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Removal of barriers to the introduction of cleaner artisanal gold mining and extraction technologies in Pak Ou and Chomptet districts. Lao PDR.

Part A : Environmental assessment – Final Report.

BRGM/RC-53310- FR
November, 2004

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Ph. Freyssinet, S. Vilaypaseuth , V. Laperche, M. Babut

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Executive summary

Introduction

This survey is a part of a larger UNIDO program 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 study is to assist a pilot suite of developing and emerging 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.

A contract was signed in July 2003 between the United Nations Industrial Development Organisation (UNIDO) and the BRGM, in order to carry out the environmental and health surveys in the Pak Ou and Chomphet districts in the Province of Luang Prabang. The operation was carried out between French teams (BRGM, University of Montpellier and CEMAGREF) and Lao teams (Department of Geology and Mines, the Ministry of Agriculture, the Ministry of Health). BRGM in cooperation with the Lao Department of Geology and Mines 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 February 29th to March 20th, 2004. A previous report (Laperche *et al.*, 2004) details the information collected in the field and the sampling methodology.

The aim of this survey was to collect environmental and health data in some selected villages of Pak Ou and Chomphet districts and to evaluate the potential impacts caused by mercury to the local population and their close environment. The environmental and health assessments, based on a preliminary sociological survey (Earth System Lao, 2003), was performed on 5 villages, North of Luang Prabang, along the Mekong (Houay Gno, Houay Koh, Pak Ou) and the Ou River (Latthahai, Pak Chek). An extra village without practice of artisanal mining was selected as a reference (Houay Yen Gnai) located on the Khan River, South East of Luang Prabang.

In each village both environmental and health surveys were carried out with the exception of Pak Chek where only the environmental survey was performed.

Mining practices and use of mercury

Ore excavation is located in the lowest alluvium terrace of the Mekong and Ou Rivers that is why gold mining can only be performed during the peak of the dry season. Excavation takes place in the vicinity of the villages and implies only small groups of

10-20 people, mostly composed of women. The procedures used by local people are representative of relatively poor peoples using simple and traditional practices. During our stay, most of the activities were performed by women in the Mekong River, including the hard tasks of digging and excavation of the alluvium. Along the Ou River, the artisanal mining was practised both by men and women.

The alluvium excavation and gold recovery processes is a very classical and traditional process. The procedure varies slightly between villages situated on the Ou River and those situated on the Mekong River. In villages along Mekong River, gold is relatively fine. At the end of the panning process, mercury is poured in the pan to separate gold and the remaining heavy minerals. The mercury-gold amalgam is then squeezed through a fine cloth, and the excess mercury is collected for re-use.

In villages along the Nam Ou River (Pak Chek and Latthahai) there is almost no heavy mineral in the pan concentrate and gold is coarser than in the Mekong. Gold is separated from residual minerals by heating and blowing. The fine residual gold concentrate remaining after the 'heating and blowing' stage may nevertheless be added to a small volume of mercury. This is then stored until a sufficient quantity of gold has accumulated to form an amalgam, at which point the amalgam is roasted to remove the mercury.

Most of the Hg loss occurs during the final step of roasting. For confidentiality reasons, these step are carried out on the cooking fireplace in the home kitchen and usually by women. The amalgam is fully roasted usually without any precaution to recover the evaporated mercury. The size of the amalgams observed during our study ranged from 2 to 6 mm.

The mercury-gold is stored until a suitable quantity has accumulated for the purpose of sale to a gold merchant. Depending on the village and gold content of the alluvial sediment, this might be on a weekly or monthly basis. It is estimated that there is an average annual consumption of about 40 to 50 g Hg per household of artisanal miners. There are slight differences between the villages according to the process of gold separation and the duration of the mining season.

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 main target identified are local peoples. Potential risks to the ecosystem and the quality of water were considered to be minor in that process.

Two sub-systems can be described, (i) the village, where Hg is stored and amalgams are roasted and (ii) the River where Hg is used during panning.

	Village sub-system	River sub-system
SOURCES	- Household Hg storage - Accidental Hg spill - Amalgam roasting in the kitchen	- Contamination of sediments during panning - Accidental Hg spill
TRANSFER & PATHWAYS	- Household dust contamination - Hg vapor dissemination contaminating the house and its environment - Soil contamination in the vicinity of contaminated houses	- Sediment transportation - Transfer to the biological chain (seaweed and fishes)
TARGETS	Humans: - Hg inhalation during roasting - Household dust and soil ingestion (mostly children) - Fish consumption - Seaweed consumption *- Contaminated poultry consumption** *- Contaminated pork consumption**	Ecosystem * - Bio-accumulation

In the River sub-system, sampling was oriented on fishes and sediments. In the villages, sampling focussed on top soils, household dust, air monitoring. About four houses per village inhabited by artisanal miners were selected for sampling, plus one reported without mining activity considered as a reference. A similar procedure was followed by the health survey.

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 seaweed by atomic fluorescence (BRGM laboratory).

Soil contamination

According to the analysis of the system, the most probable contamination of soil in villages is supposed to be related to atmospheric deposition of mercury during the roasting and the dissemination of household dust in the vicinity of houses were amalgam roasting is practised. That is why soil was only sampled in the top part from 0 to 2 cm depth. The background contents (median) in the villages of artisanal miners range from 100 to 200 ng g^{-1}. However these contents are 2 to 3 times higher than in Houay Yen Gnai, the reference village. Surprisingly, the contents in Latthahai are significantly higher with some peak values ranging around 1,000-1,700 ng g^{-1}.

The highest contents in soils (> 500 ng g^{-1}) are observed around the houses of artisanal miners. School yards and the main squares of villages, that are relatively away from the potential source of Hg emissions, show relatively low Hg contents close to the median of the sample population ranging from 15 to 180 ng g^{-1}.

Domestic dust

In the reference village (Houay Yen Gnai), domestic dust shows relatively homogeneous contents, ranging from 60 to 460 ng g^{-1}. In the villages of Houay Gno and Pak Chek, domestic dust samples show similar Hg contents than in the reference village. The other villages of artisanal miners (Latthahai, Houay Gno, and Pak Ou) show relatively high Hg contents in the domestic dust ranging from 130 to 335,000 ng g^{-1} with strong nugget effects. We observed significant Hg contamination of domestic dust in some houses of artisanal miners (400 to 70,000 ng g^{-1}). In Pak Ou and Houay Koh, the highest contaminations are measured in the kitchens, but in Latthahai, they are observed in the dust of living rooms, this probably may reflect a change in the practice.

Indoor amalgam roasting may significantly contaminate the dust of the buildings. This may produce in some cases a long lasting as in Pak Ou where artisanal mining is no longer performed by local people (houses B and E) for several years.

Air monitoring

The monitoring sequences were performed to estimate the air quality breathed by the population under different typical situations. Air monitoring was analysed outdoor to check the Hg background, and in some selected houses in order to measure the Hg concentration in the atmosphere before, during and after the process of amalgam roasting. Outside Hg concentrations in air range between 1 to 20 ng m^{-3}. Domestic air control shows similar backgrounds (10-20 ng m^{-3}).

Lighting the fireplace increases the Hg content of about 15 ng m^{-3} in the reference house and 130 ng m^{-3} in the house of an artisanal miner. That demonstrates the contamination of fireplaces in the houses of artisanal miners. Roasting of amalgams generates usually two peaks of Hg above 24,000 ng m^{-3} (up to 90,000 ng m^{-3}). The first peak appears when Hg is evaporating from the amalgam, the second one, 2-3 minutes later is attributed to a late release of mercury aerosols that condensed at the roof of the kitchen. After roasting, it takes about 8-15 mn in a kitchen to reach the background concentration of the atmosphere.

Sediments

Mercury contents ranged from 6 to 110 ng g^{-1} on a dry weight (dw) basis in Mekong River sediments, and between 23 and 261 ng g^{-1} (dw) in the Ou River. The mercury concentrations in Nam Ou River sediments are significantly higher than in Mekong. There is no Hg significant decrease downstream the villages of miners in the Mekong River sediments. In any case, the Hg concentrations in sediments of both the Ou River and Mekong are relatively low and do not show important levels of contamination.

Along the Ou River, the highest levels in sediments are downstream the village of Houay Lo and within a dam close to Phathung respectively, where the gold-miners from this village are supposed to look more for gold dust rather than for nuggets. Sediment analyses suggest that a number of Hg sources spread all along the Ou River, with some hotspots. The actual sources related to these hotspots are not clearly

identified yet. As for the Mekong River, no clear up- to downstream trend can be inferred from mapping the contamination.

The significant difference between mercury concentrations in the Ou River and Mekong sediments can be attributed to natural (changes in geological background) or anthopic origin such as the present day artisanal mining or the former industrial mining around PakChek.

Seaweed – vegetables

A few seaweed samples (5) were collected to check their Hg content, as they are consumed dried by local peoples. The Hg contents in seaweeds of Mekong River range between 0.1 to 0.7 µg g^{-1}(dw). This type of concentration is significantly above ubiquitous concentrations for aquatic plants. It is not possible with such a small number of samples to draw up conclusions, but these results on seaweed should be controlled in a further step.

Fishes

Fifty five specimens were collected in Mekong River between Houay Gno and Tinh-Hong villages and 10 more in the Ou River. The majority of fishes were herbivorous; most herbivorous fishes display concentrations below or equal to 0.07 µg g^{-1} (ww). Most herbivorous fishes display concentrations below or equal to 0.01 µg g^{-1} (ww). The "carnivorous" fishes are significantly more contaminated than the "herbivorous" with mean contents respectively of 0.17 µg g^{-1} and 0.05 µg g^{-1} (ww). There is no obvious trend in contamination from the sites upstream (B. Houaygno, B. Mouang) to downstream (B. Tinh Hong). Only 1 fish displays a contamination level very close to the WHO standard of 0.5 µg g^{-1} (ww). It seems therefore very likely that some of the fishes eaten by the villagers along the Mekong, if not the Nam Ou River, are contaminated over the standard of 0.5 µg g^{-1} Hg, but the average fish consumption seems to be beyond that limit.

Evaluation of exposure to mercury

The main risk of exposure to mercury occurs in the villages, as Hg is mostly manipulated at home by the artisanal miners without specific precaution. This risk is increased because the exposed population is mostly composed by women and their young children.

Village sub-system	Probability of occurrence	Comments
- Hg inhalation during roasting	**	- Main situation of Hg inhalation
- Domestic dust and soil ingestion (mostly children)	***	
- Fish consumption	* ?	- Needs further control
- Seaweed consumption	** ?	- Needs further control
- *Contaminated poultry consumption*[1]	?	- Possible contamination of poultry?
- *Contaminated pork consumption*[1]	?	
- *Drinking water*[1]	no	- Unprobable as drinking is from wells
- *Vegetable consumption*	no	- Unprobable as no contamination of fields

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

The monitoring of air quality showed that Hg concentrations may reach relatively elevated concentrations. However amalgam roasting seems to be an occasional procedure performed on a weekly or monthly basis. The exposure of the artisanal miners is relatively short compared to the exposure limits for professional workers exposed to mercury (**25 µg m^{-3}** average air concentration for an **8 hour shift,** WHO, 1994). We measured that people are only exposed to elevated mercury concentrations for about 10 to 20 mn. However as roasting is performed mostly by women and at home, we should also consider the possible exposure of children.

In the described system, there is a way of oral exposure related to dust ingestion in addition to fish and seaweed consumption. Domestic dust may reach elevated concentrations (up to 335,000 ng g^{-1}) and is dispersed both in the kitchen and living rooms. We consider that it constitutes the main risk of exposure for peoples, and particularly children. Dust (soil+domestic dust) is relatively important for children (especially in the living conditions of local peoples), and this may cause a potential risk of contamination of the miners and their family.

Soils around the houses of artisanal miners show moderate levels of contamination (100-300 ng g^{-1}). Such concentrations are relatively low compared to threshold values for soils in residential areas (7,000 to 10,000 ng g^{-1} in Europe). Thus there is no apparent risk related to soil ingestion.

The other risk of exposure, on a minor level, is related to the consumption of fishes and seaweed. However regular consumption of fishes and seaweed may increase the daily intake of mercury to the population exposed to mercury through their mining activity.

Seaweed seems to be one of the main consumed vegetable, at least during the dry season. The few samples analysed showed concentrations ranging from 0.1 to 0.7 µg g^{-1} (dw). These kinds of concentration are above ubiquitous concentrations for aquatic plants. This point should be checked in a further step as there are not enough samples to draw up conclusions.

Acknowledgements

This work was greatly facilitated by the support and contribution of the Laotian authorities. BRGM is grateful to the Department of Geology and Mines, the Ministry of Agriculture and the Ministry of Health that were very helpful in the organisation of the field work.

Authors greatly appreciated the contribution and the motivation of the Lao team from Vientiane and Luang Prabang who allowed to the success the field work. Special thanks to Vanphanom Sichaleun, who greatly facilitated the contact with the local villagers.

Authors are indebted to the help of Christian Beinhoff (UNIDO) who greatly facilitated the contacts with local authorities and helped us during the field work.

Fish analysis was developed on the basis on valuable contributions by Mrs Régine Maury-Brachet and Professor Alain Boudou (University of Bordeaux, CNRS-LEESA).

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1. Introduction

This survey is part of a larger UNIDO program 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.

A contract was signed in July 2003 between the United Nations Industrial Development Organisation (UNIDO) and BRGM, in order to carry out the environmental and health surveys in the Pak Ou and Chomphet districts in the Province of Luang Prabang in Lao PDR.

The Department of Geology and Mines (DGM) of Lao PDR coordinated and supported the field survey with the assistance of the Ministry of Health and the Ministry of Agriculture.

The area is characterised by the presence of several villages of artisanal gold miners along Mekong and Ou Rivers using mercury to recover gold under very artisanal conditions. The aim of the project is to evaluate the impact of mercury contamination on the environment and on the health of the local population. 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 the decision taken during a meeting with UNIDO in November 2003 at Vienna, the BRGM planned to survey in March, 2004 before the monsoon and during the artisanal mining season. The sampling campaign and health survey took place from February 29th to March 20th, 2004.

A previous report (Laperche *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 villages of Pak Ou and Chomphet districts and to evaluate the potential impacts caused by mercury to the local population and their close environment. These districts are located in the Luang Prabang Province, a region of Lao PDR where the practice of artisanal gold mining has been identified by UNIDO. It is intended to assess the level of mercury exposure in the local communities and potential impact in the environment. Another village, Houay Yen Gnai, in the Xieng Ngeun district South-East of Luang Prabang 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.

- To characterise the source of the pollution and its potential dissemination in the environment. Different media were sampled according to the protocols recommended by UNIDO (Veiga and Baker, 2003).

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 (Laperche *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 entire duration of this field mission were as follows:

Environmental Survey

- Dr. Philippe Freyssinet: BRGM team leader, environmental geochemist.
- Mr. Sayphet Vilaypaseuth: Department of Geology and Mines (DGM), Deputy Director of Mining Concession Management Division and Representative of UNIDO Country Focal Point, coordination of the Lao team.
- Dr. Valérie Laperche: BRGM, geochemist, in charge of *in situ* analyses and sampling.
- Dr. Marc Babut: CEMAGREF, biologist in charge of sediment and fish sampling.

Health Survey

- Prof. A. Rambaud, University of Montpellier, epidemiologist, coordinator of the health survey.
- Dr. Tayphasavanth Fengthong, medical doctor, UNIDO expert, and coordination of the Lao health team.
- Dr. F. Portet, neurologist, Montpellier University Hospital.
- Dr. Vanphanom Sychaleun, UNIDO expert, sociologist and Head of Postgraduate Trainings (Faculty of Medecin NUOL Research Division).

3.1.2. Local assistance

Different Lao institutions provided staff to perform the field campaign (ill. 1).

Name	Position	Organization
Ms Phengsy Syrithongdy	Deputy Director of Mineral Analysis Center	Department of Geology and Mines (DGM)
Mr Sounthone Laolo	Geologist	DGM
Mr Bounngong Sidavong	Mining Engineer	DGM
Mr Khankhong	Director of STEA	Science Technology and Environment Agency of Luang Prabang Province
Mr Bounkhong	Chief	Commercial and Industry Office of Pak Ou District
Mr Somsanit	Technical officer	Department of Industry and Handicraft of Luang Prabang Province
Mr Sisavath	Chief	Industry and Handicraft Office of Comphet Province
Mr Hansila	Doctor in Medecin	Ventiane
Mrs Thongsy Chittivongsa	Nurse	Luang Prabang hospital
Mr Bounpheng Latsamy	Male nurse	Luang Prabang hospital
Mr Sisomephone	Representatif	District of Xieng Ngeu
Mr Synuan	DRiver	DGM

Illustration 1 - List of the Lao team during the field campaign.

About 25 local workers were hired on a daily basis for different tasks:

- Boat transportation.
- Fish collection.
- Preparation of the health survey sites.
- Communication with local people and help in the organisation of the environmental and health assessment (heads of villages).

3.2. PLANNING

The main steps of the projects are summarized as follows (ill. 2):

- Signature of the contract: July 7th, 2004.

- Kick off meeting at UNIDO Vienna: November, 14th, 2004.
- Field campaign in Lao: February 29th to March 20th, 2004. The details of the tasks performed in the field are described in the Field Report (Laperche *et al.*, 2004).
- Analysis and data processing: from May to August, 2004.
- Final Report: November, 2004.

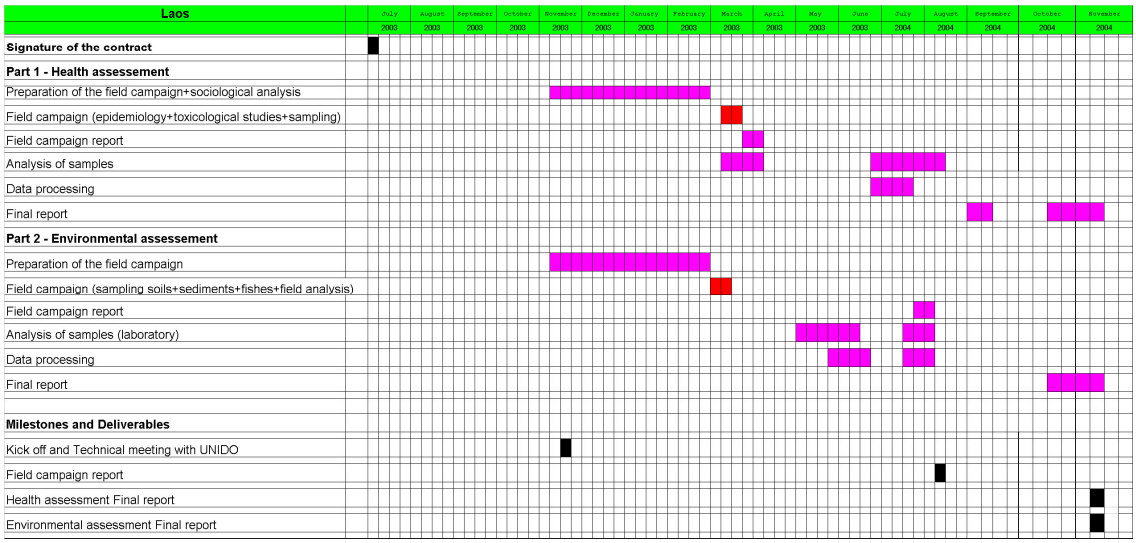


Illustration 2 - Work program of the Lao Project.

4. Description of field conditions

4.1. GENERAL CONTEXT

The study area is situated along the Mekong River and Ou River in the Province of Luang Prabang, approximately 300 km North of Vientiane (ill. 3).

Illustration 3 - General map of the Lao PDR.

The Province covers a total area of 20,000 km^2, encompassing approximately 420,000 inhabitants in 11 districts.

The region consists predominantly of lowland flood plains, with altitudes ranging between 200 m and 500 m above sea level, annual precipitation between 1,600 mm and 2,000 mm and an average annual temperature of approximately 24 °C. The mining activity occurs during the dry season (November to April) depending on the water level or Rivers, with a peak in March-April.

The environmental and health assessments were performed on 8 villages along the Mekong and the Ou River (Earth System Lao, 2003).

Based on the information reported in the sociological survey carried out by Earth System Lao (2003), five villages of artisanal miners were selected. The villages are located in two different districts North of Luang Prabang (ill. 4):

- Houay Gno (district of Chomphet).
- Houay Koh (district of Chomphet).
- Latthahai (district of Pak Ou).
- Pak Chek (district of Pak Ou).
- Pak Ou (district of Pak Ou).

In each village both environmental and health surveys were carried out with the exception of Pak Chek where only the environmental survey was performed.

An extra village was selected as a reference. The selection criteria were the lack of any mining tradition in the area, but similar sociological and environmental conditions to the 5 studied villages. The village of Houay Yen Gnai (ill. 5) located on the Khan River; south east of Luang Prabang was selected for that purpose.

llustration 4 - Map of the region with the 8 selected villages (based on topographical map 1:100,000 – Pak Ou sheet F-48-133). There is a mistake on the map; the name of one of the village is Houay Koh instead of Vangle.

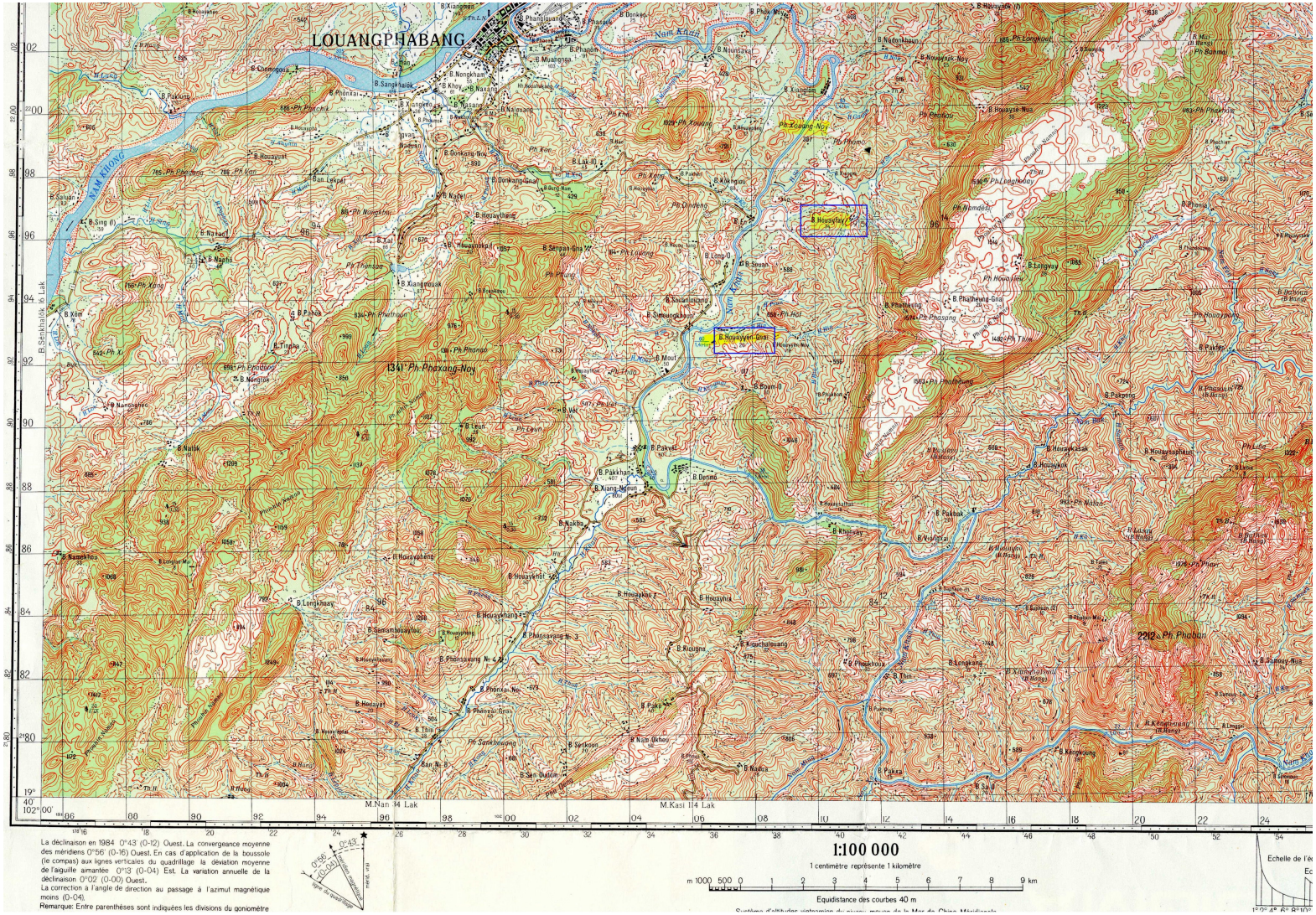


Illustration 5 - Map of the region with the reference village (based on topographical map 1:100,000 – Luang Prabang sheet E-48-1).

4.2. LOCAL MINING PRACTICES AND USE OF MERCURY

Artisanal small scale mining (ASM) in Luang Prabang Province began in the mid-1970s, with the peak mining season occurring between January and April. This is towards the end of the dry season, when the water level is low enough to allow excavation of the alluvial sediments on exposed riverbanks and ephemeral islands. In the surveyed area, artisanal gold mining is not considered to be illegal.

Both men and women operate equipment for ore extraction (such as shovels and chisels), while women and children transfer the alluvium to bowls and sluice boards, pan the alluvium and perform the gold extraction processes (which are usually carried out in the home).

The scale of ASM varies somewhat between villages, with some identifying an active participation in the activity and others a decline. Reflecting this variability, the sample population of each village currently engaged in ASM varies between a few percent in Pak Ou to 76 % in Latthahai (Earth System Lao, 2003).

4.2.1. Mining practices

Mining practices are clearly described in the sociological survey (Earth Systems Lao, 2003). Ore excavation is located in the lowest alluvium terrace of the Mekong and Ou Rivers that is why gold mining can only be carried out during the peak of the dry season. Excavation takes place in the vicinity of the village and implies only small groups of 10-20 peoples, mostly composed of women. 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 in the Mekong River, including the hard tasks of digging and excavation of the alluvium. In the Ou River area, the excavation was processed both by men and women.

The alluvium excavation and gold recovery processes vary between villages situated on the Ou River and those situated on the Mekong River. The process involves the following steps:

1. Site preparation and removal of the overburden

Riverbanks are cleared of any vegetation or large debris that may interfere with ore extraction, and are checked for structural stability. If underwater excavation of the ore is carried out, a large float is suspended mid-stream from which women and men will dive to the riverbed and upon which women and children will perform sieving and panning activities.

2. Digging of the excavation pit for mobilisation of the alluvium

The process of alluvium extraction is typically carried out by men, and varies in method depending on the village and the location of the ore extraction site. Simple tools (such

as shovels, buckets and long chisels (ill. 6a) are used when excavation is performed on the riverbank and on ephemeral islands, loosening the ore and transferring it into buckets for panning and sieving.

3. Transfer of the alluvium to sluice boards

The alluvium is transferred onto the riverbank where it is mixed with water to form slurry which is then passed over sluice boards. This step, described by Earth System Lao (2003), was not observed during our field trip and probably occurs mostly at the peak of the season when men are more involved in the process.

4. Panning and sieving of the ore

Women and children pan and sieve the remaining material on the river using wood pans, shallow bowls and sieves made from fishing nets (ill. 6b). Panning is done in two steps. Firstly, sediments are washed to separation clays and light minerals (i.e. quartz, calcite, etc), heavy minerals are collected and disposed in a bucket. The second step is only performed at the end of the day, pan concentrates are then reprocessed to eliminate the heavy minerals (magnetite, hematite, rutile, etc) and collect the final concentration for amalgamation.

Illustration 6 - (a) Digging of the alluvium in the riverbed of the Mekong (close to Houay Gno); (b) panning of the alluviums.

Comment: We noted that in most of the cases (Houay Gno and Pak Ou) there was very little amounts of Hg (a few grams) used at the Riverside to complete the panning process. In Houay Koh, just downstream the Nam Ou outlet, the alluvium contain 3 to 5 times more heavy minerals than in the villages upstream. In that site, people seem use more mercury at the Riverside to separate gold flakes and heavy minerals.

5. Amalgamation

When mercury is added at the end of the panning process to form an amalgam, the mercury-gold amalgam is then squeezed through a fine cloth, and the excess mercury is collected for re-use (ill. 7).

Illustration 7 - (a) Mercury added directly in the pan (Houay Koh); (b) remove of excess of mercury in a small cloth (Houay Gno); (c) the amalgam after squeezing; (d) recovery of the excess of mercury.

In villages along the Nam Ou River (Pak Chek and Latthahai) there is almost no heavy minerals in the pan concentrate. Gold is separated from residual minerals by blowing. Thus the use of mercury is very limited in the process and only used occasionally. The fine gold-ore concentrate remaining after the 'heating and blowing' stage may nevertheless be added to a small volume of mercury. This is then stored until a sufficient quantity of gold has accumulated to form an amalgam, at which point the amalgam is roasted to remove the mercury.

6. Roasting of the amalgam

As noted by Earth System Lao (2003), roasting is a task that seems to be devoted almost exclusively to women. For confidentiality reasons, roasting seems to be systematically performed at home in the kitchen's houses. There was no reported case where roasting was usually performed outdoor, excepting in Pak Ou (ill. 8).

The remaining amalgam is then heated in a metallic plate on the kitchen fireplace. The size of the amalgams observed during our study ranged from 2 to 6 mm.

Mercury in most of the cases is evaporated and not recovered.

Illustration 8 - Roasting amalgam in the kitchen.

At some few places, the remaining amalgam is then heated and the evaporated mercury is collected in a short bamboo tube, erected above the stove (ill. 9). A feather

is used to remove the mercury condensed in the tube, and citrus is added to mercury for purification before re-use.

Illustration 9 - Recovery of evaporated mercury in a bamboo tube. The amalgam is covered by the bamboo tube, mercury condense along the walls of the bamboo tube (Pak Ou).

The mercury-gold amalgam is not typically heated to separate the two elements on a daily basis. Rather, it is stored until a suitable quantity has accumulated for the purpose of sale to a gold merchant. Depending on the village and production, this might be on a weekly or monthly basis.

Local practices to recover gold can be summarised in two processes:

Type 1 (ill. 10):

This process concerns the villages along the Mekong River (Houay Gno, Houay Kho and Pak Ou). Hg contamination is rather limited due to the small amount of Hg used by local people. In this process, Hg is used at the excavation site along the River to prepare the amalgam. After squeezing, Hg is recovered in a small bucket and stored.

Most of the Hg loss occurs during the final steps of gold separation (roasting). For confidentiality reasons, these steps are carried out in the home kitchen, usually by women. The amalgam is fully roasted usually without any precaution to recover the evaporated mercury.

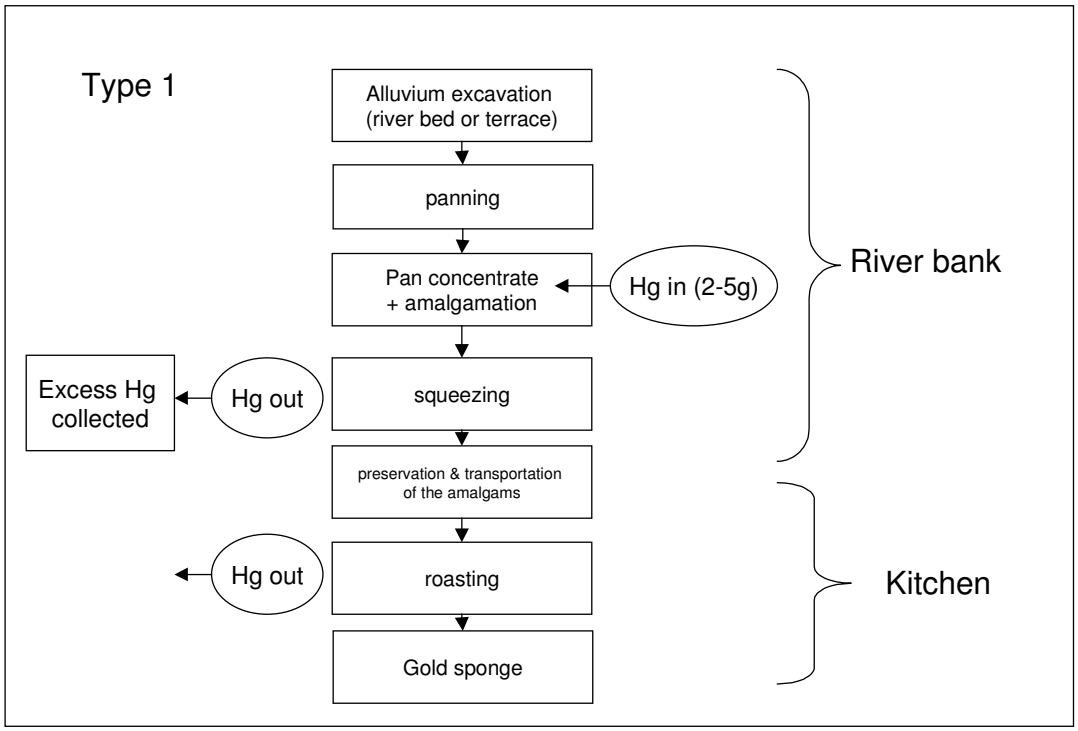


Illustration 10 - Use and location of mercury in the system.

Type 2 (ill. 11):

This second process does not require the use of Hg on the panning site as shown on illustration 7. The main difference with the process n°1, corresponds to the separation between gold grains and heavy minerals. In that case, separation is done after a heating and blowing step. This procedure is mostly used by the villages along the Ou River, because gold grains appear much coarser than in the Mekong River and are easier to separate from heavy minerals.

A final amalgamation is performed in home kitchens to recover very fine gold particles from heavy mineral concentrates. It seems that this process requires smaller amounts of Hg than in type 1, but some villages seem to produce more gold than those along the Mekong River and then seem to use at least equivalent amounts of mercury than those along the Mekong River (Earth System Lao, 2003). This is particularly true for the village of Lattahai.

The fine-gold ore concentrate is stored and a small quantity of mercury is added until a sufficient quantity of gold has been accumulated to form an amalgam. In some villages along the Ou River, villagers report they can roast only once a

year. On the other hand, villagers at Houay Koh added mercury directly to the pan because the ore concentrates contained a lot of heavy minerals such as ilmenite.

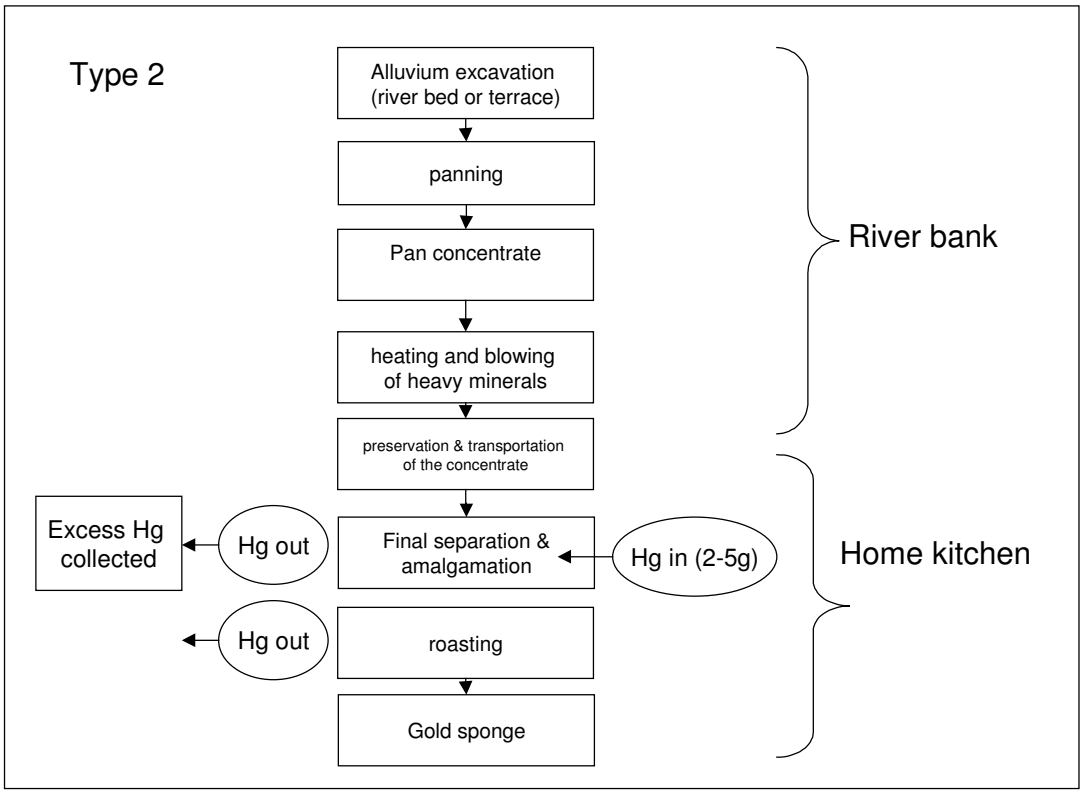


Illustration 11 - Use and location of mercury in the system.

4.2.2. Use of mercury

According to our field observations and the estimations performed by Earth System Lao (2003), the use of mercury is very limited per household. It is estimated that there is an average annual consumption of about 40 to 50 g Hg per household of artisanal miners. There are slight differences between the villages according to the process of gold separation and the duration of the mining season (ill. 12).

It was difficult to evaluate the amount of mercury used per annum in the villages along the Ou River, but they also use mercury to separate fine gold and as their mining activity is more developed than in the Mekong villages, we estimated that they use roughly the same amount of mercury per village, excepting in Pak Chek where people report they don't use mercury at all.

Local gold production is sold directly to gold merchants who visit the villages on a weekly basis during the mining season. The gold merchants typically originate from Luang Prabang and onward sell the gold to larger dealerships. Between 30,000 kip and 35,000 kip (approximately US $2.8 and $3.3) will be paid for one Hun of gold (approximately 0.39 grams), depending on its purity (e.g. its mercury / silver content). Where the gold contains a quantity of mercury or other impurities, the gold merchant may be required to further refine it prior to sale at a regional market or directly to a jeweler. The gold merchants also provide the villagers with mercury.

Village	Hg use per Household ($g\ y^{-1}$)	Estimated Hg use ($g\ y^{-1}$)	Estimated Au production ($g\ y^{-1}$)
Houay Gno	40	592	280
Houay Koh	44	576	480
Latthahai	38	920	1890
Pakchek	?	?	1520
Pak Ou	?	?	?
Houay Yen Gnai - reference	0	0	0

Illustration 12 - Estimated Hg use and Au production per year in the studied villages (Earth System Lao, 2003).

The main characteristics of the villages in term of mining practices are summarised in the illustration 13.

Village	Observations
Houay Gno	Process type 1. Very poor village with little use of mercury per household. Little use of mercury at the Riverside. Little gold production. No access by road.
Houay Koh	Process type 1. Very poor village with some use of mercury at the end of panning at the Riverside (more than in Houay Gno). Little gold production. No access by road.
Latthahai	Process type 2. No use of Hg at the Riverside. Poor village. Medium gold production. Use of mercury for fine gold refining.
Pakchek	Process type 2. No use of Hg at the Riverside. Poor village. Moderate gold production. Possible use of mercury for fine gold, but no reported case.
Pak Ou	Process type 1. Emerging economy thanks to the tourism. Almost no ongoing mining activity. Reported mining activity older than 5-7 years, but relatively extended.
Houay Yen Gnai - reference	Reference village. No historical use of mercury.

Illustration 13 – Summary of mining practices per village.

5. Methodology

5.1. SAMPLING STRATEGY

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 (ill. 14).

Two sub-systems can be described, (i) the village, where Hg is stored and amalgams are roasted, and (ii) the River where Hg is used during panning.

	Village sub-system	River sub-system
SOURCES	- Household Hg storage - Accidental Hg spill - Amalgam roasting in the kitchen	- Contamination of sediments during panning - Accidental Hg spill
TRANSFER & PATHWAYS	- Household dust contamination - Hg vapor dissemination contaminating the house and its environment - Soil contamination in the vicinity of contaminated houses	- Sediment transportation - Transfer to the biological chain (seaweed and fishes)
TARGETS	Humans: - Hg inhalation during roasting - Household dust and soil ingestion (mostly children) - Fish consumption - Seaweed consumption *- Contaminated poultry consumption** *- Contaminated pork consumption**	Ecosystem * - Bio-accumulation

Illustration 14 - Main components of the risk analysis (not considered in that study).*

The analyses of the system lead to reinforce the sampling in the villages and particularly in and around the houses of artisanal gold miners. The main targets identified are local people. Potential risks to the ecosystem and the quality of water were considered to be minor in that process.

It was then decided to focus the sampling on the following medias:

Village sub-system

- Top soils: potentially submitted to ingestion by local people, mostly children, poultry

and pork. Sampling was focussed around the houses of artisanal gold miners, school yard and the main square of each village.

- Household dust: as amalgam roasting occurs in the kitchen, dust was sampled both in the kitchen and in the living room of selected houses.

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

In each village, five houses were selected, except in Latthahai. Pak Chek village had the largest population (645 persons) but only five houses were selected because the villagers use only very limited amounts of mercury. In Latthahai, we selected eight houses as the village is bigger (580 people vs ~300 people in most of the other villages). All the houses sampled for the environmental study are identified on the maps of each village (appendix 1).

Based on information from the sociological survey, a reference house was identified in each village. The selection criteria were based on the lack of artisanal mining activity for the concerned household. In the other selected houses at least one person in the family had to be involved in artisanal mining last mining season and/or continues to be actively involved now.

In Latthahai village, we selected two reference houses and six other houses where at least one person is involved in artisanal mining in the recent past.

Comment: However, after spending a few days in each village and interviewing people about mercury use, we realised that for the villages there were was almost no houses without strict commitment in mining business over the past 10 years. Nevertheless, we kept our sampling strategy to check if mercury was still detectable in the samples in houses with people that had no mining activities in the past few years (versus never in the past).

The houses selected in each village are listed in tables 1 to 6 (Appendix 3) of the field report (Laperche *et al.* 2004).

River system

Sampling strategy of the Mekong and Ou Rivers followed a classical methodology with sampling of sediments in the excavation areas and at irregular intervals upstream and downstream the hot spots. In this context, the first objectives were *to evaluate the nature and extent of the mercury pollution in the River system adjacent to the mining area and in the vicinity of the studied villages*, Therefore, as in previous studies with similar objectives (e.g. in Ghana, Babut *et al.* 2003), sediments and fish samples were needed, as well as, where possible, (relative) reference samples.

Fishes were bought to fishermen along the River and at local tourist restaurants in Pak Ou, where a procedure was settled to get some information from fishermen about the

location of the selected fishes. The objective of the fish sampling was mostly focus on the evaluation of the contamination in relation with the main diet of local peoples.

As seaweeds are consumed by local people, instead to sample them in the rivers, they were bought in the villages in order to focus the sampling on the people diet.

5.2. SAMPLING PROCEDURES

Sampling procedures are described in detail in the field report (see Laperche *et al*., 2004). The following table illustrates the distribution of samples per village and River (ill. 15).

Village	**Soil**	**Household dust**	**Air monitoring (Nb Sites)**
Houay Gno	21	7	3
Houay Koh	22	10	4
Latthahai	34	14	1
Pak Ou	22	10	1
Pak Chek	22	10	0
Houay Yen Gnai	21	10	0
TOTAL	142	61	9
River	**Sediments**	**Fishes**	**Seaweed**
Mekong	55	45	5
Ou	40	10	0
TOTAL	95	55	5

Illustration 15 - 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 (ill. 16) is designed to analyze 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 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.

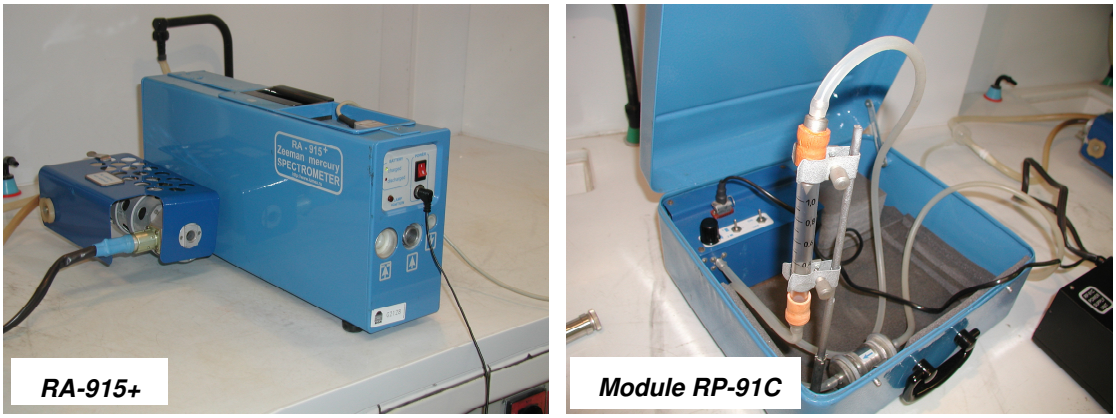


Illustration 16 - The LUMEX RA-915$^+$ analyzer equipped with the RP 91C attachment.

The detection limit is 0.01 mg kg^{-1}. For high concentrations (between 0.5 mg kg^{-1} up to 1000 mg kg^{-1}) a specific single-path cell is used in place of the multiple-path cell. After stabilization (about 40 minutes) of the equipment (lamp of the RA 915$^+$ and pyrolisis attachment), a calibration curve was obtained with five points. During mercury determination, the calibration curve was checked and the apparatus drift followed every ten samples determinations by analyzing reference materials (NIST 8407 and LGC 6156). A sample (20 mg to 300 mg) is placed into a quartz spoon and inserted in the oven (800 °C). The signal acquisition is automatically collected through a monitoring software on a laptop linked to the LUMEX RA915$^+$. The RA-915$^+$ analyzer does not differentiate between mercury forms; it yields a total mercury concentration.

Quality control procedures are summarised in appendix 7.

5.3.2. Air monitoring

The LUMEX RA-915$^+$ analyzer without the oven (ill. 17) is also intended for measuring the mercury vapor concentration of ambient air, both in a stationary and continuous mode (without a pre-concentration step in the absorption trap). Currently, there is no generally available methodology for measuring low levels of mercury in ambient air.

The RA-915^{+} analyzer (Lumex) needs an external mercury supply such as a gas cylinder for calibration.

Illustration 17 - The RA-915^{+} (Lumex).

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 is 2 ng m^{-3} and the flow rate is 20 L mn^{-1}. Concentrations less than below 3 times the limit of detection can not be considered significantly different. 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}).

5.3.3. Analysis of fishes

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 dorsal 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). Each series of measurements included three standard biological reference materials (TORT-2, lobster hepatopancreas; DORM-2, dogfish muscle; and DOLT-2, dogfish liver, from NRCC-CNRC, Ottawa, Canada) for quality control (appendix 7).

The detection limit (DL) for total Hg was derived as 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 dorsal muscle concentrations were reported on a dry weight basis (40 °C over 2 days).

5.3.4. Analysis of vegetables

A few seaweed samples were collected to check their Hg content, as they represent the main source of vegetables consumed by local people. Seaweeds samples were preserved in sample bags and kept frozen in the field and at the laboratory until analyses began.

The sample preparation and analysis is composed of the following steps:

- After defrosting, samples have been rinsed several times with ultrapure water to remove solid particles. Samples were then dried at 40 °C during 3 days.

- Between 0.1 and 0.2 g of dried samples were then digested at 90 °C during 24 h in closed teflon bottles with 6 ml aqua regia. The samples were then diluted to 50 mL 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 gas–liquid separator purged with argon and an atomic fluorescence detector. Measurements were controlled by the PSA software. The reductant solution was 5 % m/v SnCl2 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.

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 houses. Thus, soils around the houses were sampled on each side of the houses (noted North, South, East and West) in order to evaluate the level of contamination in the vicinity of artisanal miner houses. Composite top soil samples were collected in five different locations of the school yard and of the main square to evaluate the geochemical content at longer distance of the source of emissions.

Soil was only sampled in the top part from 0 to 2 cm depth, about 2 m away from the house's walls to get the most recent geochemical signal. Results are reported in Appendix 2.

The table below illustrates the average level of Hg content in the different villages (ill. 18). The background contents (median) in the villages of artisanal miners range from 100 to 200 ng g^{-1}, which is relatively homogeneous and do not show significant difference.

However these contents are 2 to 3 times higher than in the Houay Yen Gnai, the reference village. The average geochemical content in the village of Houay Yen Gnai can probably be considered as an Hg level close to natural geochemical backgrounds in tropical soils that range usually between 30 to 100 ng g^{-1} (Lacerda and Salomons, 1998).

SOILS			Hg content (ng g^{-1})			
village	river		N	median	mean	std
Houay Koh	Mekong		22	106	156	125
Pak Ou	Mekong		22	155	212	140
Houaygno	Mekong		21	97	117	78
Pak Chek	Ou		22	195	209	169
Latthahai	Ou		35	158	337	418
Houay Yen Gnai	reference		21	53	58	25

Illustration 18 - Average Hg content in soil per village (N: number of soil samples and std: standard deviation).

Illustration 19 shows the distribution of Hg contents in soil in term of the villages. If Houay Koh, Houay Gno and Pak Chek show similar range of contents, surprisingly, the contents in Latthahai are significantly higher with some peak values ranging around

1000-1700 ng g^{-1}. This constitutes an interesting result as the mining practice (type 2) does not require much use of mercury. However the sociological survey revealed that artisanal mining in that village is more developed with a gold production significantly more important.

In Latthahai, the Hg annual consumption seems to be about two times more important than in the other villages and that is reflected by a higher level of contamination in soils.

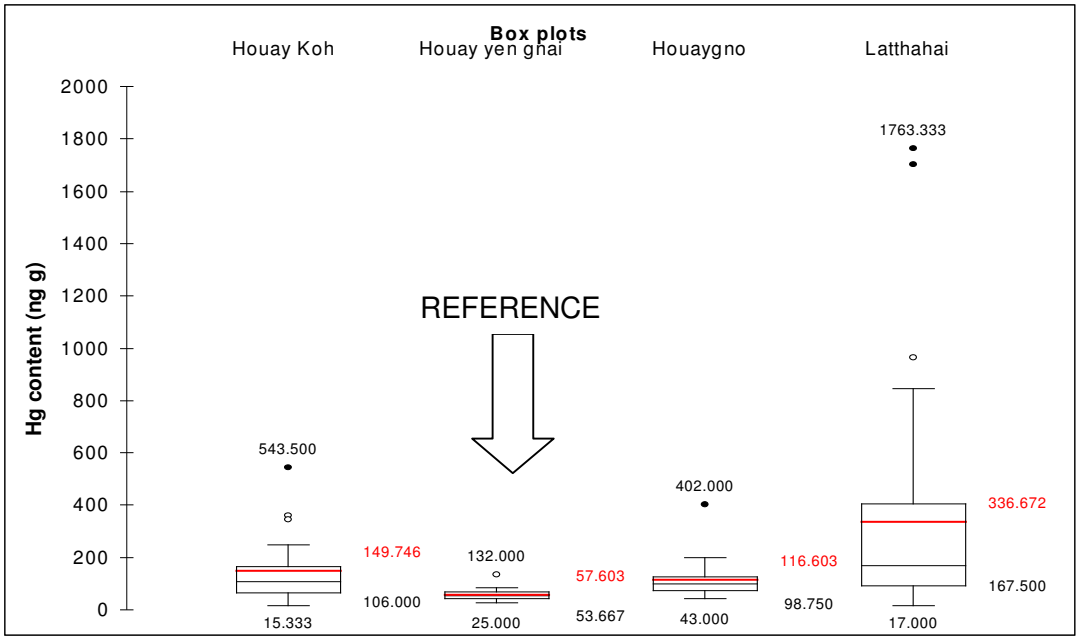


Illustration 19 - Box plots of Hg contents in soils per village (inside boxes red bar = mean, black bar = median).

School yards, which are usually outside the village show lower Hg contents (30 to 160 ng g^{-1}) than soils sampled around houses of artisanal miners (ill. 20).

Hg content of soils in the main square of the village are away from the potential source of Hg emissions (tens to hundreds of meters). They show relatively low Hg contents ranging from 15 to 180 ng g^{-1}.

On average, soils around the houses of artisanal miners are usually enriched in Hg (150 to 800 ng g^{-1}) compared to the reference houses where no amalgam roasting has been reported in recent years. This is particularly verified in Latthahai, Houay Gno and Pak Ou.

In some villages, the soils around the reference houses (i.e. Pak Chek) show similar Hg contents, or even higher contents, than those around artisanal miners' house.

However, these soils are significantly enriched in comparison to the school yards or main squares. This can be interpreted as a problem of reliability in the selection of the reference houses. People may had probably mined in the past few years ago, but did not clearly stated that during the interviews.

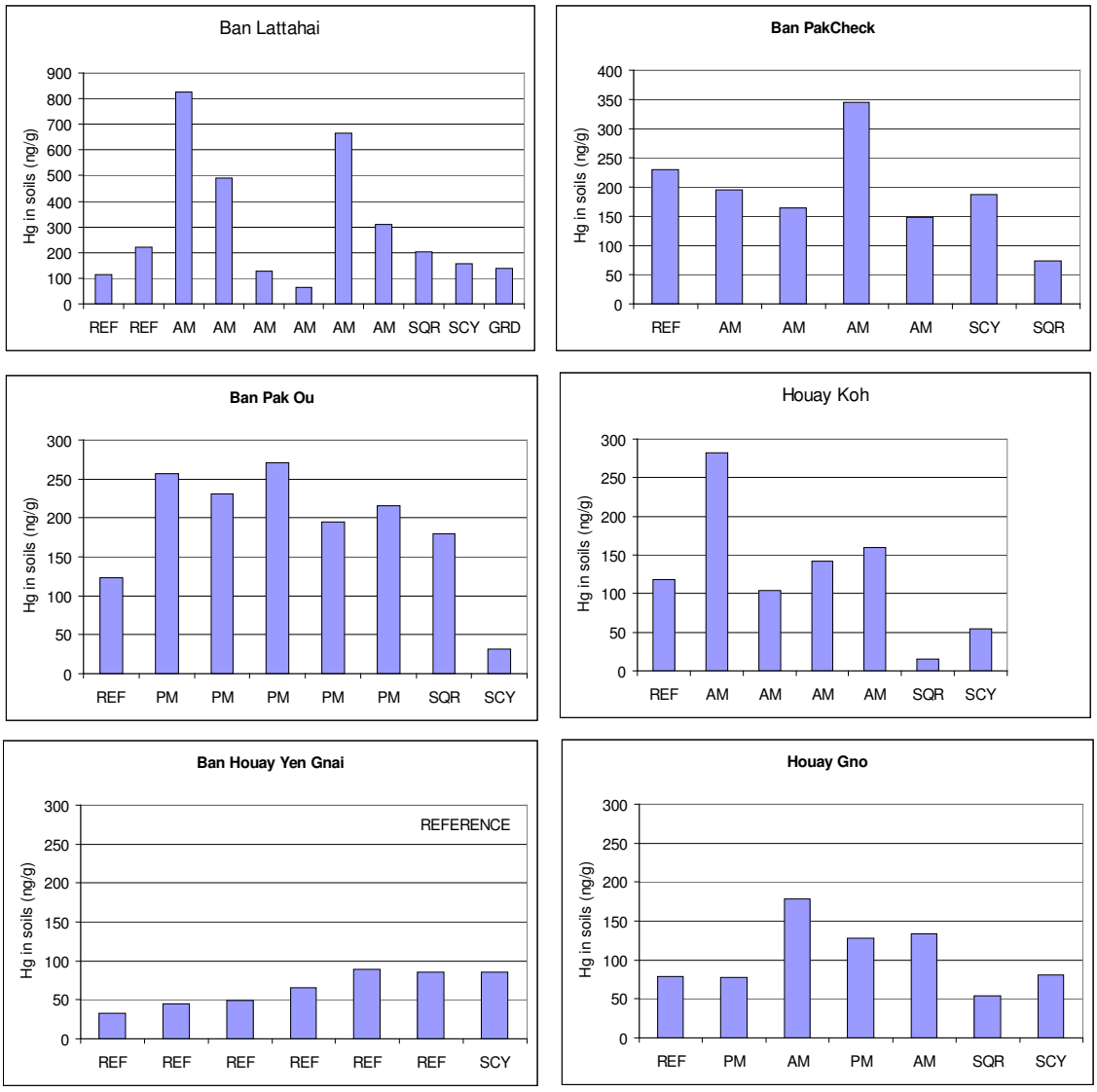


Illustration 20 - Average Hg content in soils around reference houses (REF), artisanal miner houses (AM), past miners (PM), main squares (SQR), garden (GRD) and school yards (SCY) in the studied villages.

As soil samples were taken close to each wall of the houses to evaluate the heterogeneity of Hg contents around a single house. It seems that around the houses of artisanal miners, the Hg contents are heterogeneous, with peak contents usually on one or two samples corresponding probably to walls where Hg vapors escape preferentially. In many cases, enriched samples correspond to the side of the kitchen (ill. 21, see in appendix 2, Houay Koh houses 8 and 11). In the reference village, the Hg contents in the samples are more homogeneous (ill. 21, see Houay Yen Gnai).

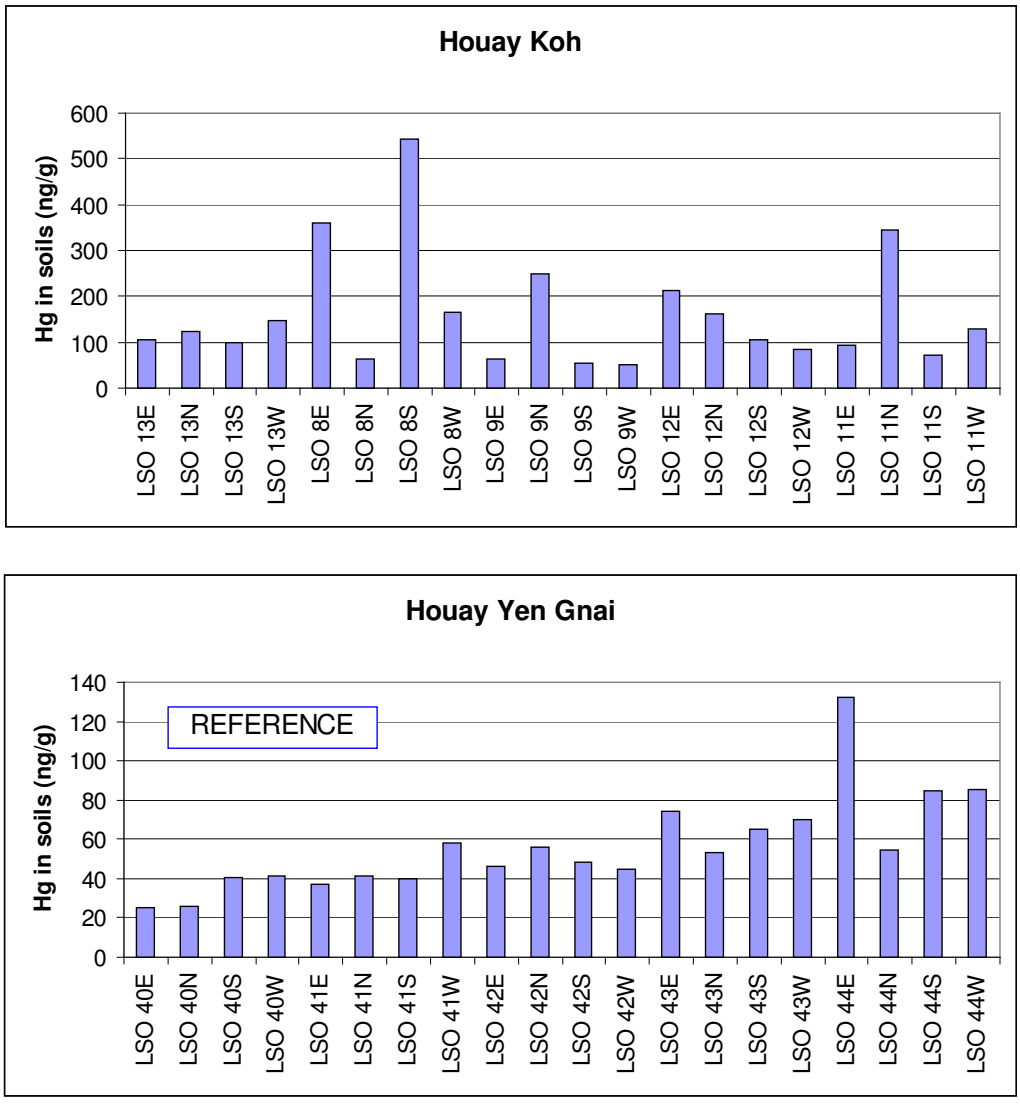


Illustration 21 - Hg content in soil samples around wall of houses in Houay Koh and Houay Yen Gnai; samples are labelled according to the number of the house and the orientation of the wall.

6.2. DUST SAMPLES

Because women roast the amalgams inside the house, we collected dust samples in the two main rooms:

- Kitchen, where amalgam roasting is carried out on the cooking fireplace.
- Living-room, where people are used to take their meals sitting on the floor, where children play and, in some cases, may sleep.

The floors of each selected house (hard ground, bamboo, wood or cement floor) were brushed to collect dust ill. 22). We collected 2 bulk dust samples (noted kitchen and living-room) per house. 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 22 - Dust sampling in a kitchen.

Results are summarized in the following table (ill. 23, see appendix 2).

In the reference village (Houay Yen Gnai), domestic dust shows relatively homogeneous contents, ranging from 60 to 460 ng g^{-1}. They are however higher than in the soils collected outdoor. That implies that domestic activities (wood burning, use of detergents, batteries,…) may lead to an enrichment of Hg in the dust. The Hg contents are significantly higher in the living room (370 ng g^{-1}) compared to the kitchen (77 ng g^{-1}), maybe because the floor of kitchens is made of hard ground, whereas living

room floors are often made of cement that may content higher Hg backgrounds or may be cleaned up with contaminated detergents ?

In the villages of Houay Gno and Pak Chek, domestic dust samples show similar Hg contents than in the reference village. This is a surprising result, as the other villages of artisanal miners show much higher Hg contents in the domestic dust. In Pak Chek, this can be interpreted as a consequence of the local gold separation practice by blowing that do not require the use of mercury. As observed in the sociological survey, people in Pak Chek use probably very limited amount of mercury. In Houay Gno, the situation is different, people use mercury in their mining process (type 1). The relative lack of mercury in the domestic dust could maybe be interpreted by a seasonal effect. Indeed, the mining season just started few days ago, and no amalgam had been roasted at this stage in that village.

The other villages of artisanal miners (Latthahai, Houay Gno, and Pak Ou) show relatively high Hg contents in the domestic dust ranging from 130 to 335,000 ng g^{-1} with strong nugget effects. Average contents show significant contamination of domestic dust in some houses of artisanal miners. Domestic dust is significantly more enriched in mercury than the soils of the villages. It is clearly demonstrated that indoor amalgam roasting may significantly contaminate the dust of the buildings. This contamination may be a long lasting effect as in Pak Ou, where artisanal mining is no longer performed by local peoples (houses B and E) for several years and where dust contamination is still rather high.

In Pak Ou and Houay Koh, the highest Hg contents are measured in the kitchens. On the contrary, in Latthahai, they are observed in the dust of the living rooms, this may reflect a change in the practice, with probably an amalgam roasting taking place in the living room and not on wood fire. This point should be verified in a further step.

Domestic dust	Hg (ng g^{-1})	mean	median	std
Houay Koh	kitchen	69 865	3 423	148 506
	living room	3 259	3 237	1 658
Houay Gno	kitchen	311	299	208
	living room	305	269	164
Latthahai	kitchen	649	748	284
	living room	12 480	2 200	15 015
Pak Chek	kitchen	147	150	27
	living room	242	268	127
Pak Ou	kitchen	27 677	539	48 823
	living room	1 112	662	1 303
Houay Yen Gnai	kitchen	81	77	22
	living room	342	370	115

Illustration 23 - Average Hg contents in domestic dust per village.

6.3. AIR MONITORING

6.3.1. Methodology

The villages selected for air monitoring were Houay Gno, Houay Koh, Pak Ou and Latthahai. Pak Chek was not selected because the villagers did not use mercury.

The miners, mostly women, roast usually in their kitchens except in Pak Ou where a few women used to roast outside the house with a short bamboo tube above the amalgam to recover the mercury as a kind of “artisanal retort”.

Most of the villagers did not have many amalgams ready to be roasted because March is only the beginning of the mining season.

The objective of the air monitoring was to focus on the same houses than for dust, soil survey, but also the health assessment. Most of the time this was not possible, for the following reasons:

- The selected villagers did not have amalgams ready to be roasted the day we showed up.
- They were panning at the River and they did not want to stop to come to the village to roast an amalgam (it was difficult for us to give an appointment to the villagers because we spent only 1 or 2 days in each village).
- When we made an appointment some forgot to show up.
- Also, other villagers that were not selected for the environmental study showed up spontaneously with their amalgams.

In each village, we tried to monitor at least one amalgam roasting in a selected house where soil and dust sampling were collected.

Nineteen air monitoring sequences were performed in four villages. They can be classified as (ill. 25):

1. Outdoor air monitoring:
    - playground of the school,
    - main square of the village,
    - in front of the house.
2. Indoor air monitoring:
    - before roasting in kitchen with or without mercury history,
    - during the roasting in the kitchen and in the living room,
    - after the roasting in the kitchen and in the living room.

Village	House	Amalgam ∅ mm	Estimated weight Hg (g)	Comments
Houay Gno	Mrs Hung (house A)	---		Background
	Mrs Thitkaen Maekdala (house C)	4	1.8	Outside & inside kitchen
	Mrs Pheng (house E)	5 (x4)	3.5x4	Outside & inside kitchen
Houay Koh	Mr Chandry (house B)	3 (x2)	0.8x2	Outside & inside kitchen
	Mr Sybanedone	3	0.8	Outside & inside kitchen
	Mrs La	3 (x3)	0.8x3	Outside & inside kitchen
	Mrs Nang	3	0.8	Outside kitchen
Latthahai	Mr Nanchai	2 & 4	0.2&1.8	Inside kitchen
Pak Ou	Mrs Aon Chantamala (house B)	3 (x3)	0.8x3	Outside house, use of bamboo tube as a "retort"

Illustration 24 - List of air quality monitoring events in the villages, the houses selected for soil and dust sampling are mentioned (see appendix 2). Estimated Hg weight in the amalgams is based on a ratio Au/Hg of 1.

The monitoring sequences were performed to estimate the air quality breathed by the population under different typical situations. For this, the intake hose of the RA-915$^+$ analyzer was installed approximately at nose height of the persons involved in the mining activities (ill. 25)

For background air monitoring in open place (such as the playground monitoring at the school), the intake hose of the RA 915$^+$ analyzer was held approximately 1-1.2 m above the ground.

Inside the school building, the intake hose was at 20-30 cm above the desk where the children sat.

During the amalgam roasting phase, the intake hose was placed on the shoulder (50-60 cm height) of the person performing the roasting. Monitoring was also carried out in the living room, the intake hose was held at the same position (at 50-60 cm height) in order to evaluate the dissemination of the volatilized Hg in the house and 3-4 m away of the fire.

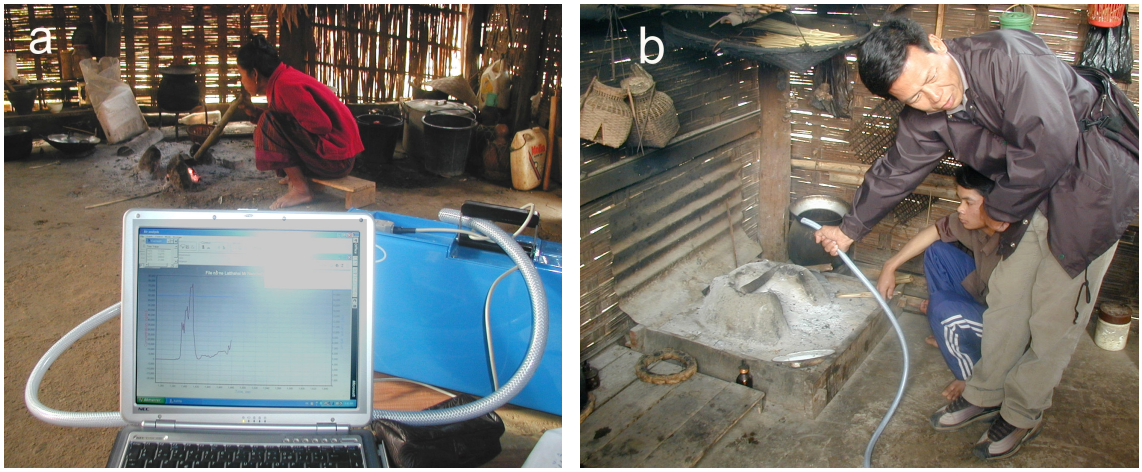


Illustration 25 – Air monitoring in kitchens during an amalgam roasting (a); monitoring of Hg emissions during lighting of the fireplace (b).

6.3.2. Description of results

Only a few monitoring sequences are described in this section because other spectrums provided very similar results (see appendix 7).

We selected different situations to monitor the air quality :

1. In an open place: playground and inside the building of the school at Houay Koh.
2. In a kitchen of a reference house at Houay Gno without reported roasting actitivity.
3. In a kitchen before and during the roasting of an amalgam at Houay Gno.
4. In a kitchen and a living-room during the roasting of the amalgam at Houay Koh.
5. An open place: during the roasting of an amalgam at Pak Ou using a bamboo as “artisanal retort”.

Comment : the monitoring were performed with the LUMEX RA915+ under field conditions. At this stage, there is no existing validation of this device for air monitoring in the literature or performed by BRGM. Thus Hg air concentrations are consistent for comparison site by site, but absolute Hg concentration values have to be considered as indicative values.

Open place

Most commonly in the villages, the school was on the edge of the village or outside the village on the top of a small hill. The school in the village of Houay Koh was on the

North-West side at the end of the village (Appendix 1). We recorded 2 times 15 minutes in the playground and inside the building of the school (ill. 26 and 27).

Illustration 26 - Typical interior of school village.

The mercury concentration was about 1±1 ng m^{-3} with a maximum of 5 ng m^{-3} at the playground and 4 ± 4 ng m^{-3} with a maximum of 15 ng m^{-3} in the school building.

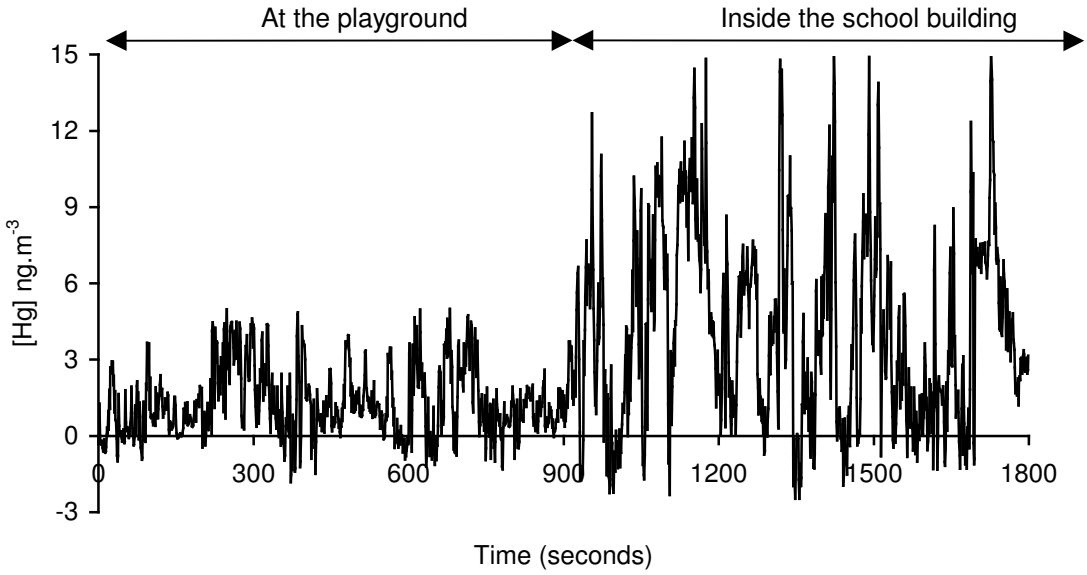


Illustration 27 - Air monitoring at the school of the village of Houay Koh. At the playground from 300 to 600 seconds and inside the school building from 0 to 300 seconds.

Due to the high vapor pressure at ambient temperature (1.2×10^{-3} mm at 20 °C), the main source for the release of mercury from the Earth's crust is degassing of elemental mercury. Typical background concentrations in air range from 1 to 4 ng m^{-3} (Pichard, 2000) with a background average concentration of 1.5 ng m^{-3} (http://www.epa.gov/ttn/atw/nata/haptbl.html).

The mercury concentration in the main square of the villages was in the range of typical background concentrations in air. The concentration inside the school building was slightly higher than outside but the differences were not statistically significant. This slight increase is probably due to air confinement rather than a result of the some anthropogenic activity.

Monitoring in a reference kitchen

The house of the Hung's family was close by the school and the occupants stated that they had never been involved in mining activities. They owned a little grocery next to the house in Houay Gno.

The mercury concentration was 5 ± 7 ng m^{-3} with a maximum of 36 ng m^{-3} inside the kitchen and 7 ± 7 ng m^{-3} with a maximum of 30 ng m^{-3} outside the house (Illustration 28).

The average concentration inside the house was a little bit lower than outside with a high standard deviation in both cases. The mercury concentration increased after the fire was lighted but the maximum was lower than 40 ng m^{-3}. These values were higher than at the school site probably because of the closeness to the houses of artisanal miners.

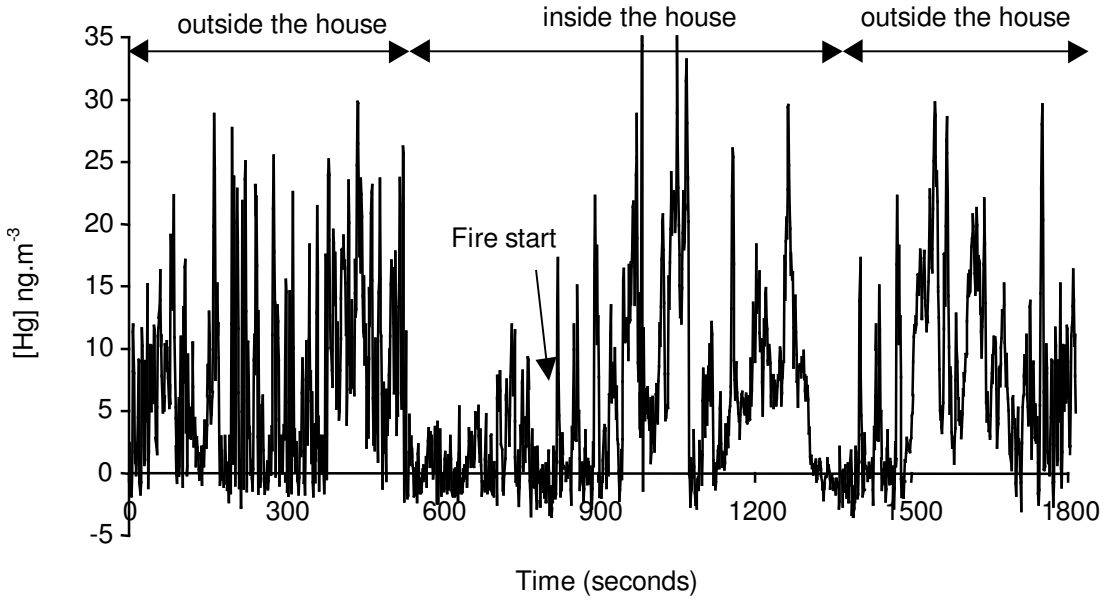


Illustration 28 - Air monitoring inside and outside a kitchen without reference of amalgam roasting.

Air monitoring before and during the roasting of an amalgam

The house of the Maekdala's family was on the East side of Houay Gno and Mrs Maekdala had always mined and used to roast the amalgams in her kitchen on her cooking fireplace.

There are 5 steps during the monitoring of the amalgam roasting : before and after the lighting of the fire, the lighting of the fire, the roasting and after the roasting.

The indoor background concentration was around 9 ± 14 ng m^{-3} with a median at 3 ng m^{-3} before the lighting of the fire, 130 ± 224 ng m^{-3} with a median at 21 ng m^{-3} during the lighting of the fire then the mercury concentration decreased to reach the background as before the lighting of the fire. When the roasting started, the mercury concentration increased abruptly to 24,800 ± 28,200 ng m^{-3} with a median at 12,000 ng m^{-3}. Two large peaks were detected, the first one when the amalgam boiled (ill. 29, between 1,300 and 1,500 seconds) and a second one when the boiling process stopped (ill. 27, between 1,500 and 1,800 seconds). The mercury concentration

decreased progressively after 8 minutes to reach levels similar to those measured before the onset of the roasting.

There were two important observations:

- The fireplace in this house emitted about 10 times more concentrated mercury vapors than the fireplace in a reference house.
- For about 10 min, people present in the kitchen during the roasting phase breath an air contaminated with mercury (an average concentration of 25,000 ng m^{-3}). The exposure limit for workers exposed to mercury is 25,000 ng m^{-3} average air concentration for an 8 hour shift (WHO, 1994).

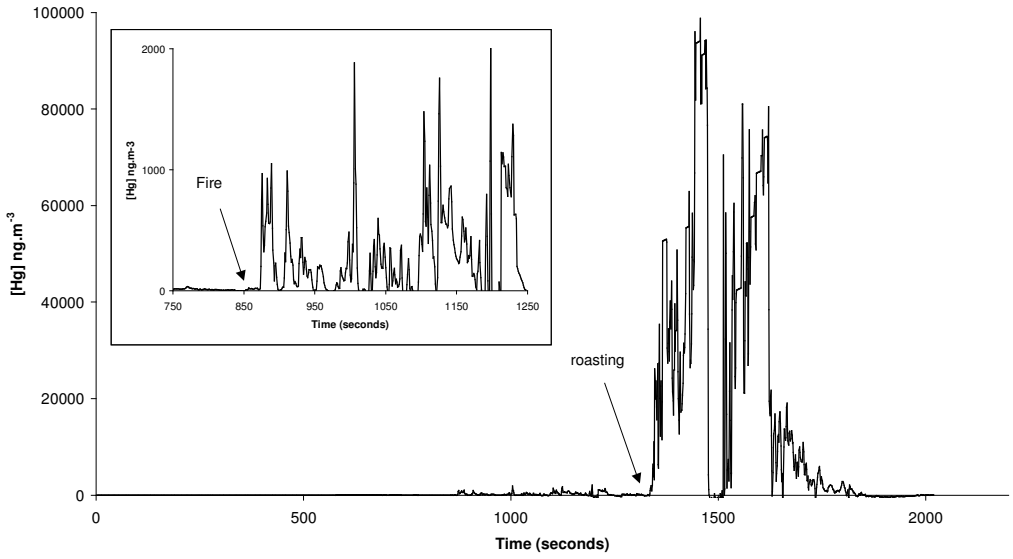


Illustration 29 - Air monitoring in an kitchen before and during the roasting of an amalgam at the village of Houay Gno.

A kitchen and a living-room during the roasting of the amalgam

The house of the Chandry's family is located at the entrance of Houay Koh. Mrs Chandry had always mined and roasted the amalgams on her cooking fireplace. The kitchen was upstairs and there was a second room (« living-room »), but not separated with a wall. In this room, there was a hanging blanket to separate the room from the bed-room.

We recorded two amalgam roasting; the first monitoring was performed in the kitchen and the second one in the « living-room ».

During the first amalgam roasting, as shown in the illustration 30, we observed two large peaks: the first when the amalgam boiled (ill. 30, between 570 and 660 seconds) and a second peak when the boiling process stopped (ill. 30, between 660 and ~820 seconds). The first peak is attributed to the volatilisation of the mercury from the amalgam, and the second peak is probably due to a late release of mercury aerosols that condensed at the roof of the kitchen. This process has been observed at several places and seems to be a common phenomenon.

In the living room, during the roasting of the second amalgam, only one peak was monitored (ill. 30, between 1650 and ~2000 seconds), representative of a single air plume progression within the room.

The intensity of the 3 peaks was similar than the ones described in Mrs Maekdala' house (~90,000 ng m^{-3}) but the mercury concentration was elevated for a shorter period. For the first amalgam, the mercury concentration decreased to pre-roasting levels after 3 min. This shorter time is most likely due to the small size of the amalgam that was roasted (∅ ~2 mm).

The important point at this location is that this house, made of bamboo walls, had no separation between the kitchen and the other rooms. The volatilized Hg can disperse within the whole house and can be breathed by the whole family. The walls and the floor can be contaminated on a longer term basis.

In other places, we also recorded the air quality of the living-rooms in the houses build with concrete and with a separation between the kitchen and the living room. In these cases, the average mercury concentration in the living room was only 21 ± 16 ng m^{-3} with a median of 20 ng m^{-3} and a maximum of 165 ng m^{-3}. This was higher than in the reference houses but lower than in houses without separation between the living-room and the kitchen.

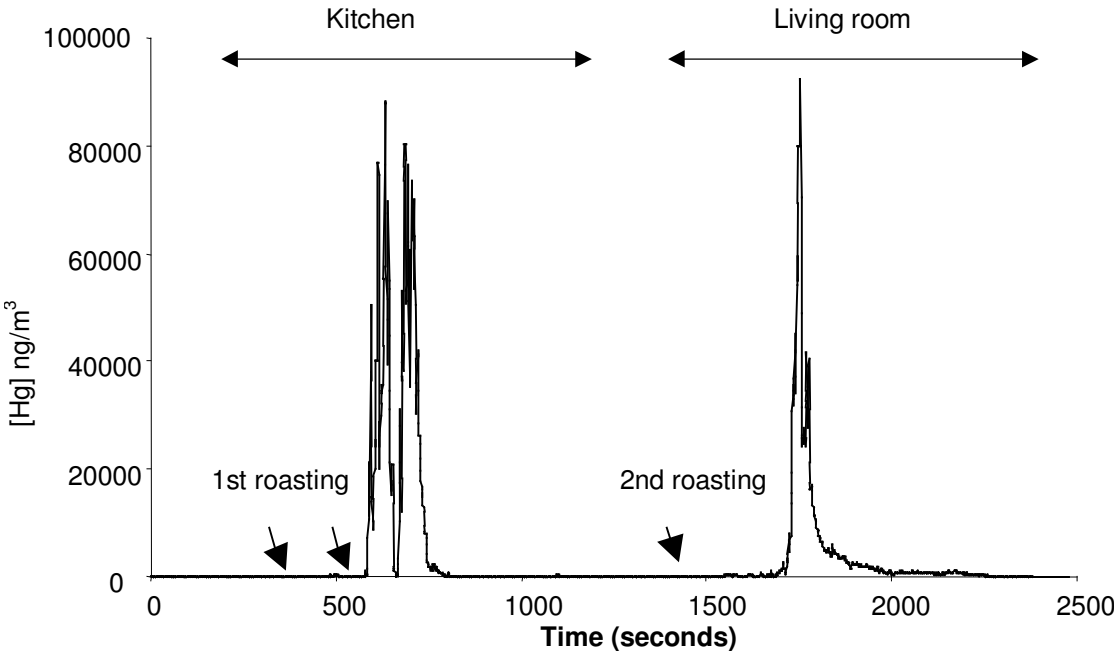


Illustration 30 - Air monitoring in a kitchen and a living-room during the roasting of two amalgams at the village of Houay Koh.

An open place: during the roasting of the amalgam

In the village of Pak Ou, a few women performed a demonstration with an « artisanal retort » (ill. 31). They roasted the amalgam outside their house and used a short bamboo tube as a retort. The mercury trapped in the bamboo tube was retrieved using a feather.

Illustration 31 - Woman roasting amalgam outside and using a bamboo tube in Pak Ou.

We asked the villagers to roast successively 3 amalgams (with about the same size, ∅ ~3 mm) to check the efficiency of the bamboo shot. The tools used were rustic, the plate was in metal and the bottom was battered.

We observed two differences in comparison with the procedure of amalgam roasting inside the kitchens (ill. 31):

- There is only one peak during the roasting of the amalgam.
- The maximum mercury concentration was relatively lower (~70,000 ng m^{-3}) compared to the amalgam roasting in a kitchen.

The contact between the plate and the bamboo tube was not continuous. Most of the time, there was some space between the plate and the bamboo allowing some leaks of mercury vapors (roasting 1 and 2). While occasionally contact was better and less vapors escaped (roasting 3). The lack of the second peak was most likely due to the dilution of mercury vapors in the atmosphere.

At the end of the roasting, we examined the bamboo tube and we noticed some mercury droplets in the cracks of the bamboo.

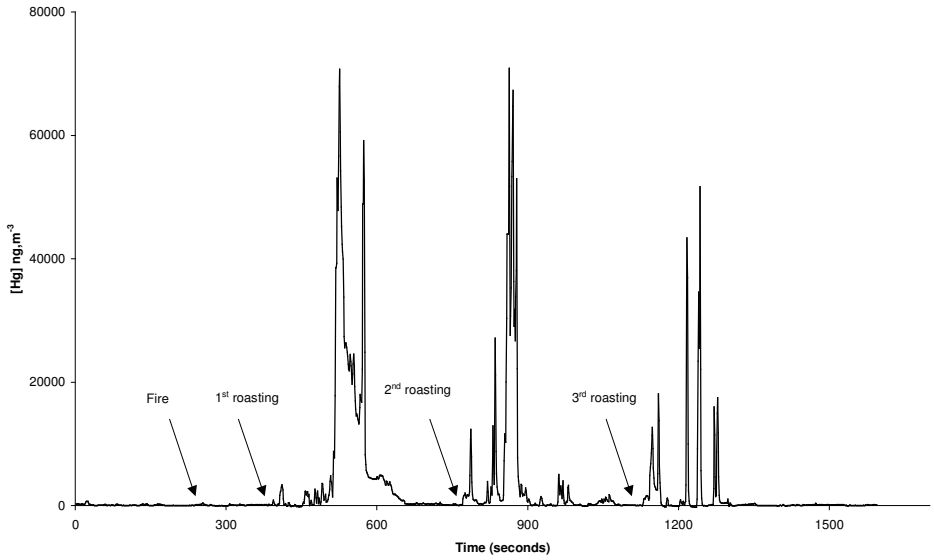


Illustration 32 - Air monitoring at an open place during the roasting of 3 amalgams at the village of Pak Ou.

6.4. SEDIMENTS

6.4.1. Sampling strategy

Sediments were collected from a boat with an Eckman grab sampler (Ill. 33), the sampling procedures are described in the field report (Laperche *et al.*, 2004). Two profiles of sediments were performed, one on Mekong and one on the Ou River in order to evaluate the level of potential contamination related to the artisanal mining activities in the area.

The strategy was adapted to the field conditions; sediments were sought mainly along the shores and in midstream when possible; we collected either sands or silty sediments. Ninety-five samples were collected, 56 in the Mekong and 41 in its tributary the Ou River. Sixty-three of them were sands or predominantly sand. The complete list of samples and results is given in the appendix 3.

Illustration 33 - Sampling sediment a boat with an Eckman grab sampler

6.4.2. Description of results

Mercury contents ranged from 6 to 110 ng g^{-1} on a dry weight (dw) basis in Mekong River sediments, and between 23 to 261 ng g^{-1} (dw) in the Ou River. Most of the samples display concentrations below 62 ng g^{-1} in the Mekong, and 97 ng g^{-1} in the Nam Ou, as summarised in illustration 34.

	Mekong River	Nam Ou River
N	55	40
mean	40	75
median	34	64
standard deviation	27	49

Illustration 34: Summary of the Concentrations observed in Mekong and Nam ou Rivers sediments (in ng g^{-1}, dry weight)

The respective distributions are presented in illustration 35 for Mekong and Ou River sediments.

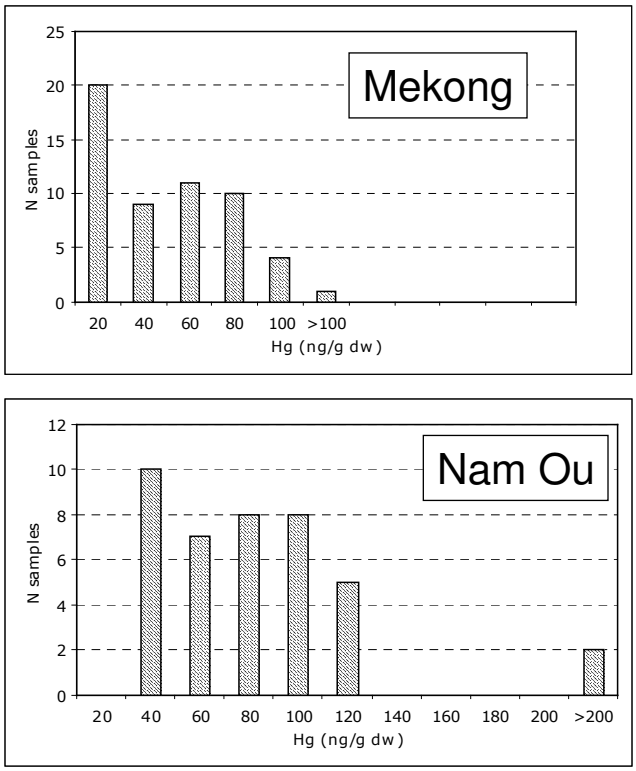


Illustration 35 - Distribution of mercury concentrations in Mekong and Ou River sediments.

These distributions look quite similar; as such, they evoke either multiple or remote mercury sources, or both, with the exceptions of few samples. A t-test was performed on the whole dataset, in order to compare the mean concentrations in the Ou and Mekong subsets, after having checked the homogeneity of variances. The mercury concentrations in the Ou River sediments are significantly higher than in Mekong[1] ($p = 0.05$).

Mercury sources – mapping of the study area

Regarding raw data, there is no significant decrease of Hg contents downstream the villages of miners in the Mekong River sediments. Hg values range between 50 to 100 ng g^{-1} and above 100 in one case. These latter samples were mostly taken in sedimentation areas[2], and were made of finer particles than the less contaminated samples.

All the sampling points upstream the village of Houay Gno, show relatively low Hg contents (< 15 ng g^{-1}). That is the village at the upper range of the stream section

[1] the few samples collected near Luang Prabang had not been removed from the Mekong subset

[2] such as the area circled with an ellipse on the map

which was under study, but it does not necessarily means that there is no mercury released upstream. These samples were mostly composed of sand, more or less coarse, and thus with less fine fraction which usually the most enriched fraction. Nevertheless, higher concentrations (50-100 ng g^{-1}) were retrieved downstream the places where gold is processed along the River (ill. 36), whereas low Hg contents (1-50 ng g^{-1}) are preferentially located in remote places of the villages.

Illustration 36 - Map of the sediment contamination in the area of Pak Ou

When representing the distribution of mercury concentrations in the Ou sediments on a graph after having sorted the data according to the longitude (iIl. 37), it comes out that a lot of points are within a range 50 – 100 ng g^{-1}. A few points exceed slightly 100 ng g^{-1}, whereas a dozen are distinctly below 50 ng g^{-1}. Many of them (e.g. LSE65, 66, 70, 87), correspond to sandy samples.

The highest levels reported (LSE79, LSE67) are located downstream the village of Houay Lo and within a dam close to Phathung respectively. The gold-miners from this village are supposed to look more for gold dust than for nuggets, as compared to people from upstream villages. The dam is a sedimentation area, where either the contaminated particles can settle down, or the dissolved mercury can precipitate. Interestingly, this latter sample was mainly made of sand. This pattern clearly suggests a number of Hg sources spread all along the River, with some hotspots. The actual sources related to these hotspots are not clearly identified yet; furthermore, probably not all the hotspots were identified. As for the Mekong River, no clear up- to downstream trend can be inferred from mapping of the contamination (ill. 37 and 38).

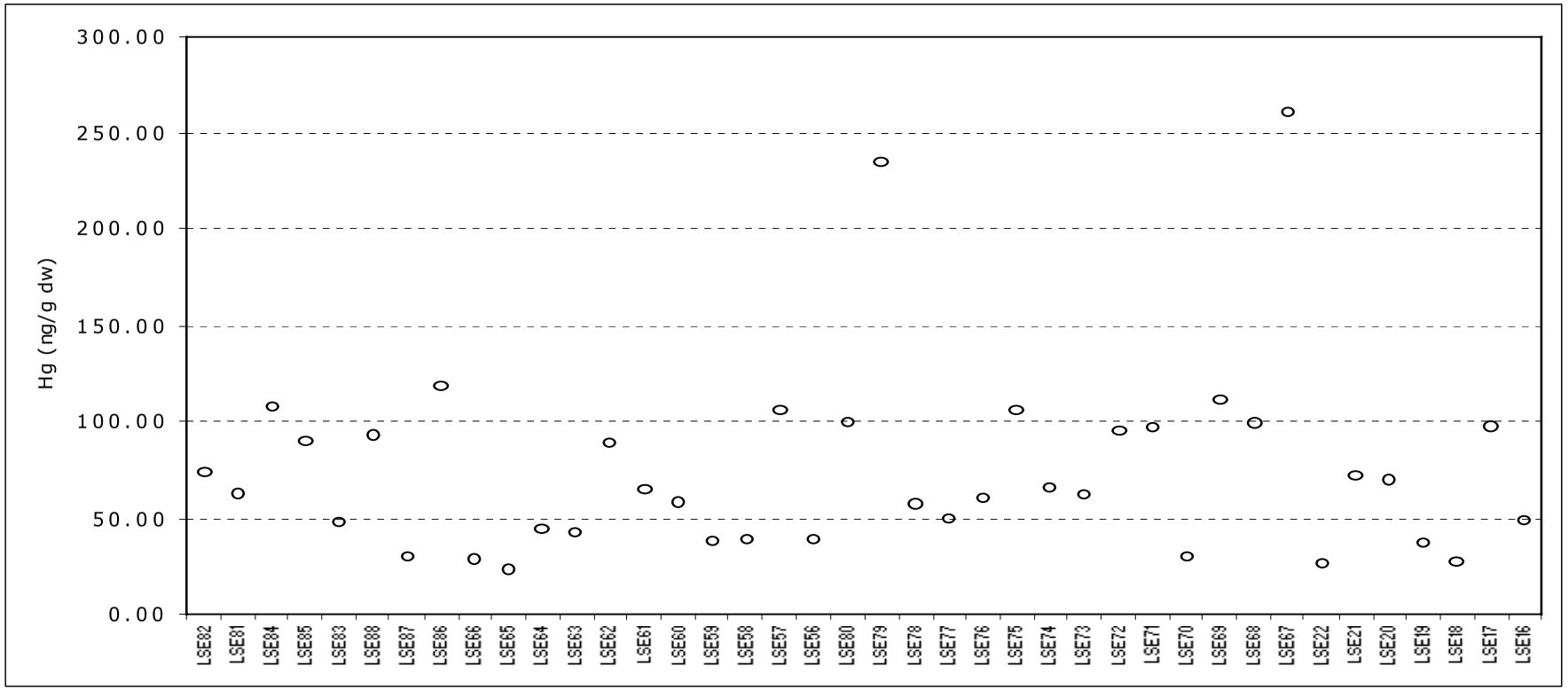


Illustration 37 - Nam Ou sediments up- downstream contamination pattern.

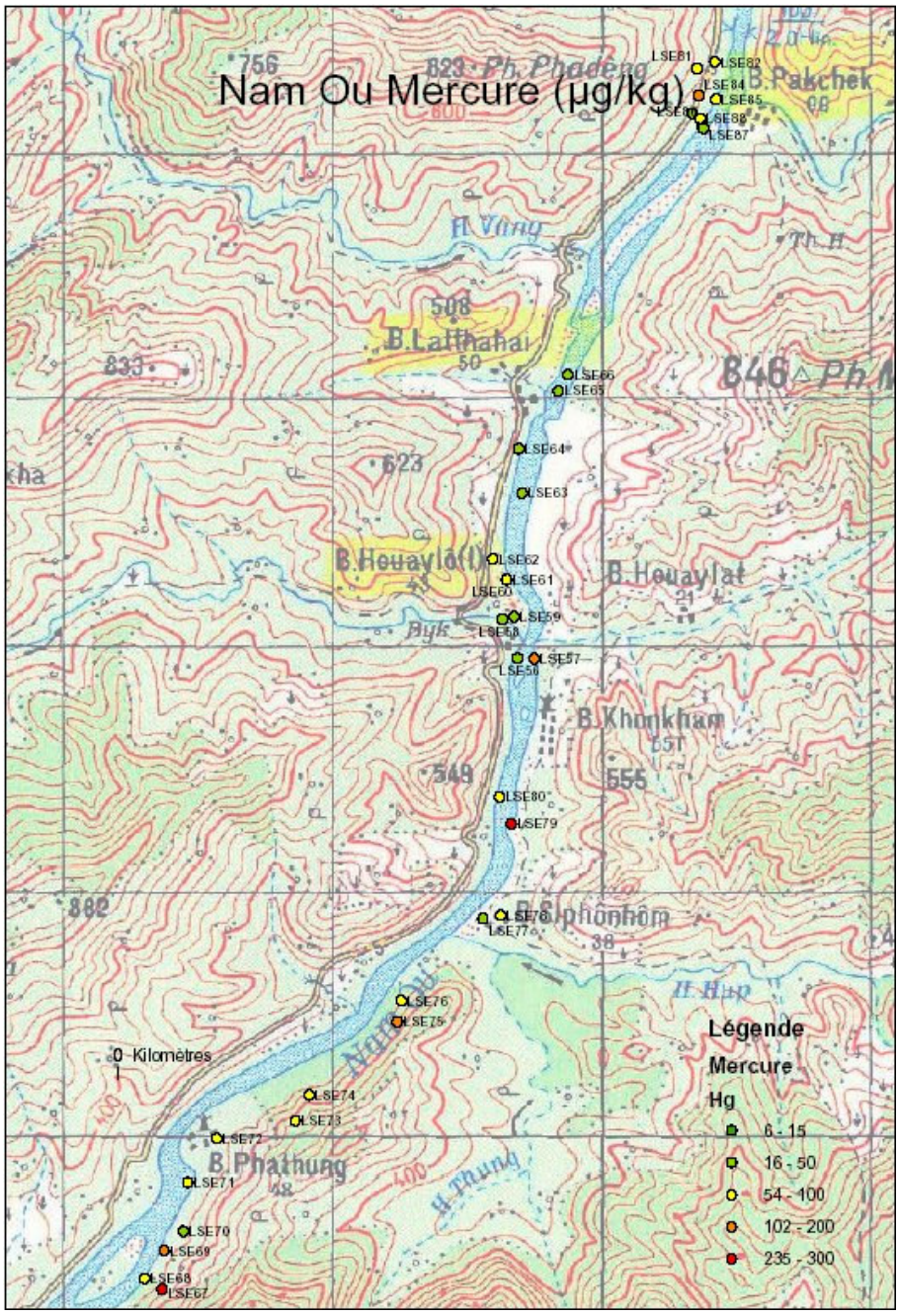


Illustration 38 - Map of the Hg contamination along the Ou River.

According to Pakchek villagers, a former gold mine has been exploited several decades ago by an industrial Chinese mining company, using mercury for gold extraction. The effluents from the mine were released in the Chek brook, a tributary of

the Ou River, which flows across the village of Pakchek. According to the villagers, some metallic mercury is quite often found in the sand they process for their own gold extraction.

Several samples were taken up- and downstream the tributary's outlet, along both Riverside of the Ou River. The corresponding concentrations are shown on illustration 39. Although the measured concentrations in the upstream samples are already elevated, as compared to the mean concentration in the Ou River, there is clearly an increase of Hg content at the confluence with the Ou River and downstream that point. The extent of this specific contamination could not be assessed, because of the rapids located some meters downstream. The sample LSE87, taken close to the rapids, was made of sand and can therefore be considered as an outlier.

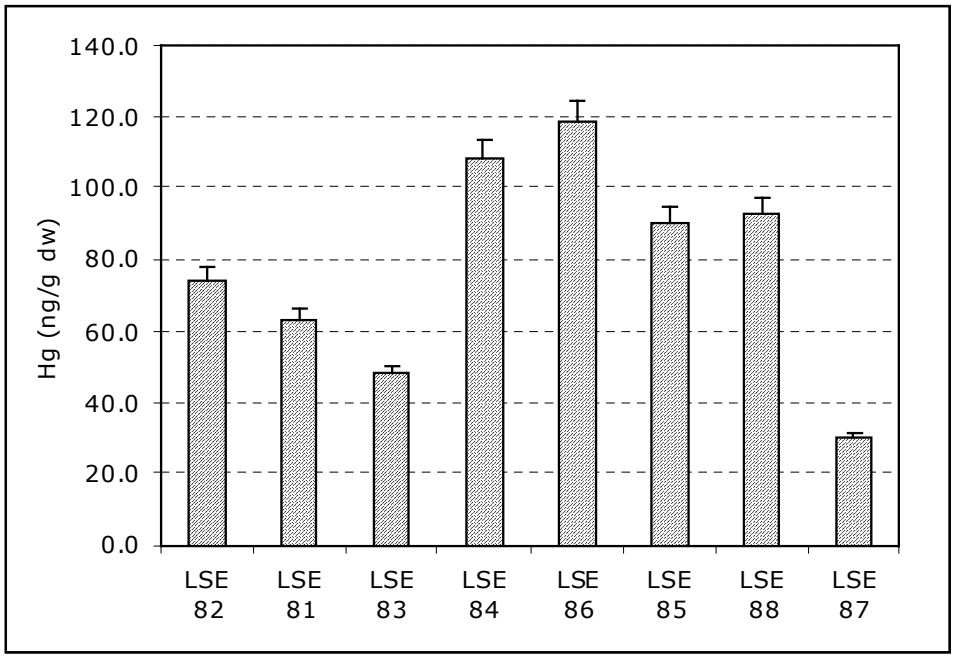


Illustration 39 - Mercury in sediments up- and downstream Chek River outlet[3].

However, LSE84 and 86 were sampled very close to an extraction area, which was active at the time of sampling. Artisanal gold miners ensured that they were looking only for nuggets, but this allegation is unverifiable. So, though it appeared clearly that there is a source of mercury at the outlet of Chek brook, the respective contributions of the former mine and of artisanal gold mining cannot be discriminated.

[3] upstream on the left side of the graph, downstream on the right

To summarize the results on sediments, the significant difference between mercury concentrations in the Ou River and Mekong sediments can be due to natural or anthopic origin such as:

- a change of local geology with a higher geochemical background in the sediments of Nam Ou area,

- the former mine releases, and the lower flow in the Ou River, implying a lower dilution rate.

Some higher Hg contents downstream to artisanal mining spots may probably to attributed to local effects of contamination (i.e. Houay Koh, Latthahai), but the observed potential Hg release seems too low to contaminate significantly the sediments on long distances in the Ou River and Mekong.

In anycase, the Hg concentrations in sediments of both the Nam Ou and Mekong are relatively low and do not show important levels of contamination in regard to the usual guideline values for sediment management in Europe or the North America (see illustration 53).

6.5. SEAWEEDS - VEGETABLES

A few seaweed samples were collected to check their Hg content, as they are consumed dried by local peoples. It was decided to focus the sampling of vegetables on this seaweed. All of the samples were collected in Houay Kho, (except one sample in Pak Ou). Both dried and wet seaweed were collected (ill. 40 and 41).

As field observation indicated no significant contamination of the sediment by local artisanal miners, it was not intended to control the Hg level in these seaweeds as bio-indicators of the River ecosystems. Sampling was then focussed to evaluate the contribution of these seaweeds in the mercury daily intake of the local population.

Illustration 40 - (a) women transporting wet weed from Mekong River; (b) band of weed drying before consumption.

Sample	Location	River	Remarks	Hg en µg/g dry weight (LQ = 0,05µg/g)
LVG1	Pak Ou	Mekong	Fresh seaweed	0.50
LVG2	Houay kho	Mekong	Fresh seaweed	0.14
LVG3	Houay kho	Mekong	Dried seaweed	0.08
LVG4	Houay kho	Mekong	Fresh seaweed	0.68
LVG5	Houay kho	Mekong	Fresh seaweed	0.25

Illustration 41 - Analysis of the seaweed samples.

The Hg contents in seaweed of Mekong River range between 0.1 to 0.7 µg g^{-1} of dry mass with a mean of 0.3 ± 0.25 µg g^{-1}. If one considers an average water content of 90% in these aquatic plants, the Hg concentrations range 0.01 to 0.07 µg g^{-1} of wet weight.

The sample of dried seaweed ready for consumption shows the lowest content of mercury (0.08 µg g^{-1}). It is of course not significant, but the possible evaporation of mercury during the drying phase should be verified.

Mercury in aquatic plants may be detected both in organic and inorganic species (Czuba and Mortimer, 1980) and thus the speciation in the seaweed should be checked. There is no published guideline value for that type of food in the US or in Europe.

This type of concentration is significantly above ubiquitous concentrations for aquatic plants. It is not possible with such a small number of samples to draw up conclusions, but these results on seaweed 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.

6.6. FISHES

Fifty five specimens were collected along the Mekong River, in 4 areas and 10 more were obtained along the Ou River. Small dorsal muscle samples were taken and kept in formalin to be analysed at the University of Bordeaux-CNRS LEESA Laboratory in France.

Fish is exposed to the mercury present in waters, either through passive (respiratory) exposure or through the diet (Snodgrass, Jagoe *et al*., 2000). Therefore, fish species are good indicators of the contamination trends of this medium. In the meantime, fish constitutes a substantial proportion of the protein intake of the populations living along these Rivers. Thus, it can subsequently represent a source of exposure to mercury, aside the direct exposure of the people extracting gold and their families.

6.6.1. Fish characteristics

Mekong River

45 specimens from 17 species were collected along the Mekong River between Houay Gno and Tinh-Hong villages. The majority of them were herbivorous (ill. 42). These fishes were heterogeneous in size as well as in weights; moreover, in most size classes only few individuals could be collected (ill. 43). Conversely, most individuals of one single species (Pa Keng) were in the same size class; this species constituted also the largest group.

Feeding	N spp.	N indiv.
Herbivorous	10	31
Carnivorous	4	8
Omnivorous	1	3
Detritivore	2	3
	17	45

Illustration 42 - Summary of the samples collected in the Mekong River.

The statistical analyses were then performed on the basis of two categories: herbivorous species on the one hand, carnivorous-omnivorous and detritivore species on the other. This can be justified for the sake of statistical reliability as well as on the ground of consideration of exposure to mercury (see discussion).

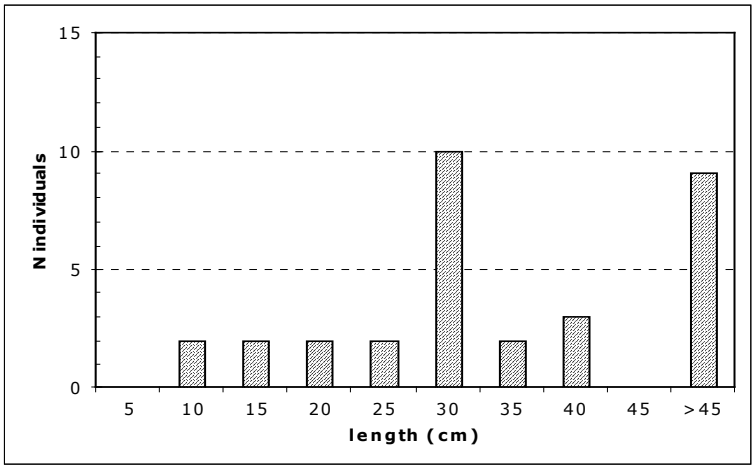


Illustration 43 - Length distribution for Mekong River fishes.

The median length is equal to 29 cm (27 cm for herbivorous fishes), and the maximum to 70 cm (54 cm for herbivorous fishes). The same heterogeneity can be observed for weights, which ranged between 8 and 6,360 g (median 406 g).

Due to the low number of individuals for each species, it is not significant to derive length-weight relationships.

Ou River fishes

10 specimens from 8 different species were collected. Again, most of them were herbivorous (ill. 44).

Feeding	N spp	N ind
Herbivorous	5	6
Carnivorous	2	2
Omnivorous	1	2
Detritivore	-	-
	8	10

Illustration 44 - Summary of the samples collected in the Ou River.

Except one individual, all fishes caught in the Ou River displayed lengths between 20 to 30 cm (ill. 45). The median length is equal to 23 cm and the maximum to 52.5 cm; median and maximum weights were 282 g and 970 g respectively.

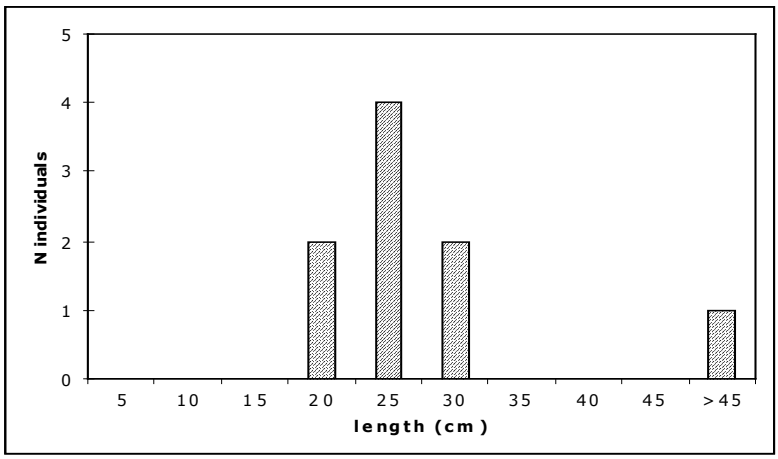


Illustration 45 - Length distribution for Ou River fishes

6.6.2. Mercury contamination

Fishes from Mekong

An overview of the concentrations observed in fishes from the Mekong River is shown on illustration 46. The detailed results are given in Appendix 4 and 5. Mercury was detected and quantified in all fish samples, meaning that this element is present everywhere in the system.

	Overall	Herbivorous	Carnivorous *et al.*
Median	0.054	0.044	0.118
Mean	0.088	0.052	0.172
standard deviation	0.094	0.032	0.126
Maximum	0.490	0.184	0.490
Number	45	31	14

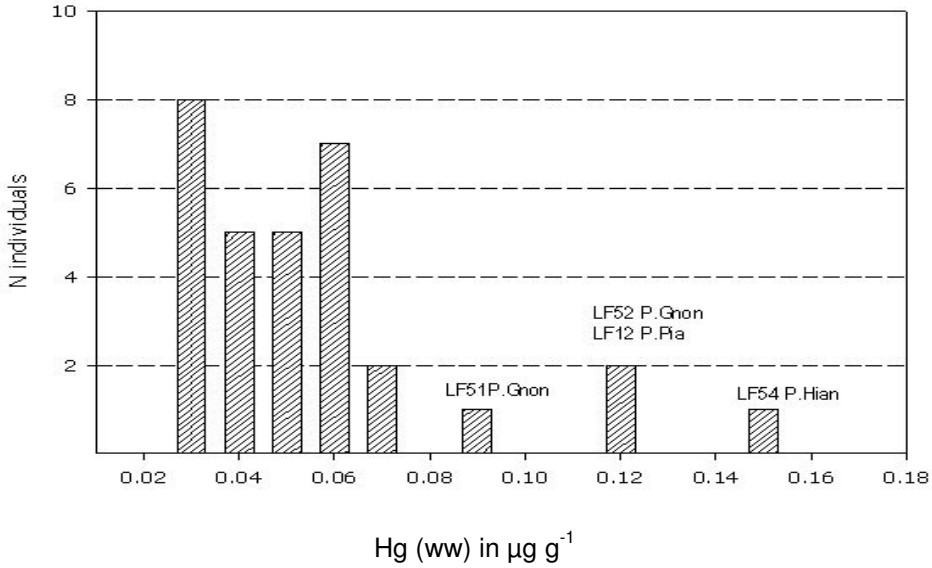
Illustration 46 - Summary of Hg content in Mekong fishes, in µg g^{-1} (ww).

According to a Kolmogorov-Smirnov test[4], the hypothesis of normality is rejected for the sub-group “herbivorous”, and accepted for the sub-group “carnivorous”, which includes also supposed omnivorous and detritivore species. There is no easy explanation for this observation. It might be due, at least in part, to the sampling biases. The “herbivorous” sub-group is mainly composed of rather big individuals, bought by local fishermen, while the “carnivorous and other categories” subgroups include smaller fishes collected along the shores.

Most herbivorous fishes display concentrations below or equal to 0.07 µg g^{-1}; among the few in higher classes of contamination, 2 specimens of Pa Gnon, 1 of Pa Hian (both species provided small size individuals) and 1 of Pa Pia (ill. 47). This raises some concerns about the assignment of feeding regime, at least for some of the small species.

As this assignment was done on the basis of information collected from local people, it is impossible to check or adjust it unless the species scientific names are made available. This would allow to gather accurate data on the ecology of the sampled species.

[4] statistics were done with Statistica ® v 6, from Statsoft



HgHIllustration 47 - Mercury concentrations in Mekong River herbivorous fishes

The samples belonging to the "carnivorous" subgroup are significantly more contaminated than those from the "herbivorous" one (Student t-test, $p < 0.05$; ill. 46).

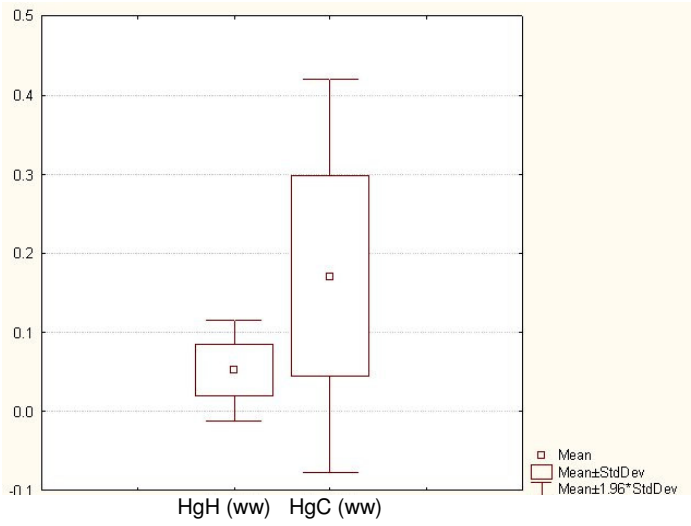


Illustration 48 - box plot of mercury contamination of Mekong River fishes. HgH (dw): mercury in herbivorous fishes, dry weight concentrations; HgC (dw) mercury in carnivorous, omnivorous and detritivore fishes, dry weight concentrations. All concentrations are in µg g^{-1}.

There is no obvious trend in contamination from the sites upstream (B. Houaygno, B. Mouang) to downstream (B. Tinh Hong). This kind of interpretation is however rather tricky, and would need careful consideration of fish characteristics (behaviour, size-age relationships). Basically, there are not enough data for assessing this type of trend; this is not only a matter of database size, but refers also to the lack of supporting information, such as fish behaviour, and size-age relationships.

Fishes from the Ou River

An overview of the concentrations observed in fishes from the Ou River is given on illustration 49. The detailed results figure in Appendix 4.

	Overall
median	0.052
mean	0.066
standard deviation	0.048
maximum	0.142
number	10

Illustration 49 - Summary of Nam Ou fishes contamination, in µg g^{-1} (ww).

Due to the small number of samples, no discrimination was done according to the feeding regime, nor any attempt to compare Nam Ou and Mekong fishes contamination.

6.6.3. Fish exposure pattern and feeding regime

A Principal Component Analysis (PCA) was performed on the whole dataset, with the *catchment* and the *species* as supplementary variables (Ill. 50). Not surprisingly, due to the limited size of the dataset, most of the overall variability was explained by the variables length and weight (first component, 46.76 % of the total variance), and by mercury contamination (second component, 35.87 % of the total variance). The variable *feeding regime*, which was given 4 modalities coded 1 to 4, was mainly linked to the second component. However, the correlation with mercury remained low (correlation coefficient of about 0.44).

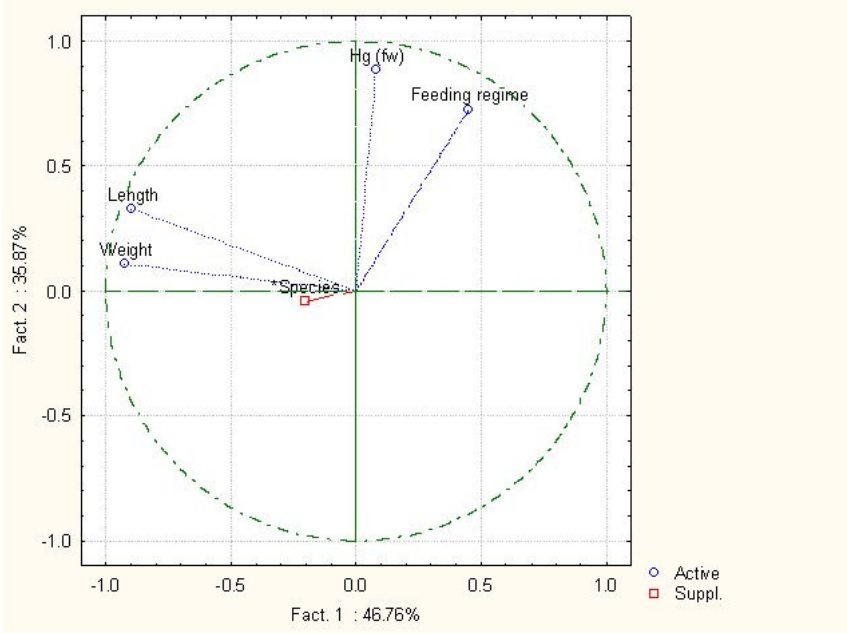


Illustration 50 - Projection of the variables on the factorial plan.

The variable *catchment* did not help to improve the analysis: the samples from the Ou River were not distinct from those of the Mekong on the graph displaying the projection of all individuals on the factorial plan made of the two principal components.

Therefore, this analysis does not provide definitive arguments supporting the grouping of fishes in 2 categories, namely *herbivorous* versus *carnivorous and omnivorous and detritivore*. Conversely, it does not show that this grouping is illegitimate, or not supported by the data.

The hypothesis behind such a grouping is that fish exposure through the diet encompasses several pathways. For instance, carnivorous fishes will eat invertebrates or other fishes; as mercury (as methyl-mercury) is biomagnified, these species will display higher levels of mercury. Other pathways can be invoked either: species living in contact with sediments might be exposed through gill contact with pore water containing mercury; fishes feeding on sediment will also be exposed to higher concentrations, though less than carnivorous fishes.

This hypothesis is not fully supported by the literature: for example, Snodgrass *et al.* (2000) studied 3 species with contrasted feeding regimes, in an array of wetlands in south eastern United States. They found that the benthic detritivore species was less contaminated than a mudfish, and also much less than a top carnivore.

According to the mercury concentrations, some feeding regimes assignments may appear curious:

- 2 specimens belonging to the species “Pa Gnon” (LF51, LF 52, see pictures in appendix 5), both captured in the Mekong River, were classified as herbivorous on

the spot. However, their mercury concentrations appear quite high (0.11 and 0.08 µg g^{-1} respectively), regarding their size (13 and 16 cm; 22 and 40 g). These levels suggest a higher exposure to mercury than that provided by a strict herbivorous feeding.

- The same observation arises for the species “Pa Hian”, of which 2 specimens were captured in the Mekong (LF54, see picture in annex) and the Nam Ou River (LF46). Again, this species was considered as herbivorous, but mercury concentrations grow up to 0.18 and 0.11 µg g^{-1} respectively, the sizes remaining rather small (27 cm - 376 g, 29 cm - 418 g). As for Pa Gnon samples, these levels suggest that these species do not feed only on macrophytes and algae, but also on sediment or maybe invertebrates.

- Conversely, the only specimen of the species “Pa Oad”, which was caught in Mekong (LF32, see picture in appendix 5) and considered as carnivorous, displayed a low mercury concentration (0.04 µg g^{-1}). According to its mouth characteristics, it is possible that this assignment was erroneous.

However, the statistics were not run again. It seems incautious to rely only on this kind of arguments for modifying the database, and assigning the fishes to another feeding category without knowing more. Typically, the knowledge of the scientific names, which would allow to access to information on species ecology, would help a lot in this debate.

6.6.4. Comparison with other studies

The data compiled in illustration 51 were obtained from an extensive literature survey (Babut *et al.*, 2001). As compared to these studies, the fishes captured in the Mekong River and its tributary the Ou River appear less contaminated than in other investigated gold mining areas.

They are also less contaminated than in both UNIDO-sponsored studies in Ghana (Babut, *et al.*, 2001; Babut and Sekyi, 2003). In the 22 studies in Ghana, wet weight concentrations ranged between 0.136 and 1.59 µg g^{-1} in the vicinity of a hard-rock site), and 0.12 – 0.75 µg g^{-1} around an alluvial site.

The lower concentration range noticed in the Lao study suggests a more diffuse contamination of the River, which seems in accordance with the extraction process.

River	***Country***	***Range***	***Species***	***Ref***
Magdalena	Colombia	0.0074 - 1.084	Various	(Olivero et Solano, 1998)
(marshes) Magdalena, Cauca	Colombia	0.022 - 1.236	10 species	(Olivero, Solano *et al.*, 1998)
Lake Victoria	Tanzania	1.8 - 2.4	tilapia	(Ikingura et Akagi, 1996)
		6.9 - 11.7	Nile perch	
		7.8 - 16.9	soga	
		2.2	catfish	
		5.4 - 8.3	furu	
Maroni	France (Guyana)	0.01 – 0.880	44 species	(Fréry, Jouan *et al.*, 1999)
Madeira	Brazil (Amazon)	0.165 – 3.920	50 species	(Malm, 1998)
Madeira		0.060 – 3.960	22 species	
Madeira		0.011 – 0.500	-	
Tapajos		0.025 – 5.960	23 species	
Tapajos		0.046 – 2.200	12 species	
Tapajos		0.132 – 1.354	19 species	
Tapajos		0.120 – 3.580	9 species	
Negro		0.226 – 4.231	18 species	
Tucurui res.		0.200 – 5.900	8 species	
Balbina res.		0.049 – 1.103	6 species	
Tapajos	Brazil	0.190 – 0.650	carnivorous spp	(Castilhos, Bidone *et al.*, 1998)
		0.009 – 0.115	non carn. spp	
Tapajos	Brazil	0.062 – 0.880	carnivorous spp	(Bidone, Castilhos *et al.*, 1997)
		0.009 – 0.137	non carn. spp	
Cuiaba	Brazil (Pantanal)	2.33 - 12.31	8 species	(Alho et Vieira, 1997)
Bento Gomes		2.29 - 13.28		
Paraguay		1.21 - 1.36		

Illustration 51 - Comparison with fish contamination in other gold mining areas (in µg g^{-1} Hg, ww).

6.6.5. Toxicological implications

The average dry to wet weight ratio for muscle samples was 0.20 µg g^{-1} Hg. On this basis, the safety level is 2.5 µg g^{-1} Hg (dw) corresponding to the World Health Organization (WHO) standard of 0.5 µg g^{-1} Hg (wet weight, ww) (WHO, 1989). On this basis, only 1 fish displays a contamination level very close to this threshold, without exceeding it (LF33, Pa Kop, a carnivorous fish of 680 g caught around Pak Ou - see appendix 4). A second specimen of the same species (LF38), weighing about 50 % less than LF33, was caught in the same area and displayed a concentration of 0.26 g g^{-1} Hg (ww).

However, this approach remains rather inaccurate; the percentage of water in fish muscle may vary to some extent. Moreover, the analytical result is given with an uncertainty of ± 5 % (see the “Methodology” section). Thus, there is no certainty either that none of the fishes exceeds the safety limit of 0.5 µg g^{-1} Hg (ww).

According to sampling biases already mentioned, it seems therefore very likely that some of the fishes eaten by the villagers along the Mekong, if not the Ou River, are contaminated over the standard of 0.5 µg g^{-1} Hg (ww).

7. Evaluation of exposure to Hg

7.1. RIVER SUB-SYSTEM

As there are little amounts of Hg used at the extraction sites by artisanal miners, the Hg releases to the River appear very limited. This was confirmed by the analysis of sediments near the extraction sites that show contents ranging between 50 to 300 ng g^{-1}. Even if these values show an anthropogenic input, the level of contamination of the riverbed of Mekong and the Ou River cannot be considered as seriously contaminated by the artisanal mining activity in that area. This is particularly true for Mekong where Hg releases may be diluted by the annual flux of sediments.

The concentration of Hg in the seaweed is strongly depending on the Hg concentration in the sediments and in water and of the bioconcentration factor. There are few references dealing with aquatic plants, but it seems that the measured concentrations (0.1 to 0.7 µg g^{-1}) are above ubiquitous levels in such kind of plants (< 0.1 µg g^{-1}). Thus, seaweed contamination is contributing to fish exposure, including herbivorous fishes which are generally considered as accumulating less mercury than carnivorous species. There are nevertheless not enough data for assessing accurately fish exposure to water-borne or algae-borne mercury.

The Hg contents in fishes show a common feature with a higher Hg level in carnivorous fishes than in herbivorous. The average contents measured in Mekong River are respectively of 0.05 and 0.16, with only one fish reaching the WHO safety limit of 0.5 µg g^{-1}.

These elements show that the River sub-system does not appear as a pristine natural ecosystem. There is clearly an anthropogenic impact, which appears moderate. It is not demonstrated whether the local artisanal mining activity is the main cause of impairment of the studied River ecosystems quality or not. This is particularly showed by the distribution of Hg contents in sediments. The level of Hg contamination is probably also related to other sources (industry, mines, ?) located upstream of the studied area.

7.2. THE VILLAGE SUB-SYSTEM

As described in the section on mining practices (see 4.2.2), the main risk of exposure to mercury occurs in the villages as it is mostly manipulated at home by artisanal miners without specific precaution. This risk is increased because the exposed population is mostly composed by women and their young children (see Part B: Health Assessment).

The probability of occurrence of exposure to mercury is summarised in the illustration 52:

	Village sub-system	Probability of occurrence	Comments
SOURCES	- Accidental Hg spill	**	
	- Amalgam roasting in the kitchen	***	
TRANSFER & PATHWAYS	- Household dust contamination	***	
	- Hg vapor dissemination contaminating the house and its environment	***	
	- Soil contamination in the vicinity of contaminated houses	*	
TARGETS	Humans:		
	- Hg inhalation during roasting	**	- Main situation of Hg inhalation
	- Domestic dust and soil ingestion (mostly children)	***	
	- Fish consumption	* ?	- Needs further control
	- Seaweed consumption	** ?	- Needs further control
	- *Contaminated poultry consumption*[1]	?	- Possible contamination of poultry?
	- *Contaminated pork consumption*[1]	?	
	- *Drinking water*[1]	no	- Unprobable as drinking is from wells
	- *Vegetable consumption*	no	- Unprobable as no contamination of fields

Illustration 52 - Probability of occurrence to Hg exposur. ([1] not considered in that study).

Inhalation

In that case inhalation concerns only volatilised Hg°. The monitoring of air quality showed that Hg concentrations may reach relatively elevated concentrations. However amalgam roasting seems to be an occasional procedure occurring on a weekly or even monthly basis (Earth Systems Lao, 2003). 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 20 mn during the amalgam roasting. However as roasting is performed mostly by women and at home, we should also consider the possible exposure of children and use air quality standards for non professional exposure.

Chronic inhalation of Hg enriched atmosphere may also appear in some cases as walls and floors of houses are contaminated and if people sleep close to the floor.

Oral exposition

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

We noticed that houses of artisanal miners are contaminated due the procedure of amalgam roasting on the fireplace of the kitchen. Thus walls, roofs and domestic dust are contaminated in the home 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 335,000 ng g^{-1}) and is dispersed both in the kitchen and living rooms. We estimate that it constitutes the main risk of exposure for the population, and particularly children. Dust ingestion (soil+domestic dust) is 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.

We did not find in the literature similar situations of exposure reported with dust ingestion. There is no existing guideline value for mercury for soil and dust ingestion.

The soils of main square of the village and school playground are not contaminated. Soils around the houses of artisanal miners show moderate levels of contamination (100-300 ng g^{-1}). Such concentrations are relatively low compared to threshold values for soils in residential areas (7000 to 10,000 ng g^{-1} in Europe). Thus there is no apparent risk related to soil ingestion.

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 export poultry meat.

Vegetable gardens and rice fields are usually located in remote places and thus are preserved from the source of emissions.

The other risk of exposure, on a minor level, is related to the consumption of fishes and seaweed. It was shown that fishes are usually below the WHO safety limit of 0.5 µg g^{-1} (ww) and only one fish showed an Hg concentration close to that limit. So fish consumption may not constitute a major risk in that area. However regular consumption of fishes may increase the daily intake of mercury to the population exposed to mercury through their mining activity. The limited number of fishes analysed in that study do not allow to conclude on the contamination of fishes with regard to the sanitation guidelines.

Seaweeds seem to be one of the main consumed vegetable, at least during the dry season. They show concentrations ranging from 0.1 to 0.8 µg g^{-1} (dw) which corresponds to concentrations of about 0.01 to 0.08 µg g^{-1} of wet weight. This kind of concentration is above ubiquitous concentrations for aquatic plants. In term of risk assessment, it seems that the contribution of the seaweed consumption cannot be avoided in the evaluation of the daily intake of mercury. There is no published guideline value for that type of food in the US or in Europe. This point should be checked in a further step as there are not enough samples of seaweed to draw up conclusions.

We must point out that this study on seaweed was limited to a small number of samples (7) and only in Mekong. The speciation of Hg in these plants should be checked to evaluate their potential toxicity. As for fishes, regular consumption of seaweed may increase the daily intake of mercury to the population exposed to mercury through their mining activity.

		Mean values	Max.	(unit)	Guideline values
River sub-system					
Fishes	Mekong - Herb.	0,25	0,6	µg/g (dw)	0.5 WHO safety limits
	Mekong - Carn.	0,8	2,5		
	Ou river	0,33	0,7		
Sediments	Mekong	40	101	ng/g	700 PEL (US)
	Ou river	75	260		200 (LEL Canada)
					2000 (SEL Canada)
Seaweeds	Mekong	0,3	0,7	µg/g (dw)	background < 0.1
Village sub-system					
Air	Outdoor	1-5		ng/m^3	200 MRL inhalation, WHO, 2000
	indoor	10-20			1000 (NOAEL, WHO, 2000)
	amalgam roast.	90000-100000			25000 / 8h (WHO prof. exposure)
	fire lighting	100-300			
Soil	villages	100-300	1760	ng/g	27 ng/g PNEC (INERIS, 2003)
	ref. background	50	100		
Domestic dust	ref. village	80-350		ng/g	none
	miners village	300-70000			7000 ng/kg/day MRL , WHO, 2000

Illustration 53 - 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, University of Montpellier, CEMAGREF) and Lao teams (Department of Geology and Mines with the collaboration of the Ministry of Agriculture and the Ministry of Health). The sampling campaign and health survey took place from February 29th to March 20th, 2004 at the beginning of the mining season. The aim of this survey was to collect environmental and health data in some selected villages of the Pak Ou and Chomphet districts and to evaluate the potential impacts caused by mercury. The environmental and health assessments were performed simultaneously on 5 villages, north of Luang Prabang, along the Mekong (Houay Gno, Houay Koh, Pak Ou) and the Ou Rivers (Latthahai, Pak Chek). An extra village was selected as a reference (Houay Yen Gnai) located on the Khan River, south east of Luang Prabang.

8.1. MAIN OUTCOMES OF THE ENVIRONMENTAL SURVEY

- Excavation takes place in the vicinity of the village and implies only small groups of 10-20 peoples. 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 in the Mekong River. Along the Ou River, the artisanal mining was practised both by men and women.

- The alluvium excavation and gold recovery processes is a very traditional process. Two types of alluvium processing were identified. Firstly, in villages along the Mekong, gold is relatively fine. At the end of the panning process, mercury is poured in the pan to separate gold and the remaining heavy minerals. The mercury-gold amalgam is then squeezed through a fine cloth, and the excess mercury is collected for re-use. Secondly, in villages along the Ou River, gold is coarser and is separated from residual minerals by blowing. The residual fine gold concentrate remaining after the 'heating and blowing' stage may nevertheless be added to a small volume of mercury.

- The roasting of the amalgams seems to be a task devoted almost exclusively to women and is performed at home on the cooking fireplace. Mercury in most of the cases is usually evaporated without any precaution and not recovered. The size of the amalgams observed during our study ranged from 2 to 6 mm. Depending on the village and gold content of the alluvial sediment, this might be on a weekly or monthly basis. It is estimated that there is an average annual consumption of about 40 to 50 g of mercury per household of artisanal miners.

- The most probable contamination of soils in villages is supposed to be related to atmospheric deposition of mercury during the roasting and of the dissemination of household dust in the vicinity of houses where amalgam roasting is practised. The

contamination of soils is moderate and do not show a strong level of pollution. The background contents (median) in the villages of artisanal miners is about 100 to 200 ng g^{-1}, which is 2 to 3 times more than in the reference village (Houay Yen Gnai). The highest contents in soils (> 500 ng g^{-1}) are observed around the houses of artisanal miners. School yards and the main squares of villages that are relatively away from the potential source of Hg emissions show relatively low Hg contents (15 to 180 ng g^{-1}).

- It was demonstrated in that case that in-house amalgam roasting may significantly contaminate the dust of the buildings. Domestic dust shows significant mercury contamination in some houses of artisanal miners (400 to 335,000 ng g^{-1}). In Pak Ou and Houay Koh, the strongest contamination is measured in the kitchens, in Latthahai, they are observed in the dust of living rooms. In the reference village (Houay Yen Gnai), domestic dust shows relatively homogeneous contents, ranging from 60 to 460 ng g^{-1}. Contamination of domestic dust may be a long lasting effect as observed in some houses of Pak Ou where amalgam roasting has not been performed for several years. We estimate that it constitutes the main risk of exposure for people, and particularly children. Dust (soil + domestic dust) is relatively important for children (especially in the living conditions of local peoples), and this may cause a potential risk of contamination of the artisanal miners and their families.

- The monitoring of air quality showed that Hg concentrations may reach relatively elevated concentrations. However amalgam roasting seems to be an occasional procedure occurring on a weekly or even monthly basis (Earth Systems Lao, 2003). The exposure of the artisanal miners was relatively short compared to the exposure limits for professional workers (25,000 ng m^{-3} for 8 h exposure). However as roasting is performed mostly by women and at home, 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 attributed to a late release of mercury aerosols that condensed at the roof of the kitchen. After roasting, it takes in a kitchen about 8-15 mn to reach the background level of the atmosphere.

- The Hg concentrations in sediments of both the Ou River and the Mekong are relatively low and do not show important levels of contamination. Mercury contents in sediments range from 6 to 110 ng g^{-1} (dw) in Mekong River sediments, and between 23 to 261 ng g^{-1} (dw) in the Ou River. The mercury concentrations in the Ou River sediments are significantly higher than in Mekong. There is no Hg significant decrease downstream the villages of miners in the Mekong River sediments and it is not proved that the Hg concentration in sediments is related to the local artisanal mining activity.

- The other risk of exposure, on a minor level, is related to the consumption of fishes and seaweed. It was shown that fishes are usually below the WHO safety limit of 0.5 µg g^{-1} (ww) and only one fish showed an Hg concentration close to that limit. The limited number of fishes analysed in that study do not allow to conclude on the

contamination of fishes with regard to sanitation guidelines. The regular consumption of fishes in that area does not seem to constitute a major risk. However it may increase the daily intake of mercury for the people exposed to mercury through their mining activity. The “carnivorous” fishes are significantly more contaminated than the “herbivorous” with mean contents respectively of 0.17 µg g^{-1} and 0.05 µ g g^{-1}. There is no obvious trend in contamination from the sites upstream (B. Houaygno, B. Mouang) to downstream (B. Tinh Hong). Only 1 fish displays a contamination level very close to the WHO standard of 0.5 µg g^{-1}.

- Seaweeds seem to be one of the main consumed vegetable, at least during the dry season. A few seaweed samples (5) were collected and show concentrations ranging from 0.1 to 0.8 µg g^{-1} (dw) which corresponds to concentrations of about 0.01 to 0.08 µg g^{-1} of wet weight. These contents are above background values for aquatic plants and need further confirmation. In term of risk assessment, if these concentrations are confirmed than the seaweed consumption should be taken into account in the evaluation of daily intake of mercury.

8.2. RECOMMANDATIONS

1. 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 River sub-system, the sampling of fishes and seaweed should be extended to evaluate the real level of contamination in the area. The environmental assessment only concerned the environment of artisanal miners. Potential contamination of gold shops in Luang Prabang should also be considered to complete this assessment.

2. Domestic dust is one of the main sources of Hg in that system. We suspect that Hg accumulates during the mining season in the houses of artisanal miners. A regular monitoring of some selected houses should be performed on a monthly basis in order to evaluate the trends of Hg concentration in domestic dust during and after the mining season.

3. As the practice of local artisanal miners is very traditional with a very limited use of mercury, there is no strong need to develop 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. The action should focus on the roasting procedure in order to promote a safer procedure. The main objective being a change of the location to roast the amalgams.

4. Change in local mining practices would require a raising awareness campaign with education of women on the risks they face themselves and their family. According to our field observations and the sociological survey, roasting the amalgam seems to be a private activity, almost confidential. That is why it is performed at home on the cooking fireplace. Some work in collaboration with the local artisanal miners should be carried out around that concept. The objective would be to propose

appropriate spots, distant from the village and dedicated to the roasting. This place should be designed to avoid dispersion of Hg in the environment.

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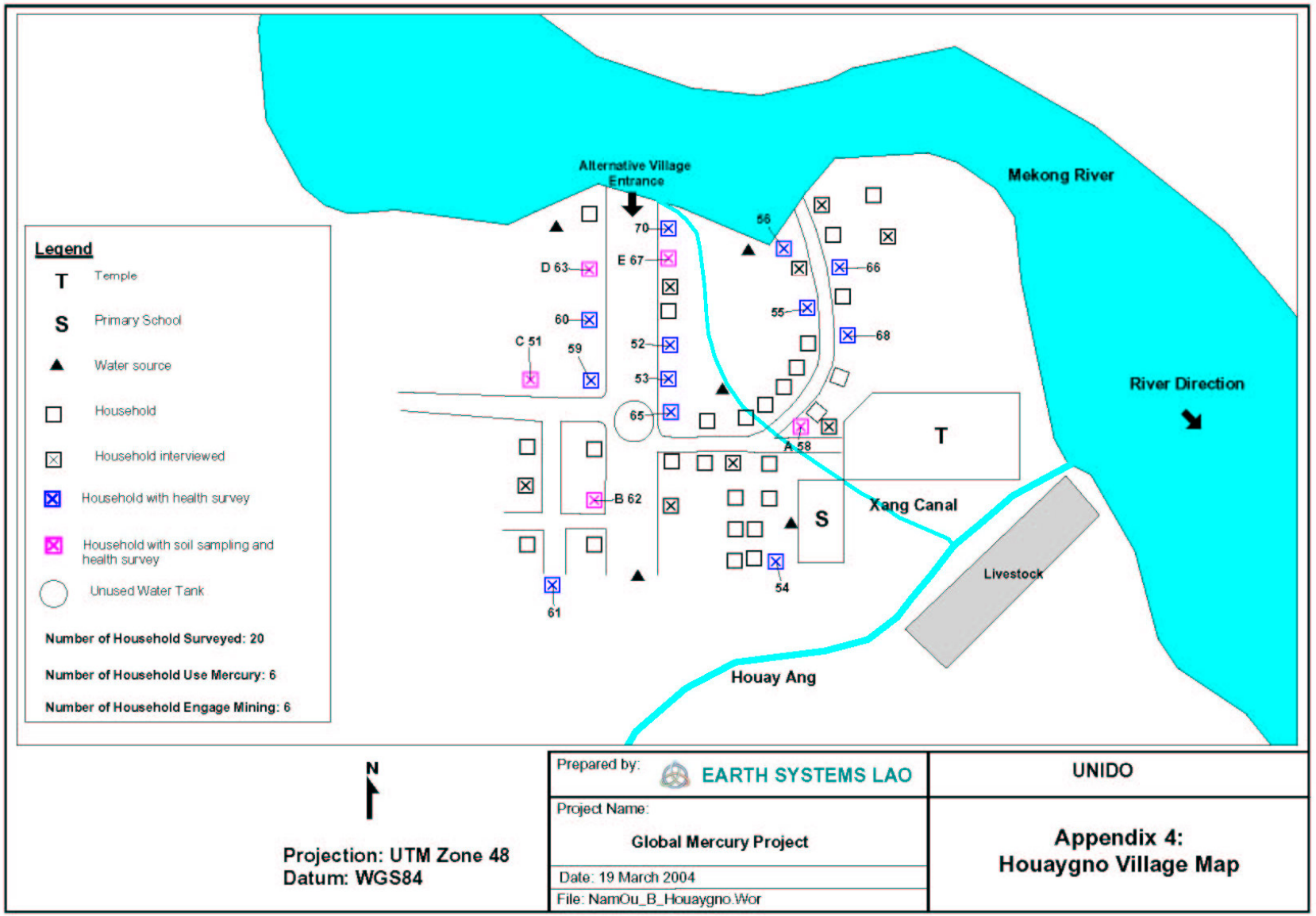
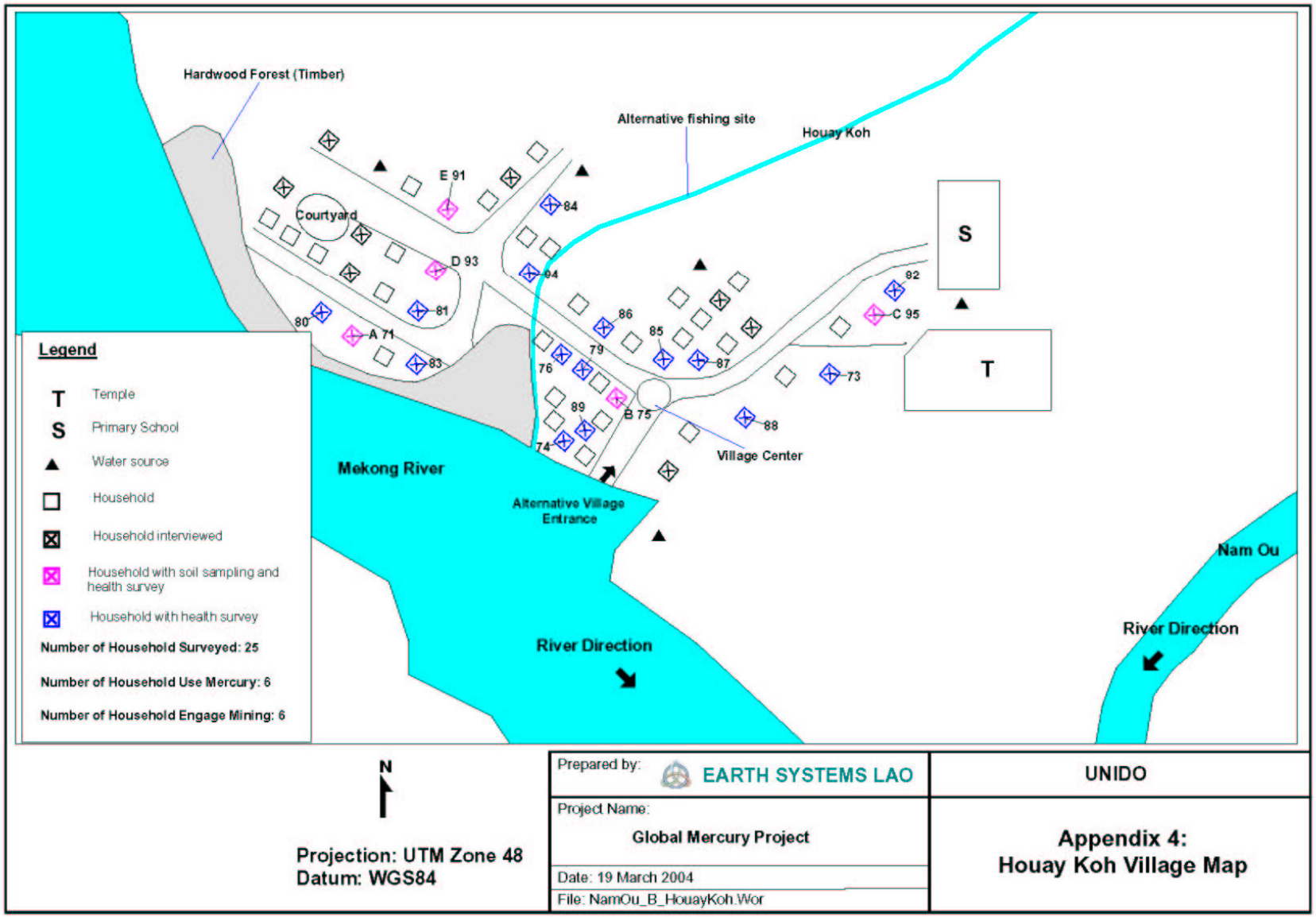
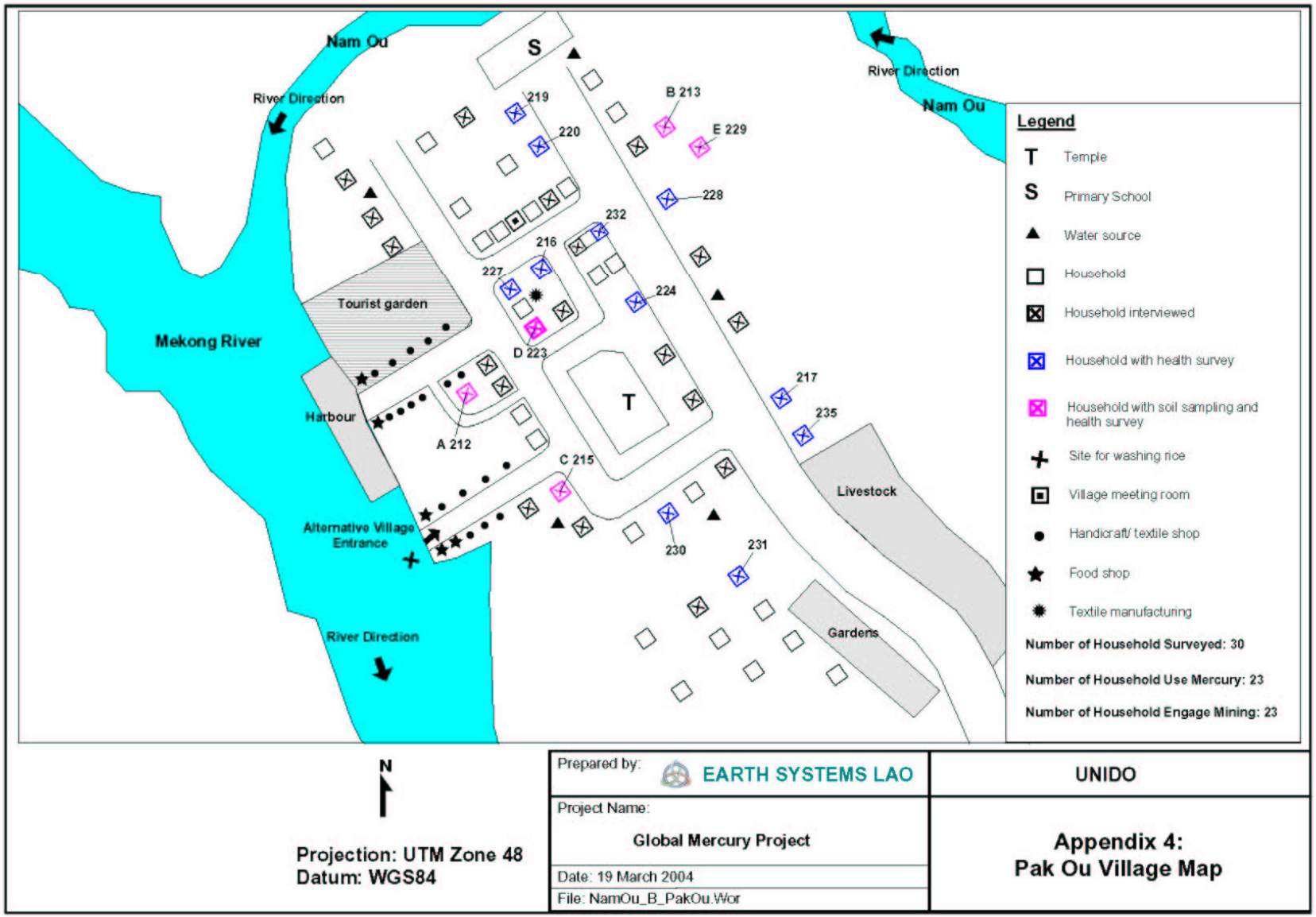
Appendix 1

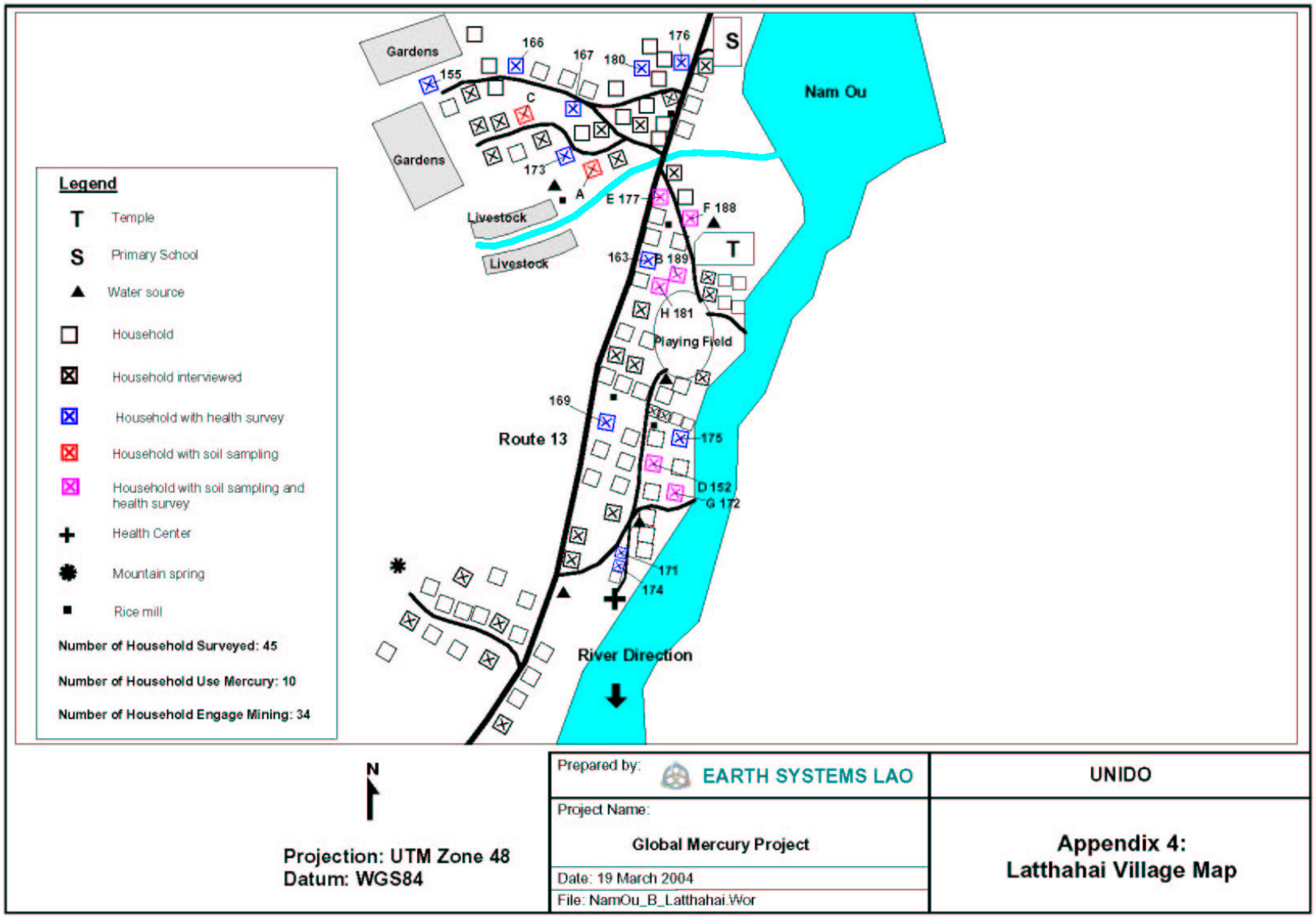
Village maps with location of surveyed households

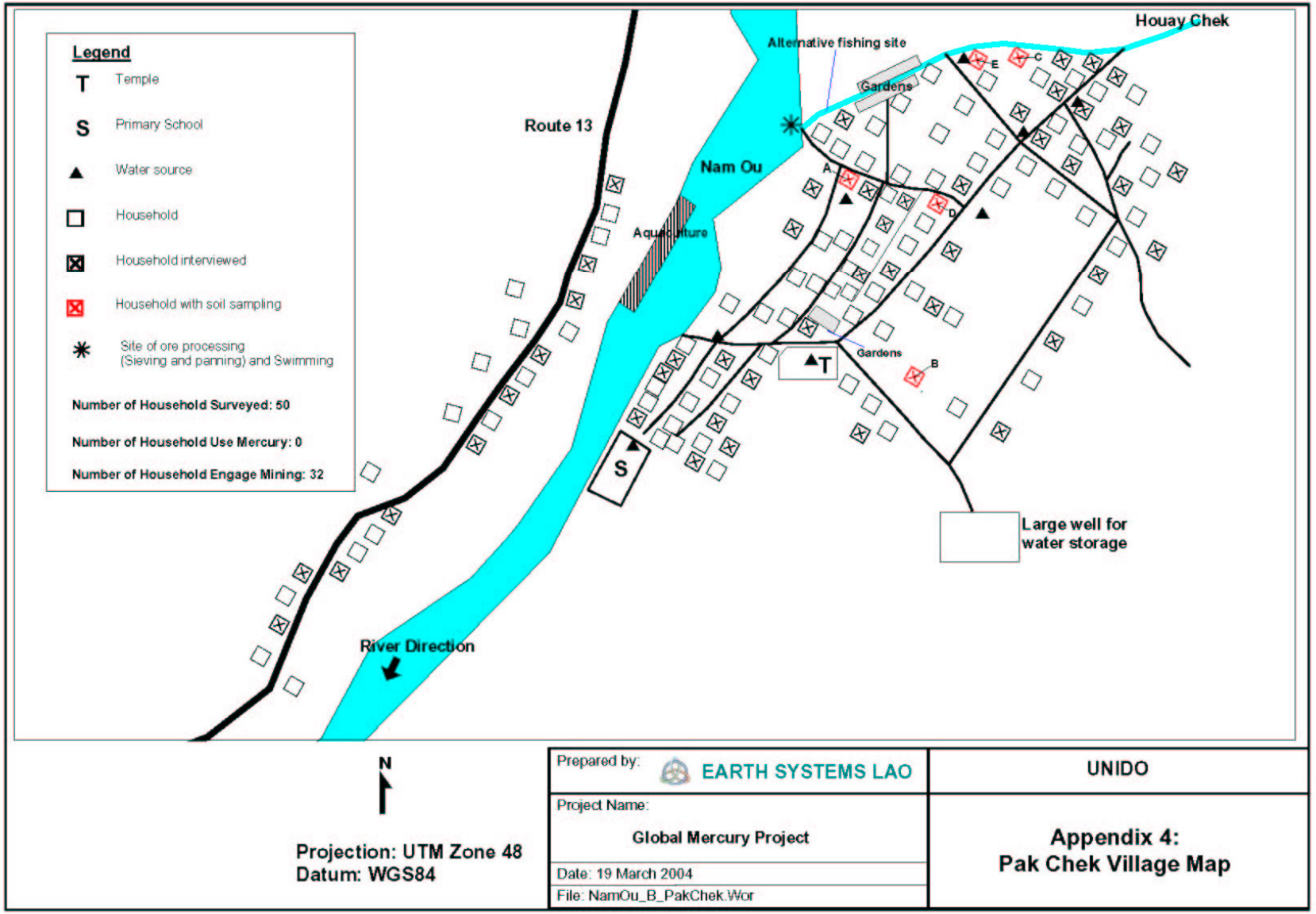
(maps produced by Earth System Lao).

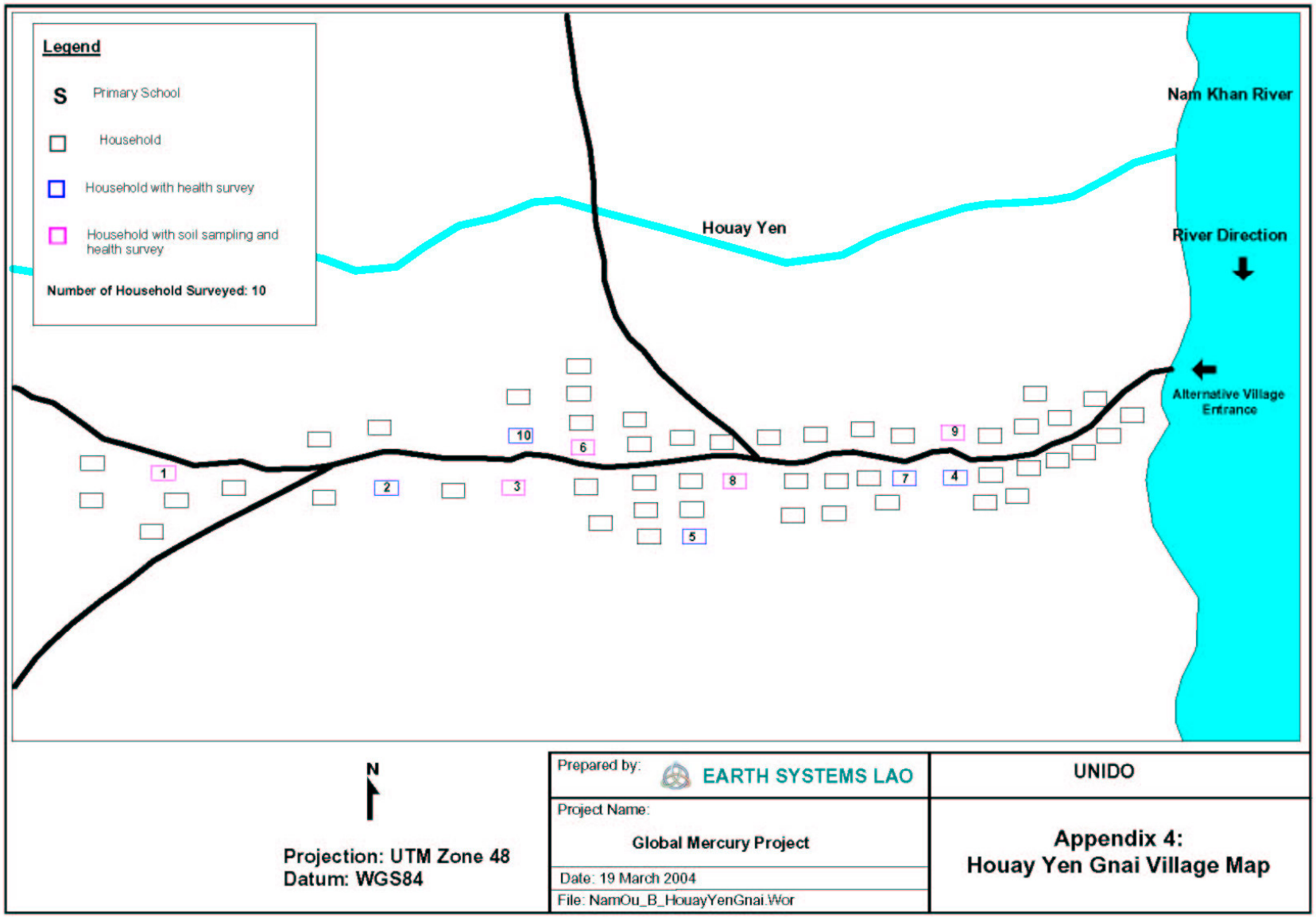

Legend
T Temple
S Primary School
Water source
Household
Household interviewed
Household with health survey
Household with soil sampling and health survey
Unused Water Tank
Number of Household Surveyed: 20
Number of Household Use Mercury: 6
Number of Household Engage Mining: 6
Alternative Village Entrance
Mekong River
River Direction
Xang Canal
Houay Ang
Livestock
T
S
70
E 67
D 63
60
C 51
59
52
53
65
B 62
61
56
66
55
68
A 58
54
N
Projection: UTM Zone 48
Datum: WGS84
Prepared by: EARTH SYSTEMS LAO
Project Name:
Global Mercury Project
Date: 19 March 2004
File: NamOu_B_Houaygno.Wor
UNIDO
Appendix 4:
Houaygno Village Map


Hardwood Forest (Timber)
Alternative fishing site
Houay Koh
Courtyard
E 91
D 93
84
94
81
80
A 71
83
86
85
87
79
76
89
B 75
74
88
92
C 95
73
S
T
Village Center
Mekong River
Alternative Village Entrance
River Direction
Nam Ou
River Direction
Legend
T Temple
S Primary School
Water source
Household
Household interviewed
Household with soil sampling and health survey
Household with health survey
Number of Household Surveyed: 25
Number of Household Use Mercury: 6
Number of Household Engage Mining: 6
N
Projection: UTM Zone 48
Datum: WGS84
Prepared by: EARTH SYSTEMS LAO
UNIDO
Project Name:
Global Mercury Project
Date: 19 March 2004
File: NamOu_B_HouayKoh.Wor
Appendix 4:
Houay Koh Village Map


Nam Ou
River Direction
S
219
220
B 213
E 229
228
232
216
227
224
Tourist garden
Mekong River
D 223
T
217
235
Harbour
A 212
C 215
Livestock
Alternative Village Entrance
230
231
River Direction
Gardens
River Direction
Nam Ou
Legend
T Temple
S Primary School
Water source
Household
Household interviewed
Household with health survey
Household with soil sampling and health survey
Site for washing rice
Village meeting room
Handicraft/ textile shop
Food shop
Textile manufacturing
Number of Household Surveyed: 30
Number of Household Use Mercury: 23
Number of Household Engage Mining: 23
N
Projection: UTM Zone 48
Datum: WGS84
Prepared by:
EARTH SYSTEMS LAO
UNIDO
Project Name:
Global Mercury Project
Date: 19 March 2004
File: NamOu_B_PakOu.Wor
Appendix 4:
Pak Ou Village Map


Gardens
Gardens
Livestock
Livestock
Nam Ou
Route 13
Playing Field
River Direction
166
167
180
176
155
C
173
A
E 177
F 188
163
B 189
H 181
169
175
D 152
G 172
171
174
S
T
Legend
T Temple
S Primary School
Water source
Household
Household interviewed
Household with health survey
Household with soil sampling
Household with soil sampling and health survey
Health Center
Mountain spring
Rice mill
Number of Household Surveyed: 45
Number of Household Use Mercury: 10
Number of Household Engage Mining: 34
N
Projection: UTM Zone 48
Datum: WGS84
Prepared by:
EARTH SYSTEMS LAO
UNIDO
Project Name:
Global Mercury Project
Date: 19 March 2004
File: NamOu_B_Latthahai.Wor
Appendix 4:
Latthahai Village Map


Legend
T Temple
S Primary School
Water source
Household
Household interviewed
Household with soil sampling
Site of ore processing (Sieving and panning) and Swimming
Number of Household Surveyed: 50
Number of Household Use Mercury: 0
Number of Household Engage Mining: 32
Houay Chek
Alternative fishing site
Route 13
Nam Ou
Gardens
Aquaculture
Gardens
Large well for water storage
River Direction
N
Projection: UTM Zone 48
Datum: WGS84
Prepared by: EARTH SYSTEMS LAO
UNIDO
Project Name:
Global Mercury Project
Date: 19 March 2004
File: NamOu_B_PakChek.Wor
Appendix 4:
Pak Chek Village Map


Legend
S Primary School
Household
Household with health survey
Household with soil sampling and health survey
Number of Household Surveyed: 10
Nam Khan River
Houay Yen
River Direction
Alternative Village Entrance
1
2
3
10
6
8
5
7
4
9
N
Projection: UTM Zone 48
Datum: WGS84
Prepared by:
EARTH SYSTEMS LAO
UNIDO
Project Name:
Global Mercury Project
Date: 19 March 2004
File: NamOu_B_HouayYenGnai.Wor
Appendix 4:
Houay Yen Gnai Village Map

Appendix 2

Hg analysis for soil, dust in the villages

Soil samples

Description	Village	Sample	[Hg] (ng/g)			[Hg] (ng g^{-1})	SD (ng g^{-1})	RSD (%)
			assay1	assay2	assay3	average		
House A / east : reference (never mine)	**Houay Koh**	LSO 13E	100	108		104	6	5.4
House A / north : reference (never mine)	**Houay Koh**	LSO 13N	123			123		
House A / south : reference (never mine)	**Houay Koh**	LSO 13S	99			99		
House A / west : reference (never mine)	**Houay Koh**	LSO 13W	146			146		
House B / east : continue to mine	**Houay Koh**	LSO 8E	359			359		
House B / north : continue to mine	**Houay Koh**	LSO 8N	62			62		
House B / south : continue to mine	**Houay Koh**	LSO 8S	548	539		544	6	1.2
House B / west : continue to mine	**Houay Koh**	LSO 8W	165			165		
House C / east : continue to mine	**Houay Koh**	LSO 9E	64			64		
House C / north : continue to mine	**Houay Koh**	LSO 9N	248	253	244	248	5	1.8
House C / south : continue to mine	**Houay Koh**	LSO 9S	55			55		
House C / west : continue to mine	**Houay Koh**	LSO 9W	51	49		50	1	2.8
House D / east : continue to mine	**Houay Koh**	LSO 12E	209	220		215	8	3.6
House D / north : continue to mine	**Houay Koh**	LSO 12N	162			162		
House D / south : continue to mine	**Houay Koh**	LSO 12S	106			106		
House D / west : continue to mine	**Houay Koh**	LSO 12W	85			85		
House E / east : continue to mine	**Houay Koh**	LSO 11E	94			94		
House E / north : continue to mine	**Houay Koh**	LSO 11N	344			344		
House E / south : continue to mine	**Houay Koh**	LSO 11S	71	67	74	71	4	5.0
House E / west : continue to mine	**Houay Koh**	LSO 11W	128			128		
main square	**Houay Koh**	LSO 10	15	13	18	15	3	16.4
school playground	**Houay Koh**	LSO 14	54			54		

Description	Village	Sample	[Hg] (ng/g)			[Hg] (ng g^{-1})	SD (ng g^{-1})	RSD (%)
			assay1	assay2	assay3	average		
House A / est : reference (never mine)	**Houay yen gnai**	LSO 40E	25			25		
House A / north : reference (never mine)	**Houay yen gnai**	LSO 40N	26			26		
House A / south : reference (never mine)	**Houay yen gnai**	LSO 40S	39	42		41	2	5.2
House A / west : reference (never mine)	**Houay yen gnai**	LSO 40W	41			41		
House B / est : reference (never mine)	**Houay yen gnai**	LSO 41E	37			37		
House B / north : reference (never mine)	**Houay yen gnai**	LSO 41N	41	42		42	1	1.7
House B / south : reference (never mine)	**Houay yen gnai**	LSO 41S	40			40		
House B / west : reference (never mine)	**Houay yen gnai**	LSO 41W	54	60	61	58	4	6.5
House C / est : reference (never mine)	**Houay yen gnai**	LSO 42E	47	46		47	1	1.5
House C / north : reference (never mine)	**Houay yen gnai**	LSO 42N	56			56		
House C / south : reference (never mine)	**Houay yen gnai**	LSO 42S	48			48		
House C / west : reference (never mine)	**Houay yen gnai**	LSO 42W	45			45		
House D / est : reference (never mine)	**Houay yen gnai**	LSO 43E	74			74		
House D / north : reference (never mine)	**Houay yen gnai**	LSO 43N	53			53		
House D / south : reference (never mine)	**Houay yen gnai**	LSO 43S	67	63		65	3	4.4
House D / west : reference (never mine)	**Houay yen gnai**	LSO 43W	70			70		
House E / east : reference (never mine)	**Houay yen gnai**	LSO 44E	132			132		
House E / north : reference (never mine)	**Houay yen gnai**	LSO 44N	57	55	51	54	3	5.6
House E / south : reference (never mine)	**Houay yen gnai**	LSO 44S	85			85		
House E / west : reference (never mine)	**Houay yen gnai**	LSO 44W	86	85		86	1	0.8
school playground	**Houay yen gnai**	LSO 45	86			86		

Description	Village	Sample	[Hg] (ng/g)			[Hg] (ng g^{-1})	SD (ng g^{-1})	RSD (%)
			assay1	assay2	assay3	average		
House A / east : reference (never mine)	**Houaygno**	LSO 2E	88			88		
House A / north : reference (never mine)	**Houaygno**	LSO 2N	98	96		97	1	1.5
House A / west : reference (never mine)	**Houaygno**	LSO 2W	55			55		
House B / east : mined in the past	**Houaygno**	LSO 3E	73			73		
House B / north : mined in the past	**Houaygno**	LSO 3N	92	109		101	12	12.0
House B / south : mined in the past	**Houaygno**	LSO 3S	43			43		
House B / west : mined in the past	**Houaygno**	LSO 3W	105	84	93	94	11	11.2
House C / east : continue to mine	**Houaygno**	LSO 4E	51	61		56	7	12.6
House C / north : continue to mine	**Houaygno**	LSO 4N	125			125		
House C / south : continue to mine	**Houaygno**	LSO 4S	131			131		
House C / west : continue to mine	**Houaygno**	LSO 4W	402			402		
House D / east : mined in the past	**Houaygno**	LSO 6E	104			104		
House D / north : mined in the past	**Houaygno**	LSO 6N	92			92		
House D / south : mined in the past	**Houaygno**	LSO 6S	115	121		118	4	3.6
House D / west : mined in the past	**Houaygno**	LSO 6W	199			199		
House E / east : continue to mine	**Houaygno**	LSO 7E	62			62		
House E / north : continue to mine	**Houaygno**	LSO 7N	174	192	197	188	12	6.4
House E / south : continue to mine	**Houaygno**	LSO 7S	166			166		
House E / west : continue to mine	**Houaygno**	LSO 7W	126	115		121	8	6.5
main square	**Houaygno**	LSO 01	54			54		
school playground	**Houaygno**	LSO 05	81			81		

Description	Village	Sample	[Hg] (ng/g)			[Hg] (ng g^{-1})	SD (ng g^{-1})	RSD (%)
			assay1	assay2	assay3	average		
House A / east : reference (never mine)	**Latthahai**	LSO 15E	70	76	88	78	9	11.8
House A / north : reference (never mine)	**Latthahai**	LSO 15N	51			51		
House A / south : reference (never mine)	**Latthahai**	LSO 15S	267			267		
House A / west : reference (never mine)	**Latthahai**	LSO 15W	56			56		
House B / east : reference (do not use Hg)	**Latthahai**	LSO 19E	358			358		
House B / north : reference (do not use Hg)	**Latthahai**	LSO 19N	188	167		178	15	8.4
House B / south : reference (do not use Hg)	**Latthahai**	LSO 19S	206			206		
House B / west : reference (do not use Hg)	**Latthahai**	LSO 19W	150	131		141	13	9.6
House C / east : continue to mine	**Latthahai**	LSO 16E	1760	1910	1620	1763	145	8.2
House C / north : continue to mine	**Latthahai**	LSO 16N	963			963		
House C / south : continue to mine	**Latthahai**	LSO 16S	471			471		
House C / west : continue to mine	**Latthahai**	LSO 16W	103			103		
House D / east : continue to mine	**Latthahai**	LSO 21E	484			484		
House D / north : continue to mine	**Latthahai**	LSO 21N	138			138		
House D / south : continue to mine	**Latthahai**	LSO 21S	521	481		501	28	5.6
House D / west : continue to mine	**Latthahai**	LSO 21W	845			845		
House E / east : continue to mine	**Latthahai**	LSO 24E	44			44		
House E / north : continue to mine	**Latthahai**	LSO 24N	344			344		
House E / south : continue to mine	**Latthahai**	LSO 24S	107	101		104	4	4.1
House E / west : continue to mine	**Latthahai**	LSO 24W	17			17		
House F / east : continue to mine	**Latthahai**	LSO 17E	74			74		
House F / north : continue to mine	**Latthahai**	LSO 17N	61	63		62	1	2.3
House F / south : continue to mine	**Latthahai**	LSO 17S	53			53		
House F / west : continue to mine	**Latthahai**	LSO 17W	68	71	69	69	2	2.2
House G / east : continue to mine	**Latthahai**	LSO 22E	360	400		380	28	7.4

Description	Village	Sample	[Hg] (ng/g)			[Hg] (ng g^{-1})	SD (ng g^{-1})	RSD (%)
			assay1	assay2	assay3	average		
House G / north : continue to mine	**Latthahai**	LSO 22N	154			154		
House G / south : continue to mine	**Latthahai**	LSO 22S	1700			1700		
House G / west : continue to mine	**Latthahai**	LSO 22W	433			433		
House H / east : continue to mine	**Latthahai**	LSO 20E	722			722		
House H / north : continue to mine	**Latthahai**	LSO 20N	151			151		
House H / south : continue to mine	**Latthahai**	LSO 20S	105	117		111	8	7.6
House H / west : continue to mine	**Latthahai**	LSO 20W	266	272	244	261	15	5.7
main square	**Latthahai**	LSO 23	201			201		
school playground	**Latthahai**	LSO 25	158	157		158	1	0.4
garden	**Latthahai**	LSO 18	138			138		

Description	Village	Sample	[Hg] (ng/g)			[Hg] (ng g^{-1})	SD (ng g^{-1})	RSD (%)
			assay1	assay2	assay3	average		
House A / north : reference (never mine)	**Pak Chek**	LSO 33N	250	261	~	**188**		
House A / oueast : reference (never mine)	**Pak Chek**	LSO 33E	233	~	~	**233**		
House A / south : reference (never mine)	**Pak Chek**	LSO 33S	283	~	~	**283**		
House A : kitchen + living room (one room)	**Pak Chek**	LSO 33W	238	196	~	**217**		
House D / east : continue to mine	**Pak Chek**	LSO 34E	35	~	~	**35**		
House D / north : continue to mine	**Pak Chek**	LSO 34N	91	62	~	**77**		
House D / south : continue to mine	**Pak Chek**	LSO 34S	361	~	~	**361**		
House D / west : continue to mine	**Pak Chek**	LSO 34W	347	308	271	**309**		
House E / east : continue to mine	**Pak Chek**	LSO 35 E	206	207	~	**207**		
House E / north : continue to mine	**Pak Chek**	LSO 35N	253	~	~	**253**		
House E / south : continue to mine	**Pak Chek**	LSO 35S	54	~	~	**54**		
House E / west : continue to mine	**Pak Chek**	LSO 35W	145	~	~	**145**		
House C / east : continue to mine	**Pak Chek**	LSO 36E	202	~	~	**202**		
House C / north : continue to mine	**Pak Chek**	LSO 36N	266	~	~	**266**		
House C / south : continue to mine	**Pak Chek**	LSO 36S	74	88	~	**81**		
House C / west : continue to mine	**Pak Chek**	LSO 36W	835	~	~	**835**		
House B / east : continue to mine	**Pak Chek**	LSO 37E	73	95	84	**84**		
House B / north : continue to mine	**Pak Chek**	LSO 37N	88	~	~	**88**		
House B / south : continue to mine	**Pak Chek**	LSO 37S	109	~	~	**109**		
House B / west : continue to mine	**Pak Chek**	LSO 37W	313	~	~	**313**		
school playground	**Pak Chek**	LSO 38	188	~	~	**188**		
main square	**Pak Chek**	LSO 39	74	~	~	**74**		

Description	Village	Sample	[Hg] (ng/g)			[Hg] (ng g^{-1})	SD (ng g^{-1})	RSD (%)
			assay1	assay2	assay3	average		
House A / east : reference (never mine)	**Pak Ou**	LSO 26E	121			121		
House A / north : reference (never mine)	**Pak Ou**	LSO 26N	145	138		142	5	3.5
House A / south : reference (never mine)	**Pak Ou**	LSO 26S	122			122		
House A / west : reference (never mine)	**Pak Ou**	LSO 26W	108	103	106	106	3	2.4
House B / east : mined in the past	**Pak Ou**	LSO 30E	466	442		454	17	3.7
House B / north : mined in the past	**Pak Ou**	LSO 30N	100			100		
House B / south : mined in the past	**Pak Ou**	LSO 30S	169			169		
House B / west : mined in the past	**Pak Ou**	LSO 30W	304			304		
House C / east : mined in the past	**Pak Ou**	LSO 28E	389			389		
House C / north : mined in the past	**Pak Ou**	LSO 28N	360			360		
House C / south : mined in the past	**Pak Ou**	LSO 28S	50	55		53	4	6.7
House C / west : mined in the past	**Pak Ou**	LSO 28W	123			123		
House D / east : mined in the past	**Pak Ou**	LSO 27E	304			304		
House D / north : mined in the past	**Pak Ou**	LSO 27N	216	192	174	194	21	10.9
House D / south : mined in the past	**Pak Ou**	LSO 27S	106			106		
House D / west : mined in the past	**Pak Ou**	LSO 27W	446	512		479	47	9.7
House E / east : mined in the past	**Pak Ou**	LSO 29E	76	74		75	1	1.9
House E / north : mined in the past	**Pak Ou**	LSO 29N	410			410		
House E / south : mined in the past	**Pak Ou**	LSO 29S	98			98		
House E / west : mined in the past	**Pak Ou**	LSO 29W	196			196		
main square	**Pak Ou**	LSO 32	327			327		
school playground	**Pak Ou**	LSO 31	32			32		

Domestic dust

Description	Room	Village	Sample	Samples grounded except LDU sieved at 500 µm					
				[Hg] (ng g^{-1})			[Hg] (ng g^{-1})	SD (ng g^{-1})	RSD (%)
				assay1	assay2	assay3	average		
House A : kitchen	K	**Houay yen gnai**	LDU 54	61	58	65	61	4	5.7
House B : kitchen	K	**Houay yen gnai**	LDU 55	65	63	70	66	4	5.5
House C : kitchen	K	**Houay yen gnai**	LDU 57	72	88	80	80	8	10.0
House D : kitchen	K	**Houay yen gnai**	LDU 59	111	114	130	118	10	8.6
House E : kitchen	K	**Houay yen gnai**	LDU 61	79	68	85	77	9	11.1
House A : living room	LV	**Houay yen gnai**	LDU 53	443	313	353	370	67	18.0
House B : living room	LV	**Houay yen gnai**	LDU 56	246	248	273	256	15	5.9
House C : living room	LV	**Houay yen gnai**	LDU 58	192	199	182	191	9	4.5
House D : living room	LV	**Houay yen gnai**	LDU 60	439	492	455	462	27	5.9
House E : living room	LV	**Houay yen gnai**	LDU 62	434	374	481	430	54	12.5
House A : kitchen	K	**Pak Ou**	LDU 33	165	156	142	154	12	7.5
House B : kitchen	K	**Pak Ou**	LDU 41	21500	26700	25000	24400	2651	10.9
House C : kitchen	K	**Pak Ou**	LDU 37	564	540	512	539	26	4.8
House D : kitchen	K	**Pak Ou**	LDU 35	308	262	303	291	25	8.7
House E : kitchen	K	**Pak Ou**	LDU 39	113000	110000	116000	113000	3000	2.7
House A : living room	LV	**Pak Ou**	LDU 34	87	87	118	97	18	18.4
House B : living room	LV	**Pak Ou**	LDU 42	910	932	855	899	40	4.4
House C : living room	LV	**Pak Ou**	LDU 38	3270	3190	3690	3383	269	7.9
House D : living room	LV	**Pak Ou**	LDU 36	550	513	496	520	28	5.3
House E : living room	LV	**Pak Ou**	LDU 40	667	686	632	662	27	4.1

Description	Room	Village	Sample	Samples grounded except LDU sieved at 500 µm					
				[Hg] (ng g^{-1})			[Hg] (ng g^{-1})	SD (ng g^{-1})	RSD (%)
				assay1	assay2	assay3	average		
House A : kitchen (north)	K	**Houay Koh**	LDU 17	1290	1290	1180	1253	64	5.1
House B : kitchen	K	**Houay Koh**	LDU 19	3690	3050	3530	3423	333	9.7
House C : kitchen	K	**Houay Koh**	LDU 11	2370	2720	3130	2740	380	13.9
House D : kitchen (south)	K	**Houay Koh**	LDU 15	6230	6300	6700	6410	254	4.0
House E : kitchen (north)	K	**Houay Koh**	LDU 13	342000	354500	310000	335500	22951	6.8
House A : living room	LV	**Houay Koh**	LDU 18	2860	2820	3000	2893	95	3.3
House B : living room	LV	**Houay Koh**	LDU 20	1500	1260	1390	1383	120	8.7
House C : living room	LV	**Houay Koh**	LDU 12	4010	3970	3890	3957	61	1.5
House D : living room	LV	**Houay Koh**	LDU 16	2280	2710	2560	2517	218	8.7
House E : living room	LV	**Houay Koh**	LDU 14	4790	5670	5080	5180	448	8.7
House A : kitchen	K	**Latthahai**	LDU 19	456	387	432	425	35	8.2
House B : kitchen	K	**Latthahai**	LDU 23	753	828	851	811	51	6.3
House D : kitchen	K	**Latthahai**	LDU 27	738	742	765	748	15	1.9
House E : kitchen	K	**Latthahai**	LDU 31	145	120	119	128	15	11.5
House F : kitchen	K	**Latthahai**	LDU 21	897	958	1030	962	67	6.9
House G : kitchen	K	**Latthahai**	LDU 29	654	940	864	819	148	18.1
House H : kitchen	K	**Latthahai**	LDU 25	760	643	537	647	112	17.2
House A : living room	LV	**Latthahai**	LDU 20	1340	1640	1420	1467	155	10.6
House B : living room	LV	**Latthahai**	LDU 24	2150	2340	2110	2200	123	5.6
House D : living room	LV	**Latthahai**	LDU 28	27300	28000	29100	28133	907	3.2
House E : living room	LV	**Latthahai**	LDU 32	308	300	314	307	7	2.3
House F : living room	LV	**Latthahai**	LDU 22	39900	33300	33800	35667	3675	10.3
House G : living room	LV	**Latthahai**	LDU 30	266	313	297	292	24	8.2
House H : living room	LV	**Latthahai**	LDU 26	21800	19500	16581	19294	2616	13.6

Description	Room	Village	Sample	Samples grounded except LDU sieved at 500 µm					
				[Hg] (ng g^{-1})			[Hg] (ng g^{-1})	SD (ng g^{-1})	RSD (%)
				assay1	assay2	assay3	average		
House B : kitchen	K	**Houaygno**	LDU 05	615	556	560	577	33	5.7
House C : kitchen	K	**Houaygno**	LDU 07	63	77	71	70	7	10.0
House D : kitchen	K	**Houaygno**	LDU 09	354	308	279	314	38	12.1
House B : living room	LV	**Houaygno**	LDU 06	447	483	522	484	38	7.7
House C : living room	LV	**Houaygno**	LDU 08	154	186	148	163	20	12.6
House D : living room	LV	**Houaygno**	LDU 10	204	351	253	269	75	27.8
House A : kitchen + living room	One room	**Houaygno**	LDU 04	367	246	241	285	71	25.1
House A : kitchen	K	**Pak Chek**	LDU 43	183	200	176	186	12	6.6
House B : kitchen	K	**Pak Chek**	LDU 51	128	138	129	132	6	4.2
House C : kitchen	K	**Pak Chek**	LDU 49	145	96	105	115	26	22.6
House D : kitchen	K	**Pak Chek**	LDU 45	148	162	150	153	8	4.9
House E : kitchen	K	**Pak Chek**	LDU 47	135	164	150	150	15	9.7
House A : living room	LV	**Pak Chek**	LDU 44	306	327	340	324	17	5.3
House B : living room	LV	**Pak Chek**	LDU 52	195	153	156	168	23	13.9
House C : living room	LV	**Pak Chek**	LDU 50	76	63	54	64	11	17.2
House D : living room	LV	**Pak Chek**	LDU 46	399	387	366	384	17	4.3
House E : living room	LV	**Pak Chek**	LDU 48	244	270	289	268	23	8.4

Appendix 3

Hg analysis in sediments

Sample	River	Type	Measurements			[Hg] (ng g^{-1})	SD	RSD (%)	Comments
LSE 01	Mekong		12	16	~	**14**	3	20.2	
LSE 02	Mekong		16	~	~	**16**	~	~	
LSE 03	Mekong		19	~	~	**19**	~	~	
LSE 04	Mekong		11	10	11	**11**	1	5.4	
LSE 05	Mekong		6	~	~	**6**	~	~	
LSE 06	Mekong		41	~	~	**41**	~	~	
LSE 07	Mekong		19	24	~	**22**	4	16.4	
LSE 08	Mekong		79	~	~	**79**	~	~	
LSE 09	Mekong		102	~	~	**102**	~	~	
LSE 10	Mekong		52	56	~	**54**	3	5.2	
LSE 11	Mekong		11	~	~	**11**	~	~	
LSE 12	Mekong		43	~	~	**43**	~	~	
LSE 13	Mekong		11	10	11	**11**	1	5.4	
LSE 14	Mekong		78	~	~	**78**	~	~	
LSE 15	"soil"		110	~	~	**110**	~	~	Ban Houaygno
LSE 16	Nam Ou		49	~	~	**49**	~	~	
LSE 17	Nam Ou		96	100	~	**98**	3	2.9	
LSE 18	Nam Ou		27	~	~	**27**	~	~	
LSE 19	Nam Ou		37	~	~	**37**	~	~	
LSE 20	Nam Ou		70	62	77	**70**	8	10.8	
LSE 21	Nam Ou		72	~	~	**72**	~	~	
LSE 22	Nam Ou		26	~	~	**26**	~	~	
LSE 23	Mekong		20	19	~	**20**	1	3.6	bank (alluvium)
LSE 24	Mekong		48	51	49	**49**	2	3.1	panning place
LSE 25	Mekong		10	~	~	**10**	~	~	
LSE 26	Mekong		14	~	~	**14**	~	~	
LSE 27	Mekong		41	44	~	**43**	2	5.0	
LSE 28	Mekong		74	~	~	**74**	~	~	

Sample	River	Type	Measurements			[Hg] (ng g^{-1})	SD	RSD (%)	Comments
LSE 29	Mekong		89	~	~	**89**	~	~	
LSE 30	Mekong		39	39	~	**39**	0	0.0	
LSE 31	Mekong		69	~	~	**69**	~	~	
LSE 32	Mekong		44	~	~	**44**	~	~	
LSE 33	Mekong		80	73	89	**81**	8	9.9	
LSE 34	Mekong		62	~	~	**62**	~	~	
LSE 35	Mekong		62	~	~	**62**	~	~	
LSE 36	Mekong		15	~	~	**15**	~	~	
LSE 37	Mekong		68	79	~	**74**	8	10.6	
LSE 38	Mekong		70	~	~	**70**	~	~	
LSE 39	Mekong		50	~	~	**50**	~	~	
LSE 40	Mekong		72	74	75	**74**	2	2.1	
LSE 41	Mekong		56	~	~	**56**	~	~	
LSE 42	Mekong		24	~	~	**24**	~	~	
LSE 43	Mekong		18	22	~	**20**	3	14.1	
LSE 44	Mekong		15	~	~	**15**	~	~	
LSE 45	Mekong		10	~	~	**10**	~	~	
LSE 46	Mekong		14	17	~	**16**	2	13.7	
LSE 47	Mekong		24	~	~	**24**	~	~	
LSE 48	Mekong		25	~	~	**25**	~	~	
LSE 49	Mekong		61	57	~	**59**	3	4.8	
LSE 50	Mekong		34	~	~	**34**	~	~	
LSE 51	Mekong		72	~	~	**72**	~	~	
LSE 52	Mekong		6	8	7	**7**	1	8.8	
LSE 53	Mekong		59	~	~	**59**	~	~	
LSE 54	Mekong		27	~	~	**27**	~	~	
LSE 55	Mekong		16	20	~	**18**	3	15.7	

Sample	River	Type	Measurements			[Hg] (ng g^{-1})	SD	RSD (%)	Comments
LSE 56	Nam Ou		40	38	~	**39**	1	3.6	
LSE 57	Nam Ou		106	~	~	**106**	~	~	
LSE 58	Nam Ou		39	~	~	**39**	~	~	
LSE 59	Nam Ou		39	37	38	**38**	1	2.6	
LSE 60	Nam Ou		58	~	~	**58**	~	~	
LSE 61	Nam Ou		65	~	~	**65**	~	~	
LSE 62	Nam Ou		92	86	~	**89**	4	4.8	
LSE 63	Nam Ou		43	~	~	**43**	~	~	
LSE 64	Nam Ou		44	~	~	**44**	~	~	
LSE 65	Nam Ou		21	25	~	**23**	3	12.3	
LSE 66	Nam Ou		29	~	~	**29**	~	~	
LSE 67	Nam Ou		269	252	~	**261**	12	4.6	
LSE 68	Nam Ou		99	~	~	**99**	~	~	
LSE 69	Nam Ou		112	~	~	**112**	~	~	
LSE 70	Nam Ou		37	24	~	**31**	9	30.1	
LSE 71	Nam Ou		97	~	~	**97**	~	~	
LSE 72	Nam Ou		95	~	~	**95**	~	~	
LSE 73	Nam Ou		61	54	70	**62**	8	13.0	
LSE 74	Nam Ou		66	~	~	**66**	~	~	
LSE 75	Nam Ou		106	~	~	**106**	~	~	
LSE 76	Nam Ou		63	58	~	**61**	4	5.8	
LSE 77	Nam Ou		50	~	~	**50**	~	~	
LSE 78	Nam Ou		57	~	~	**57**	~	~	
LSE 79	Nam Ou		235	~	~	**235**	~	~	
LSE 80	Nam Ou		92	105	102	**100**	7	6.8	
LSE 81	Nam Ou		63	~	~	**63**	~	~	
LSE 82	Nam Ou		74	~	~	**74**	~	~	
LSE 83	Nam Ou		48	48	~	**48**	0	0.0	

Sample	River	Type	Measurements			[Hg] (ng g^{-1})	SD	RSD (%)	Comments
LSE 84	Nam Ou		108	~	~	**108**	~	~	
LSE 85	Nam Ou		90	~	~	**90**	~	~	
LSE 86	Nam Ou		116	121	~	**119**	4	3.0	
LSE 87	Nam Ou		30	~	~	**30**	~	~	alluvium extraction (bank)
LSE 88	Nam Ou		93	~	~	**93**	~	~	
LSE 89	Mekong		31	~	~	**31**	~	~	
LSE 90	Mekong		14	16	~	**15**	1	9.4	
LSE 91	Mekong		29	~	~	**29**	~	~	
LSE 92	Mekong		82	~	~	**82**	~	~	
LSE 93	Mekong		92	92	86	**90**	3	3.8	
LSE 94	Mekong		12	~	~	**12**	~	~	
LSE 95	Mekong		9	~	~	**9**	~	~	
LSE 96	Mekong		43	42	~	**43**	1	1.7	

Appendix 4

Hg analysis in fish samples

Origin	*Local name*	*diet*	*Ref*	*Length (cm)*	*Weight (g)*	*Hg concentration (µg Hg g^{-1} wet wt)*
Mekong						
Houaygno	Pa Chok	herbivorous	LF22	55	4120	0.058
	Pa Keng	herbivorous	LF24	35	880	0.034
			LF25	27	432	0.029
	Pa Kot	omnivorous?	LF26	24.5	260	0.115
			LF27	22	168	0.179
			LF28	20	126	0.073
	Pa Pia	herbivorous	LF12	49	3670	0.109
	Pa Wa	herbivorous	LF23	63	6360	0.028
Khokham	Pa Pia	herbivorous	LF37	54	4060	0.057
Mouang	Pa Chok	herbivorous	LF35	46	2120	0.061
	Pa Keng	herbivorous	LF3	27	368	0.030
			LF4	27	356	0.027
			LF9	27	406	0.037
			LF10	27.5	380	0.024
			LF11	29.5	546	0.035
	Pa Kop	carnivorous	LF45	38	400	0.220
	Pa Oad	Carnivorous ?	LF32	53	1820	0.038
	Pa Sae	herbivorous	LF1	35	998	0.041
			LF8	28.5	462	0.051
	Pa Wa	herbivorous	LF2	26	408	0.035
Pak Ou	Pa Bou	detritivorous?	LF20	9	16	0.022
	Pa Dang Deng	carnivorous	LF30	45.5	610	0.120
			LF31	42.5	450	0.099
	Pa Gnon	herbivorous	LF52	13	22	0.105
	Pa Hian	Herbivorous or omnivorous	LF54	27	376	0.18
	Pa Keng	herbivorous	LF6	36	1170	0.054
			LF13	28.5	486	0.023
			LF14	27	396	0.024
			LF15	29	498	0.023
			LF29	29	502	0.041
	Pa Kop	carnivorous	LF33	48.5	680	0.489
			LF38	38	340	0.260
	Pa Nai	herbivorous	LF53	6.5	8	0.044
	Pa Pa	herbivorous	LF55	18.5	166	0.027
	Pa Pia	herbivorous	LF39	54	3810	0.057
	Pa Sae	herbivorous	LF7	29	488	0.044
	Pa Sakang	herbivorous	LF17	10.5	36	0.062
			LF18	9	24	0.048
			LF19	11	30	0.055
	Pa Sangoa	carnivorous	LF5	70	3280	0.242
			LF16	25	86	0.107
	Pa Chok	herbivorous	LF36	51	400	0.056
Tinh Hong	Pa Gnon	herbivorous	LF51	16	40	0.083
	Pa Khe	detritivorous?	LF21	15.5	52	0.105
			LF50	20.5	100	0.325

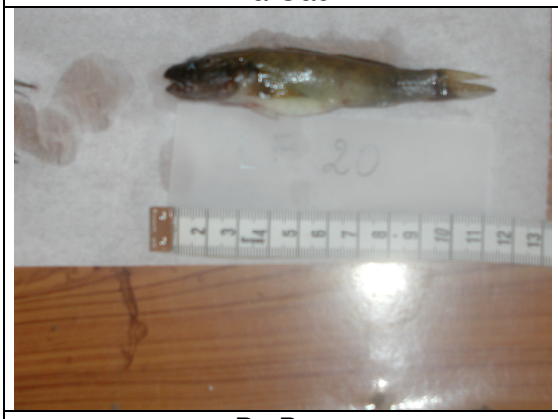
Origin	***Local name***	***diet***	***Ref***	***Length (cm)***	***Weight (g)***	***Hg concentration (µg $Hg.g^{-1}$ wet wt)***
Nam Ou						
Khonekham	Pa Pak	herbivorous	LF34	23	296	0.051
Houaylo	Pa Kot	omnivorous?	LF44	20	122	0.054
Pak Chek	Pa Kheung	carnivorous	LF48	23	160	0.065
	Pa Kot	omnivorous?	LF49	25	268	0.142
	Pa Sangoa	carnivorous	LF47	52.5	970	0.139
Xonkham	Pa Gnon	herbivorous	LF42	19	110	0.018
			LF43	21	140	0.023
	Pa Hian	Herbivorous or omnivorous	LF46	29	418	0.109
	Pa Keng	herbivorous	LF40	26	400	0.027
	Pa Pa	herbivorous	LF41	23.5	336	0.034

Appendix 5

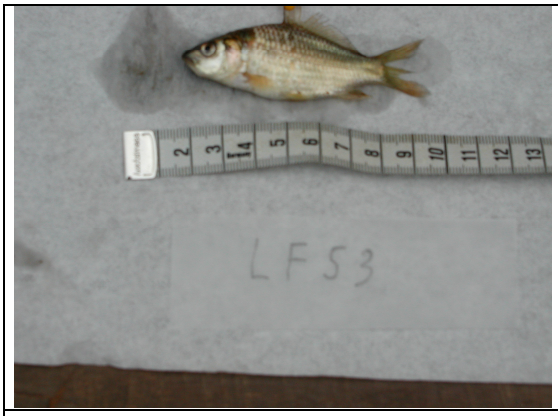
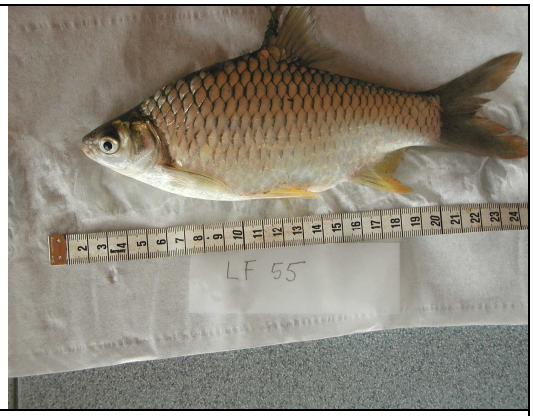
Characteristics of fish samples

	
Pa Chok	Pa Keng
	
Pa Kot	Pa Pia
	
Pa Wa	Pa Kop

Photograph of the different species caught in the Mekong and Nam Ou Rivers.

	
Pa Oad	Pa Sae
	
Pa Bou	Pa Dang Deng
	
Pa Gnon	Pa Hian

Photograph of the different species caught in the Mekong and Nam Ou Rivers.

	
Pa Nai	Pa Pa
	
Pa Sakang	Pa Sangoa
	
Pa Khe	Pa Pak

Photograph of the different species caught in the Mekong and Nam Ou Rivers.

	
Pa Kheung	

Photograph of the different species caught in the Mekong and Nam Ou Rivers.

Appendix 6

Quality control of Hg analysis in solid samples and fish analysis

Quality control of Lumex analyses *vs* Standard Reference Materials (SRM):

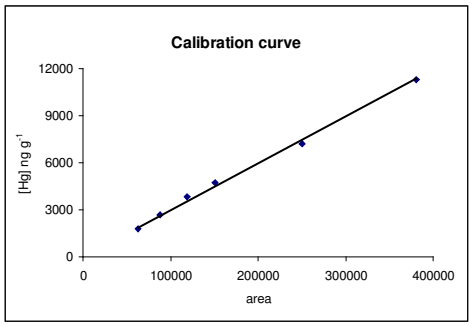
The analyzer can be calibrate in two ways:

- Calibration by a single standard sample.
- Calibration by several standard samples.

We choose the calibration by a single standard sample at 10100 ng g^{-1} but we selected several standard samples to check the quality of the calibration curve.

1-To make the calibration curve, we weight a few times a different amount of the single standard sample as in the illustrations:

N	Standard	Mass mg	[Hg] ng g^{-1}	Peak area
1	Std__10100	17.8	1798	62500
2	Std__10100	26.7	2697	87700
3	Std__10100	37.6	3798	119000
4	Std__10100	47.0	4747	151000
5	Std__10100	71.5	7222	250000
6	Std__10100	111.7	11282	381000

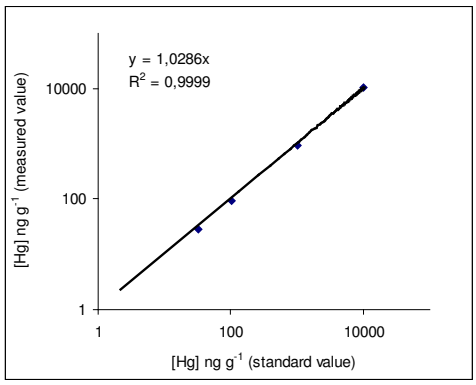


2-Quality control of the calibration curve:

We used 4 samples: a sand without any mercury and 4 SRM with different mercury concentrations at 32, 102, 1000 and 10100 ng g^{-1}.

The results (see illustrations) showed that the Lumex underestimate by 8 to 10 % the mercury content in the samples for the mercury concentration lower than 1000 ng g^{-1}. For higher mercury concentration, the result is correct.

Sample	[Hg] ng g^{-1}	Δ %
sand	2.2	
Std__32	29.0	-10.3
Std__102	93.0	-9.7
Std__1000	922.0	-8.5
Std__10100	10400.0	+2.9



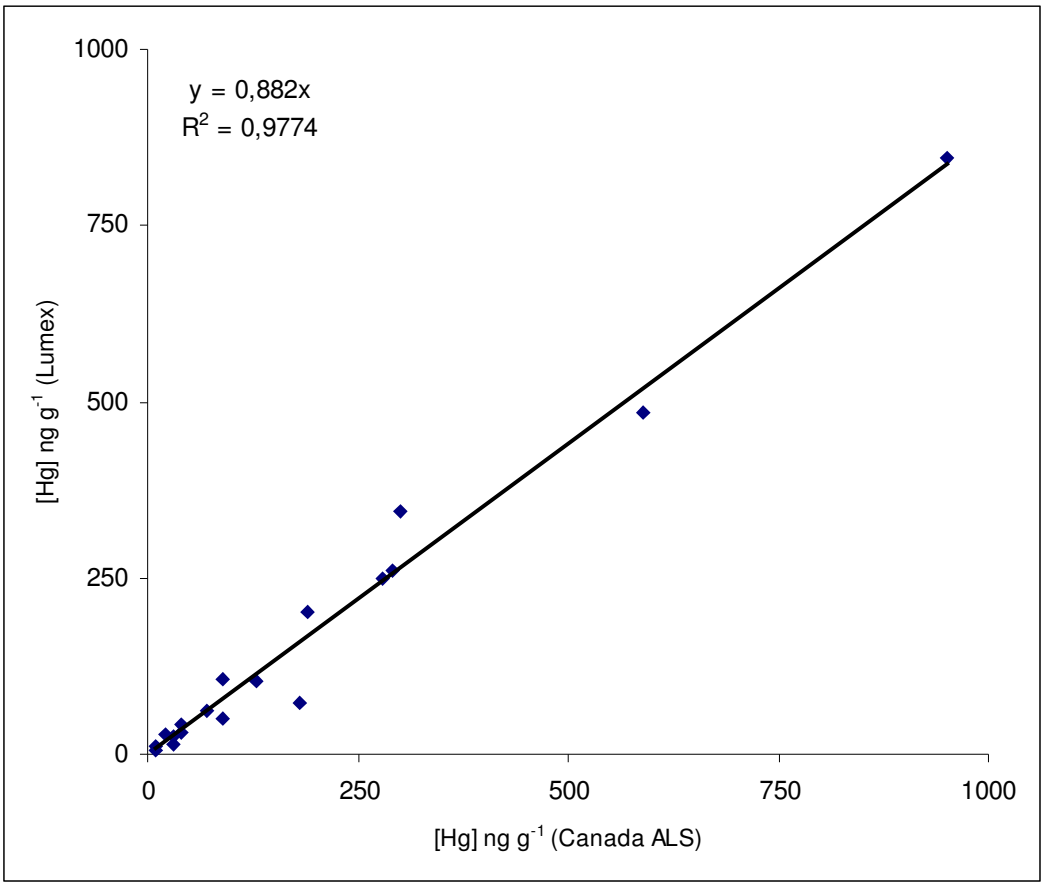
Quality control of Lumex analyses *vs* a control laboratory (Chemex ALS):

All the samples collected in the Lao PDR (soil, sediment and dust samples) and brought back to France were analyzed with the LUMEX in the BRGM laboratory. Less than 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.

In the analytical protocol of the BRGM laboratory, all the samples are analyzed 1 time, 30 % 2 times and 10 % 3 times.

Samples	BRGM laboratory (Lumex)						Chemex ALS
	ng g^{-1}			Mean ng g^{-1}	SD ng g^{-1}	RSD %	ng g^{-1}
LSO 31	32	~	~	32	~	~	40
LSO 30N	100	106	~	103	4.0	4.1	130
LSO 10	15	13	18	15	2.5	16.4	30
LSO 9N	248	253	244	248	4.7	1.8	280
LSO 9W	51	49	~	50	1.4	2.8	90
LSO 11N	344	~	~	344	~	~	300
LSO 23	201	~	~	201	~	~	190
LSO 21E	484	~	~	484	~	~	590
LSO 21W	845	~	~	845	~	~	950
LSE 57	106	~	~	106	~	~	90
LSE 67	269	252	~	261	12.0	4.6	290
LSE 76	63	58	~	61	3.5	5.8	70
LSE 82	74	~	~	74	~	~	180
LSE 05	6	~	~	6	~	~	10
LSE 45	10	10	~	10	0.0	0.0	10
LSE 48	25	~	~	25	~	~	30
LSE 54	27	~	~	27	~	~	20
LSE 96	43	42	~	43	0.7	1.7	40

BRGM laboratory mercury concentrations vs Chemex ALS mercury concentrations. SD: Standard Deviation and RSD: Relative Standard Deviation.

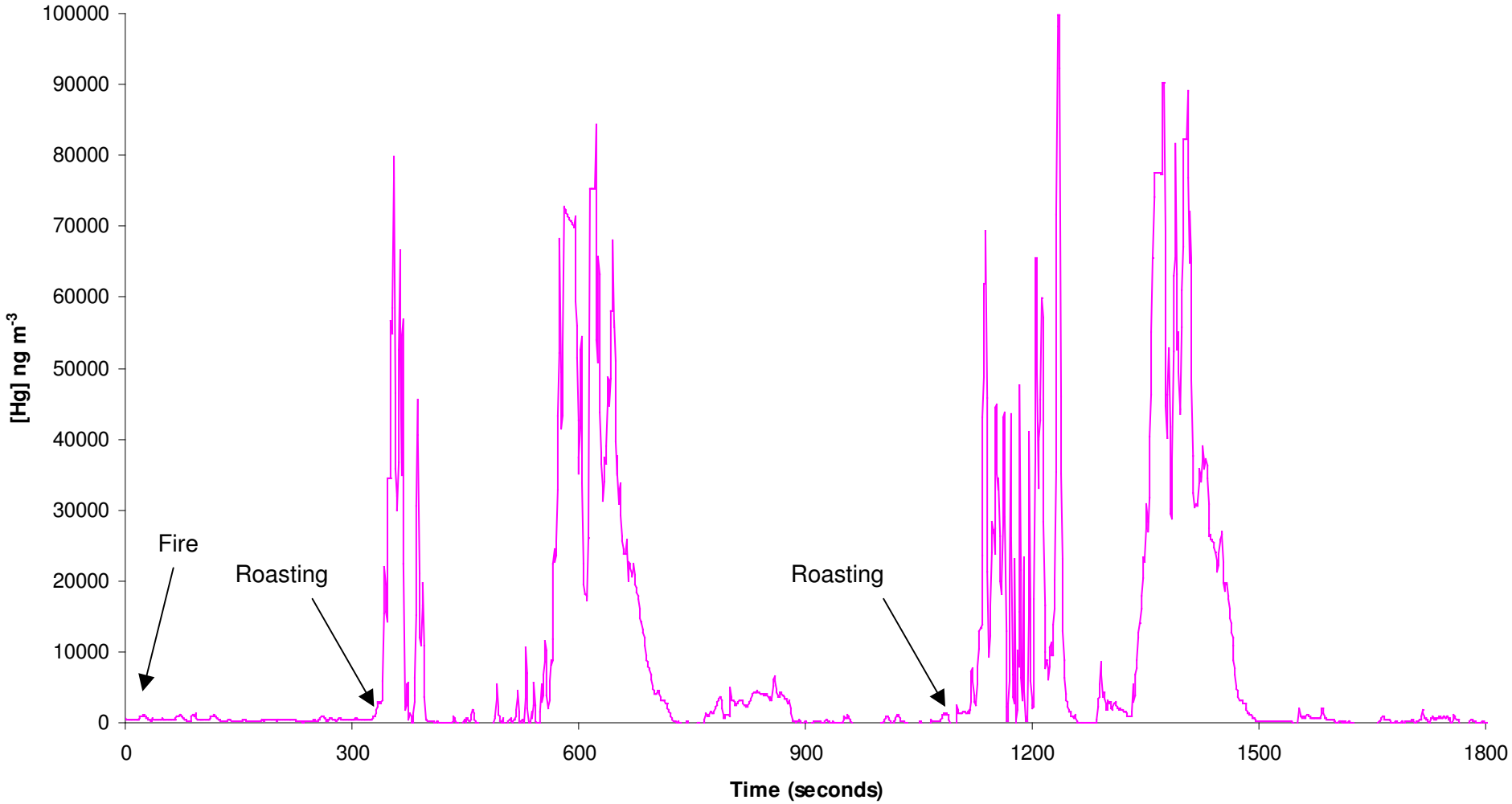


Comparison between Lumex and Chemex-ALS analysis for a selection of solid samples.

The relationship between the Chemex ALS results and Lumex (BRGM) results is good (r^2 = 0.9774) but as showed before with the SRM samples, the Lumex results are lower by ~10 % than the expected results (Chemex ALS).

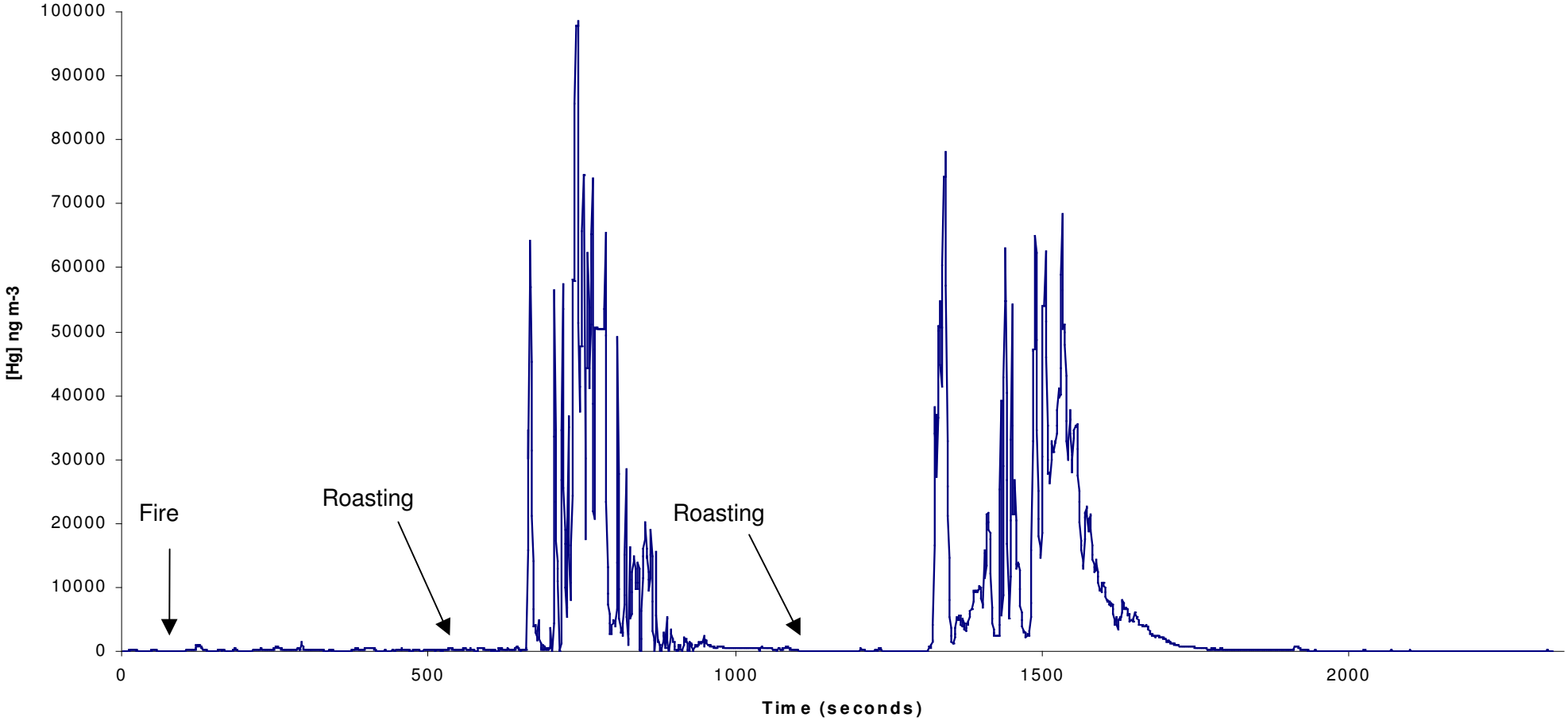
Appendix 7

Hg air monitoring



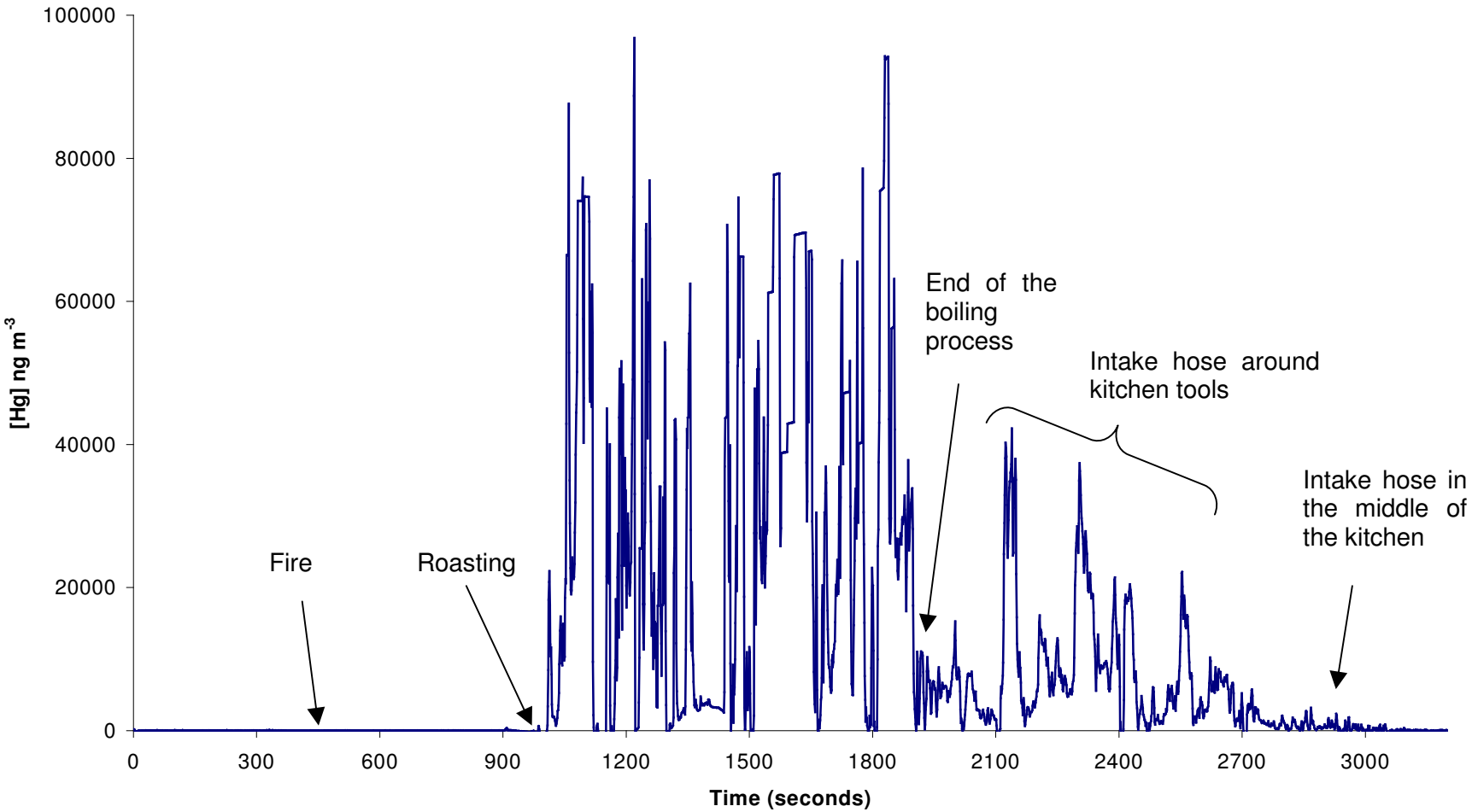
Air monitoring in a kitchen before and after the roasting of two amalgams at the village of Latthahai (Mr Nanchai's house).

Two air monitoring sessions were recorded in Mr Nanchai's kitchen The results are similar to those obtained in the villages of Houay Koh and Houay Gno (ill. 29 and 30).



Air monitoring outside the kitchen before and after the roasting of two amalgams at the village of Houay Koh (Mrs Nang's house).

Two air monitoring sessions were done in Mrs Nang's house. The kitchen and living-room were in the same large room (i.e. without a wall or hanging blanket separation). The air monitoring took place in the living-room area, 4-5 m away from the fire place. The result is a combination between a record from the kitchen and a record from the living-room separated from the kitchen with a blanket (ill. 30).



Air monitoring in a kitchen before and after the roasting of amalgams at the village of Houay Gno (Mrs Pheng's house).

Air monitoring of three amalgams roasted at the same time was recorded in Mrs Pheng's kitchen The result were similar to the ones obtained from the villages of Houay Koh and Houay Gno (ill. 29 and 30) except that the peaks are larger due to a bigger amount of mercury roasted. At the end of the boiling when the mercury vapors decreased in the room, the intake hose of the analyzer was move on the wall next to the fire where the kitchen tools were located. Each peak (2150, 2300 and 2550 sec) is due to the presence of a tool. All tools were covered by charcoal.

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