



Risk of Dietary Mercury Exposure via Marine Fish Ingestion: Assessment Among Potential Mothers in Malaysia

Pravina Jeevanaraj^{1,2} · Zailina Hashim² · Saliza Mohd Elias² · Ahmad Zaharin Aris³

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Abstract

Mercury (Hg) is a very toxic heavy metal that can permanently damage the brain of a developing fetus, particularly through maternal fish consumption. Being the highest seafood consumers in South East Asia, Malaysian mothers are probably at Hg exposure risk. Hence, this study was undertaken to assess the health risk associated with Hg from marine fish consumption and the types of fish that could possibly increase the exposure dose. Assessment was done among potential mothers ($n = 311$) in the coastal rural and urban parts of Selangor, the most dense and developed state of Malaysia. Coastal rural women consumed significantly higher amounts of fish than their urban counterparts (164.0 vs. 111.7 g/day, $p = 0.03$) with Indian mackerel and torpedo scad being the most consumed species. These species also contributed to the highest average daily dose (ADD) of Hg. Consistent with the fish intake rate, coastal rural women were also clearly at higher risk of Hg exposure than their urban counterparts. The fish species that contributed to a significant Hg dose for both respondent groups was Indian mackerel. In addition, torpedo scad, yellow-banded scad, fourfinger threadfin, and golden snapper were the other species that significantly increased the exposure dose among coastal rural women, whereas for urban women, it was Indian scad, Japanese threadfin bream, and pale-edged stingray. Although the HQ calculated based on THg was lower than the unity HQ = 1.0, the identified species should be consumed with caution, especially by sensitive population groups.

Keywords Mercury · Marine fish · Health risk · Hazard quotient

Introduction

Mercury (Hg) is considered to be a very toxic metal found in water bodies and of serious concern due to its persistence and bio-accumulative nature. Non-occupational Hg exposure to humans occurs mainly through the ingestion route, and fish consumption is a major pathway. Elemental (Hg^0) and inorganic Hg (IHg) from industrial and urbanization activities settle onto the sediment and the aquatic

environment where it is microbiologically transformed into methylmercury (MeHg) through a process called methylation (Zahir et al. 2005). Both the IHg and MeHg are taken up by phytoplankton and then assimilated and retained across the food chain from small animals (usually zooplankton), to small fish that feed on zooplankton followed by larger fish that feed on small fish. Being at the top of food chain, fish thus concentrate larger amounts of Hg, which is then finally assimilated by humans at the highest concentration upon consumption (Abdel-Baki et al. 2011; Bastos et al. 2016; Liu et al. 2014).

Fish is the main protein source in the Asian diet, particularly among Malaysians, who are the highest seafood consumers in Southeast Asia. This is in agreement with the increase in the fish consumption pattern of Malaysians (Tan and Lee 2005; Teh 2012), as well as the protein intake whereby fish constitutes 60–70% of the national animal protein intake, with a per capita consumption of 47.8 kg per year (Bako et al. 2013). Furthermore, the Malaysian Adult Nutrition Survey (MANS) found that 51.3% of the rural population and 33.6% of the urban population consume

✉ Zailina Hashim
zailina@upm.edu.my

¹ Department of Diagnostic and Allied Health Science, Faculty of Health and Life Sciences, Management and Science University, Shah Alam, Malaysia

² Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, Serdang, Malaysia

³ Department of Environmental Science, Faculty of Environmental Studies, Universiti Putra Malaysia, Serdang, Malaysia

fish at least once a day (Norimah et al. 2008), while the Ministry of Health reported that the demand for marine fish among Malaysians has increased over the years (Hajeb et al. 2009). Unfortunately, studies have shown that certain fish that are available for consumption in Malaysia, such as long tail tuna, snappers, short-bodied mackerel, and giant perch have elevated Hg concentrations (Agusa et al. 2005; Ahmad et al. 2015; Alina et al. 2012; Hajeb et al. 2009; Jeevanaraj et al. 2016).

From a dietetic standpoint, fish contain high levels of protein, minerals, vitamins, and omega-3 fatty acids. These nutrients are attributed to lowering the risks of coronary heart diseases and stroke (Din et al. 2004). In addition, epidemiological studies have suggested links between fish consumption and a reduction in the risk of succumbing to many chronic diseases. However, Hg contamination in fish may counter its health benefits. To make it worse, Hg, mainly MeHg, is found predominantly in the edible portion—the muscle tissues (~ 90%)—rather than the fatty deposits. Thus, trimming or skinning does not reduce the Hg content in fish muscles (WHO 2008).

The populations most sensitive to Hg exposure are those who are of reproductive age, pregnant and lactating women, as well as the fetus, infants, and children. Both MeHg and IHg ingested by mothers can pass through the placenta and breast milk (WHO 2008) and cause adverse neurodevelopmental outcomes (Ask et al. 2002; Goldman and Shannon 2001; Jeevanaraj et al. 2016; Yau et al. 2014). Considerable attention has been given to MeHg as it also readily crosses the blood–brain barriers (Ramirez et al. 2000; Salehi and Esmaili-Sari 2010; Sakamoto et al. 2008). Accordingly, the fetus and children, as well as pregnant and lactating mothers along with women of reproductive age, are at utmost risk. Not only that, populations with a traditionally high intake of seafood, such as those whose main trade is fishing and those living in the neighborhood are at higher risk due to their inclination towards fish consumption (WHO 2008).

Despite the significantly high fish intake rate among the Malaysian population and the reported Hg levels in the local fish species, in addition to the proven toxicology track of Hg, there is no systematic study that focuses on the health risk of Hg exposure via fish consumption among the sensitive population in Malaysia. The available studies have focused on the relationship between fish intake and the Hg level in biomarkers of exposure, such as hair (Aldroobi et al. 2013; Hajeb et al. 2008; Jeevanaraj et al. 2015; Sarmani and Alakili 2004; Tengku Hanidza et al. 2010). As an exception, Agusa et al. (2005) evaluated the health risk to the general Malaysian population by estimating the exposure dose based on the Hg concentration in fish and the daily fish consumption. It was found that 48% of the marine fish analyzed may expose the population to Hg levels higher than the guideline value. Hence, this study was undertaken to further fill the

gap in the Hg exposure risk assessment, focusing on women of reproductive age, residing in fishing villages due to their added risk of frequent fish consumption and compared to the urban community. We have determined the total Hg ingestion dose via marine fish consumption, and fish species that significantly contribute to the THg dose and the overall non-carcinogenic health risk.

Methodology

Study Location

The Department of Environment (DOE) Malaysia in its environmental quality report stated that Selangor was the only state that was categorized as ‘poor’ for Hg pollution in Class II waterbodies (Marine Life, Fisheries, Coral Reefs, Recreational, and Mariculture); with an Hg limit of 0.16 µg/l (0.04 µg/l where seafood for human consumption is applicable) based on the Malaysian Marine Water Quality Criteria and Standards (MWQCS) (DOE 2011). This can be related to the fact that Selangor has a high level of urbanization and industrialization. To make it worse, the Straits of Malacca are seriously contaminated by oil spills due to international shipping activities, ultimately releasing Hg into the aquatic environment (Agusa et al. 2007), and promoting bio-accumulation across the aquatic food chain. This may put the population at exposure risk, especially the sensitive group, who consume the marine fish caught from the surrounding waterbodies by local fishermen.

Hence, the assessment was undertaken among the communities in Selangor (3.3333°N, 101.5000°E), which comprises nine districts (Fig. 1) and 226 sub-districts. Sub-districts containing fishing villages were identified as the study location and referred to as coastal rural. For comparison purposes, the urban populations from the developed sub-districts of Selangor were also selected. The study sites were selected following area probability sampling; a probability proportionate to size (PPS) method that incorporates elements of simple random, systematic, cluster, and stratified sampling (Aday and Cornelius 2006). Based on the identified study sites, the respondent selection was done by the Department of Statistics (DOS) Malaysia using the National Household Sampling Frame (NHSF).

Community Survey

A detailed survey on the habitual intake of marine fish species was conducted among women of childbearing age (18 to 49 years old; $n = 311$) in the selected areas using a semi-quantitative fish frequency questionnaire. The participants were asked about their usual consumption frequency, portion size, and number of servings of the listed fish (Abdelouahab

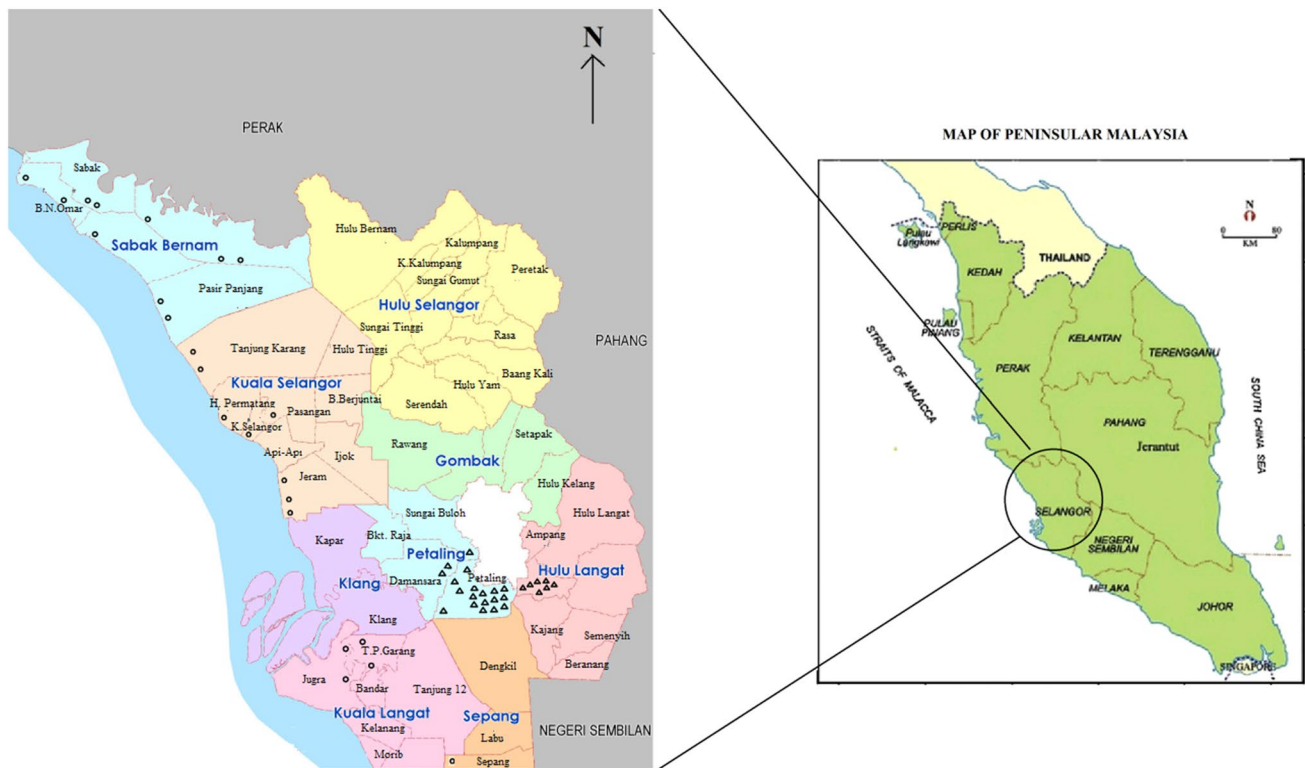


Fig. 1 Study location; sampling was done by DOS, Malaysia (O=coastal rural; Δ=urban). *Source* Economic Planning Unit of Selangor

et al. 2008). The responses were *Never*, *Less than once a month*, *Once a month*, *2–3 times a month*, *Once a week*, *2–3 times a week*, *4–6 times a week*, *Once a day*, and *More than once a day*. To facilitate recall and identification, a booklet containing portion size (One portion, palm-size = 85 g) and fish pictures with local and English names was shown (Hajeb et al. 2008).

Fish Sampling and Hg Quantitation

The preferred species were identified from the survey responses and were purchased from the wholesale market of the Fisheries Development Authority of Malaysia (LKIM) and the Fishermen's Market, based on the close proximity to the community survey location (Fig. 1). The latter was created as an alternative channel to provide fishermen with opportunities to directly market their catch. Fish samples were transferred into a polyethylene bag with labels for temporary storage at + 4 °C.

Cleaned fish muscles were dried at 80 °C until a constant weight was obtained and ground on an agate mortar to obtain a fine homogeneous powder. Samples (~ 0.5 g) followed by HNO₃ 65% v/v (5.0 ml) and H₂O₂ 30% v/v (2.0 ml) were added into quartz vessels of Multiwave 3000 (8NXQ80) for digestion. Mercury quantitation was carried out using the VP90 Continuous Flow Vapor System

of Thermo Fisher Scientific with a D2 QuadLine background correction. The detailed operating conditions for Multiwave 3000 and VP90 were described in Jeevanaraj et al. (2016).

The linear equation was obtained by plotting the peak area against the concentration of standards at six calibration points in the range of 0–10 µg/l. The resulting peak area of the sample was replaced in the linear equation to obtain the corresponding concentration, which was later adjusted to the dilution factor and sample mass. The species and number of fish samples analyzed, along with the respective geometric mean (GM), minimum, and maximum Hg concentrations in the muscle tissues are given in Table 1.

The sample preparation and analysis were thoroughly validated to ensure the credibility of the data. The factors considered were the determination coefficient (R^2), linearity, recovery, precision, limit of detection (LOD), and the limit of quantification (LOQ). The R^2 for the calibration curve was greater than 0.995 while the recovery checked using DORM4 fish muscles (~ 0.5 g) was 94.21% (SD = 3.44). The precision was measured using six replicates under repeatability and reproducibility conditions, giving an overall relative standard deviation (RSD) of less than 10%. The LOD and LOQ, which were calculated as the mean blank reading plus 3SD and 10SD, were 0.27 and 0.55 µg/l, respectively. The calibration check standard solutions were

Table 1 Name and total mercury (THg) concentration in muscles of marine fish species. Source Jeevanaraj et al. (2016)

Species scientific name	Species common name	Sample size, <i>n</i>	Total mercury (mg/kg dry wt)		
			GM	Minimum	Maximum
<i>Decapterus macrosoma</i>	Indian scad	11	0.26	0.21	0.35
<i>Mugil cephalus</i>	Flathead grey mullet	8	0.27	0.23	0.30
<i>Parastromateus niger</i>	Black pomfret	10	0.26	0.20	0.35
<i>Pampus argenteus</i>	Silver pomfret	11	0.25	0.19	0.31
<i>Sillago sihama</i>	Silver whiting	5	0.31	0.27	0.35
<i>Rastrelliger kanagurta</i>	Indian mackerel	15	0.26	0.16	0.40
<i>Selaroides leptolepis</i>	Yellow-banded scad	12	0.27	0.14	0.45
<i>Megalaspis cordyla</i>	Torpedo scad	11	0.35	0.24	0.64
<i>Chirocentrus dorab</i>	Dorab wolf herring	6	0.39	0.28	0.48
<i>Eleutheronema tetradactylum</i>	Fourfinger threadfin	11	0.35	0.16	0.54
<i>Scomberomorus guttatus</i>	Spanish mackerel	10	0.39	0.26	0.62
<i>Euthynnus affinis</i>	Eastern little tuna	6	0.36	0.31	0.41
<i>Dasyatis zugei</i>	Pale-edged stingray	6	0.36	0.19	0.71
<i>Johnius dussumieri</i>	Sin croaker	7	0.33	0.22	0.57
<i>Lutjanus johnii</i>	Golden snapper	8	0.50	0.29	0.90
<i>Epinephelus areolatus</i>	Areolate grouper	9	0.31	0.24	0.36
<i>Nemipterus japonicus</i>	Japanese threadfin bream	11	0.36	0.27	0.46
<i>Lutjanus argentimaculatus</i>	Red snapper	7	0.36	0.23	0.52
<i>Lates calcarifer</i>	Giant perch	11	0.24	0.17	0.32

analyzed at the beginning, after every 10th sample and at the end of the analysis.

Non-carcinogenic Health Risk Assessment

The hazard quotient (HQ) was applied to identify the possible chronic non-carcinogenic health risk associated with dietary Hg exposure. The HQ is defined as the ratio of exposure level to a single substance in relation to an RfD or to the level at which no adverse effects are expected (USEPA 2011; WHO 2008). The exposure level was assessed based on the average daily dose (ADD), which was calculated using the daily fish intake rate and Hg concentration in each fish species. As women of reproductive age are one of the most sensitive groups, assessment was done taking the worst case into consideration to calculate the HQ, i.e., GM and maximum THg concentration in fish muscles, as well as the RfDs for both the THg and MeHg (assuming that all Hg is in MeHg form).

Daily Fish Intake Rate

The reported intake frequency of each listed fish was converted into conversion factors (CF) to reflect the number of times a day the specific fish was consumed (Table 2) (Norimah et al. 2008). This CF along with portion size, number of servings, and the weight of fish in one serving were used as

Table 2 Conversion factor to estimate intake frequency; adapted from Malaysian Adult Nutrition Survey. Source Norimah et al. (2008)

Frequency of intake	Frequency	Conversion factor (CF)
Not at all	0	0
Per day	1 time	1
	2 times	2
	3 times	3
Per week	1 time	0.14 (1/7)
	2–3 times	0.36 (2.5/7)
	4–6 times	0.71 (5/7)
Per month	1 time	0.03 (1/30)
	2–3 times	0.08 (2.5/30)

inputs to calculate the estimated amount of fish consumption (g/day) (Formula 1).

$$IR_m = CF_m \times P_m \times N_m \times W, \quad (1)$$

where IR_m is the daily intake rate of fish m (g/day), CF_m the conversion factor for frequency of fish m intake, P_m the portion size of fish m , N_m the number of servings of fish m , and W is the fish weight in one serving (85 g).

Average Daily Dose (ADD)

The ADD was calculated in agreement with the guidelines provided by the United States Environmental Protection Agency (USEPA), Human Health Risk Assessment

Supplemental Guidance (USEPA 2014), and the Integrated Risk Information System (USEPA 2006). The daily Hg dose (Formula 2) from each fish species was calculated using the fish intake rate (Formula 1) and Hg concentration (GM and maximum) in each fish species (Table 1). The survey responses concerning the habitual intake frequency of each fish species was used to obtain the frequency of exposure to the particular fish (days/year) (Formula 3). This information, along with the individual body weight, exposure duration (ED) (30 years for non-carcinogenic health risk), and averaging time (AT) ($ED \times 365$) were used to calculate the ADD (Formula 4).

The formulas used are given below.

$$DD_m = C_m \times IR_m \quad (2)$$

$$EF_m = CF_m \times 365 \quad (3)$$

$$ADD = \frac{\sum DD_m \times EF_m \times ED}{B_w \times AT}, \quad (4)$$

where ADD is the average daily dose ($\mu\text{g Hg/kg bw-day}$); sum of all the fish species, DD_m the daily dose of fish m ($\mu\text{g/day}$), EF_m = the frequency of exposure to fish m (days/year), ED the exposure duration (30 years), B_w the body weight (kg), AT the averaging time ($ED \times 365$ days/year), the CF_m the conversion factor for frequency of fish m intake, C_m the average total mercury concentration in muscles of fish m ($\mu\text{g/g dry wt.}$) – GM and maximum THg, IR_m is the daily intake rate of fish m (g/day).

Hazard Quotient (HQ)

The Joint FAO/WHO Expert Committee on Food Additives (JECFA) has recommended an RfD of $0.23 \mu\text{g Hg/kg bw/day}$ for MeHg (Abdelouahab et al. 2008; Moon et al. 2011; WHO 2008). However, the USEPA RfD value is $0.1 \mu\text{g Hg/kg bw/day}$ for MeHg and $0.7 \mu\text{g Hg/kg bw/day}$ for THg is given in USEPA IRIS (2006). These RfDs were used to calculate the HQ in order to determine the threat of Hg exposure via fish ingestion. In cases where the HQ does not exceed unity ($HQ < 1$), it is assumed that no chronic risks are likely to occur.

$$HQ = \frac{ADD}{\text{Oral RfD}}, \quad (5)$$

where HQ is the hazard quotient; non-cancer hazard index, ADD the average daily dose ($\mu\text{g Hg/kg bw-day}$), and Oral RfD is the oral reference dose of mercury ($\mu\text{g Hg/kg bw-day}$).

Statistical Analysis

All the calculations and statistics were performed using SPSS version 21.0. The Mann–Whitney U test was used to find the significant difference in the fish intake rates between the coastal rural and urban women, while multiple linear regression (MLR) with stepwise method was used to predict the fish species that increase the THg ADD.

Results

Fish Intake Rate

Overall, on average, the women consumed about 136.4 g/day ($SD = 147.1$) of marine fish with coastal rural women consuming a significantly higher amount than their urban counterparts (164.0 vs. 111.7 g/day , $p = 0.03$). Figure 2 illustrates the average species-specific marine fish intake rates for the two groups of respondents. The most consumed species were Indian mackerel (coastal rural vs. urban = 56.1 vs. 25.0 g/day), followed by torpedo scad (32.7 vs. 11.6 g/day); both of which were consumed in significantly higher quantities by coastal rural women. In addition, on average, the coastal rural women also consumed a significantly higher amount of sin croaker, silver pomfret, flathead grey mullet, and fourfinger threadfin. In contrast, the urban women consumed more yellow-banded scads, eastern little tuna, Spanish mackerel, and red snapper. This reflects the difference in fish preference among the communities, varying with stratum.

Average Daily Dose of Mercury

Coherent with the fish intake rates, the Indian mackerel and torpedo scad also contributed to the highest THg ADD: Indian mackerel (ADD GM/Max THg = $0.0759/0.1168 \mu\text{g Hg/day-kg bw}$) and torpedo scad (ADD GM/Max THg = $0.0393/0.0719 \mu\text{g Hg/day-kg bw}$) (Table 3). The Hg ADD was higher among the coastal rural women for silver pomfret, flathead grey mullet, silver whiting, torpedo scad, Indian mackerel, pale-edged stingray, fourfinger threadfin, and sin croaker, whereas for the urban women, it was Spanish mackerel, red snapper, and yellow-banded scad among others. Overall, the total ADD for coastal rural women was significantly higher, equivalent to their fish intake rate (ADD GM THg = 0.2712 vs. $0.1502 \mu\text{g Hg/day-kg bw}$; ADD Max THg = 0.4318 vs. $0.2197 \mu\text{g Hg/day-kg bw}$); tested using the Mann–Whitney U test.

Non-cancer Health Risk

Although THg was measured, a high precautionary scenario is represented by assuming that the fish may also contain

Fig. 2 Marine fish intake rates (g/day) among coastal rural and urban women (*significantly different at p value = 0.05, tested with Mann–Whitney U test)

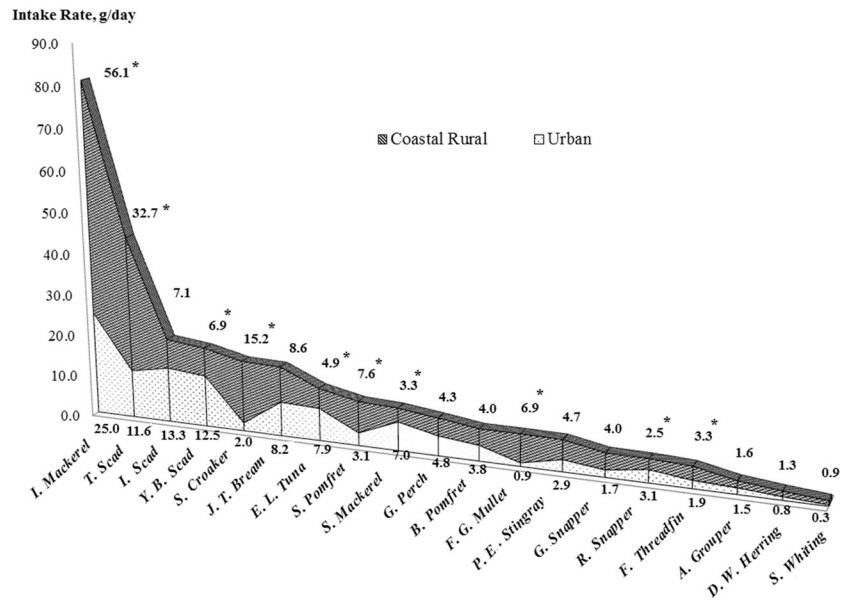


Table 3 Species-specific average daily dose of total mercury via ingestion route

Fish species		Average daily dose ($\mu\text{g Hg/day}\cdot\text{kg bw}$)						
		Overall	Coastal rural	Urban	Overall	Coastal rural	Urban	
Black pomfret	Based on	0.0010	0.0009	0.0011	Based on	0.0014	0.0013	0.0015
Silver pomfret	GM THg	0.0030	0.0055	0.0007	Max THg	0.0037	0.0068	0.0009
Flathead grey mullet		0.0067	0.0135	0.0007		0.0075	0.0150	0.0008
Silver whiting		0.0001	0.0002	0.0000		0.0002	0.0003	0.0000
<i>Torpedo scad</i>		0.0393	0.0672	0.0143		0.0719	0.1229	0.0261
Golden snapper		0.0031	0.0045	0.0018		0.0055	0.0080	0.0033
Dorab wolf herring		0.0002	0.0002	0.0002		0.0003	0.0003	0.0003
<i>Indian mackerel</i>		0.0759	0.1217	0.0349		0.1168	0.1872	0.0537
Spanish mackerel		0.0050	0.0030	0.0068		0.0080	0.0048	0.0108
Giant perch		0.0022	0.0013	0.0030		0.0029	0.0017	0.0039
Pale-edged stingray		0.0025	0.0028	0.0022		0.0049	0.0055	0.0043
Fourfinger threadfin		0.0012	0.0015	0.0010		0.0019	0.0022	0.0016
Red snapper		0.0016	0.0012	0.0020		0.0024	0.0018	0.0029
Indian scad		0.0227	0.0059	0.0378		0.0306	0.0079	0.0509
Eastern little tuna		0.0118	0.0028	0.0198		0.0134	0.0032	0.0226
Japanese threadfin bream		0.0088	0.0093	0.0083		0.0112	0.0118	0.0106
Yellow-banded scad		0.0089	0.0032	0.0139		0.0148	0.0054	0.0232
Sin croaker		0.0129	0.0263	0.0009		0.0223	0.0454	0.0015
Areolate groupper		0.0005	0.0003	0.0008		0.0006	0.0003	0.0009
Total		0.2074	0.2712*	0.1502		0.3200	0.4318*	0.2197

Italic denotes abbreviation for which the full term is given subsequently

GM THg geometric mean of total mercury in fish muscle (mg/kg dry wt), Max THg maximum total mercury in fish muscle (mg/kg dry wt)

* Significantly high at p value = 0.001 tested with Mann–Whitney U test

almost 100% MeHg. Hence, the health risk assessment was done based on the RfDs for THg as well as MeHg. Based on Fig. 3a, when the Hg level in the fish species consumed is equivalent to the GM level found, the HQ for coastal rural

and urban women would be 2.7 and 1.5 (based on USEPA-MeHg RfD); 1.2 and 0.7 (based on JECFA-MeHg RfD); and 0.4 and 0.2 (based on USEPA-THg RfD), respectively. However, if the Hg level in the fish species consumed reaches the

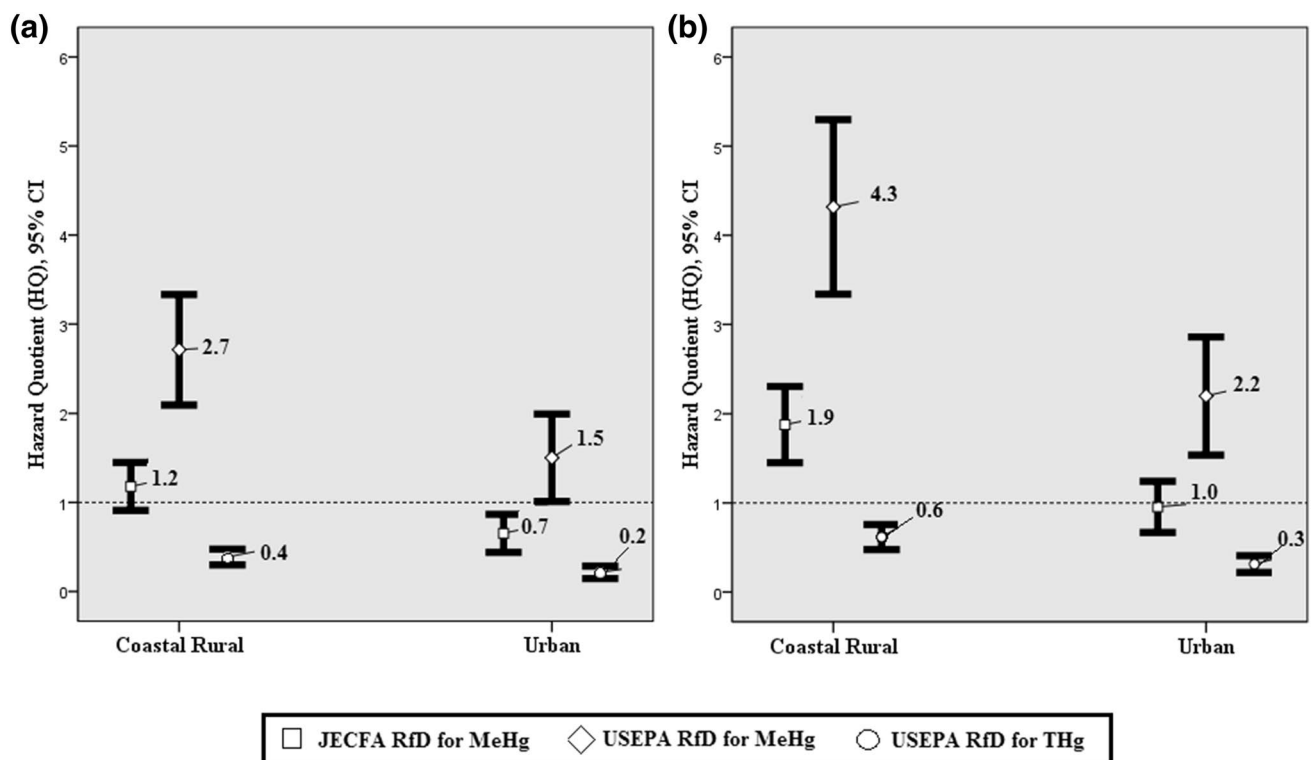


Fig. 3 Hazard quotient based on different reference doses; **a** HQ based on GM THQ and **b** HQ based on Max THQ (dot-line indicate non-cancer risk at unity, HQ = 1.0)

maximum level found, the HQ for the coastal rural and urban women would be 4.3 and 2.2 (based on USEPA-MeHg RfD); 1.9 and 1.0 (based on JECFA-MeHg RfD); and 0.6 and 0.3 (based on USEPA-THg RfD), respectively. Consistent with the fish intake rate, coastal rural women are clearly at higher risk. If the Hg found in fish exists as MeHg, the population under study might be an exposure risk. Nonetheless, as far as the THg level is concerned, neither group may be at chronic non-cancer risk.

Fish Species Contributing to Mercury Dose

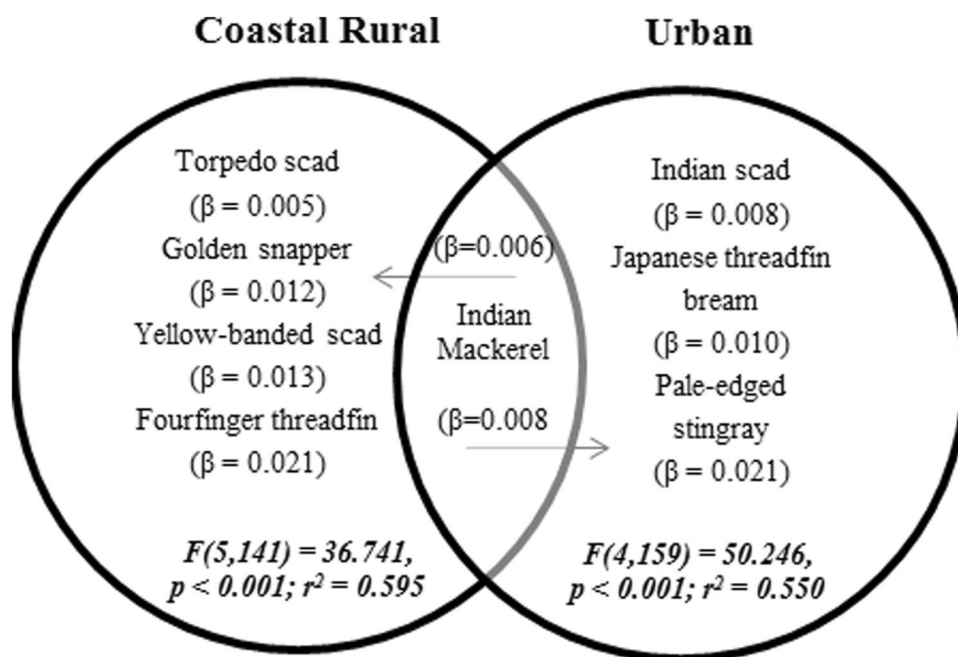
In order to predict the fish species that has the potential to increase exposure, stepwise multivariable linear regression was performed separately for the coastal rural and urban women, taking fish intake rates as independent variables and log ADD GM THg as the dependent variable. The Venn diagram (Fig. 4) illustrates that Indian mackerel significantly increased the ADD among both the coastal rural and urban women (each g increase in intake rate increased the log ADD by 0.006 and 0.008 units, respectively). Other fish species that significantly contributed to the ADD among coastal rural woman, in descending order were fourfinger threadfin ($\beta = 0.021$), yellow-banded scad ($\beta = 0.013$), golden snapper ($\beta = 0.012$), and torpedo scad ($\beta = 0.005$), whereas for the urban women, it was pale-edged stingray ($\beta = 0.021$),

Japanese threadfin bream ($\beta = 0.010$), and Indian scad ($\beta = 0.008$). The adjusted r^2 indicates that 59.5 and 55.0% of the variation in THg ADD for coastal rural and urban women was explained by consumption of the fish species.

Discussion

Malaysia is indeed a high fish consuming nation. The Household Expenditure Survey for Malaysia in 2004/2005 showed that fish expenditure (22.1%) was the second largest after cereals (23.9%), and the trend showed an increase when compared to the previous 1999/2000 survey (21.8%). As predicted, women in the coastal rural area consumed a significantly higher amount of marine fish than their urban counterparts. A similar result was also reported by Ahmad et al. (2016) and Hajeb et al. (2008). This can be attributed to the easy accessibility and availability of fish in coastal rural areas, especially among families who continued to pursue more traditional and substantial fishing activities (Benefice et al. 2010; Cheng et al. 2009). In addition, fish species can be purchased at a relatively lower price in fishing villages and their environs compared to other food items; simply due to the fishing trade being the main economic activity in the region. This also encourages the families in the coastal part to include fish in their diet more frequently.

Fig. 4 Venn diagram of fish species predicting the ADD (VIF < 10 for all the variables; no interaction between independent variables; normally distributed unstandardized residue)



The human intake of Hg depends not only on the amount of fish consumed, but also on the types of fish preferred. In line with that, Indian mackerel and torpedo scad ranked the top most consumed species among both communities. Other preferred fish species included Indian scad, yellow-banded scad, tuna, and Japanese bream. Closely related to the present study, Ahmad et al. (2016), Siti Aminah et al. (2013), and Hajeb and Jinap (2011) also reported that Indian mackerel, Spanish mackerel, pomfrets, breams, yellow-banded scad, and tuna were among the most preferred fish species by Malaysians. This can be linked to the type of common local dishes, such as Indian mackerel curry, fried Spanish mackerel, bream in coconut milk, tuna curry, fried scad, Indian mackerel in chili/sambal, and scad in chili/sambal (Hajeb and Jinap 2011).

There was a distinct difference in the choice of fish by the respondent groups. Based on the fish prices listed by the Fisheries Development Authority of Malaysia (LKIM) (2016), coastal rural communities preferred species of a lower price, while those in the urban areas mostly preferred a more expensive type of fish (Spanish mackerel, red snapper, and eastern little tuna). Researchers have found that fish consumption is positively correlated to household income with per capita fish expenditure being significantly higher for urban households (Manrique and Jensen 2001; OEHHA 2001). This is because urban households, with a relatively higher monthly income (DOS 2017), are able to spend more on household provisions, especially luxury food commodities including big and expensive fish (Tan and Lee 2005; Delgado et al. 2003). Conversely, low-income groups in rural areas preferred food sources that are high in energy but

lower in price, such as small and cheaper lean fish (Tan and Lee 2005). In addition, the households of the fishermen tend to keep the small fish from the catch for family consumption and sell the big ones.

If most Hg found in fish exists as MeHg, the HQ of coastal rural women in this study is comparable to Jayasooryan et al. (2011) and Castilhos et al. (2006), the former among communities consuming fish contaminated with Hg from Cochin backwaters and the latter among those consuming Hg-contaminated fish in the gold mining areas of Indonesia. Although Hg in the fish muscles reported by Jayasooryan et al. (2011) and Castilhos et al. (2006) were many times higher, compared to that reported by Jeevanaraj et al. (2016), the non-cancer health risk was similar. This can be explained by the amount of fish consumed by the respondents in the present study, especially in coastal rural communities, which, as far as MeHg is concerned, causes a higher Hg dose that is somewhat equivalent to the communities consuming point-source contaminated fish. However, taking THg into account, the present study showed no chronic non-cancer health risk for the population. A similar conclusion was made by Alina et al. (2012) for fish from the Straits of Malacca, whereas Hajeb and Jinap (2011) reported that the general adult population is exposed to low-level Hg from fish while the fishermen families presented a higher Hg intake. Anual (2014) and Hajeb et al. (2009) also argued that none of the fish examined exceeded the permissible weekly intake for Hg, and, hence presented no risk for human consumption.

The species contributing to most of the Hg dose was identified through statistical analysis. Unlike the intake rates, the

types of fish in terms of the exposure risk were different; golden snapper, yellow-banded scad, and fourfinger threadfin, in addition to Indian mackerel and torpedo scad among those from the coastal rural community, and Indian scad, Japanese threadfin bream, pale-edged stingray, and Indian mackerel among urban women. This reveals the fact that an excess or low fish intake rate does not guarantee the dose. Instead, exceptionally high intake rates of fish with moderate Hg contamination and consumption of fish with high Hg concentrations even at a moderate level can both result in elevated ingestion dose (Legrand et al. 2005). The variation in Hg in the fish muscles on the other hand show discrepancies in relation to length, weight, age, feeding habit, and habitat (Alina et al. 2012; Burger 2005; Hajeb et al. 2009; Jeevanaraj et al. 2016; Storelli et al. 2002). Low consumption of selected fish, such as the carnivorous Japanese threadfin bream, golden snapper, and fourfinger threadfin, as well as the bottom dweller pale-edged stingray, caused a significant rise in the ADD due to the amount of Hg bioaccumulated in the species (Jeevanaraj et al. 2016). Hence, high-risk groups, such as potential/pregnant mothers and children, should consume these fish in moderation since a large consumption pattern may result in increased health risks (Hajeb et al. 2009).

Conclusion and Recommendations

In conclusion, based on the THg limit, there may be no non-cancer risk among the respondents for dietary Hg exposure. Nevertheless, caution should be taken for sensitive groups as well as the consumption of bigger predatory fish that consist mostly of MeHg. The detection of MeHg in fish muscles is crucial to further scrutinize the risk assessment. Along with that, measuring the Hg level in biomarkers is an added advantage as it will confirm the species contributing to a higher MeHg uptake.

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