

Mercury concentration and its effect on the aquatic environment of the Lower Watut River, Morobe Province, Papua New Guinea

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Abstract

This explorative and analytical study investigated the level of mercury and its effects on the aquatic life in the Lower Watut River of the Huon Gulf District in Papua New Guinea. Samples of fish, water and sediments were collected from the Watut River that has access to three villages namely, Magaring, Kapungung and Chiatz. The samples were analysed at the National Analysis Laboratory, University of Technology. In addition, a total of 40 interviews were conducted among the alluvial miners in the Lower Watut River to explore possible effects of mercury use for gold extraction. The analysis of water has shown that the level of mercury concentration is high (0.001mg/L) when compared to Recommended Standards, such as the PNG Raw Water and Drinking Water Standards and the Australian Drinking Water Standards. The analysis of fish and sediment samples were compared with the American Environmental Protection Agency and World Health Organization Standards. The finding from interviews further confirmed the impact of mercury content in the water affecting the aquatic environment. From the interviews conducted, it was reported that there were many changes occurring in the river, such as sedimentation, flooding, dieback of vegetation, mercury found in sediments, fish dying and fish found with deformities. This study provides baseline information for more awareness into the toxicity of mercury and its effects on the environment.

Key Words: methylmercury (sometimes methyl mercury), aquatic, environmental effect,

The problem and review of related literature

The use of mercury in gold mining is toxic to both human health and the environment. In Asia, Latin America and Africa, there are tens of thousands of mining sites which use as much as 1000 tons of mercury each year. The mercury not only ravages the nervous system of miners and their families, but also travels thousands of kilometres in the atmosphere, settling in oceans and river beds and consequently moving up the food chain and into fish (Wikipedia, 2007). Clinically evident methylmercury poisoning due to consumption of contaminated fish has occurred in such diverse regions of the world as Japan, the Amazon River Basin and throughout the world where there is heavy involvement of mining activities. Exposure to high levels of

methylmercury has produced fatalities as well as devastating neurological damage among adult survivors (Wikipedia, 2007).

The events that took place in Minamata and Niigata, Japan, have paved the way for experiments and studies to assess ways to contain the effects of methylmercury poisoning. Mothers who had only mild symptoms gave birth to infants who had severe in utero methylmercury poisoning, resulting in a condition resembling cerebral palsy but also accompanied by blindness and deafness. Lower levels of methylmercury exposure can produce changes in visual functions, altered sensory and motor nerve functions, and developmental delays that reflect in utero damage to the fatal nervous system (Mahaffey, 1999). Mercury contamination of fish and mammals is a global public health concern, according to UN reports, 'Our study of fish tested in different locations around the world shows that widely accepted international exposure levels for methylmercury are exceeded, often by wide margins, in each country and area covered' (UN, 2009).

One of the common avenues by which mercury is brought into the environment is through small business activities, such as small-scale mineral mining. After the burning of fossil fuels, small-scale mining of gold is the second-worst source of mercury pollution in the world, and China is the largest user of mercury in gold mining. The history of mercury use in gold mining goes back to the Romans who forced slaves and criminals to extract gold and silver with mercury. By the 20th century, although the big miners replaced mercury with cyanide, small-scale miners continued to use mercury (Hg) as it was the easiest, fastest and the cheapest method for extracting gold. Compared to the traditional method of extracting gold, mercury easily left the gold cleaner (Patrick, 2002).

At a global level, food, water and the environment have deteriorated to the point that we are all vulnerable to chronic, low level exposure to toxic metals. Mercury exposure is the second-most common cause of toxic metal poisoning. Public health concern over mercury exposure, due to contamination of fish with methylmercury has been a topic of debate in the medical field and in politics worldwide (Patrick, 2002).

Scientifically, mercury exists in three forms, elemental mercury, inorganic mercury compounds (primarily mercuric chloride), and organic mercury compounds (primarily methylmercury). All forms of mercury are quite toxic, and each form exhibits different health effects. The most important organic mercury compound, in terms of human exposure, is methylmercury. Methylmercury exposure occurs primarily through the diet, with fish and fish products as the dominant source (Patrick, 2002).

Mercury is highly toxic, particularly as vapour and in organic complexes. Mercury and mercury complexes can cause damage to the vital organs, such as the brain and the liver. It is a cumulative poison and humans assimilate mercury mainly through food and drink although it can be absorbed from the air and through the skin.

Mercury is considered to be the most toxic metal in the freshwater environment and many organisms can take up and accumulate mercury which passes up the food chain to fish. Hence the victims of mercury poisoning may live a long way from the source of the mercury. Due to mercury being seen as a hazard to human health and the environment, its uses and handling methods at mine sites must comply with relevant Acts and Regulations and the Material Safety Data Sheets as supplied by the manufacturer or supplier of the mercury. Mercury is no longer used in larger gold mining and processing operations. However, it is still used in some small alluvial and underground mines most commonly to remove free gold from concentrates. Mercury is added to the concentrates in mixers and an amalgam is formed. In the operation, the amalgam is retorted to drive off the mercury as vapour which is then condensed and collected for re-use. The impure gold retrieved from the retort may then be further smelted to drive off any remnant mercury.

Mercury pollution has been recognised as the most disastrous aspect of the small-scale gold mining industry around the world. In Latin America, over one million people are estimated to be involved in such operations, and invariably use mercury for 'amalgamation' in order to recover the fine gold particles. The problem of mercury pollution arises from the primitive mining techniques and the ignorance of the health risks that are associated with such pollution. Particularly in Brazil, mercury pollution has become a large social problem and it is estimated that up to 200 tonnes of mercury may be used each year by small scale miners. In Papua New Guinea, where over ten thousand miners are involved in such operations, it is estimated that the extent of mercury use can be up to 10-15 tonnes a year. Remedial measures taken to eliminate the mercury pollution such as the legislation of mercury bans in other countries have been largely idle due to ineffective monitoring of many illegal mining operations that have sprung up over time (Bordia, 1998).

Developing nations such as PNG, practise artisanal or small-scale alluvial mining within village settings with minimal costs involved. At this level, economic benefit is sometimes not compromised by health and environmental risks (Kernan, 2009). Although Papua New Guinea (PNG) is ranked amongst the top ten gold producers in the world, there are limited production materials in the country, such as smelting machines to smelt gold particles that are then exported. Artisanal or small-scale gold mining has been a feature of Papua New Guinea for nearly 120 years. The recorded history of alluvial gold mining in PNG started in 1873 when Captain Moresby reported minor amounts of gold in the hills surrounding what is now Port Moresby Harbour (Lole, 2005).

Mining effectively commenced in Papua New Guinea in 1888 with the discovery of payable gold in Sudest Island (Milne Bay Province). Morobe Goldfield was first discovered in 1922, which then continued to operate until the Second World War. According to statistical standard ratings of the most successful gold fields, Morobe gold field was also regarded as a world class goldfield by the standards of the time, reaching a peak production of 8.5 tonnes/ gold in 1942. The Bulolo Gold Dredging Company that operated up to

eight dredges in the Bulolo River valley between 1932 and 1965 accounted for most of the production in an operation that was particularly remarkable for pioneering large scale air transport. Due to considerable ingenuity, the components of the 2000 tonnes dredges were airlifted in and assembled on site and the operation was largely supported by air transport as there was no road network in the country at that time. About 70 tonnes of gold were produced from Wau-Bulolo Goldfields up to 1942 and later during 1945 to 1977, the production was 47 tonnes.

The discovery in the Wau-Bulolo area sparked further exploration in both the hinterland of New Guinea and the outer islands (Bordia, 1998). Small-scale mining is still largely recognized as a legal economic activity and a significant contributor to the rural economy in PNG. Characteristics of gold mining are quite different from other industries such as cash crops, fisheries and timber because the value of the gold mined is paid directly to the miner (Susapu and Crispin, 2001).

At present there are at least 17 recognised alluvial goldfields throughout Papua New Guinea. Of these, 16 are located on the mainland and the remaining one is on Bougainville Island. The goldfields from west to east includes Amanab (West Sepik Province); Maprik, April River and Yuat River (East Sepik Province); Porgera and Timun River (Enga Province); Kuta (Western Highlands Province); Simbai (Madang Province); Kainantu-Goroka (Eastern Highlands Province); Lakekamu (Gulf Province); Wau-Bulolo and Waria River (Morobe Province); Gira-Yodda and Kereri (Northern Province); Milne Bay (Milne Bay Province); and Keita (Bordia, 1998). Although there are setbacks in terms of the practice of alluvial mining activities, these mines have contributed significantly, one way or the other in terms of economical benefits in assisting local Papua New Guineans, apart from their daily subsistence lifestyle (Bordia, 1998).

The interest of this study was focused mainly near the Wau-Bulolo electorate, in the Morobe province where one of the recognised goldfields in Papua New Guinea is found. The Wau-Bulolo District of Morobe Province has a population of approximately 77,232 with a land area of 9,278 square kilometres. The district itself is divided into the six Local Level Governments including Wau, Bulolo, Watut, Buang, Mumeng and Garaina/Waria (Bordia, 1998).

Watut River is known as the Rough River full of canyons and over 150 rapids, making it suitable for adventurous white water rafting. The Watut River tumbles from the 3000 metre Kuper Range to sea level at the rate of 20 metres a kilometres, rushing through 150 rapids. The source of Watut River begins from the Wau-Bulolo District and proceeds into the Huon Gulf district, which eventually meanders and merges into the fourth largest river in Papua New Guinea, the Markham River (Wikipedia, 2007).

More precisely, this research was carried out in the lower section of the Watut River which is situated in the Huon Gulf District. Here the fast flowing current

of the river from the rugged mountains of Wau/Bulolo meanders when it reaches the Lower Watut plains before it merges with the Markham River and flows into the sea.

The Hidden Valley Golpu and Wafi mines are the major gold operating mines in the Morobe province. These mines have contributed significantly to the rapid increase in alluvial mining activities along the river banks of the Bulolo and Watut rivers. However research has shown that alluvial mining activities actually started with the introduction of the first mines in Papua New Guinea in the late 1920s. In the Bulolo Gold rush days Wau and Bulolo were very busy mining towns. Since the introduction of these mines, there have been complaints about the changes in the aquatic life and the surrounding environment along the Lower Watut River. Evidence of a few of these changes includes fish dying and the presence of unidentified floating chemical solutions which have been noticed and reported in media.

Although a study by Subasinghe and Okada (1998) does not show alarming levels of mercury pollution in the Bulolo River Valley area, compared to those in Brazil, the researchers witnessed very dangerous practices of mercury handling by small scale miners. These dangerous practices included direct inhalation of mercury vapour during the 'cooking' process and careless and accidental spillages of mercury into the river during the panning and sluicing operations (Bordia, 1998).

The purpose of this study was to investigate the level of mercury concentration in the Watut River and to specifically explore whether the mercury content in the lower Watut River was at the recommended standard of .001mg/L? This study also investigated the effects of mercury on human lives and the aquatic environment.

Hypothesis

This study had the following hypothesis to be tested: The level of mercury content at the lower Watut River is higher than the recommended standard of 0.001mg/L for safe drinking water.

Significance of the study

To the knowledge of the authors, this is the first study to investigate the levels of mercury concentration in the Lower Watut area and its effects on the aquatic environment. The findings of this study could help the people of the Lower Watut River understand the effects of mercury on their health and the aquatic environment. This study is expected to encourage relevant authorities to carry out awareness concerning the effects of mercury in the Lower Watut area. On a more advanced note, this study could serve as a parameter for future research into the Lower Watut area in order to provide baseline information for relevant government agencies. The information could help established authorities to set-up monitoring stations along the Watut and the Markham rivers for monitoring

purposes to make sure the river water is safe for use by the villagers living in that area.

Study design

This study was explorative and analytical in nature, using laboratory analysis, interview and observation methods. First, this study explored the level of mercury concentration in the Lower Watut River, and secondly it looked at the impacts of mercury on the aquatic life in the river.

Participants

Three samples of water, fish and sediments were collected from the lower Watut river bed from three different villages. We conducted a total 40 interviews, from three separate villages, namely Magaring, Kapungung and Chiatz that were located along the Lower Watut River.

Instruments

This study was carried out using structured interviews, observations and laboratory analysis of water, fish and sediment samples.

Procedure

This study had four phases. In the first phase, interviews were conducted involving the alluvial miners concerning the usage of mercury and the changes occurring in the river. The interviews were conducted using structured questionnaires in Magaring, Kapungung and Chiatz. In the second phase, we collected water, fish and sediments from the named villages along the Watut River. Thirdly the samples were sent to the National Analysis Laboratory at the University of Technology in Lae for testing and analysis. The final phase involved compiling and reviewing using the computer laboratory and the Divine Word University library facilities.

Data collection and analysis

The water, fish and sediment were delivered to the National Analysis Laboratory in Lae, Morobe Province for testing and analysis. The results obtained from the nine samples were analysed and sent to Divine Word University. The interview responses were manually analysed.

Limitations

Some limitations of the study need to be explained. The water, fish and sediment samples are limited in number due to the cost involved in testing and analysis. Only three fish species (golden carp, catfish and karua) were tested and analysed from our findings. This study did not include other common fish species eaten in the area such as talapia, prawns and eels. The sites were selected that were safe and convenient for us to reach. We did not have visit the

very first villages of the Lower Watut area upstream due to the fact that the upstream area has rapids, the villages are located in a rugged and mountainous location and it would have been dangerous for us. We started from where the river meanders after flowing out from the Watut Mountains to the Watut Plains and later merges with the Markham River in the Markham Valley. This study did not include the human bioassays to compare with the results obtained from the samples collected from the river to see if there was a correlation. Humans usually developed mercury poisoning from consuming mercury contaminated fish and drinking contaminated river water. With all its limitations, this study, the first of this type in the Lower Watut River area, still presents baseline information for future research.

Results

Water samples: Three 1.5L bottles of water samples were collected from approximately 200 metres away from where the actual alluvial mining activity is conducted and approximately 3-5 metres inshore. This was done in order to ensure that the results obtained were not biased in any way.

Sediments: The sediments were collected from the river bank and in the river. In order to collect the sediments, we measured a distance of 5 metres from the river bank into the river and again a distance of 3 metres to the shore to avoid bias in the sampling results. Both the sediments from the riverbank and in the river were combined together and sent for testing at the National Analysis Laboratory.

Fish: The samples of fish came from fishing nets placed in the river in each of the selected villages prior to the commencement of the collection of data. As mentioned, the specific sites included Magaring, Kapungung and Chiatz. At these sites, fish samples were collected and stored in eskies with ice in order to avoid contamination. The fish samples came from different families of fish, Golden Carp, Catfish and Karua.

Level of mercury content

The results from the nine samples showed clear evidence of presence of mercury. The level of mercury in two of the water samples were found to be the same (< 0.002 mg/L) while the third sample recorded a higher level of concentration, 0.003 mg/L. The results for the sediments were higher than the recommended allowable limit set by World Health Organisation for a fresh water environment. And finally the results for two of the fish samples were in line with the standards (0.001 ug/g) because they were smaller fish, while the bigger third fish recorded a high concentration (0.24 ug/g).

Table 1. summarizes the final results of the tested samples that were received from the National Analysis Laboratory at the University of Technology.

Table 1. Testing and National Analysis Laboratory results

Samples	Analysis Results
Watut River # 1	< 0.002 mg/L
Watut River # 2	0.003 mg/L
Watut River # 3	< 0.002 mg/L
Sediment # 1	0.14 ug/g
Sediment # 2	0.33 ug/g
Sediment # 3	0.22 ug/g
Karua Fish # 1	< 0.01 ug/g
Catfish # 2	< 0.01 ug/g
Golden Carp Fish # 3	0.24 ug/g

Source: *National Analysis Laboratory, University of Technology, Lae (2009)*

1ug/g = 1 mg/g

Therefore, the hypothesis for this study that stated that the level of mercury content at the lower Watut River is higher than the recommended standard of, 0.001mg/L safe drinking water, is supported.

Summary from the interviews

Interviews: From the interviews it was found that most of the alluvial miners did not apply appropriate precautionary measures when handling mercury during the amalgamation and cooking processes (Table 2). They were self taught into conducting the alluvial mining activities without any formal education or guidance from professionals. Due to high illiteracy and semi-illiteracy level in the area, most the people did not know about the toxicity of mercury and how it affects their health, the river and the environment in which they live. All the interviewees used mercury to collect gold in amalgamation and cooking processes.

Table 2. Villagers' knowledge and handling of mercury

Dimensions	Yes	No	Total
Knowledge of using mercury	5	35	40
Usage of mercury	40	0	40
Precautionary measures taken	7	33	40
Mercury discarded	1	39	40
Knowledge about mercury effects	10	30	40

The interview findings revealed that alluvial mining was the main economic activity in the area; 60% of those interviewed carry out alluvial mining on a daily basis or regularly.

Table 3. Villagers' involvement in the alluvial mining activities

Frequency of mining activity	Number of miners involved
Full time daily	24
Twice in a week	7
Once in a week	5
Whenever I feel like	2
None at all	2
Total	40

It was also revealed that water from the Watut River is used for cooking, drinking, washing and other activities such as transportation and carrying out alluvial mining activity. Following is the summary of our findings concerning the usage of the Watut River by the Lower Watut people.

Table 4. Villagers' dependency on the river

Usage of Watut River water	Number of people
Cooking	23
Drinking	23
Washing	39
Others	25
Total	110

We also found from our interviews that fish is the main source of protein for the Lower Watut people and is eaten virtually daily.

Table 5. Sources of protein

Sources of protein	Number of people
Fish	39
Pig	21
Bandicoot	6
Birds	6
Others	17
Total	89

Level of mercury content in water, fish and sediments

Water: The recommended allowable limit of mercury for drinking water is 0.001mg/L. The results of this study (<0.002mg/L, 0.003MG/L, <0.002mg/L). have shown a greater level of mercury concentration than the recommended standards of the PNG Raw Water and Drinking Water and the Australian Drinking Water. This finding goes against the claim of Subsinghe and Okada (1998) who gave evidence that there was no alarming issue in the Watut Rivers in terms of mercury concentration.

Fish: The results (0.01ug/g) of mercury in the two small karua fish and catfish were at an accepted level for fish consumption. However the result (0.24ug/g) of mercury in the larger golden carp fish is a cause for concern. Bioaccumulation of mercury increases with the size of fish. Normally the larger fish consumes the smaller fish, so the concentration builds up. The finding is that the people along the Lower Watut River are likely to develop mercury poisoning if they regularly eat larger fish from the Waput River.

However, the level of mercury concentration is also dependent upon the daily consumption rate of the people and the half life of the mercury is vital information to consider. Half life is the time it takes for half of the substance to be eliminated from the body. Methylmercury is hydrophobic, so it will dissolve into fat and not into blood. That means that it will be difficult to clear the body through normal blood-cleansing via the kidneys, colon, or liver. The normal half-life for mercury is 2-3 days, so if a person does not allow for enough time for the digestive system to eliminate the mercury out of the body and continues to eat fish with a higher mercury content, the concentration may reach 2.0 mg/g and that can eventually cause mercury poisoning. This is the likely result that will arise to the Lower Watut area.

Sediments: The results of the analysis of three sediment samples were 0.14ug/g, 0.33ug/g and 0.22ug/g respectively. The sediments were mixtures of sediments in the river and on the river bank. The recommended allowable limit for sediments in freshwater is 0.174ug/g. The results from the second and third samples are higher than the recommended allowable limit for sediments in fresh water environment. The transformation processes for the various forms of mercury that apply in water also occur in soil and sediment. Formation and breakdown of organic mercury compounds appear to be dependent upon the same microbial and abiotic processes as in water (Anderson, 1979), and the methylation of mercury is decreased by increasing chloride ion concentration (Olson et al., 1991), although the presence of chloride ions has been suggested to increase the rate of mercury release from sediments (Wang et al., 1991). In soil, the complexing of elemental mercury with chloride ion and hydroxide ion to form various mercury compounds is dependent upon pH, salt content, and soil composition (Risher, 2003).

The researchers consider that the high level of mercury concentration and the pollution at the Watut River is caused by the large scale mining activities in the upper Watut River which in turn encourages the spread of small scale alluvial mining along the Lower Watut River.

Effects of mercury on people

Although subsistent farming was the traditional source of livelihood, today alluvial mining has become a major source of income throughout the Lower Watut area. From the interviews, it was learned that many small scale alluvial miners lack basic knowledge about the toxicity of mercury and its associated health and environmental effects. Consequently alluvial miners expose themselves to the harmful effects of mercury as they conduct their daily

activities. When the people were introduced to the practices of small scale alluvial mining, they became involved in the use of mercury to extract gold dust for economic benefit. Consequently, the use of mercury has become wide spread in the villages along the Lower Watut River posing serious threats to the peoples' health and the environment.

The process involved in the extraction of gold is not safe because the alluvial miners expose themselves to mercury when pouring it into the gold pan and using their bare hands to separate the gold from the black sand, and then inhaling the mercury vapour when cooking the amalgamated mercury and gold to collect the pure gold.

Through examining the physical condition of villagers, it was alarming to see that many of them have already developed symptoms of mercury poisoning, such as burnt fingertips and toes, yellow coloured hands, sore feet and legs. It was also reported that a number of children develop boils after washing in the Watut River. Also the elders testified to developing sudden blurred vision, while others were surprised to notice fallen hair.

Effects of mercury on the aquatic environment

The aquatic environment was closely observed and reported to have changed, with confirmation from the local villagers. Some of the reported changes included fish dying, fish being caught with some form of deformity such as no eyes, tails and big stomachs.

Sedimentation was also one of the major changes in the area due to the fact the Watut River was once a river that flowed very slowly from the Upper Watut areas in Wau/Bulolo District and merged into the Markham River. Currently the Lower Watut River flows very fast due to the process of sedimentation and this caused many changes. In a normal situation in terms of flooding, the Watut River usually floods onto the nearby vegetation but does not cause dieback to the vegetation. However, the trend has changed. Now there is evidence of dieback of forest vegetation after the flooding. From our observation of the environment, we noticed that much of the forest vegetation along the Lower Watut River was gone as if there was a bushfire. The pollution occurring from the use of mercury to extract gold has threatened the environment, including both plant and aquatic life.

Summary and conclusions

This explorative and analytical study investigated the level of mercury and its effects on the aquatic environment of the Lower Watut River of the Huon Gulf District in the Morobe Province. Mercury is used by local villagers in their alluvial gold mining activities. Samples of fish, water and sediments were collected from the Watut River accessed by three villages namely, Magaring, Kapungung and Chiatz. The samples were analysed at the National Analysis Laboratory of the University of Technology in Lae in the Morobe Province. In addition, a total of 40 interviews were conducted among the alluvial miners in

the Lower Watut River area to explore possible effects of mercury use for gold extraction.

Findings of the level of mercury in the Lower Watut River are summarized as follows. Mercury had accumulated in water, fish and sediment samples taken from the Lower Waput River area that could be attributed to gold mining activities. The water samples were analyzed and found to have mercury concentration of <0.002mg/L, 0.003mg/L and <0.002mg/L. Sediments analyzed produce mercury concentration of 0.14ug/g, 0.33ug/g and 0.22ug/g. The analysis of fish showed concentrations of <0.01ug/kg, < 0.01ug/kg and 0.24ug/kg.

Findings of the effects of mercury on the aquatic environment of the Lower Watut River are summarized as follows. Mercury levels in the water and large fish were higher than the recommended allowable limit that was safe for human consumption. Fish from the Watut River is the main source of protein for the local people and regular consumption of contaminated fish could have adverse health effects. People use water from the Lower Watut River for cooking, drinking and washing as well as for transportation. Unsafe practices were observed as people poured mercury into gold pans and used their hands to separate the gold particles from the black sand. The villagers reported that fish are dying and having deformities which could be attributed to the harmful effects of mercury used in mining activities. People reported blurred vision and skin irritation after washing in the river. Almost 60% of the forest along the Lower Watut River has already been destroyed due to sedimentation and flooding.

Around 75% of villagers interviewed lack adequate knowledge of the harmful effects of mercury for health and the environment. About 82% of those interviewed did not apply precautionary measures when handling mercury.. Approximately 60% of the alluvial miners carry out mining activities daily for survival.

To conclude, the use of mercury by the alluvial miners along the Lower Watut River has contributed to the presence of mercury in the aquatic environment in ways that are harmful to health, fish, soil and the environment. This study could provide the stimulus for further research and for the alluvial miners to find more environmentally friendly and healthy ways to carry out their alluvial mining activities.

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