A CASE HISTORY; MINAMATA MERCURY POLLUTION IN JAPAN — FROM LOSS OF HUMAN LIVES TO DECONTAMINATION

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ABSTRACT

At Minamata Bay in Japan, more than 100 people lost their lives and many thousands more were permanently paralyzed from eating mercury contaminated fish. In the long history of water pollution, this was the first known case where the natural bioaccumulation (in fish) of a toxicant from an industrial wastewater killed a large number of human beings. The mercury, discharged from a factory, was deposited on the bottom of the Bay and has remained there since the 1950's.

The fate of the mercury was traced by measuring 268 mercury concentrations in the surface sediments at Yatsushiro Sea (outside of the Bay) during the last 14 years. Twenty-four sampling stations were established to collect samples at the same location every year. Samples were analyzed for total mercury concentrations.

The concentrations of mercury in the surface sediments at the Sea were not alarming. Only 33 samples exceeded a mercury concentration of 1 ppm. The dispersion of the mercury from the Bay, however, was clearly documented with the data. On average, 3.7 tons of the mercury was transported outside from the Bay every year. A decontamination project started in 1984 dramatically decreased the flow of mercury from the Bay to the Sea. A historic rainfall in 1982 also "purified" the surface sediments. Organic mercury concentration in the sea water was 5.1 ng/l while total mercury was 120 ng/l at the center of the Bay in 1985.

KEYWORDS

Mercury Pollution; Minamata Bay, Transport, Dispersion, Organic Mercury Concentration; Sea Water, Mercury Concentration; Surface Sediments, Yatsushiro Sea.

INTRODUCTION

Over a quarter of a century ago, a tragic loss of human lives occurred at Minamata Bay in Japan (Fig. 1). More than 100 people lost their lives and many thousands more were permanently paralyzed from eating mercury contaminated fish. In a particular village facing the Bay (population 1100), 15% of the villagers were either killed or permanently paralyzed. With respect to the loss of human lives, the Minamata incident was far more tragic than that of the 1986 nuclear power reactor incident at Chernobyl in the USSR.

In the long history of water pollution, the Minamata incident was unique. This is the first known case where the natural bioaccumulation (in fish) of a toxic material (methylmercury) from industrial wastewater killed a large number of human beings. The Minamata case, therefore, is entirely different from other cases where the loss of human lives was caused by the direct intake of the contaminated water.
Fig. 1. Locations of Minamata Bay and sampling stations.

The mercury, discharged from a chemical factory (shown in Fig. 2) to Minamata Bay in the 1950's and 1960's, was deposited and accumulated in the bottom sediments. The amount of mercury was estimated as 150 tons by the Kumamoto prefecture in 1976 (Kumamoto Prefecture, 1976). Strangely, the Kumamoto prefecture (where the Bay is located) and the central Japanese government have been maintaining their original position (for 20 years) concerning the deposited mercury in the Bay: (1) "None of the mercury from the bottom of the Bay has ever escaped and dispersed to outside (Yatsushiro Sea)" and (2) "No detectable organic mercury has existed in the sea water in the Bay and Yatsushiro Sea".

The grounds for these two official positions have never been supported by any published scientific article (even in Japanese). Furthermore, it is surprising that over the past 20 years, Japanese establishment has not been challenged for its position. This is a purely scientific issue but nobody has ever had an interest in using recent scientific technology on the mercury in Minamata Bay. The scientific understanding of the movement of toxicants in the aquatic environment is of obvious benefit to all people in the world. This Minamata case can be considered as a model to prevent the future tragic loss of human lives caused by diluted industrial toxicants.

What has been actually happening to the mercury deposited in the Bay more than a quarter century ago? Is there a possibility that the mercury has been moving or dispersing outside to Yatsushiro Sea? If so, what is the increase of mercury (tons/year) in the surface sediments of Yatsushiro Sea?
Mercury pollution

Is it still impossible to determine the organic mercury concentrations in the sea water both in the Bay and the Sea? Our recent analytical knowledge and method should be able to detect the toxicant in the sea water.

These were the prime objectives when we started this investigation 15 years ago. Of course, no financial support was available from the Japanese establishment for this investigation. Therefore, the scope of this study was extremely meager and limited. Nevertheless, this report summarized the results of the last 14 year observation, some of which have already been published elsewhere (Kudo and Miyahara, 1980, 1983, 1984, 1986, 1988, Miyahara et al., 1988).

![Chemical Factory](image)

*Fig. 2. Aerial photograph of Minamata Bay before decontamination project.*

During the last 14 consecutive years, surface sediments were collected from 24 fixed sampling stations in Yatsushiro Sea. A total of 268 surface sediments were collected and analyzed. The results confirmed that the mercury has been indeed moving outside. On average, 3.7 tons of mercury escaped from Minamata Bay to Yatsushiro Sea during 1974-84 and the accumulated amount of the escaped mercury was 44.9 tons.

Furthermore, organic mercury concentrations were determined for both the Bay and the Sea in 1985. The concentration of the organic mercury was 5.1 ng/liter while total mercury concentration was 120.2 ng/liter at the center of the Bay.

In 1984, a decontamination project worth about 50 billion yen (equivalent $400 million US) was initiated at the Bay. This 5 year project was one of the largest water pollution decontamination projects in the world. A drastic decrease of mercury movement from the Bay was observed after 1985. Ironically this drastic decrease was additional proof that the mercury has been moving outside. The decontamination project involved carefully dredging the contaminated sediments, that is those which had a mercury concentration over 25 ppm. The contaminated sediments were stored inside a concrete wall and the excess water from the sediments was treated before re-releasing into the Bay. The amount of contaminated sediments dredged was over 1 million m³ and created about 100 acres of new land inside of the Bay, Fig. 3.
MATERIALS AND METHODS

Minamata Bay is a small inlet with a surface area of about 3 km² and is surrounded by steep hills with dense vegetation. It is located on a sparsely populated coast of southwestern Kyushu, Japan (Fig. 1). The only inflow of fresh water to the Bay is from a creek with an average flow rate of 0.5 m³/sec, most of which is discharged from the chemical factory. Because the inlet is deep (up to 15 m) and protected by an island (Koiji-Shima romantic island) at the mouth, it has been a natural harbor for fishermen for many centuries. Historically, people in this region have lived exclusively on fishing, because of easy access to the good fishing grounds of the Yatsushiro Sea and Minamata Bay itself. The unavailability of farm land (steep hills begin from the sea shore) has further underlined the uniqueness of fishing as the sole basis for food and income. Even 15 years after the outbreak of the Minamata disease, 144 families were still living as commercial fishermen around this small sleepy inlet (fishing has been prohibited only in the Bay itself).

The tidal effect in the area including the Bay is considerable. The average tidal difference is 2.23 m and the maximum is 3.40 m. The maximum surface water velocity caused by the tide is 5 cm/sec for inflow and 4 cm/sec for outflow at the Bay. Therefore, no bed sediment transport can be expected by the tidal action. However, about 20% (6 million tons) of the water can be exchanged twice a day by the tide. Therefore, suspended solids containing mercury can be dispersed by this tidal water exchange between the Bay and Yatsushiro Sea.

![After Decontamination Minamata Bay, Japan](https://iwaponline.com/wst/article-pdf/23/1-3/283/112469/283.pdf)

Fig. 3. Aerial photograph of Minamata Bay after completion of decontamination project.

Yatsushiro Sea is a kind of inland sea surrounded by the Amakusa islands and has 636 km² of surface area. The maximum depth of the Sea is 47 m and the total volume of the water is 13 km³. About 10% of this volume is exchanged by unpolluted external water twice a day. The maximum surface water velocity caused by the tide is 20 cm/sec within the Sea and could reach 200 cm/sec at the edge of the Sea. Therefore, some transport of bed sediments can be expected over a very limited area of the Sea under extreme conditions, but not in the central part of the Sea.
Twenty-four sampling stations were established to collect bottom sediments in the Yatsushiro Sea (Fig. 1). At least 2 kg (wet weight) of the surface sediments to a depth of 4 cm was collected from each location using an Ekman sampler. Despite considerable efforts, it was impossible to pinpoint each location every year in the open sea, and consequently some variation in texture (and hence the content of mercury) was unavoidable. Modern radar equipment on the ship located each station with an error of ±100 m. All samplings were conducted during the summer months. The sediment samples collected were a mixture of very fine sand, silt, and clay, and occasionally included some dead shells. During the past 14 years, due to various limitations including the weather, resources, and safety, 268 samples were collected and analyzed out of the planned 336 samples. A standard method adopted in Japan in 1975, called the Kanagawa method, was used to analyze the total mercury concentration in the sediment throughout the 14 years. The same analytical method and equipment (atomic absorption spectrometer) were deliberately used during the entire period for a direct comparison of data from one year to another.

RESULTS AND DISCUSSION

The concentrations of mercury in the 268 surface sediment samples collected during the past 14 years were not alarming, Table 1. The mercury concentrations in the Bay and Sea water were also at levels considered to be below acutely toxic.

Only 33 sediment samples exceeded mercury concentration of over 1 ppm. Therefore, no immediate acute health hazard was observed in this area during the period of 14 years. Three separate periods could be considered concerning the mercury concentration in the Sea between 1975 and 1988: (1) Steady increase period of 1975-84, except 1982, (2) Sudden decrease in 1982 due to historic rainfall (400 mm in 3 hours), and (3) the decontamination period of 1985-88.

(1) Steady increase period between 1975 and 1984

The mercury concentrations of 24 sampling stations gradually increased during this period. In general, sampling stations close to Minamata Bay, for example, station 4, increased more rapidly than those stations (like station 22) far from the Bay. At station 4 (8 km from the effluent and 5 km from the edge of the Bay), the increase was dramatic. The mercury concentration increased 0.615 ppm in 1975 to 0.886, 3.478, 6.059, 6.641, 10.273, 6.450, 11.547, 10.528, 2.028, 3.077, 4.663 in the years 1977 through 1984, respectively. At station 22, the...
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Increase was moderate and from 0.167 ppm in 1975 to 0.218, 0.250, 0.244, 0.261, 0.300, 0.100, 0.218, 0.284, and 0.215 ppm in the years 1976 through 1984, respectively. The background level of total mercury concentration in the surface sediments of Yatsushiro Sea was considered to be 0.100 ppm.

(2) Historic rainfall in 1982

The year of 1982 was an exceptional year for Yatsushiro Sea area with respect to the weather. Normally, this region enters a rainy season at the beginning of June. Japan has a very steady climate throughout the year because her islands are surrounded by the sea. The region of the Yatsushiro Sea did not have any rain during the month of June, 1982. This was a very rare phenomenon. All of a sudden, a historic rainfall of 400 mm in 3 hours flooded this area (this happens approximately once every 200 years). Millions of tons of fresh clean soils were washed out from the surrounding steep mountain slopes and lands, covering the surface of sediments throughout Yatsushiro Sea. The fresh sediments, thus, reduced the mercury concentrations in the surface sediments at the Sea. One month after this historic rainfall, the sediment samples were collected from 24 sampling stations. The reduced mercury concentrations in 1982 reflected the natural "purification" phenomena. The analytical results showed more "reasonable values" for the following years of 1983 and 1984.

(3) Decontamination period of 1985-88

A considerable decrease in the mercury concentrations have occurred since 1985 when the decontamination project started. At station 4, the mercury concentration dropped from 10.528 ppm in 1984 to 2.028, 3.077, 4.663, and 2.801 ppm in the years 1985 through 1988, respectively. Within 30 km from the effluent of the industrial wastewater, the mercury concentration decreased at 8 out of 9 stations analyzed. These results might be an indication that the mercury travelled about 30 km in one year in this specific location of Yatsushiro Sea, because the decrease was less noticeable at the stations between 30 and 52 km from the effluent.

The total amount of mercury in the surface sediments was calculated using the concentrations obtained for each year (Fig. 4). The amount in Yatsushiro Sea increased from 11.28 tons in 1975 to 16.78, 22.39, 33.35, 38.37, 37.71, 26.83, 43.05, 44.86, 23.49, 25.92, 33.39 and 24.04 tons in the years 1977 through 1988, respectively. There are again, three interesting periods recorded in the total amount of mercury of the surface sediments in the Sea during the past 14 years. The first is the constant increase of mercury from 1975 to 1984 (except 1982). The total amount increased from 11.28 tons in 1975 to 44.86 tons in 1984. This could be considered to be a continuous dispersion of mercury from the Minamata Bay outward into the Yatsushiro Sea. On average, an increase of 3.7 tons of mercury per year was observed over this period. The second, and most surprising of the three, is the sudden decrease in the concentration of mercury in the Sea in 1982. This sudden decrease was observed at all stations throughout the Sea and the total decrease was 10.28 tons (from 37.71 tons in 1981 to 26.83 tons in 1982). Equally surprising is the return of the amount of mercury in 1983 to a "reasonable" 43.05 tons. The third point of interest is a dramatic decrease of the total amount of mercury since 1985. The amount in the Sea decreased from 44.86 tons in 1984 to 23.49 tons in 1985 and 25.92, 32.39, and 24.04 tons in the years 1986 through 1988, respectively. This decrease is considered to be caused by the decontamination project initiated at the Minimata Bay in 1984. The project sealed most of the contaminated sediments in the Bay by means of a concrete barrier. This caused the dramatic decrease of mercury in the surface sediments of the Sea, observed between 1985 and 1988. This decrease in surface sediments, therefore, would continue and a further reduction due to natural purification processes (as observed in 1982 in intensified form) is expected until the amount levels off to a background value of 8.22 tons. In other words the amount shown in Fig 4 is not the amount of mercury dispersed from the Bay but the net amount (amount dispersed from the Bay minus the amount "purified" annually by natural processes) existing in the surface sediments of the Sea.

From these three phenomena, it is apparent that the mercury was indeed moving from Minamata Bay to Yatsushiro Sea until 1984, despite the Japanese government's position that it was "not moving". However, most commendably the government took responsible action against the mercury pollution in the Bay. The decontamination project will not only clean up the Bay itself but also will definitely protect the people around Yatsushiro Sea for years to come.
The mercury concentration in the Bay and Sea water is also interesting (Table 2). The total mercury concentration in the Bay ranged from 125.3 ng/l at the center of the Bay to 22.1 ng/l beside Koji-shima at the exit to Yatsushiro Sea. It is not known why the center of the Bay contained the highest concentration in the water in 1985. The tidal information (whether high or low tide) was not recorded at the sampling time in 1985. The amount of organic mercury ranged from 5.5 ng/l at Kiyakkenmon to 1.8 ng/l at new port and the proportion to the total mercury ranged from 10.0% at Koji-shima to 4.1% at the center of the Bay. The proportion was much lower than what is found in rivers in Japan and Canada, about 30% (Kudo et al., 1982). The reason for the lower proportion is not fully understood at the moment.

The mercury content in the water of Yatsushiro Sea was not significantly high and ranged from 25.8 ng/l at Station 14 to 16.4 ng/l at Station 18 for total mercury. As the concentration for the Pacific Ocean ranges from 5 ng/l to 10 ng/l, the concentrations found in water in 1985 are considered to be reasonable for inland waters (Kudo et al. 1982).

The relatively low mercury concentration in the water suggests that the escaping mercury is associated with suspended sediments and is not present in a soluble form. This may lead to a low bioavailability of the mercury, which could explain why there has been no reported human health hazard since the 1960's caused by the escaping mercury.

ACKNOWLEDGEMENT

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TABLE 2. Organic and Inorganic Mercury Concentrations in Minamata Bay and Yatsushiro Sea in 1985 (after Miyahara et al.)

<table>
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<th>Locations</th>
<th>Inorganic</th>
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<th>Total</th>
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*Duplicate sample of 8 liters each.

REFERENCES


