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The Mt. Diwata study on the Philippines 1999 — assessing mercury intoxication of the population by small scale gold mining

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Abstract

The region of Diwalwal, dominated by Mt. Diwata, is a gold rush area on Mindanao (Philippines) where approximately 15 000 people live. The fertile plain of Monkayo is situated downstream, where people grow crops such as rice and bananas; locally caught fish is eaten frequently. The ore is dug in small-scale mines and ground to a powder by ball-mills while still in Diwalwal. The gold is then extracted by adding liquid mercury (Hg), forming gold-amalgam. To separate the gold from the Hg, in most cases the amalgam is simply heated in the open by blow-torches. A high external Hg burden of the local population must be assumed. To evaluate the internal Hg burden of the population and the extent of possible negative health effects, 323 volunteers from Mt. Diwalwal, Monkayo and a control group from Davao were examined by a questionnaire, neurological examination and neuro-psychological testing. Blood, urine and hair samples were taken from each participant and analyzed for total Hg. A statistical evaluation was possible for 102 workers (occupationally Hg burdened ball-millers and amalgam-smelters), 63 other inhabitants from Mt. Diwata ('only' exposed from the environment), 100 persons, living downstream in Monkayo, and 42 inhabitants of Davao (serving as controls). The large volume of data was reduced to yes/no decisions. Alcohol as a possible bias factor was excluded (level of alcohol consumption and type, see Section 4.4). Each factor with a statistically significant difference of at least one exposed group to the control group was included in a medical score (0–21 points). In each of the exposed groups this score was significantly worse than in the control group (median control, 3; downstream, 9; Mt. Diwata, non-occupational exposed, 6; Hg workers, 10). In comparison to the surprisingly high Hg concentration in blood (median, 9.0 μg/l; max, 31.3) and in hair (2.65 μg/g; max, 34.7) of the control group, only the workers show elevated levels: Hg-blood median 11.4, max 107.6; Hg-hair median 3.62, max 37.8. The Hg urine concentrations of the occupational exposed and non-exposed population on Mt.

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Diwata was significantly higher than in the control group: control median 1.7 μg/l, max 7.6; non-occupational burdened median 4.1, max 76.4; and workers median 11.0, max 294.2. The participants, living downstream on the plain of Monkayo show no statistically significant difference in Hg-blood, Hg-urine or Hg-hair in comparison with the control group. The German Human-Biological-Monitoring value II (HBM II) was exceeded in 19.5% (control), 26.0% (downstream), 19.4% (Mt. Diwata, non-occupational) and 55.4% (workers) of the cases, the German occupational threshold limit in 19.6% of the workers. Only some of the clinical data, characteristic for Hg intoxication (e.g. tremor, loss of memory, bluish discoloration of the gingiva, etc.), correlate with Hg in blood or urine, but not with Hg in hair. The medical score sum correlates only with Hg in urine. The poor correlation between the Hg concentration in the biomonitors to classic clinical signs of chronic Hg intoxication may be explained by several factors: Hg in blood, urine and hair do not adequately monitor the Hg burden of the target tissues, especially the brain. Inter-individual differences in the sensitiveness to Hg are extremely large. In this area a mixed burden of Hg species must be assumed (Hg vapor, inorganic Hg, methyl-Hg). Chronic Hg burden may have established damage months or even years before the actual determination of the Hg concentrations in the bio-monitors under quite different burden was performed (Drasch G. Mercury. In: Seiler HG, Sigel A, Sigel H, editors. Handbook on metals in clinical and analytical chemistry. New York: Marcel Dekker, 1994:479–494). Therefore, a 'Hg intoxication', that should be treated, was not diagnosed by the Hg concentration in the bio-monitors alone, but by a balanced combination of these Hg values and the medical score sum. In principle, this means the higher the Hg concentration in the bio-monitors, the lower the number of characteristic adverse effects are required for a positive diagnosis. By this method, 0% of the controls, 38% downstream, 27% from Mt. Diwata, non-occupational exposed and 71.6% of the workers were classified as Hg intoxicated. A reduction of the external Hg burden on Mt. Diwata is urgently recommended. An attempt to treat the intoxicated participants with the chelating agent dimercaptopropanesulfonic acid (DMPS) is planned.

Keywords: Mercury; Mercury intoxication; Occupational burden; Environmental burden; Inorganic mercury; Gold mining; Philippines; Human; Blood; Urine; Hair; Neurological examination; Neuro-psychological tests

1. Introduction

On Mindanao, one of the major islands of the Philippines, ore containing gold is mined mainly in the area of Diwalwal that is dominated by the mountains of Mt. Diwata. Diwalwal is at the heart of a major gold rush area, where approx. 15 000 people live. Gold mining has existed here for more than one and a half decades.

Housing is poor, mainly wooden huts, and tunnels, small industrial complexes (ball-mills, cyanidation plants), shops and housing areas are haphazardly mixed together without any sign of planning. A proper disposal system of waste including excrement is lacking; waste is disposed into the river or just dumped. Tuberculosis is the main cause of severe disease and mortality and the local health center of Diwalwal is extremely poorly equipped. For several years no doctor could be found to work in the health center and it is run by midwifes and 'helots'. The health center is not equipped to diagnose mercury intoxication, nor can it treat such a condition.

The ore from the mines is ground to powder by small companies while still in Diwalwal, the ball-mills are within the housing areas. Liquid mercury is added to the powder to extract the gold in order to achieve an amalgam of gold and mercury. To extract the gold the amalgam is heated by small local companies or in private homes. The vaporized mercury is another source of mercury burden to the regional population. Tailings containing mercury can be found throughout the whole region and they are transported by wind or water into the ecosystem: Chicken and pigs roam freely within the contaminated areas of the ball-mills. The gray waters from the Naboc river flow down from Diwalwal, while downstream from Diwalwal is Monkayo, situated in a very fertile plain. Rice, bananas, vegetables, fruit and cattle are important local products. The Naboc river water is also used to irrigate the rice fields and other crops; cattle also drink this water. The local population eat locally caught fish up to three times a day.

2. Study design

To evaluate the influence of the mercury burden on the local population and the extent of the possible negative health effects, we examined 323 participants by a questionnaire on anamnestic data, neurological examination, neuro-psychological testing and the determination of the mercury concentration in blood, urine and hair. The participants consisted of: workers from Diwalwal, other inhabitants from Diwalwal, local families from Monkayo (Naboc, Tubo-Tubo, Babag and Mamunga) and a control group from Davao. The workers were mainly mercury-exposed ball-millers and amalgam smelters. Miners were intentionally excluded, but it is expected that their mercury burden will be a similar order of magnitude to other (non-occupationally mercury exposed) inhabitants on Mt. Diwata. Many of the health problems of the miners may derive from their hard underground work. Therefore it is almost impossible to distinguish in this group between negative health effects caused by mercury and by mining.

The examinations took place in a room in the local 'Women's Center' in Monkayo. A written consent of every participant was achieved before performing any examination.

2.1. Questionnaire

The participants filled in a questionnaire with assistance from midwifes or nurses. Questions included:

- Working in a gold plant or mineral processing plant?
- Working with mercury or with mercury polluted tailings?
- Burning amalgam in the open?
- Melting gold in the open or with inadequate fume hoods?
- Drinking alcohol regularly or excessively?
- Having a kind of a metallic taste?
- Suffering from excessive salivation?
- Problems with tremor/shaking at work?
- Sleeping problems?
- Has the health situation worsened since living in this area?

2.2. Neurological examination

All participants were clinically, mainly neurologically examined. Results were mainly primarily scored according to 'Skalen und Scores in der Neurologie' (Masur et al., 1995):

- signs of bluish discoloration of gums;
- rigidity and ataxia (walking or standing);
- tremor: tongue, eyelids, finger to nose, pouring, posture holding and the Romberg test;
- test of alternating movements or test for dysdiadochokinesia;
- test for irregular eye movements or so called nystagmus;
- test of the field of vision;
- reflexes: knee jerk reflex and biceps reflex;
- pathological reflexes: Babinski reflex and labial reflex;
- salivation and dysathria; and
- sensory examination.

2.3. Neuro-psychological testing

The following tests were carried out:

- memory disturbances: digit span test (part of Wechsler Memory Scale) to test the short-term memory (Masur et al., 1995);
- match box test (from MOT) to test co-ordination, intentional tremor and concentration (Zimmer and Volkamer, 1984);
- Frostig score (subtest Ia 1–9) to test tremor and visual-motoric capacities (Lockowandt, 1996); and
- pencil tapping test (from MOT) to test intentional tremor and co-ordination (Zimmer and Volkamer, 1984).

3. Biomonitoring material and method

3.1. Material and sample storage

From 323 participants in the Philippines, 323 blood samples, 313 urine samples (spontaneous urine sample 10 ml) and 316 hair samples were taken. The blood samples (10 ml) were taken in EDTA-coated vials. The urine samples were acidified with acetic acid. To avoid degradation, all samples were stored and transported by flight to Germany in an electric cooling box. Until analysis the samples were stored continuously at 4°C.

As possible in field, malaria smear and urine protein test was performed immediately.

3.2. Sample preparation

3.2.1. Hair

In all cases 0–3 cm of hair was selected from the part nearest the scalp. From 150 to 250 mg of these hair segments were treated with nitric acid (min 65%, suprapur grade, E. Merck, Darmstadt, Germany) in polypropylene test tubes in a microwave unit. After cooling, the clear solutions were filled up to 5.0 ml with redistilled water and vortexed. Aliquots of these solutions were analyzed. Intentionally washing steps with water, detergents or organic solvents like acetone were not performed before the solution. Washing procedures with different solvents are frequently applied before hair analyses with the aim to remove airborne heavy metal pollution from the surface of the hair (Kijewski, 1993). However, as shown by this author, a distinct differentiation between airborne and internal mercury cannot be achieved with such washing procedures. Pre-experiments with washing the hair samples from the Philippines supported this assumption. After washing some samples from the same person totally unreproducible results were obtained. Therefore the hair samples were dissolved without any further pre-treatment.

3.2.2. Blood, urine

Aliquots of up to 1.0 ml were measured directly without further pre-treatment. This was possible, because sodium-borohydride is used for the mercury reduction stage and all nascent mercury vapor was collected on a gold-platinum-net (method see below).

3.3. Mercury determination and quality control

The (total) amount of mercury in the samples was determined by means of so-called cold-vapor atomic absorption spectrometry (CV-AAS), using a Perkin-Elmer 1100 B spectrometer with a MHS 20 and an amalgamation unit. The determination limit for Hg was 0.25 μg/l in blood or urine and 0.01 μg/g in hair.

All analyses were performed under strict internal and external quality control. The following standard reference materials served as matrix-matched control samples: human hair powder GBW No. 7601 (certified Hg, 0.36 ± 0.05 μg/g) and Seronorm whole blood No. 203056 (certified Hg, 8.5–11.5 μg/l).

3.4. Statistical methods

Statistics were calculated with the SPSS 9.0 program (SPSS-software, Munich, Germany). As expected, the mercury concentrations in the biomonitors (blood, urine, hair) were not distributed normally but left-shifted. Therefore in addition to the arithmetic mean (only for comparison to other studies) the median (50% percentile) is given. For all statistical calculations distribution-free methods such as the Mann–Whitney *U*-test for comparing two independent groups or the Spearman rank test for correlation were used. 'Statistically significant' means an error probability $P < 0.05$ (5%).

Some graphs were shown as so-called 'box-plots', the 'box' represents the interquartile (this means from the 25% to the 75% percentile). The strong line in the box is the median (50% percentile). The 'whiskers' show the span. Out-rulers are indicated by dots.

Table 1
Concentration of total mercury in blood, urine and hair of all participants

		Philippines (this study)	Germany (for comparison)
Hg-blood (μg/l)	Case number	323	3958[a]
	Span	< 0.25–107.6	< 0.2–12.2
	Median	8.2	0.6
	Arithm. mean	11.48	0.51
Hg-urine (μg/l)	Case number	313	4002[a]
	Span	< 0.25–294	< 0.2–53.9
	Median	2.5	0.5
	Arithm. mean	11.08	1.11
Hg-urine (μg/g crea)	Case number	313	4002[a]
	Span	< 0.1–196.3	< 0.1–73.5
	Median	2.4	0.4
	Arithm. mean	8.40	0.71
Hg-hair (μg/g)	Case number	316	150[b]
	Span	0.03–37.76	0.04–2.53
	Median	2.72	0.25
	Arithm. mean	4.14	

[a]Literature for comparison: Krause et al. (1996).
[b]Literature for comparison: Drasch et al. (1997).

4. Results

4.1. Mercury concentration in urine, blood and hair

In Table 1 the mercury (total) concentration of all analyzed blood, urine and hair samples is summarized. For comparison, the results for blood and urine from a representative epidemiological study, performed in 1990/1992 in Germany (Krause et al., 1996) are reported in the same table. For a better comparison of the hair values, recently published data from Germany are also cited (Drasch et al., 1997). In the recent literature from Europe and Northern America, similar Hg concentrations in blood, urine and hair have been reported. From populations with a high consumption of methylmercury-contaminated sea food such as in Japan, the Faroe Islands, the Seychelles or Canadian Inuits, higher Hg values in the biomonitors have been recently reported (for literature in detail see, e.g. the Proceedings of the International Conferences on 'Mercury as a Global Pollutant' 1996 in Hamburg, Germany and 1999 in Rio de Janeiro, Brazil). From other areas with small-scale gold mining, such as in the Amazon, Brazil, but also in the Philippines (Akagi et al., 1999), mercury concentrations comparable to ours have been reported, e.g. see de Lacerda and Salomons (1998).

All mercury concentrations in the different biomonitors blood, urine and hair are highly significantly rank correlated (Table 2). Despite this, the individual values scatter widely (see Figs. 1 and 6–8).

4.2. Exclusion of data, forming subgroups due to residence and occupation, reducing of redundant data for statistical analysis

From the total group, 16 cases had to be excluded from further statistical analysis:

- nine cases from the control group, due to missing data (only blood samples could be taken in these cases without any further medical or neurological investigation); and
- seven due to possible bias: these participants showed severe neurological diseases, such as stroke or Parkinson's disease, and would bias the results.

To distinguish between the possible sources of

Table 2
Spearman rank correlation between the mercury concentration in the different biomonitors[a]

	Hg-blood (μg/l)	Hg-urine (μg/l)	Hg-urine (μg/g crea)
Hg-urine (μg/l)	$r_o = +0.58$, $n = 313$***		
Hg-urine (μg/g crea)	$r_o = +0.56$, $n = 313$***	$r_o = +0.88$, $n = 313$***	
Hg-hair (μg/g)	$r_o = +0.61$, $n = 316$***	$r_o = +0.34$, $n = 311$***	$r_o = +0.39$, $n = 311$***

[a] r_o = rank correlation factor; n = case number; ***$P < 0.001$.

mercury burden, we formed subgroups. The remaining group of 307 participants was subdivided due to residence and occupation criteria. The following subgroups were formed.

1. *Control*: 42 participants from Davao, without a particular Hg burden.
2. *Downstream*: 100 participants living in the barangays of Mamunga, Babag, Tubo-Tubo and Naboc in the Monkayo area at the base of Mt. Diwata. They may be secondarily Hg-exposed, especially by Hg-contaminated water flowing down from Mt. Diwata (data on the Hg concentration in the Naboc river water are not yet available). Excluded from this group are a few persons from this area who may be occupationally Hg burdened — these are grouped in 4.
3. *Diwata, no Hg occupation*: 63 participants, living in Diwalwal without any special occupational Hg-burden.
4. *Diwata, occupationally burdened*: 102 workers: 55 workers in ball mills, 41 smelting gold-amalgam, and six other mercury-exposed workers.

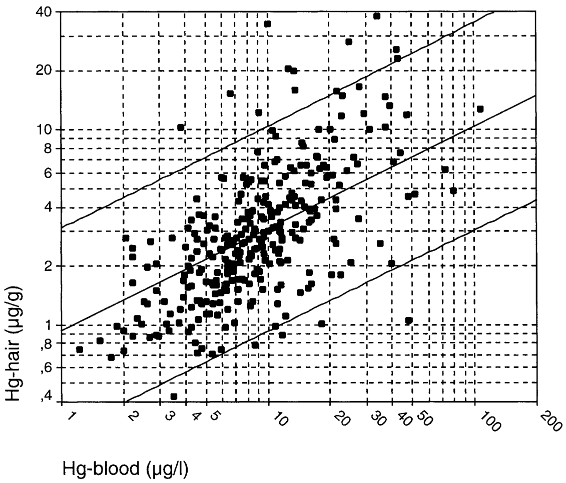

Fig. 1. Correlation of mercury in hair and blood. The line in the middle represents the regression line, the two border lines the 90% confidence interval for the individual values (i.e. 90% of all values are within these two lines).

Unless otherwise indicated, all further statistical analysis was performed with these subgroups.

4.3. Anamnestic data, clinical data, neuro-psychological tests

From the extremely large volume of data collected in field, the relevant facts and test results were selected by pre-investigations. Many test results were primarily scored (for instance: none, moderate, strong, extreme). For the anamnestic and clinical data these results could be reduced to a yes/no decision, which enables a statistical analysis and facilitates the readability of Tables 3 and 4 markedly without any relevant loss of information. The neuro-psychological data (memory, match-box, Frostig, pencil tapping) was reduced to three categories: The best performing 25% of participants of each group were given a score of 0 points, the worst performing 25% of participants were given a score of 2 points and the middle group of participants (interquartile region) received a score of 1 point. In Tables 3–5 statistically significant differences to the control group are indicated by asterisks (χ^2-test).

An evaluation so far showed statistically significant medical test results vs. the different Hg-burdened subgroups. These significant medical test results are typical clinical signs of chronic mercury intoxication, such as tremor, metallic taste, excessive salivation, sleeping problems, memory disturbances and proteinuria (Drasch, 1994;

Table 3
Anamnestic data[a]

Data or test	Score	Control	Downstream	Mt. Diwata non-occup.	Occup. burdened workers	Included in med. sum score
Case number		42	100	63	102	
Anamnestic data						
Alcohol (%)	0/1	9.5	14.0	6.3	26.5*	
Metallic taste (%)	0/1	0	22.2***	11.3*	39.2***	+
Excessive salivation (%)	0/1	0	20.2***	17.7**	36.3***	+
Tremor at work (%)	0/1	2.4	3.0	9.7	20.6**	+
Sleeping problems (%)	0/1	0	8.0***	11.1**	39.6***	+
Health problems worsened since Hg exposed (%)	0/1	11.9	36.0***	23.8*	47.1***	+

[a]Significance of difference to the control group: $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

Kommission Human-Biomonitoring, 1999; Wilhelm, 2000). Furthermore, ataxia, dysdiadochokinesia, pathological reflexes, co-ordination problems and concentration problems are clinical signs of a damaged central and peripheral nervous system. It is striking that in comparison to the control group from Davao, many test results even from the non-occupationally Hg-exposed popula-

Table 4
Clinical data[a]

Data or test	Score	Control	Downstream	Mt. Diwata non-occup.	Occup. burdened workers	Included in med. sum score
Clinical data						
Bluish coloration of gingiva	0/1	2.4	29.3***	17.5*	36.3***	+
Rigidity of gait	0/1	0	6.0	6.3	10.8*	
Ataxia of gait	0/1	0	12.0*	19.0**	21.6***	+
Ataxia of posture	0/1	69.0	81.0	67.7	69.8	
Tremor with posture holding	0/1	81.0	81.0	80.3	55.9	
Romberg standing test	0/1	95.3	91.0	88.5	90.2	
Finger to nose tremor	0/1	14.3	31.0*	19.7	25.5	+
Finger to nose co-ordination	0/1	33.3	38.0	21.3	32.4	
Dysdiadochokinesia	0/1	23.8	46.0*	30.2	57.8***	+
Tremor of tongue	0/1	75.6	94.0**	79.4	84.3	
Salivation	0/1	0	1.0	0	2.9	
Dysathria	0/1	0	1.0	0	2.0	
Pouring	0/1	71.3	75.0	78.7	63.7	
Field of vision	0/1	0	3.0	0	5.9	
Nystagmus	0/1	59.5	44.0	34.9	58.8	
Heel to knee ataxia	0/1	16.7	58.6***	42.6**	66.7***	+
Heel to knee tremor	0/1	16.7	73.7***	50.8***	73.5***	+
PSR test, strong problems	0/1	4.8	9.0	7.9	18.6*	
BSR	0/1	28.6	38.0	27.0	40.2	
Babinski	0/1	2.4	0	1.6	4.9	
Labial reflex	0/1	16.7	45.0***	30.2	40.2**	+
Sensory	0/1	0	6.1	0	5.9	
Proteinuria	0/1	4.8	16.0	6.3	21.6*	+

[a]Significance of difference to the control group: $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

Table 5
Neuro-psychological tests and medical test score[a]

Data or test	Test value	Score	Control (%)	Downstream (%)	Mt. Diwata non-occup. (%)	Occup. burdened workers (%)	Included in med. sum score
Neuro-psychological test							
Memory test				***	***	***	+
	0	0	40.5	11.1	14.8	16.7	
	1,2	1	57.1	47.5	75.4	73.5	
	3,4	2	2.4	41.4	9.8	9.8	
Match box test				***		***	+
	1–15 s	0	47.6	15.2	32.8	15.8	
	16–20 s	1	47.6	54.5	50.8	55.4	
	21–36 s	2	4.8	30.3	16.4	28.7	
Frostig test				***	***	***	+
	13–16	0	57.1	15.2	11.7	29.4	
	10–12	1	33.3	46.5	53.3	38.2	
	3–9	2	9.5	38.4	35.0	32.4	
Pencil tapping test				***	**	***	+
	65–78	0	47.6	20.2	27.9	19.6	
	54–64	1	50.0	50.5	47.5	53.9	
	23–53	2	2.4	29.3	24.6	26.5	
Medical test score	Median		3	9***	6***	10***	
	0–4		76.2	12.0	25.4	6.9	
	5–9		23.8	47.0	55.6	40.2	
	10–21		0	41.0	19.0	52.9	

[a] Significance of difference to the control group: $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

tion, living on and downstream from Mt. Diwata are considerably worse. The negative results increase even more in the occupationally Hg-burdened groups of ball millers and amalgam smelters.

4.4. Alcohol as a possible bias factor

Due to a bias of other factors than mercury, objections might be raised against our study results. In particular, alcohol could have influenced or biased our results. There are possibilities for toxico-kinetic as well as toxico-dynamic interactions between alcohol and mercury. Ethanol as an inhibitor of the enzyme catalase reduces oxidation of mercury vapor into ionic mercury in the blood (Yoshida et al., 1997). At least theoretically, this results in an increased quantity of non-oxidized mercury which reaches and crosses the blood–brain barrier after inhalation of mercury vapor. In humans this could not be proved. Weiner and Nylander (1993) reported even an association of decreased concentrations of mercury in the occipital cortex with chronic alcohol abuse. In a further study on human tissues from a non-mercury exposed German population (20 with a fatty degeneration of the liver, 38 controls, all without dental amalgam) Schupp (1994) has found that a fatty degeneration of the liver (as results from alcohol abuse) increases the concentration of methyl-mercury in the liver, the kidney and the brain, while inorganic mercury is lowered in the liver and the kidney by this liver disease, but is not significantly influenced in the brain. In a highly methyl-mercury exposed population from the Faroe Islands Grandjean and Weihe (1993) found lower mercury concentrations in the cord blood of newborns, if their mothers drunk alcohol. In rats it was shown that ethanol in combination with methyl-mercury enhances the retention of mercury in the kidney and increases the nephrotoxicity while it has no effect on the neurotoxicity of methyl-mercury (McNeil et al., 1988). Beside these toxico-kinetic interactions chronic alcoholism may cause several neurological adverse effects which were tested by us, e.g. tremor (toxico-dynamic interactions).

Therefore, every participant was questioned about their alcohol consumption habits. To test for a possible bias, first of all the alcohol consumption rate in the different Hg-burdened subgroups were compared with χ^2-test (in the same manner as the other factors). In result the alcohol consume of the Hg-workers is indeed higher than in the other groups (Table 3). But the percentage of adult males in these groups ($>75\%$) is more significant than in the other populations, too (see Table 3). To solve the problem of a bias of alcohol consumption, the total population was divided in two groups:

1. 151 males (>14 years); and
2. 156 children (<14 years) and females.

In the group of children and women only one female had declared a heavier alcohol consumption. This one female was excluded from the group, resulting in 155 children and women without any alcohol consumption of relevance. The statistical analysis, as performed with the total group ($n = 307$) was repeated with this group of children and women ($n = 155$). As to be expected, the number of Hg workers was low in this group (only nine ball-mill workers and four amalgam smelters). Therefore, the residence and occupation subgroups were reduced to control ($n = 20$), downstream ($n = 66$), and one group from Mt. Diwata (no Hg occupation and workers, $n = 69$). In result both the downstream and the Hg-burdened group differ significantly from the control group in the same parameters as do the total group of males and females ($n = 307$). For further control, analogous calculations were performed with the male group ($n = 151$), too. In principle, comparable results were obtained.

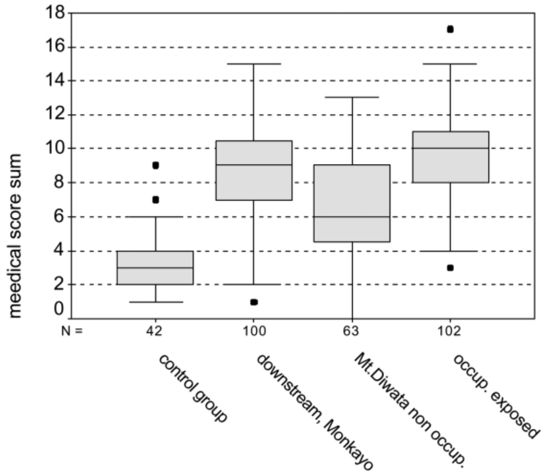

Fig. 2. Box-plots of medical score sum (for details of calculation see text).

Therefore, the higher alcohol consumption of the predominant male Hg-workers in the area of Mt. Diwata does not considerably bias the statistical results as shown in Tables 3–5.

4.5. Scoring of medical results

For a further evaluation of the medical results a medical score was established. All factors were included, for which at least one burdened group (downstream in Monkayo, non-occupationally exposed population on Mt. Diwata, mercury workers) show statistically significant differences (χ^2-test) to the control group from Davao (see Tables 3–5). The factors, included into this medical score and the score-points per factor are shown in the Tables 3–5. The higher the score total, the worse the health problems of a participant were. The maximum value of score points, which could be theoretically reached, is 21. The score points of the different burdened groups are shown in Fig. 2.

Statistic testing of the different Hg-burdened subgroups vs. the total medical score sum showed highly significant results (Mann–Whitney *U*-test) (Table 5)

5. Discussion

5.1. Clinical impression

Our clinical impression was, that mainly *workers* from Diwalwal showed severe symptoms that could very well be related to the classical picture of a mercury intoxication. They reported fatigue, tremor, memory problems, restlessness, loss of weight, metallic taste and sleeping disturbances. We found intentional tremor, mainly fine tremor of eyelids, lips and fingers, ataxia, hyperreflexia and sensory disturbances as well as a bluish discoloration of the gums. It should be noted that most workers in Diwalwal had been healthy and strong young men, before they moved into this area to find work. We may not have seen the most severe cases, since the people from Diwalwal had to come down to Monkayo for examination (2-h journey). Due to a lack of a highly developed social system in the Philippines, some very sick workers might have moved back to their original homes and families in other areas on the Philippines.

The participants from the lowland area of *Monkayo* and surrounding barangays showed less clinical signs. They complained more about other symptoms which could be related to mercury, such as headache, vision problems and nausea.

The control group in Davao — staff from the local Mines and Geoscience Office — were healthy and did not show signs of any special health problems.

In none of the participants was malaria infection diagnosed (blood smear).

One-third to one-quarter of the population in Diwalwal are children. The main health problem of *children* in Diwalwal seems to be the high exposure to mercury in the area. As they do have access to fluid mercury, they play with their hands with this mercury. They live within the houses where ball-milling or amalgam smelting is carried out, therefore they are also exposed to the mercury fumes.

Beginning at the age of 7 or 8 years, children start to work in the area, carrying sacks with rocks, ball-milling, hammering rocks to smaller pieces and many other activities. It seems the children no longer work within the tunnels (as they used to do in earlier years). However, it is still *child labor* in the very early years of life. It is physically very hard work, and the children are subjected to a high exposure level of mercury. Accidents related to work are also a health hazard for these children.

A high risk of tuberculosis exposure is also a major health hazard, due to poor sanitary conditions; infectious diseases such as gastro-intestinal infections and pneumonia are still very common and are a major reason for infant mortality.

5.2. Mercury concentration in urine, blood and hair

Statistical testing of the different Hg-burdened subgroups vs. mercury concentration in blood, urine and hair show partly significant results (Table 6). The differences in the mercury concentration in urine (Fig. 4) were much more striking than those in blood (Fig. 3) or hair (Fig. 5). These results were comparable to studies in Brazil by Cleary (1994) along the Tapjós River.

As expected, the highest burden is found in the Hg-occupational burdened groups of ball-mill workers and amalgam smelters, followed by other inhabitants of the Mt. Diwata area. The non-directly occupationally exposed population on Mt. Diwata showed significantly higher mercury concentrations in urine than the control group from Davao. Surprisingly, the mean blood and hair mercury concentrations in this group was lower than in the control group from Davao. The mercury concentrations in blood and urine of people living downstream in the Monkayo area at the base of Mt. Diwata (group downstream), were lower than in the control region of Davao, whilst mercury in hair was equal.

The mercury concentration in the blood and hair samples from the control group from Davao ($n = 42$) was unexpectedly high — not only in comparison to the population of Mt. Diwata and the Monkayo area downstream, but also in an international comparison. In contrast to this, the

Table 6
Biomonitoring data and diagnosis[a]

Data or test	Value or score	Control	Downstream	Mt. Diwata non-occup.	Occup. burdened workers
Biomonitoring					
Hg-blood	Median (μg/l)	9.0	6.8	7.0	11.4*
	> HBM II (%)	11.9	15.0	14.3	32.4**
	> BAT (%)	2.4	4.0	3.2	17.6*
	Max (μg/l)	31.3	47.5	27.6	107.6
Hg-urine (μg/l)	Median (μg/l)	1.7	1.0	4.1***	11.0***
	> HBM II (%)	0	0	6.3	25.5***
	> BAT (%)	0	0	0	6.9
	Max (μg/l)	7.6	8.6	76.4	294.2
Hg-urine (μg/g crea)	Median (μg/l)	1.4	1.4	4.0**	7.9***
	> HBM II (%)	0	0	7.9	28.4***
	Max (μg/l)	9.3	5.2	85.1	196.3
Hg-hair	Median (μg/l)	2.65	2.77	1.71	3.62*
	> 5 μg/g (%)	11.9	23.0	8.1	35.6**
	Max (μg/l)	34.71	13.17	8.91	37.76
Blood or urine or hair	> HBM II (%)	19.5	26.0	19.4	55.4***
Blood or urine	> BAT (%)	2.4	4.0	3.2	19.6**
Diagnosis					
Hg intoxication	Case no.	0	38***	17***	73***
	%	0	38.0	27.0	71.6

[a] Significance of difference to the control group: $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

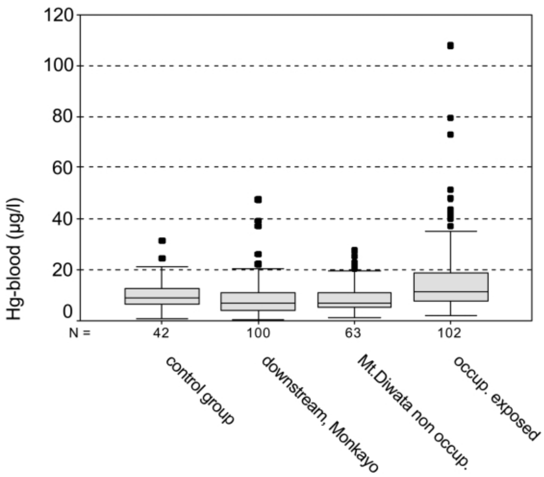

Fig. 3. Box-plots of mercury concentration in blood.

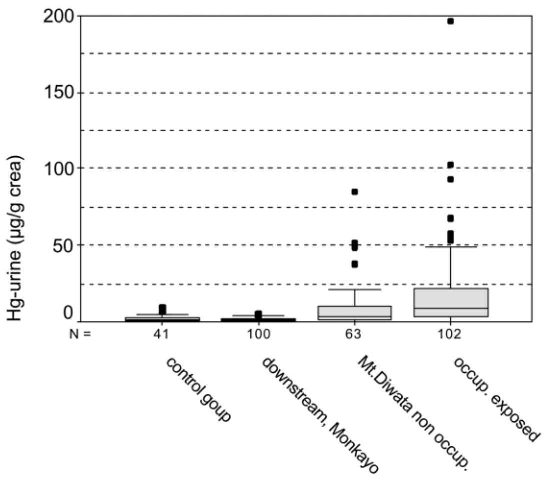

Fig. 4. Box-plots of mercury concentration in urine.

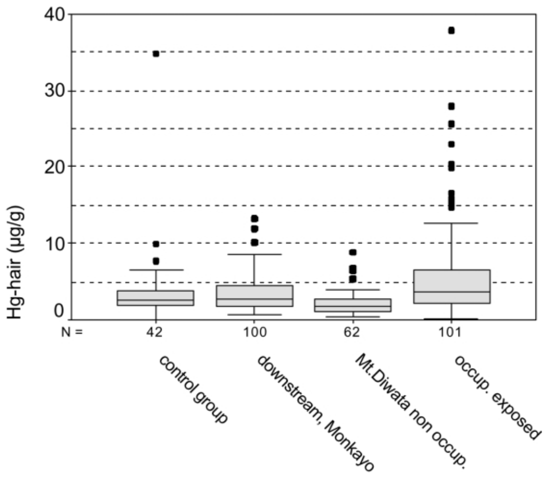

Fig. 5. Box-plots of mercury concentration in hair.

mercury concentration in urine in Davao was in an acceptable range. This distribution (high Hg in blood and hair, moderate in urine) is characteristic for a methyl-mercury burden, e.g. from highly mercury burdened marine food (de Lacerda and Salomons, 1998).

5.3. Mercury levels compared to toxicologically defined threshold limits

In the international literature only a few threshold limits for mercury in biomonitors are recommended, especially for a mixed burden with mercury vapor, inorganic mercury and methyl-mercury, as could be expected in the investigated population. Most studies in this field are performed on populations with an exclusively methyl-mercury burden from fish or sea-food, like the former data from Minamata, or the more recent data from the Seychelles (Davidson et al., 1998), the Faroe Islands (Grandjean et al., 1997) or even from the Amazon (Grandjean et al., 1999). To estimate the toxicological relevance of the mixed burden with metallic, inorganic and organic mercury of the investigated population from Mindanao, the following threshold limits were used.

5.3.1. German human-biomonitoring (HBM) values for mercury

In 1999 the German Umweltbundesamt published recommendations for reference- and human-biomonitoring-values (HBM) for mercury in blood and urine (Kommission Human-Biomonitoring, 1999, see Table 7). The ‘reference values’ only describe the actual Hg-burden in Germany and do not have any toxicological relevance. In contrast to them, the HBM-values are assessed by toxicological considerations. The HBM I was set to be a ‘check value’ — this means an elevated mercury concentration in blood or urine, above which the source of the Hg-burden should be sought and, as far as possible, eliminated. However, even when exceeding this HBM I value, the authors claimed that a health risk is not to be expected. In contrast to this, the (higher) HBM II value is an ‘intervention value’. For blood or urine levels above HBM II, especially for a longer time, adverse health effects cannot be excluded, therefore interventions are necessary. On the one

Table 7
Toxicologically established threshold limits for mercury in blood, urine and hair[a]

	Hg-blood (µg/l)	Hg-urine (µg/l)	Hg-urine (µg/g crea)	Hg-hair (µg/g)
HBM I	5	7	5	
HBM II	15	25	20	5 (in analogy)
WHO		50		7
BAT for metallic and inorganic Hg	25	100		
BAT for organic Hg	100			
BEI	15 (after working)		35 (before working)	

[a] HBM, Human Biomonitoring; BAT, Biologischer Arbeitsstoff-Toleranzwert; BEI, Biological Exposure Indices.

hand the source should be found and reduced urgently; a medical check for possible symptoms should be performed.

For hair, comparable values are not established, but the HBM II in blood is directly derived from the assumption of a stable ratio of mercury in blood and hair of 1:300 (for the correlation of mercury in blood and hair in our cases, see Fig. 1) and the result of the Seychelles study, where adverse effects could be seen at mercury concentration in hair above 5 μg/g (Davidson et al., 1998). Therefore, this value was taken in our study as an analogous value for HBM II for the toxicological evaluation of mercury concentration determined in hair. Again it must be kept in mind that this threshold limit in hair was established in a population burdened with methyl-mercury from marine food and not with mercury vapor or inorganic mercury species, as is predominant on Mt. Diwata.

In 1991 the WHO expert group stated that mercury in urine is the best indicator for a burden with inorganic mercury. The maximum acceptable concentration of mercury in urine was set at 50 μg/l (WHO, 1991). A distinct threshold for mercury in blood was not given. Mercury in hair is widely accepted as best indicator for the assessment of contamination in populations exposed to methyl-mercury (de Lacerda and Salomons, 1998). For this, a maximum allowable concentration of 7.0 μg/g hair was set by the FAO/WHO (EPA, 1997). All these limits and others, previously published, are respected at the most recent recommendation from the German Umweltbundesamt (1999), as cited above. The high numbers of recently published investigations on mercury burdened populations from gold mining areas like in South America or by seafood as on the Faroe Islands or the Seychelles, require a continuous re-evaluation of toxicologically defined threshold limits. Therefore, the latest international recommendations from the German Umweltbundesamt were taken for further comparison. Other toxicologically founded limits are occupational threshold limits. Such limits are established for mercury, e.g. in the USA [biological exposure indices (BEIs) of the American Conference of Governmental Industrial Hygienists] or Germany [BAT value (Deutsche Forschungsgemeinschaft, 2000)]. For a better comparison with the HBM-values (which, to our knowledge, are only established in Germany) the German BAT-values for metallic and inorganic mercury are taken for this study. From the definition, these BAT-values are exclusively valid for healthy adult workers under occupational medical control. The occupational burden must be stopped if this threshold is exceeded. These occupational threshold limits are not valid for the total population, especially not for risk groups like children, pregnant women, older or ill persons. Nevertheless, the BAT-values were taken for a further classifying of our high results, too. BAT-values for mercury are established only for blood and urine, but not for hair. Table 7 gives an overview of the HBM-, BAT- and BEI-values. In Figs. 6–8 the prevalence of exceeding the HBM- and BAT-limits of blood and urine in the different areas is shown. In Table 6 the percentage of the exceeding of the HBM- and BAT-limits in the various population groups of our study are summarized. As discussed later, for our population with a mixed burden (metallic–inorganic–organic mercury, acute–chronic) the biological threshold limits should not be overestimated for the diagnosis. Therefore the question, 'which of the limits are best for evaluating the results of this study', is only of secondary interest.

5.4. Statistical analysis of mercury levels versus clinical data

Only some of the medical data correlate significantly to the Hg concentration in blood or urine, none to Hg in hair (χ^2-test, Mann–Whitney *U*-test, Spearman rank correlation): only the memory test correlates significantly high to Hg in blood as in urine. The metallic taste, the complaint about the fact that the health situation has worsened since the beginning of the mercury exposure, the labial reflex and the frequency of proteinuria correlate with Hg-urine, and the Frostig test to Hg-blood.

The medical score sum (calculated as shown in Table 5) correlated statistically significant to Hg in urine, but not to Hg in blood or hair. In almost

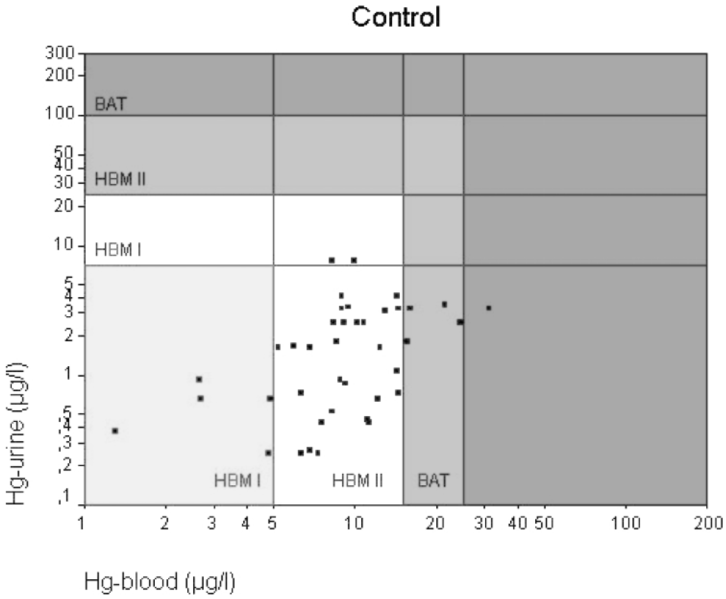

Fig. 6. Prevalence of exceeding toxicologically defined threshold limits (HBM I, HBM II, BAT) in the control group.

all cases with higher mercury concentrations in blood and/or urine showed higher medical score sum, i.e. worse health condition.

The relatively poor correlation of classic clinical signs for mercury intoxication to the mercury concentrations in the bio-monitors (blood, urine, hair) may be explained by several factors:

- The mercury concentration in the target tissues, especially the brain, correlates with the

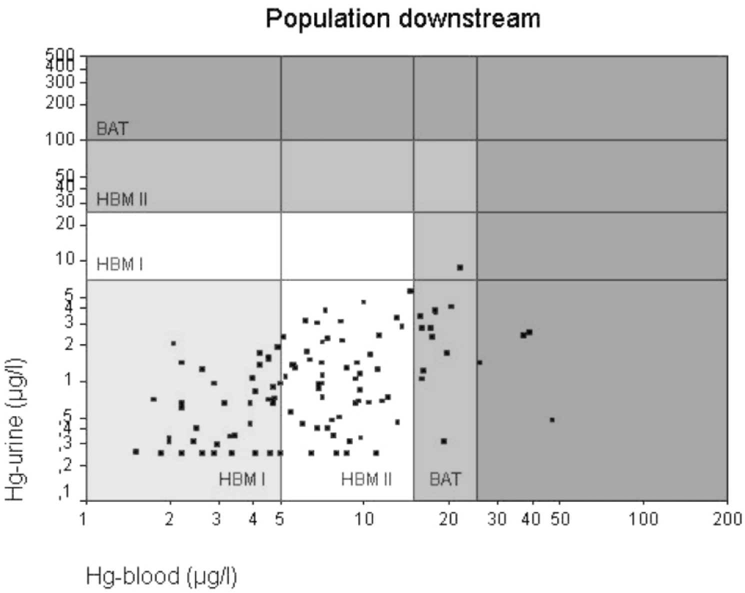

Fig. 7. Prevalence of exceeding toxicologically defined threshold limits (HBM I, HBM II, BAT) in the population living downstream in Monkayo.

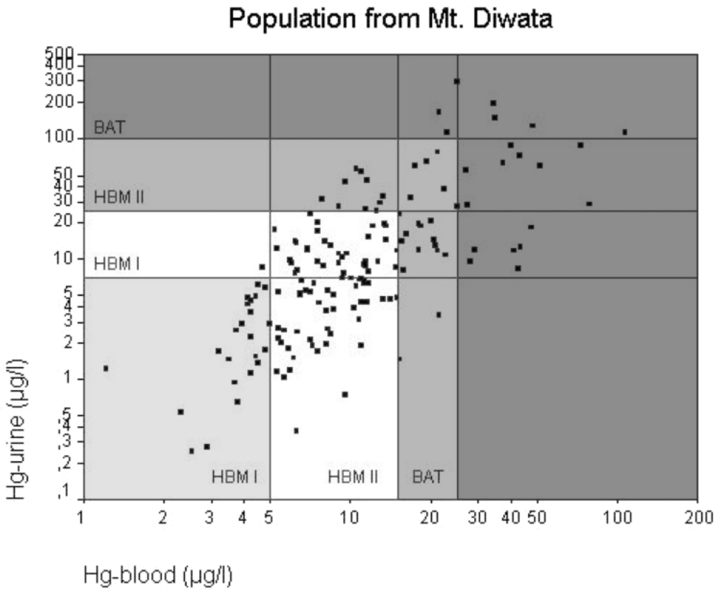

Fig. 8. Prevalence of exceeding toxicologically defined threshold limits (HBM I, HBM II, BAT) in the population living on Mt. Diwata (non-occupationally exposed and occupationally exposed).

mercury concentration in biomonitors like urine, blood or hair. This correlation is statistically significant and good enough to mirror different burdens of different groups (here, e.g. workers and non-workers). However, the *inter-individual differences* are so large that it is rather pointless to conclude the heavy metal burden in the target tissue of an individual from the concentration in the biomonitors (Drasch et al., 1997).

- From the situation in Diwalwal a mixed burden with *several mercury species* must be assumed: for instance, on Mt. Diwata a combination of mercury vapor (in the air), inorganic mercury (in the soil) and probably in addition methyl-mercury from local fish, caught in the Monkayo region. The toxicological effects and potentials of these different mercury species differ widely.
- In most cases the people are *both acute and chronically exposed* to mercury. A reversible or even irreversible damage of the central nervous system may be established months, or even years, before the actual determination of the mercury concentration in the biomonitors under a quite different burden.

5.5. Decision for the diagnosis of 'chronic mercury intoxication', prevalence of the diagnosis for mercury intoxication

For the different Hg burdened groups (< HBM I, HBM I–HBM II, HBM II–BAT, and > BAT) *no* striking differences in the results of the medical and neuro-psychological tests could be seen (for possible reasons, see above). Therefore, at least a *chronic* mercury intoxication could not be diagnosed on the basis of the blood, urine and/or hair concentration *alone*, irrespective of what the threshold limits are set to (see above). The precondition for an intoxication is an external burden, but this can be assumed for Mt. Diwata and the downstream region of Monkayo. An 'intoxication' is further defined by the presence of the toxin in the body and typical adverse health effects. Deriving from this interpretation we tried to find a balanced result by the combination of

Table 8
Decision for the diagnosis 'chronic mercury intoxication'

		Medical score sum		
		0–4	5–9	10–19
Hg in all biomonitors	< HBM I	–	–	–
Hg at least in one biomonitor	> HBM I	–	–	+
	> HBM II	–	+	+
	> BAT	+	+	+

mercury concentration in blood, urine and hair and the negative health effects, as summarized in the medical score sum, as described above in detail. The medical test scores were divided in three groups, according to the quartiles (0–25%, 25–75% and 75–100%). Table 8 shows this combination. In principle this means, that the higher the mercury concentration in at least one of the biomonitors was, the lower the number of adverse effects for a positive diagnosis of a mercury intoxication must be and vice versa. The case, that a mercury concentration above the occupational threshold limit BAT *alone* (i.e. without clinical signs, i.e. medical score 0–4) is responsible for the classification of an intoxication, can be neglected; only two cases from Mt. Diwata are classified as 'intoxicated' by this.

One case from the control group from Davao (31.3 μg Hg/l blood) exceeded the BAT-value for metallic and inorganic Hg in blood (25 μg/l) without any further signs of a mercury intoxication and a medical score sum of 2. It was decided to compare this case to the higher BAT-value of 100 μg/l blood, as established for organic mercury compounds, because the burden in Davao seems to derive predominantly from organic mercury in seafood. Therefore this case was grouped to be non-intoxicated.

By this classification the results from Table 8 were obtained. It is striking that nobody from the control group is marked as intoxicated, although the mercury concentration, especially in blood, in this group is in the mean higher than, for instance, in the downstream group. This supports the assumption that the mercury burden of the control group from the coastal population of Davao derives from other mercury species (mainly methyl-mercury from fish) than in the downstream and especially the Mt. Diwata populations. The higher — in comparison to metallic and inorganic mercury (25 μg/l) — BAT-value in blood for organic mercury compounds (100 μg/l) shows that in the case of a burden mainly with organic mercury (like methyl-mercury) higher blood concentrations can be tolerated without signs of an intoxication.

6. Conclusion

From the medical point of view, the mercury burden of humans, living on Mt. Diwata or downstream in the plain of Monkayo represent a unacceptably high toxic range. In the instance of an intoxication, the first step must be to stop exposure to the harmful toxin or at least drastically reduce exposure in this area. This means a stop or a dramatic reduction in the use of mercury for the extraction of gold from the ore by the amalgamation technique. Considerable effort has to urgently be taken to improve these working habits. Amalgam burning and gold melting in closed vessels is essential for a reduction of the mercury burden. A safer storage and handling of liquid mercury is urgently necessary, too. One main step to reduce the health hazards in Diwalwal might be a proper zoning into industrial areas, commercial areas and housing areas.

Moreover, the environmentally important pathways of mercury down from Mt. Diwata to the basin of Monkayo should be investigated — whether it is with water, sediment, air or food. If a prevention or reduction of mercury exposure is not carried out within the near future, any medical treatment can only be of a short-term benefit, since by re-exposure a re-intoxication is more than likely.

Medical treatment of the intoxicated participants should be performed with a newer chelating agent, such as DMPS (dimercaptopropanesulfonic acid) (Aaseth et al., 1995; Aposhian et al., 1995; Gonzalez-Ramirez et al., 1998). Compared to previously used antidotes such as BAL (Dimercaprol), DMPS has many advantages, such as less toxicity and (especially necessary for an application in field) the possibility of an oral application. Another possible antidote, D-Penicillamin, is much less effective (Cichini, 1989). From the medical results, it seems very likely that the neurological symptoms are predominant (like tremor), it has to be doubted to which extent the severe symptoms of the chronic mercury intoxication can still be treated at all. It must be taken into consideration that neuronal tissue, for example the brain, is the only tissue of the body, that cannot be replaced after a cell damage. Moreover, it is questionable whether DMPS can transport mercury to a relevant extent out of the brain tissues through the lipophilic brain–blood barrier. A better prognosis can be given for the reversibility of mercury-induced damage of the kidney by a DMPS treatment. Judging between the possible benefits, risks and (even if not very ethical) costs of a treatment with a chelating agent, at least an attempt for such a medical treatment is strongly recommended. Meanwhile (summer 2000) with the support of UNIDO a treatment with DMPS is offered to all participants of this study with the diagnosis of a mercury intoxication. It is performed under a scientific study design, able to evaluate both the extent of reduction of the internal mercury burden and of mercury-related symptoms. Until now, there are no comparable studies published in the international literature on the treatment of a population chronically intoxicated by a mixture of different mercury species (metallic, inorganic, organic) in this order of magnitude with a chelating agent like DMPS, especially under adverse field conditions, such as in the Mt. Diwata area.

As far as possible speciation in inorganic and organic mercury in blood, urine and hair samples will be performed. The results will provide further information on the distribution and predominance of mercury species in the different subgroups. From this more information can be obtained, e.g. on questions, such as:

- Is the population on Mt. Diwata (especially the non-occupationally involved) and the population downstream in the plain of Monkayo predominantly exposed to metallic or inorganic mercury or by mercury, methylated in the aquatic food chain?
- What is the source of the unexpected high mercury burden in the control group of Davao from?

A better risk assessment for the different populations and better suggestions for an effective harm reduction will be obtained from this data.

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