (424 and 886 ng g^{-1}) without apparent contamination downstream (Illustration 18).
- The black organic matter-rich silty sediment collected on the banks of the Roseires dam, presents Hg contents (157 to 386 ng g^{-1}) close[5] to those of contaminated stream from mining villages located several tens of kilometer upstream. The dam is a sedimentation area, where either the contaminated particles can settle down, or the dissolved mercury can precipitate. The Roseires reservoir located on the Blue Nile collects drainage waters from several artisanal gold mining activities (Illustration 2) including Wadi Maganza draining the Gugub site. The mercury in the Blue Nile may be released from other artisanal gold mining sites in activity, such as ~12 km east of the Blue Nile bank at Belguwa-Sakatna, sites ~80 km southeast of Ad Damazin. Mercury input may also come from other artisanal gold mining sites within the river catchment as far as Qeissan some 150 km to the south.

It is not possible to compare the results obtained on dry samples from the villages of Gugub and Khor Gidad with samples taken somewhere else in flowing rivers. The conditions of sampling (focussed on dry samples with organic matter) explain certainly partially the high values encountered. The Hg contamination of sediments exist in this villages where amalgamation and roasting took places but it seems restricted to a narrow zone of a few hundreds of meters around, and, at the present time, without apparent contamination downstream through Wadi Maganza.

6.6. VEGETABLES

Some vegetables have been sampled in a few huts to evaluate the contribution of these vegetables in the mercury daily intake of the local population.

The lifestyle of the communities is influenced both by traditional nomadic customs and sedentary habits. They depend mainly on livestock and farming. In the Gugub and Khor Gidad villages, women cultivate corn and sorghum along stream terraces or in small private gardens close to the huts and Hg-processing spots. The common diet in the Gugub area is based on two meals per day. Sorghum and corn porridge constitute the main meal. During the summer, sorghum and corn are dried in the huts by suspending them from the roof just above the home fires (Illustration 44) until they eventually become black. There is no doubt that these vegetables are exposed to smoke from the fire, with Hg vapors from the roasting phases.

In summer, no fresh vegetables from the mining area are available, so we decided to focus our sampling on the dry corn and sorghum fixed on the roofs of the huts. As we plan to carry out a few vegetable analyses, all the samples were collected inside the huts at Gugub (6) and Taga (2) for control purposes. Four huts were sampled and two samples taken in each (1 corn and 1 sorghum). Two huts are considered as control: one at Gugub and the other at Taga.

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[5] Except high value from Khor Alyas.

SVG1 to SVG4 are dusty smoked pieces of maize or sorgo hanging on the roof of the hut (since October 2003). In these huts, roasting operations are regularly performed. SVG5 to SVG8 are pieces of maize and sorgo collected in reference huts in Gugub or Taga (reference village). These latest pieces of vegetables were rather clean samples compared to SVG1 to SVG4. The results are given in the Illustration 43 below.

Remark: the quantities of mercury in the first cleaning water are given in ng of mercury (estimation for a 50 mL solution). In order to compare these results, it should be noticed that the pieces of vegetables were of equivalent size.

Sample	**Location**	**Type**	**Remark**	**Hg content on clean vegetable (mg/kg dry weight)**	**Hg (ng) in the first cleaning water**
SVG1	GUGUB	Sorgo	Hut with roasting	<0.05	290
SVG2	GUGUB	Maize	Hut with roasting	0.11	340
SVG3	GUGUB	Sorgo	Hut with roasting	<0.05	120
SVG4	GUGUB	Maize	Hut with roasting	<0.05	<10
SVG5	GUGUB	Sorgo	Reference hut without roasting	0.12	<10
SVG6	GUGUB	Maize	Reference hut without roasting	<0.05	<10
SVG7	TAGA	Sorgo	Reference hut without roasting	<0.05	<10
SVG8	TAGA	Maize	Reference hut without roasting	<0.05	<10

Illustration 43 - Analysis of the sorgo and maize samples.

Two conclusions can be drawn from these results:

- The Hg content of the analysed vegetables is very low both in the reference hut and hut with roasting.

- Significant quantities of mercury are present in the dusts deposited on the vegetables hanging on the roofs of huts were roasting is performed (except SVG4). This mercury is eliminated with a simple cleaning with water. This reveals another potential impact of the operation of roasting (in addition of the contamination of air during the operation).

These results on sorgo and maize should be controlled in a further step as apparently they may contribute to the evaluation of the daily intake of mercury for the local population.

Illustration 44 - Example of sorghum and corn fixed on the roof of a hut.

6.7. FISHES

At the four fish sampling spots, catches were made by local fishermen, using nets.

Fifteen different species were collected, with a total of 108 individuals (Illustration 22). The 15 fish species collected are shown on Appendix 5. Small dorsal muscle samples were taken and kept in formalin to be analysed at the University of Bordeaux-CNRS LEESA Laboratory in France.

The main biogeochemical processes linked to mercury input from artisanal gold mining sites within freshwater systems are summarized in Appendix 5.

Analysis of the results relating to the level of mercury contamination in the fish must necessarily bear in mind the constraints imposed by the sampling conditions and the absence of any direct relationship with the gold mining site and the village of Gugub. Nevertheless, they will show the current state of mercury contamination in the biological component of the hydrosystems in this region of Sudan, especially around the dam, which is downstream from several gold mining sites.

In many countries, fish constitutes a substantial proportion of the protein ration for the populations living along the hydrosystems (rivers, lakes, estuaries), and can consequently represent a major source of exposure to MMHg, as well as the direct professional exposure of goldminers and their families.

6.7.1. Global biometric characteristics and fish mercury contamination levels

Mean biometric data – total body weight (g, wet weight) and standard length (cm) – and mercury concentrations measured in the dorsal skeletal muscle are shown in Illustration 46, for the 4 sampling spots (1 to 4) and the different species.

Only 5 species were common to 2 or 3 sampling spots (Illustration 45), notably between the reservoir (sampling spots: 1, 2, 3) and the water hole in the North of Gugub (sampling spot 4):

Genus	Species	Sampling spot	Fish number
Clarias	*gariepinus*	1	5
		2	4
		4	1
Oreochromis	*niloticus*	3	5
		4	15
Sarotherodon	*galilaeus*	1	6
		2	5
Schilbe	*intermedius*	1	5
		3	4
Synondontis	*schall*	2	6
		3	6

Illustration 45 - Fish species common between the four sampling spots.

In biometric terms, the fish were small in size, with the mean standard length of each species being usually under 20 cm. Considerable differences emerged between batches of fish of the same species but taken from different sampling spots, probably due to differences in age and/or to nutritional intake, depending on the sites. For example, for the species *Clarias gariepinus*, marked differences appeared between the body weights from the Roseires Reservoir: 17.8 ± 10.6 g (ww) at sampling spot 1; 555.5 ± 46.5 g (ww) at sampling spot 2.

Globally, mercury contamination levels in fish are low, or even very low. The general mean, from the 108 fish collected, is 0.246 ± 0.048 µg g^{-1}, on the dry weight basis. It must be remembered that concentrations expressed on the wet weight basis, the criterion traditionally used to define safety levels, are about five times lower (wet weight /dry weight = 5). Thus the safety standard defined by the WHO is 0.5 Hg µg g^{-1} on the wet weight basis or 2.5 Hg µg g^{-1} on the dry weight basis (WHO, 1990). The extreme mean values range from 0.056 ± 0.006 µg g^{-1} (dw) for the species *Labeo niloticus* (n = 5) to 0.708 ± 0.052 µg g^{-1} (dw) for the species *Lates niloticus* (n = 6), from sampling spot 1 (Roseires reservoir).

Family	Genus	Species	Food regime	Sampling spot	Standard length (cm)	Body weight (g, fw)	Hg concentration (µg.g-1 dw)	N
Clariidae	*Clarias*	*gariepinus*	Benthivorous	1	19.7 ± 0.7	76.8 ± 10.6	0.085 ± 0.011	5
Cyprinidae	*Labeo*	*niloticus*	Benthivous	1	15.6 ± 0.4	61.6 ± 4.3	0.056 ± 0.006	5
Schilbeidae	*Schilbe*	*intermedius*	Carnivorous	1	15.6 ± 1.1	47.2 ± 10.1	0.405 ± 0.069	5
Alestiidae	*Hydrocinus*	*forskalii*	Carnivorous	1	21.3 ± 1.5	116.4 ± 21.4	0.694 ± 0.076	5
Centropomidae	*Lates*	*niloticus*	Carnivorous	1	14.1 ± 0.7	55.7 ± 8.7	0.708 ± 0.052	6
Cichlidae	*Sarotherodon*	*galilaeus*	Herbivorous	1	9.0 ± 0.1	24.0 ± 0.9	0.113 ± 0.012	6
Alestiidae	*Brycinus*	*nurse*	Omnivorous	1	13.3 ± 0.2	51.2 ± 1.6	0.107 ± 0.013	5
Clariidae	*Clarias*	*gariepinus*	Benthivorous	2	39.1 ± 1.7	555.5 ± 46.5	0.098 ± 0.029	4
Cichlidae	*Sarotherodon*	*galilaeus*	Herbivorous	2	16.9 ± 0.6	163.6 ± 12.5	0.105 ± 0.020	5
Mochokidae	*Synondontis*	*schall*	Omnivorous	2	9.6 ± 0.6	20.0 ± 3.7	0.285 ± 0.086	6
Schilbeidae	*Schilbe*	*intermedius*	Carnivorous	3	23.4 ± 0.7	133.5 ± 3.6	0.539 ± 0.085	4
Mormyridae	*Mormyrus*	*niloticus*	Carnivorous	3	24.0 ± 1.0	122.0 ± 16.0	0.098 ± 0.002	2
Cichlidae	*Oreochromis*	*niloticus*	Herbivorous	3	20.3 ± 0.5	266.4 ± 20.4	0.080 ± 0.010	5
Mormyridae	*Marcusenius*	*senegalensis*	Carnivorous	3	21.0 ± 1.0	105.0 ± 7.0	0.103 ± 0.023	2
Mormyridae	*Hyperopisus*	*bebe*	Omnivorous	3	27.5 ± 0.5	189.0 ± 5.0	0.092 ± 0.015	2
Mochokidae	*Synondontis*	*schall*	Omnivorous	3	14.3 ± 0.6	66.0 ± 6.7	0.614 ± 0.149	6
Clariidae	*Clarias*	*gariepinus*	Benthivorous	4	22.0	68.5	0.243	1
Cyprinidae	*Labeo*	*horie*	Benthivorous	4	9.7 ± 0.7	19.3 ± 3.8	0.194 ± 0.043	14
Cichlidae	*Oreochromis*	*niloticus*	Herbivorous	4	7.3 ± 0.6	16.4 ± 3.4	0.057 ± 0.003	15
Bagridae	*Auchenoglanis*	*occidentalis*	omnivorous	4	22.0 ± 0.1	133.3 ± 64.8	0.150 ± 0.093	2
x	x	x	x	4	11.8 ± 1.5	26.5 ± 7.2	0.336 ± 0.115	4

Illustration 46 - Mean biometric data for the fish species collected in the four sampling (Standard length and body weight, mercury concentrations in the dorsal skeletal muscle and food regime spots (data are means ± standard error – N: number of fish).

6.7.2. Mercury contamination levels according to the fish trophic level and to the sampling sites

In agreement with the large amount of data available in the literature (for example, Durrieu *et al.*, 2004; Roulet and Maury-Brachet, 2001; Veiga *et al.*, 1999; Wiener *et al.*, 2002), mercury concentrations measured in the fish muscle vary according to the food regime of the species and its position along the trophic networks.

Data from sampling spot 1 on the Roseires Reservoir (Illustration 47) reveal marked differences between fish species and food regimes. The average concentration for the three carnivorous species (*Schilbe intermedius, Hydrocinus forskalii, Labeo niloticus*) is 0.60 µg g^{-1} (dw). This is about 8 and 5 times higher than those determined for the benthivorous and herbivorous species, respectively. However, these values are clearly below the safety level (2.5 µg g^{-1}, dw).

The relationships between fish body weights and Hg concentrations in the muscle[6] show marked differences between the species collected: for five species, bioaccumulation levels are independent of the fish weight; for the two carnivorous species - *Lates niloticus* and *Schilbe intermedius* - two opposing correlations were observed, negative and positive, respectively.

Numerous field studies in European countries and North-America/Canada have shown a significant positive correlation between Hg concentrations in fish muscle and biometric criteria (body weight or standard length), indicating an increase in bioaccumulation as a function of the age of the fish. Recent studies in Amazonia (South America: Brazil and French Guiana) have shown several types of relationships (no correlation, positive or negative correlations), as a function of fish species, food regimes and also developmental stages (alevins/adults) (Roulet *et al.*, 1999; Frery *et al.*, 2001; Durrieu *et al.*, 2004).

Data from spot 3, on the Roseires reservoir, where six fish species were collected (Illustration 48), show marked differences between the three carnivorous species and also between the two omnivorous species. Several hypotheses can be put forward to explain these results: differences between their ecological niches (for example, for the two omnivorous species, *H. bebe* is described as a demersal species, living in the deep layers of the water column; *S. schall* is a benthopelagic species, confined to the sediment/water interface); changes in food regimes, following the impacts on the foodwebs when the reservoir flooded.

No carnivorous species were collected at sampling spots 2 and 4. Small concentrations were measured in the benthivorous, omnivorous and herbivorous species (Illustration 46). For example, the mean Hg concentration in *Oreochromis niloticus* (N = 15), an herbivorous species, was 0.057 ± 0.003 µg g^{-1} (dw). No significant correlation was observed between body weight and mercury levels in the muscle (Illustration 49).

[6] These relationships were established from a small number of samples. For this reason, their representativity is limited.

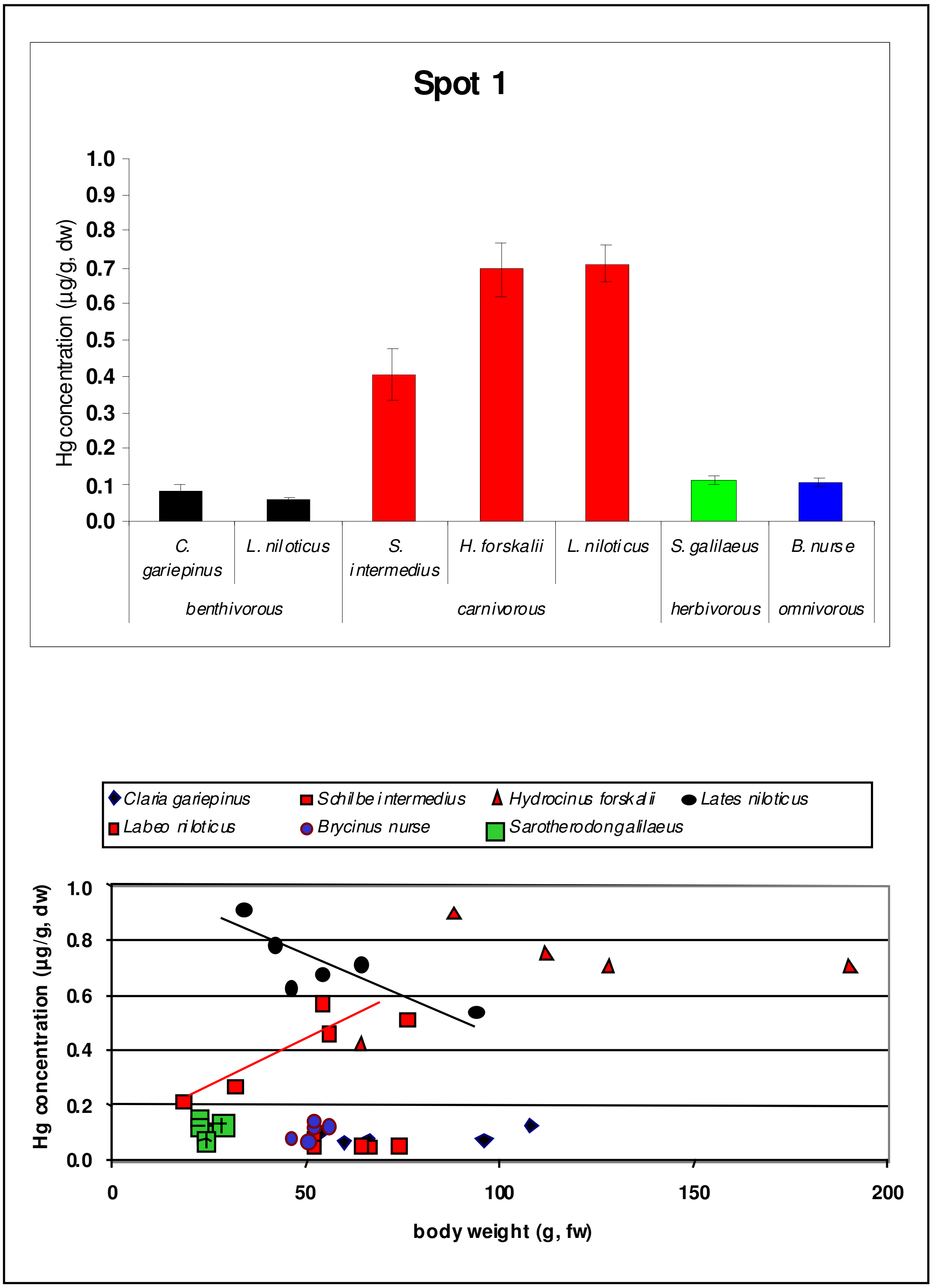

Illustration 47 - Mercury concentrations in the muscle of the seven fish species collected from the sampling spot 1, on the Roseires reservoir – relationships between fish body weight and mercury concentration in the skeletal muscle.

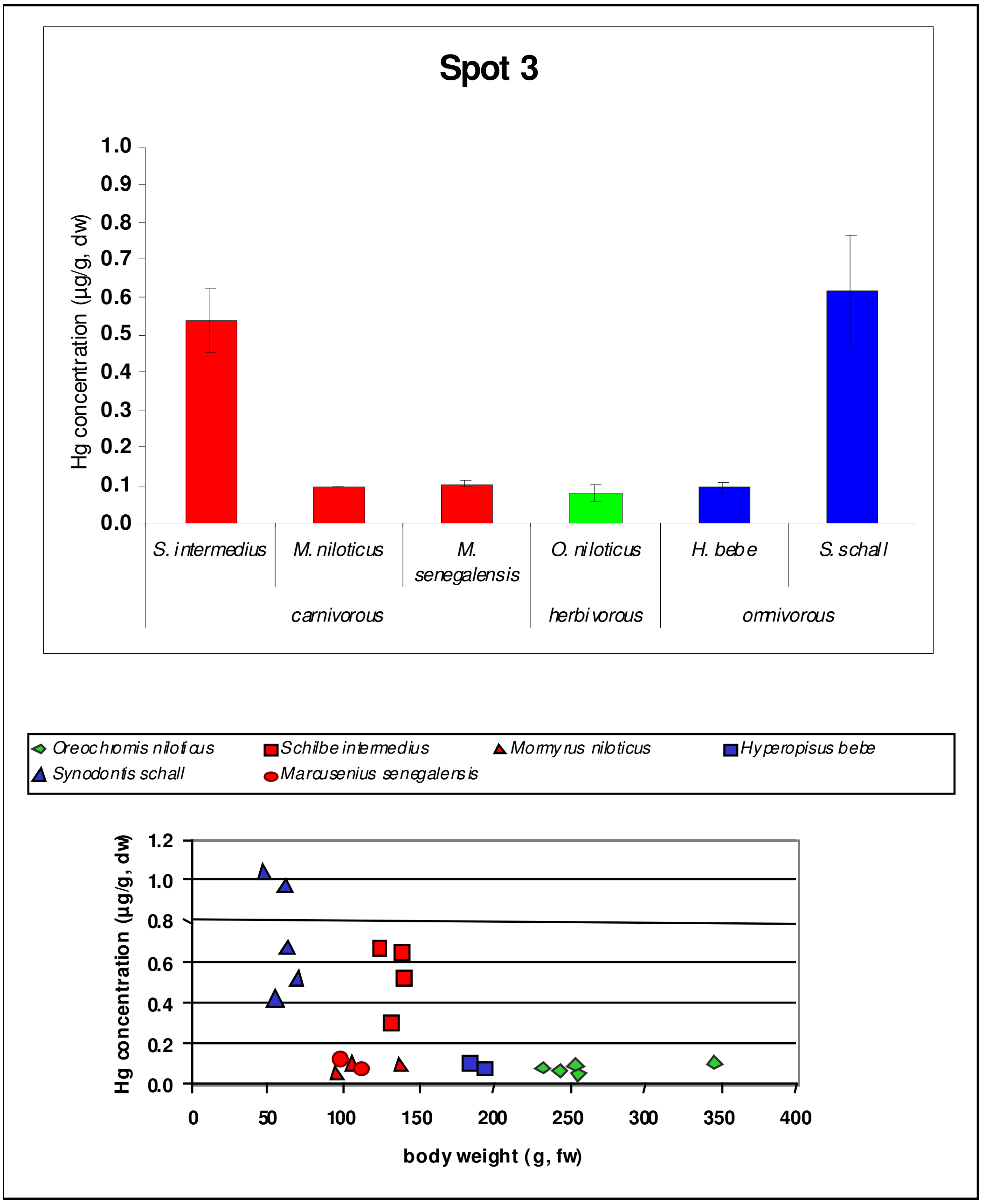

Illustration 48 - Mercury concentrations in the muscle of the seven fish species collected from the sampling spot 3, on the Roseires reservoir – relationships between fish body weight and mercury concentration in the skeletal muscle.

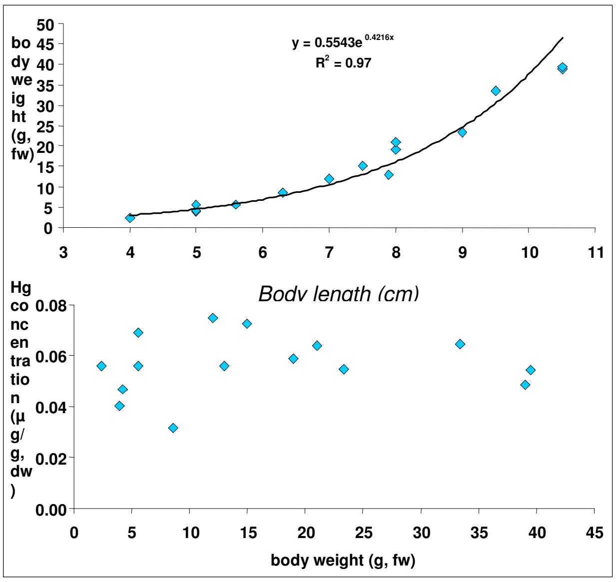

Illustration 49 - Relationships between fish body weight and standard length and between fish body weight and mercury concentration muscle of the herbivorous species Oreochromis niloticus (15 individuals) collected from the sampling spot 4.

6.7.3. Conclusions

There is a poor representativity of mercury contamination levels in fish species in relation to artisanal gold mining in Sudan owing to the poor sampling conditions

The levels of contamination in fish muscle samples (15 species - 108 individuals) is very low and there is no fish above the WHO safety limit of 2.5 Hg µg g^{-1}, on the dry weight basis – the global mean Hg concentration was 0.246 ± 0.048 µg g^{-1} and 0.49 ± 0.10 µg g^{-1} for the carnivorous species.

The data from rivers directly affected by gold mining sites using amalgamation procedures must be considered insufficient to produce conclusions relating to fish advisory, or health related matters for this area of Sudan.

7. Evaluation of exposure to Hg

The artisanal gold miner families (~300) and the (10-15) local gold merchant shops in Gugub and in Khor Gidad constitute the same broad mercury hotspots. The main targets identified are local people. Potential risks to the ecosystem were considered to be minor in that system.

7.1. VILLAGES

Information on mining practices and field study proved that the main risk of exposure to environmental mercury occurs in the villages as mercury is mostly manipulated at home or around the gold merchant shops by artisanal miners without specific precaution. This risk is increasing because the exposed population is mostly composed by women and their young children working hardly on mining sites. The risk is also present in the huts or in the yard of “family unit”.

The probability of occurrence of exposure to mercury is summarised in the Illustration 50.

Inhalation

In that case inhalation concerns only volatilised Hg°. The monitoring of air quality showed that Hg concentrations may reach relatively elevated concentrations. However, the exposure of the artisanal miners was relatively short compared to the exposure limits for professional workers exposed to mercury (25 µg m^{-3} average air concentrations for an 8 hour shift, WHO, 1994). We measured that people are only exposed to elevated mercury concentrations for about 10 to 15 mn during the amalgam roasting. Roasting takes place outside or inside the hut depending on the families. When roasting is done indoor, the same fireplace is used for cooking. During the mission, we never observed any roasting phase without asking for a demonstration. Most of these demonstrations were done by men but in presence of family members including women and children. We should also consider the possible exposure of women and children and use air quality standards for non professional exposure.

	Description	Probability of occurrence	Comments
SOURCES	- Accidental Hg spill during deals or amalgamation - Amalgam roasting - Disposal of contaminated tailings	*** *** **	
TRANSFER & PATHWAYS	- Hut dust contamination - Hg vapor dissemination contaminating the hut and its close environment - Soil contamination in the vicinity of contaminated huts - Sediment contamination by panning of tailings in pools	*** *** ? *	- Contamination of the soil of the mosque and other "reference" spots - occasional
HUMAN TARGETS	- Hg inhalation during roasting - Domestic dust and soil ingestion (mostly children) - Fish consumption - Vegetable consumption - Contaminated poultry consumption[1] - *Drinking water*[1]	** *** * * ? ?	- Main situation of Hg inhalation - Needs further control - Needs further control - Possible contamination of poultry? - Needs further control

Illustration 50 - Probability of occurrence to Hg exposure ([1] not considered in that study).

Ingestion

In the described system, oral exposure may occur in different situations like soil and dust ingestion or food consumption.

We demonstrated that huts of artisanal miners are contaminated due the procedure of amalgam roasting in the hut. Thus walls, suspending sorghum and corn and domestic dust are contaminated in the hut of artisanal miners. Metallic mercury may progressively accumulate in the houses during the mining season. We showed that domestic dust may reach elevated concentrations (up to 840,000 ng g^{-1}). We estimate that it constitutes one of the main risks of exposure for the population, and particularly for children.

The soil of school playground of the Gugub village is not contaminated. Soils in and around the shops or soils of amalgamation areas around huts of artisanal miners show same high levels of contamination than the dust inside the huts (mean 2,480- 40,230 ng g^{-1}). Such concentrations are relatively high compared to threshold values for soils in residential areas (7,000 to 10,000 ng g^{-1} in Europe) (Illustration 51). However the higher values are related to specific restricted areas (shops, amalgamation area of several meters square in size). Except these hotspots, Hg contents of the soils of the yards are, in both villages, in average lower (mean 763 – 2,116 ng g^{-1}) and clearly under threshold values mentioned before.

The amount of soil and dust that is ingested has been discussed extensively in the literature (Simon, 1998; Calabrese, 1989, Calabrese *and al.*, 1991) but there is no existing guideline value for mercury for soil and dust ingestion. Geophagic activity has not been described by the sociological study. Data collected during this works were not sufficient to appreciate real quantity of inadvertent ingestion of dusts and soils by peoples. Dust ingestion (soil + domestic dust) could be relatively important for children (especially in the living conditions of local people), and this may cause a potential risk of contamination for the artisanal miners and their families.

A possible contamination of poultry may exist in relation with contaminated soils and domestic dust. This point was not checked because the field survey took place during the avian flue crisis of 2003-04, it was then forbidden to sample and import poultry meat in Europe by that time.

The other risk of exposure is related to the consumption of fishes and vegetables (sorghum and corn). There is a poor representativity of mercury contamination levels in fish species in relation to artisanal gold mining owing to the poor sampling conditions. The levels of contamination in fish muscle samples (15 species - 108 individuals) is very low and there is no fish above the WHO safety limit of 2.5 Hg µg g^{-1}, on the dry weight basis – the global mean Hg concentration was 0.246 ± 0.048 µg g^{-1} and 0.49 ± 0.10 µg g^{-1} for the carnivorous species. Being located ~50 km away from the Blue Nile western banks, the community of Gugub and the surroundings have no frequent access to fresh fish supply. However, dry fish is available in the Gugub market. The occasional consumption of fishes in that area, (only 2 % of the people report eating fish occasionally) does not seem to constitute a major risk. However, the data from rivers directly affected by gold mining sites using amalgamation procedures must be considered insufficient to produce conclusions relating to fish advisory, or health related matters for this area of Sudan.

Sorghum and corn porridge constitute the main meal of the communities. In the Gugub and Khor Gidad villages, women cultivate corn and sorghum along stream terraces or in small private gardens close to the huts and Hg-processing spots. The average contents in garden ranging between 130 and 280 ng g^{-1} are close to the background level and below UK and Canadian standard of permissible concentration of Hg in agricultural soil ranging from 1,000 to 8,000 ng g^{-1}. The Hg content of the analysed sorghum and corn is very low and do not present risk but significant quantities of mercury are present in the dusts deposited on the vegetables hanging on the roofs of huts were roasting is performed. This mercury is eliminated with a simple cleaning with water. These results on sorghum and corn should be controlled in a further step as apparently they may contribute to the evaluation of the daily intake of mercury for the local population.

7.2. WADIS AND KHORS

There is no major flowing river close to the mining and processing areas, only seasonal drainage. Miners pan alluvial gold on banks and terraces when the local stream is flowing during rainy season between July and December but in those sites miners do not use mercury and recover only visible gold during rainy season. It appears that in Gugub and Khor Gidad villages, the mercury pollution of stream sediments could be mainly controlled by the surface run-off from gold amalgamation and roasting processing sites located in the villages. We supposed that Fe-rich laterite and seasonal run-off act probably as natural barriers against this type of Hg dispersion in the sediments.

In Gugub and Khor Gidad, most of the sediment samples show concentrations below 400 ng g^{-1}. In the village of Khor Gidad, Hg contents are mainly below 200 ng g^{-1} without apparent contamination downstream. In the village of Gugub, the highest values (ranging from 1,066 to 1,649 ng g^{-1}) are located along the *Khor Alyas* where during rainy season part of the tailings and residues are sometime panned in pools. This practice appears as the only one presenting risk for the local stream.

Downstream, the Hg concentrations in sediments of the main collector, Wadi Maganza, are relatively low (ranged from 42 to 148 ng g^{-1}) and do not show important levels of contamination in regard to the usual guideline values for sediment management in Europe or the North America.

It is not possible to compare the results obtained on dry samples from the villages of Gugub and Khor Gidad where sampling could make exactly on one layer or a particular place in the narrow stream with samples taken somewhere else in flowing rivers. Analysis of the results relating to the level of mercury contamination in the sediment must necessarily bear in mind the constraints imposed by the sampling conditions, the absence of any water flowing observed during the mission, the limited number of samples taken in the wadi Maganza and that intensive use of mercury in the area is quite recent.

The conditions of sampling, focussed on dry samples rich in organic matter, may, for example, partially explain the some high values encountered close to the villages. The anthropogenic Hg contamination of sediments exist in this villages where amalgamation and roasting took places but it seems restricted to a narrow zone of few hundreds of meters around, and, at the present time, without apparent contamination downstream through Wadi Maganza. These elements show that the stream appears as preserved natural ecosystem.

		Mean values	Max. (unit)		Guideline values
Fishes	Roseires Dam	0.25	0.7	$\mu g\ g^{-1}$ (dw)	2.5 WHO safety limits
	Roseires - Carn.	0.6	2.5		
	Others	0.15	0.3		
Sediments	Villages	196-308	1649	ng/g	700 PEL (US)
	Roseires Dam	250	386		200 (LEL Canada)
	Wadi Maganza	75	148		2000 (SEL Canada)
Vegetables	Sorghum & corn	< 0.05	0.12	$\mu g\ g^{-1}$ (dw)	background <0.1
	Cleaning water	250	340	ng (for 50ml)	
Air	Sqeezing	500		$ng\ m^{-3}$	200 MRL inhalation, WHO, 2000
	amalgam roast.	90,000-100,000			1,000 (NOAEL, WHO, 2000)
	fire lighting	200-300			25,000 / 8h (WHO prof. exposure)
Soil & tailings	villages	2,480-40,230	1,000,000	$ng\ g^{-1}$	27 ng/g PNEC (INERIS, 2003)
	ref. background	100	150		
Domestic dust	ref. village	180		$ng\ g^{-1}$	none
	miners village	1,236-103,000	840,000		7,000 ng/kg/day MRL , WHO, 2000

Illustration 51 - Synthesis of the results and published guideline values. (PEL : Probable Effect Level; LEL : Low Effect Level; SEL : Strong Effect Level; MRL : Minimum Risk Level; NOAEL : No Effect Level; PNEC : Probable Non Effect Concentration).

8. Conclusions & recommendations

The operation was carried out between French teams (BRGM, Universities of Montpellier and Bordeaux) and Sudanese teams (Geological Research Authority of Sudan and University of Nileen). The sampling campaign and health survey took place from March 29th to April 18th, 2004 during the hot dry summer before rainy season and the main alluvial mining season. The aim of this study was to collect environmental and health data in the Gugub and Khor Gidad villages of the Bau district in the Ingessana Hills (Blue Nile State of Sudan) to assess the level of mercury exposure in the local communities and the potential impact in the environment. Another small village, Taga was added as a reference village (i.e. a village without a mining history). There was no major flowing river close to the mining and processing areas, only seasonal drainage. No water flowing was observed during the mission; although there were small pools along main wadis, there was no panners.

Mining of gold-bearing quartz vein was the only type we observed during the field mission.

8.1. MAIN OUTCOMES OF THE ENVIRONMENTAL SURVEY

Use of mercury

Use of mercury in the area is quite recent and depends on the type of mining activities.

Artisanal gold mining activities in the Ingessana Hills started in 1996. Intensive use of mercury in the area is quite recent (around 3 years and may be less) and mainly developed in Gugub where gold was first discover and in Khor Gidad after the gold rush of September 2003. During our mission those two sites were the only one's in activity. At the present time, the village of Khor Gidad is an extraction and processing site and the village of Gugub is a processing site only. The other sites mentioned in the sociological reports (i.e. Turda, Khor Neiwi) are alluvial types, without mercury use and presently abandoned.

Miners pan alluvial and elluvial gold when the local stream is flowing during rainy season between July and December. In those sites miners do not use mercury and recover only visible gold during rainy season. Results of Hg Analyses carried out in this study confirm this allegation: soils, tailing and sediments sampled around alluvial panning area are not contaminated by Hg.

During dry season, due to shortage of water in pit sites, only primary gold associated with quartz vein are mined. The procedures used by local people are representative of very poor people using simple and traditional practices. Mercury is used only to recover gold from this primary ore. Most of these activities were performed by women (13-35 years old), including the hard tasks of digging and excavation. Men are only involved in mining at deeper depths and in roasting phases. There is no use of Hg on the mining site; the selected ore is transported to the village for crushing, manually milling and panning in the yard of «family unit».

Gold production and mercury consumption

Gold production estimates based on two independent sources (workers production and dealers) gave similar results: the quantity of gold produced from quartz vein in the 2 studied villages is 75-300 g Au/day and 22.5-90 kg Au/year. Workers and dealer probably underestimated their production and that actual values may be higher.

We demonstrate that to produce such quantities (100-300 g Au/day) from the Gugub sites workers involved must be 800 to 1000 and gold grade 30 to 72 g t^{-1} respectively. According to the data available and observations made (average gold grades measured by GRAS of less than 5 g t^{-1} and 300 families living on the sites) works in Gugub can not produce the quantity of gold mentionned before from the quartz vein mining alone. A large part of the gold sell during dry season (probably 50 %) probably comes from alluvial production and also from gold reserves made by workers during rainy season. According to our field observations and the estimations performed, the use of mercury in the Gugub district is between 250 and 500 g Hg per household of artisanal miners.

Taking into account these information, the Hg lost/Au produced ratio is probably higher than 3 in the Gugub area.

Contamination due to amalgamation practices

According to the analysis of the process, the most probable contamination of soil is supposed to be related to solid deposition of mercury during the amalgamation process, to atmospheric deposition of mercury during the roasting and to the dissemination of household dust in the vicinity of artisanal miner huts.

Last panning and then amalgamation are performed in one daily sequence at home or close to the shops dealing mercury. In both case there is no specific place for amalgamation. The miners collect the amalgam by hand, taking no precautions at all.

The soils in the yards are contaminated by Hg. The average geochemical Hg content in the village of Gugub and Khor Gidad are ten times higher than the local background (100 to 150 ng g^{-1}). The contamination is punctual with probable nugget effects. Higher value in the 2 villages (up to 10^6 ng g^{-1} in Khor Gidad and up to 27,626 ng g^{-1} in Gugub) are related to zone of amalgamation where Hg droplets were sometimes visible after panning. These zones showing values several times higher than others places where values are close to local background are principal hotspots.

School yard in Gugub show background Hg contents (106 ng g^{-1}).

Contamination due to roasting of amalgams

The gold amalgam is roasted in the village in mobile bonfires, outside close to the dealer shop where they buy mercury; in the yard of the «family unit» or inside the huts. It was rather difficult to identify what was the main place of roasting. In Khor Gidad, roasting outside seem to be the main way of roasting. It is seem that the proportion is approximately 50-50 in Gugub. It is especially the men who practise the roasting. Daily, they roast the amalgam without taking any precautions.

Average contents show also significant contamination of domestic dust in some hut and yard of artisanal miners (500 - 2,760 ng g^{-1} in Gugub and 123 - 840,000 ng g^{-1} in Khor Gidad). It is clearly demonstrated that indoor amalgam roasting may significantly contaminate the dust of the huts but there are no big differences between the Hg contents in soils compare to Hg contents in dusts in all villages. Also, there is no significant difference depending on the dust location (hut with or without roasting). It was impossible, at this stage of investigation, to appreciate the ratio between contamination of soil by amalgamation process and by roasting. The information supplied by the inhabitants can be indistinct but these results show at least that the contamination is rather general and homogeneous on the scale of household and on the scale of the village.

The monitoring of air quality carried out inside and outside huts showed that Hg concentrations may reach relatively elevated concentrations (around or above 25,000 ng m^{-3}). However, in the worse case, the exposure of the artisanal miners (around 10 mn per day) was relatively short compared to the exposure limits for professional workers (25,000 ng m^{-3} for 8 h exposure). Amalgam roasting seems to be an occasional procedure occurring on a daily or weekly basis.

However as roasting is sometimes performed in huts, we should also consider the possible exposure of children. The roasting of amalgams generates usually two peaks of Hg above 80,000 ng m^{-3}. The first peak appears when Hg is evaporating from the amalgam, the second one, occurring few minutes later, is probably due to a late recondensation of mercury aerosols emitted during roasting. This condensation phase indicates that a large part of mercury emitted in the hut remains inside and therefore could accumulate in dusts on the floor, on walls, on vegetables hanging at the top of the hut. The second point is that this condensation phase could concern the entire hut unlike the period of roasting (local evaporation near the fire). All the people present in the hut at this moment could therefore breathe this mercury vapor. The condensation effect is lower in huts allowing rather good evacuation of smoke due to openings at the junction of walls and roof.

For the roasting outside, the duration with light mercury concentration is shorter than in the hut (around 100 s compared to 500 s in a hut) and the second peak of probable condensation of mercury vapor observed in the hut is absent.

Remobilization of Hg in the stream sediment

The remobilisation of Hg from processing zone to local streams seems very low. The Hg contents in sediments of wadi and khor flowing from the villages of Gugub and Khor

Gidad are similar (median under 200 ng g^{-1}) with higher contents near the zones of amalgamation (villages). The Hg contents decreased downstream the villages of miners some hundreds meters. The Hg concentrations in sediments of the main collector wadi Maganza are also relatively low and do not show important levels of contamination in regard to the usual guideline values for sediment management in Europe or in North America. It is not possible to compare the results obtained on dry samples from the villages of Gugub and Khor Gidad with samples taken somewhere else in flowing rivers. The conditions of sampling (focussed on dry samples with organic matter) explain certainly partially the high values encountered. The Hg contamination of sediments exist in this villages where amalgamation and roasting took places but it seems restricted to a narrow zone of few hundreds of meters around, and, at the present time, without apparent contamination downstream through Wadi Maganza.

Contamination of tailings and effect on stream

The phases of grinding, amalgamation and roasting generate heaps of mixed tailings, residues, ash or waste, sometimes several cubic meters in size, often thrown on the ground near the zones of operation, in or around enclosures dwelling or even gardens. Hg analyses carried out on these tailings show a heterogeneous contamination depending on their composition which can be sometimes high or very high (62,300 and 72,500 ng g^{-1} in Khor Gidad). Their number and location in gardens or within the "family unit" is a problem to be taken into account in the future operations of environmental management of the area.

Workers indicated that during rainy season part of this tailings and residues are sometime panned in pools located in the *Khor Alyas, at* south of Gugub. The highest Hg contents in sediment (ranging from 1,066 to 1,649 ng g^{-1}) are located along this *Khor Alyas* where aquatic life is unknown but where a water well supplying village with drinking wate. Control analyses on water well must be carried out in priority.

Principal hotspots

The artisanal gold miner families (~300) and the (10-15) local gold merchant shops in Gugub and in Khor Gidad constitute the same broad mercury hotspots. Potential risks to the ecosystem were considered to be minor in that process. The main targets identified are local people practising gold concentration processes at home. The shops and surroundings represent also a particular hotspot : the strongest Hg contents come from soils and dusts taken on the ground of trade shops (several values ranging from 20,000 to 1,000,000 ng g^{-1}).

We identified 4 sources of lost of mercury in the environment:

- Wrong manipulation of mercury at the shop or at home;
- Lost of Hg on the ground or in the tailings during amalgamation phase;
- Evaporation during roasting phase;
- Occasional panning of tailing in the pools.

Consumption of fishes and vegetables

The other risk of exposure, on a minor level, is related to the consumption of fishes and vegetables (sorghum and corn). There is a poor representativity of mercury contamination levels in fish species in relation to artisanal gold mining owing to the poor sampling conditions. The levels of contamination in fish muscle samples (15 species - 108 individuals) is very low and there is no fish above the WHO safety limit of 2.5 Hg µg g^{-1}, on the dry weight basis – the global mean Hg concentration was 0.246 ± 0.048 µg g^{-1} and 0.49 ± 0.10 µg g^{-1} for the carnivorous species. Compared with Zimbabwe, for fish of a similar size, the mean Hg concentrations were about ten times lower. Analysis of the results relating to the level of mercury contamination in the fish must necessarily bear in mind the constraints imposed by the sampling conditions and the absence of any direct relationship with the gold mining site and the village of Gugub. The occasional consumption of fishes in that area, (only 2 % of the people report eating fish occasionally) does not seem to constitute a major risk. The data from rivers directly affected by gold mining sites using amalgamation procedures must be considered insufficient to produce conclusions relating to fish advisory, or health related matters for this area of Sudan

Sorghum and corn are the main consumed vegetable, at least during the dry season. The average Hg contents in soil garden (cultivation of sorghum and corn) around the «family unit» ranging between 130 and 280 ng g^{-1} in Khor Gidad and Gugub, respectively; These values are close to the background level, and below UK and Canadian standard of permissible concentration of Hg in agricultural soil ranging from 1,000 to 8,000 ng g^{-1}. This indicates low mercury remobilization probably due to Fe-rich laterite acting as natural barriers and attenuating the widespread dispersion of Hg.

The Hg content of the analysed sorghum and corn is very low and do not present risk but significant quantities of mercury are present in the dusts deposited on the vegetables hanging on the roofs of huts were roasting is performed. This mercury is eliminated with a simple cleaning with water. These results on sorghum and corn should be controlled in a further step as apparently they may contribute to the evaluation of the daily intake of mercury for the local population.

8.2. RECOMMENDATIONS

This study was conducted on a short period and do not allow final conclusions in term of impact assessment, particularly some aspects would require further control.

- In the wadis and khor, the sampling of fishes and sediments should be extended during rainy season and all along wadi Maganza to evaluate the real level of contamination in the river system. The first results indicate that the risk of high contamination of fishes is low.

- The environmental assessment concerned only the environment of artisanal miners. Contamination of gold shops and surroundings was proved in the 2 villages studied. We also expect that roasting tends to be incomplete and at least 15 - 25 % of the *"doré"* contains residual mercury. To complete this assessment particular attention should be pay on the more exposed population that constitute dealers, merchants and their families.
- Results on sorghum and corn should be controlled in a further step as apparently they may contribute to the evaluation of the daily intake of mercury by the local population. The washing of hands and vegetables should be a priority even if sometimes water is restricted in use.

As the practice of local artisanal miners is quite recent, very traditional and with a limited use of mercury, there is no strong need to propose an important program to develop alternative technologies, on a short term basis. However we strongly recommend that some habits in the artisanal mining practices to be changed. Change in local mining practices would require a raising awareness campaign with education of population and specially women, mainly involved, on the risks they face themselves and theirs children. The action should focus on the amalgamation and the roasting procedure in order to promote a safer procedure.

- The main objective being a change of the location to roast the amalgams. Outside roasting must be strongly recommended and exposure to mercury vapours could be avoidable with the application of simple technological improvements such as retorts. Roasting the amalgam does not seem to be a private and confidential activity. It is frequently carried out in the street or at the shops. This fact can help to work in collaboration with the local artisanal miners to found appropriate spots, distant from the village and dedicated to the roasting. This place should be designed to avoid dispersion of Hg in the environment. Presence of children and pregnant women should be avoided during roasting.
- Authorities needs to insure that all amalgamation is carried out in cemented places and that all tailing from the amalgamation are stored in appropriate cemented storage area that prevent dispersal of Hg contamination onto adjacent land and into water drainage.
- Carefull clean up of contaminated huts should be recommended in order to decrease the hg content of domestic dust.
- Amalgamation zone located in the "enclosed family unit" must be marked and fenced in order to prevent children or animal ingestion.
- As use of mercury is recent, the most urgent requirement is to prevent any new Hg input to the river sediment by stopping or at least strictly controlling panning of contaminated tailings in the pools during rainy season.

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Appendix 1

List of the dust samples

SAMPLE	SAMPLING		COORDINATE DD		ALT	AREA	SITE	SPOT	SAMPLE	LOCATION		ACTIVITY
N°	DATE	TIME	LAT N	LONG E	m	NAME		N°	TYPE			ZONE
SDU001	09-APR-04	09:18:36	11.37455	34.01638	789.4	GUGUB	VILLAGE	1	DUST	Family unit	Hut	Roasting
SDU002	09-APR-04	09:51:02	11.37393	34.01635	791.0	GUGUB	VILLAGE	2	DUST	Shop	Shop	
SDU003	09-APR-04	10:15:28	11.37385	34.01615	792.0	GUGUB	VILLAGE	2	DUST	Shop	Yard	
SDU004	09-APR-04	10:24:23	11.37390	34.01621	790.1	GUGUB	VILLAGE	2	DUST	Shop	Hut	Roasting
SDU005	09-APR-04	11:16:40	11.37385	34.01647	792.0	GUGUB	VILLAGE	3	DUST	Family unit	Hut	Roasting
SDU006	09-APR-04	15:13:42	11.37542	34.01535	785.5	GUGUB	VILLAGE	4	DUST	School	Yard	Reference
SDU007	09-APR-04	15:31:50	11.37418	34.01632	790.1	GUGUB	VILLAGE	5	DUST	Mosque	Yard	Reference
SDU008	09-APR-04	17:08:30	11.37411	34.01662	795.4	GUGUB	VILLAGE	7	DUST	Family unit	Hut	Roasting
SDU009	10-APR-04	08:56:47	11.37447	34.01649	792.2	GUGUB	VILLAGE	1	DUST	Family unit	Hut	
SDU010	10-APR-04	09:02:43	11.37391	34.01621	787.4	GUGUB	VILLAGE	2	DUST	Family unit	Hut	
SDU011	10-APR-04	09:34:04	11.37284	34.01787	784.1	GUGUB	VILLAGE	9	DUST	Family unit	Hut	Roasting
SDU012	10-APR-04	10:21:11	11.37093	34.02053	771.3	GUGUB	VILLAGE	10	DUST	Family unit	Hut	Reference
SDU013	10-APR-04	11:46:16	11.36847	34.01578	812.7	GUGUB	VILLAGE	11	DUST	Family unit	Hut	Roasting
SDU014	11-APR-04	14:02:33	11.37190	34.01658	783.8	GUGUB	VILLAGE	27	DUST	Shop	Shop	
SDU015	11-APR-04	14:15:29	11.37195	34.01635	779.5	GUGUB	VILLAGE	27	DUST	Shop	Hut	
SDU029	15-APR-04	11:10:45	11.37428	34.01710	791.8	GUGUB	VILLAGE	64	DUST	Family unit	Hut	
SDU016	11-APR-04	15:47:06	11.41933	34.02030	742.3	KHOR GIDAD	VILLAGE	28	DUST	Shop	Hut	Reference
SDU017	11-APR-04	16:06:04	11.41924	34.02034	735.5	KHOR GIDAD	VILLAGE	28	DUST	Shop	Yard	Roasting
SDU018	11-APR-04	16:26:16	11.41868	34.02063	739.1	KHOR GIDAD	VILLAGE	29	DUST	Dealer Dwelling	Hut	
SDU019	11-APR-04	16:33:08	11.41886	34.02069	736.5	KHOR GIDAD	VILLAGE	29	DUST	Dealer Dwelling	Hut	Roasting
SDU020	11-APR-04	16:56:20	11.41887	34.02088	743.5	KHOR GIDAD	VILLAGE	30	DUST	Shop	Yard	Roasting
SDU021	11-APR-04	17:12:23	11.41741	34.02087	746.3	KHOR GIDAD	VILLAGE	31	DUST	Shop	Hut	
SDU022	11-APR-04	17:21:11	11.41742	34.02084	737.5	KHOR GIDAD	VILLAGE	31	DUST	Shop	Yard	Roasting
SDU023	11-APR-04	17:28:53	11.41746	34.02100	738.7	KHOR GIDAD	VILLAGE	31	DUST	Shop	Shop	Dealing
SDU024	11-APR-04	18:13:04	11.41650	34.02117	736.5	KHOR GIDAD	VILLAGE	32	DUST	Shop	Shop	Dealing
SDU025	11-APR-04	18:16:57	11.41643	34.02124	741.5	KHOR GIDAD	VILLAGE	32	DUST	Shop	Yard	Roasting
SDU026	12-APR-04	10:30:06	11.41713	34.02117	740.1	KHOR GIDAD	VILLAGE	33	DUST	Shop	Hut	
SDU027	12-APR-04	12:21:11	11.41975	34.01910	748.0	KHOR GIDAD	MINING	35	DUST	Miner Dwelling	Hut	
SDU028	14-APR-04	10:50:06	11.41315	34.02100	736.7	KHOR GIDAD	VILLAGE	47	DUST	Miner Dwelling	Hut	
SDU030	15-APR-04	13:21:57	11.38844	34.05503	713.4	TAGA	VILLAGE	66	DUST	Family unit	Hut	Reference

SAMPLE N°	Description
SDU001	fine dust in the roasting hut coming from ground and roof (living site)
SDU002	fine wet dust on the ground of the shop; Monitoring 2 in front of in the street
SDU003	fine dust in the living yard
SDU004	fine dust in the roasting hut coming from ground and roof (living site) poorly ventilated
SDU005	fine dust in the roasting hut coming from ground and roof (living site) Monitoring 1
SDU006	reddish dust from the ground; School could be considered as the reference point without Hg used in the village
SDU007	reddish dust from the ground front of the mosque; Mosque could be considered as the reference point without Hg used in the village
SDU008	brown to grey dust in a hut with frequent roasting
SDU009	fine dust on the ground , sleeping hut without roasting
SDU010	fine dust on the ground , sleeping hut without roasting
SDU011	fine dust on the ground
SDU012	fine dust in the living hut (Ingessana Tribe- IT)
SDU013	fine dust
SDU014	fine greyish dust on the ground
SDU015	fine greyish dust on the ground (no roasting hut)
SDU016	fine dust from the ground (no roasting)
SDU017	fine dust around usual roasting area
SDU018	fine dust in the living hut (no roasting)
SDU019	fine dust in the living hut (roasting)
SDU020	reddish fine-grained soils, ash on the top
SDU021	fine dust (no roasting)
SDU022	fine dust (ash) around roasting area
SDU023	fine dust on the ground
SDU024	fine dust
SDU025	fine dust (ash) around roasting area
SDU026	fine dust in the living hut (no roasting)
SDU027	fine dust , quite new Hut (no roasting, no amalgamation
SDU028	fine dust
SDU029	fine dust
SDU030	fine dust in the living hut

Appendix 2

List of the soil samples

SAMPLE	SAMPLING		COORDINATE DD		ALT	AREA	SITE	SPOT	SAMPLE	LOCATION		ACTIVITY
N°	DATE	TIME	LAT N	LONG E	m	NAME		N°	TYPE			ZONE
SSO001	09-APR-04	08:42:01	11.37443	34.01642	789.8	GUGUB	VILLAGE	1	SOIL	Family unit	Yard	Amalgamation
SSO002	09-APR-04	09:10:20	11.37460	34.01641	788.4	GUGUB	VILLAGE	1	SOIL	Family unit	Yard	
SSO003	09-APR-04	09:25:51	11.37450	34.01642	789.6	GUGUB	VILLAGE	1	SOIL	Family unit	Yard	
SSO004	09-APR-04	09:40:09	11.37434	34.01647	793.7	GUGUB	VILLAGE	1	SOIL	Garden	Garden	
SSO005	09-APR-04	10:07:11	11.37391	34.01625	794.2	GUGUB	VILLAGE	2	SOIL	Shop	Yard	Amalgamation
SSO006	09-APR-04	10:32:38	11.37385	34.01614	794.4	GUGUB	VILLAGE	2	SOIL	Shop	Yard	
SSO007	09-APR-04	11:21:58	11.37375	34.01644	788.6	GUGUB	VILLAGE	3	SOIL	Family unit	Yard	Amalgamation
SSO008	09-APR-04	12:24:30	11.37367	34.01657	792.0	GUGUB	VILLAGE	3	SOIL	Garden	Garden	
SSO009	09-APR-04	15:17:43	11.37560	34.01522	786.7	GUGUB	VILLAGE	4	SOIL	School	Yard	Reference
SSO010	09-APR-04	15:38:03	11.37411	34.01640	791.8	GUGUB	VILLAGE	5	SOIL	Mosque	Yard	Reference
SSO011	09-APR-04	16:49:42	11.37354	34.01679	789.1	GUGUB	VILLAGE	3	SOIL	Garden	Garden	
SSO012	09-APR-04	17:07:12	11.37409	34.01660	796.3	GUGUB	VILLAGE	6	SOIL	Family unit	Yard	Amalgamation
SSO013	09-APR-04	17:24:30	11.37305	34.01716	793.7	GUGUB	VILLAGE	7	SOIL	Family unit	Yard	Amalgamation
SSO014	09-APR-04	17:35:52	11.37270	34.01744	789.8	GUGUB	VILLAGE	7	SOIL	Garden	Garden	
SSO015	09-APR-04	17:40:52	11.37312	34.01769	784.8	GUGUB	VILLAGE	7	SOIL	Garden	Garden	
SSO016	10-APR-04	09:41:41	11.37287	34.01775	786.5	GUGUB	VILLAGE	8	SOIL	Track	Track	Amalgamation
SSO017	10-APR-04	10:16:42	11.37088	34.02045	783.1	GUGUB	VILLAGE	9	SOIL	Family unit	Yard	
SSO018	10-APR-04	11:18:19	11.36851	34.01571	772.3	GUGUB	VILLAGE	10	SOIL	Family unit	Yard	Reference
SSO019	10-APR-04	11:25:26	11.36827	34.01578	812.4	GUGUB	VILLAGE	11	SOIL	Family unit	Yard	Amalgamation
SSO020	10-APR-04	11:38:13	11.36847	34.01578	809.1	GUGUB	VILLAGE	11	SOIL	Family unit	Yard	Amalgamation
SSO021	10-APR-04	11:53:48	11.36849	34.01584	810.8	GUGUB	VILLAGE	11	SOIL	Family unit	Yard	
SSO022	10-APR-04	13:55:45	11.37182	34.01669	811.0	GUGUB	VILLAGE	11	SOIL	Family unit	Garden	
SSO023	11-APR-04	14:07:42	11.37190	34.01652	782.2	GUGUB	VILLAGE	27	SOIL	Shop	Yard	Amalgamation
SSO024	11-APR-04	14:18:18	11.37189	34.01661	792.0	GUGUB	VILLAGE	27	SOIL	Shop	Yard	Amalgamation
SSO025	11-APR-04	15:43:17	11.41923	34.02028	781.4	GUGUB	VILLAGE	27	SOIL	Shop	Yard	Roasting
SSO026	11-APR-04	15:48:59	11.41928	34.02028	739.6	KHOR GIDAD	VILLAGE	28	SOIL	Shop	Yard	Amalgamation
SSO027	11-APR-04	15:53:51	11.41938	34.02038	740.8	KHOR GIDAD	VILLAGE	28	SOIL	Shop	Yard	Amalgamation
SSO028	11-APR-04	15:59:06	11.41925	34.02036	741.5	KHOR GIDAD	VILLAGE	28	SOIL	Shop	Yard	Amalgamation
SSO029	11-APR-04	16:19:05	11.41879	34.02061	739.9	KHOR GIDAD	VILLAGE	28	SOIL	Shop	Yard	Reference
SSO030	11-APR-04	16:36:09	11.41859	34.02059	741.3	KHOR GIDAD	VILLAGE	29	SOIL	Dealer Dwelling	Yard	Amalgamation
SSO031	11-APR-04	16:48:39	11.41882	34.02086	741.1	KHOR GIDAD	VILLAGE	29	SOIL	Dealer Dwelling	Yard	

SAMPLE	SAMPLING		COORDINATE DD		ALT	AREA	SITE	SPOT	SAMPLE	LOCATION		ACTIVITY
N°	DATE	TIME	LAT N	LONG E	m	NAME		N°	TYPE			ZONE
SSO032	11-APR-04	17:15:38	11.41736	34.02092	742.7	KHOR GIDAD	VILLAGE	30	SOIL	Shop	Yard	Amalgamation
SSO033	11-APR-04	17:25:30	11.41736	34.02087	743.2	KHOR GIDAD	VILLAGE	31	SOIL	Shop	Yard	Amalgamation
SSO034	11-APR-04	17:59:38	11.41639	34.02122	738.2	KHOR GIDAD	VILLAGE	31	SOIL	Shop	Yard	
SSO035	11-APR-04	18:06:09	11.41649	34.02123	738.2	KHOR GIDAD	VILLAGE	32	SOIL	Shop	Yard	Amalgamation
SSO036	11-APR-04	18:10:12	11.41706	34.02111	741.3	KHOR GIDAD	VILLAGE	32	SOIL	Shop	Yard	
SSO037	12-APR-04	10:22:12	11.41716	34.02118	736.0	KHOR GIDAD	VILLAGE	33	SOIL	Shop	Yard	Amalgamation
SSO038	12-APR-04	10:37:04	11.41705	34.02115	737.0	KHOR GIDAD	VILLAGE	33	SOIL	Shop	Yard	Amalgamation
SSO039	12-APR-04	10:53:05	11.41898	34.02030	735.3	KHOR GIDAD	VILLAGE	33	SOIL	Shop	Yard	
SSO040	12-APR-04	10:57:58	11.41898	34.02029	740.6	KHOR GIDAD	VILLAGE	34	SOIL	Dealer Dwelling	Yard	Amalgamation
SSO041	12-APR-04	11:08:36	11.41895	34.02027	741.8	KHOR GIDAD	VILLAGE	34	SOIL	Dealer Dwelling	Yard	Amalgamation
SSO042	12-APR-04	11:13:22	11.41898	34.02029	747.1	KHOR GIDAD	VILLAGE	34	SOIL	Dealer Dwelling	Yard	Amalgamation
SSO043	12-APR-04	12:22:42	11.41975	34.01911	740.6	KHOR GIDAD	VILLAGE	34	SOIL	Dealer Dwelling	Hut	
SSO044	12-APR-04	12:36:49	11.41963	34.02037	746.6	KHOR GIDAD	MINING	35	SOIL	Miner Dwelling	Yard	
SSO045	12-APR-04	12:39:10	11.41961	34.02033	746.8	KHOR GIDAD	MINING	36	SOIL	Miner Dwelling	Yard	
SSO046	12-APR-04	15:07:10	11.41607	34.02163	747.8	KHOR GIDAD	MINING	36	SOIL	Miner Dwelling	Yard	
SSO047	12-APR-04	15:17:42	11.41608	34.02170	733.1	KHOR GIDAD	VILLAGE	39	SOIL	Miner Dwelling	Yard	Amalgamation
SSO048	12-APR-04	15:31:47	11.41565	34.02207	740.3	KHOR GIDAD	VILLAGE	39	SOIL	Miner Dwelling	Yard	
SSO049	12-APR-04	15:39:24	11.41314	34.02101	738.7	KHOR GIDAD	VILLAGE	39	SOIL	Garden	Garden	
SSO050	14-APR-04	10:31:57	11.41309	34.02102	739.9	KHOR GIDAD	VILLAGE	47	SOIL	Miner Dwelling	Yard	Amalgamation
SSO051	14-APR-04	10:42:26	11.41311	34.02105	740.3	KHOR GIDAD	VILLAGE	47	SOIL	Miner Dwelling	Yard	Amalgamation
SSO052	14-APR-04	10:56:13	11.41285	34.02127	735.5	KHOR GIDAD	VILLAGE	47	SOIL	Miner Dwelling	Yard	Reference
SSO053	14-APR-04	12:31:07	11.41586	34.02277	743.2	KHOR GIDAD	VILLAGE	47	SOIL	Garden	Garden	
SSO054	14-APR-04	16:03:55	11.41811	34.02077	732.6	KHOR GIDAD	VILLAGE	51	SOIL	Garden	Garden	Reference
SSO055	14-APR-04	16:07:26	11.41813	34.02069	745.9	KHOR GIDAD	MINING	52	SOIL	Miner Dwelling	Yard	
SSO056	14-APR-04	11:15:56	11.37424	34.01706	741.1	KHOR GIDAD	MINING	52	SOIL	Miner Dwelling	Yard	
SSO057	15-APR-04	11:19:12	11.37427	34.01705	791.0	GUGUB	VILLAGE	64	SOIL	Family unit	Yard	Amalgamation
SSO058	15-APR-04	11:23:55	11.37430	34.01705	792.0	GUGUB	VILLAGE	64	SOIL	Family unit	Yard	Amalgamation
SSO059	15-APR-04	11:25:14	11.37429	34.01706	789.8	GUGUB	VILLAGE	64	SOIL	Family unit	Yard	Amalgamation
SSO060	15-APR-04	11:38:16	11.37333	34.01574	792.2	GUGUB	VILLAGE	64	SOIL	Family unit	Yard	Amalgamation
SSO061	15-APR-04	11:40:47	11.37329	34.01572	802.1	GUGUB	VILLAGE	65	SOIL	Family unit	Yard	
SSO062	15-APR-04	11:42:37	11.37336	34.01578	795.4	GUGUB	VILLAGE	65	SOIL	Family unit	Yard	

SAMPLE	SAMPLING		COORDINATE DD		ALT	AREA	SITE	SPOT	SAMPLE	LOCATION		ACTIVITY
N°	DATE	TIME	LAT N	LONG E	m	NAME		N°	TYPE			ZONE
SSO063	15-APR-04	11:43:42	11.38840	34.05509	796.1	GUGUB	VILLAGE	65	SOIL	Family unit	Yard	
SSO064	15-APR-04	13:32:47	11.38842	34.05509	715.6	TAGA	VILLAGE	66	SOIL	Family unit	Yard	Reference
SSO065	15-APR-04	13:35:40	11.38840	34.05524	713.7	TAGA	VILLAGE	66	SOIL	Family unit	Yard	Reference
SSO066	15-APR-04	16:30:19	11.37367	34.01676	715.3	TAGA	VILLAGE	66	SOIL	Family unit	Garden	Reference

SAMPLE N°	Description
SSO001	reddish fine soil with beige bed (1cm) - possible ancient tailings
SSO002	fine to coarse reddish soil around hut of roasting, close to bedrock
SSO003	reddish coarse to fine soil close to bedrock around fire places
SSO004	garden of dry maize located 25 m far on the slope
SSO005	fine to coarse reddish soil around amalgamation areas
SSO006	fine to coarse reddish soil around hut of roasting, close to tailings heaps
SSO007	brown coarse soil on main amalgamation area; Visible Hg droplets and gold specks after panning, galena and arsenopyrite visible
SSO008	soil from garden of dry maize located 25 m far on the slope, tailing visible in the garden
SSO009	reddish vegetal mottle soil from the ground; School could be considered as the reference point without Hg used in the village
SSO010	reddish soil front of the mosque; Mosque considered as the top point of the village center
SSO011	trench in the garden across surface drainage coming from the main amalgamation site located 25 m far up
SSO012	mottled rocky soil, close to bed rock
SSO013	reddish coarsed to fine soil
SSO014	trench in a garden across surface drainage coming from the main amalgamation site located far up
SSO015	trench in a garden across surface drainage coming from the main amalgamation site located far up
SSO016	coarsed reddish soil on cross section
SSO017	fine to coarse reddish soil; Panning indicate 1 Hg drop and mercury associated with fine in suspension (!?)
SSO018	rocky coarse brown soil
SSO019	mottled brown soil - group of dwelling out of and above the main village, on the slope, strong Hg activity, visible Hg droplets on panning concentrate but no gold
SSO020	mottled brown soil - bedrock (sloping), visible Hg
SSO021	reddish coarse to fine soil close to bedrock around the roasting hut
SSO022	medium-grained reddish soil in a terrace cultivation located along the superficial drainage of the enclosure
SSO023	reddish fine to coarse soil
SSO024	reddish fine to coarse soil
SSO025	reddish fine to coarse soil
SSO026	reddish fine-grained soils, ash on the top
SSO027	reddish fine-grained soils,
SSO028	reddish fine-grained soils,
SSO029	reddish fine-grained soil (reference)
SSO030	reddish fine to coarse soil, several Hg droplets on panning concentrate, Hg + fine sediment suspension (?)
SSO031	reddish fine-grained soils,
SSO032	reddish fine-grained soils around main hut

SAMPLE N°	Description
SSO033	reddish fine-grained soils,
SSO034	reddish fine-grained soils,
SSO035	brown to reddish fine grained soil, visible Hg droplets in the soil without panning
SSO036	reddish fine-grained soils,
SSO037	reddish fine-grained soils,
SSO038	reddish fine-grained soils, enclosure dedicated to amalgamation
SSO039	reddish fine-grained soils,
SSO040	reddish fine-grained soils, around hut
SSO041	reddish fine-grained soils, around hut
SSO042	reddish fine-grained soils, around hut
SSO043	mixture of soil and dust in the living hut
SSO044	red fine soil, quite new Hut (no roasting, no amalgamation
SSO045	red fine soil, quite new Hut (no roasting, no amalgamation
SSO046	red fine soil, quite new Hut (no roasting, no amalgamation
SSO047	brown to black fine quartz and argileous soil on bedrock, visible gold nuggets on panning concentrate
SSO048	brown to black fine soil on bedrock
SSO049	brown to reddish fine to coarse argileous soil (Sorgo field)
SSO050	dry brown vegetal soil
SSO051	dry brown vegetal soil
SSO052	dry brown vegetal soil (out of amalgamation zone)
SSO053	brown to reddish fine to coarse argileous soil (Sorgo field)
SSO054	vegetal brown soil
SSO055	vegetal brown soil
SSO056	vegetal brown soil
SSO057	fine to coarse reddish soil around hut, close to bedrock
SSO058	fine to coarse reddish soil around hut, close to bedrock
SSO059	fine to coarse reddish soil around hut, close to bedrock
SSO060	fine to coarse reddish soil around hut, close to bedrock
SSO061	fine to coarse reddish soil along fences, close to bedrock, slope
SSO062	fine to coarse reddish soil along fences, close to bedrock, slope
SSO063	fine to coarse reddish soil along fences, close to bedrock, slope
SSO064	fine brown vegetal soil

SAMPLE N°	Description
SSO065	fine brown vegetal soil
SSO066	fine brown vegetal soil

Appendix 3

List of the termite, tailing and vegetable samples

SAMPLE	SAMPLING		COORDINATE DD		ALT	AREA	SITE	SPOT	SAMPLE	LOCATION		ACTIVITY
N°	DATE	TIME	LAT N	LONG E	m	NAME		N°	TYPE			ZONE
STA001	09-APR-04	08:58:46	11.37454	34.01639	787.0	GUGUB	VILLAGE	1	TAILING	Family unit	Yard	
STA002	09-APR-04	16:53:45	11.37350	34.01681	791.0	GUGUB	VILLAGE	6	TAILING	Family unit	Yard	
STA003	10-APR-04	12:02:27	11.36841	34.01588	811.5	GUGUB	VILLAGE	11	TAILING	Family unit	Garden	
STA004	11-APR-04	11:13:56	11.35979	34.02003	791.0	GUGUB	MINING	25	TAILING	Mining	Pits	Mining
STA005	11-APR-04	11:50:08	11.37042	34.03042	755.7	GUGUB	MINING	26	TAILING	Mining	Pits	Mining
STA017	15-APR-04	11:27:10	11.37436	34.01704	792.7	GUGUB	VILLAGE	64	TAILING	Family unit	Garden	Tailing
STA006	11-APR-04	16:23:21	11.41877	34.02057	738.7	KHOR GIDAD	VILLAGE	29	TAILING	Dealer Dwelling	Yard	Tailing
STA007	11-APR-04	17:34:52	11.41742	34.02098	741.1	KHOR GIDAD	VILLAGE	31	TAILING	Shop	Track	Amalgamation
STA008	12-APR-04	10:40:14	11.41706	34.02123	736.5	KHOR GIDAD	VILLAGE	33	TAILING	Shop	Yard	Tailing
STA009	12-APR-04	11:15:58	11.41894	34.02026	742.5	KHOR GIDAD	VILLAGE	34	TAILING	Dealer Dwelling	Yard	Tailing
STA010	12-APR-04	12:34:34	11.41963	34.02033	744.2	KHOR GIDAD	MINING	36	TAILING	Miner Dwelling	Yard	Tailing
STA011	12-APR-04	12:43:11	11.41966	34.02042	749.7	KHOR GIDAD	MINING	36	TAILING	Miner Dwelling	Yard	Tailing
STA012	12-APR-04	15:13:32	11.41609	34.02166	736.0	KHOR GIDAD	VILLAGE	39	TAILING	Miner Dwelling	Yard	Crushing
STA013	14-APR-04	10:39:17	11.41306	34.02103	741.1	KHOR GIDAD	VILLAGE	47	TAILING	Miner Dwelling	Yard	Tailing
STA014	14-APR-04	15:47:48	11.41856	34.01987	744.4	KHOR GIDAD	MINING	53	TAILING	Mining	Bank	Panning
STA015	14-APR-04	15:52:36	11.41866	34.01984	742.7	KHOR GIDAD	MINING	53	TAILING	Mining	Bank	Panning
STA016	14-APR-04	18:07:17	11.41590	34.02038	731.7	KHOR GIDAD	KHOR GIDAD	61	TAILING	Mining	Pit	Panning
STE001	09-APR-04	10:58:41	11.37379	34.01642	790.1	GUGUB	VILLAGE	3	HANT HILL	Family unit	Hut	
STE002	09-APR-04	11:04:38	11.37386	34.01642	789.8	GUGUB	VILLAGE	3	HANT HILL	Family unit	Yard	
STE003	09-APR-04	11:35:01	11.37386	34.01652	793.9	GUGUB	VILLAGE	3	HANT HILL	Garden	Garden	
STE004	09-APR-04	12:22:28	11.37361	34.01650	789.8	GUGUB	VILLAGE	3	HANT HILL	Garden	Garden	
STE005	10-APR-04	10:31:10	11.37092	34.01929	768.9	GUGUB	VILLAGE	10	HANT HILL	Family unit	Garden	Reference
STE006	12-APR-04	14:59:01	11.41631	34.02163	740.3	KHOR GIDAD	MINING	38	HANT HILL	Mining	Garden	Panning
STE007	14-APR-04	16:50:21	11.41648	34.02278	729.5	KHOR GIDAD	MINING	58	HANT HILL	Drainage	Bank	
STE008	14-APR-04	17:55:55	11.41988	34.02377	742.7	KHOR GIDAD	MINING	60	HANT HILL	Mining	Pit	
SVE001	09-APR-04	10:25:23	11.37390	34.01621	790.1	GUGUB	VILLAGE	2	VEGETABLE	Shop	Hut	Roasting
SVE002	09-APR-04	10:26:23	11.37390	34.01621	790.1	GUGUB	VILLAGE	2	VEGETABLE	Shop	Hut	Roasting
SVE003	09-APR-04	11:17:40	11.37385	34.01647	792.0	GUGUB	VILLAGE	3	VEGETABLE	Family unit	Hut	Roasting
SVE004	09-APR-04	11:18:40	11.37385	34.01647	792.0	GUGUB	VILLAGE	3	VEGETABLE	Family unit	Hut	Roasting
SVE005	10-APR-04	10:22:11	11.37093	34.02053	771.3	GUGUB	VILLAGE	10	VEGETABLE	Family unit	Hut	Reference
SVE006	10-APR-04	10:23:11	11.37093	34.02053	771.3	GUGUB	VILLAGE	10	VEGETABLE	Family unit	Hut	Reference
SVE007	15-APR-04	13:22:57	11.38844	34.05503	713.4	TAGA	VILLAGE	66	VEGETABLE	Family unit	Hut	Reference
SVE008	15-APR-04	13:23:57	11.38844	34.05503	713.4	TAGA	VILLAGE	66	VEGETABLE	Family unit	Hut	Reference

SAMPLE N°	Description
STA001	small heap of roasting fire ashes mixed with tailings
STA002	grey to brown tailing mainly composed of ash.
STA003	Beige quartzy soil mainly composed by tailing of panning concentrate, along fence
STA004	quartz medium size tailing
STA005	quartz and microgabbro medium size tailing
STA006	Heaps of Tailing of Amalgamation, mixture of grinded quartz and reddish argileous soil
STA007	mixture of soil and amalgamation residues in front of the shop
STA008	fine grained residues of amalgamation compose by grinded quartz
STA009	fine grained residues of amalgamation compose by grinded quartz
STA010	residues of crushing
STA011	residues of panning
STA012	fine grained residues of panning compose by grinded quartz
STA013	fine amalgamation residues mixed with ash
STA014	alluvial residues of panning (reddish argiliceous quartz mixture)
STA015	alluvial residues of panning (reddish argiliceous quartz mixture)
STA016	brown coarsed grained soil
STA017	fine amalgamation residues mixed with ash
STE001	mottled red soil - Recent ant hill on the historical site of beginning of amalgamation in Gugub; the house is recent, less than 1 year
STE002	mottled red soil - Recent ant hill (5 days) on the historical site of beginning of amalgamation in Gugub
STE003	mottled red soil - Ant hill on the edges of the garden
STE004	mottled red soil - Ant hill on the edges of the garden
STE005	mottled red soil - area supposed without amalgamation and roasting
STE006	mottled red soil , Ant hill close to panning area
STE007	grey dry mottled soil
STE008	reddish dry mottled soil
SVE001	dusty smoked Sorgo pieces hanging on the Roof (in place from October 2003)
SVE002	dusty smoked Maize pieces hanging on the Roof (in place from October 2003)
SVE003	dusty smoked Sorgo pieces hanging on the Roof (in place from October 2003)
SVE004	dusty smoked Maize pieces hanging on the Roof (in place from October 2003)
SVE005	sorgo pieces without black dust (IT)
SVE006	maize pieces without black dust (IT)
SVE007	sorgo pieces without black dust suspended on the roof
SVE008	maize pieces without black dust suspended on the roof

Appendix 4

List of the sediment samples

SAMPLE	SAMPLING		COORDINATE DD		ALT	AREA	SITE	SPOT	SAMPLE	LOCATION		ACTIVITY
N°	DATE	TIME	LAT N	LONG E	m	NAME		N°	TYPE			ZONE
SSE001	09-APR-04	17:56:11	11.37148	34.01786	776.9	GUGUB	VILLAGE	12	SEDIMENT	Drainage	Stream	
SSE002	09-APR-04	18:05:55	11.37104	34.01796	778.1	GUGUB	VILLAGE	13	SEDIMENT	Drainage	Stream	
SSE003	10-APR-04	14:10:35	11.37122	34.01649	782.2	GUGUB	K. ALYAS	14	SEDIMENT	Drainage	Stream	Panning
SSE004	10-APR-04	14:14:24	11.37118	34.01655	775.7	GUGUB	K. ALYAS	14	SEDIMENT	Drainage	Stream	Panning
SSE005	10-APR-04	14:26:05	11.37122	34.01647	779.3	GUGUB	K. ALYAS	14	SEDIMENT	Drainage	Stream	Panning
SSE006	10-APR-04	14:34:18	11.37102	34.01604	783.1	GUGUB	K. ALYAS	14	SEDIMENT	Drainage	Stream	
SSE007	10-APR-04	15:03:07	11.37116	34.01759	773.5	GUGUB	K. ALYAS	15	SEDIMENT	Drainage	Stream	
SSE008	10-APR-04	15:11:40	11.37152	34.01718	778.5	GUGUB	K. ALYAS	16	SEDIMENT	Drainage	Stream	
SSE009	10-APR-04	15:25:08	11.36987	34.01934	771.8	GUGUB	K. ALYAS	17	SEDIMENT	Drainage	Stream	Panning
SSE010	10-APR-04	15:35:27	11.36975	34.02017	768.9	GUGUB	K. ALYAS	18	SEDIMENT	Drainage	Stream	
SSE011	10-APR-04	15:47:21	11.36997	34.02172	770.1	GUGUB	K. ALYAS	19	SEDIMENT	Drainage	Stream	
SSE012	10-APR-04	16:21:27	11.36988	34.02570	756.4	GUGUB	K. SHAREBAN	20	SEDIMENT	Drainage	Stream	Panning
SSE013	10-APR-04	16:24:09	11.36989	34.02569	756.4	GUGUB	K. SHAREBAN	20	SEDIMENT	Drainage	Bank	Panning
SSE014	10-APR-04	16:25:05	11.36990	34.02570	757.4	GUGUB	K. SHAREBAN	20	SEDIMENT	Drainage	Bank	Panning
SSE015	10-APR-04	17:22:50	11.37621	34.01574	786.5	GUGUB	VILLAGE	21	SEDIMENT	Drainage	Stream	
SSE016	10-APR-04	17:31:09	11.37714	34.01635	784.8	GUGUB	VILLAGE	22	SEDIMENT	Drainage	Stream	
SSE017	10-APR-04	17:42:14	11.37817	34.01748	768.2	GUGUB	VILLAGE	23	SEDIMENT	Drainage	Stream	
SSE018	10-APR-04	17:53:51	11.37641	34.01682	778.8	GUGUB	VILLAGE	24	SEDIMENT	Drainage	Stream	
SSE019	11-APR-04	11:08:02	11.35952	34.02018	793.2	GUGUB	MINING	25	SEDIMENT	Drainage	Stream	Mining
SSE020	11-APR-04	12:09:33	11.36444	34.02109	769.7	GUGUB	MINING	26	SEDIMENT	Mining	Stream	Mining
SSE021	12-APR-04	12:51:29	11.41989	34.02062	743.7	KHOR GIDAD	MINING	36	SEDIMENT	Miner Dwelling	Stream	
SSE022	12-APR-04	13:06:31	11.41840	34.02156	743.0	KHOR GIDAD	MINING	37	SEDIMENT	Drainage	Stream	
SSE023	13-APR-04	07:50:59	11.76021	34.37371	479.6	ROSEIRES	DAM	40	SEDIMENT	Dam	Bank	Fishing
SSE024	13-APR-04	07:57:27	11.76052	34.37346	476.9	ROSEIRES	DAM	40	SEDIMENT	Dam	Bank	Fishing
SSE025	13-APR-04	08:48:14	11.69051	34.33598	479.8	ROSEIRES	DAM	41	SEDIMENT	Dam	Bank	Fishing
SSE026	13-APR-04	08:51:26	11.69032	34.33598	479.6	ROSEIRES	DAM	41	SEDIMENT	Dam	Bank	Fishing
SSE027	13-APR-04	10:06:57	11.61800	34.31837	483.7	ROSEIRES	W.MAGANZA	42	SEDIMENT	Pool	Stream	
SSE028	13-APR-04	10:16:50	11.61788	34.31810	480.8	ROSEIRES	W.MAGANZA	42	SEDIMENT	Pool	Bank	
SSE029	13-APR-04	11:00:39	11.58692	34.30362	492.6	ROSEIRES	W.MAGANZA	43	SEDIMENT	Drainage	Stream	
SSE030	13-APR-04	11:04:37	11.58693	34.30358	492.1	ROSEIRES	W.MAGANZA	43	SEDIMENT	Drainage	Bank	
SSE031	13-APR-04	19:01:08	11.46732	34.16645	589.9	ROSEIRES	W.MAGANZA	44	SEDIMENT	Drainage Torrent	Stream	

SAMPLE	SAMPLING		COORDINATE DD		ALT	AREA	SITE	SPOT	SAMPLE	LOCATION		ACTIVITY
N°	DATE	TIME	LAT N	LONG E	m	NAME		N°	TYPE			ZONE
SSE032	13-APR-04	19:04:59	11.46728	34.16658	591.1	ROSEIRES	W.MAGANZA	44	SEDIMENT	Drainage Torrent	Bank	
SSE033	14-APR-04	09:48:58	11.38314	34.01795	761.5	GUGUB	KHOR ?	45	SEDIMENT	Drainage Torrent	Stream	
SSE034	14-APR-04	10:01:08	11.38527	34.01671	753.6	GUGUB	KHOR ?	46	SEDIMENT	Drainage Torrent	Stream	
SSE035	14-APR-04	10:05:33	11.38530	34.01663	759.3	GUGUB	KHOR ?	46	SEDIMENT	Drainage Torrent	Stream	
SSE036	14-APR-04	11:03:13	11.41313	34.02138	734.6	KHOR GIDAD	VILLAGE	47	SEDIMENT	Drainage	Stream	
SSE037	14-APR-04	11:10:41	11.41268	34.02216	734.3	KHOR GIDAD	VILLAGE	47	SEDIMENT	Drainage	Stream	Reference
SSE038	14-APR-04	11:42:27	11.41426	34.02369	727.4	KHOR GIDAD	KHOR GIDAD	48	SEDIMENT	Drainage	Stream	Panning
SSE039	14-APR-04	11:57:42	11.41520	34.02415	728.6	KHOR GIDAD	KHOR GIDAD	49	SEDIMENT	Drainage	Stream	Panning
SSE040	14-APR-04	12:08:34	11.41483	34.02491	728.8	KHOR GIDAD	KHOR GIDAD	50	SEDIMENT	Drainage	Stream	Panning
SSE041	14-APR-04	15:11:46	11.42010	34.01612	742.5	KHOR GIDAD	MINING	54	SEDIMENT	Mining	Pit	Panning
SSE042	14-APR-04	15:28:22	11.41884	34.01873	742.5	KHOR GIDAD	MINING	54	SEDIMENT	Drainage	Stream	Panning
SSE043	14-APR-04	16:17:32	11.41805	34.02134	743.5	KHOR GIDAD	MINING	55	SEDIMENT	Drainage	Bank	
SSE044	14-APR-04	16:29:48	11.41807	34.02137	738.7	KHOR GIDAD	MINING	56	SEDIMENT	Drainage	Stream	
SSE045	14-APR-04	16:36:32	11.41737	34.02248	737.9	KHOR GIDAD	MINING	57	SEDIMENT	Drainage	Bank	
SSE046	14-APR-04	16:59:09	11.41636	34.02294	736.5	KHOR GIDAD	KHOR GIDAD	59	SEDIMENT	Drainage	Stream	
SSE047	14-APR-04	18:40:29	11.37873	34.03216	730.0	GUGUB	W.ABU DJAL	61	SEDIMENT	Drainage	Stream	Panning
SSE048	15-APR-04	09:55:05	11.38106	34.00716	797.8	GUGUB	STREAM	62	SEDIMENT	Pool	Stream	Fishing
SSE049	15-APR-04	10:16:10	11.38425	34.00890	780.7	GUGUB	STREAM	63	SEDIMENT	Pool	Stream	Fishing

SAMPLE N°	Description
SSE001	fine brown dry sediment downstream south of the village
SSE002	fine brown dry sediment with black organic matter layers downstream south of the village (Khor Alyas)
SSE003	fine brown dry sediment
SSE004	fine brown dry sediment (galena specks)
SSE005	fine brown dry sediment rich in organic matter (mm-size black layers)
SSE006	fine brown dry sediment
SSE007	fine brown dry sediment rich in organic matter (mm-size black layers)
SSE008	fine brown dry sediment
SSE009	fine brown dry sediment rich in organic matter (mm-size black layers)
SSE010	fine brown dry sediment
SSE011	fine brown dry sediment
SSE012	stream gravels sediment (dry)
SSE013	fine brown dry sediment rich in organic matter (mm-size black layers)
SSE014	fine brown dry sediment rich in organic matter (mm-size black layers)
SSE015	fine brown dry sediment rich in organic matter (mm-size black layers)
SSE016	medium to fine homogeneous sediment
SSE017	medium to fine homogeneous sediment
SSE018	medium to fine homogeneous sediment with black beds (OM)
SSE019	medium to fine homogeneous sediment
SSE020	fine brown sediment
SSE021	brown to reddish fine sediment with vegetals pieces, stream close to previous samples
SSE022	brown fine sediment with vegetal debris
SSE023	wet black MO-rich fine mud or muck
SSE024	wet black MO-rich fine mud or muck
SSE025	wet black MO-rich fine mud or muck
SSE026	wet black sand-rich fine mud or muck
SSE027	wet black MO-rich fine mud or muck
SSE028	dry black MO-rich fine mud (flood deposit)
SSE029	dry coarse-grained sandy sediment
SSE030	dry black MO-rich fine mud (flood deposit)
SSE031	dry coarse-grained sandy sediment (large wadi , 50m)

SAMPLE N°	Description
SSE032	Dry black MO-rich fine mud (flood deposit)
SSE033	dry fine to medium grained black sediment
SSE034	dry fine to medium grained black sediment
SSE035	Dry black MO-rich fine mud (flood deposit)
SSE036	fine brown sediments
SSE037	brown sediments poor in fine particules
SSE038	coarsed-grained quartzy sediment
SSE039	coarsed-grained quartzy sediment
SSE040	coarsed-grained quartzy sediment
SSE041	fine black clay on the upper part of a pit
SSE042	coarsed-grained quartzy sediment
SSE043	fine black clay on "inselbergs"
SSE044	coarsed-grained quartzy sediment
SSE045	coarsed-grained quartzy sediment
SSE046	coarsed-grained quartzy sediment
SSE047	consolidated fine brown sediment
SSE048	Wet black sand-rich fine mud or muck
SSE049	Wet black sand-rich fine mud or muck

Appendix 5

Description of the fish samples

family	gender	species	habitat	feeding	Feeding details	Fish number				Total Number
						Roseires			Gugub	
						1	2	3	4	
Clariidae	Clarias	gariepinus	benthopelagique	benthivore	bottom feeder: insects invertebrates, fish, rotting flesh and plants	**5**	**4**		**1**	**10**
Cichlidae	Oreochromis	niloticus	demersal	herbivore	phytoplankton, benthic algae			**5**	**14**	**19**
Cichlidae	Sarotherodon	galilaeus	demersal	herbivore	algae and fine organic debris	**6**	**5**			**11**
Schilbeidae	Schilbe	intermedius	pelagique	carnivore	Invertebrates including terrestrial insects, fish	**5**		**4**		**9**
Alestiidae	Hydrocinus	forskalii	pelagique	carnivore	fishes, insects	**5**				**5**
Alestiidae	Brycinus	nurse	pelagique	omnivore	zooplankton, shrimps, insects, vegetation	**5**				**5**
Centropomidae	Lates	niloticus	demersal	carnivore	fishes, shrimps	**6**				**6**
Cyprinidae	Labeo	niloticus	demersal	benthivore	bottom feeder, vegetarian, epilithic algae	**5**			**14**	**19**
Mormyridae	Mormyrus	niloticus	pelagique	carnivore	insects, invertebrates			**2**		**2**
Mormyridae	Hyperopisus	bebe	demersal	omnivore	plankton, molluscs, aquatic insects			**2**		**2**
Mormyridae	Marcusenius	senegalensis	demersal	insectivore				**2**		**2**
Mochokidae	Synondontis	schall	benthopelagique	omnivore	invertebrates, fish, molluscs		**6**	**6**		**12**
Bagridae	Auchenoglanis	occidentalis	demersal	omnivore	plankton, insects, molluscs, seeds and detritus			**2**		**2**
Unidentified species									**4**	**4**
					Total	**37**	**15**	**23**	**33**	**108**

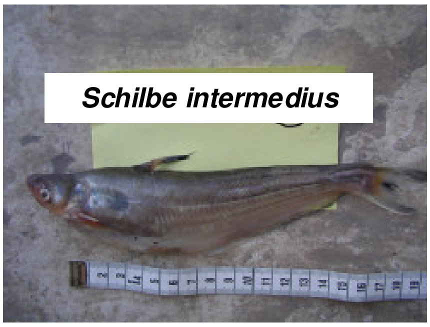
PHOTOGRAPHS OF FISH SPECIES COLLECTED

FROM THE DIFFERENT FISHING SPOTS

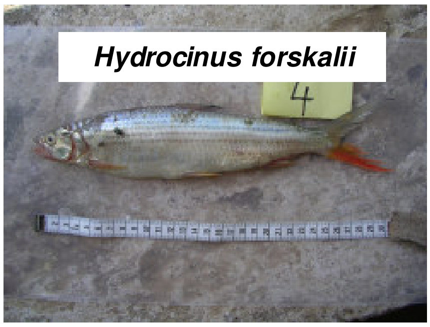
(x: undetermined fish species)

Clarias gariepinus

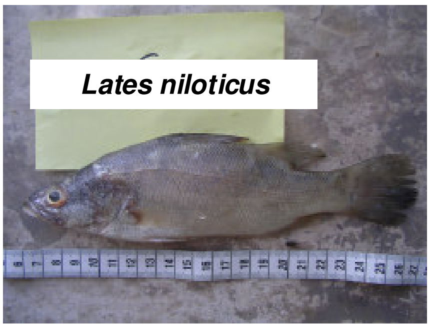
Sarotherodon galilaeus



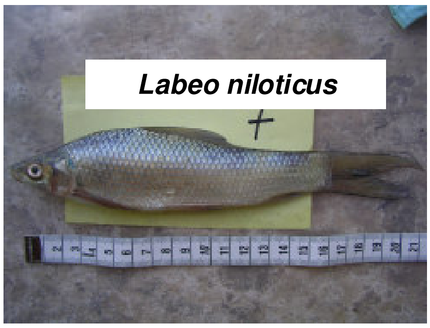
Schilbe intermedius



Hydrocinus forskalii

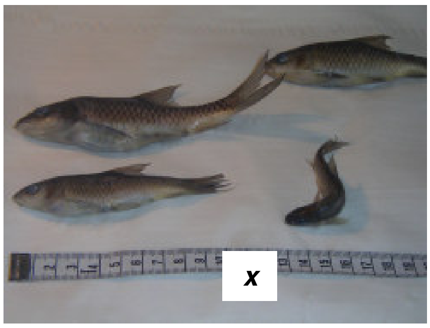


Lates niloticus



Labeo niloticus

Labeo horie



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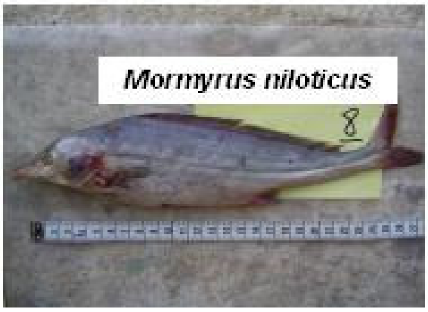
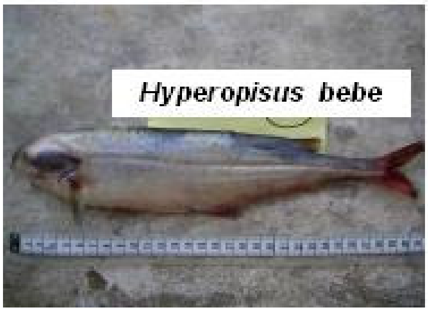
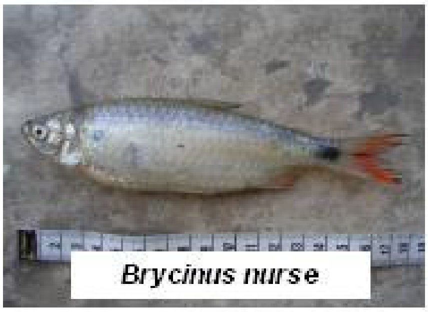

Mormyrus niloticus
8


Hyperopisus bebe


Synondontis schall


Brycinus nurse


Sarotherodon galilaeus


Marcusenius senegalensis
13

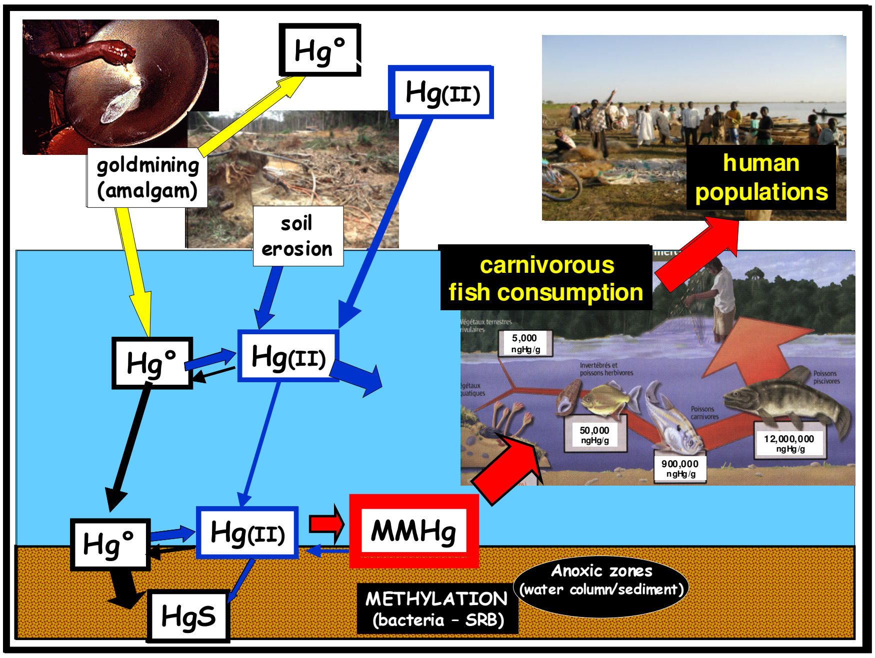

Auchenoglanis occidentalis

BIOMETRIC DATA AND MERCURY CONCENTRATIONS MEASURED AT THE INDIVIDUAL FISH LEVEL (N = 108)

Family	Genus	Species	Food regime	Standard length (cm)	Body weight (g, fw)	Hg conc (µg/g, dw)	Sampling spot
Clariidae	*Clarias*	*gariepinus*	benthivorous	19.5	60	0.062	1
Clariidae	*Clarias*	*gariepinus*	benthivorous	18.0	54	0.099	1
Clariidae	*Clarias*	*gariepinus*	benthivorous	22.0	108	0.122	1
Clariidae	*Clarias*	*gariepinus*	benthivorous	18.5	66	0.070	1
Clariidae	*Clarias*	*gariepinus*	benthivorous	20.5	96	0.073	1
Schilbeidae	*Schilbe*	*intermedius*	carnivorous	17.0	54	0.569	1
Schilbeidae	*Schilbe*	*intermedius*	carnivorous	18.0	76	0.514	1
Schilbeidae	*Schilbe*	*intermedius*	carnivorous	17.0	56	0.460	1
Schilbeidae	*Schilbe*	*intermedius*	carnivorous	14.0	32	0.266	1
Schilbeidae	*Schilbe*	*intermedius*	carnivorous	12.0	18	0.217	1
Alestiidae	*Hydrocinus*	*forskalii*	carnivorous	19.3	88	0.894	1
Alestiidae	*Hydrocinus*	*forskalii*	carnivorous	26.5	190	0.698	1
Alestiidae	*Hydrocinus*	*forskalii*	carnivorous	22.5	128	0.701	1
Alestiidae	*Hydrocinus*	*forskalii*	carnivorous	17.5	64	0.426	1
Alestiidae	*Hydrocinus*	*forskalii*	carnivorous	20.5	112	0.751	1
Centropomidae	*Lates*	*niloticus*	carnivorous	15.0	64	0.713	1
Centropomidae	*Lates*	*niloticus*	carnivorous	17.0	94	0.539	1
Centropomidae	*Lates*	*niloticus*	carnivorous	13.0	42	0.783	1
Centropomidae	*Lates*	*niloticus*	carnivorous	13.7	54	0.677	1
Centropomidae	*Lates*	*niloticus*	carnivorous	13.3	46	0.629	1
Centropomidae	*Lates*	*niloticus*	carnivorous	12.5	34	0.907	1
Cyprinidae	*Labeo*	*niloticus*	benthivorous	16.0	66	0.048	1
Cyprinidae	*Labeo*	*niloticus*	benthivorous	15.0	52	0.078	1
Cyprinidae	*Labeo*	*niloticus*	benthivorous	17.0	74	0.051	1
Cyprinidae	*Labeo*	*niloticus*	benthivorous	14.5	52	0.049	1
Cyprinidae	*Labeo*	*niloticus*	benthivorous	15.5	64	0.054	1
Alestiidae	*Brycinus*	*nurse*	omnivorous	13.0	46	0.081	1
Alestiidae	*Brycinus*	*nurse*	omnivorous	13.5	52	0.121	1
Alestiidae	*Brycinus*	*nurse*	omnivorous	14.0	56	0.122	1
Alestiidae	*Brycinus*	*nurse*	omnivorous	13.0	52	0.141	1
Alestiidae	*Brycinus*	*nurse*	omnivorous	13.0	50	0.072	1
Cichlidae	*Sarotherodon*	*galilaeus*	herbivorous	9	22	0.154	1
Cichlidae	*Sarotherodon*	*galilaeus*	herbivorous	9	24	0.104	1
Cichlidae	*Sarotherodon*	*galilaeus*	herbivorous	9	24	0.092	1
Cichlidae	*Sarotherodon*	*galilaeus*	herbivorous	9	22	0.124	1
Cichlidae	*Sarotherodon*	*galilaeus*	herbivorous	9.2	28	0.131	1
Cichlidae	*Sarotherodon*	*galilaeus*	herbivorous	8.7	24	0.072	1
Clariidae	*Clarias*	*gariepinus*	benthivorous	35.0	430	0.167	2
Clariidae	*Clarias*	*gariepinus*	benthivorous	38.0	622	0.039	2
Clariidae	*Clarias*	*gariepinus*	benthivorous	43.0	630	0.061	2
Clariidae	*Clarias*	*gariepinus*	benthivorous	40.5	540	0.127	2
Cichlidae	*Sarotherodon*	*galilaeus*	herbivorous	18.0	180	0.110	2
Cichlidae	*Sarotherodon*	*galilaeus*	herbivorous	16.0	142	0.169	2
Cichlidae	*Sarotherodon*	*galilaeus*	herbivorous	18.5	204	0.051	2
Cichlidae	*Sarotherodon*	*galilaeus*	herbivorous	16.0	138	0.112	2
Cichlidae	*Sarotherodon*	*galilaeus*	herbivorous	16.0	154	0.082	2
Mochokidae	*Synondontis*	*schall*	omnivorous	10.5	26	0.518	2
Mochokidae	*Synondontis*	*schall*	omnivorous	11.5	34	0.582	2
Mochokidae	*Synondontis*	*schall*	omnivorous	10.0	22	0.224	2
Mochokidae	*Synondontis*	*schall*	omnivorous	9.0	14	0.119	2
Mochokidae	*Synondontis*	*schall*	omnivorous	9.0	14	0.157	2
Mochokidae	*Synondontis*	*schall*	omnivorous	7.5	10	0.112	2

Family	Genus	Species	Food regime	Standard length (cm)	Body weight (g, fw)	Hg conc (µg.g-1 dw)	Sampling spot
Cichlidae	Oreochromis	niloticus	herbivorous	22.0	346	0.105	3
Cichlidae	Oreochromis	niloticus	herbivorous	20.0	244	0.069	3
Cichlidae	Oreochromis	niloticus	herbivorous	20.5	256	0.049	3
Cichlidae	Oreochromis	niloticus	herbivorous	20.0	232	0.083	3
Cichlidae	Oreochromis	niloticus	herbivorous	19.0	254	0.093	3
Schilbeidae	Schilbe	intermedius	carnivorous	24.0	132	0.308	3
Schilbeidae	Schilbe	intermedius	carnivorous	25.0	140	0.517	3
Schilbeidae	Schilbe	intermedius	carnivorous	22.0	124	0.677	3
Schilbeidae	Schilbe	intermedius	carnivorous	22.5	138	0.655	3
Mormyridae	Mormyrus	niloticus	carnivorous	23.0	106	0.100	3
Mormyridae	Mormyrus	niloticus	carnivorous	25.0	138	0.096	3
Mormyridae	Hyperopisus	bebe	omnivorous	27.0	184	0.107	3
Mormyridae	Hyperopisus	bebe	omnivorous	28.0	194	0.077	3
Mochokidae	Synondontis	schall	omnivorous	17.0	96	0.062	3
Mochokidae	Synondontis	schall	omnivorous	13.0	48	1.039	3
Mochokidae	Synondontis	schall	omnivorous	14.0	70	0.519	3
Mochokidae	Synondontis	schall	omnivorous	13.0	56	0.417	3
Mochokidae	Synondontis	schall	omnivorous	13.5	64	0.670	3
Mochokidae	Synondontis	schall	omnivorous	15.0	62	0.977	3
Mormyridae	Marcusenius	senegalensis	carnivorous	22.0	112	0.080	3
Mormyridae	Marcusenius	senegalensis	carnivorous	20.0	98	0.126	3
Bagridae	Auchenoglanis	occidentalis	omnivorous	24.0	256	0.046	3
Bagridae	Auchenoglanis	occidentalis	omnivorous	22.0	198	0.057	3
Clariiidae	Clarias	gariepinus	benthivorous	22.0	69	0.243	4
Cichlidae	Oreochromis	niloticus	herbivorous	5.0	4	0.041	4
Cichlidae	Oreochromis	niloticus	herbivorous	5.0	4	0.047	4
Cichlidae	Oreochromis	niloticus	herbivorous	4.0	2	0.056	4
Cichlidae	Oreochromis	niloticus	herbivorous	7.9	13	0.056	4
Cichlidae	Oreochromis	niloticus	herbivorous	5.6	6	0.069	4
Cichlidae	Oreochromis	niloticus	herbivorous	5.0	6	0.056	4
Cichlidae	Oreochromis	niloticus	herbivorous	7.0	12	0.075	4
Cichlidae	Oreochromis	niloticus	herbivorous	6.3	9	0.032	4
Cichlidae	Oreochromis	niloticus	herbivorous	7.5	15	0.072	4
Cichlidae	Oreochromis	niloticus	herbivorous	8.0	19	0.059	4
Cichlidae	Oreochromis	niloticus	herbivorous	8.0	21	0.064	4
Cichlidae	Oreochromis	niloticus	herbivorous	9.0	23	0.055	4
Cichlidae	Oreochromis	niloticus	herbivorous	9.5	33	0.065	4
Cichlidae	Oreochromis	niloticus	herbivorous	10.5	39	0.049	4
Cichlidae	Oreochromis	niloticus	herbivorous	10.5	40	0.054	4
Cyprinidae	labeo	horie	benthivorous	6.5	4	0.099	4
Cyprinidae	labeo	horie	benthivorous	6.0	5	0.103	4
Cyprinidae	labeo	horie	benthivorous	11.0	22	0.325	4
Cyprinidae	labeo	horie	benthivorous	9.0	13	0.225	4
Cyprinidae	labeo	horie	benthivorous	10.0	14	0.109	4
Cyprinidae	labeo	horie	benthivorous	11.5	25	0.666	4
Cyprinidae	labeo	horie	benthivorous	12.0	40	0.075	4
Cyprinidae	labeo	horie	benthivorous	11.5	26	0.082	4
Cyprinidae	labeo	horie	benthivorous	9.5	16	0.102	4
Cyprinidae	labeo	horie	benthivorous	11.5	30	0.198	4
Cyprinidae	labeo	horie	benthivorous	14.0	47	0.109	4
Cyprinidae	labeo	horie	benthivorous	11.0	20	0.174	4
Cyprinidae	labeo	horie	benthivorous	5.0	2	0.246	4
Cyprinidae	labeo	horie	benthivorous	7.0	6	0.204	4
x	x	x	x	9.0	13	0.227	4
x	x	x	x	10.0	18	0.208	4
x	x	x	x	12.0	30	0.682	4
x	x	x	x	16.0	45	0.227	4

MAIN BIOGEOCHEMICAL STEPS BETWEEN GOLDMINING ACTIVITIES USING AMALGAMATION PROCEDURE AND HUMAN POPULATION EXPOSURE, VIA THE INGESTION OF CARNIVOROUS FISH SPECIES, AT THE TOP OF THE AQUATIC FOODWEBS (FROM BOUDOU A., 2004).



Fish are exposed to mercury present in the aquatic systems, either through passive (respiratory) exposure or through the diet (Snodgrass, Jagoe *et al.*, 2000), where contamination levels in the water column are generally very low, close to the ppt level (ngHg/L), and consist mainly of the inorganic form (HgII). Thus, the trophic route of exposure, *via* ingestion of the metal accumulated in prey and absorption through the intestinal wall, represents the major contamination source for the different fish species, with biomagnification playing a key role along the aquatic food chains (Boudou & Ribeyre, 1997; Mason *et al.*, 1995; Wiener et al, 2002). Biomagnification is essentially based on cumulative trophic transfers of the methylated form of mercury (MMHg: monomethylmercury – CH_3HgX) between prey and predators, leading to extremely high concentrations in the different organs of carnivorous species, notably in the skeletal muscle tissue (Bloom, 1992; Boudou & Ribeyre, 1997). So, within the complex biogeochemical cycle of mercury, the elemental form Hg° used for amalgamation has to be oxidized in the atmosphere and/or in the water (HgII) and then methylated by bacteria (SRB: sulfur-reducing bacteria), mainly under hypoxic/anoxic conditions (Morel *et al.*, 1998; Rudd, 1995).

Appendix 6

Results of Hg analysis

SEDIMENTS				
	ID	PM 40° C %	Hg Results	
				double
			mg kg-1	mg kg-1
1	SSE001	0.88	0.133	
2	SSE002	0.96	0.225	
3	SSE003	0.62	1.649	
4	SSE004	0.53	1.46	
5	SSE005	1.00	1.066	
6	SSE006	1.42	0.221	
8	SSE007	1.15	0.14	
9	SSE008	0.95	0.132	
10	SSE009	0.87	0.276	0.283
11	SSE010	0.89	0.072	
12	SSE011	0.86	0.153	
13	SSE012	1.26	0.042	
14	SSE013	1.47	0.059	
15	SSE014	1.72	0.077	
16	SSE015	1.52	0.092	
17	SSE016	1.06	0.116	
18	SSE017	0.93	0.121	
19	SSE018	0.98	0.078	0.08
20	SSE019	1.65	0.324	
21	SSE020	3.02	0.211	
22	SSE021	1.59	0.081	
23	SSE022	1.09	0.199	
24	SSE023	53.7	0.265	
25	SSE024	67.1	0.386	
26	SSE025	24.0	0.19	
27	SSE026	23.0	0.157	
28	SSE027	49.3	0.148	
29	SSE028	12.9	0.072	
30	SSE029	2.63	0.053	0.056
31	SSE030	2.15	0.078	
32	SSE031	0.90	0.042	
33	SSE032	1.47	0.059	
34	SSE033	1.62	0.203	
35	SSE034	1.04	0.16	
36	SSE035	1.41	0.176	
37	SSE036	1.32	0.065	
38	SSE037	1.39	0.424	0.422
39	SSE038	1.50	0.12	
40	SSE039	1.29	0.101	
41	SSE040	1.04	0.087	
42	SSE041	0.88	0.176	
43	SSE042	0.79	0.048	

SEDIMENTS (Cont'd)				
	ID	PM 40° C %	Hg Results	
44	SSE043	1.29	0.077	
45	SSE044	0.98	0.886	
46	SSE045	1.06	0.163	
47	SSE046	1.31	0.118	0.118
48	SSE047	1.35	0.081	
49	SSE048	30.8	0.251	
50	SSE049	31.3	0.316	

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DUST				
	ID	PM 40° C %	Hg Results	
				double
			mg kg^{-1}	mg kg^{-1}
51	SDU001	1.69	0.914	
52	SDU002	1.81	2.751	
53	SDU003	0.88	2.662	
54	SDU004	1.19	1.42	
55	SDU005	1.51	1.433	
56	SDU006	0.91	0.052	
57	SDU007	0.87	0.157	
58	SDU008	2.67	1.219	
59	SDU009	0.85	1.999	
60	SDU010	1.03	0.973	0.997
61	SDU011	1.28	0.505	
62	SDU012	1.31	0.116	
63	SDU013	1.25	0.434	
64	SDU014	1.38	1.024	
65	SDU015	0.83	1.835	
66	SDU016	1.59	1.469	
67	SDU017	1.01	3.414	
68	SDU018	1.36	7.206	
69	SDU019	3.71	3.177	
70	SDU020	1.30	0.992	0.941
71	SDU021	1.16	5.546	
72	SDU022	0.87	2.77	
73	SDU023	1.60	840	
74	SDU024	1.32	465	
75	SDU025	1.04	9.523	
76	SDU026	1.03	0.664	
77	SDU027	0.75	0.123	
78	SDU028	1.30	0.338	
79	SDU029	0.92	1.96	
80	SDU030	1.48	0.183	0.173

SOILS				
	ID	PM 40° C %	Hg Results	
				double
			mg kg^{-1}	mg kg^{-1}
88	SSO001	0.54	8.516	
89	SSO002	0.75	1.716	1.74
90	SSO003	0.81	4.966	
91	SSO004	0.90	0.312	
92	SSO005	0.96	27.626	
93	SSO006	0.78	2.53	
94	SSO007	0.90	4.209	
95	SSO008	-0.09	0.221	
96	SSO009	0.94	0.106	0.099
97	SSO010	1.04	0.648	
98	SSO011	0.87	0.213	
99	SSO012	1.58	0.868	
100	SSO013	0.91	2.585	
101	SSO014	0.92	0.133	
102	SSO015	0.83	0.142	
103	SSO016	0.75	1.012	
104	SSO017	0.79	2.574	
105	SSO018	0.95	0.083	0.091
106	SSO019	0.54	0.275	
107	SSO020	0.68	0.544	
108	SSO021	0.57	0.492	
109	SSO022	0.60	0.675	
110	SSO023	0.64	1.307	
111	SSO024	0.30	3.571	
112	SSO025	0.59	1.213	
113	SSO026	0.49	4.01	
114	SSO027	0.50	7.805	
115	SSO028	1.31	170	
116	SSO029	0.39	1.345	
117	SSO030	2.09	13.65	
118	SSO031	0.34	0.391	
119	SSO032	0.72	1.885	
120	SSO033	0.74	4.977	6.847/5.334
121	SSO034	1.02	1.779	
122	SSO035	0.77	1000	
123	SSO036	0.76	1.665	
124	SSO037	1.23	0.965	
125	SSO038	0.95	0.466	

SOILS (Cont'd)				
	ID	PM 40° C %	Hg Results	
				double
			mg kg^{-1}	mg kg^{-1}
126	SSO039	1.31	0.209	
127	SSO040	1.17	0.283	
128	SSO041	1.31	2.037	
129	SSO042	1.10	0.677	
130	SSO043	1.63	3.328	3.213
131	SSO044	0.81	0.119	
132	SSO045	1.08	0.179	
133	SSO046	1.35	0.128	
134	SSO047	0.68	0.437	
135	SSO048	1.25	0.251	
136	SSO049	0.90	0.151	
137	SSO050	1.00	1.595	
138	SSO051	0.93	1.047	
139	SSO052	0.89	0.602	
140	SSO053	0.69	0.114	0.116
141	SSO054	1.77	0.1	
142	SSO055	1.02	0.1	
143	SSO056	0.97	0.24	
144	SSO057	0.74	2.31	
145	SSO058	0.82	3.19	
146	SSO059	0.74	2.79	
147	SSO060	0.67	5.26	
148	SSO061	0.77	0.43	
149	SSO062	0.79	1.29	
150	SSO063	0.80	3.83	3.83
151	SSO064	1.03	0.09	
152	SSO065	0.99	0.12	
153	SSO066	1.22	0.11	

TAILINGS				
	ID	PM 40° C %	Hg Results	
				double
			mg kg^{-1}	mg kg^{-1}
154	STA001	1.25	1.55	
155	STA002	1.17	0.35	
156	STA003	0.89	2.63	2.7
157	STA004	1.92	0.28	
158	STA005	2.00	0.12	
159	STA006	1.69	1.02	
160	STA007	1.66	62.3	61.5
161	STA008	1.65	0.15	0.13
162	STA009	1.85	0.13	
163	STA010	2.05	0.1	
164	STA011	1.83	0.13	
165	STA012	0.72	0.1	
166	STA013	0.47	72.5	71.4
167	STA014	1.94	0.08	
168	STA015	1.97	0.07	
169	STA016	2.36	0.19	
170	STA017	1.55	1.64	1.6

TERMITES				
	ID	PM 40° C %	Hg Results	
				double
			mg kg^{-1}	mg kg^{-1}
81	STE001	3.07	0.315	
82	STE002	1.48	0.083	
83	STE003	1.06	0.115	
84	STE004	1.59	0.044	
7	STE006	1.43	0.072	
85	STE005	1.72	0.041	
86	STE007	1.50	0.028	
87	STE008	1.29	0.094	

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Appendix 7

Quality control of Hg analysis in solid samples

QUALITY CONTROL OF LUMEX ANALYSES *VS* STANDARD REFERENCE MATERIALS (SRM):

Internal quality control

As described in the report, the analyzer LUMEX has been calibrated for each analytical sequence with two reference materials (one material for low mercury quantities introduced in the device and the other one for high quantities).

NIST 2711 agricultural soil : reference value 6.25 mg kg^{-1}

STSD1 (CANMET) : river sediment : reference value 0.11 mg kg^{-1}.

The validity of calibration was daily checked with a third reference material : NIST 2709 in the middle of the calibration range (results for seven independant analyses of this material are given in the table below).

NIST 2709	
Reference Value	1.40 ± 0.08 mg kg^{-1}
Measured Value	1.36 ± 0.18 mg kg^{-1} (n=7)

1. 10% of samples have been analyzed twice.

2. In a previous study, 7 reference material (soils, sediments and dusts) have been analysed and have given good results in comparison with reference value (see table below)

Reference Material	**Référence value (mg kg^{-1})**	**Measured value (mean n = 5)**
2711	6.25 ± 0.19	6.60 ± 0.37
LKSD3	0.29 (1)	0.29 ± 0.04
STSD4	0.93 (1)	0.99 ± 0.14
JLK1	0.142 (1)	0.15 ± 0.01
jsd3	0.254 (1)	0.25 ± 0.02
2782	1.10 ± 0.19	1.17 ± 0.09
lgc6156	10.1 ± 1.6	9.9 ± 0.3

(1) Indicative value

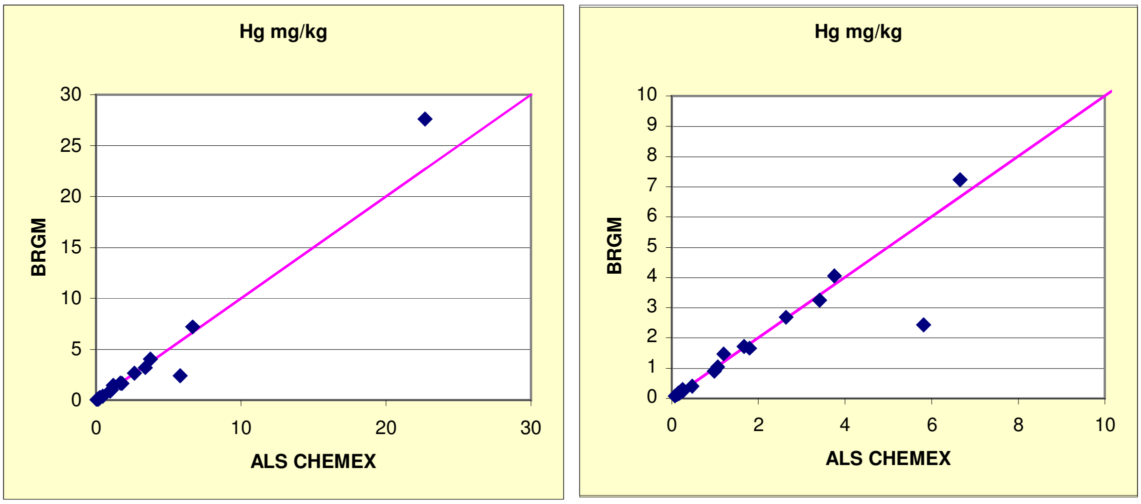
External quality control

All the samples collected and brought back to France were analyzed with the LUMEX in the BRGM laboratory. 10 % of the samples (18 samples) were selected and send to an independant laboratory (Chemex ALS, Canada) to verify the results obtained in the BRGM laboratory with the Lumex. The analyses of Chemex ALS laboratory were performed by CV-AAS.

Sample	ALS CHEMEX CVAAS mg kg^{-1}	BRGM LUMEX mg kg^{-1}
SSE004	**1,20**	**1,46**
SSE011	**0,18**	**0,15**
SSE024	**0,47**	**0,39**
SSE036	**0,08**	**0,07**
SSE044	**0,98**	**0,89**
STA017	**1,80**	**1,64**
STE003	**0,13**	**0,12**
SDU003	**2,64**	**2,66**
SDU018	**6,66**	**7,20**
SDU025	**5,82**	**3.17**
SSO005	**22,70**	**27,60**
SSO011	**0,26**	**0,21**
SSO016	**1,06**	**1,01**
SSO026	**3,76**	**4,01**
SSO036	**1,67**	**1,67**
SSO048	**0,25**	**0,25**
SSO058	**3,41**	**3,19**
SSO066	**0,15**	**0,11**

BRGM laboratory mercury concentrations vs Chemex ALS mercury concentrations.

Comparison between Lumex and Chemex-ALS analyses for a selection of solid samples (two different scales).



The correlation between the Chemex ALS results and Lumex (BRGM) results is quite good for most of samples. Only the sample SDU025 (dust sample) showed a lower value by lumex than by the reference method. It seems that this sample is rather inhomogeneous as indicated by some repetitions done with Lumex. This could explain the difference beetween the two results.

Geoscience for a sustainable Earth

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