NATIONALE ZOOLOGISCHE COLLECTIE VAN SURINAME/CENTRUM VOOR MILIEU-ONDERZOEK

FINAL TECHNICAL REPORT MERCURY POLLUTION IN THE GREENSTONE BELT

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Forward

Over the past decades, researches have concluded that human related mercury emissions have increased significantly in the atmosphere approximately 3-5 folds over the pre-industrial times and the rate of deposition is concomitantly higher. These releases are very well documented by UNIDO's Global Mercury Project, European Environmental Bureau, Mercury Policy Project, Mercury Advocate Groups (BAN HG-WG, Zero Mercury Working Group, Health Care Without Harm) and WWF Guianas among others. The researches on environmental mercury contamination have been largely driven by the health risk of methylmercury exposure which results from the consumption of some fish species, aquatic mammals and shell fish.

From a scientific prospective, it is evident that the global mercury problem is driven by emissions into the air, followed by atmospheric transport, deposition and eventually the biological transformation and accumulation in the aquatic ecosystem. These events cause significant risks for the human population and wildlife. Mercury is now considered as a major global pollutant and is even observed in areas that do not release mercury to the environment, for example the Arctic region.

The developing fetus, infants and young children are the most vulnerable to damages by mercury and mercury related compounds. Methylated mercury- the widely available form in fishes higher up in the food chain, affects the development of the brain and central nervous system. It can alter nerve cell migration in the fetal brain, and interferes with nerve cell differentiation and division-preventing normal brain structure. Even at low levels of prenatal exposure, symptoms of neurological effects have been observed.

Mercury is threatening fish as a local food source in the Guianas. It is the most widely available form of protein for indigenous and maroons groups. Contamination of this important food source can bring about serious economic and health problems to these communities.

The recent spike in gold prices has caused an increase in small and medium scale goldmining activities where mercury amalgamation is the preferred method of recovery. Mercury amalgam is heated in most cases in open air releasing mercury vapor. This source is considered by many experts as one of the highest contributors to the anthropogenic levels to the environment (approximately 800-1000t/yr). Several persons from the interior communities and their families are exposed to the toxic forms of mercury.

Appropriate mercury regulations and restrictions in the Guianas are lacking and wherever there are laws, the enforcement is often inadequate. In French Guiana for example, the use of mercury for mining was banned from January 2006; however, enforcement of this new law is minimal because of the large insurgent of illegal miners from neighboring countries, and the regulatory agencies lack of financial and personnel resources to take appropriate action.

WWF Guianas Forestry Project, through its Goldmining Pollution Abatement Component, is working in collaboration with several regulatory agencies, educational institutions, indigenous and maroons groups, miners' associations and several other stakeholders to reduce the impact on the environment. Some of these initiatives include: the support for improve mining regulations, education and awareness campaigns on mercury and other environmental issues, supporting regulatory institutions to improve the management of the sector, promoting best practices for miners including mercury free techniques and the use of mercury retorts, and monitoring of mercury in the environment. These activities come under the team of "**leaving a living planet for our future generations**".

Rickford Vieira
Regional Goldmining Pollution Abatement Coordinator
WWF Guianas

EXECUTIVE SUMMARY

The increase gold mining activities in the interior have caused significant destruction to aquatic ecosystems. Surface sheet-wash contributes substantially to an increasing sediment load in streams and rivers. This has a negative impact on aquatic biota and can result in complete changes in biota diversity of aquatic ecosystems.

Because of irresponsible use of mercury during gold mining activities, mercury enters the aquatic ecosystem and accumulates in biota, especially in biota on the highest level of the food chain, e.g. predatory fishes. Fish is the most important protein source of villagers in the interior. By eating these fishes, villagers may endanger their health.

During this study an overview was made of the mercury pollution in the Greenstone Belt, where most gold mining activities occur. The results were compared with data gathered also in control sites, which are located southeast of the gold mining sites and localities, which are northeast of the gold mining sites. High mercury concentrations have been found for water, bottom sediment and predatory fish in gold mining sites, control sites and sites downstream of the gold mining sites. This means that the control sites and the sites downstream of the gold mining sites are affected by the gold mining activities as well. It is suspected that through atmospheric transportation, mercury is transported to upstream sites and causes pollution in these sites. More research is needed to confirm this.

Downstream sites are probably polluted by the transportation of mercury with water and sediment/organic particles from the upstream areas.

Measurements for turbidity in the gold mining sites show that the sediment load in the streams and rivers cause high levels for turbidity. These levels exceed international standards for turbidity in aquatic ecosystems and will negatively impact the biodiversity of biota in these systems.

A study was also done on the relation between fish consumption and measured mercury concentrations in hair of villagers of the Poesoegroenoe area and the Nieuw Jacobkondre area. It can be concluded that consumption of predatory fish is positively related to increased mercury concentration in the human body. To avoid mercury poisoning, villagers must avoid eating predatory fishes with high mercury concentration. The most important fishes that must be avoided to consume, are: *Serrasalmus rhombeus*, *Hoplias aimara*, *Hoplias marabaricus* and *Cichla ocellaris*. It is also recommended to avoid big predatory fishes, because accumulation of mercury is positively related to the length of fish (Lindqvist, 1991).

CONTENT

TABLES AND FIGURES

1. PREFACE

From the ’80 on, gold mining activities have increased exponentially in Suriname. The activities are mainly carried out in the northern and southeastern part of the Greenstone Belt, a volcano-sedimentary series of the Armina Formation composed of mafic to intermediate volcanics, associated with meta-gabbros and intercalated with meta-cherts and phyllites, meta-sandstones, meta-conglomerates with local meta-volcanics. Siltstones, sandstones and conglomerates with intermediate volcanics, called Rosebel Formation are found in the Rosebel area, west of the Brokopondo village. The primary gold deposits as well as the gold placers occur in the northern and the southeastern part of the Greenstone Belt (Pollack et al, 1998).
During the process of gold extraction, mercury is used for the amalgamation process. The amount of mercury used for the amalgamation process is dependent on the expected amount of gold. It is estimated that for every kilogram of gold, one kilogram of mercury enters the environment (Veiga, 1997) when the amalgam is being heated and the mercury evaporates to the atmosphere. With rainfall mercury is deposited in aquatic and terrestrial ecosystems. Mercury also enters the environment directly, for example when the mats of the sluice box, which can have rest of mercury on it, are being washed in creeks and rivers.
Mercury has a very negative impact on aquatic ecosystems. Mercury is easily taken up by organisms, which will result in accumulation of mercury in the food chain. Humans may be affected as they eat fish polluted with mercury, causing a variety of clinical symptoms. Because of the different fate of the chemical forms of mercury in humans and their pattern, the severity of the clinical symptoms are dependent on the form of mercury and the kind of exposure. The most toxic form of mercury, methyl mercury, is a well-established neurotoxicant that can have serious adverse effects on the central nervous system, the area of the brain regulating the sensory, visual, auditory functions and coordination (IPCS, 1990).

This report gives an overview of the mercury pollution in the Greenstone Belt of Suriname, in areas without gold mining activities and in areas, downstream the Greenstone Belt, who are also affected by the upstream gold mining activities. Areas mostly affected by the mercury pollution are indicated and changes over time are also documented.
This report also presents the results of a study done on the fish consumption pattern of local communities of the Poesoegroenoe area and the Nieuw Jacobkondre area.

This study has been carried out by the Center for Environmental Research (CMO), an institute of the Anton de Kom University of Suriname. With this study, CMO, wants to make decision makers and the community aware of the problems related to the use of mercury in the gold mining activities, so measures can be taken to abandon the use of mercury in gold extraction activities and to make use of other present alternatives. Villagers should also be informed about healthy food strategies to avoid mercury poisoning.

1.1 Goal

The goal of this project is to produce an overview of mercury pollution in the Greenstone Belt in Suriname to help focus decision-makers and project developers to the most affected areas and to increase awareness about the seriousness and extend of mercury pollution.

1.2 Objective

Produce an overview of mercury pollution in the Greenstone Belt.

1.3 Outputs

The following outputs have been set for this project:

1. Upgrading of CMO laboratory
2. Completion of first series of surveys in 19 selected sites on mercury pollution and fish consumption patterns in two selected sites (2004)
3. Preliminary mapping of areas most seriously affected (2004)
4. Preliminary technical report on mercury pollution and fish consumption patterns of local communities (2004)
5. Completion of second series on survey on mercury pollution of 19 selected sites (2005)
6. Mapping of areas most seriously affected (2005)
7. Second technical report on mercury pollution in the Greenstone Belt (2005)
8. Comparative analysis of 2004 and 2005 results and analysis of trends in mercury pollution

1.4 Project Activities

Project activities started November 2003. According to the agreement, the project should be finished by October 2005. Due to unforeseen circumstances, the project activities were extended to May 2006.
For each output a set of project activities were planned.

Table 1 gives an overview of the activities planned during the implementation of the project and the level of achievement for each project activity.

	Activity	Level of achievement
1.	**Upgrading of CMO laboratory**	
1.1	Purchase of equipment and materials	Achieved
1.2	Improvement of CMO laboratory infrastructure	Achieved
1.3	Training of 3 employees of CMO in ArcView mapping techniques	Achieved
1.4	Development of method for the destruction of hair samples	Achieved
1.5	Presentation of monitoring protocol and the selected water quality parameters	Achieved
2.	**Completion of first series of survey on mercury pollution and fish consumption patterns of two selected sites**	
2.1	Sampling of water, bottom sediment, fish and human hair at the selected sites during dry season 2004 and measurement of the selected various water quality parameters	Partly achieved
2.2	Conduct meetings with selected communities to inform them and raise awareness on mercury pollution	Partly achieved
2.3	Interviews to determine fish consumption patterns of selected local communities during the dry season 2004	Achieved
2.4	Analysis of samples for mercury levels dry season 2004	Achieved
2.5	Sampling of water, bottom sediment, fish and human hair at selected sites during the rainy season and measurement of various water quality parameters	Achieved
2.6	Interviews to determine fish consumption patterns of selected local communities during the rainy season	Achieved
2.7	Analysis of samples of mercury levels	Achieved
3.	**Preliminary technical report on mercury pollution and fish consumption patterns of local communities (2004)**	
3.1	Preparation of overview mercury pollution	Achieved
3.2	Preparation of overview fish consumption pattern of local communities	Achieved
3.3	Determining risky food fish and possible advice on more healthy fish consumption patterns	Achieved
3.4	Presentation of preliminary results at Regional Workshop in Suriname	Not achieved
4.	**Preliminary mapping of areas most seriously affected (2004)**	
4.1	Identification of areas most seriously affected by mercury pollution	Achieved
4.2	First digital mapping of areas most seriously affected by	Achieved

	mercury pollution	
5.	**Completion of second series on survey on mercury pollution of 22 selected sites**	
5.1	Second set of sampling water, bottom sediment, fish and human hair at the selected during dry season and measurement of the selected water quality parameters	Achieved
5.2	Presentation of preliminary results in the different communities	Partly achieved
5.3	Analysis of second set of samples of mercury levels	Achieved
5.4	Second set of sampling water of bottom sediment, fish and human hair at the selected sites during the rainy season and measurement of the selected water quality parameters	Achieved
5.5	Analysis of second set of samples of mercury levels	Achieved
6.	**Second technical report on mercury pollution in the Greenstone Belt (2005)**	
6.1	Preparation of overview of mercury pollution	Achieved
6.2	Presentation of the second technical report on mercury pollution in the Greenstone Belt	Not achieved
7.	**Mapping of areas most seriously affected (2005)**	
7.1	Completion of mapping of areas mostly affected by mercury pollution	Achieved
8	**Comparative analysis of 2004 and 2005 results and analysis of trends in mercury pollution**	
8.1	Comparison of data with former data on mercury levels	Achieved
8.2	Analysis and description of trends in mercury pollution	Achieved
8.3	Presentation of results to the scientific community (lecture)	Not achieved
8.4	Presentation of comparative results at regional workshop in Cayenne	Not achieved
8.5	Publication of monitoring results	Achieved

Table 1. An overview of the activities planned during the implementation of the project and the level of achievement for each project activity.

2. STRATEGIES AND METHODOLOGIES

In cooperation with the Institute for Biodiversity and Environmental Education and Research (IBER), CMO was supplied with all needed equipment for the measurements of the water quality parameters and the analysis of mercury in the water, bottom sediment and fish samples.

2.1 Field activities

According to the sampling localities selected in the project proposal, a sampling schedule was set up for each sampling period (short dry season 2004, long rainy season 2004, short dry season 2005 and long rainy season 2005). Sampling localities were reached by plane, car or boat. To work efficiently, sampling localities were grouped to be reached in one period. After the first sampling period, some changes have been made in the sampling localities. Some areas, for example Java, were very difficult to reach. Alternative localities were selected for these areas. The localities have been divided in: gold mining sites, control sites (upstream of the gold mining sites) and sites which are downstream of the gold mining sites.

River/Riversystem	**Gold mining site**	**Control site**	**Downstream gold mining site**
Marowijne (with Lawa River and Tapanahoni River)	Benzdorp	Anapaike	Albina
	Drietabbetje	Tepoe	Galibi
	Stoelmanseiland		
Suriname River	Brokopondo Lake (east and west)	Pikin rio	Klaaskreek
	Piki Pada		Pomona
	Grankreek		
Saramacca River	Nieuw Jacobkondre	Poesoegroenoe	Kwakoegron
			Santigron
			Boskamp

Table 2. An overview of the selected sampling sites

For each trip a team was selected which consist of one or two field assistants and one researcher.

The research team consisted of the following people:
- Dr. P. Ouboter Project coordinator
- Dr. J. Mol Researcher
- Drs. F. van der Lugt Researcher
- Drs. J. Quik Researcher

- G. Landburg BSc.	Coordinator logistics/Field assisstant
- R. Jairam	Field assistant
- U. Satnarain	Field assistant
- J. Metjo	Chemical analyst/field assistant
- I. Nanden - Asraf	Chemical analyst/field assistant
- C. White	Consultant fish consumption study

During the field trips, the team members tried to inform the local communities on the results and to advice them on healthy fish consumption strategies. The head of the district Brokopondo, advised us not to present data to the local communities, because he was afraid of any confrontation between the local communities and the government on the subject of mercury pollution.

2.2 Sampling

At each site, water quality parameters were measured and samples were taken of water, bottom sediment, and fish for the mercury measurements.

2.2.1 Water sampling

Water was analyzed for the following parameters:

- temperature
- pH
- conductivity
- dissolved oxygen
- turbidity (or secchi depth)
- alkalinity
- chloride
- tannin-lignin (humic acids)
- aluminum
- iron
- mercury

At each locality, temperature, pH, conductivity and dissolved oxygen were measured electro-chemically with portable Hach meters, near the left and the right shore and in the middle of the stream.
At the same localities 1 L samples were taken and mixed in a white plastic container. From this mixed 3 L sample, three 300 mL samples are taken in pre-cleaned PET-bottles, containing 0.5 mL concentrated ultra-pure nitric acid. These bottles were pre-cleaned with hydrochloric acid, nitric acid and distillated water. These 300 mL samples were transported to the laboratory on ice and used for the analysis of aluminum and iron. Mercury was taken in the middle of the stream sampled. The remainder of the 3 L sample was used for analysis of the rest of the remaining parameters: Alkalinity and chloride were determined titrimetric, using a digital titrator. Tannin-lignin was measured with a

Hach colorimeter, while turbidity was measured colorimetric with a Hach turbidity meter/colorimeter or a secchi disc (depending on availability).

2.2.2 Sediment sampling

Bottom sediment is sampled in shallow water or at low tide near the left and right shores of a stream. It is sampled with 100 mL polypropylene containers, covered and transported to the laboratory on ice. Containers were pre-cleaned with hydrochloric acid, nitric acid and distillated water.

2.2.3 Fish sampling

At each locality, predatory fish are caught with gill nets overnight or bought from local fishermen. In the field the standard length (exclusive the tail) is measured and the fish are weighed and identified. If possible a piece of muscle tissue is sampled from the lateral side below the dorsal fin and weighted as well. This sample (or the whole fish) is carefully packed in plastic bags and transported to the laboratory on ice. If the fish cannot be identified in the field, they are taken whole for later identification in the laboratory.

2.2.4 Laboratory analysis

Mercury measurements were carried out with a Bacharach mercury analyzer, using the "Cold Vapor Atomic Absorption" technology (Clesceri et al. 1998).
Sediment samples are dried at room temperature where after they are ground. From the finely ground samples 0.5 g is weighted in 250 ml BOD bottles and 2.5 ml concentrated H_2SO_4 and 2.5 ml concentrated HNO_3 is added and left overnight at room temperature. Samples are digested for 1 hour at 75 ºC, where after they are diluted with 100 ml deionised water. 15 ml $KMnO_4$ 5% is added to each sample. After 15 minutes the sample are once again placed in a water bath for 2 hour at 95 ºC. After cool off, 6 ml natriumchloridehydroxylamine hydrochloride and 5 ml $SnCl_2$ is added to the samples and the absorption can be measured.
For fish samples, 0.5 g is weighted for sample analysis. The destruction and measurement phase is the same as mentioned above.
To check the accuracy of the analysis, standard solutions of mercury are analyzed before the samples are measured. A quality control is developed to check the results of the analyses through regression analysis.

2.3 Fish consumption study

At two selected sites, Poesoegroenoe (non-mining site) and Nieuw Jacobkondre (mining site), in the Saramacca River, a fish consumption study was carried out during the project. The goal of the research was to assess the quality and quantity of protein intake among populations at risk of mercury poisoning in Suriname. Of particular interest was the amount of mercury (in g) consumed of different fish species. The local people were asked to contribute human hair for the mercury analysis.

This research is aimed at linking fish consumption to mercury levels in the general population not directly associated with small scale gold mining and to identify risky consumption patterns. An understanding of the relation between diet and the symptoms associated with chronic mercury toxicity will allow us to make recommendations to decrease health risks of vulnerable groups, such as pregnant women and prepubescent children.

The first sample site was the Nieuw Jacobkondre area (sample site #1). It consisted of four village clusters; Misolibbe, Nieuw Jacobkondre, Balen, and Belowatra. This site is easily accessible, as daily flights are available to this region. There is at least one continually operated store in each village, with a total of eight stores in continuous operation. This cluster also boasts a clinic, primary school, electricity, and two telephone lines. At the time of the study the population count was approximately 150 residents.

The second sample site was Poesoegroenoe region (sample site #2), the study area, consisted of six village clusters; Baetel, Poesoegroenoe, Toetima, Tevreden, Soekibakka, Pietie, and Padua. This region was accessible mainly by chartered flights, or a boat trip of 4 days in the dry season. In terms of services, electricity was only available at a clinic in Toetima, while there where no schools within this area. Due to these factors the population in this area is considerably lower, with a total population of approximately 75 individuals.

To assess the feasibility of the study, the survey format was tested beforehand at Nieuw Jacobkondre. However, it was not possible to test the survey in the Poesoegroenoe sample region due to cost and time constraints. On the basis of this pretest, a final survey instrument was developed. Questions that posed skeptical results were excluded from the final survey. During this period, two research assistants from the village were selected and later trained to collect hair samples and dietary information. All data were systematically collected and recorded in the local language by the local surveyors and when feasible the primary researcher.

The targeted number of households for each sample region was fifteen. In Poesoegroenoe a total of 13 households, spread over 7 villages, were assessed. However, due to increased volunteering because of the perceived health threat caused by local small-scale gold mining, 29 households were assessed from the Nieuw Jacobkondre study area in both seasons.
Households were identified and included in the study based on the presence of target individuals: pregnant women and children between the ages of six and twelve who were willing to participate (Clarkson, 2002). The average age of the child sample group from both regions was 7. In the Nieuw Jacobkondre region 11 pregnant women were included in the study while 1 was included from the Poesoegroenoe study area. Each participating household received a small monetary compensation for their time.

Socio-demographic variables regarding age, sex, education, work status, health conditions, and length of occupancy in the sample region were collected for each individual who physically resided in the household. This data allowed the researchers to determine the household size and composition, mobility, exposure to education, and non-traditional sources of livelihood. The qualitative data also helped to determine the awareness of participants of the sources and causes of mercury contamination.

Health status data was recorded during the wet and dry season rotations. The goal was to assess whether or not individuals reported any symptoms of chronic mercury toxicity such as numbness, dizziness, impaired hearing or vision, and or, slurred speech to their local health care provider within the past year. In addition, to ascertain if they were currently prescribed medication associated with these symptoms. It should be noted that many reports of dizziness and or body pains were often associated with malaria, which has a high incidence in the gold mining region.

Dietary data was collected through daily surveys of protein intake during a two-week rotation in both the wet and dry season. Interviews were conducted to identify variations in lifestyle that may influence dietary patterns.

Fish dietary data were recorded for each participating household at two mealtimes during the sampling rotation. Moreover, to assess a more realistic volume of household consumption, additional data were recorded whenever the opportunity arose. For accuracy and clarity fish were visually identified with the aid of a color identification chart and or photographed and labeled with the local name. Before the daily meal was to be prepared, all the fishes were counted and the total length and the wet weight of all the fishes were measured.

The dietary survey focused on:

(1) Sources of fish from the city, self caught, or obtained as a gift
(2) Species identification
(3) The status of each fish sample before consumption: fresh, dried, or salt preserved
(4) Method of preparation: boiled or fried
(5) Other types of protein, which can contribute to mercury intake

3. RESULTS

3.1 Water quality

Tables 1a, 1b, 1c and 1d in appendix 1 gives an overview of the average results for the water quality measurements.

The pH of all waters sampled was slightly acidic to neutral. (5.13 – 7.60). Low pH was found at Santigron in both dry (average pH = 5.13) and wet season (average pH = 5.53) and in Poesoegroenoe in the wet season (average pH = 5.23).

In general, conductivity is lower in the Interior than in the Coastal Plain. (Ouboter, 1993). The lowest measurement for conductivity was at Tepoe (average: 15.08 μS/cm, wet season) in the Tapanahoni River. Low measurements for conductivity were also found in localities in the Saramacca River (Kwakoegron (average: 17.60 μS/cm, dry season; average: 18.93 μS/cm, wet season) and at Drietabbetje, in the Tapanhoni river, for both wet and dry season (average: 18.05 μS/cm/ average: 17.23 μS/cm).

Because of the turbulence, which favors aeration, the oxygen content in most rivers in the Interior is very high (> 5.5 mg/l). Low oxygen content is found in the Coastal Plain at the localities Pomona (average: 3.22 mg/l, wet season) and Santigron (3.97 mg/l, wet season).

For salinity, high measurements for chloride were found in the Coastal Plain (> 5 mg/l Cl), but in the Interior low levels were found (< 3 mg/l Cl).

High turbidity levels were found for all rivers in the Coastal Plain. This, because of the influence of the Guyana current, which runs before the coast of Suriname. In the Interior high levels for turbidity were found at the gold mining sites Brokopondo Lake (average: 48.96 NTU, dry season; average: 60.9 NTU, wet season), Grankreek (average: 31.4 NTU, dry season), Stoelmanseiland (average: 32.27 NTU, dry season) and Benzdorp (average: 28.4 NTU, dry season).

The highest levels for the metals, aluminium and iron, were found in the Coastal Plain at the localities Galibi (average Al: 2.3 mg/l, dry season; 2.12 mg/l, wet season; average Fe: 8.1 mg/l, dry season; 5.75 mg/l, wet season), Pomona (average Al: 2.89 mg/l, dry season; average Fe: 8 mg/l, dry season) and Boskamp (average Al: 37.5 mg/l, dry season, 20.88 mg/l, wet season; average Fe: 54 mg/l, dry season; 27.75 mg/l, wet season). High levels of iron were found in the gold mining sites of the Interior, Piki Pada (average Fe: 2 mg/l, dry season; 4 mg/l, wet season) and Gran kreek (average Fe: 1.71 mg/l, dry season; 1.59, wet season).

The form in which mercury will be present in the aquatic ecosystem is dependent on the water quality, especially the pH and the chloride concentration (vanLoon et al, 2000).

With a pH between 5 and 7, mercury can be present as Hg^{2+} and can form complexes with other complexing agents for example organic matter (as result methyl mercury) and chloride $HgCl_2$ (aq).

3.2 Mercury

Table 2 in Appendix 1 gives an overview per river system of the results of the analysis of mercury in water, sediment and predatory fish for both dry and wet season. Predatory fishes caught during the surveys and used for data analysis are:

- *Hoplias aimara* (124)
- *Serrasalmus rhombeus* (181)
- *Hoplias marabaricus* (28)
- *Cichla ocellaris* (15)
- *Brycon falcatus* (2)
- *Plagioscion squamosissimus* (33)

A total of 383 fishes of the species mentioned above were caught during the survey. From the sampled fishes 62.4% of Serrasalmus rhombeus (113), 25% of Hoplias aimara (31), 53.3 % of Cichla Ocellaris (8), 17.9 % of Hoplias marabaricus (5) and 18.2 % of Plagioscion squamosissimus (6) were above the international standard (0.5 µg/g).

The focus is mainly on *Hoplias aimara* and *Serrasalmus rhombeus* because they are caught in all river systems assessed and in general they show the highest mercury concentrations. They are also most consumed by the local people. Data of *Hoplias aimara* and *Serrasalmus rhombeus* are shown in histograms, while data for all predatory species can be found in table 3.

All levels are compared to international standard (WHO) for mercury levels acceptable for aquatic ecosystems: 0.1 µg/l for mercury in water, 0.14 µg/g for mercury in bottom sediment and 0.5 µg/g for mercury in fish. Appendix 2 gives maps with an overview of mercury in water, bottom sediment and fish. International standards are also included.

3.2.1 Suriname River

Figure 1 gives the average of the mercury level in the Suriname River for water, bottom sediment, *Hoplias aimara* and *Serrasalmus rhombeus* for all sampling periods.

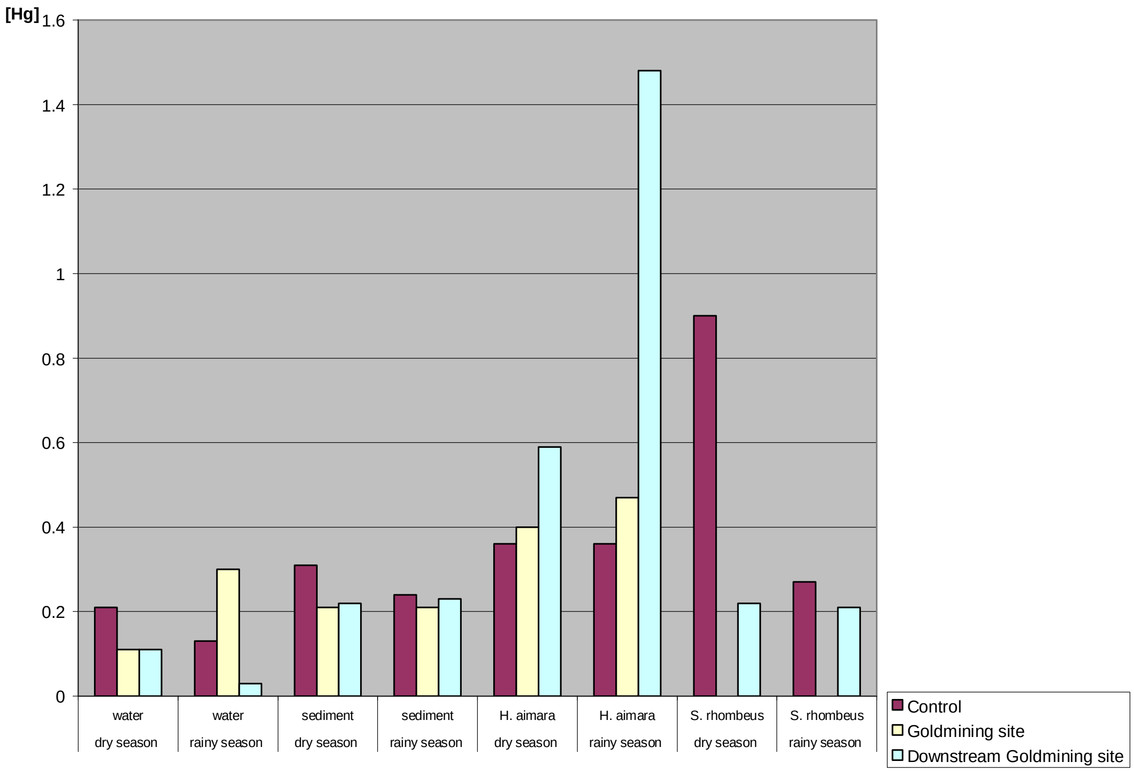

Figure 1. The average level of mercury in water, bottom sediment, Hoplias aimara and Serrasalmus rhombeus for localities in the Suriname River

The highest levels of mercury in water were found at the gold mining sites in and around the Brokopondo Lake: in the Lake (average: 0.11 µg/l, dry season; 0.28 µg/l, wet season), Piki Pada (average: 0.57 µg/l, wet season) and Grankreek (average: 0.13 µg/l, dry season). In the first year of sampling a mercury concentration of 1.06 µg/l, wet season (10 x the international standard) was measured in the Brokopondo Lake (see also Appendix 2, Maps).
The control site Pikin rio, showed also a high level for mercury (0.21 µg/l, dry season; average: 0.13 µg/l, wet season). The downstream site, Klaaskreek showed a high level for mercury in the dry season (0.11 µg/l) and a low level in the wet season (average: 0.03 µg/l). See also Appendix 2, Maps.

High levels for mercury in sediment were found at all gold mining sites (> 0.15 µg/g), at the control site, Pikin rio (> 0.24 µg/g) and in all downstream sites (> 0.22 µg/g). See also Appendix 2, Maps.

The highest level for mercury in *Hoplias aimara* was found at the downstream site Klaaskreek (average: 0.59 µg/g, dry season; 1.48 µg/g, wet season), while for *Serasalmus rhombeus*, high levels were found at all gold mining sites (>1.16 µg/g): the Brokopondo Lake showed levels of 1.637 µg/g in the first year and 1.36 µg/g in the second year. The control site also showed high levels for mercury in *Serasalmus rhombeus* (0.902 µg/g, dry season). The downstream site, Klaaskreek, shows low levels of mercury in *Serasalmus rhombeus* (< 0.218 µg/g). See also Appendix 2, Maps.

3.2.2 Saramacca River

Figure 2 gives the average of the mercury level in the Saramacca River for water, bottom sediment, *Hoplias aimara* and *Serrasalmus rhombeus* for all sampling periods.

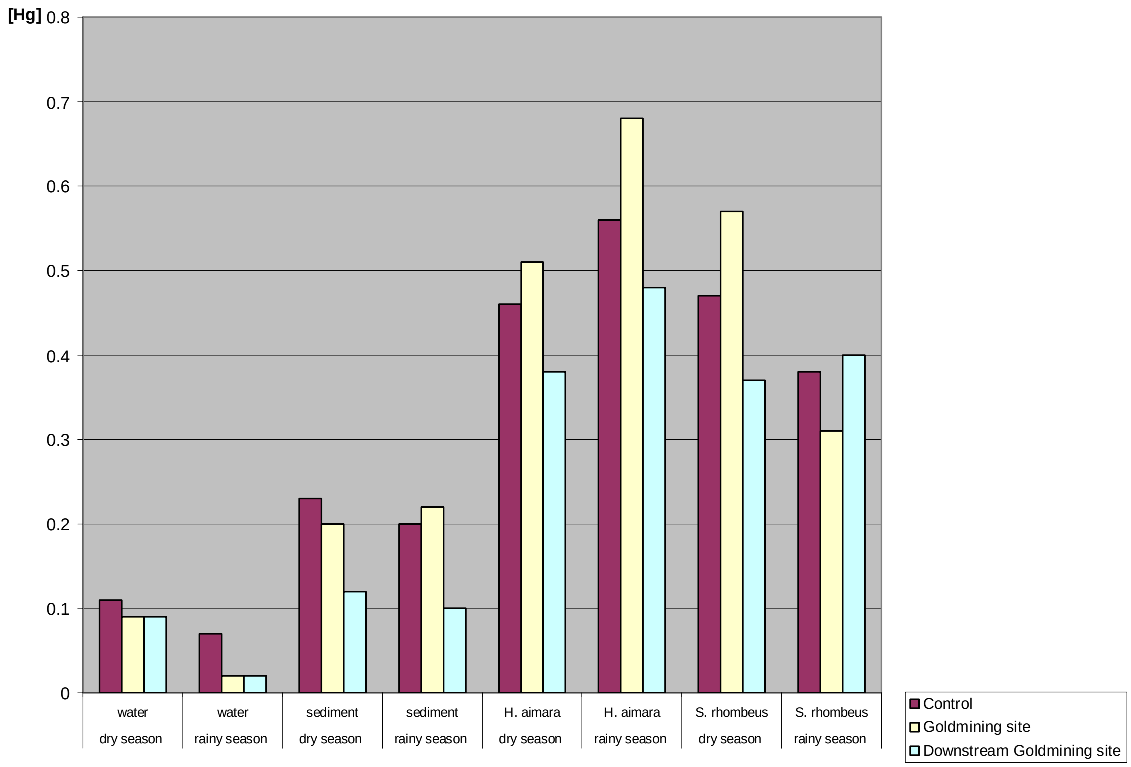

Figure 2. The average level of mercury in water, bottom sediment, Hoplias aimara and Serrasalmus rhombeus for localities in the Saramacca River

High levels for mercury in water were found at the gold mining site Nieuw Jacobkondre (0.13 µg/l, dry season), the control site, Poesoegroenoe (0.11 µg/l, dry season) and in the downstream site Santigron (0.13 µg/l, dry season). All other localities showed level < 0.08 µg/l). See also Appendix 2, Maps.

Both the gold mining site and the control site, showed high levels for mercury in sediment for both dry and wet season (> 0.2 µg/g). High levels were found at the downstream sites Kwakoegron (average: 0.15 µg/g, dry season; 0.14 µg/, wet season) and Santigron (average: 0.14 µg/g, dry season). See also Appendix 2, Maps.

For *Hoplias aimara*, high levels were found at Nieuw Jacobkondre (average 0.51 µg/g, dry season; 0.68 µg/g, wet season) and in Poesoegroenoe (average:0.56 µg/g, wet season). High levels for mercury in *Serrasalmus rhombeus* were found at Nieuw

Jacobkondre (average: 0.57 µg/g, dry season) and at Kwakoegron (average: 0.64 µg/g, dry season; 0.61 µg/g, wet season). See also Appendix 2, Maps.

3.2.3 Tapanahoni River

Figure 3 gives the average of the mercury level in the Tapanahoni River for water, bottom sediment, *Hoplias aimara* and *Serrasalmus rhombeus* for all sampling periods.

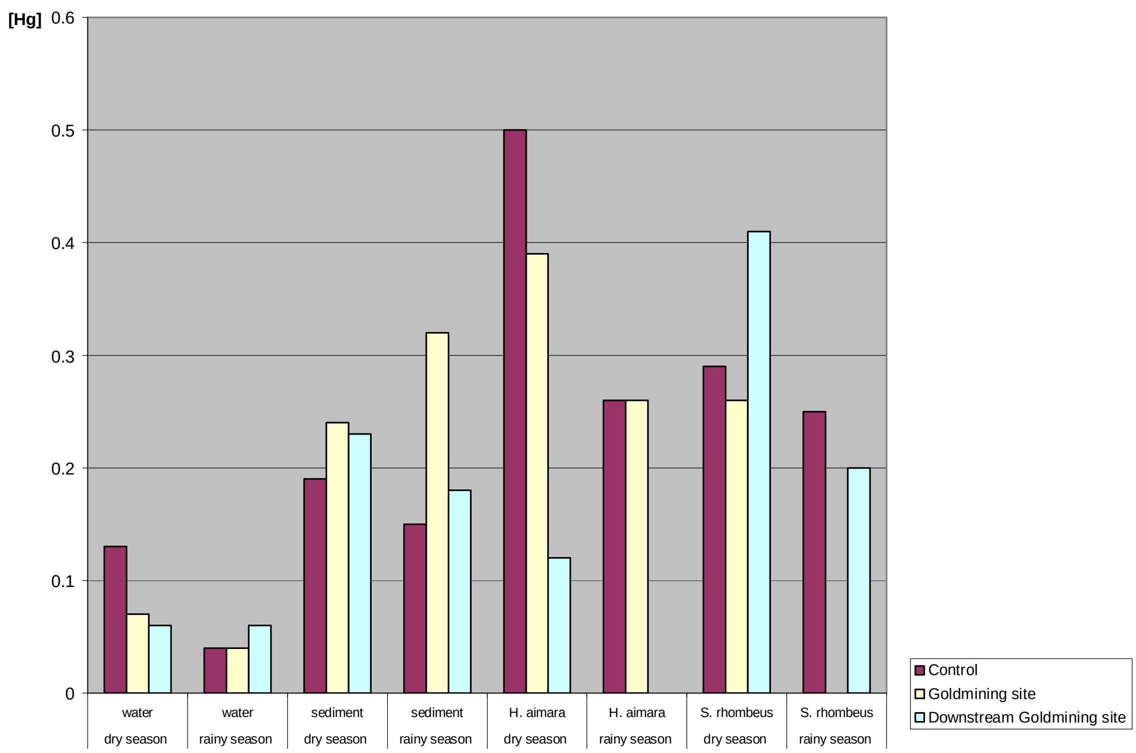

Figure 3. The average level of mercury in water, bottom sediment, Hoplias aimara and Serrasalmus rhombeus for localities in the Tapanahoni River

Low levels for mercury in water were found at all gold mining sites and the downstream sites (< 0.07 µg/l). The control site, Tepu, showed a level of 0.13 µg/l in the dry season. See also Appendix 2, Maps.

High levels for mercury in bottom sediment were found at all gold mining sites, the control site and the downstream sites for both dry and wet season (> 0.15 µg/g). See also Appendix 2, Maps.

For *Hoplias aimara*, low mercury levels were found at the gold mining sites Drietabbetje (average: 0.34 µg/g, dry season; 0.12 µg/g, wet season) and Stoelmanseiland (average: 0.44 µg/g, dry season; 0.39 µg/g, wet season). The downstream site Albina showed a mercury level in the dry season of 0.12 µg/g. The control site Tepoe showed a mercury level of average 0.5 µg/g in the dry season and average 0.26 µg/g in the wet season.

Low levels were found for *Serrasalmus rhombeus* at all localities (<0.41 µg/g) for both sampling periods. See also Appendix 2, Maps.

3.2.4 Lawa River

Figure 4 gives the average of the mercury level in the Tapanahoni River for water, bottom sediment, *Hoplias aimara* and *Serrasalmus rhombeus* for all sampling periods.

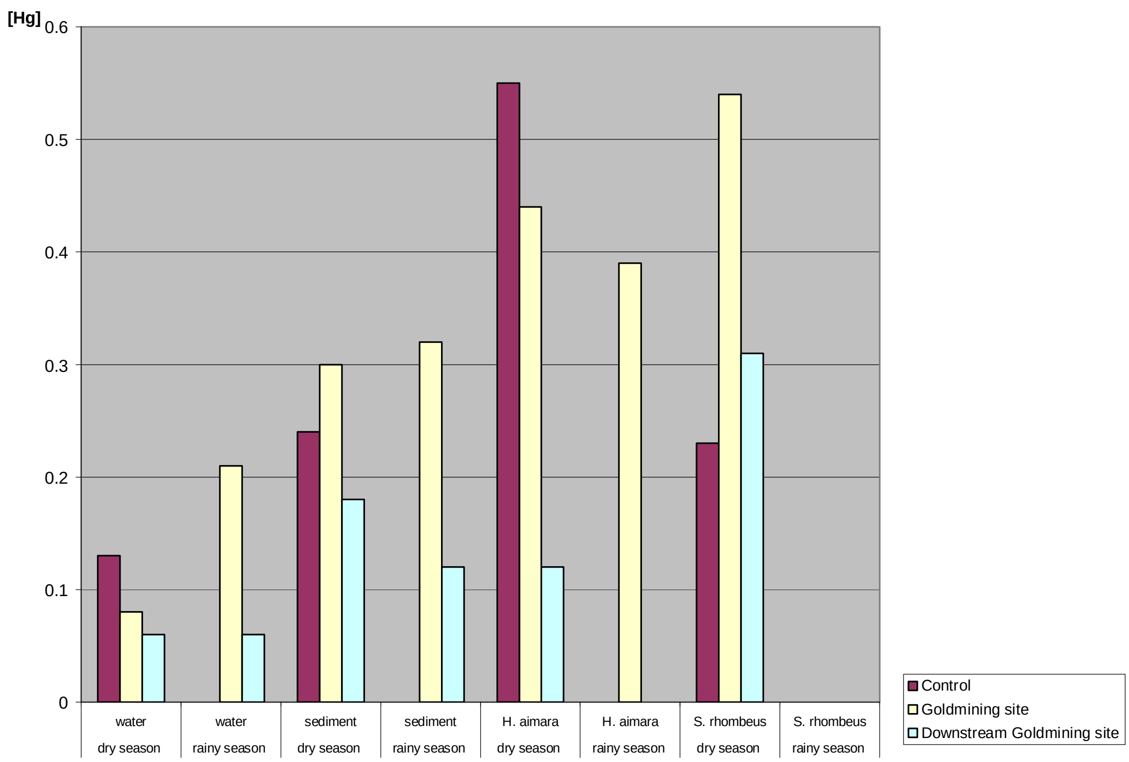

Figure 4. The average level of mercury in water, bottom sediment, Hoplias aimara and Serrasalmus rhombeus for localities in the Lawa River

High levels for mercury in water were found at the control site Anapaike (0.19 µg/l, dry season) and at the gold mining site Benzdorp (0.39 µg/l, wet season). All other localities showed low levels of mercury (< 0.08 µg/l) for both sampling periods. See also Appendix 2, Maps.

High levels for mercury in bottom sediment were found at all locations for both sampling periods (> 0.17 µg/g), except for the downstream locality Albina (average: 0.12 µg/g, wet season). See also Appendix 2, Maps.

High levels for mercury in *Hoplias aimara* at the control site Anapaike (average: 0.55 µg/g, dry season). For the downstream site and the gold mining site mercury levels were below 0.44 µg/g for both sampling periods. For *Serrasalmus rhombeus* high levels were found at the gold mining site Benzdorp (average: 0.7 µg/g, dry season). All other localities showed levels < 0.41 µg/g for all sampling periods. See also Appendix 2, Maps.

Table 4 gives an overview of all predatory fishes caught. These fishes were not caught in all river systems during the sampling periods.

	CONTROL	SITES	GOLD MINING	SITES	DOWNSTR GOLD	MINING SITES
	Dry season	**Wet season**	**Dry season**	**Wet season**	**Dry season**	**Wet season**
Serrasalmus	0.47± 0.264	0.3 ± 0.057	0.79 ± 0.519	0.97 ± 0.426	0.34 ± 0.206	0.3 ± 0.179
rhombeus						
Hoplias aimara	0.47 ± 0.07	0.39 ± 0.125	0.42 ± 0.056	0.3 ± 0.181	0.36 ± 0.192	0. 98 ± 0.500
Hoplias	0.17 ± 0.027	0.26 ± 0.132	0.52 ± 0.106	0.36 ± 0.021		0.36 ± 0.057
marabaricus						
Plagioscion				0.39 ± 0.255	0.43 ± 0.308	0.29 ± 0.106
squamosissimus						
Cichla occelaris		0.37	0.33 ± 0.085	0.55 ± 0.198	0.48 ± 0.057	0.33
Brycon falcatus		0.07		0.25		

Table 4. Average mercury concentrations in Hoplias marabaricus, Plagioscion squamosissimus, Cichla Ocellaris and Brycon falcatus for all sampling periods.

Fish consumption by locals includes both predatory and non-predatory fishes. Although predatory fishes contribute the most to mercury intake, it is important to know the mercury intake with the consumption of non-predatory fishes. During the second sampling period of the second year, non predatory fishes that have been caught in the gill nets were also taken for mercury analysis. Table 5 gives an overview of the mercury concentrations in non-predatory fishes. All results of the measurements were under the international standard.

Species	**Family**	**GOLDMINING SITES**	**CONTROL SITES**
Leporinus friderici	Anostomidae	0.065 ± 0.007	0.08 ± 0.021
Leporinus lebailli	Anostomidae	0.105 ± 0.007	
Leporinus Maculata	Anostomidae	0.07 ± 0.064	
Poptella brevispina	Characidae		0.18
Geophagus surinamensis	Cichlidae	0.14 ± 0.03	0.07 ± 0.033
Geophagus harreri	Cichlidae	0.17 ± 0.057	0.085 ± 0.007
Prochilodus reticulatus	Curimatidae	0.11 ± 0.042	
Curimata cyprinoides	Curimatidae	0.19	0.1 ± 0.023
Semaprochilodus varii	Curimatidae	0.07 ± 0.016	
Platydoras cf dentatus	Dorаridae	0.12	
Doras cf micropoeus	Doraridae	0.185 ± 0.005	
Hemiodus unimaculatus	Hemiodidae	0.11	
Pseudancistrus barbatus	Loricariidae	0.07± 0.01	
Hypostomus gymnorhynchus	Loricariidae	0.068 ± 0.039	0.045 ± 0.007
Metaloricaria paucidens	Loricariidae	0.18	
Hypostomus Ventromaculatus	Loricariidae		0.05 ± 0.021
Pachypops fourcroi	Scianidae	0.12	
Myleus rubripinnis	Serrasalmidae	0.015 ± 0.0071	0.04 ± 0.011
Myleus ternetzi	Serrasalmidae	0.01	0.01
Myleus rhomboidalis	Serrasalmidae	0.00	
Acnodon oligacanthus	Serrasalmidae	0.005	0.01± 0.007

Table 5. An overview of mercury concentrations in non-predatory fishes

3.3 Fish consumption survey

3.3.1 Fish consumption patterns

Fish proves to be the main source of food among the Maroon people in both sampling regions. Fish is caught in the rivers and creeks around the villages with lines and gillnets. During the dry season, when the water level is lower an additional method of fishing is used, called ‘Neku hunting’. Neku is a root used to stun or numb the fish in shallow waters. Fishers throw pieces of Neku pulp in the shallow pool where fishes are trapped and the root paralyzes or numbs the fishes, which are then easily caught.
A total of 42 species of fishes (see table 6) were documented during both sampling seasons: 19% predatory species and 81% non-predatory species. Expressed in total biomass, there is a difference in the consumption of predatory fish and non predatory fish for the dry and the wet season (see figure 6). In de dry season more predatory fish is being consumed in both sampling region (69% in Poesoegroenoe and 72% in Nieuw Jacobkondre) than nonpredatory fish (31% in Poesoegroenoe and 28% in Nieuw Jacobkondre). In the wet season less predatory fish is being consumed in Nieuw Jacobkondre (39%) than predatory fish (61%), while in Poesoegroenoe more predatory fish is being consumed (75%) than non predatory fish (25%).
The most common predatory species eaten in the Poesoegroenoe region are *Brycon falcatus*, *Serrasalmus rhombeus* and *Hoplias aimara* for both sampling periods. In the Nieuw Jacobkondre area, the most common predatory species eaten are *Serrasalmus rhombeus*, *Hoplias aimara* and *Cichla ocellaris*.

Fish Species Variety	**Poesoegroenoe**		**Nieuw Jacobkondre**	
	Dry Season	**Wet Season**	**Dry Season**	**Wet Season**
Acestrorhynchus falcatus		288		
Alogohdi*		40		
Brycon falcatus	1330	2506	60	246
Brycon pesu		40	122	
Charax pauciradiatus		58		
Cichla ocellaris		138	7290	1652
Crenicichla albopunctata		6		254
Cynodon aff. Gibbus	206	196		
Cyphocharax punctata		3000		
Cyphocharax spilurus		986		
Doras cf. Micropoeus	376	1444		
Geophagus surinamensis	72	170		
Guianacara owroewefi		106		
Haritia surinamensis		154		
Helogenes marmoratus				366

Hemiodus unimaculatus		156	186	
Hoperythrinus unitaeniatus				160
Hoplias aimara	12000		653	714
Hoplias malabaricus		832		
Hypostomus gymnorhynchus	120		674	
Hypostomus ventromaculatus		4		2750
Kakafissi*		1800		
Kamusu*		1862		
Kesesi*				4
Krobia itanyi		36		136
Leporinus fasciatus	590	852		826
Leporinus gossei	626	2806	2158	1970
Leporinus maculatus		8		
Leporinus nijsseni		12		
Moenkhausia georgiae	278	786	2964	976
Moenkhausia oligolepis		55		
Myleus rhomboidalis	1586	3104	660	1055
Myleus rubripinnis	2230	580		
Pimelodella geryi			186	72
Pimelodus ornatus	36			
Prochilodus reticulatus ssp.	234			
Pseudoplatystoma fasciatum		50000		
Schizodon fasciatum		12		
Semaprochilodus varii	787			
Serrasalmus rhombeus	3566	1148	9737	2084
Triportheus rotundatus	266	122		
Wanakoe	218			
Total	**24521**	**73307**	**24690**	**13265**

Table 6. The total biomass of each fish species consumed for the two sampling regions during dry and wet seasons.

3.3.2 Alternative Protein Consumption

During the dry season 100% of all households sampled at Nieuw Jacobkondre reported consuming at least one other protein in the form of bush meat (white-lipped peccary, *Tayassu pecari*, and collared peccary, *Tayassu tajacu*), a variety of wild fowl, and domesticated fowl eggs. Only 50% of Poesoegroenoe households reported consuming any variety of these proteins at this time. In the wet season there was a 50% decrease in the consumption of white-lipped peccary, collared peccary, fowl, and or egg consumption in this location (see table 3 in Appendix 1).

3.3.3 Mercury measurements in human hair

Table 7 gives an overview of the people of both sampling regions, who contributed hair. Besides the target group (children between 6 and 12, pregnant women and women with new born), two people from the New Jacobkondre area, the captain and his wife, also contributed hair.

	POESOEGROENOE	**NIEUW JACOBKONDRE**
CHILDREN		
Boys	10	5
Girls	3	12
WOMEN		
Pregnant	1	5
Women + new born child		5
Others		2

Table 7. Overview of people of the Poesoegroenoe area and the Nieuw Jacobkondre area who contributed hair

Table 8 gives the results of the mercury analysis on hair samples collected from people from the Poesoegroenoe area and the Nieuw Jacobkondre area. A detailed overview with mercury level per person can be found in table 3 of Appendix 1.

	POESOEGROENOE	**NIEUW JACOBKONDRE**
CHILDREN		
Boys	6.92 ± 2.874 (3.56 – 12.11 µg/g)	3.454 ± 1.308 (1.70 – 5.25 µg/g)
Girls	5.53 ± 1.562 (3.4 – 7.10 µg/g)	3.432 ± 2.113 (0.95 – 7.75 µg/g)
WOMEN		
Pregnant	2.08	3.706 ± 2.045 (1.65 – 6.10 µg/g)
Women + new born child		2.85 ± 1.989 (0.51 – 6.10 µg/g)
Others		3.345 ± 2.485 (0.86, 5.83 µg/g)

Table 8. Average results of mercury in hair from the target groups in the Poesoegroenoe and the Nieuw Jacobkondre area.

An average on mercury in hair samples among all above mentioned categories, gives for the Poesoegroenoe area 6.28 ± 2.85 and for the Nieuw Jacobkondre area 3.44 ± 2.02. Compared with the NOAEL (no observed adverse effect level), set by the WHO of 10 µg/g in hair (UNEP, 2002) shows that 14% of the assessed villagers of the Poesoegroenoe area have a mercury concentration higher than the NOAEL (12.11 µg/g, 11.17 µg/g). Remarkable was that these high mercury concentrations were measured in two children of 6 and 12 years old. None of the villagers of the Nieuw Jacobkondre area had a mercury concentration higher than the NOAEL.

4. DISCUSSION

4.1 Gold mining sites versus control sites versus downstream sites

The purpose of the mercury overview is to describe the pollution by mercury in the gold mining sites. These sites are compared to the mercury pollution in the control sites, which are located upstream of the gold mining sites and which wouldn't be influenced by the gold mining activities in the downstream located gold mining sites. A comparison is also made between the gold mining sites and the sites which are located downstream the gold mining sites.
Except for the high turbidity in the coastal areas, which is caused by the Guyana current, high turbidity levels are found in the gold mining sites (see table 1 in Appendix 1). The gold mining activities result in an increasing sediment load in streams and rivers. Increasing turbidity results in changes in the abundance of present biota in streams and rivers (Mol & Ouboter, 2003). Increasing turbidity also results in polluting of high quality drink water for the local people in the gold mining areas. Comparison of the measured turbidity levels with the water quality guidelines set by the EPA (inducing of 5 NTU when background is less than or equal to 50 NTU) shows that some of the gold mining sites, for example Lake Brokopondo already exceeded these standards.

Figure 5 gives the average levels of the mercury levels for water, bottom sediment, *Hoplias aimara* and *Serrasalmus rhombeus* in the gold mining sites, the control sites and the sites downstream of the gold mining sites. The figures in Figure 5 show that high levels for mercury are also found in the control sites. This means that the control sites are also affected by the gold mining activities northeast. During the surveys the research team was informed by some people in the Pikin rio area that occasionally gold miners are surveying in the Pikin rio area. It wasn't clear if the gold mining activities were permanent.
High mercury concentrations were also found in some areas in West Suriname (Ouboter, Quik & Mol, 2003), areas without gold mining activities (Lucie River: average of 0.72 µg/g for *Hoplias aimara*; Amatopo (Corantijn): average of 0.66 µg/g for *Hoplias aimara*, average of 0.79 µg/g for *Serrasalmus rhombeus*). Because these areas are free from gold mining activities, the origin of the mercury could only be natural (through erosion of bed rock) or by atmospheric transportation. Areas in Central Suriname (Central Suriname Nature Reserve) with another geological formation as in the areas mentioned above showed also high mercury concentrations in water, bottom sediment and fish. Study on the geological formations in West and Central Suirname resulted in the absence of mercury in these formations. With this information mercury can be excluded as a source of mercury emission in these areas (Landburg, 2005). Atmospheric transportation of mercury seems to be the only source of mercury in these areas. With the north-east wind mercury can be transported to Central and South Suriname, where it possibly can be deposited with rainfall. Through high rainfall at the lee side of the mountain ranges in Central and South Suriname, deposition of mercury can be stimulated in these areas. More research on this subject is needed to confirm this hypothesis.

Figure 5 shows also that high concentrations of mercury are found downstream of the 'gold mining'sites. Especially sediments show high concentrations of mercury (average 0.15 µg/g in dry season; 0.14 µg/g in wet season). All the rivers with intensive gold mining activities upstream (Suriname River, Marowijne River with the Lawa and the Tapanhoni River and the Saramacca River) show high levels of mercury in sediments downstream. It is possible that mercury is transported from the gold mining sites to the downstream sites and accumulates there in bottom sediment. High mercury concentrations are also found in fish (average *Hoplias aimara*: 0.98 µg/g). This means that the downstream sites are also affected by the gold mining activities upstream.
There is a significant difference between the gold mining sites, the control sites and the downstream sites for water, dry season in the second sampling year and for bottom sediment, dry season in the second sampling year ($P < 0.05$). Overall there is no noticeable difference between the mercury concentrations found in water, bottom sediment, *Hoplias aimara* and *Serrasalmus rhombeus* from the gold mining sites, the control sites and the downstream sites.

Kruskal-Wallis Test	Result
Water	
Dry season 2004	-
Rainy season 2004	P > 0.5
Dry season 2005	P < 0.05
Rainy season 2005	P > 0.9
Bottom sediment	
Dry season 2004	P > 0.5
Rainy season 2004	P > 0.1
Dry season 2005	P < 0.05
Rainy season 2005	P > 0.995
Hoplias aimara	
Dry season 2004	P > 0.1
Rainy season 2004	P > 0.9
Dry season 2005	P > 0.995
Rainy season 2005	P > 0.1
Serrasalmus rhombeus	
Dry season 2004	P > 0.1
Rainy season 2004	P > 0.5
Dry season 2005	P > 0.5
Rainy season 2005	P > 0.1

Table 9. Results of the Kruskal-Wallis test for a significant differences in [Hg] between the gold mining sites, the control sites and the downstream gold mining sites for water, bottom sediment, Hoplias aimara and Serrasalmus rhombeus. The highlighted cells indicate that there is a significant difference.

Other areas outside of the gold mining areas are also affected by the use of mercury in the gold mining activities (see Appendix 2, Maps). Through atmospheric transportation, areas southwest of the gold mining area may be affected by mercury pollution, while mercury is transported by water and fish to areas downstream of the gold mining areas.

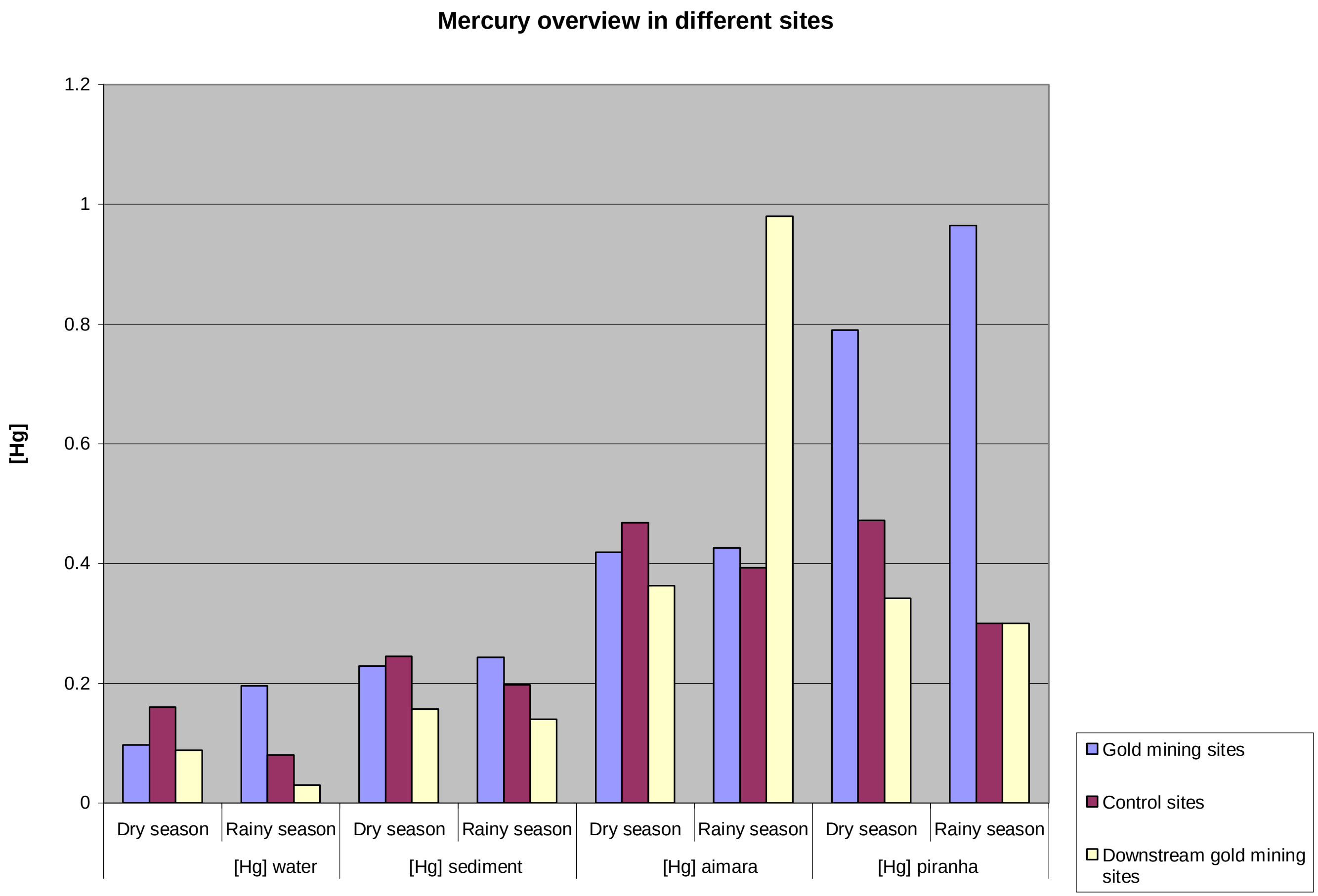

Figure 5. The average levels of the mercury for water, bottom sediment, Hoplias aimara and Serrasalmus rhombeus in the gold mining sites, the control sites and the sites downstream of the gold mining site

4.2 Dry season versus rainy season

In the rainy season lower levels of mercury are expected in the aquatic ecosystem. Due to rainfall, more water enters the aquatic ecosystem, which favors the dilution effects of the concentration of chemical compounds. From Figure 5 it is clear that in the gold mining sites the highest levels for mercury in the aquatic ecosystem are found in the rainy season. Because of the need for water for the gold mining activities, the rainy season is favorable for gold mining activities. At the control sites and the downstream sites, lower levels are found in the rainy season. No noticeable difference was found for water, bottom sediment, *Hoplias aimara* 2004 and *Serrasalmus rhombeus* 2004/2005 ($P > 0.1$). For Hoplias aimara 2005 a significant difference ($P < 0.025$) was found between the wet season and the dry season.

4.3 Year 1 versus year 2

Samples have been taken over a period of two years (2004 and 2005). By personal observations, it seems that the gold mining activities have increased in the second year. But the levels of mercury in some of the areas were much lower than the first year. There is a noticeable difference ($P > 0.1$) between the mercury levels of year 1 and year 2. Data on rainfall of the second year show that during the long rainy season there was a high rainfall average in the gold mining sites (324.05 mm). These data were compared to the average rainfall during 1978 – 1987 (230.29 mm) (Meteorological Service Suriname). Rainfall data of 2004 was not available to make any comparison between 2004 and 2005. High rainfall can result in dilution in the aquatic ecosystem and also lower measured levels for mercury.

4.4 Fish consumption study

Although there are no gold mining activities in the Poesoegroenoe area, the villagers show a higher average level of mercury in hair (6.28 ± 2.85) than the villagers of the Nieuw Jacobkondre area (3.44 ± 2.02). From the villagers of the Poesoegroenoe area 14% show mercury concentrations higher than NOAEL. The mercury levels measured are lower than the average measured in four Wayana populations in French Guiana :11.4 ± 4.2 µg/g (Fréry, N. et al, 2001). In the USA (McDowell M.A. et al, 2004) mercury concentrations in women and children are lower (women: 0.2 ± 0.02 µg/g, children: 0.12 ± 0.01 µg/g) than in the Poesoegroenoe and Nieuw Jacobkondre area.

Correlated with fish consumption, it can be stated that the villagers of the Poesoegroenoe area eat more predatory fish than non-predatory fish (see figure 6). The high mercury levels measured can be a result from the high consumption of predatory fish. Due to incomplete data gathering it is not possible to estimate the daily mercury intake for the villagers (Fréry, N. et al, 2001).

Another explanation can be the position of Poesoegroenoe near the mountain ranges in Central and South Suriname. If the hypothesis of high deposition of mercury, near the mountain ranges in Central and South Suriname is correct, villagers of the Poesoegroenoe area are also exposed to this deposition. This can favor accumulation of mercury in human body. More research is needed to confirm this.

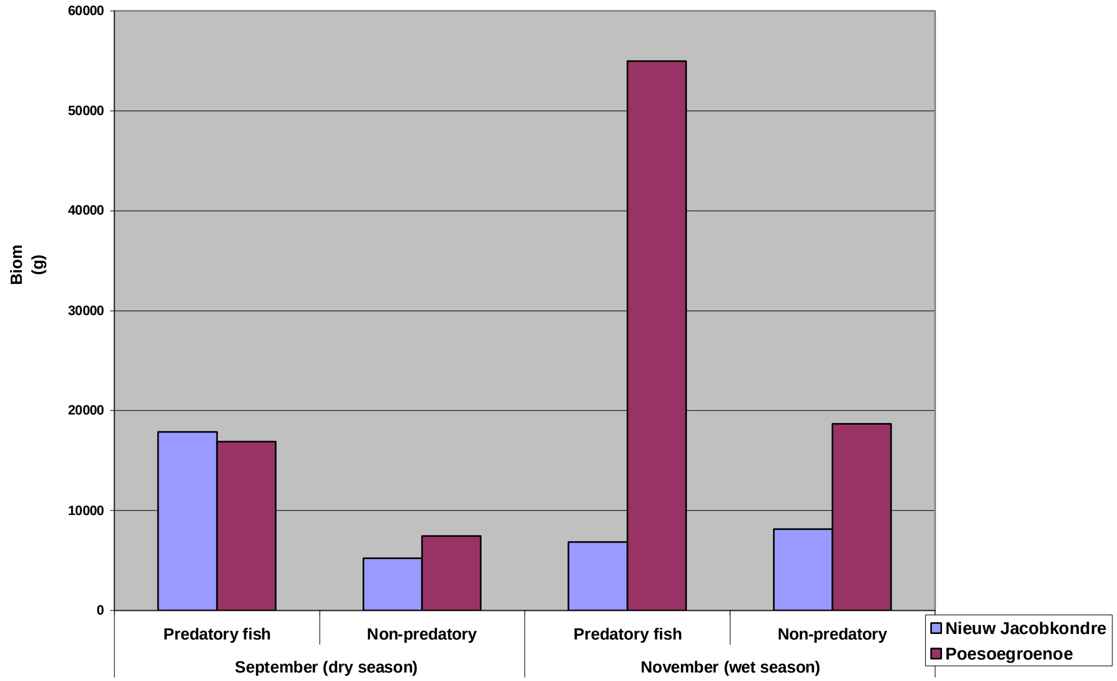

Figure 6. Fish consumption pattern in Poesoegroenoe and Nieuw Jacobkondre

5. CONCLUSIONS AND RECOMMENDATIONS

- Due to gold mining activities mercury levels are increasing in the aquatic ecosystem of the gold mining sites. The quality of the aquatic ecosystems in these areas is also decreasing because of draining of waste water of gold mining activities in the rivers and creeks. This has resulted in increased turbidity in these rivers and creeks and inducing of mercury in the aquatic ecosystem. Villagers, who are very dependable on these aquatic ecosystems for their drink water and fish, endanger their health by drinking polluted water and consuming fish with high mercury concentrations.
An alternative method for gold extraction needs to be implemented and the use of mercury prohibited so that further destruction of the aquatic ecosystem can be prevented. A monitoring program should also be set up to guarantee rehabilitation of these areas.

- Control sites are also affected by the northeast located gold mining sites. Possible explanations are that through atmospheric transportation, mercury is transported to upstream localities. This can result in high mercury levels in the aquatic ecosystem of the control sites. According to the high levels of mercury in hair samples, it can be concluded that also the villagers upstream are affected by the gold mining activities northeast. This could be related to atmospheric transported mercury. Further study on atmospheric transportation in the upstream sites is needed to assess this problem.

- Consumption of predatory fishes contributes to the intake of mercury in the human body. This can result in chronic mercury poisoning, which can be seen in changes in the function of e.g. the nervous system. To prevent mercury poisoning, villagers must avoid predatory fish, especially the big ones, that shows high levels of mercury, but eat more non-predatory fish. The following table gives a list of predatory fishes which should be avoided eating.

Scientific name	**Local name**
Cichla ocellaris	Tukunari
Hoplias aimara	Anjoemara
Hoplias marabaricus	Pataka
Serrasalmus rhombeus	Piranha

Table 14. Predatory fishes which should be avoided eating

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APPENDIX 1

- **Table 1a. Average results of water quality analyses – dry season 2004/2005**
- **Table 1b. Average results of water quality analyses – dry season 2004/2005 (con't)**
- **Table 1c. Average results of water quality analyses – wet season 2004/2005**
- **Table 1d. Average results of water quality analyses – wet season 2004/2005 (con't)**
- **Table 2. Results of mercury analysis on water, bottom sediment and fish per river system**
- **Table 3a. Fish consumption survey, Nieuw Jacobkondre Area, dry season**
- **Table 3b. Fish consumption survey, Nieuw Jacobkondre Area, wet season**
- **Table 3c. Fish consumption survey, Nieuw Jacobkondre Area, dry season**
- **Table 3d. Fish consumption survey, Nieuw Jacobkondre Area, wet season**

TABLE 1A. AVERAGE RESULTS OF WATER QUALITY ANALYSES - DRY SEASON 2004/2005

Locality	Secci	Temp	pH	Con	DO
	(cm)	(ºC)		(µS/cm)	(mg/l)
GOLD MINING SITES					
Lake Brokopondo		30.38 ± 1.324	7.18 ± 0.002	31.87 ± 2.186	6.84 ± 1.029
Nw Jacob Kondre		29.3 ± 1.881	6.58 ± 0.368	22.69 ± 1.86	7.71 ± 1.138
Piki pada	71.67	30.49 ± 1.011	6.97 ± 0.184	20.14 ± 6.456	7.23
Grankreek	67.5	26.34	7.17	32.05	6.89
Benzdorp	28.33	26.51 ± 0.092	6.36	20.82 ± 2.666	5.51 ± 1.032
Drietabbetje	33.34	27.87 ± 0.898	5.8 ± 1.46	18.05 ± 2.786	7.39 ± 0.445
Stoelmanseiland	68.33	26.49 ± 0.014	6.3 ± 0.66	19.5 ± 3.415	7.56 ± 0.389
CONTROL SITES					
Poesoegroenoe		27 ± 0.8	5.47 ± 0.332	21.55 ± 1.344	6.1 ± 0.21
Pikin Rio		27.62 ± 0.453	6.1 ± 0.88	20.12 ± 4.787	6.7 ± 0.29
Tepoe		25.71 ± 1.096	6.38 ± 0.247	16.74 ± 3.91	6.82 ± 0.785
Anapaike	73.33	26.41 ± 0.057	6.11	17.19 ± 3.231	6.47
DOWNSTR GOLDM SITE					
Montresor		28.65± 0.354	6.8 ± 0.28	39.22 ± 22.22	6.4 ± 1.188
Pomona	21	28.29 ± 1.676	7.61 ± 0.269	16.46 ± 7.71	7.21 ± 0.806
Galibi	17	29.125 ± 0.035	7.2 ± 1.0	23.52 ± 14.96	7.29 ± 0.12
Santigron	48	29.73	5.13	34.27	4.59
Klaaskreek		27.39 ± 1.252	6.96 ± 0.368	20.6 ± 7.92	7.24 ± 0.53
Kwakoegron		28.85 ± 2.192	6.13 ± 1.174	17.6 ± 5.23	5.64± 1.973
Albina		27.2	7.1	20.51	4.54
Boskamp	9	28.5	6.6	673.67	5.37

Temp - *Temperatuur, Con* - *Conductivity, DO* - *Dissolved oxygen*

TABLE 1B. AVERAGE RESULTS OF WATER QUALITY ANALYSES - DRY SEASON 2004/2005

Locality	Alk	Cl	Turb	Al	Fe	Tan-Lig
	(mg/l)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)
GOLD MINING SITES						
Lake Brokopondo	7.07 ± 0.702	3.78 ± 1.564	124	0.12 ± 0.025	0.2 ± 0.09	0.55 ± 0.173
Nw Jacob Kondre	3.2 ± 1.10	4.25 ± 1.626	13.24 ± 0.757	0.38 ± 0.099	0.86 ± 0.247	1.4 ± 0.16
Piki pada	6.6 ± 2.76	4.2 ± 1.84	12.17	0.27 ± .014	0.63 ± 0.078	1.4 ± 0.28
Grankreek	10.9	10		0.32	1.71	1.4
Benzdorp	3.75 ± 0.837	3.8 ± 0.57	28.4	0.58 ± 0.219	1.27 ± 0.085	1.5 ± 0.14
Drietabbetje	2.84 ± 1.464	5.65 ± 4.738	9.1	0.36 ± .148	0.62	1.67 ± 0.94
Stoelmanseiland	3.25 ± 1.768	3.1	32.27	0.37 ± 0.021	0.98 ± 0.283	1.3 ± 0.42
CONTROL SITES						
Poesoegroenoe	1.7 ± 0.28	3.8 ± 2.12	14.02 ± 3.748	0.33	0.5	0.95 ± 0.636
Pikin Rio	2.75 ± 0.919	4.8 ± 3.82	7.04 ± 0.191	0.33 ± 0.148	0.66 ± 0.057	1.9 ± 0.42
Tepoe	2.4	3.75 ± 2.051	8.97 ± 3.344	0.22	0.65 ± 0.2	2.05 ± 0.212
Anapaike	3.75 ± 0.837	3.6 ± 0.14	16.27	0.46	0.93 ± 0.134	1.0 ± 0.3
DOWNSTR GOLDM SITE						
Montresor	33.5 ± 14.85	> 1000	202	1.87	2.39	lim/10.0
Pomona	48.65 ± 9.546	>1000	107	5.4	14.4	lim/10.0
Galibi	51.5 ± 26.16	>1000	253.5 ± 9.19	2.3 ± 0.28	8.1 ± 3.96	lim/10.0
Santigron	2.8	15	55	0.67	2.12	3.4
Klaaskreek	14.5 ± 10.67	6.15 ± 5.445	20	0.4 ± 0.14	1.01	0.85 ± 0.354
Kwakoegron	10 ± 4.2	9 ± 4.2	30	0.72	1.08	1.7 ± 0.99
Albina	2	12	33	0.72	1.22	2
Boskamp	9	150		37.5	54	4.5

Alk - Alkalinity, Cl - Chloride, Turb - Trubidity, Al - Aluminium, Fe - Ijzer,Tan Lig - Tannin Lignin

TABLE 1C. AVERAGE RESULTS OF WATER QUALITY ANALYSES - WET SEASON 2004/2005

Locality	Secci	Temp	pH	Con	DO
	(cm)	(°C)		(µS/cm)	(mg/l)
GOLD MINING SITES					
Lake Brokopondo	21	30.388 ± 0.796	6.97 ± 0.450	33.5	6.77 ± 0.351
Nw Jacob Kondre	130	27.85 ± 1.344	6.5	23.83 ± 5.996	7.43 ± 0.035
Piki pada	80	29.49 ± 0.969	6.42 ± 1.054	20.29 ± 4.363	5.56
Benzdorp	39	26.8	6.36	26.33	6.64
Grankreek	75	25.16 ± 0.863	6.38 ± 0.396	32.47 ± 2.878	7.79 ± 0.445
CONTROL SITES					
Poesoegroenoe	150	26.47 ± 0.332	5.23	18.93 ± 3.076	6.88 ± 0.064
Pikin Rio	143.33	27.45 ± 1.344	6.09 ± 0.87	19.64 ± 2.348	6.74
Tepoe	48	25.37 ± 1.131	6.1 ± 1.03	15.08 ± 1.867	7.59
Anapaike					
DOWNSTR GOLDM SITE					
Montresor	153	26.8	7.8	349.6	0.55
Pomona	49	28.07	6.83	16.12	3.22
Galibi		32.1 ± 0.141	7.3	104	6.66 ± 0.332
Santigron		28	5.53	144.13	3.97
Klaaskreek	95	28.62 ± 0.021	5.77 ± 0.368	25.54 ± 1.506	5.45 ± 0.085
Kwakoegron	48.33	28.5 ± 2.26	5.97 ± 0.198	141.7	5.73 ± 1.867
Albina	9	29.6 ± 0.95	6.1	142.97	7.17 ± 0.247
Drietabbetje	95	27.97 ± 2.213	6.3 ± 0.21	17.23 ± 0.10	7.09 ± 1.141
Stoelmanseiland	48.33	28.45 ± 0.537	6.82 ± 0.728	23.22 ± 3.231	7.17
Boskamp	9	27.73	7.1	373	5.28

Temp - Temperatuur, Con - Conductivity, DO - Dissolved oxygen

TABLE 1D. AVERAGE RESULTS OF WATER QUALITY ANALYSES - WET SEASON 2004/2005

Locality	Alk	Cl	Turb	Al	Fe	Tan-Lig
	(mg/l)	(mg/l)	(NTU)	(mg/l)	(mg/l)	(mg/l)
GOLD MINING SITES						
Lake Brokopondo	7.7 ± 0.50	3.85 ± 0.778	165	0.11 ± 0.044	0.22 ± 0.095	0.4
Nw Jacob Kondre	3.85 ± 1.485	3.7 ± 1.84	28.8	0.31 ± 0.007	0.91± 0.438	1.2 ± 0.28
Piki pada	4.45 ± .636	4.65 ± 1.344	10.57	0.44 ± 0.41	2 ± 1.3	1.8 ± 0.57
Benzdorp	8.1	1.7	19	0.35	1.12	1
Grankreek	9.15 ± 2.616	7.8	31.4	0.2 ± 0.05	1.59 ± 0.057	0.9 ± 0.14
CONTROL SITES						
Poesoegroenoe	2.9 ± 0.14	3.3 ± 1.70	9.33	0.23 ± 0.049	0.54 ± 0.049	0.9 ± 0.14
Pikin Rio	3.5 ± 0.42	3.65 ± 1.768	10.77	0.28 ± 0.099	0.79 ± 0.085	1.3 ± 0.14
Tepoe	2.6 ± 1.27	4.5	6.73	0.29 ± 0.134	0.59 ± 0.071	1.0 ± 0.3
Anapaike						
DOWNSTR GOLDM SITE						
Montresor	10.3	92	202	6.15	11	5.2
Pomona	57.6		107	6	4	8.1
Galibi	43 ± 4.2	6600	208 ± 55.2	4.05	11	9.6 ± 0.57
Santigron	5.1	3.7	26	0.26	1.74	2.8
Klaaskreek	8.45 ± 2.475	16	23	0.27 ± 0.12	0.87 ± 0.453	0.9 ± 0.14
Kwakoegron	6.45 ± 0.845	3.75 ± 1.344	28 ± 19.8	0.41 ± 0.092	1.27 ± 0.226	1.9 ± 0.71
Albina	7.5	3.5	25 ± 0.7	0.53 ± 0.148	1.51 ± 0.156	1.55 ± 0.212
Drietabbetje	2.7 ± 1.27	3.55 ± 1.202	13.63	0.57 ± 0.148	0.73 ± 0.085	1.1 ± 0.14
Stoelmanseiland	5.7 ± 1.70	3.45 ± 0.919	18.43	0.48 ± 0.134	0.99 ± 0.332	1.1 ± 0.424
Boskamp	36	13	154	4.25	11.5	7.5

Alk - Alkalinity, Cl - Chloride, Turb - Trubidity, Al - Aluminium, Fe - Ijzer,Tan Lig - Tannin Lignin

TABLE 2 Results of mercury analysis on water, bottom sediment and fish per river system

Riviersysteem	WATER		SEDIMENT		*HOPLIAS AIMARA*		*SERRASALMUS RHOMBEUS*	
	dry season	rainy season	dry season	rainy season	dry season	rainy season	dry season	rainy season
SARAMACCA RIVER								
Control	0.11	0.07	0.23	0.2	0.46	0.56	0.47	0.38
Goldmining site	0.09 ± 0.029	0.02 ± 0.008	0.2 ± 0.04	0.22 ± 0.037	0.51	0.68	0.57 ± 0.27	0.308 ± 0.215
Downstream Goldmining site	0.09	0.02	0.117	0.097	0.38	0.48	0.37	0.395
SURINAME RIVER								
Control	0.21	0.13	0.31	0.24	0.36	0.36	0.902	0.27
Goldmining site	0.113 ± 0.012	0.297± 0.217	0.21±0.049	0.207± 0.019	0.403 ± 0.011	0.47± 0.016		
Downstream Goldmining site	0.11	0.03	0.22	0.23	0.59	1.48	0.218	0.21
TAPANAHONI RIVER								
Control	0.13	0.04	0.19	0.15	0.5	0.26	0.29	0.25
Goldmining site	0.065 ± 0.005	0.035 ± 0.005	0.235 ± 0.15	0.315 ± 0.2	0.39 ± 0.05	0.255 ± 0.135	0.255 ± 0.125	
Downstream Goldmining site	0.06	0.06	0.23 ± 0.04	0.18 ± 0.01	0.12		0.41	0.2
LAWA RIVER								
Control	0.13		0.24		0.55		0.225	
Goldmining site	0.075 ± 0.005	0.21 ± 0.18	0.3	0.315 ± 0.085	0.44	0.39	0.54 ± 0.16	
Downstream Goldmining site	0.06	0.06	0.18 ± 0.01	0.12	0.12		0.305 ± 0.105	

TABLE 3D. FISH CONSUMPTION SURVEY, POESOEGROENOE AREA WET SEASON

Village	H/H	Person ID#	Sex	Work	Pregnant	Age	Time in Region	Health status	Predatory fish consumed (g)	Non-predatory fish consumed (g)	Other Protein	[Hg] (μg/g)
Baetel	Gertrude	2 01 01	F	farm	yes	16	2 years					
	Henki	2 01 02	F	na		1	1 year	NOT AVAILABLE / NO DATA COLLECTED				
Baetel	Nolda	2 02 01	F	other		39	2 years					
	Henki	2 02 02	M	other		46	2 years					
		2 02 03	F	na		11	2 years	NOT AVAILABLE / NO DATA COLLECTED				
		2 02 04	F	na		9	2 years					
		2 02 05	M	na		6	2 years					
		2 02 06	F	na		5	2 years					
Baetel	Sonja	2 03 01	F	farm		36	2 years	na	*Brycon falcatus* (992)	*Leporinus gossei* (172)		
	Henki	2 03 02	M	other		43	2 years	na		*Myleus rhomboidalis* (164)		
		2 03 03	F	na		14	2 years	malaria		kamusu (1392)		
		2 03 04	M	na		6	2 years	na				5.3
		2 03 05	F	na		1	2 years	na				
Baetel	Sila	2 04 01	F	shop keeper		29	2 years	na	*Serrasalmus rhombeus*(12)	*Myleus rhomboidalis*(2780)		
	Elmont	2 04 02	M	other		33	2 years	na	*Cichla ocellaris* (138)	*Leporinus gossei* (1960)		
		2 04	F	na		13	2 years	na	*Hoplias malabaricus*	*Geophagus surinamensis* (66)		

		03							(428)			
		2 04 04	M	na		10	2 years	na		*Cyphocharax punctata* (3000)		2.92
		2 04 05	F	na		6	2 years	na		*Charax pauciradiatus* (58)		7.1
		2 04 06	F	na		4	2years	na		*Leporinus nijsseni* (12)		
		2 04 07	F	na		1	1 year	na		*Moenkhausia georgiae*(48)		
										kakafissi (1800)		
Baetel	Ethel	2 05 01	F			51	2 years	malaria	*Brycon falcatus* (238)	*Leporinus fasciatus* (232)		
		2 05 02	M			12	2 years	malaria	*Serrasalmus rhombeus*(1088)	*Leporinus gossei* (148)		12.11
										kamusu (470)		
Pietei	Fanfillia	2 08 01	F	farm		36	1 year					
	Karden	2 08 02	M	farm		12	1 year	NOT AVAILABLE / NO DATA COLLECTED				
		2 08 03	M	farm		9	1 year					
Pietei	Kerda	2 09 01	F	farm		46	2 years	na	*Brycon falcatus* (364)	*Doras cf. micropoeus* (840)		
	Bailey	2 09 02	M	farm		14	2 years	na		*Cynodon aff.gibbus* (196)		
		2 09 03	M	farm		12	2 years	na		*Pseudoplatystoma fasciatum* (50000)		7.67
		2 09 04	M	farm		10	2 years	body pains		*Myleus rubripinnis* (580)		6.2
		2 09 05	F	farm		8	2 years	na		*Myleus rhomboidalis* (160)		3.4
		2 09 06	F	farm		5	2 years	na		*Leporinus gossei* (206)		
		2 09 07	M	farm		59	2 years	na		*Haritia surinamensis* (106)		

Soekibakka	Silva	2 10 01	F	hossel		45	1 year	body pains	*Hoplias malabaricus* (90)	*Haritia surinamensis* (48)	eggs	
	King	2 10 02	M	electrician		48	1 year	na	*Crenicichla albopunctata* (6)	*Hypostomus ventromaculatus* (4)		
									Serrasalmus rhombeus (48)	*Guianacara owroewefi* (38)		
		2 10 03	F	na		4	1 year	cavaties	*Brycon pesu* (28)	*Leporinus nijsseni* (12)		
		2 10 04	M	na		6	1 year	diarheaa		*Cyphocharax spilurus* (986)		6.75
		2 10 05	M	na		6	1 year	diarheaa		*Moenkhausia georgiae* (516)		3.56
										Leporinus maculatus (8)		
										Moenkhausia oligolepis (55)		
										akindonia (346)		
										Doras cf. micropoeus (604)		
										Acestrorhynchus falcatus (288)		
										Triportheus rotundatus (122)		
										Hemiodus unimaculatus (72)		
Pietei	Ado	2 11 01	M	Bashia		44	2 years	na	*Brycon pesu* (12)	*Moenkhausia georgiae* (150)	egg	
	Adoma	2 11 02	F	school		11	2 years	na		*Hemiodus unimaculatus* (44)		
		2 11 03	M	na		6	2 years	malaria		*Guianacara owroewefi* (68)		11.17
		2 11 04	F	na		19	2 years	na		*Leporinus fasciatus* (24)		
		2 11 05	F	school		13	2 years	na		*Geophagus surinamensis* (22)		
		2 11 06	F	na		6	2 years	na				6.09
Pietei	Pauline	2 12 01	F	farm		73	2 years	body pains	*Hoplias malabaricus* (314)	*Geophagus surinamensis* (62)	fowl, egg	
	Adams	2 12 02	F	na		4	2 years	na	*Brycon falcatus* (296)	*Leporinus fasciatus* (548)		
		2 12 03	M	school		7	2 years	na				8.57

Pietei	Brigita	2 13 01	F	farm	yes	30	2 years	na	*Brycon falcatus* (616)	*Krobia itanyi* (36)	egg	2.08
	Eva	2 13 02	M	farm		9	2 years	malaria		*Leporinus fasciatus* (48)		
		2 13 03	M	farm		7	2 years	na		alogohdi (40)		4.95
		2 13 04	F	farm		4	2 years	na		*Hemiodus unimaculatus* (40)		
		2 13 05	M	farm		3	2 years	na		*Moenkhausia georgiae* (72)		
		2 13 06	M	farm		1	1 year	na		*Geophagus surinamensis* (20)		
										Leporinus gossei (320)		

Table 3d gives on overview of the fish concumption survey. Household members are identified by person, sex, age, residence time, health status, pregnant or having a newborn, fish and other protein consumed. An overview of the measured [Hg] is also given.

APPENDIX 2
MAP

Selected Sampling Points