Assessment Report

Mercury exposure level for citizens in Palau due to high-level fish consumption in daily diet

2023

Palau Environmental Quality Protection Board,
Republic of Palau

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Glossary, acronyms, and abbreviations

AAS	Atomic absorption spectrometry
AIT	Asian Institute of Technology
APMMN	Asia Pacific Mercury Monitoring Network
BMDL	Benchmark dose lower confidence limit
bw	Body weight
EFSA	European Food Safety Authority
EQPB	Environmental Quality Protection Board, Palau
EU	European Union
JECFA	Joint FAO/WHO Expert Committee on Food Additives
MOEJ	Ministry of the Environment, Japan
MOHLWJ	Japan, Ministry of the Health, Labour and Welfare
MOHWJ	Japan, Ministry of the Health and Welfare
MOYAI Initiative	A Japan's commitment made at the Diplomatic Conference in 2013 to support developing countries and to promote voices and messages from Minamata.
NIMD	Japan, National Institute for Minamata Disease
NOAEL	No-observed adverse effect level
PTWI	Provisional tolerable weekly intake. The maximum intake of substances in food, such as nutrients or contaminants, that can be consumed weekly over a lifetime without risking adverse health effects.
ROAP	Regional Office for Asia and the Pacific
SOP	Standard operating procedure
UNEP	United Nations Environment Programme
USEPA	United States of America, Environmental Protection Agency
USFDA	United States of America, Food and Drug Administration
QA	Quality assurance
QC	Quality control
WHO	World Health Organization
ww	Wet weight

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EXECUTIVE SUMMARY

Mercury is a chemical element that has existed on Earth since its creation. Excessive exposure to mercury, especially methylmercury, will pose risk to vulnerable population, particularly pregnant women as methylmercury actively passes through placenta barrier by amino acid transporter to fetus.

People in Palau frequently consume fish as part of their daily diet. The volume and types of fish species for individual consumption varies, but no systematic survey has been conducted. The human hair is sampled for the target population, which is a simple and reliable method to measure the methylmercury exposure. The results were consolidated and analysed statistically based on the guideline values elaborated by WHO. WHO reference values are based on the NOAEL equivalent to the 14 mg/kg hair mercury level. The 2.2 mg/kg was derived for women in childbearing age (18-39 years old) and 4.4 mg/kg for adults other than above. For children (17 years or below), both 2.2 and 4.4 mg/kg are referred as lower and upper range.

87% of the adult participants other than women in childbearing age were within the WHO reference of 4.4 mg/kg. The proportion for women in childbearing age was lower (59 %) than that for adults. The proportion for children was between 55 and 100 % as lower and upper values, respectively. Overall, approx. 20% (18-23 %) of the participants exceeded the WHO reference values. No participant exceeded the NOAEL value of 14 mg/kg set by WHO. These values are within the range of fish consumer group and coastal area in the pacific, which could confirm the population in Palau is in the similar exposure levels with similar geographic and/or dietary groups. Therefore, the issues discussed for fish consumers and/or coastal population equally apply to Palau.

As there were no adverse symptoms reported by the participants, it may not be necessary to impose immediate alert to the general public against the elevated mercury level. Communication on dietary advisory may be more appropriate to raise awareness on mercury issue, particularly for female in child-bearing age.

Long term measure is the reduction of mercury level in fish in general, but Palau, as a single country, is not able to address the global mercury issue by itself. The multilateral commitment of the Minamata Convention calls for the global actions to ease the health burden caused by mercury. Thanks to its pristine nature, Palau can be the ideal point to monitor the global progress of the mercury management. If the people's health and environment situation in Palau improves, it proves the improvement in the world. This could be the most important role of Palau to work on mercury issue.

1 INTRODUCTION

1.1 Background

The Republic of Palau is an archipelago in the Western Pacific Ocean with a total land area of 458 km^2 and 19,000 inhabitants. The 85% of Palau's population lives in the states of Koror and Airai. Koror is currently the most urbanized area in Palau. The Palau Public Utilities Corporation (PPUC) provides energy to nearly all the inhabited islands using diesel power generators.

The major industry of Palau is natural tourism, particularly underwater wonder is considered one of the top-ranking diving spots in the world. Soil in Palau is highly acidic with very thin top layer, which makes large-scale agriculture unfeasible. Widespread open burning practice depletes soil organic matter, kills microorganisms, and leads to long-term land degradation. Although in small scale, Palau's commercial fishing industry provides local supply as well as export. There are a few foreign companies, mainly targeting tuna, processing and exporting the products.

Mercury is a chemical element that has existed on Earth since its creation. Mercury is released from natural sources by processes, such as volcanic activity and permafrost melting. In recent years, more mercury has been released through human activities, such as the combustion of fuels, mining activities, and the consumption of mercury-added products.

Excessive exposure to mercury, especially methylmercury, will pose risk to vulnerable population, particularly pregnant women as methylmercury actively passes through placenta barrier by amino acid transporter to fetus. Due to its environmental behaviours and anthropogenic emissions and releases, growing concerns about mercury risks have resulted in the adoption and entry into force of the Minamata Convention on Mercury (the Convention). It is one of the newest multilateral environmental agreements aiming at protecting human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds.

The sources of mercury emissions and releases in Palau is largely from imported mercury-added products for essential use. Raw material such as fuel, health care and household products, research and laboratory instruments and supplies would be potentially releasing mercury to the environment after use. There is a general need to protect the subsistence livelihood of the population by preventing contamination of water, air, land and marine ecosystems. Some end-of-use mercury-added products such as batteries and medical waste have separate collection schemes, but waste management scheme specific to mercury has not been established. Waste collection service covers approx. 80 % of the population in Palau.

Mercury exposure may occur through dietary intake and/or household products such as skin whitening cosmetics. Occupational exposure may also possible particularly in the waste recycling industry and handling end-of-life mercury products. As marine products are the main protein source of people in Palau, food safety is particular concern.

National legislation should be developed, or existing regulation should be enhanced to comprehensively address mercury management including, but not limited to, the import/export, storage and transport, spillage and clean up, waste disposal, etc. It is also important to build capacity to track all mercury and mercury-added products from import to use and disposal. Proper disposal option needs to be elaborated.

Monitoring capacity in Palau is still basic. The Water Quality Laboratory of the national government analyses general water quality criteria but mercury is not included. A wet deposition sampler was donated by Asia Pacific Mercury Monitoring Network (APMMN) and air sampling kit by Ministry of the Environment, Japan (MOEJ). Further technical assistance will be provided by these organizations.

1.2 Objective of the Survey

People in Palau frequently consume fish as part of their daily diet. The volume and types of fish species for individual consumption varies, but no systematic survey has been conducted. Therefore, this survey aims to assess the mercury exposure risks for the citizens in Palau, particularly methylmercury intake from fish and shellfish. It is able to identify the level of risks and population groups with special concern. The outcome contributes to the development of health strategy in Article 16 of the Minamata Convention.

The human hair is sampled for the target population, which is a simple and reliable method to measure the methylmercury exposure. It is non-invasive and follows well-established procedures developed by WHO. Hair is easily collected and shipped to the laboratory for analysis by people without medical license. Acquiring hair sampling skills will enable the communities to plan and undertake similar surveys based on their own needs and concerns.

2 METHODOLOGY

2.1 Preparatory Works

Any human subject research in Palau must go through the review of the Palau Institutional Review Board. EQPB, UNEP and AIT has jointly developed the survey plan and applied for the approval particularly ethical clearance for hair sample collection. The procedures for maintaining confidentiality of the data, how to protect the data from access by those not authorized were described. Also, no conflict of interest to all investigators and study staff engaged in the design, conduct, or reporting results of the survey and/or their immediate family members was declared. The board approved the application on 20 April 2023.

The survey was conducted by voluntary surveyors for collecting hair samples and questionnaires. Hands-on training was provided on 21 April 2023 to familiarise the process and skills for hair sampling survey in line with WHO guidelines.

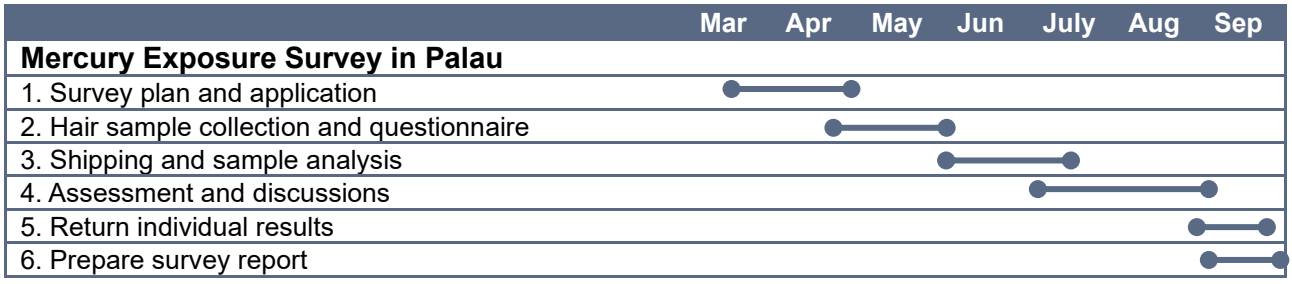
2.2 Materials and Methods

Name of research institutions and investigators

- EQPB: Michael Blesam, Chief Executive Officer
- UNEP: Mick Saito, Programme Management Officer
- AIT: Dulyarat Sathainthammanee, Research Assistant, IDEA R&D Centre in AIT

Research period

- From April 2023 to September 2023.



Method for sample collection and analysis

The survey involves the collection of hair samples, shipping, and analysis at a foreign laboratory in Thailand. It is because no mercury analysers are available in Palau. Target population was the residents in Palau in various attributes, gender, age range, occupation, etc. Together with the hair collection, the participants were asked to complete a questionnaire regarding her/his residential status, age, gender, occupation, and the diet (fish and shellfish consumption). Prior to the sampling, informed consent was obtained by explaining the consent document. For small children, the informed consent from their parents was obtained.

The sample collection was conducted in line with the WHO procedures[1]. Approximately 40 hair strands were collected from individuals subject to the survey. For females or participants with long hair, the hair was grabbed and tied near the root with adhesive tape. The bundle of hair was then cut from the root with scissors so as not to injure the scalp. The collected hair was put in an envelope for transportation to prevent scattering and keep it away from dust. For males or participants with short hair, the hair was directly trimmed and put into the envelope. For the participants with their hair shaved, beard/moustache hair are collected instead.

Mercury in hair is stable and no specific preservation measure is necessary. Each sample were kept in a paper envelope after collection until the mercury level is analysed. For shipping to Thailand, the travel blank was included in the package to ensure no unusual exposure occurred.

The hair samples were analysed by Thermal decomposition CVAAS (NIC MA-3000). Mercury existing as organic mercury, such as methylmercury, or oxidised mercury in the sample is mineralised or reduced during the heating process, and eventually sent to the detector in the form of elemental mercury.

Firstly, the sample was cut approximately 3 cm from scalp which corresponds the exposure in the past 3 months. Then, it was rinsed well with deionized water, dried with acetone, put in a petri dish, and shredded into fine pieces with scissors. Then, it was weighed in a sample boat.

To check the quality of the analysis, following QA/QC procedures were in place: travel blank, duplicate analysis, and random check. Two (2) travel blanks were prepared for ensuring no contamination via carrying or shipping of samples from Palau to Thailand, one each for two batches of sample deliveries. All samples were analysed at least twice to ensure no mechanical trouble during the analytical operation. In addition, 10 % of the total samples were randomly selected and double checked to ensure no bias in the quality control process. The random selection was proportionally done to the zoning of the sample collection. A certified reference material was also

[1] WHO (2018).

included to examine the validity of the analysis results. Finally, the average values of multiple analysis were reported.

Questionnaire survey

A questionnaire was used to collect the attributes of the participants. Firstly, general information about the nationality, residential location and length of stay were asked to check the eligibility of the participants. Personal information such as gender, age, occupation, and fish consumption were asked as internal factors within the population. The questionnaire further asked of the possibility of confounding factors such as permanent wave hair treatment and skin whitening cosmetics that might affect mercury in hair. Finally, the participants were asked if they have developed symptoms typical to mercury exposures. The questionnaire form is annexed to this report (Annex 1).

Statistical analysis

The results of the questionnaire and hair mercury concentration were consolidated and analysed statistically. There are several guidelines referred by countries and organizations. The values differ in different guidelines. For this study, the analysis was based on the reference values elaborated by WHO as the target population covers globally.

Table 1 Reference values of mercury in hair

	Benchmark dose / NOAEL	Uncertainty factor	Guideline
WHO[2]	14 mg/kg maternal hair on child neurodevelopment.	6.4	2.2 mg/kg*
Japan[3]	11 mg/kg maternal hair on child neurodevelopment.	4	2.8 mg/kg
USA[4]	46-70 µg/L maternal blood (equivalent to 11-20 mg/kg hair) on child neurodevelopment.	10	1.0 mg/kg

*: Intakes of up to about two times higher than the value would not pose any risks of neurotoxicity in adults.

The WHO guideline is for the PTWI (Provisional tolerable weekly intake). The hair mercury level is not actually the guideline but the reference to derive the PTWI. This report uses the term hair mercury guideline for a simplified explanation. WHO chose 14 mg/kg as the BMDL (Benchmark dose limit)/NOAEL (No-observed adverse effect level) for maternal hair (Box 1). Applying the uncertainty factor of 6.4 gives 2.2 mg/kg as the reference value for women of childbearing age. The explanatory note also includes that the tolerance for adults is approx. two times higher, which derives 4.4 mg/kg as the guideline value for the purpose of study. As for infants and children up to 17 years old, they

[2] JECFA (2007).
[3] Japan, Food Safety Commission (2005).
[4] USEPA (2001).

will be more sensitive than adults but not more sensitive than embryo and fetus, which falls between 2.2 and 4.4 mg/kg but no firm conclusions is drawn.

Box 1 Evaluation of methylmercury by JECFA

Epidemiology studies conducted in children from the Faroe Islands and the Seychelles. Children 5.5-7 years old were assessed for neurodevelopmental endpoints, and maternal hair Hg levels were measured. An average BMDL/NOAEL of 14 mg/kg was derived for concentrations of mercury in maternal hair in the studies of neurodevelopmental effects, which was calculated to arise from a daily mercury intake of 1.5 µg/kg-body weight. The PTWI (Provisional tolerable weekly intake) was derived by dividing this intake by a total uncertainty factor of 6.4 to give a value of 1.6 µg/kg-body weight.

The JECFA (Joint FAO/WHO Expert Committee on Food Additives) confirmed the existing PTWI of 1.6 µg/kg-body weight, based on the most sensitive toxicological endpoint (developmental neurotoxicity) in the most susceptible species (humans).

For adults, the Committee considered that intakes of up to two times higher than the existing PTWI would not pose any risk of neurotoxicity, although in the case of women of childbearing age, intake should not exceed the PTWI in order to protect the embryo and fetus.

Concerning infants and children up to 17 years, no firm conclusions may be drawn regarding their sensitivity compared to that of adults. While they are clearly not more sensitive than the embryo or fetus, they may be more sensitive than adults due to continuing neurodevelopment in infancy and childhood. Therefore, the Committee could not identify a level of intake higher than the existing PTWI that would not pose a risk of developmental neurotoxicity.

The Committee has previously noted that fish makes an important contribution to nutrition, especially in certain regional and ethnic diets and recommends that the known benefits of fish consumption be taken into consideration in any advice aimed at different subpopulations. The Committee concluded that the setting of guideline levels for methylmercury in fish may not be an effective way of reducing exposure for the general population. The Committee noted that advice targeted at population subgroups that may be at risk from methylmercury exposure may be effective in lowering the number of individuals with exposures greater than the PTWI.

WHO (2007). Methylmercury. Evaluations of the Joint FAO/WHO Expert Committee on Food Additives.

Method for protecting personal information

Hair samples and questionnaires are managed by unique identification codes (ID numbers) without individual names. The questions in the questionnaire include some personal attribute such as gender, age, and occupation, but the multiple samples with the same attributes are systematically collected to avoid pinpointing particular individuals from questionnaire data only.

Personal information including name and address are collected on a different form and managed separately, which is used for sending back the analytical results to the participants only. This information will be managed by EQPB and will not be shared to third parties and other research members. The results will be returned to the participants by either sealed envelope or email attachment with password.

After the analysis, the participants will receive their mercury levels and reference values such as WHO guidelines so that the results can be properly interpret by each individual. The results are sent either by sealed envelopes or password protected zip files to secure confidential information is not inadvertently disclosed.

3 RESULTS AND DISCUSSIONS

3.1 Participant Profiles

The target participants are the general public in Palau who are regularly exposed mercury by consuming fish as their staple diet. The target number of samples was 100. Nationality and/or citizenship is not restricted but residency in the same zone for more than 3 years is eligible to participate in the survey. Based on the demographic distribution and geographic characteristics, 40 % of the sample collection was allocated to Koror Island, the most populous island, and 60 % was allocated to Babeldaob Island, the largest island which occupies over 70% of the land area in Palau.

The sample attributes were structured by zone (geography), gender, and age group.

Table 2 Criteria of structured sample collection

Criteria	Category
Geography	Koror Island (Zone 1): 40 % Babeldaob Island: - East (Zone 2): 20 % - North (Zone 3): 20 % - West (Zone 4): 20 %
Gender	Female (F): 50 % Male (M): 50 %
Age group	19 or below (1): 20 % 20-29 (2): 20 % 30-39 (3): 20% 40-49 (4): 20% 50 or above (5): 20%

In total, 108 samples were collected and shipped to the AIT laboratory in Thailand. 103 participants confirmed that they have been living the same zones for more than 3 years. 5 participants indicated that their stay was less than 3 years or not indicated any length, so these samples were excluded from further study.

Table 3 Actual sample collection result by category

Gender	F					M					NA	Total	Not
Age	1	2	3	4	5	1	2	3	4	5			Eligible
Zone 1	2	5	3	9	3	3	4	3	5	2	1	40	3
Zone 2	2	3	1	3	2	2	2	2	2	2	0	21	1
Zone 3	0	2	2	2	3	2	2	2	2	2	0	19	1
Zone 4	2	2	3	2	1	2	3	2	2	2	1	22	0
NA	1	0	0	0	0	0	0	0	0	0	0	1	0
Total	7	12	9	16	9	9	11	9	11	8	2	103	5

There are slight variations for actual samples collected from original target sample numbers, but the attributes are well distributed among all three criteria. Thus, all 103 samples will be used for further study. Three participants did not indicate the age or resident location. The samples will be excluded when such criteria are needed for analysis.

3.2 Overall Survey Statistics

General statistics

The overall statistics for all 103 samples are listed below.

Table 4 General statistics of the survey

Parameter	Result
Sample count	103
Average	2.85 mg/kg
Geometric mean	2.38 mg/kg
Standard deviation	2.03 mg/kg
Maximum	13.9 mg/kg
75 % quartile	3.26 mg/kg
Median	2.45 mg/kg
25 % quartile	1.72 mg/kg
Minimum	0.44 mg/kg

Before analysing the result, the effect of hair treatment and skin whitening cosmetics are examined. The hair treatment such as bleaching and permanent wave may deplete hair mercury and may reduce readings. Skin whitening cosmetics such as soap and creams may inadvertently adhere to hair if they contain inorganic mercury compounds. Based on the questionnaire, some participants indicated the usage of such products and services. The samples are divided to subgroups who treated hair (4 data) or not (99 data), and who use skin whitening cosmetics (13 data) or not (90 data). The box and whisker charts have shown the data distribution patterns of these subgroups. The medians and the data ranges between 25 % and 75 % quartiles for the subgroups are comparable without significant differences. The minimum and maximum values are reliant to the total numbers of samples as the large sample may include extreme values. Based on the results, it can be concluded that the use of these goods and services did not affect the purpose of the survey, and all samples will be used for further study.

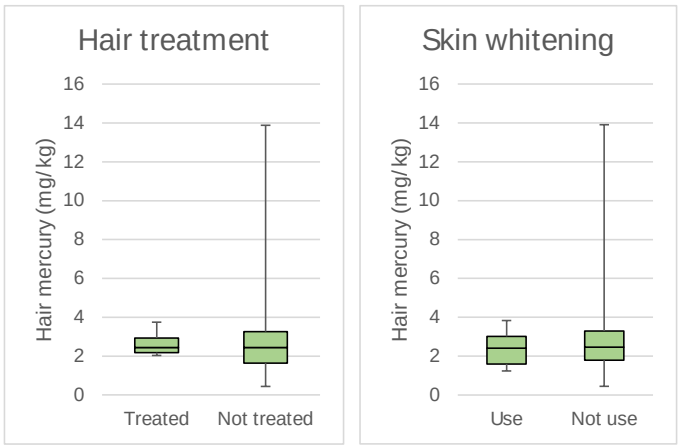


Figure 1 Comparison of data distribution patterns by (a) hair treatment and (b) skin whitening

Results of the hair mercury level is summarised in the histogram in Figure 2. The highest frequency appears in the range between 2 and 3 mg/kg. The distribution shape is distorted (different from normal distribution) to upper side with long tailing of very high concentration.

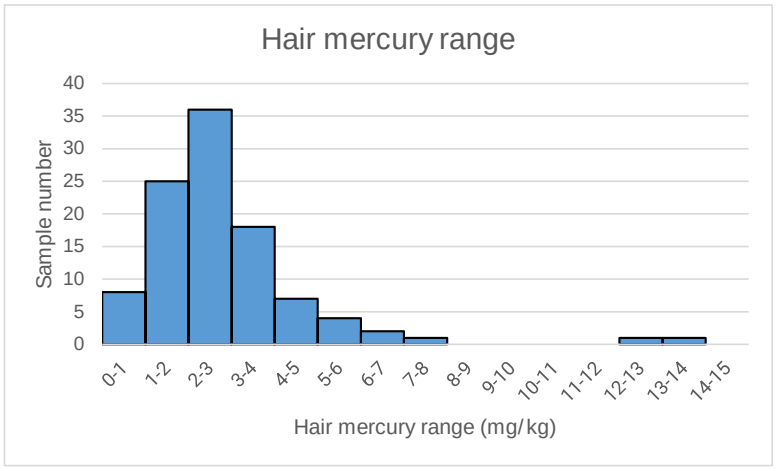


Figure 2 Histogram of hair mercury range

Comparison against WHO reference values

WHO reference values are based on the NOAEL equivalent to the 14 mg/kg hair mercury level. The 2.2 mg/kg was derived for women in childbearing age (18-39 years old) for the safety to the child neurodevelopment, and 4.4 mg/kg for adults other than above (as the intake of up to about two times higher than the value would not pose any risks of neurotoxicity in adults). For children (17 years or below), both 2.2 and 4.4 mg/kg are referred as lower and upper range. The compliance against the WHO reference for 101 samples where the age of the participants was known are listed in Table 5.

Table 5 Compliance against WHO reference value

Hair mercury (mg/kg)	Adults	Childbearing age	Children	Against reference	
Below 2.2	21 (31 %)	13 (59 %)	6 (55 %)	Below reference	78 (77 %)
Between 2.2 and 4.4	38 (56 %)	8 (36 %)	5 (45 %)	Range for children	5 (5 %)
Between 4.4 and 14	9 (13 %)	1 (5 %)	0 (0 %)	Above reference	18 (18 %)
14 or more	0 (0 %)	0 (0 %)	0 (0 %)	Above NOAEL	0 (0 %)
Total	68	22	11		101

87% of the adult participants other than women in childbearing age were within the WHO reference of 4.4 mg/kg. The proportion for the women in childbearing age was lower (59 %) than that for adults. The proportion for the children was between 55 and 100 % as lower and upper values, respectively. Overall, approx. 20% (18-23 %) of the participants exceeded the WHO reference values. No participant exceeded the NOAEL value of 14 mg/kg set by WHO.

3.3 Parametric Analysis

The analytical results are further examined with the information collected by the questionnaire together with the hair samples.

Age and gender

It is generally recognized that the mercury level in human hair increases with the increase of the age due to long term accumulation of methylmercury. Likewise, male often exhibits higher hair mercury level than female due to several situations. The average, maximum, median and minimum of each category is shown in Table 6, Figure 3, and Figure 4.

Table 6 Hair mercury levels by gender and age range

	Sample	Average (mg/kg)	Max (mg/kg)	Median (mg/kg)	Min (mg/kg)
Female	54	2.81	13.9	2.44	0.76
Male	49	2.91	12.8	2.45	0.44
19 or below	16	1.97	4.32	2.03	0.65
Between 20-29	23	2.17	6.71	1.86	0.78
Between 30-39	18	2.46	5.66	2.62	0.44
Between 40-49	27	2.92	7.71	2.77	0.78
50 or above	17	4.61	13.9	3.53	1.25

The hair mercury levels increased along with the increase of the age. Particularly, the age group of 50 or above shows much higher mercury level than those in other age groups. The minimum levels are not very much varied in different age groups, but the increase of the maximum level resulted in the elevated mercury in higher age groups. In this survey, no significant difference was observed between female and male.

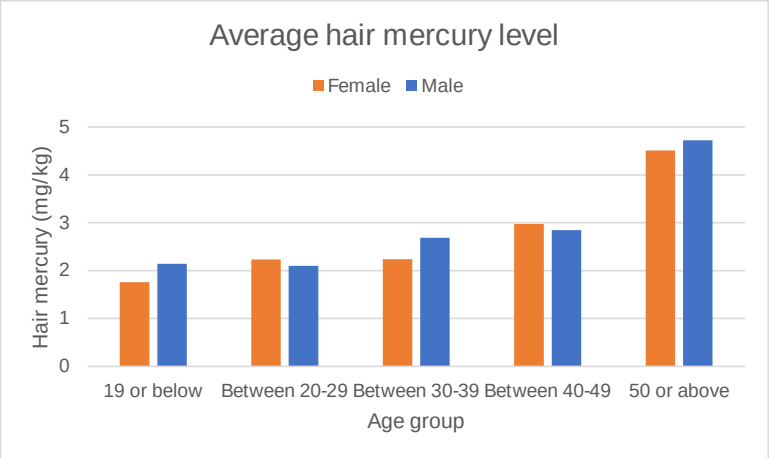


Figure 3 Average hair mercury level by gender and age group

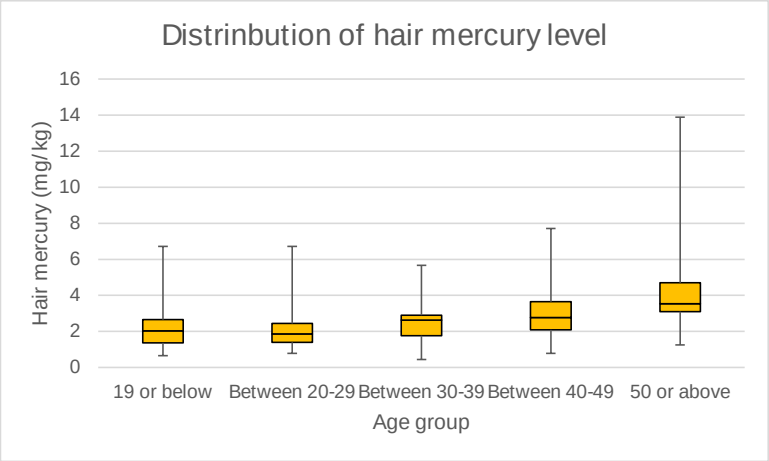


Figure 4 Median, 25 and 75 percentile, maximum and minimum values by age group

The individual data are plotted by age and hair mercury level in Figure 5. The result is in good fitting in lognormal plotting. The regression curve shows increasing trend by age but also shows large variety within the same age, which indicates the other factors have affected the hair mercury levels in the individuals.

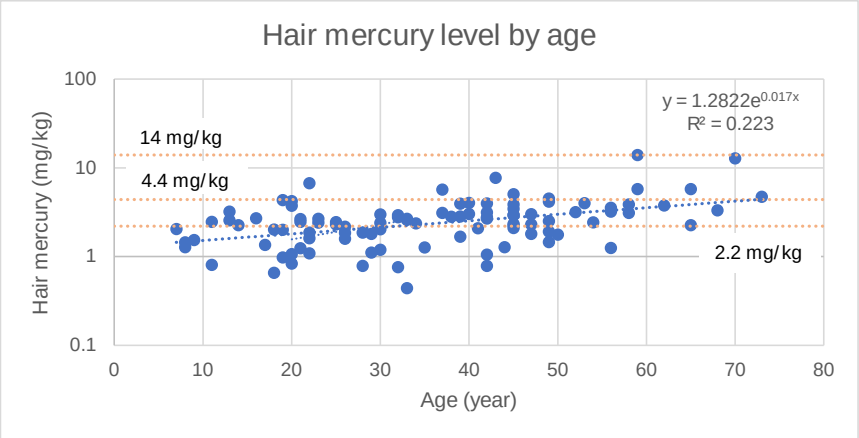


Figure 5 Distribution of hair mercury level by age with trendline

Fish consumption

Fish is important diet in Palau and a major exposure source of mercury. As no local industry and mining activities exist in country, the fish consumption could be the most relevant to indicate the mercury exposures. In the questionnaire, the participants were asked the frequency, consumption per meal, and preferred type of fish (Table 7).

Table 7 Hair mercury levels by fish consumption

	Sample	Average (mg/kg)	Max (mg/kg)	Median (mg/kg)	Min (mg/kg)
Everyday	20	3.86	13.9	2.39	1.19
2-3 timed per week	66	2.72	7.71	2.57	0.65
Once per week	13	2.15	3.21	2.26	0.44
Once per month	3	2.44	3.95	2.30	1.06
Seldom	1	2.09	2.09	2.09	2.09
Below 50 g	23	2.46	5.74	2.40	0.65
Between 50-100 g	63	2.82	13.9	2.33	0.44
Between 100-200 g	10	3.18	7.71	2.81	1.11
Above 200 g	6	4.20	6.71	3.53	2.77
Fresh reef fish	89	2.90	13.9	2.42	0.44
Canned inshore fish	35	2.44	12.8	2.04	0.44
Pelagic fish	55	3.04	12.8	2.77	0.44
No preference	2	2.65	3.21	2.65	2.09

As the frequency and amount increased, the hair mercury levels also increased (Figure 6, Figure 7). There is slight difference in mercury level for the preferred types of fish. The population who preferred pelagic fish such as tuna showed slightly higher and canned fish such as sardine slightly lower (Figure 8). The most dominant eating pattern in surveyed population was consuming between 50 and 100 g of fresh reef fish for 2-3 times per week.

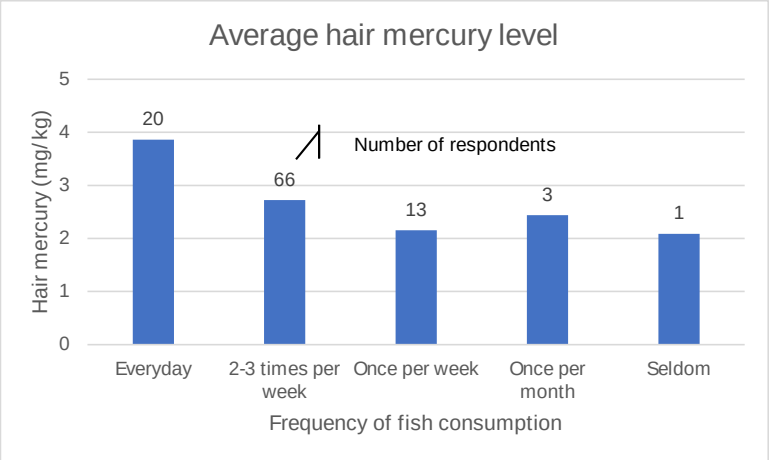


Figure 6 Average mercury level by the frequency of fish consumption

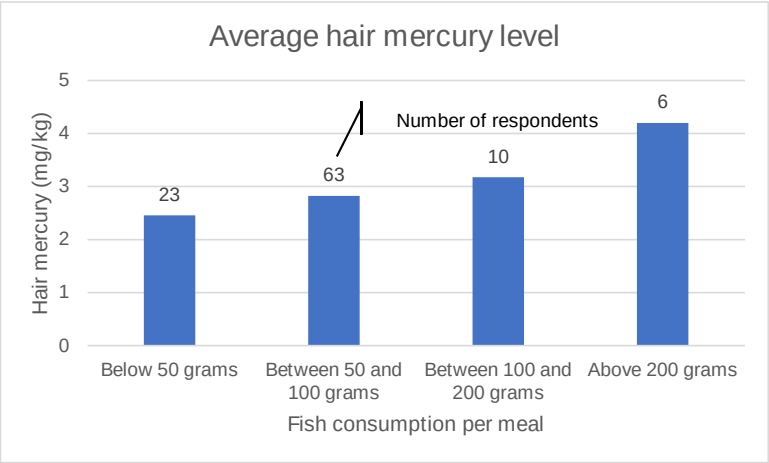


Figure 7 Average mercury level by the amount of fish consumption per meal

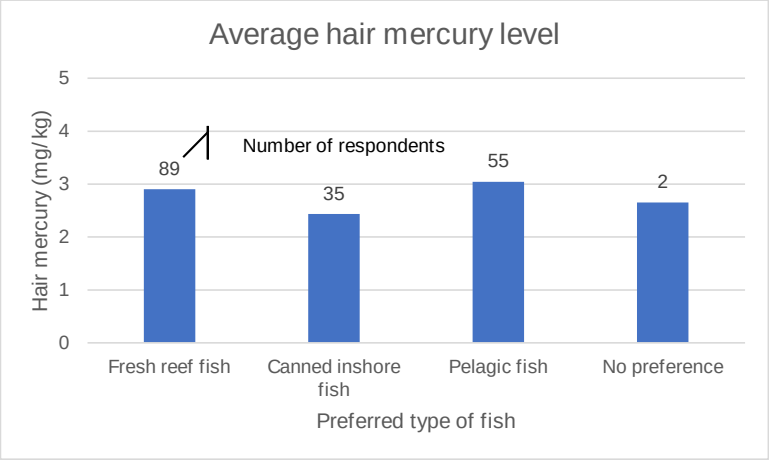


Figure 8 Average mercury level by type of preferred fish

Geographical zone

Four (4) survey zones were set for this survey to examine the geographical factors that might affect the mercury levels of the residents. 40 % of the sample collection was allocated to Koror Island, which is Zone 1. Zones 2, 3, and 4 represent east, north, and west area of the Babeldaob Island, respectively. 20 % of the sample collections was allocated to each of these three zones.

Basic statistics for each zone are shown in Table 8. Median, 25 and 75 percentile, maximum and minimum values in each zone are compared in Figure 9. There is no significant difference between zones while the major differences are outlying data (maximum) in each zone.

Table 8 Hair mercury levels by geographic zone

	Sample	Average (mg/kg)	Max (mg/kg)	Median (mg/kg)	Min (mg/kg)
Zone 1	40	2.97	7.71	2.66	0.44
Zone 2	21	2.56	5.75	2.42	0.80
Zone 3	19	2.29	4.70	2.02	0.76
Zone 4	22	3.44	13.9	2.32	0.98
Total	103	2.86	13.9	2.45	0.44

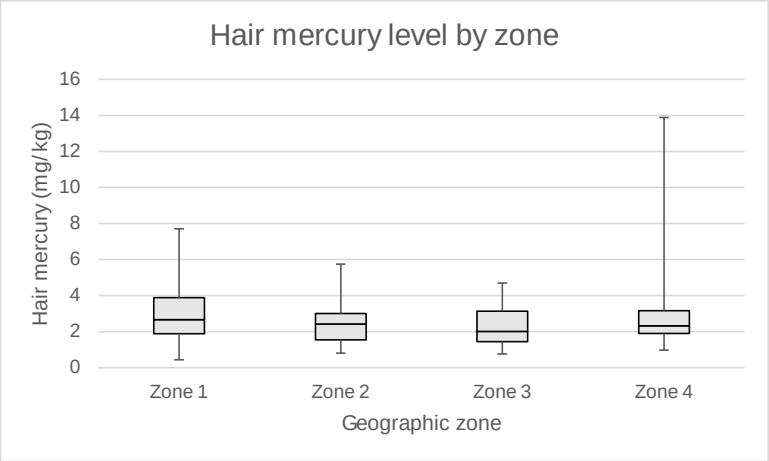


Figure 9 Median, 25 and 75 percentile, maximum and minimum values by zone

Occupation group

Occupation groups are not the controlling parameter for this survey. The number of participants in each occupational group (Figure 10) shows uneven distribution between the occupations, which is not aligned with the national profile. Thus, this parameter will not be used for further analysis.

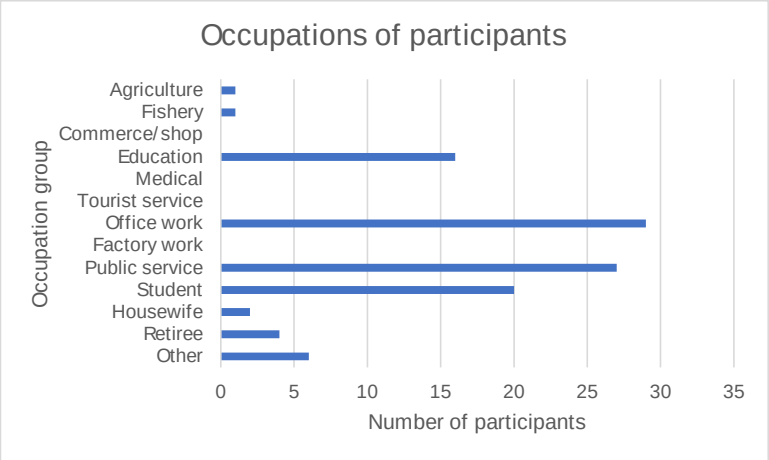


Figure 10 Number of participants to the survey per occupational group

Health problem

The participants were asked if they have health problems typical to mercury poisoning, e.g., tremor, mental disorder, etc. Out of the 103 participants, 2 participants informed that they were coughing. Only one participant informed that she/he had respiratory problem. Other symptoms that the participants identified were noncommunicable diseases such as hypertension and diabetes that are not typical to mercury poisoning. Overall, health problems due to mercury exposure was not visible in the participants.

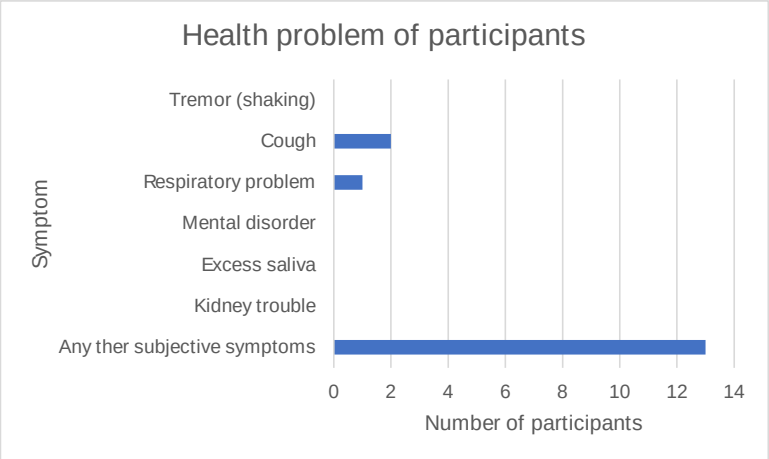


Figure 11 Number of participants to the survey informing health problem

3.4 Discussions

The population surveyed had certain level of mercury exposure most likely through the dietary intake. Table 5 shows that approx. 20 % of the population may have the mercury level higher than reference value set by WHO (2.2 and 4.4 mg/kg). No participant has shown the level higher than NOAEL (14 mg/kg). It means that all participants were below the mercury exposure level that may develop adverse symptoms at the time of survey. As the entire population is approx. 19,000 in Palau, statistically extrapolated maximum value is likely to exceed the NOAEL. In addition, individual food consumption fluctuates from time to time, so some participants with high mercury exposure may have had the exposure level exceeded prior to this survey.

Comparison with other surveys

It is also important to know the mercury level in Palau in comparison with other countries and regions. A State-of-the-science review of mercury biomarkers in human populations worldwide between 2000 and 2018[5] was conducted when preparing the UNEP Global Mercury Assessment 2018 (Relevant data are excerpted in Table 9).

Table 9 Central and upper median hair mercury levels (mg/kg) from the cross-sectional studies

	No. of Group*2	No. of Individual	Central value*3			Upper value*4		
			25 %	50 %	75 %	25%	50 %	75 %
Total	214	69,910	0.45	0.99	2.49	1.79	6.15	19.92
Western Pacific*1	56	22,900	0.67	1.40	1.98	1.95	6.32	17.76
Fish consumer	23	8,398	0.71	3.04	8.00	3.2	11.67	47.00
Coastal - Pacific	43	19,757	1.40	1.75	2.50	6.30	11.30	21.36

*1: WHO region.
*2: Sub-population groups in each study.
*3: Reported as geometric mean, median, average, etc. in each study.
*4: Reported as 95th, 90th, 75th, max, etc. in each study.

The results of this survey were 2.38, 2.45, and 2.85 mg/kg for geometric mean, median, and average, respectively, and 3.26 and 13.9 mg/kg for 75th and maximum, respectively (Table 4). These values are within the range of 'fish consumer group' and 'coastal area in the pacific', which could confirm the population in Palau is in the similar exposure levels with similar geographic and/or dietary groups. On the other hand, these levels are higher than the levels in Western Pacific regions (including China, Japan, and Korea as well as Pacific countries) and global population. Therefore, the issues discussed for fish consumers and/or coastal population equally apply to Palau.

[5] Basu *et al.* (2018).

Vulnerable population groups

The principal vulnerable population groups are female in childbearing age and children below 18 years old. This survey found that 41 % of the women in age between 18 and 39 exceeded the hair mercury level (2.2 mg/kg) referred by WHO. While none of them reached the NOAEL (14 mg/kg) as the maximum value reported in this group was 6.71 mg/kg (Table 10). It means that there is an insufficient safety margin for this population group to confirm that are no adverse effects to the entire population group.

No survey to infant was conducted in this survey, so the adverse effects to mercury due to prenatal exposure cannot be assessed. As for the post-natal exposure, it is generally understood that breastfeeding of mothers with high mercury level will not pose adverse effect to the infant. Therefore, the WHO reference is applicable prior to and during pregnancy.

As for the children subject to this survey is 3 years old or more as the minimum stay in the same district was set as the eligibility criteria. At this age range, no one exceeded the WHO reference for adults (4.4 mg/kg) but 45 % of them exceeded 2.2 mg/kg (Table 5). While it was clear that they are not more sensitive than the embryo or fetus, they might be more sensitive than adults because significant development of the brain continues in infancy and childhood. For safe side estimation, 2.2 mg/kg should be applied for management purpose.

Table 10 Basic statistics for vulnerable population group

Parameter	Children (<18)	Women (18-39)	Total surveyed
Sample count	11	22	103
Average	1.96 mg/kg	2.17 mg/kg	2.85 mg/kg
Geometric mean	1.83 mg/kg	1.89 mg/kg	2.38 mg/kg
Maximum	3.21 mg/kg	6.71 mg/kg	13.9 mg/kg
75 % quartile	2.50 mg/kg	2.80 mg/kg	3.26 mg/kg
Median	2.04 mg/kg	1.85 mg/kg	2.45 mg/kg
25 % quartile	1.39 mg/kg	1.24 mg/kg	1.72 mg/kg
Minimum	0.80 mg/kg	0.75 mg/kg	0.44 mg/kg

Occupational exposure is not examined in this study. Some occupation such as fishery may have higher fish consumption, but the guidance to such population group is not different from the guidance to the general public. For subsistence fishers who rely on their own fish catch may have higher consumption, but mercury level for small reef fish is relatively low. For commercial fishers such as pelagic catch boat clues may have some concerns for consuming their own catch.

Dietary advisory

As there were no adverse symptoms reported by the participants, it may not be necessary to impose immediate alert to the general public against the elevated mercury level. Communication on dietary

advisory may be more appropriate to raise awareness on mercury issue, particularly for female in child-bearing age. There are some examples on dietary advisory released by the health authority. WHO releases the communication material with its own guideline values although hair mercury level is not explicitly referred to[6]. National Institute for Minamata Disease, Japan issues a brochure to general public on mercury and health in plain language[7]. More specifically, Ministry of Health, Labour, and Welfare, Japan developed more targeted material for female in childbearing age[8]. Food and Drug Administration and Environmental Protection Agency, USA have issued advice regarding eating fish and shellfish. This advice is for those who might become pregnant, are pregnant, or are breastfeeding as well as parents and caregivers who are feeding children[9]. European Food Safety Authority adopted an opinion to compare the health risks associated with methylmercury exposure and other benefits of fish consumption during pregnancy[10].

Types of fish preferably eaten by citizens and serving styles differ between countries, so the advisory should be country specific. The typical consumption pattern found in this survey may serve as the basis of such advisory. Based on the mercury levels in different fish species available in the local market, guidance could be developed.

There is also another possible communication from food processing companies. The export of food products to EU requires mercury inspection. If they are regularly conducting mercury monitoring for their products, the disclosure may improve the confidence of people consuming such product preferably. Japan also sets provisional mercury levels in fish. Table 11 refers to some examples on mercury standards for foodstuffs.

Table 11 Maximum levels for mercury in foodstuffs

		Total mercury	Methylmercury
EU[11]	Fishery products and muscle meat of fish excluding below.	0.5 mg/kg-ww	

6 WHO (2021).
7 NIMD (2023).
8 MHLWJ (2010).
9 USFDA and USEPA (2021).
10 EFSA (2014).
11 EU (2006).

		Total mercury	Methylmercury
	Muscle meat of the following fish: Anglerfish, Atlantic catfish, bonito, eel, emperor, orange roughy, rosy soldierfish, grenadier, halibut, marlin, megrim, mullet, pike, plain bonito, poor cod, Portuguese dogfish, rays, redfish, sail fish, scabbard fish, seabream, pandora, shark, snake mackerel or butterfish, sturgeon, swordfish, and tuna.	1 mg/kg-ww	
Japan[12]	Fish and shellfish excluding tuna species (e.g., tuna, marlin, and skipjack) and freshwater fish and shellfish.	0.4 mg/kg-ww	0.3 mg/kg-ww
USA[13]	Fish, shellfish, crustaceans, other aquatic animals (fresh, frozen, or processed).		1 mg/kg in edible portion
	Wheat (pink kernels only).	1 mg/kg on pink kernels	

[12] MHWJ (1973).
[13] USFDA (2000).

4 CONCLUSIONS

As a chemical element, mercury has existed on Earth since its creation. Mercury is released from natural sources by processes such as volcanic activity and permafrost melting. Once released, mercury poses risks to human health and the environment. In recent years, more mercury has been released through human activities, such as the combustion of fuels, mining activities, and the consumption of mercury-added products. Mercury emitted to the atmosphere remains for a long time and will be transported long distances. Atmospheric mercury is gradually oxidized and deposited in the ocean or on land. Inorganic mercury in water bodies can be methylated by microbial activity and bioaccumulated in biota at higher trophic levels. Eventually, fishing brings mercury back to human society through consumption[14].

The survey 'Mercury exposure level for citizens in Palau due to high-level fish consumption in daily diet' disclosed the level of mercury in general public, which is not an imminent threat, but the safety margin is very narrow, particularly for the female in childbearing age. Thus, any further increase of mercury levels in fish cannot be tolerated. On the other hand, it is also important to be noted that fish contains many useful nutrients for such as polyunsaturated fatty acids, therefore, simple avoidance of fish consumption may negatively impact human health. In this vein, it is recommendable to develop advisory materials for fish selection prior to and during pregnancy. Such campaign will improve the understanding of maternity health as well.

Another possible measure could be, although very long term, the reduction of mercury level in fish in general. Palau's mercury emissions and releases are negligible in global perspective, but the most toxic effect of mercury occurs for their citizens by consuming fish and marine products. It means that the global mercury emissions and releases disproportionally affect populations such as in Palau.

The Minamata Convention on Mercury is a multilateral legally binding environmental agreement aiming to protect the human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds[15]. Palau, as a single country, is not able to address the global mercury issue by itself. This multilateral commitment calls for global actions to ease the health burden caused by mercury. The countries that are the most affected by mercury such as Palau will benefit most by the progress of the Convention.

Thanks to its pristine nature, Palau can be the ideal point to monitor the global progress of the mercury management. If the people's health and environment situation in Palau improves, it proves

[14] UNEP (2022).
[15] Minamata Convention (2013).

the improvement in the world. This could be the most important role of Palau to work on mercury issue. Mercury monitoring is a continuous effort, which will indicate the trendlines over time. This survey could serve as the baseline for the future monitoring to track the successful implementation of the Minamata Convention.

Besides the human biomonitoring, Palau can offer an excellent environmental monitoring site as no local emission sources exists in proximity to the country. It can enroll in international research programmes and/or monitoring networks and provide scientific evidence to urge global community for improving their mercury management.

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6 ANNEX

Annex 1: Mercury exposure survey in Palau (Questionnaire for mercury hair sampling analysis).

Annex 2: Informed consent

Annex 3: Informed consent (Copy to participants)

Annex 4: Result return form

ID Number: _____ (Int'l survey team)

Mercury Exposure Survey in Palau

(Questionnaire for mercury hair sampling analysis)

Resident status

Your nationality.	
State or district of your residence.	
How long have you been staying in the state mentioned above?	[ ] Less than 3 years, [ ] More than 3 years.

Note: Nationality and/or citizenship is not restricted. Only resident staying in the same district more than 3 years are eligible to the survey.

Personal Information

Your gender identification.	[ ] Female, [ ] Male, [ ] Prefer not to tell.
Your age.	
Your occupation.	[ ] Agriculture, [ ] Fishery, [ ] Commerce/shop, [ ] Education, [ ] Medical, [ ] Tourist service, [ ] Office work, [ ] Factory work, [ ] Public service, [ ] Student, [ ] Housewife, [ ] Retiree, [ ] Other (Please specify) _____
How often do you eat fish/shellfish?	[ ] Everyday, [ ] 2-3 times per week, [ ] Once per week, [ ] Once per month, [ ] Seldom, [ ] Never.
Could you estimate the amount of fish/shellfish per meal when you eat?	[ ] Below 50 grams, [ ] Between 50 and 100 grams, [ ] Between 100 and 200 grams, [ ] Above 200 grams.
What are your favourite fish/shellfish you often eat?	[ ] Fresh reef fish, e.g., snappers, [ ] Canned inshore fish e.g., sardines, [ ] Pelagic fish e.g., tuna, [ ] No preference.
Did you have an artificial hair waving "permanent wave" in the past 3 months?	[ ] Yes, [ ] No.
Do you use skin-whitening creams or soaps?	[ ] Yes, [ ] No.
Do you have any health problems?	[ ] Tremors (shaking), [ ] Cough, [ ] Respiratory problem, [ ] Mental disorder, [ ] Excess saliva, [ ] Kidney trouble, [ ] Any other subjective symptoms _____

Note: For the purpose of the survey, only the persons identified her/his gender are eligible.

ID Number: _____
(Gov/Palau)

Informed Consent

(Do you agree to provide hair sample for mercury analysis?)

Hair mercury content is the best biomarker for methylmercury exposure from fish consumption. This survey is the first ever conducted in Palau to investigate the mercury exposure level of the citizens. The mercury levels are analysed and statistically assessed for recognising the current status in country, which will be open for public access. The individual personal information is codified and will not be disclosed by any means. The result will be informed individually by securely confidential means. If you want to withdraw from the survey, please inform us via email or telephone provided below.

Do you agree the terms of the condition and submit your hair to the survey?

[ ] Yes [ ] No.

Signature: _____ Date: _____

Person in charge for the survey

Michael Blesam | 488-1639/3600 | palaueqpb@gmail.com

Palau Environmental Quality Protection Board, Republic of Palau

Dulyarat Sathainthammanee

IDEA R&D Centre, Asian Institute of Technology

Mick Saito

United Nation Environment Programme, Asia and the Pacific Office

Web: https://www.unep.org/regions/asia-and-pacific/our-projects/promoting-minamata-convention-mercury

Mercury exposure survey in Palau

Informed Consent (Copy to participant)

(Do you agree to provide hair sample for mercury analysis?)

Hair mercury content is the best biomarker for methylmercury exposure from fish consumption. This survey is the first ever conducted in Palau to investigate the mercury exposure level of the citizens. The mercury levels are analysed and statistically assessed for recognising the current status in country, which will be open for public access. The individual personal information is codified and will not be disclosed by any means. The result will be informed individually by securely confidential means. If you want to withdraw from the survey, please inform us via email or telephone provided below.

Do you agree the terms of the condition and submit your hair to the survey?

[ ] Yes [ ] No.

Signature: _____ Date: _____

Person in charge for the survey

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Dulyarat Sathainthammanee

IDEA R&D Centre, Asian Institute of Technology

Mick Saito

United Nation Environment Programme, Asia and the Pacific Office

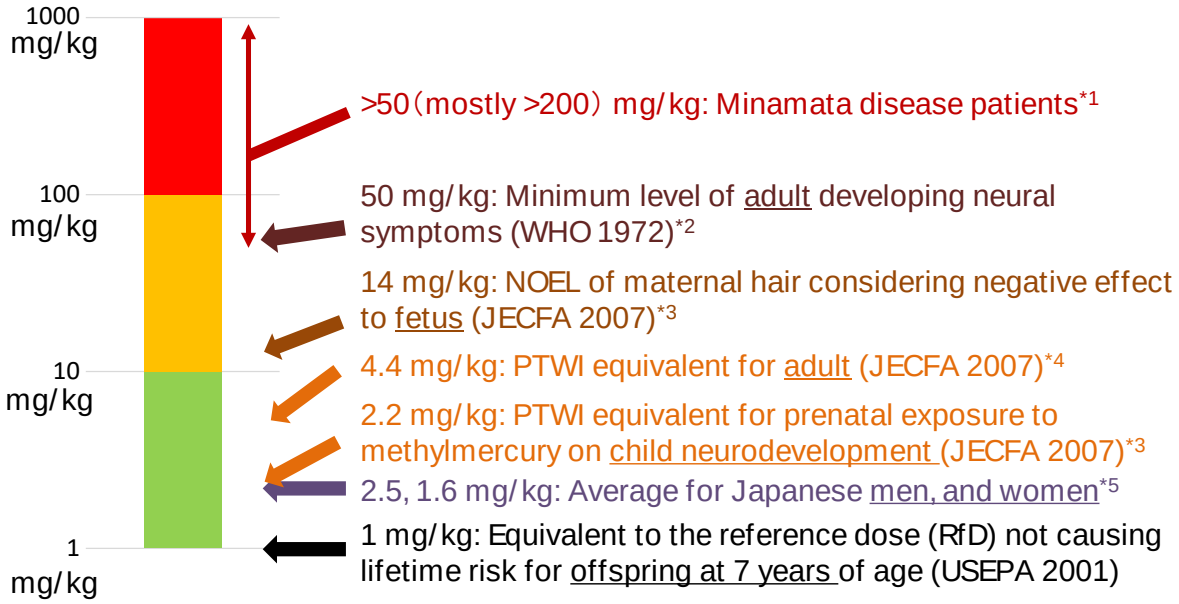
Web: https://www.unep.org/regions/asia-and-pacific/our-projects/promoting-minamata-convention-mercury

ID Number: _____

We would like to inform the result of mercury analysis in your hair collected at Earth Day 2023 event and subsequent survey.

Total mercury concentration: *.** mg/kg (ppm)

For your information, we show some indicative values of mercury concentration below:



*1: Most of the Minamata disease patients registered in Niigata had hair mercury level above 200 ppm except one case among 26 cases with 56.8 ppm. (Source: NIMD (1999). What we have learned from Minamata disease, Social Scientific Study Group on Minamata Disease.)

*2: Provisional tolerable weekly intake (PTWI) derived from lowest level for a patient showing neurological symptoms in Niigata. (Source: Joint FAO/WHO Expert Committee on Food Additives (1972). Evaluation of certain food additives and the contaminants mercury, lead and cadmium.)

*3: Provisional tolerable weekly intake (PTWI) derived from non-observed-effect level (NOEL) divided by the uncertainty factor of 6.4. (Source: Joint FAO/WHO Expert Committee on Food Additives (2007). Evaluation of certain food additives and contaminants.)

*4: Intakes of up to about two times higher than the PTWI would not pose any risk of neurotoxicity in adults. (Source: JECFA 2007).

*5: Multi-site survey in Japan by NIMD 2000-2004. (Source: NIMD (2013). Mercury and health, V4.1)

Methylmercury accumulates in the body mainly through dietary intake, and a part of it is assimilated into the hair proportional to the body burden. Thus, mercury concentration in human hair is a good indicator for methylmercury exposure.

Susceptibility to methylmercury is different in different ages. Fetus is the most vulnerable to methylmercury, thus, methylmercury level for pregnant women or women in child-bearing age are carefully considered (2.2 mg/kg). For adults, intakes of up to about two times higher than this level would not pose any risk (4.4 mg/kg). Infants and children are less sensitive than fetus but might be more sensitive than adults.

As most of the mercury in hair exists as methylmercury, the analytical result of total mercury is used for evaluating methylmercury exposure risk. In some case, however, elemental or inorganic mercury might be adhered on the hair surface on the hair surface due to the high concentration of mercury vapour (such as the ASGM situation) or mercury added products. In such a case, the mercury risk cannot be evaluated correctly by this scale.

Any further query, please contact: Ms. Kliu Basilius, Palau Environmental Quality Protection Board, Republic of Palau | 488-1639/3600 | palaueqpb@gmail.com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