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Mercury and water quality study

Impact of Gold Mining in the Song Bung 4
Project Area, Central Vietnam

FINAL REPORT



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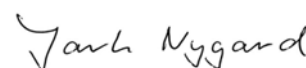
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Abstract <p>The aim of this study is to elucidate any impact that the mining activity in the catchment of Song Bung River has on the water quality, sediment quality, as well as for the fish and the fish flesh quality in the mainstream river and in some tributaries in the Song Bung 4 hydropower development project area. In Song Bung mainstream enhanced concentrations of mercury were found both in the water and in the sediments in the river stretch where gold dredging activity was carried out. The concentrations were however low, much lower than problem levels both in national and internationally recognized environmental quality guidelines. This also applied for the tributaries. For arsenic and all other heavy metals normally confined with mining activity, observed concentrations were all lower than levels known to give environmental or consumption concerns. In the downstream part of the tributaries no traces of cyanide pollution were detected. The concentrations of mercury and other heavy metals in fish flesh were all low, and well below the WHO standards for consumption. The sediment dredging had only moderate impact on river water turbidity. However, the dredging made large physical disturbances of river habitats in the dredged sections of the rivers. Otherwise the water quality of Song Bung River was good and was to a low degree impacted by human activities. The mercury pollution of river sediments from the gold mining was so small that it will not create problems in the planned reservoir of Song Bung 4 Hydropower plant.</p>		
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Central Vietnam

FINAL REPORT

Oslo, November 15, 2006

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Preface

This study is part of the Song Bung 4 Environmental Impact Assessment Project (ADB TA 4625-VIE). However, the study is partly financed by a separate study (ADB TA 4475-VIE). The split was made only from budgetary reasons. As the content of the study: "*Impact of mining on Song Bung River*", cannot be split, it will be given as one report. Part of this report will be taken into the Song Bung 4 EIA-report.

The field work of the study was conducted in the period March 19-26 2006 by Dag Berge, Norwegian Institute for Water Research (NIVA), Pham Thai Nam, Institute of Geological Science (Hanoi), and Nguyen Kiem Son, Institute of Ecology and Bio-Resources (Hanoi). The chemical analyses are done at NIVA.

Dag Berge has been the project leader, and performed most of the reporting after getting input from the local experts. The co-operation has been pleasant and fruitful throughout the project.

The report is amended after comments from the client and from NIVA's Quality Assurance System.

Oslo, November 15 2006

Dag Berge

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Executive Summary

The aim of this study is to elucidate any impact that the mining activity in the catchment of Song Bung River has on the water quality, sediment quality, as well as on the fish and the fish flesh quality in the mainstream Song Bung River and in some tributaries in the Song Bung 4 hydropower development project area. The largest mining activity is the extraction of gold from river sediments, and river banks, using "floating gold washing machines" mounted on barges. 11 such gold washing barges are operating in Song Bung mainstream from Pa Dhi Village - to just upstream the Ta Vinh tributary. Several machines are operating in the A Kia tributary and also in Ta Vinh tributary. In the catchment of Ta Vinh there is also ongoing hard rock mining. In the sediment dredging, mercury is used for extraction of gold. In the hard rock mining, cyanide is used for extraction of the gold. Both these techniques are known to have created serious pollution problems in many rivers around the world.

In Song Bung mainstream enhanced concentrations of mercury were found both in the water and in the sediments in the river stretches with gold dredging activity. The concentrations were, however, low, and much lower than problem levels defined in both national and internationally recognized environmental quality criteria. Among the tributaries, the Ta Vinh had the highest concentrations of mercury in both sediments and in the water phase. This tributary had the highest concentrations of all the sampled stations. The highest concentration in Bung River was 12 ng/l at a site in the downstream end of the gold dredging impacted reach. The Ta Vinh tributary had the highest observed Hg concentration of 21 ng/l. The other tributaries, as well as Song Bung upstream Pa Dhi, did not show enhanced concentrations of mercury. The Vietnamese water quality criteria's guidance value is 1000 ng Hg/l, the US EPA says that no damage to biological life is observed at concentrations of Hg below 700 ng Hg/l. The Canadian WQG also has a limit of water use of 1000 ng Hg/l. The concentration of mercury in Song Bung decreased from Ta Vinh and downstream.

For arsenic the highest concentration in Song Bung water was in the range of 0.8-1.2 µg As/l. In the tributaries the highest concentration is found in Ta Vinh (2.3 µg/l). The values are well below the limit that WHO set for drinking water (10 µg/l). The Vietnamese standards set a limit of 50 µg/l. Arsenic, which often follows iron, showed maximum values in the Song Bung sediments of 9.2 µg/g and 14 µg/g in Ta Vinh sediments. The Canadian guideline is 5.9 µg/g, and the level for possible environmental impacts is set to 17 µg/g.

For all the other heavy metals the concentrations were well below recommended limits given in national and international environmental criteria.

The content of mercury and other heavy metals in fish filets did not show values of concern, neither for environmental impacts, nor for human consumption. The highest mercury concentration in fish filet was found in a 3 kg large *Bagarius yarrelli* (carnivorous) at Thon 2 Village (0.18 ppm Hg), which is in the downstream end of the gold dredging area in Song Bung. WHO has 0.5 ppm Hg as a general guideline for fish for human consumption. Plant-eating fish, and omnivorous fish (eats both plants and small animals, insects larvae, etc.) had much lower concentrations. The largest fish analysed, a 7 kg large *Spinibarbichthys denticulatus*, had only 0.06 ppm Hg in the fish filet.

No traces of cyanide were detected in any of the tributaries, nor in the Ta Vinh where hard rock mines are actively using this compound for gold extraction. The lower parts of the tributaries do not seem to be impacted by this activity, which also implicates that Song Bung mainstream is not affected by the hard rock mining.

The sampling was performed in the high season for the gold dredging. 11 barges were actively operating in Song Bung mainstream 24 hours a day during the field work, and many in the A Kia Tributary. Despite this, the river water showed only moderate turbidity. The highest turbidity was measured to 28 FNU in the middle part of the gold dredging stretch. It was dry weather during the sampling period, so other erosion activities were low. This indicates that the gold mining does not have any great impact on siltation in the river, other than local impacts.

This is logical as the dredging takes place in river sand that the river has "washed" previously. During rainy periods, the turbidity of Song Bung can reach 200 FNU and more, due to catchment and river side erosion.

The dredging makes, however, large physical disturbances to the river, creating big heaps of gravel and sand scattered around in the river. This destroys fish habitats and other aquatic life. However, this represents only local impacts on the dredged stretches.

With respect to other water quality parameters, Song Bung River has nutrient poor waters, with 100 % oxygen saturation, and showed negligible impacts of human activities. It is not likely that the reservoirs of Song Bung River will get eutrophication problems with the present low human activity in the catchment. This item is more thoroughly treated in the Aquatic life study of the EIA.

1. Introduction

In the PPTA Phase 1 study (Bird et al 2005) several water quality problems are addressed that can affect both the aquatic life and the human use of the river resources. The most serious of these impacts are related to the more or less unregulated gold mining activities in the catchment. Concerns also exist related to possible remnants from the use of defoliators (e.g. Agent Orange) during the Vietnam War. Other human activities in the catchment were also believed to give impacts (nutrients, manure, hygienic discharges, etc.). Some of these data are provided by the analytical programme of the PECC3 (2005, 2006), but the most important pollutants are not included in their analytical programme. Some of their analyses also were anticipated to be wrong, as for example the oxygen analyses (Basberg 2006).

In Song Bung River there has been going on gold mining for many years, but the activities have increased considerably in recent years. Most gold is extracted from the river sediments, mostly by the use of gold-mercury amalgam technique (artisanal gold mining). The mining is both in large scale by use of dredging barges and by an unknown number of small scale gold panners using in effect the same technique. The comprehensiveness of the mining activities in the catchment is described in a separate report (Nam 2006).

In short the technique can be described as follows: Firstly, the fine mud is removed by flotation. In the residual sand there are small amounts of gold that have to be collected. Liquid metallic mercury is mixed with the sand. The small scale panners often use a cloth which they are moulding and squeezing by their hands for 15 minutes to one hour squeezing out the surplus of mercury through the pores of the cloth, and letting the remainder reacting with the gold to make a lump of amalgam. The lump of amalgam is removed from the sand, and heated over fire. The mercury then evaporates and the pure gold remains.

The technique is the same for those who use barges as the small scale panners do. The surplus of mercury that is pressed out of the cloth ends up either directly in the water, or on the ground on the river bank, or is collected for later use. Parts of the mercury that evaporates do not travel far in air, and fall out in the vicinity. That mercury also has a tendency to enter the water. In more advanced techniques this mercury is recovered by distillation.

Metallic mercury is sinking to the sediments where it reacts with organic material which it is often tightly bound to.

If a reservoir is formed in the river, sediments which contain lots of organic material originating from the litter in the inundated terrestrial catchment will be built up. This sediment will have low oxygen content. Under such conditions certain methanogenic bacteria form the very bio-accumulative methyl-mercury. This compound accumulates very efficiently in the organisms, and, as they don't have any ability to excrete methyl-mercury, it becomes a so-called bio-magnifiable compound. This means that it becomes up-concentrated through the nutrient chain.

In river sediments the methyl-mercury is not formed that fast as these sediments are better oxygenised and they are often not permanent. Every flood season these sediments are re-disturbed and some of them are transported further downstream, while others are permanently settled in the inundated areas. If a reservoir is built in a river where the sediments contain mercury from mining, it may easily result in heavily contaminated fish that might be dangerous to eat.

It has therefore been important to study the content of mercury in the sediments and the fish of the river, both in the reservoir area, and upstream.

In the mountains in upper part of Song Bung river catchment there are several small gold mines which extract gold from layers of ore in the mountain. They follow the gold ore by blasting tunnels, and take out the gold containing rock layers. They crush this material to fine sand and silt, and do separation by use of a three step washing in running water. The two first steps is a physical gravitational separation of the gold from the stone

material. The third step includes a pond where the gold containing slurry is mixed with sodium cyanide. The cyanide dissolves the gold into the water – cyanide solution. The gold is then precipitated onto metal shavings, most commonly used is zinc shavings or zinc powder. The metals in the precipitate are separated by heating as they have different melting points.

The cyanide containing remaining water and sludge are very toxic to fish and aquatic life above certain concentrations. At low concentration cyanide does little harm. It is broken down to carbon dioxide (CO₂) and nitrogen (NH₄) and disappears.

Therefore it has been important to check the cyanide content of the tributaries coming from areas where hard rock gold mining is taking place.

In addition to elucidate the impact from mining, the study also aims at describing the general water quality, i.e. pH, conductivity, turbidity, nutrients, main ions, oxygen, etc., as an addition to the material collected by PECC3.

This study is part of the Song Bung 4 EIA study and will be partly also be reported in that context.

2. Methodology

2.1 Sampling stations

According to the Terms of Reference, 6 stations in the main stream Song Bung and 6 tributaries should be sampled. However, two of the tributaries were dry, so more stations in main stream river were sampled instead, as well as 4 tributaries suspected to be impacted by gold mining. Two of the tributaries were impacted by gold dredging, and some by hard rock mining in the upstream areas. The sampling stations are shown in Figure 1.



Figure 1. The Samplings sites for the mercury and water quality study March 19-26 in the Song Bung 4 Hydropower Project Area.

2.2 Study media

Mercury and heavy metals are often not very soluble in water. They bind to particles and are settling to the bottom. Here they contaminate the sediments. Many of the bottom dwelling animals are living like the earthworm, eating the bottom sludge and are then getting the heavy metals into their body. The fish are eating bottom animals and in this way the fish get contaminated. Some of the metals are not excreted so easily from the body as they are taken in, and thereby tend to accumulate in the body. As a consequence older and larger fish contain more metals than a young fish (called bio-accumulation). Particularly mercury, which is hardly excreted from the

body at all, increases in concentration throughout the nutrient chain (called bio-magnification). Therefore, the most important is to look for contamination in large carnivorous fish. The carnivorous fish is also often the most popular fish in the diet of people, because they are large, and good tasting.

Therefore we took samples of the three media listed below:

- Water samples
- Sediment samples
- Samples of filets from large fish (also some small fish when we were unable to catch large specimens)

2.2.1 Water sampling

Oxygen and Temperature were measured in the field using an YSI instrument (Yellow Springs Instruments Inc.). Prior to the sampling the electrode were equipped with a new membrane, filled with new KCL-solution and calibrated in air-bubbled distilled water.

Water samples were taken from the river by wading out in the river filling the bottle upstream of the sampler. Water for mercury and heavy metals were taken on specially rinsed bottles, which contained stabilising solution that were poured out just before the bottles were filled by river water. Water for analyses of general water chemistry was taken on bottles washed with Deconex lab flask cleaning soap and thereafter rinsed in distilled water.

2.2.2 Sediment sampling

Sediment samples were taken from quiet pools where particulate matter was allowed to build up soft sediments on the river bottom. The sediment was taken by a sediment corer, a plastic tube that was pressed down into the sediment. A stopper was put on the top end of the corer, and the sediment core pulled out from the sediment. Before taking the core out of the water, a stopper was also put in the lower end of the tube. The core, which then contained 15 cm of sediments in the bottom and 15 cm of water on the top, was brought to the shore. Here the bottom stopper was replaced by a piston while the top stopper was removed. The piston was pressed up allowing the surface of the sediment to come to the top of the tube. The uppermost two cms of the sediment were placed in a plastic box and brought to the laboratory for analysis.

2.2.3 Fish sampling

To be sure that the fish really was caught in Song Bung River, we initially tried to carry out the fishing ourselves. However, it turned out that we only were able to catch small fish during day time, see **Figure 2**. We therefore, on our way upstream, arranged with professional fishermen to try to catch big fish for us, so we could buy from them on our way back. In this way we managed to get samples from large specimen of fish that people normally use for food along the Song Bung River, see **Figure 3**.





Figure 2. Fishing ourselves during the field trip (day time) gave only small fishes. Here young stages of *Spirobarbichthys denticulatus* to the left and *Hainania serrata* to the right. The first of these species can grow to 8-10 kilos in Song Bung.



Large representatives for the same species as above, *Tor Strachey* (4 kg) to the left and *Spinibarbichthys denticulatus* (7 kg) to the right



Bagarius yarelli (3 kg)



Samples for mercury and heavy metal analysis were taken from the fish filets



And conserved in 70 % ethanol prior to analysis

Figure 3. When we let local fishermen do the fishing, large fishes were caught.

The fish samples were taken from the filets and conserved in 70 % ethanol prior to the analysis.

2.3 Analytical parameters

2.3.1 Water samples

The water samples were analysed for the following parameters:

Temperature, pH, conductivity, turbidity, oxygen concentration, oxygen saturation, alkalinity, total phosphorus, total nitrogen, ammonium, nitrate, chloride, sulphate, cyanide (tributaries), fluoride, calcium, magnesium, sodium, potassium, iron, manganese, cadmium, cobalt, chromium, arsenic, copper, mercury, nickel, lead, and zinc.

2.3.2 Sediment samples

The sediment samples were analysed for the following parameters:

Arsenic, cadmium, cobalt, chromium, copper, iron, manganese, mercury, nickel, lead, and zinc.

2.3.3 Fish filet samples

The fish filet samples were analysed for the following parameters:

Arsenic, cadmium, cobalt, chromium, copper, iron, manganese, mercury, nickel, lead, and zinc.

2.4 Analytical methods

The analyses were carried out according to accredited methods (NS-ISO 17025) at the Norwegian Institute for Water Research. In most cases these are the same as Norwegian Standards (NS) and International Standards (ISO).

3. Gold Mining areas and methods

3.1 Gold Dredging

Dredging for gold is ongoing in Bung River from Pa Dhi Village and down to approximately the entrance of Ta Vinh tributary. There are also several barges operating in the A Kia tributary. In total 11 barges are operating in the Song Bung mainstream. A separate report describes the different mining activities in the catchment area (Nam 2006).

The way of washing and extracting the gold is described in the series of photos shown below:



1. The gold mining barges eat their way sideways into the river banks



2. Eating old grass-covered banks in the front end, washing the material and spitting it out in the rear end



3. A continuous excavator belt with half a meter between the grabs is fairly efficient.



4. Digging down to 1.5 m below the water surface, and 1 m above the water surface



5. The material is transported up to a washing tower at the rear end of the barge



6. Here the material is separated, the stones and gravels are dumped backwards, while the sand and fine material go to both sides.



7. The gold and some sand are retained between the fibres in a nylon carpet, like the door mats used to clean dirty shoes.



8. After some hours of operation the mats are thoroughly washed in a half barrel filled with water. The water is thereafter carefully decanted off.



9. After a last mechanical separation where some coarse sand and debris are taken out, the remaining material is mixed with mercury and moulded in a cloth. The mercury reacts with the gold forming amalgam, the sand does not react. The surplus of mercury is squeezed through the cloth and collected.



10. The result of four days and nights of gold washing. A lump of amalgam of the size of a ping pong ball. This is heated and the mercury vaporizes off, and the pure gold and some silver are left back. This last extraction is not performed on board the barge, but in town, we were told.



11. In addition to potential pollution, the gold dredging makes large physical and ecological impacts on the river bed, as well as making the river water turbid



12. Here it is not easy to go boating, nor for the fish to find back to its old living places.



13. The dredging machines are pre-built in sections at small workshops in the forest.



14. Thereafter transported to the site on old military terrain vehicles.

3.2 Hard Rock Mining

Within the catchment of Song Bung river, it is only in the upper part of Ta Vinh tributary that they are performing hard rock mining after gold for the time being (Nam 2006). They exploit the gold ore in rocks by blasting tunnels, and take out the gold containing rock layers (ore). They crush this material to fine sand and silt, and do separation by using a combination of gravity washing and dissolution with sodium cyanide. The chemical step includes a pond where the gold containing slurry is mixed with sodium cyanide. The cyanide dissolves the gold into the water – cyanide solution. The gold is then precipitated onto metal shavings, most commonly used is zinc shavings or zinc powder. The metals in the precipitate are separated by heating as they have different melting points.

The cyanide containing remaining water and sludge are very toxic to fish and aquatic life above certain concentrations. At low concentration cyanide does little harm. It is broken down to CO₂ and nitrogen (NH₄) and disappears. More about the method of hard rock gold mining in the catchment is shown in **Figure 4**



1. Gold bearing ore are taken out by blasting (tunnel mining)



2. The ore is crushed to a particle size of fine sand and finer



3. The crushed material is mixed with water, forming a slurry, which is led down a gentle sloping canal with a transverse rib system in the bottom. Heavy particles are retained between the ribs, while the lighter particles follow the water. The rib system is cleared for gold bearing particles at certain intervals.



4. The water that escapes the rib settling system is led through ponds where more material settles out. The sediments here are taken up and led over the rib canal system once more for collecting more material.

Figure 4. From the hard rock mining in the Song Bung catchment

In the heavy particulate material taken out by gravity in the way described in **Figure 4** the gold is still sticking to the mineral particles. This material is now put into a plastic lined pond of a typical size of approximately 2x2m wide and 1 m deep and treated with cyanide. The miners would not tell us how this process was done (business secret), but here we cite the most common way of using cyanide-extraction in small scale gold mining. In addition to the gold containing sediment the pond is filled with water and a small amount of sodium cyanide is added. The pond is stirred thoroughly by blowing in compressed air (oxygen is necessary for the process). The gold is now dissolved from the mineral particles and goes into aqueous solution. This process takes a couple of days. The solution is then led into another plastic lined pond and zinc shavings (or zinc powder) are added. The gold, some silver and copper will be precipitated onto the zinc particles (like in plating) and will settle to the bottom of the pond. The metals in this precipitate can be separated by heating according to the different melting points they have. In some systems a step using activated charcoal is also used (but not here we were told).

4. Water Quality

4.1 General water quality

Some general water quality parameters from Song Bung mainstream are given in **Figure 5** while those from the tributaries are given in **Figure 6**. Temperature varied from 26 to 28 degrees Centigrade. The water was saturated with oxygen at all stations, also in the tributaries. The PECC3 found that the water had only around 60 % oxygen saturation, which most likely was wrong due to the fact that they brought the water samples to the lab without conserving the oxygen in the field. The oxygen will then be consumed by micro organisms on the way to the lab. The pH was slightly alkaline from 7.8 to 8.1. The water was relatively soft with conductivity values around 9-10 mS/m, and alkalinity of 0.9 mmol/l. The turbidity was moderate at all stations during the days of sampling and showed values from 8-35 FNU, including in the tributaries. As the relationship between turbidity measured as FNU and suspended particulate matter measured as mg/l is not far from 1:1 (Berge et al 1995), this indicates that the concentration of particulate matter was in the range of 10-30 mg/l. These represent normal values in the region for the dry season of the year, with low erosion activity. According to the PECC3 study and the hydrodynamic modelling study the concentration can increase to 200 mg/l during rainy weather (Basberg 2006). During the period we were sampling, the gold mining barges were operating at full speed (11 only in the Song Bung between Pa Dhi and Ta Vinh), but this did not cause any large increase in the turbidity of the river water, and much lower than is known to cause any problems for aquatic life. According to water quality criteria of the European Inland Fishery Commission (EIFAC, see Alabaster & Lloyd 1980), no damage is proven to occur to aquatic life below 35 mg/l of particulate matter. On the other hand they state that it is impossible to have good fish productivity in a river if the concentration of suspended sediments is above 100 mg/l.

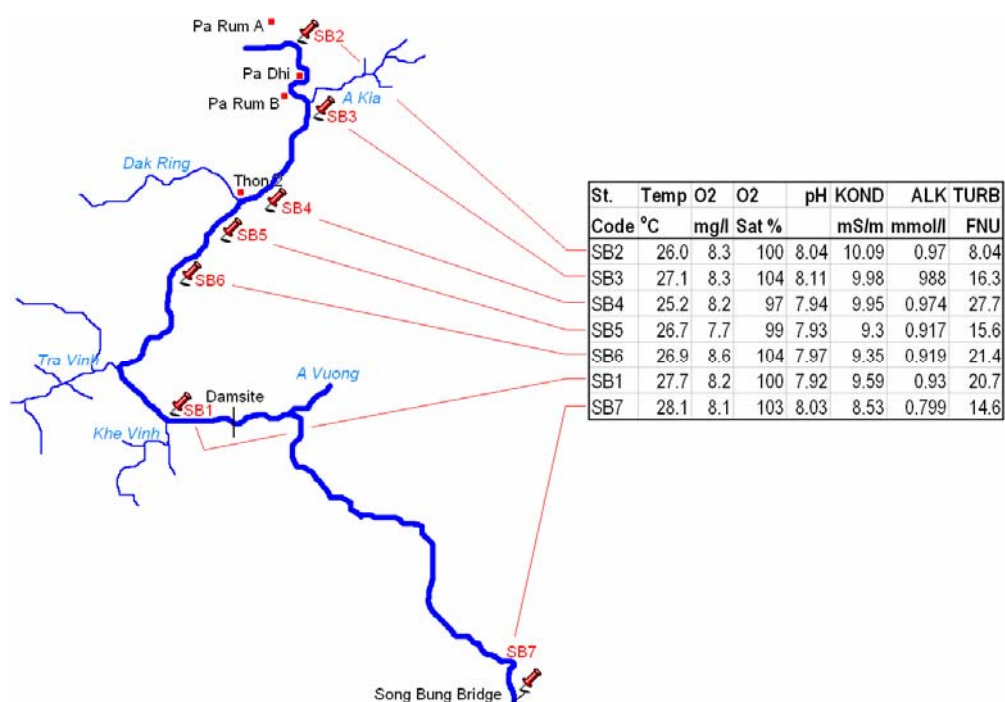


Figure 5. Some parameters of general water quality at different sites in the Song Bung River, March 19-26 2006.

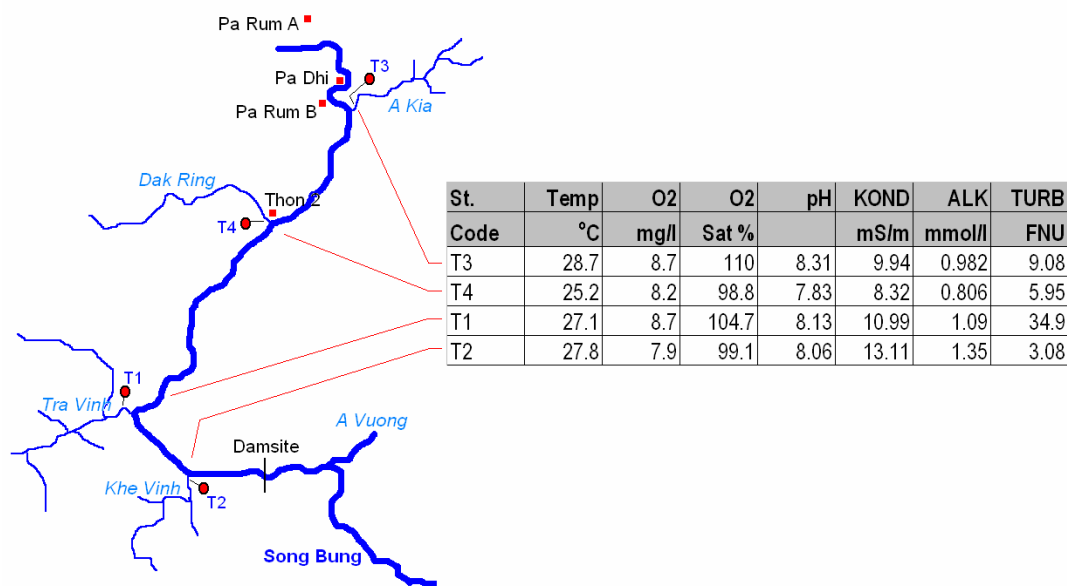


Figure 6. Some parameters of general water quality in different tributaries of Bung River, March 19-26 2006.

4.2 Nutrients and main ions

The results from the analyses of nutrients (nitrogen and phosphorus components) and major ions, are given for Song Bung mainstream in Figure 7, and for the tributaries in Figure 8.

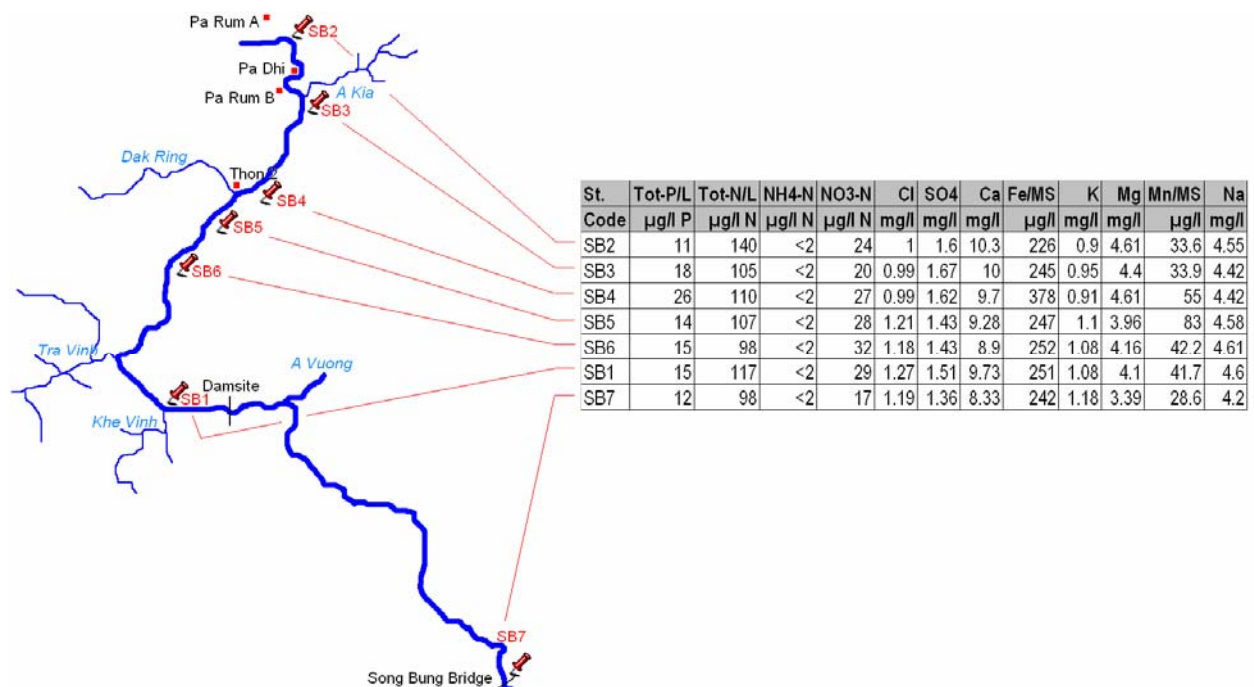


Figure 7. Nutrients and main ion composition at different sites in Sung Bung River March 19-26 2006.

The concentration of both phosphorus and nitrogen is low. The P shows the same variations between stations as the turbidity, which indicates that it is P adsorbed to particulate matter that constitutes the concentration and not discharges from human activity. The concentration of total nitrogen and other N fractions are very low, and indicate almost pristine natural values, and no use of chemical fertilizer in the catchment. The concentrations of the main ions seem very natural. There are relatively high concentrations of iron and manganese, which however, is also normal in this type of soils which is dominating in the catchment (Ferrallite soils and Ferralic Acrisols, cf NHP 2005).

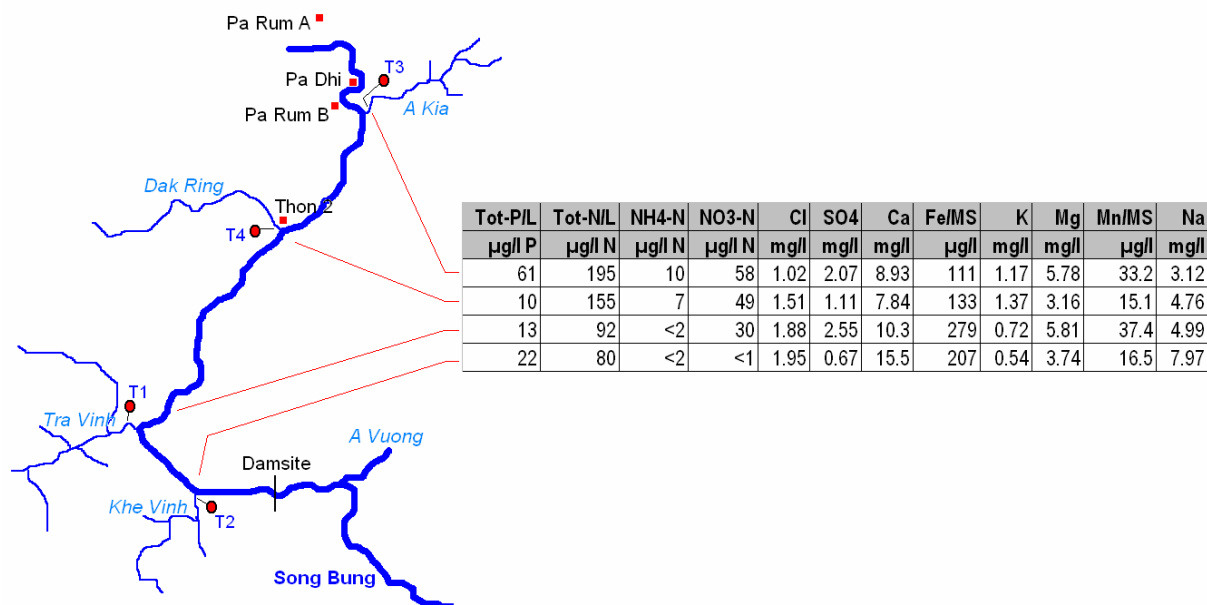


Figure 8. Nutrients and main ion composition in different tributaries of Song Bung River March 19-26 2006.

4.3 Mercury and other heavy metals

The results from the water analyses of mainstream Song Bung River is given in **Figure 9** while the values for tributaries are given in **Figure 10**. For arsenic the highest concentration in Song Bung was from 0.8-1.2 µg As/l. In the tributaries, the highest concentration is found in Ta Vinh (2.3 µg/l). The values are well below the limit that WHO set for safe dinking water (10 µg/l). The Vietnamese standards set a limit of 50 µg/l. Several places in Northern Vietnam high content of arsenic in ground water is a problem for dinking water. For example in the raw drinking water wells for Hanoi City the arsenic content is from 240-320 µg/l, and after treatment it is varying from 25-91 µg As/l (Berg et al 2001).

For mercury, which is used to extract gold from the river sediments, the concentration in the water was also found to be low at all stations. The highest concentration in Bung River was 12 ng/l and was found at the downstream end of the gold mining impacted reach. There was a gradually increase from 2 ng/l upstream of Pa Dhi, which is upstream of the gold dredging area, and to the Ta Vinh area. At the 2 lowermost stations (Khe Vinh and Song Bung Bridge) the concentrations were lower. The Ta Vinh tributary had the highest observed Hg concentration of 21 ng/l. In this river there are going on several gold panning activities in the upstream reaches, and metallic mercury is used in the extraction. The other tributaries had values about as in Bung River upstream Pa Dhi, which can be regarded as natural background levels.

In the Bung River from Pa Dhi to Ta Vinh tributary, as well as in Ta Vinh it self, the water had enhanced mercury concentrations clearly above natural background levels. The levels were, however, low compared to what is regarded as safe water both in national and international water quality standards. The Vietnamese water quality criteria advices that the concentration should be below 1000 ng Hg/l, the US EPA says that no damage to

biological life is observed at concentrations of Hg below 700 ng Hg/l. The Canadian WQG also has a limit of 1000 ng Hg/l for water use.

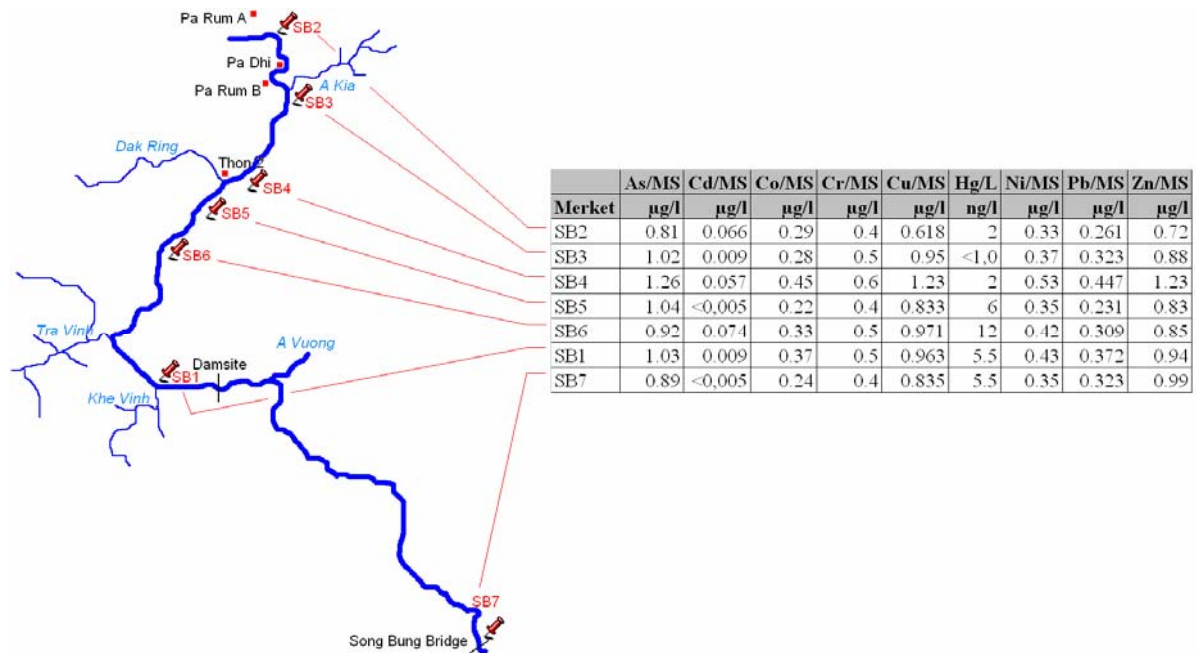


Figure 9. Concentrations of mercury and other heavy metals in the water at different sites of Song Bung main-stream, March 19-26 2006

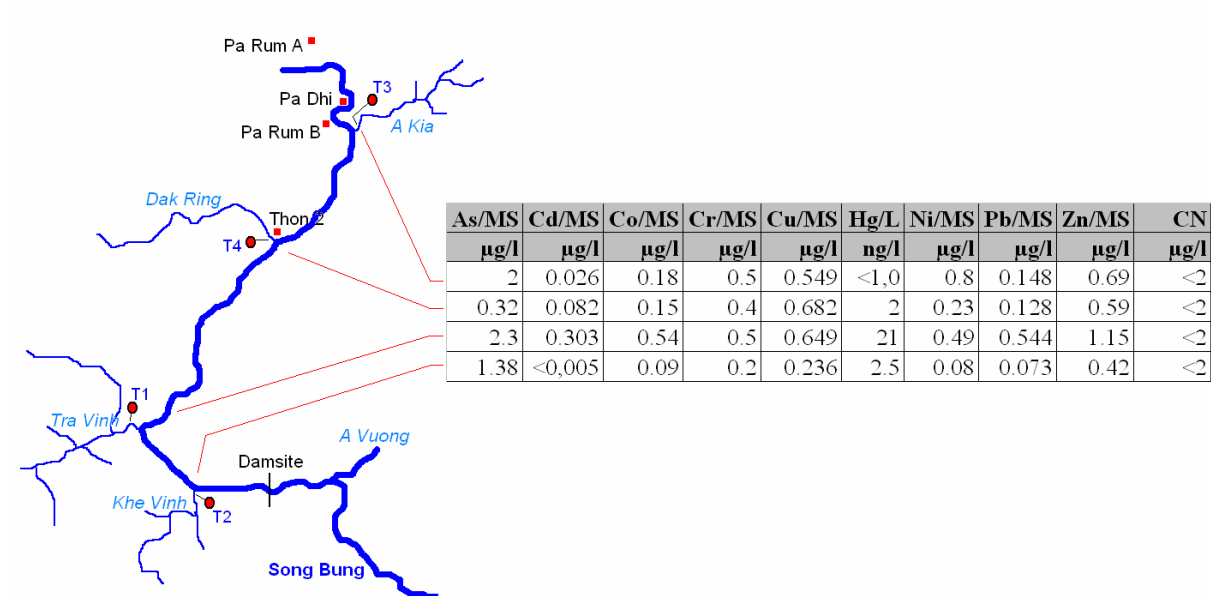


Figure 10. Concentrations of mercury and other heavy metals, and cyanide in the water of different tributaries of Song Bung, March 19-26 2006

The other heavy metals did all show values well below the limits of concern both in the Vietnamese- and the cited international water quality guidelines.

5. River Sediments

5.1 Mercury and other heavy metals

The analytical results from the sediment samples from the Bung River itself are given in Figure 11, whereas the results from tributary sediments are given in Figure 12.

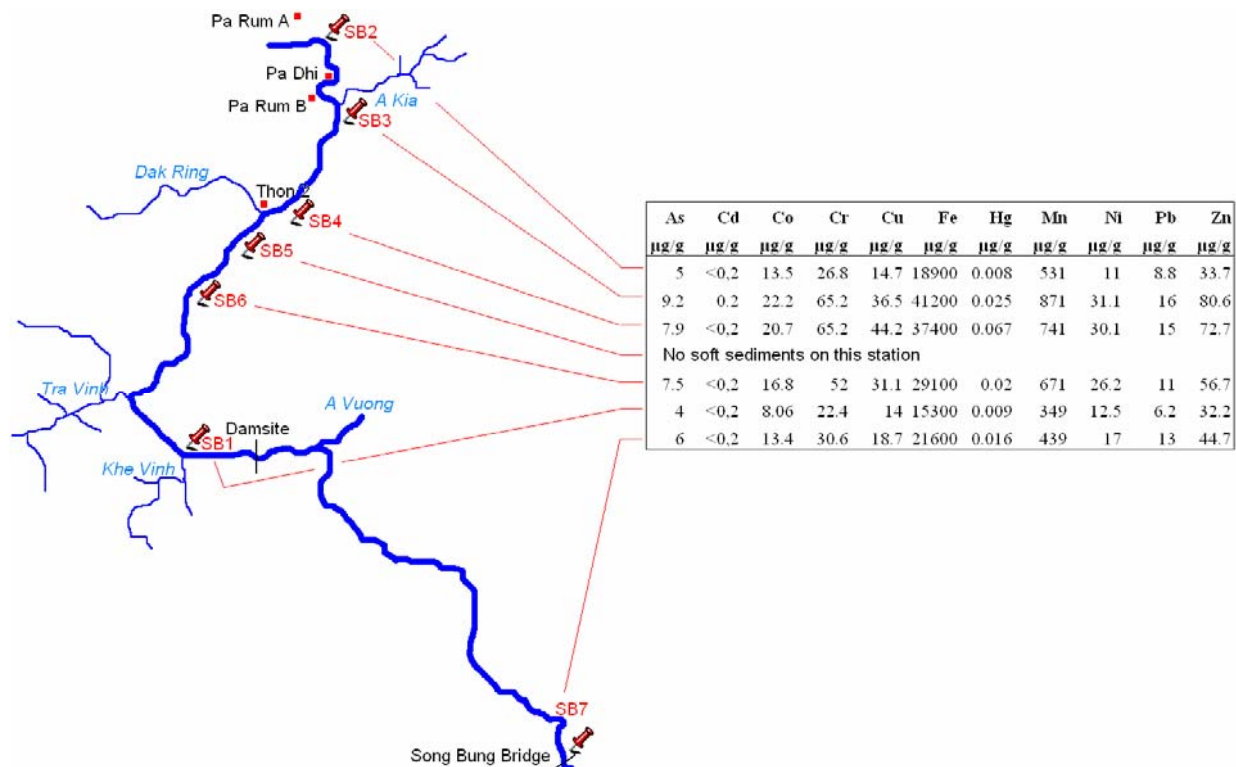


Figure 11. Concentrations of mercury and other heavy metals in the bottom sediments at different sites of Song Bung mainstream, March 19-26 2006

Only a few nations have adopted quality guidelines for sediments. Vietnam has not. Canada has adopted a set of sediment quality guidelines where they operate with 2 limiting levels. They give one level above which possible environmental impacts can occur, and based on that, they give a recommended level well below this as a guideline for water managers to try to keep the water recipients below. The Canadian Environmental Guidelines are among the strictest in the world. With respect to mercury, which is the most dangerous heavy metal, the Canadian Environmental Quality Guidelines gives a recommended guideline of 0.170 µg/g, and a value of possible environmental effects of 0.486 µg/g sediment. In Bung River the highest sediment concentration of 0.067 µg/g was recorded in the middle of the gold dredging area at Thon 2. This is well below the Canadian guidelines.

Among the tributaries, the highest concentration of mercury was found in the sediments from Ta Vinh (0.110 µg/g). This is approaching the Canadian guideline, but is still well below the limits of observed environmental impacts given in the Canadian Environmental Guideline system.

The highest sediment Hg-concentrations were found in the same sites as the highest water phase Hg-concentrations were found, which correspond to the places where sediment extraction of gold has the highest activity. This shows that the gold dredging and the use of mercury can be detected in water and sediment contamination, but the contamination is low, and well below the limit that is regarded as impacting the environment and the people.

Iron showed high concentrations in the sediments. However, iron is an essential element with high biological demand and is not among the metals that are regarded as toxic. The type of soils in the catchment area (Ferralsite soils and Ferralic Acrisols, cf NHP 2005), is known for having high iron content. It is not given values for iron in most sediment quality guidelines because iron is not known to cause environmental problems.

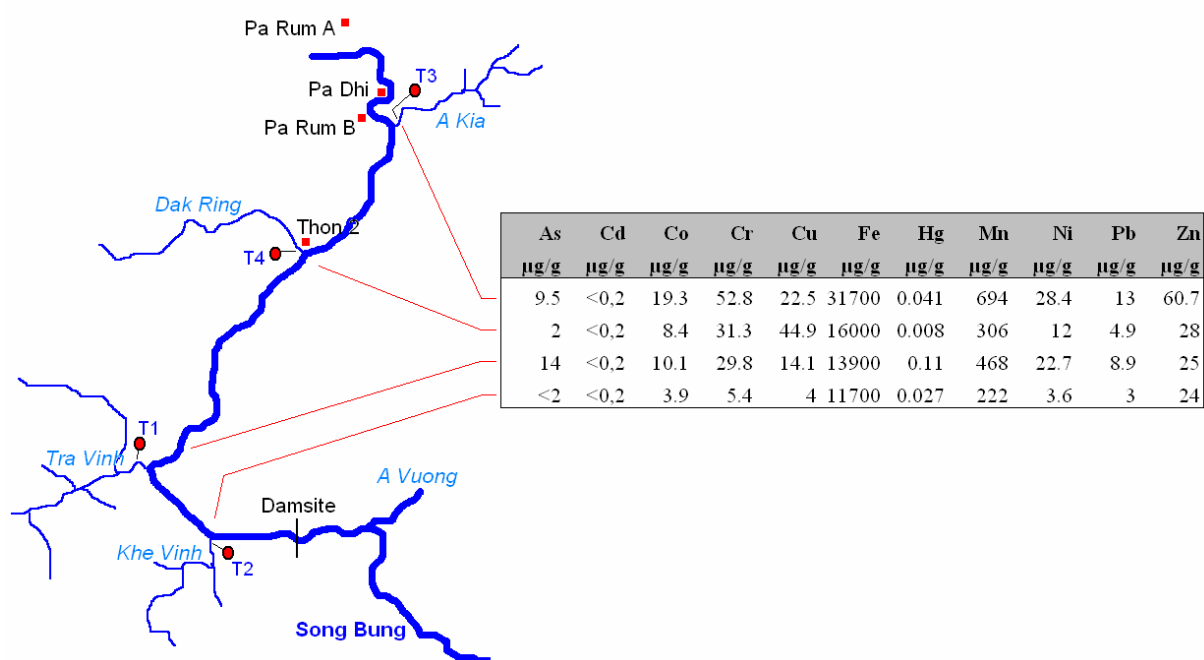


Figure 12. Concentration of mercury and other heavy metals in the bottom sediments in different tributaries of Song Bung March 19-26 2006

Arsenic, which often follows iron (Berg et al 2001, Tran Hong Con et al 2003) showed maximum values in the Song Bung sediments of 9.2 µg/g and 14 µg/g in the Ta Vinh sediments. The Canadian guideline is 5.9 µg/g, and the level for possible environmental impacts is set to 17 µg/g. The soils in Vietnam are rich in both iron and arsenic (Berg et al 2001, Tran Hong Con et al 2003, Christen 2001). This creates great problems with respect to utilising groundwater as drinking water without treatment. For example in the deep soil of the Red River flood plane (Berg et al 2001) found from 600-3300 µg/g arsenic. This gives high concentrations of arsenic in the ground water. In that region, a large number of people are subjected to health wise dangerously high concentration of As in their drinking water from private deep wells, which do not have any water treatment. The values from Song Bung sediments must be regarded as low in comparison with many areas in SE-Asia, and they are all below the level of environmental impact given in the Canadian Environmental Guidelines, which are among the strictest guidelines in the world.

For copper, the maximum concentration of 44 µg/g was found in Song Bung at Thon 2. The Canadian guideline recommends a limit of 36 µg/g, whereas the limit of possible environmental impact is estimated to 200 µg/g. The sediment content of copper is therefore not anticipated to give any environmental problems in Song Bung.

All the other heavy metals showed values that are well below recommended levels in the international sediment quality guidelines and far below the values where environmental impacts are likely to occur.

6. Fish Flesh Contamination

6.1 Mercury and other heavy metals

Heavy metals tend to be associated with particulate matter, which settles out in calm water zones in the rivers and ends up in the sediments. A large part of the bottom dwelling animals are eating sediments, like the earth worm, digesting the organic material that is in the sediments. The fish feed on the bottom animals. In this way heavy metals tend to accumulate in fish. Mercury is particularly dangerous in this respect, which has led to many incidents of seriously poisoning of humans. The most well known accident is the Minimata case in Japan in the 1950ies and 60ies (c.f. Canuel et al 2006) where a factory over many years had released methyl mercury into the waters where people were fishing for daily consumption. Large carnivorous fish are those with the highest concentrations of heavy metals in their body flesh. We therefore tried to catch big fishes from the impacted river stretch for the study.

The results from analyses of fish are given in **Table 1**. Except for the small *Hainania serrata* of 10 g, where the whole fish was analysed as a mixed sample, the other samples are from bone free fish filets. The result from the *Hainania serrata* analysis is strongly impacted by the "sediment-containing" gut contents, and is not comparable with the results from the other fishes.

The *Bagarius yarelli* is a purely carnivorous fish, while the large *Spinibarbichthys denticulatus* is mainly a plant eater, which however also eats insect larvae and small bottom worms in periods. The highest concentration of mercury was found in large carnivorous *Bagarius yarelli* from the Thon 2 area, which is in the central part of the gold dredging area. The maximum value of 0.18 µg/g (= 0.18 ppm) must however be regarded as rather low. WHO has 0.5 ppm Hg as a general limit for human consumption. In the 6.5 kg *Spinibarbichthys denticulatus*, the concentration was only 0.005 ppm. In Sweden they use 1 ppm mercury in the flesh as a general limit for consumption. In some lakes in Norway and Sweden, which have been polluted with mercury from pulp and paper industry, the mercury content in big carnivorous fish can be found as high as 10 ppm and above (cf. Berge 1983).

All the other elements in the fish filet analyses showed low values of no concern with respect to eating the fish in Song Bung River.

Table 1. Concentrations of mercury and other heavy metals in the flesh of fishes in the reach of Song Bung River impacted by gold mining.

Site	Fish species	Weight	As	Cd	Co	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
		gr.	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g
Thon 2	<i>Spinibarbichthys denticulatus</i>	6500	<0,05	0.019	0.016	0.13	0.412	18.9	0.005	0.471	0.03	<0,02	7.82
Khe Vinh	<i>Hainania serrata</i>	10	0.335	0.055	0.187	0.83	1.24	348	0.084	16	0.35	0.215	62.3
Thon 2	<i>Tor Strachey</i>	3400	<0,05	0.03	0.017	0.2	0.561	25.8	0.11	0.513	0.043	0.02	10.4
Pa Di	<i>Bagarius Yarelli</i>	2500	<0,05	0.011	0.018	0.33	0.585	14.2	0.11	0.346	0.053	<0,02	9.38
Thon 2	<i>Bagarius Yarelli</i>	3000	<0,05	0.019	0.011	0.17	0.267	6.6	0.18	0.339	<0,02	<0,02	5.81
Tra Vinh	<i>Spinibarbichthys denticulatus</i>	80	0.058	0.03	0.012	0.14	0.303	12.6	0.06	0.512	0.027	0.024	6.81

The fact that no metal accumulation was found in the fish, confirms the findings of low, and environmentally insignificant, values of heavy metals both in the water phase and the sediment phase in the Song Bung River and tributaries.

It is believed that the mercury contamination of fish in many rivers, like for example in the Amazon, is due to this gold mining using mercury as extraction technique (ref. Castilhos et al 2004). However, it is metallic mercury that is used and this is not very bio-accumulative. Recent research indicates that it may be the mobilisation of methyl

mercury from deforestation in the Amazon catchment that is the reason for much of this environmental contamination that the gold mining has been blamed for. It is the burning of coal and heavy oil that is the main source for the diffuse mercury contamination of the world wilderness areas. It is widely spread through atmospheric fallout and it binds to the organic material, both living biomass and organic material in the soil. Deforestation accelerates the mineralisation of forest litter, wheel tracks causes drainage, which causes mineralisation and erosion of top soils. All this results in leakage of organic mercury, which is highly bio-accumulative in fish (c.f. Willis 2006).

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