Health assessment for mercury exposure among schoolchildren residing near a gold processing and refining plant in Apokon, Tagum, Davao del Norte, Philippines

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Abstract

Artisanal gold-mining activities in the Philippines have proliferated since the early 1980s. Presently, environmental and health monitoring conducted by several governmental agencies is limited to the determination of total mercury only. Previous studies undertaken focused mainly on the exposure of adults and workers to mercury during mining/processing operations. However, in one area in Mindanao, mined ores are brought down and processed in the lowlands where residential communities are exposed to environmental pollutants resulting from gold processing/refining operations. The area of study is Apokon, Tagum, Davao del Norte, which has 29 gold processing and refining plants. Health complaints among schoolchildren in Apokon Elementary School were received by the Department of Health and were attributed to the mercury pollution in the environment. As part of a collaboration with the Health Department, UP-National Poisons Control and Information Service, the National Institute for Minamata Disease (NIMD), Japan, provided technical assistance in the analytical determination of mercury in biological and environmental samples. Elevated mercury concentrations were noted in some of the river systems up to 15 km from the mining areas. Environmental quality monitoring showed T-Hg sediment levels ranged from 0.553 to 66.471 μg/g dry wt. while water samples from river systems exhibited mercury levels from 72.8 to 78.4 ng/ml. Twenty-seven sediment samples from river systems near mining operations and seven water samples were also brought to the Institute for analysis. Fish samples collected showed levels ranging from 1.07 to 438.8 ng/g for total mercury and 0.71–377.18 ng/g for methylmercury. Methylmercury content in fish is predominant. All water and sediment samples collected from three sampling sites have elevated T-Hg level while three fish species have elevated T-Hg and methylmercury levels (WHO/CDC, 1994). Blood and hair samples from 162 schoolchildren aged 5–17 years were collected and analyzed at the NIMD for mercury analysis. Analytical procedures used in the NIMD for...

mercury testing were applied. Laboratory results showed that total mercury hair samples ranged from 0.278 to 20.393 \( \mu \text{g/g} \) while methylmercury hair results were from 0.191 to 18.469 \( \mu \text{g/g} \). Methylmercury in hair showed levels from 45.96 to 99.81\%. Total blood mercury levels ranged from 0.757 to 56.88 \( \mu \text{g/l} \) while Me-Hg blood levels ranged from 1.36 to 46.73 \( \mu \text{g/l} \). It was determined that 10 children had elevated T-Hg blood levels while one child had high total and methylmercury levels in hair. A summary of physical examination results showed that the predominant findings include under-height, gingival discoloration, adenopathy, underweight and dermatologic abnormalities among children examined. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Mercury; Inorganic mercury; Methylmercury; Tagum

1. Introduction

Studies on the health and environmental impact of mercury as a result of environmental pollution has been reported worldwide. Foremost of which during the post-war era is the outbreak of Minamata Disease in 1956 in certain villages around Minamata Bay in Kumamoto Prefecture, Japan. A similar incident has been reported in 1965 along the Agano River, in Niigata Prefecture, Japan. As of March 1997, 2952 Minamata Disease patients have been certified in Japan (Environment Agency of Japan, 1997).

Clinical and epidemiological studies were undertaken among the Canadian–Indian population groups to assess their level of exposure to methylmercury through the consumption of fish. Signs and symptoms associated with methylmercury exposure have been reported, however, the authors concluded that these were relatively mild and were thought to be due to other factors (Wheatley et al., 1979).

In the Philippines, mercury exposure may be attributed to small-scale gold mining activities which have proliferated in many parts of the country since the early 1970s. Aside from this, a joint study by the Department of Health and the University of the Philippines National Poisons Control and Information Service among former workers of a mining company producing mercury, also showed significant health findings attributed to their occupational exposure to the chemical in the late 1960s.

2. Study site

Gold rush activities emerged in the early 1980s in Davao del Norte, which is located 1545 km south of Manila. Mining activities are undertaken at the outskirts of the municipality or at the mountainside. Gold ores obtained from these mining areas are processed/refined in the mining site itself or brought down to Tagum, the capital town of Davao del Norte, which has become the center for gold processing and trading since the gold rush started. It has been estimated that 140 tons of mercury flux has been dumped into the river systems as a result of the small-scale gold-mining activities. Based on the Environmental Department’s monitoring, levels of mercury in the river systems reached a maximum of 1539 \( \mu \text{g/l} \) for inorganic Hg which is beyond government and international standards and regulations (Miranda et al., 1997).

During this time, the small town of Apokon which is located some 4 km along the highway from Tagum has become the gold processing/refining capital of the province. It has a population of approximately 13 000. As a result, instant communities emerged overnight with a conglomeration of people in these areas. The local government unit has classified the barrio as a residential and light industry area. From 1986 to 1995, 11 gold mills and processing plants were constructed adjacent the Apokon Elementary School. Meanwhile, the number of makeshift ball-milling stalls and shops mushroomed along
the main streets during the height of the gold rush activities.

3. Gold processing/refining operations

Processing operations have recently shifted to the carbon in pulp (CIP) methodology but the amalgamation process remains one of the most popular methods because of the lower costs involved. However, some processors have combined the two methods, applying both CIP and amalgamation methods. In the CIP method, the raw materials used come from small-scale gold-mining processors who sell waste tailings still containing 40–60% gold content. No attempt is made to recover the mercury content from these waste materials. Thus, since crude methods are applied for small-scale gold processing, the raw materials used still contain residual mercury.

Wastewater containing mercury and cyanide from processing operations are then stored in a tailings pond or directly dumped into the main tributary draining Tagum (Hiyo River) without any recovery process. While conventional methods mostly rely upon the reaction of sunlight in the conversion of cyanide into its lesser toxic components, such as CO₂ and NO₃, there had been reports of acute effects primarily among livestock and marine life which come into contact with the contaminated waste-water. This two-pronged health and environmental problem now persists in most of the gold processing operations in the country.

To date, there are approximately 29 gold mills and processing plants operating in the area. An inventory of the establishments conducted by the Department of Environment and Natural Resources in 1996 revealed that only four of the 29 had passed the environmental clearance required for certification by the government prior to operation. While the industry provided jobs and livelihood to the community as well as income and resources to the government, health and environmental problems were encountered and were readily attributed by the community to the gold processing operations in the area.

4. Background information

A number of health studies were undertaken in the past which were mainly focused on the occupational exposure of small-scale gold miners utilizing mercury in the gold processing/refining process. A thorough health examination, which included physical and neurologic evaluation, was undertaken together with biological monitoring. Blood and urine specimens from volunteer subjects were collected and submitted to the laboratory for total mercury and cyanide levels in the blood, blood chemistry, liver and kidney function and hematologic tests.

In 1997, the students, teachers and residents of Apokon complained of the unbearable and deafening noise and the offensive odor emanating from the gold processing activities. The common health complaints were easy fatigability, frequent headaches and stomachaches, pallor and malnutrition. The request for assistance to determine the cause of these symptoms were referred personally from the community to a professor of the College of Public Health who endorsed the matter to the NPCIS and the Department of Health. With the support of the government and the academy, the community banded themselves together to form a non-government organization to actively pursue their cause for a clean environment and healthy people. Meanwhile the health department and the academy jointly outlined a comprehensive health assessment plan to determine the health status of the schoolchildren in the affected area.

Based on an actual survey of the area, investigators surmised that these schoolchildren could be exposed to inorganic mercury by direct inhalation of Hg vapor during the process of torching and refining of Hg–Au amalgam. Aside from this, another possible source of exposure could be the waste water coming from the refining process which was not treated but directly discharged into the water bodies. Methylation of Hg can possibly occur and ultimately bio-accumulate to a significant level in the aquatic flora and fauna. Thus, the community would be at risk of exposure to toxic levels of mercury since the people including children could be considered as mainly fish-eaters.
Although it is difficult to specifically identify the risk probability that the population have been exposed to, this study sought to investigate the extent of mercury pollution and its impact on health and the environment.

5. Environmental and health exposure assessment

The study on the health impact of mercury from gold processing/refinery operations among schoolchildren in Apokon, Davao del Norte, was started in March 1996. A cross-sectional descriptive analysis was undertaken among a segment of these children with the following materials and methods:

1. Social preparation of the community in collaboration with the non-governmental organization.
2. Face-to-face interview of parents/guardian with a prepared questionnaire translated into the local dialect. Demographic data obtained include age, sex, nutritional intake, distance of residence from ball-mill operations, neurodevelopmental history of the child including the occupational histories of the parents, etc.
3. Complete medical and neurological examination; and a simplified mental status test.
4. Biological examination: blood samples for total mercury and hair samples for total and methylmercury; hematology, blood chemistries and fecalysis.
5. Environmental monitoring of drinking water, water quality (estuarine) in four major river tributaries, and sediment and fish samples which were collected for total mercury and methylmercury determination.

6. Study population

Out of the 1500 schoolchildren from Apokon Elementary School, 220 (14.67%) volunteered to be examined by a team of medical specialists. However, only 162 of the 220 (74%) have sufficient biological specimen. Parental consent was required prior to the health examination. Of the 162 schoolchildren examined, 91 (56.17%) were females while the rest were males (43.83%). Mean age was 12.1 years.

- Inclusion criteria:
  - living within 500 m from a ball-mill/gold processing plant;
  - enrolled at the Apokon Elementary School for the last 3 years from date of the health examination;
  - willing to be included in the study; and
  - with informed consent.

- Exclusion criteria:
  - those previously included in preliminary studies;
  - those who refuse to be included in the study; and
  - those who fail to meet the inclusion criteria.

7. Analysis and data evaluation

Data collected were encoded using EPI Info ver. 6. A descriptive analysis of the basic demographic profile and physical findings has been undertaken. Socio-demographic profiles, physical examination findings, environmental levels and laboratory results were evaluated. A regression analysis to determine statistical correlation was also undertaken.

8. Laboratory methods

Samples were analyzed at the National Institute for Minamata Disease, Japan, using the cold vapor atomic absorption spectrometry with a semi-automated mercury analyzer. The detection limit was 0.5 ngHg. Sample preparation for total mercury analyses of blood, urine, hair and fish tissues included pre-treatment and digestion of the samples through the addition of nitric-perchloric and sulfuric acid solution. The digested sample was then heated at the prescribed range of 230–250°C for 20 min and cooled for analysis.
Fig. 1. Analytical procedures for T-Hg in biological and environmental samples.

For methylmercury analysis, samples were analyzed using gas-chromatography–electron capture detectors. For the analysis of methylmercury in hair, an acid leaching process was used utilizing aqueous HCl solution at high temperatures, together with the use of an organic solvent for extraction. Hair samples were treated with ethanol and hydrochloric acid. The sample solution was then heated and centrifuged. Toluene was then added to the solution before analysis. Combined techniques of dithizone extraction, back extraction into alkaline Na₂S, and re-extraction with dithizone were applied. The detection limit was 5 ng Me-Hg/g. Fish and blood samples were digested with KOH in ethanol solution treated with EDTA, acidified with HCl and hexane. A dithizone–toluene solution was added to extract methylmercury from the solution. The sample was then analyzed by GC-ECD (Fig. 2).

An outline of the method is shown in Figs. 1 and 2.

9. Results of environmental monitoring

9.1. Mercury pollution in selected study areas

Samples from three main river systems affected
by the small-scale gold mining processing activities were collected and analyzed at the NIMD laboratory (Tables 1 and 2).

Hijo River is the main tributary in Tagum. According to the townsfolk, the river used to be one of the main food sources and livelihood of the people prior to the gold processing operations in the area. They noted that their fish-catch had slowly diminished through the past years. The river system was green colored with slight turbidity; algal blooms and moss formations were noted in some portions of the area. Water and sediment samples were taken from the river system within a distance of 5 km (Fig. 3). Results obtained for total mercury ranged from 0.55 to 1.36 μg/g dry wt. At present, there is still no existing national standard for acceptable limits of mercury values for sediment contamination in the country. However, comparing with the standards in the Netherlands, which set an acceptable level of 0.3 μg/g, the results showed that all samples exceeded the limit values for soil and sediments. Water samples collected from the river showed a level of 78.4 μg/l which exceeded both national (RP) standards for receiving bodies and effluents at 2 μg/l and 5 μg/l, respectively.

Naboc River is the main receptacle of waste water coming from the mining and processing operations from the mountains of Mt. Diwalwal which further drains into several tributaries and empties its load at Butuan Bay, some 200 km further northwest. The Regional Health Office has constantly received complaints of livestock dying while grazing along the riverbanks in this

![Analytical Procedures for Me-Hg in Biological and Environmental Samples](image)

Fig. 2. Analytical procedures for Me-Hg in biological and environmental samples.
area. Marine life is almost non-existent due to the turbid, milky white, murky water of the river. Water and sediment samples were taken from the river system within a distance of 5 km. Results of the sediment samples from 10 stations showed values ranging from 7.723 to 16.227 μg/g dry wt. total mercury. Water samples collected from the river showed a level of 72.8 μg/l which exceeded the national standards. A second sampling after a span of 6 months showed a higher level of 79.83 μg/l.

Pantukan is another municipality which was reported to be teeming with gold rush activities in the late 1980s but tapered from 1990 to 1996, however, a significant increase in mining activities has been reported for the past year. Sediment samples were also collected from Kingking River in Pantukan showed levels ranging from 3.01 to 4.39 μg/g dry wt. Water samples collected from the river system gave a value of 75.2 μg/l, which also exceeded the national standards.

The Environment Department also provided eight sediment samples coming from the ball-milling/processing sites in Mt. Diwalwal where the highest sediment level was recorded at 66.471 μg/g.

9.2. Fish samples

A market basket sampling was undertaken in Apokon, Tagum (Table 3). Seventeen fish samples and one seaweed variety locally known as ‘lato’ were analyzed for total and methylmercury. The fish were reportedly coming from the nearby town of Pantukan which is also actively engaged in small-scale gold mining.

<table>
<thead>
<tr>
<th>Sampling site</th>
<th>T-Hg (ng/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hijo River (Tagum)</td>
<td>78.4</td>
</tr>
<tr>
<td>Kingking River (Pantukan)</td>
<td>75.2</td>
</tr>
<tr>
<td>Naboc River (Monkayo)</td>
<td>72.8</td>
</tr>
</tbody>
</table>

Table 1: Total mercury determination of water samples from river systems

<table>
<thead>
<tr>
<th>Sampling site</th>
<th>No. of samples</th>
<th>Range of T-Hg level (μg/g dry wt.)</th>
<th>S.D. (μg/g dry wt.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naboc river</td>
<td>10</td>
<td>7.723–16.227</td>
<td>10.968 ± 2.983</td>
</tr>
<tr>
<td>Pantukan</td>
<td>4</td>
<td>3.015–4.39</td>
<td>3.507 ± 0.606</td>
</tr>
<tr>
<td>Hijo River</td>
<td>5</td>
<td>0.553–5.092</td>
<td>1.784 ± 1.881</td>
</tr>
<tr>
<td>DENR samples (Mt. Diwalwal/Naboc River)</td>
<td>10</td>
<td>0.921–66.471</td>
<td>21.03 ± 24.943</td>
</tr>
</tbody>
</table>

Table 2: Sediment sampling for total mercury determination

Total mercury levels for fish samples collected ranged from 1.07 to 438.8 ng/g. Methylmercury levels ranged from 0.71 to 377 ng/g while the percentage of methylmercury ranges from 45.96 to 99.81%. Fish samples collected showed a higher percentage of methylmercury content except for one sample. Seaweed collected had a level of 6.39 mg/kg for total mercury while methylmercury levels were non-detectable. All fish samples were within the recommended US FDA standards of 0.5 μg/g for mercury content (Akagi et al., 1996).

However, if we are to compare the results with the WHO environmental criteria for mercury concentrations in freshwater fish from non-polluted areas of 100–200 ng/g (0.1–0.2 μg/g), three

<table>
<thead>
<tr>
<th>Fish sample</th>
<th>Mean T-Hg (ng/g)</th>
<th>Mean Me-Hg (ng/g)</th>
<th>Mean % Me-Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bariles tuna</td>
<td>438.8</td>
<td>377.18</td>
<td>85.96</td>
</tr>
<tr>
<td>Bugaong (grant)</td>
<td>107.85</td>
<td>103.09</td>
<td>97.86</td>
</tr>
<tr>
<td>Lapu-Lapu (gopher)</td>
<td>102.37</td>
<td>101.69</td>
<td>99.30</td>
</tr>
<tr>
<td>Tuna</td>
<td>84.8</td>
<td>83.84</td>
<td>98.87</td>
</tr>
<tr>
<td>Bankan (mullet)</td>
<td>29.38</td>
<td>27.97</td>
<td>95.20</td>
</tr>
<tr>
<td>Tamban</td>
<td>26.44</td>
<td>24.25</td>
<td>91.72</td>
</tr>
<tr>
<td>(Indian sardines)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maya-Maya A (napper)</td>
<td>18.31</td>
<td>17.24</td>
<td>93.32</td>
</tr>
<tr>
<td>Bangus (milkfish)</td>
<td>12.92</td>
<td>10.36</td>
<td>80.19</td>
</tr>
<tr>
<td>Tilapia</td>
<td>10.33</td>
<td>9.895</td>
<td>95.40</td>
</tr>
<tr>
<td>Seaweed*</td>
<td>6.39</td>
<td>nd</td>
<td></td>
</tr>
<tr>
<td>Peret (small tuna)</td>
<td>5.74</td>
<td>5.485</td>
<td>95.95</td>
</tr>
<tr>
<td>Samaral A</td>
<td>1.34</td>
<td>0.725</td>
<td>56.16</td>
</tr>
</tbody>
</table>

Table 3: Marine samples analyzed for total and Me-Hg

4 US FDA standards = 0.5 μg/g or 500 ng/g; WHO for non-polluted water bodies = 100–200 ng/g; nd = non-detectable.

Results of mercury levels in fish samples as compared with the WHO criteria showed that mean levels in grunt, gopher and tuna (bariles) were elevated, with the tuna recording the highest level of 438.8 ng/g for total mercury and 377.18 ng/g for methylmercury. The mean proportion of Me-Hg to T-Hg in all fish samples was in the range 56.16–99.38%, indicating that most of the mercury in the fish sampled were in the form of methylmercury. The gopher registered the highest percentage of methylmercury content.

9.3. Health assessment

9.3.1. Blood and hair samples

Hair samples were collected from schoolchil-
dren with total mercury values ranging from 0.757 to 56.88 μg/g with methylmercury levels between 0.332 and 20.393 μg/g (Table 4). It was found that the proportion of methylmercury in hair ranged from 29.865% to 99.2%. A higher proportion of mercury in blood samples among 158/163 (96.93%) of the subjects was found to be methyl rather than inorganic mercury (Fig. 4).

The reference level for total mercury was set at 2 μg/g and levels greater than 30 μg/g of total mercury is considered as ‘high risk’ based on WHO criteria. For methylmercury the WHO define 10–20 μg/g methylmercury as the ‘risk’ range for fetal exposure (Wheatley and Wheatly, 1998). Five out of 163 (3.07%) of the hair samples had exceeded the reference levels for mercury.

The US Center for Disease Control recommended a level of 7.5 ppb for blood total mercury in children (Akagi et al., 1996). Results revealed that 10/163 (6.14%) of the schoolchildren had elevated total mercury in their blood levels.

9.3.2. Health findings/results

Health assessment results (Table 5) showed that one fourth or 25.68% of the schoolchildren examined were undernourished while almost 80% of height measurements were below the national standards. Peak expiratory flow rates in 2.11% of the children examined were below the recommended values.

Physical examination showed that adenopathy (28%), gingival discoloration (26.97%) and dermatological abnormalities (18.2%) were common among schoolchildren examined. Other significant findings that were noted among the schoolchildren include the lungs, nasal congestion and pallor (conjunctival).

Results of mental status examination that includes a visual perception motor screening and category testing showed average results.

Significant neurological findings were mainly on the cranial nerves (17.1%), reflexes (5.1%), sensory (5.1%), cerebellars (3.89%) and motor nerves (1.2%). This is characterized by cranial nerve (VIII) abnormalities (6.87%), decreased vibratory sense, distally (2.69%), palmental reflex deficiency (2.4%), cranial nerve (I) (2.40%), visual acuity (2.10%) and babinski (1.50%).

10. Discussion of results

Blood, hair and urine mercury concentrations are considered as biomarkers of exposure to mercury. A thorough evaluation of total mercury exposure includes occupational and non-occupational intakes. Non-occupational groups are primarily exposed through the diet. Long-term consumption of fish is the primary source of methylmercury in individuals. Dental mercury fillings are also reported to release mercury vapor into the oral cavity. Concentration of mercury in

<table>
<thead>
<tr>
<th>Parameter</th>
<th>N</th>
<th>Total Hg Range</th>
<th>Mean ± S.D.</th>
<th>N</th>
<th>Methyl Hg Range</th>
<th>Mean ± S.D.</th>
<th>% Methyl Hg Range</th>
<th>Mean ± S.D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both sexes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood (ng/g)</td>
<td>162</td>
<td>0.757–56.88</td>
<td>3.82 ± 4.58</td>
<td>29</td>
<td>1.36–46.73</td>
<td>6.00 ± 8.26</td>
<td>26.4–99.22</td>
<td>76.45 ± 22.74</td>
</tr>
<tr>
<td>Hair (μg/g)</td>
<td>162</td>
<td>0.332–20.393</td>
<td>0.99 ± 1.6</td>
<td>163</td>
<td>0.191–18.469</td>
<td>0.799 ± 1.45</td>
<td>29.87–99.2</td>
<td>79.26 ± 12.77</td>
</tr>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood (ng/g)</td>
<td>91</td>
<td>1.49–10.35</td>
<td>3.78 ± 1.8</td>
<td>11</td>
<td>1.38–8.18</td>
<td>4.82 ± 2.45</td>
<td>43.36–98.75</td>
<td>70.63 ± 24.18</td>
</tr>
<tr>
<td>Hair (μg/g)</td>
<td>91</td>
<td>0.332–4.026</td>
<td>0.94 ± 0.52</td>
<td>69</td>
<td>0.216–2.364</td>
<td>0.72 ± 0.38</td>
<td>29.86–99.2</td>
<td>77.94 ± 14.77</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blood (ng/g)</td>
<td>71</td>
<td>0.76–56.88</td>
<td>3.84 ± 5.85</td>
<td>18</td>
<td>1.36–46.73</td>
<td>6.73 ± 10.36</td>
<td>26.4–99.2</td>
<td>93.84 ± 4.66</td>
</tr>
<tr>
<td>Hair (μg/g)</td>
<td>71</td>
<td>0.348–20.393</td>
<td>1.03 ± 2.07</td>
<td>94</td>
<td>0.191–18.469</td>
<td>0.86 ± 1.88</td>
<td>47.26–99.07</td>
<td>80.22 ± 11.06</td>
</tr>
</tbody>
</table>
the ambient air and drinking water should also be included as part of the exposure measurement. Clinical observations also suggested that women are more sensitive to the toxic effects of methylmercury during pregnancy (WHO, 1991; Klaassen et al., 1996).

The correlation between levels of mercury in hair and blood samples from schoolchildren is shown in Fig. 5. Based on statistical analysis, total mercury in hair is significantly correlated with total mercury in blood ($r = 0.92$). From the regression equation, an overall average ratio of 322 was obtained for hair total mercury levels to blood total mercury levels.

Furthermore, statistical analysis showed a significant correlation between total mercury and methylmercury in blood samples ($r = 0.81$) as shown in Fig. 6. Speciation of hair and blood samples showed a higher methylmercury proportion among the schoolchildren. There was not much difference in the average total mercury and methylmercury hair levels between males and females as well as total blood mercury levels. However, mean methylmercury blood levels in females were higher than males by 1.5 $\mu$g/L.

This points to the fact that the dietary intake of the schoolchildren, fish being one of their staple diets, has a significant contribution to their overall mercury intake. This could be attributed to the fact that the fish habitat showed significantly elevated levels of total mercury specifically in water and sediment samples collected. Anthropogenic sources of mercury pollution in the environment in the area could be attributed to the gold refining processes which release mercury into the river systems and the ambient air. This significantly contributes to the mercury intake of the children. Thus, the schoolchildren are exposed to

![Image](image1.png)

**Table 5**

<table>
<thead>
<tr>
<th>Physical examination</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td></td>
</tr>
<tr>
<td>Underweight</td>
<td>25.68</td>
</tr>
<tr>
<td>Normal</td>
<td>61.67</td>
</tr>
<tr>
<td>Overweight</td>
<td>12.69</td>
</tr>
<tr>
<td>Height</td>
<td></td>
</tr>
<tr>
<td>Under-height</td>
<td>80.97</td>
</tr>
<tr>
<td>Normal</td>
<td>19.03</td>
</tr>
<tr>
<td>PEFR</td>
<td></td>
</tr>
<tr>
<td>Normal for age</td>
<td>97.89</td>
</tr>
<tr>
<td>Low for age</td>
<td>2.11</td>
</tr>
</tbody>
</table>
at least two forms of mercury — inorganic and methylmercury — simultaneously.

In the 33rd report of the Joint FAO/WHO Expert Committee on Food Additives (JECFA), it was recommended that the permissible tolerable weekly intake (PTWI) for methylmercury in adults be maintained at 200 μg (3.3 μg/kg body wt.) (WHO, 1978; WHO 1989b). However, the committee noted that pregnant women and nursing mothers are likely to be at greater risk (WHO, 1991).

Studies have shown that a daily methylmercury intake of 0.48 μg/kg body wt. will not result in any detectable adverse effects. However, a daily
intake of 3–7 μg/kg body wt. would cause adverse effects on the nervous system, manifested as an approximately 5% increase in the incidence of paraesthesia. It has been estimated that humans have a daily intake of approximately 2.4 μg methylmercury from all sources, and a daily uptake of approximately 2.3 μg.

The level of mercury in fish, even for humans consuming only small amounts (10–20 g fish/day) can markedly affect the intake of methylmercury. Daily mercury intake, elimination, retention and excretion will depend on a number of factors. Research studies should also include special populations at risk including children, pregnant and nursing women and the elderly. Calculations indicate that an intake of 50 μg/day in an adult would involve a risk of approximately 0.3% of the symptoms of paraesthesia, whereas an intake of 200 μg/day would involve a risk of approximately 8% (WHO, 1991).

11. Conclusions

11.1. Environment

1. Levels of total mercury for all water samples and sediments exceeded the national and international limits.
2. Fish samples based on WHO criteria showed three fish species [gopher, brunt and tuna (domestically used)] to have elevated total mercury while 11 fish species showed Me-Hg levels within the recommended levels.

11.2. Health

1. Of the 163 children, 10 (6.13%) had elevated T-Hg blood levels. For methylmercury only one child exceeded the WHO limit.
2. Of the 163 children, 2.5 (3.07%) had elevated total mercury hair levels, while Me-Hg was elevated in one child as compared with the WHO criteria of 6 ppm and 10 ppb, respectively.
3. On physical examination, abnormalities were found in all 163 children with the following five predominant abnormalities: under-height, gingival discoloration, underweight, adenopathy and dermatologic abnormalities.

11.3. Recommendations

1. There is a need to establish a laboratory to undertake a comprehensive inorganic and methylmercury determination in the area to provide the necessary guidelines to the community especially to high-risk groups such as pregnant women and children.
2. Education of high-risk groups, e.g. pregnant women/children.
3. For the local government units to conduct the following:
   3.1. continue health and environmental monitoring activities in the affected areas;
   3.2. require establishments to install anti-pollution devices for air pollution and waste treatment recovery/treatment facilities;
   3.3. relocation of ball-milling/refining process into an industrial zone;
   3.4. remediation/mitigation measures in the environment should be undertaken to ensure that exposure limits to mercury will be kept at a minimum or within permissible limits; and
   3.5. conduct monitoring of fish especially those with high levels.

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