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Projektarbete 15 hp

Mars 2015

Human Exposure from Mercury in Rice in the Philippines

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A Minor Field Study in Palawan, the Philippines

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June – August 2014

Masters Programme in Environmental and Water engineering

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Abstract

In the western part of the Philippines, in the Palawan province, studies have shown that large quantities of mercury are spread to the surrounding area during heavy rainfall. In addition, mercury is spread to rice fields and bioaccumulated in marine fish and seafood. The mercury originates from the abandoned Palawan Quicksilver Mine. Since mercury is toxic for the human body and new studies have shown that mercury accumulates in rice, it is important to investigate human exposure from mercury in rice.

This project investigates the total amount of mercury and methylmercury (MeHg) accumulated in rice, soil and water from four different rice fields in Palawan. The soil samples have been taken directly from the fields and water samples have been taken from nearby streams and springs. Rice grains harvested earlier this year from the same fields have been collected from farmers. The soil, water and rice samples were analyzed in Manila and rice samples were as well analyzed in Sweden and China. Furthermore, this project contains a dietary survey and calculation of daily exposure values of MeHg. The survey investigates how often people eat fish and rice and if they have dental amalgam. It also investigates possible health problems related to mercury exposure from rice and fish consumption.

The analyses from China show that rice samples from all barangays contain total mercury and MeHg. Analyses from Sweden also show that rice from the barangays contains total mercury but the levels were found to be higher than the ones analyzed in China. Furthermore, the health problems found in the diet survey were hard to relate to mercury exposure from rice since the health problems can be caused by other factors. When calculating daily exposure values, the values were found to be as high as the recommended maximum acceptable daily intake in one of the barangays. There might therefore be a risk of eating rice from these four barangays. It is important to consider that these daily exposure values were only based on MeHg exposure from rice consumption, not taking dental amalgam and fish consumption into consideration. This means that the daily exposure values might be even higher than the ones calculated in this study.

Table of Contents

1 Introduction

1.1 Mercury problem on a global scale

Mercury is a naturally occurring element in many minerals, including cinnabar, found all over the world. Since there are many natural sources, the background environmental levels of mercury have been present long before humans appeared. Although, the levels are generally quite low (UNEP, 2013).

Since the 1800s, human activity such as burning of coal and mining has increased the amounts of mercury in the atmosphere, soils, oceans and fresh water. 30 % of all present mercury emissions are anthropogenic (UNEP, 2013). The main industrial sources of atmospheric mercury are mining, coal burning and industrial activities that process ores to produce metals or to process other raw materials in cement production. Mercury is present as an impurity in these processes and is thereby emitted and referred to as “unintentional” or “by-product”. Artisanal and small-scale gold mining (ASGM) and coal burning contribute to most of the anthropogenic emissions followed by ferrous and non-ferrous metal production (UNEP, 2013). In ASGM, liquid mercury is added to powder from the ore. This results in an amalgam of gold and mercury. The amalgam is then heated to extract the gold and the mercury is vaporized The annual emission of mercury from ASGM is estimated to be around 727 t. It is hard to determine the exact emission from ASGM since most of the activity is unregulated or illegal and thus it is hard to find reliable official data (Drasch et al. 2000; UNEP 2013).

Because of industrialization, mercury emissions to the air peaked in the 1970s. Afterwards, emissions decreased the following 20 years with a small increase between 2000 and 2005 (UNEP, 2013). Though, it is hard to compare emissions 25 years ago with today’s because of changes in reporting systems, inventory systems and additional sectors. Asia is increasing the use of coal for power generation and industry, thereby increasing the emissions of mercury to the air. As a result of more stringent regulations, improved combustion efficiency and wider use of air pollution control, most of the mercury emission arising from higher coal consumption has been offset (UNEP, 2013).

In their report of 2013, United Nations Environment Programme (UNEP) stated that the mercury level in the top 100 m of oceans is twice as high as 100 years ago. The slow transfer of mercury from surface water to deep water leads to high mercury accumulation in many marine animals; in some species the mercury content is 12 times higher than before industrialization. Over a long time scale, inorganic mercury is accumulated in deep waters. With upwelling, a big amount of this mercury is recycled back to the surface.

Anthropogenic mercury is continuously loading the sediments of lakes and rivers. By some microorganisms, organic mercury can easily be transferred to methylmercury (MeHg), which is the most toxic form (UNEP, 2013).

The biggest sources of mercury in water are contaminated sites such as old mines, landfills and waste disposals but also industrial sites such as power plants and factories. ASGM was evaluated separately and estimated to have a yearly release of about 800 t of mercury to water, compared to power plants and factories which release about 185 t a year. In total, anthropogenic mercury released to water is approximately 1000 t a year (UNEP, 2013).

Additionally, global climate changes complicate the globalization of mercury. Higher temperature may increase the rate of transformation of inorganic mercury to MeHg by anaerobic bacteria. Thawing of northern frozen peat lands may also release big amounts of stored mercury and organic matter to water (UNEP, 2013).

1.2 Mercury problem in Palawan

The Palawan Quicksilver Mine (PQM) in the province of Palawan, Philippines, has been of high economic importance for the locals since mercury started to be sold and used in the gold mining industry. The mine is now abandoned but was in operation between 1953 and 1976, producing about 140 t of mercury a year. During 1953-1976, about 2,000,000 t of mine calcines (product from the mining process calcination) were produced and half of these were used to construct a jetty in Honda Bay about 3 km from the mine, facilitating mine operations. Honda Bay is currently a local fishery and recreational area, and home to a couple of hundred people. Mine tailings were also used as topsoil and land filling in adjoining communities (Maramba et al., 2006).

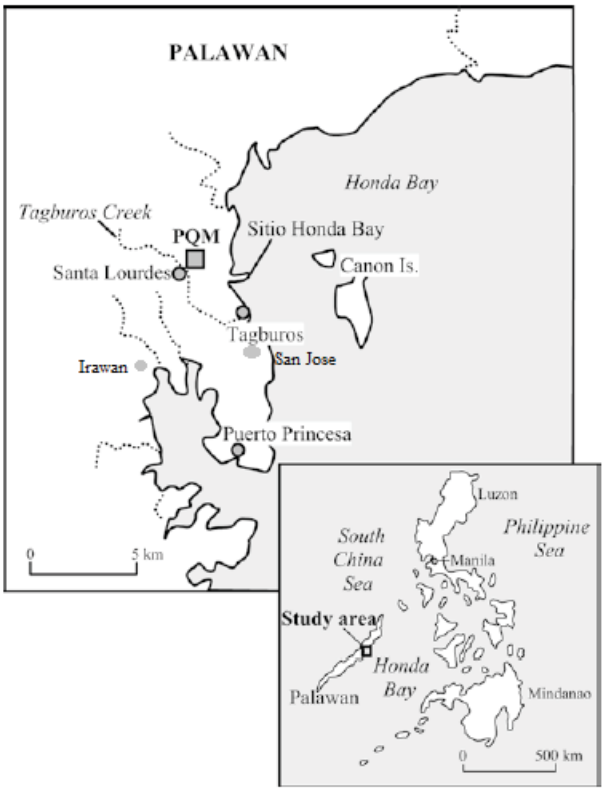

Figure 1. Map of the PQM and its surroundings (Gray et al., 2003).

In 1994, the Provincial Health Office contacted the Department of Health asking them for assistance investigating complaints of unusual symptoms such as tooth loss, miscarriages, muscle weakness and anemia among people living in the three barangays Tagburos, San Jose and Santa Lourdes, close to Honda bay. The investigation was conducted on 43 people, most of them former mine workers. For 12 of the participants, the mercury level in the blood was above the recommended exposure level of 20 ppb. Gum bleeding, gingivitis, mercury lines, numbness, weakness and incoordination were also found among the participants (Maramba et al., 1996).

Field work done in year 2000 showed a lack of physical and regulatory restrictions for human activity at the PQM. There were several residential homes near the mine-waste calcines and a domestic water well was drilled into calcines. Children played at the mining site and farm animals grazed on grass growing on the calcines (Gray et al., 2003).

1.3 Aim

The aim of this study is to investigate if people living close to the PQM can be exposed to mercury by eating rice possibly containing mercury. The study consists of two parts: sampling of rice, soil and water from three possible contaminated rice fields and a diet survey.

Questions to be answered in the study:

- What are the amounts of MeHg and total mercury in rice in areas around Honda Bay?
- What are the amounts of total mercury in soil and water in the area?
- Are there any symptoms related to mercury poisoning among the local population?
- Is there a risk for the local population to be exposed to mercury by rice consumption and in that case, how severe is the exposure?

2 Background

2.1 Mercury in general

Mercury is a very dangerous toxic substance that cannot be destroyed or broken into harmless elements (EPA, 2013). Once mercury is released it circulates globally between air, water, sediment, soil and biota (UNEP, 2002). It varies between three different forms: elemental mercury, inorganic mercury salts and organic mercury (Erle et al., 1997). Some microorganisms can convert mercury to its most toxic form, organic methylmercury (MeHg or CH_3Hg) (Venugopal and Luckey, 1978).

2.2 MeHg in rice

For a long period of time, consumption of fish and other marine animals has been considered the main pathway of human exposure to MeHg because of its tendency to bio magnify in the food chain (Melin, 2010). It is widely known that consuming too much fish might be unhealthy considering the high levels of mercury. However, recent studies have elucidated that rice consumption might be the main pathway of human exposure to MeHg. The rice fields (paddies) are submerged during the rice growing season and then flooded again during the postharvest phase to speed up the rate of stalk decomposition. This results in anoxic conditions, which facilitates the growth of sulfur-reducing bacteria (SRB). SRB can transform mercury to MeHg, leading to MeHg accumulation in rice. Therefore, in mercury mining areas, rice consumption might be the main pathway of human exposure to MeHg since it is the dominant staple food in the Philippines and other parts of South and East Asia (Chen et al., 2011).

In 2011, the Institute of Geochemistry at the Chinese Academy of Sciences in Guiyang conducted an investigation on how MeHg is distributed in rice plants during the plant-growing season. The study showed that even if the levels of mercury and MeHg in the soil of rice fields in the beginning are low, it can still be increased by a factor 2.5 and 6.2, respectively, if the air contains mercury vapor. Mercury in air can be deposited into the soil of rice fields and then in situ methylated. Newly deposited mercury also has a higher affinity to undergo methylation than old mercury in soil. It is earlier known that MeHg from air at contaminated sites and irrigation water is negligible. The increase of MeHg levels in the soil of rice fields depends on mercury influx from air and high temperature in the soil which speeds up the methylation rate. Once MeHg is created in soil, it can readily cross root barriers and then bioaccumulate in rice tissues above ground. Further studies are necessary to completely understand the complex methylation of mercury in soil (Chen et al., 2011)

Observing MeHg in rice roots during the whole rice growing season, MeHg levels in rice are higher in fields where total mercury levels in soil are high. Statistical analysis showed positive correlation between soil and roots meaning that high MeHg levels in soils also result in high concentrations in roots (Chen et al., 2011). MeHg in roots is reduced after approximately 60 days of growing, it might be a result of translocation from the roots to the seed. The highest MeHg levels in stalk and leaf were reached before 60 days of growing. Thereafter, MeHg in stalk and leaf declined and reached the lowest levels when harvested. This is also explained by the start of seed growing in the plant where all plant growth is focused on increasing the biomass of the rice grain. In the end of growing season, seeds contained higher MeHg than root, stalk and leaf tissues. The study also showed that rice plants exposed to an elevated level of MeHg in soil develop grains containing higher MeHg levels than rice plants growing in soil containing low mercury concentrations (Chen et al., 2011).

Comparing rice growing in soils that contain low levels of mercury with rice growing in soil with high levels, the rice tissues contain higher mercury levels if they grow in contaminated soil. This demonstrates the potential for increased MeHg production as a function of background total mercury in soil. Chen et al:s (2011) interpretation is that concentration of MeHg in paddy soils is the only factor controlling MeHg concentration in tissues of rice plants. The soil in rice paddies is also the major source of MeHg to rice plants. The fact that MeHg can be formed in situ in rice tissues cannot be ignored. The study shows that MeHg in soil is first absorbed by roots and then combined with polysaccharide, nucleic acid and protein. The MeHg is located in leaves and stalks in the premature plant and then transferred to the seeds during the ripening period (Chen et al., 2011).

2.3 Mercury methylating bacteria

The methylating process of mercury mostly occurs by a specific bacterial activity, caused by sulfate reducing bacteria (SRB) and iron reducing bacteria (FeRB). SRB are obligate anaerobes, which means that they demand an anoxic environment during their whole life cycle. During the respiration process, where chemical energy from hydrocarbons is converted into metabolic energy, sulfate is used as an electron acceptor (Benoit et al., 2003; Fenchel et al., 1999). It is likely that uncharged mercury complexes diffuse passively over the cell membrane and into the bacteria cell. It is during the sulfate reduction that the methylation of Hg (II) occurs. How the methylation occurs has been well discussed but today scientists state that a methyl group (CH_3) is transferred from methylcobalamin, which is a vitamin B12, to Hg (II). The exact reaction chain is still unknown but indications show that the methylation occurs by chance, a side reaction (Benoit et al., 2003). There are a couple of factors influencing the activity of the SRB and thereby also effect the production of MeHg. The factors are supply of hydrocarbons (electron donator), sulfate supply (electron acceptor), temperature and supply of dissolved and uncharged mercury complexes (Drott et al., 2007b).

Since high iron concentrations overlap with high concentrations of MeHg, scientists suspect that also iron reducing bacteria are capable of methylate Hg (II). Though, most facts indicate that the microbial conversion of sulfur has the biggest effect on mercury methylating in anaerobic environments (Regnell, 2005).

2.4 Exposure

Severe exposure to mercury can be harmful for the brain, heart, kidneys, lungs and immune system. The MeHg form is a neurotoxin and can easily pass through both the placental barrier and the blood-brain barrier. It can also cause blindness, chromosome damage, paralysis and birth defects (Venugopal and Luckey, 1978). High levels of MeHg in the blood of fetus and young children can cause harmful effects on the developing nervous system, resulting in reduced learning ability. Symptoms like impairment of peripheral vision, speech, hearing and walking, disturbances in sensations, lack of coordination and muscle weakness can be an effect of MeHg poisoning (Medicine net, 2014). The elemental (metallic) form of mercury mainly causes health effects due to inhalation where it can be absorbed through the lungs. For elemental mercury, symptoms may include tremors, emotional changes, insomnia, head ache, changes in nerve responses and performance deficits on tests of cognitive function. Exposure at high levels can lead to kidney effects, respiratory failure and also death (Medicine net, 2014).

Mercury can also be used as dental amalgam for teeth fillings. When chewing, drinking hot beverages, brushing etc., mercury can be released from the amalgam and absorbed by the human body. Dental amalgam weighs around 1.5 g to 2 g per filling; half of that amount consists of mercury (Crinnion, 2014). In addition, mercury can be emitted when bodies are cremated and during production of fillings (Global Mercury Assessment, 2014).

2.5 Guideline values

The US EPA (Environmental Protection Agency) has calculated a reference dose (RfD) level for MeHg. An RfD describes the maximum acceptable daily exposure to humans that would not cause harmful effects during a lifetime. Currently, the RfD is 0.1 µg MeHg/kg body weight/day, last revised in 2001 (US EPA, 2014). The maximum contaminant level for mercury in drinking water is 0.001 mg/L in EU (Livsmedelsverket, 2014). Since there are no guideline values for rice, WHO's guideline value for fish can be used for comparison. WHO recommend that the total mercury content should not be above 0.5 µg/g in fish (Kemikalieinspektionen, 2014).

2.6 Previous studies

In 1996, the British Geological Survey conducted a preliminary assessment of mercury concentrations in sediments of Honda Bay (Williams et al., 1996). The average mercury levels were 40 µg/kg soil, which is within global background levels. Studies on down core mercury profiles also indicated no significant adjustment of mercury influx during the past 100 years. The levels in stream, aquifer water and fish also fell within normal range. On the other hand, blood samples from humans and tissue samples from green mussel near Honda Bay showed high mercury levels compared to control populations (Maramba et al., 2006).

The United States Geological Survey also conducted a study on the abandoned mine in the early 1990s (Benoit et al., 1994). Sediment samples from Tagburos creek and a mine pit-lake showed mercury concentrations between 4 and 400 µg/g and MeHg concentrations between 2.0 and 2.1 ng/g. Mercury levels in local marine fish varied between 0.05 to 2.2 µg/g (wet weight). Levels in green mussels were 0.86-4.4 µg/g compared to levels of 0.24-0.58 µg/g for samples collected 6 km from Honda Bay. The mussel samples also suggested higher MeHg levels at the PQM area and a higher bioaccumulation than areas further away from the PQM (Maramba et al., 2006).

3 Materials and methods

3.1 Sampling of rice, soil and water

Samples were collected from four different barangays (areas): San Jose, Tagburos, Santa Lourdes and Irawan. The last barangay, Irawan, was used as a reference area since it is located further away from the PQM (approximately 15 km) and has a similar geology. Due to this, Irawan can be expected to have low levels of mercury and MeHg. San Jose, Tagburos and Santa Lourdes are located 14 km, 10 km respectively 3 km from the mine (Maramba et al., 2006).

To investigate the relationships between the mercury levels in the samples, the rice, water and soil must originate from the same rice field. Due to hot weather and the start of rainy season, water samples could not be collected directly from the rice fields. Instead they were collected from irrigation water leading into the fields. In Santa Lourdes, the water was taken directly from the river and in San Jose and Tagburos it was taken from a spring. In Irawan, water was taken from a well. The water was kept in 1 L plastic bottles and within 8 hours of collection, the water samples were acidified with 5 ml nitric acid. Since the rice was harvested in March, no rice grains could be collected from the fields. Therefore, the rice grains were collected from farmers who had harvested the studied field. To collect soil samples, three different samples were taken in a diagonal from the rice field. Soil was taken from a depth of approximately 1 dm with a small shovel. Both rice and soil samples were collected in plastic zipper bags. Soil, rice and water samples were sent to a laboratory in Manila for total mercury analysis. Rice samples were also sent to China for total mercury and MeHg analysis. In Sweden, rice samples were analyzed for total mercury. All total mercury levels were analyzed with the AAS method and MeHg levels with gas chromatography. For total mercury and MeHg analyzed in China, between four and seven samples from each sample are were analyzed. For the total mercury analysis in Sweden, between two and three samples were analyzed.

3.2 Atomic absorption spectroscopy (AAS)

The “ground state” atom of the element being studied absorbs light energy of a specific wavelength and then enters the “excited state”. The amount of light absorbed increases with the number of atoms in the light path. A quantitative determination can be made of the amount of analyte, by measuring the light absorbed. To determine specific elements, special light sources can be used combined with carefully selected wavelengths (The Perkin-Elmer Corporation, 1996).

3.3 Gas chromatography – cold vapor atomic fluorescence spectrometry (GC-CVAFS) and US EPA method 1630

The rice samples sent to China were analysed for MeHg with this method. First, dissolved MeHg samples are filtered through a capsule filter. HCl is added to fresh water samples for preservation, while H_2SO_4 solution is added to saline samples. The samples are distilled at 125ºC under N_2 flow. After distillation, the samples are adjusted to pH 4.9 with an acetate buffer and ethylated by the addition of sodium tetraethyl borate. The methylethyl mercury (the ethyl analog of MeHg), is separated from solution by purging with N_2 onto a graphitic carbon trap. After the separation the methylethyl mercury is thermally desorbed from the carbon trap into an inert gas stream that carries the released methylethyl mercury first through a pyrolytic decomposition column. The column converts organo mercury forms to elemental mercury. Then the stream carries the elemental mercury into the cell of a cold-vapor atomic fluorescence spectrometer (CVAFS) for detection (US EPA, 1998). The CVAFS technique is an extremely sensitive detector. The elemental mercury atoms are excited, in an inert gas stream, by a source of ultraviolet radiation. At a wavelength of 253.5 nm excitation and fluorescence occur (Díez et al., 2002).

3.4 Diet survey

The diet survey was conducted in the three barangays: San Jose, Tagburos, and Santa Lourdes. Ten families and 18 people in total took part in the survey; three families from San Jose, three from Tagburos and four from Santa Lourdes. One to three people were interviewed in each family, depending on how many family members the family had. Both male and females between 18 and 81 years old were interviewed. The interview procedure consisted of one questioner and a note-taker. For interview questions, see appendix 1.

3.5 Daily intake of MeHg

Daily exposure values of MeHg from rice were calculated. The calculations were based on the results for MeHg in rice from Tagburos, average weight for men and women and average daily consumption of rice. For calculation see appendix 2.

4 Results

4.1 Analyses in the Philippines

The mercury levels were determined with the AAS method. All rice, water and soil samples had mercury levels below the detection limits for the analytical method. The detection limit for soil and rice were 0.025 µg/g and for water 0.001 mg/L.

4.2 Analyses in China

The total mercury levels were determined with the AAS method and the MeHg levels with the GC-CVAFS method. Levels for total mercury and MeHg are presented in Tables 1.

Table 1. Total mercury in the four barangays.

Sample area	***Total mercury (ng/g)***	***MeHg (ng/g)***
Tagburos	**8.71**	**7.0**
Santa Lourdes	**11.5**	**6.8**
San Jose	**3.98**	**3.3**
Irawan	**2.86**	**2.6**

Total mercury levels are presented in Figure 2. Santa Lourdes, which is located closest to the PQM, has the highest mercury level.

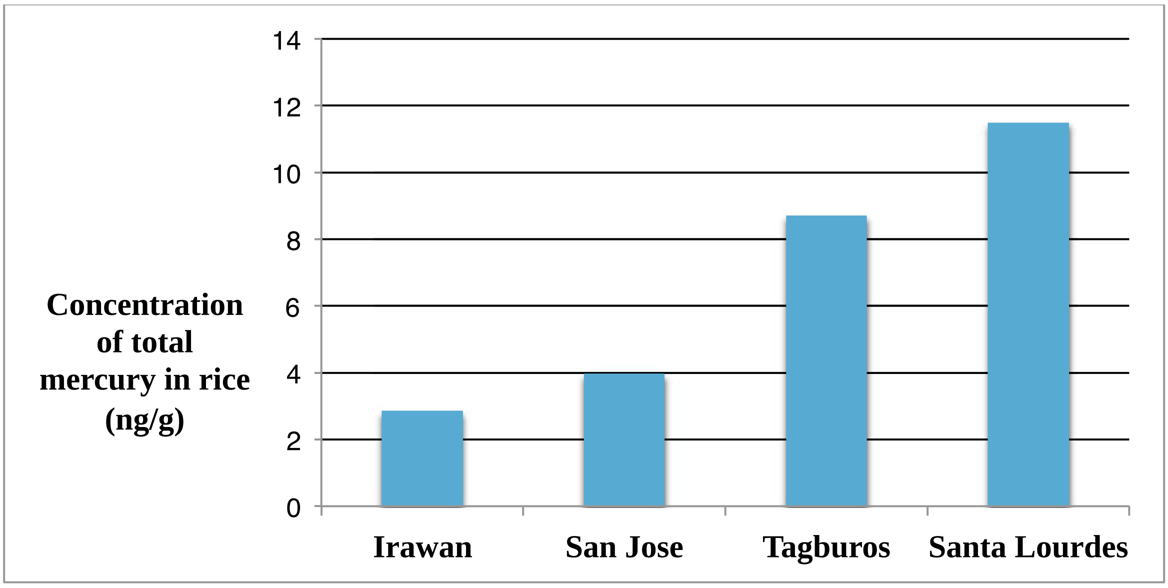

Figure 2. Total mercury in the four barangays.

In Figure 3, most of the total mercury occur in the MeHg form**,** in the barangays Irawan, Santa Lourdes and Tagburos. The amount of MeHg compared to total mercury in Santa Lourdes is not as high as in the other barangays.

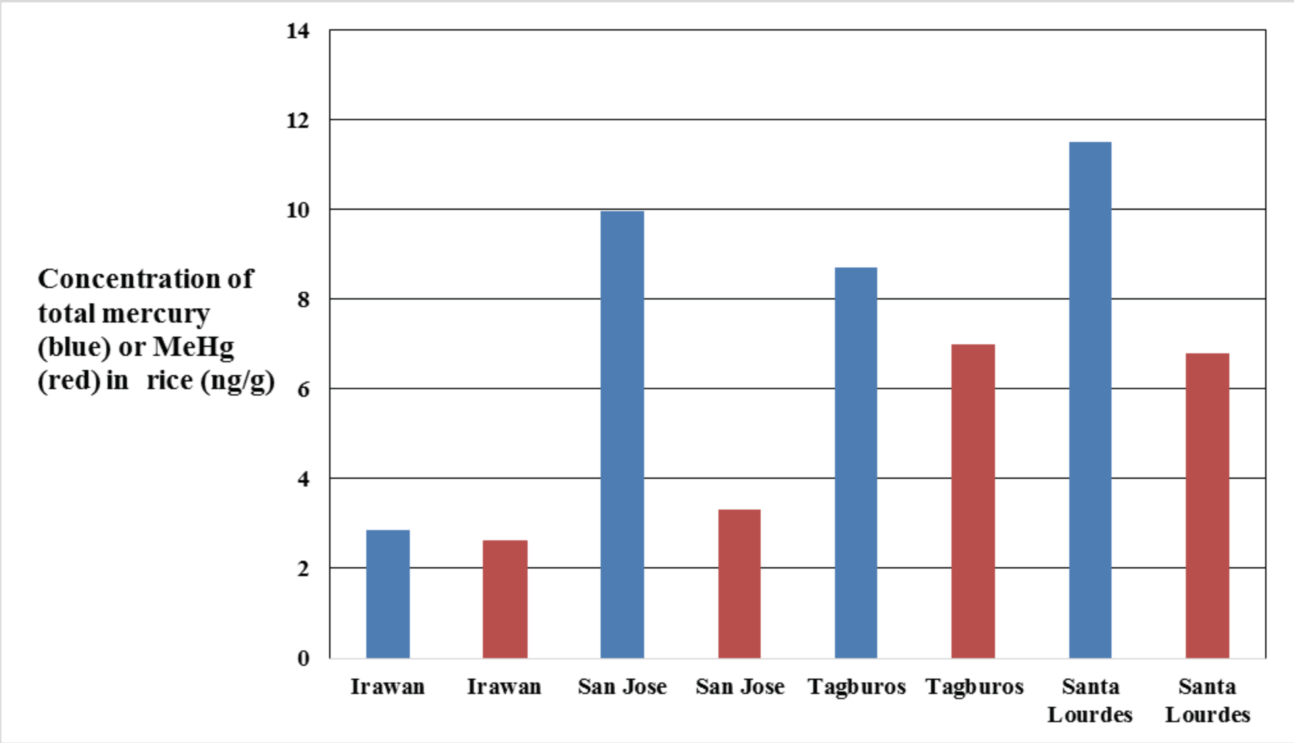

Figure 3. Total mercury and MeHg in rice from the four barangays.

The highest levels of MeHg were found in Tagburos and Santa Lourdes (Figure 4), the barangays located 14 km respectively 3 km from the mine. The lowest level of MeHg is found in the reference area Irawan. San Jose, located 10 km from the PQM, also has a relatively low MeHg level. The reference area, Irawan, has the highest percent of MeHg, 90.9 %. Santa Lourdes has the lowest percent, 59.1 %, while San Jose and Tagburos have similar levels (83 % and 80.4 %).

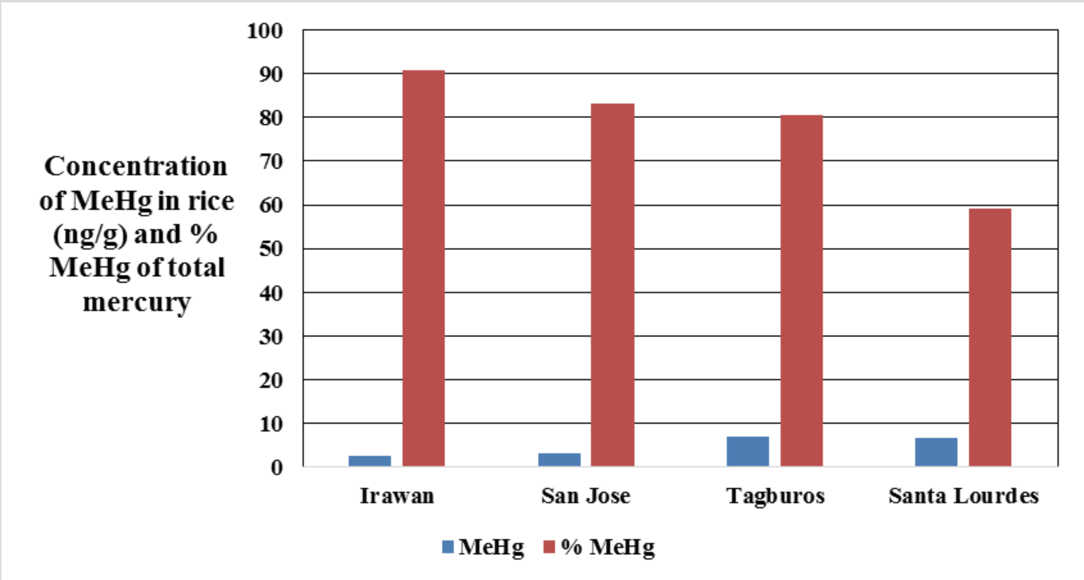

Figure 4. MeHg and percent MeHg of total mercury in the four barangays.

4.3 Analyses in Sweden

Total mercury in rice were determined with the AAS method. For each sample area, two or three samples were analyzed.

Table 2. Total mercury in rice for the four barangays.

Sample Area	*Total mercury (ng/g)*
Tagburos	15.18
Santa Lourdes	13.99
San Jose	3.81
Irawan	4.32

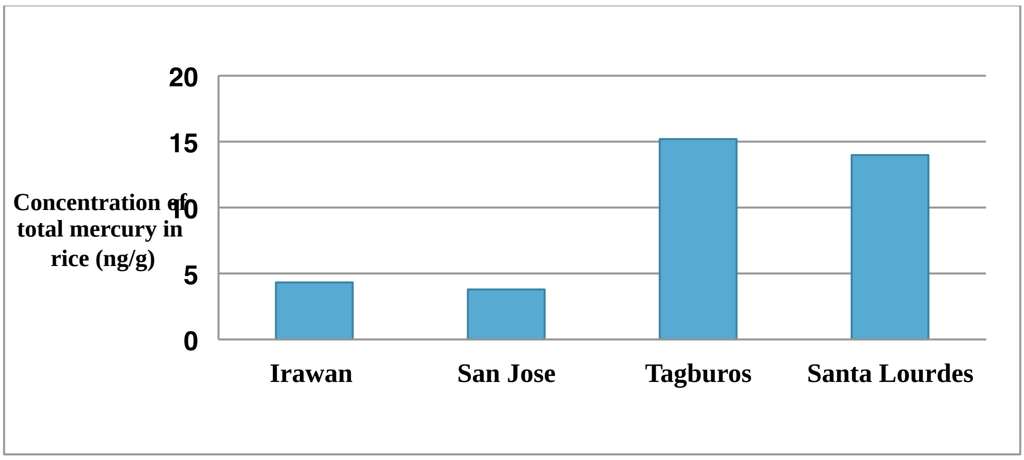

Figure 5. Total mercury concentrations in the four barangay

4.4 Comparison of mercury content

In Figure 6, a comparison of mercury content from rice analyzed in China and Sweden is presented.

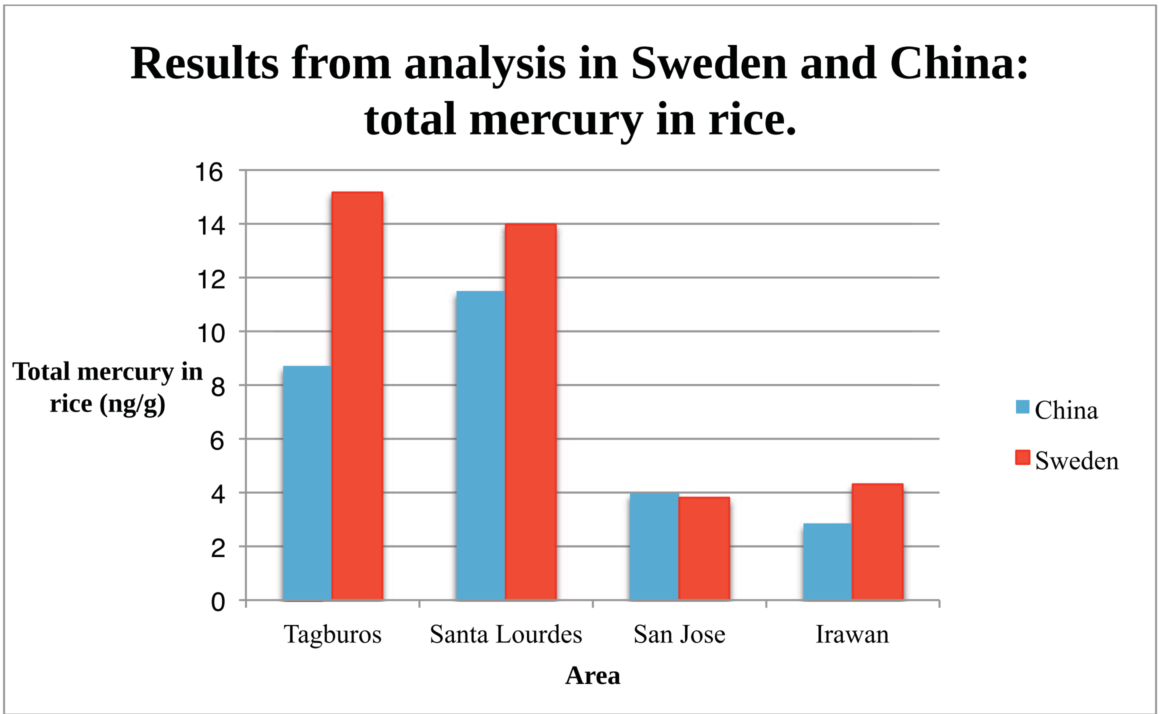

Figure 6. Comparison of mercury content in rice analyzed in China and Sweden. For San Jose, the results are quite similar while, for the other three barangays, the results from Sweden are higher than the results from China.

4.5 Diet survey

Rice and fish consumption for the participants in the diet survey are presented in Figures 7 and 8. In average, women eat 100-200 g rice/meal and men 200-300 g rice/meal. Both sexes eat approximately 200 g fish/meal. Every person interviewed eat rice at least once a day and most common is to consume rice three times a day.

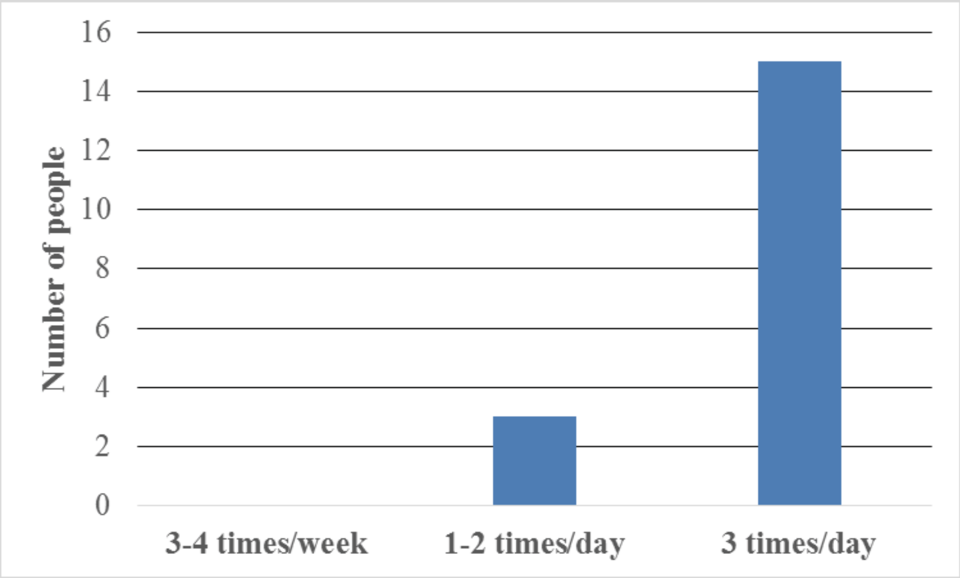

Figure 7. Rice consumption of all participants.

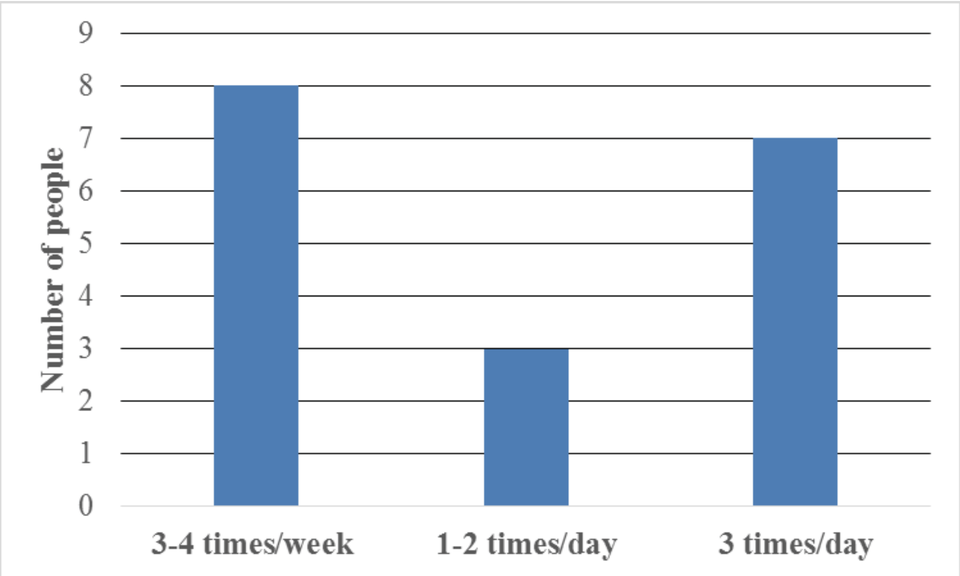

Figure 8. Fish consumption of all participants.

Symptoms observed among the participants are presented in Figure 9. Only two out of all 18 participants had dental amalgam in their teeth fillings. There were also two former mine workers among them, both of them living in Santa Lourdes.

A woman that took part in the survey had very evident symptoms compared to other participants. She had reduced muscle weakness and touch sensations in the left side of her body, troubled speech, enlarged heart and migraine, among others. Her health status was a result of frequent intake of mercury in the 1970s since it was considered healthy at the time.

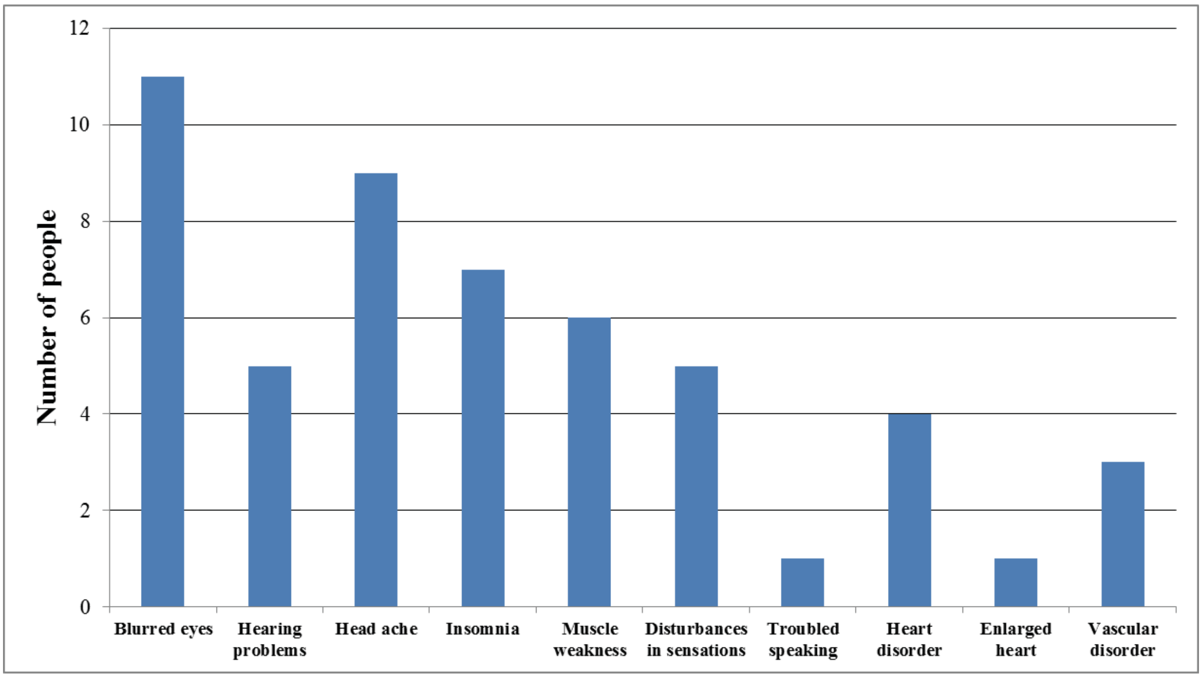

Figure 9. Possible symptoms of all participants. One participant can have different kinds of symptoms.

4.6 Daily intake of MeHg

Using average values for MeHg in rice from Tagburos, the average consumption of rice for male and female participating in the diet survey and average body weight, the daily exposure values were calculated. The results show that men are more exposed than women. For calculation see section 8.2.

Table 4. Daily exposure of MeHg from rice. The results are based on mean values for body weight, rice consumption and MeHg in rice from Tagburos.

Sex	*Daily exposure of MeHg from rice (µg MeHg/kg BW)*
Female	0.08
Male	0.10

5 Discussion

5.1 Laboratory analysis

The rice, water and soil samples analyzed in Manila all results were under the detection limit. The laboratory used a detection limit of 0.025 µg/g for the rice and soil. For the water, they used a detection limit of 0.001 mg/L. This means that the total mercury content in rice and soil is less than 0.025 µg/g and the water contains less than 0.001 mg/L total mercury. WHO does not have a guideline value for rice but for fish they recommend that the total mercury content should not be above 0.5 µg/g (Kemikalieinspektionen, 2014). Compared to WHO's guideline value for fish, the laboratory's detection limit for total mercury in rice and soil are about a factor ten lower. Having a detection limit so close to WHO's limit value can be a big risk. The concentration of mercury in the samples might be just below the detection limit set by the lab, and taking into consideration that people eat rice about three times a day in the Philippines, people might be severely exposed even though the mercury levels are just below the detection limit.

The detection limit for water is the same as the EU guideline value of 0.001 mg/L. For the same reasons as for the rice and soil there is a risk in having such a high detection limit since the concentrations might be just below 0.001 mg/L. Taking into consideration that people drink the water every day they might be highly exposed.

When looking at the results, Santa Lourdes has the highest level of total mercury and since it is located closest to the PQM this was expected. If you look at Irawan, the reference barangay, barangays further away seems to have lower total mercury and MeHg levels. Irawan has the lowest total mercury and MeHg level. An interesting result is that Irawan has a relatively high MeHg concentration. Out of all total mercury in Irawan, 90.9 % of the total mercury is in the MeHg form. When looking at the percent MeHg in total mercury, Santa Lourdes has the lowest amount of MeHg. 59.1 % of total mercury is in the MeHg form. San Jose and Tagburos are quite the similar (83 % compared to 80.4 % of total mercury is in the MeHg form). The reason for the high percent of MeHg out of total mercury in Irawan might be that this rice field is less irrigated than the ones in Tagburos, San Jose and Santa Lourdes. If the field in Irawan contains more water, oxygen is a limited source, which means that anaerobic bacteria can convert mercury to MeHg.

When comparing analysis of total mercury made in China and Sweden differences were found (see Figure 6). Overall, the results from Sweden have a tendency to be higher than the results from China. The difference found is that in China, Irawan has the lowest level of total mercury in rice while in Sweden it was stated that San Jose has the lowest level. Still, the levels of total mercury in San Jose were quite similar between the two analysis, 3.81 ng/g compared to 3.98 ng/g. The other results differed. For Irawan the levels of total mercury were 4.32 ng/g for Sweden and 2.86 ng/g for the rice analyzed in China. The highest difference was found between the results for Tagburos. The smallest difference was between the results for San Jose, they differed only in 4.5 %.

5.2 Diet survey

The diet survey could have been conducted on a larger population. This was hard because during our interviewing period, adults were out in the fields working and we choose not to interview small children due to short exposure time of mercury. In addition, our interpreter did not have the time to go with us for more than a couple of days.

It is hard to say if the health problems discovered in our survey are directly connected to mercury exposure. Symptoms like headache, insomnia etc. can have many other origins. Anyhow, it is important to take into consideration that mercury exposure can be the source for some of the health problems discovered in the survey. The interview with the woman who had been drinking water containing mercury and now suffers from paralysis, shows how toxic mercury intake can be.

5.3 Daily intake of MeHg

The mean values for daily exposure of MeHg for women and men eating rice from Tagburos are in the same order as EPA’s recommended value, 0.1 µg MeHg/kg body weight/day. This means that the values are about 1000 times lower than the maximum acceptable daily intake. Still, it is important to take into consideration that these calculations are only made for daily exposure from rice. All of the participants in the diet survey eat fish at least a couple of times every week and fish also contains MeHg. In addition, some people might have dental amalgam which also contributes to the daily MeHg intake.

6 Conclusion

The conclusion of this study is that there might be a risk for people eating rice from the different barangays. Daily exposure values of MeHg for women and men eating rice from Tagburos show that, for men, the values are as big as EPA's recommended level of 0.1 µg MeHg/kg body weight/day. For women, the calculated value was 0,08 µg MeHg/kg body weight/day. It is important to take into consideration that these daily exposure values are only based on daily exposure as a result of rice consumption. People are also exposed of MeHg when they eat fish and if they have dental amalgam, which means that their daily exposure of MeHg might be even higher.

Daily exposure values were only calculated from data of MeHg in rice from Tagburos. The calculations were based on rice from Tagburos since this barangay had the highest levels of MeHg. This means that the same daily exposure calculations based on our data of MeHg in rice from the other barangays would be slightly smaller. Since MeHg in rice were only analyzed in China and couldn´t be compared to other analysis, a bigger study with more samples and more replicates analyzed, is necessary to make a clear statement that the MeHg levels in rice from these barangays, and thereby also the daily exposure values are as high as calculated in this study.

When comparing the results from the analysis in Sweden and China, there are some differences. Generally, the results of total mercury in rice, analyzed in Sweden have a tendency to be higher than the results from China. This mean that there might be an error in the analyses from China and that the analyses in Sweden are ok, or vice versus.

It is hard to say if the health problems found in our diet survey are related to mercury exposure from rice consumption. Since some of them also have dental amalgam and all of them eat fish at least a couple of times every week, the health problems can be related to that instead of rice consumption. These health problems can also be a consequence of something else and not only related to mercury exposure from rice consumption.

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8 Appendix

8.1 Interview questions

How often do you eat rice? How much each time?

Do you know where the rice is coming from?

How often do you eat fish? How much each time?

Do you know where the fish is coming from?

Do you experience any of the following symptoms?

- Head ache
- Insomnia, trouble to sleep
- Muscle weakness
- Lack of hearing
- Lack of eyesight
- Heart or vascular disorder
- Disturbance in sensation
- Development disorder
- Lack of coordination

Do you have dental amalgam?

8.2 Calculations

Table 5. Mean body weight (BW) for men and women in the Philippines (Food and nutrition research institute, 2003).

Sex	*Mean bodyweight (kg)*
Female	53.0
Male	60.3

Table 6. Rice consumptions per day. The values are the highest found in the diet survey.

Sex	*Rice consumption/day (kg)*
Female	0.6
Male	0.9

Mean value for MeHg in rice from Tagburos: 7 µg MeHg/kg rice.

Daily intake of MeHg for women: (7*0.6)/53 = 0.08 µg MeHg/kg BW.
Daily intake of MeHg for men: (7*0.9)/60.3 = 0.10 µg MeHg/kg BW.