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Heavy Metal Levels and Risk Assessment from Consumption of Marine Fish in Peninsular Malaysia

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Abstract

Fish consumption is one of the primary sources of protein in Malaysia. However, harmful substances, including heavy metals released from anthropogenic sources may accumulate in marine organisms through the food chain. Hence, human health risks may occur through the consumption of fish contaminated by heavy metals. This study was conducted to determine the concentrations of heavy metals and to assess health risks in edible tissues of 296 commonly consumed marine fish throughout Peninsular Malaysia. The marine fish samples were collected from selected major fish landing ports throughout Peninsular Malaysia. This paper focused on nine heavy metals concentrations namely selenium (Se), cadmium (Cd), lead (Pb), copper (Cu), zinc (Zn), antimony (Sb), tin (Sn), chromium (Cr) and manganese (Mn) in 46 species of marine fish. The fish samples were digested using a microwave digestion system (Multiwave 3000, Anton Paar). Heavy metals concentrations were analyzed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) ELAN 9000 (Perkin Elmer, Sciex, Canada). The heavy metals concentrations in marine fish samples were found to be dominated by Zn followed by Sn, Se, Cu, Mn, Cr, Pb, Cd and Sb which ranged between 15.9612 mg/kg (Zn) and 0.0002 mg/kg (Sb) wet weight. Among the investigated fish species, *Otolithoides biauritus* demonstrated the lowest concentration for all heavy metal except for Pb. The estimated weekly intakes (EWI) for all samples in this study were below the established PTWI by JECFA of FAO/WHO. Risk assessment results showed that the hazard quotient (HQ) and hazard index (HI) values were lower than 1 in all fish species. The results indicate that exposure to the studied metals poses a low non-carcinogenic risk and considered safe for human consumption.

Keywords

Trace Elements, Hazard Quotient, Hazard Index, ICP-MS, PTWI

1. Introduction

Fish is widely consumed by many people throughout the world because of its high protein content and provides various vitamins, minerals and polyunsaturated omega-3 fatty acids that help reduce the risk of certain types of cancer and cardiovascular diseases [1] [2] [3] [4]. Consumption of fish is a foremost source of protein for the Malaysian population. The Malaysian Adult Nutrition Survey (MANS) reported that the average daily consumption of fish is one and a half of medium size fish per day for the adult population in Malaysia [5] [6]. However, the health benefits provided through fish consumption may be compromised with the presence of contaminants in the fish which can pose a significant threat to the health of consumers [7].

Industrial and urbanisation activities have contributed to the increase of contamination, including heavy metal in the marine environment and have directly influenced coastal ecosystems [8] [9]. The harmful minerals and metals existing in the environment can be absorbed into living organisms from the surrounding water, sediment, and diet. Heavy metals enter the food chain through direct consumption of water or organisms or uptake processes and can be potentially accumulated in fish [10]. Therefore, fish are vulnerable to the effects of chemical contaminants, including heavy metals which bioaccumulate and biomagnify through the aquatic food chain [11]. Feeding habits, size, lifestyle and species of fish may influence metal bioaccumulation ability [12] [13] [14]. The concentrations of heavy metals in the tissues and organs of fishes indicate the concentrations of heavy metals in water, and their accumulation in food chains [4] [15]. The toxic elemental contaminants in fish are transferred into human metabolism through consumption of contaminated fish that could cause unhealthy effects towards human health [16] [17] [18].

Concerning the toxicology effect of heavy metals from fish consumption, the Joint of Food and Agriculture Organization and World Health Organization (FAO/WHO) Expert Committee on Food Additives (JECFA) has set a provisional tolerable weekly intake (PTWI) for protection of the consumer. PTWI is the safe level of intake or the maximum amount of a contaminant that be exposed to a person weekly over a lifetime without an intolerable risk of health effects associated with the consumption of foods [7] [19] [20]. These limits can also be species-specific as metal accumulation is affected by different development and metabolic rates of different organisms [21]. To estimate the potential of health risk due to exposure to the contaminant, the United State Environmental Protection Agency (USEPA), created the reference dose (RfD). RfD is an estimate of daily oral exposure of contaminant to the human population that is likely to be without considerable risk of harmful effects during a lifetime [22].

Numerous studies have investigated heavy metal concentrations in fishes in other parts of Malaysia [9] [11] [23]-[27]. However, most of the studies were focusing on a specific locality, and few studies assessed the potential health effect due to the consumption of fish. Therefore, this study was conducted to determine the concentrations of heavy metals and to assess health risks for the edible tissues of 296 commonly consumed marine fish samples from fish landing ports and wholesale markets throughout Peninsular Malaysia. Estimated Weekly Intake (EWI) of elements of fishes was calculated to estimate the risk of consuming contaminated fish. Whereas, the risk of non-carcinogenic effects from fish consumption was assessed by estimating the ratio of the exposure dose to the reference dose from USEPA.

2. Materials and Methods

2.1. Sampling and Sample Preparation

A total of 394 seafood samples were collected from selected major fish landing ports of Fisheries Development Authority of Malaysia (*Lembaga Kemajuan Ikan Malaysia*, *LKIM*) and wholesale markets in Peninsular Malaysia. The sampling was conducted from June to December 2009. This paper reported results for nine heavy metals concentrations, which consisted of 296 numbers of samples included 46 species of marine fish. The selection of fish was based on the most popular/consumed seafood by the local population as described elsewhere [6]. Six major fish landing complexes of LKIM and five wholesale wet markets throughout Peninsular Malaysia were selected as the sampling location. The selected sampling locations are the main fish landing port where fishes were distributed throughout the Peninsular Malaysia, which is represented the whole population consumption of fish (**Figure 1**). The complete methodology of the sample calculation and collection has been described by Ahmad *et al.*, 2015a [6].

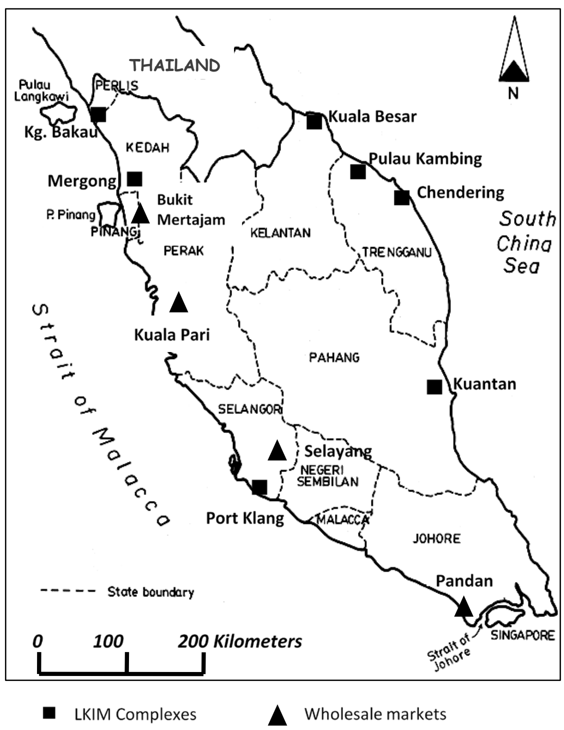

Figure 1. Map of sampling location in Peninsular Malaysia [6].

2.2. Apparatus and Reagent

All single elements stock solution (selenium, cadmium, lead, copper, zinc, antimony, tin, chromium and manganese) and mixed internal standard solution (indium, yttrium, holmium, and scandium) with the concentration of 10 mg/L were delivered by Perkin Elmer® and certified for purity and concentration. A mixed working standard with the concentration of 1 mg/L was prepared by pipetting 5 mL of each stock solution into a 50 mL volumetric flask and diluted up to 50 mL with 0.2% nitric acid (HNO_3 Suprapur®, Merck). This standard solution was used for calibration. All the laboratory apparatus were decontaminated by soaking in 10% v/v HNO_3 for 24 hours before analysis. Ultra-pure water with 18.2 M-ohm was used for the preparation of all solution and reagents.

2.3. Digestion Procedure

The dried fish samples were weighted for 0.5 g and digested with a mixture of 5 mL concentrated nitric acid and 2 mL of hydrogen peroxide in a microwave digestion system (Multiwave 3000, Anton Paar). The power profile for the digestion process was as follows: During the first phase, the power of the digestion system was set at 600 W, followed by 5 minutes ramping and holding, respectively. At the second phase, the power was increased to 1400 W followed by 5 minutes ramping and 10 minutes holding time. Finally, in the third phase, the power was turned to zero withholding time of 15 minutes. After the digestion process, samples were filtered through a 0.45 μm acid resistant membrane. The solution was transferred into a 25 ml volumetric flask and diluted with ultrapure water. The analytical reagent blanks also prepared in the same manner but without the dried fish samples [6] [28].

2.4. Heavy Metals Analysis

The heavy metals were analyzed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) ELAN 9000 (Perkin Elmer, Sciex, Canada) equipped with a Meinhard concentric quartz nebuliser, cyclonic spray chamber, nickel sampler, nickel skimmer cones and an autosampler (Perkin Elmer). The calibration curves were established using a mixed working standard solution containing 1 mg/L (Se, Cd, Pb, Cu, Zn, Sb, Sn, Cr and Mn) as described before by subsequent dilution into concentrations of 10, 40, 70 and 100 μg/L of each element, with 20 μg/L of mixed internal standard (In, Y, Ho, and Sc). The calibration curve showed linearity with a correlation coefficient of higher than 0.9995 ($r^2 > 0.9995$). Limits of detection were determined for each element by using seven replicate aliquots of the fortified reagent blank (0.2% HNO_3 + 0.05 μg/L of each element). Three times of the standard deviation of the aliquots readings were calculated to determine the detection limit and the sample analyses were conducted triplicate to ensure accuracy of the samples. The concentrations of heavy metals were converted to wet basis values in order to compare with PTWI. The formula as follows; wet weight concentration = dry wet concentration ×

(100/100 moisture percentage) [6]. The moisture content of the fish was calculated based on the study by Tee *et al.*, 1997 [29] and Nurnadia *et al.*, 2011 [30].

2.5. Quality Control

The precision of the method was evaluated by adding 20 µg/L of the standard solution of multi-elements (Se, Cd, Pb, Cu, Zn, Sb, Sn, Cr and Mn) to the fish sample. The concentration of the sample before and after the addition was measured. The recovery values of these elements were between acceptable ranges, which were within 85% to 115%. The standard reference samples (NIST SRM® 1946-Lake Superior Fish Tissue) were analyzed to ensure quality control of this analysis. The average recovery of reference standards was 90.7%.

2.6. Estimated Weekly Intake (EWI)

To prevent human health impairment by heavy metals originating from dietary sources, the Joint FAO/WHO Expert Committee on Food Additives (JECFA) assigned a PTWI [31] for total Cd, Pb, Cu, Zn and Sn that are 0.007, 0.025, 3.5, 7.0 and 14.0 mg/kg b.wt./week respectively [20] [21]. According to FAO 2009, fish consumption for an average age of Malaysian per capita is 160 g/day/person [32] [33]. The average body weight for the Malaysian population is 62 kg [34]. In order to estimate the risk of exposure from consuming fish, Estimated Weekly Intake (EWI) of elements of fish was calculated as follows [20]:

$$\text{EWI} = \frac{\text{concentration of metals}\left(\text{mg/kg, wet weight}\right)\times\text{weekly consumption}}{\text{body weight}\left(\text{kg}\right)} \quad (1)$$

2.7. Health Risk Assessment Procedure

Risk assessment is a tool to estimate the probability of health effects due to exposure to the hazard, which in this study is the exposure through consumption of fish. USEPA developed the oral reference dose (RfDs) for Se as $5E^{-3}$ mg/kg/day; Cd as $1E^{-3}$ mg/kg/day; Zn as $3E^{-1}$ mg/kg/day; Sb as $4E^{-4}$ mg/kg/day; and Mn as $1.4E^{-1}$ mg/kg/day (Risk Information System (IRIS), USEPA). There is no established reference of dose for Pb, Cu, Sn and Cr under IRIS USEPA. The health risks assessment for non-carcinogen metals were calculated based on the following equation [22] [35] [36]:

$$\text{HQ} = \frac{\text{EF}\times\text{ED}\times\text{FIR}\times\text{C}}{\text{RfD}\times\text{BW}\times\text{AT}}\times10^{-3} \quad (2)$$

where HQ is chemical-specific Hazard Quotient; EF is the exposure frequency (350 days/year); ED is the exposure duration (30 years); FIR is the fish ingestion rate (160 g/day/person); C is the metal concentration in the muscle of fishes (mg/kg wet weight); RfD is the oral reference dose (IRIS, USEPA); BW is the average adult body weight (62 kg) and AT is the average exposure time for non-carcinogen (365 days/year × number of exposure years, assuming 30 years).

A summation of the hazard quotients for all chemicals to which an individual is exposed was used to calculate the hazard index as described in following equation [35] [36]:

$$HI = HQ_{Se} + HQ_{Cd} + HQ_{Zn} + HQ_{Sb} + HQ_{Mn} \quad (3)$$

where HI is the hazard index; HQ_{Se} is the target hazard quotient for Se intake; HQ_{Cd} is the target hazard quotient for Cd intake; HQ_{Zn} is the target hazard quotient for Zn intake; HQ_{Sb} is the target hazard quotient for Sb intake; HQ_{Mn} is the target hazard quotient for Mn intake. If the HQ and HI values were greater than 1, then it is implied that there is a potential non-carcinogenic health risk related to the studied metals.

2.8. Data Analysis and Statistics

Before statistical analysis, the data was cleaned and checked for discrepancies. The non-parametric technique was chosen for analysis as the data was not normally distributed because of the presence of outliers. The median was calculated using SPSS (version 11.5 for Windows, 2002, SPSS Inc.). The median was calculated from triplicate analysis of each sample and interquartile range was calculated to show dispersion of dataset. The statistical significance of difference was assessed using Mann-Whitney's (MW) test for two groups and Kruskal-Wallis's (KW) test for three groups or more. The level of significance was designated as $p < 0.05$ (5%).

3. Results

3.1. Heavy Metals Concentration in Marine Fish Samples

A total of 296 marine fish samples were analyzed in this study. The samples included 177 samples of pelagic fish, which were classified into two families; *Carangidae* (80 samples) and *Scrombidae* (97 samples). There were 119 samples of demersal fish samples which were categorized into five families; *Lutjanidae* (24 samples), *Latidae* (14 samples), *Dasyatidae* (25 samples), *Sciaenidae* (25 samples), and *Nemipteridae* (31 samples). The size of fish from collected samples ranged between 12.0 cm (*Selaroides leptolepis*) to 142.0 cm (*Himantura uarnak*), the smallest weighed between 0.02 kg and 0.29 kg and the largest weighed between 2.26 kg and 3.04 kg (**Table 1**).

Heavy metals median concentration of nine elements (Se, Cd, Pb, Cu, Zn, Sb, Sn, Cr and Mn) from marine fish samples were summarized in **Table 2**. Results were expressed in wet weight (w/w) basis for comparison later with PTWI. Overall, the heavy metals accumulation in marine fish samples was found to be dominated by Zn followed by Sn, Se, Cu, Mn, Cr, Pb, Cd and Sb which ranged between 15.9612 mg/kg (Zn) to 0.0002 mg/kg (Sb) wet weight. Among the heavy metals studied, Zn showed the highest level of accumulation and *Decapterus macrosoma* showed the highest concentration of Zn (15.9612 mg/kg) whereas *Otolithoides biauritus* showed the lowest concentration of Zn (2.3000 mg/kg). Sb showed the lowest level of accumulation, which was ranged between 0.0048 mg/kg (*Decapterus macrosoma*) and 0.0002 mg/kg (*Selar crumenopthalmus*, *Otolithoides biauritus*, *Nemipterus tambuloides*). *Otolithoides biauritus* demonstrated the lowest concentration for all heavy metal except for Pb. The highest concentration of Cd (0.0786 mg/kg), Zn (15.9612 mg/kg) and Sb (0.0048 mg/kg) were found to be in *Decapterus macrosoma* samples. Sample *Himantura gerrardi* demonstrated the highest concentration of Pb (0.057 mg/kg) while sample *Nemipterus tambuloides* showed the highest concentration of Sn (5.717 mg/kg). The highest concentration of Se was found in *Thunnus tonggol* (1.221 mg/kg) while the highest concentration of Cu was found in *Megalaspis cordyla* (1.614 mg/kg). *Nemipterus nemurus* showed the highest concentration of Cr (0.411 mg/kg) while *Dasyatis zugei* showed the highest concentration of Mn (1.542 mg/kg).

Table 1. List of marine fish samples collected from LKIM complexes and wholesale market in Peninsular Malaysia.

No.	Groups/family/species	Common name	n	Size range (cm)	Weight range (kg)
	Pelagic fish				
	Carangidae **(80)**				
1.	*Selaroides leptolepis*	Yellowstripe scad	13	12.6 - 19.6	0.028 - 0.290
2.	*Selar boops*	Oxeye scad	3	19.0 - 24.8	0.009 - 0.212
3.	*Selar crumenopthalmus*	Bigeye scad	1	23.8	0.186
4.	*Atule mate*	Yellowtail scad	4	23.1 - 26.3	0.150 - 0.224
5.	*Caranx sexfasciatus*	Bigeye trevally	1	22.7	0.140
6.	*Seriola dumerili*	Greater amberjack	1	19.6	0.106
7.	*Decapterus kurroides*	Redtail scad	4	18.5 - 26.8	0.066 - 0.224
8.	*Decapterus muruadsi*	Round scad	7	18.1 - 36.2	0.071 - 0.294
9.	*Decapterus russelli*	Slender scad	10	16.5 - 30.1	0.052 - 0.420
10.	*Decapterus macrosoma*	Shortfin scad	1	-	-
11.	*Megalaspis cordyla*	Torpedo scad	20	22.2 - 34.3	0.101 - 0.300
12.	*Parastromateus niger*	Black pomfret	15	15.6 - 40.3	0.082 - 1.466
		Total	**80**		
	Scrombidae **(97)**				
13.	*Rastrelliger kanagurta*	Indian mackerel	13	13.4 - 24.3	0.200 - 0.360
14.	*Rastrelliger faughni*	Faughn's mackerel	6	19.0 - 21.8	0.100 - 0.180
15.	*Rastrelliger brachysoma*	Indo-Pacific mackerel	3	16.6 - 25.5	0.050 - 0.280
16.	*Scomber australasicus*	Blue mackerel	18	17.0 - 22.4	0.040 - 0.152
17.	*Scomberomorus guttatus*	Indo-Pacific king mackerel	12	29.6 - 55.5	0.176 - 1.066
18.	*Scomberomorus commerson*	Narrowbarred Spanish mackerel	14	40.1 - 85.5	0.394 - 4.550
19.	*Gymnosarda unicolor*	Dogtooth tuna	10	19.8 - 49.5	0.082 - 5.000
20.	*Sarda orientalis*	Striped bonito	6	25.5 - 48.0	0.232 - 1.600

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21.	*Thunnus tonggol*	Longtail tuna	8	17.2 - 50.0	0.082 - 1.733
22.	*Auxis thazard thazard*	Frigate tuna	2	29.6 - 31.2	0.334 - 0.412
23.	*Euthymus affinis*	Kawakawa	5	29.4 - 69.3	0.370 - 4.733
		Total	**97**		
	Demersal fish				
	Lutjanidae **(24)**				
24.	*Lutjanus argentimaculatus*	Mangrove red snapper	3	38.3 - 38.5	1.033 - 1.175
25.	*Lutjanus gibbus*	Humpback red snapper	1	20.2	0.148
26.	*Lutjanus sebae*	Emperor red snapper	11	18.1 - 62.0	0.102 - 3.300
27.	*Lutjanus malabaricus*	Malabar blood snapper	5	27.9 - 49.75	0.394 - 1.175
28.	*Lutjanus russellii*	John's snapper	4	66.0	4.050
		Total	**24**		
	Latidae **(15)**				
29.	*Lates calcarifer*	Giant sea perch	11	26.6 - 71.6	0.046 - 4.650
30.	*Psammoperca waigiensis*	Waigeu sea perch	4	34.6 - 38.3	0.396 - 0.875
		Total	**15**		
	Dasyatidae **(25)**				
31.	*Himantura gerrardi*	Sharpnose stingray	10	21.4 - 116.3	0.208 - 2.880
32.	*Neotrygon kuhlii*	Bluespotted stingray	7	45.7 - 114.0	0.510 - 4.300
33.	*Dasyatis zugei*	Pale-edged stingray	5	40.7 - 147.3	0.188 - 1.157
34.	*Himantura uarnak*	Honeycomb stingray	3	131.6 - 142.0	2.266 - 3.040
		Total	**25**		
	Sciaenidae **(25)**				
35.	*Chrysochir aureus*	Reeve's croaker	3	19.0 - 25.4	0.074 - 0.220
36.	*Otolithoides ruber*	Tigertooth croaker	6	13.0 - 24.2	0.04 - 0.113
37.	*Nibea soldado*	Soldier croaker	15	15.3 - 21.6	0.041 - 0.274
38.	*Otolithoides biauritus*	Bronze croaker	1	20.9	0.132
		Total	**25**		
	Nemipteridae **(31)**				
39.	*Nemipterus bathybius*	Yellowbelly threadfin bream	6	15.7 - 33.7	0.063 - 0.516
40.	*Nemipterus japonicus*	Japanese threadfin bream	11	16.9 - 29.2	0.063 - 0.212
41.	*Nemipterus furcosus*	Forktail threadfin bream	3	18.2 - 21.4	0.102 - 0.162
42.	*Nemipterus thosaporni*	Threadfin bream	4	17.0 - 24.0	0.059 - 0.210
43.	*Nemipterus tambuloides*	Fivelined threadfin bream	2	17.5 - 21.4	0.086 - 0.109
44.	*Nemipterus nematophorus*	Doublewhip threadfin bream	2	16.1 - 25.6	0.058 - 0.154
45.	*Nemipterus marginatus*	Red filament threadfin bream	2	23.0 - 25.5	0.11 - 0.24
46.	*Nemipterus nemurus*	Redspine threadfin bream	1	17.8	0.096
		Total	**31**		

Table 2. Concentration of heavy metals in marine fish sampled from LKIM complexes and wholesale market in Peninsular Malaysia.

No.	Groups/family/species	Common name	n	Concentration of heavy metals in median mg/kg, wet weight (IQR)								
				Se	Cd	Pb	Cu	Zn	Sb	Sn	Cr	Mn
	Pelagic fish											
	***Carangidae* (80)**											
1	*Selaroides leptolepis*	Yellowstripe scad	13	0.438 (0.1)	0.019 (0.0)	0.014 (0.1)	0.500 (0.9)	7.201 (1.5)	0.001 (0.0)	1.789 (3.3)	0.216 (0.6)	0.158 (0.1)
2	*Selar boops*	Oxeye scad	3	0.389 (0.0)	0.008 (0.0)	0.015 (0.0)	0.646 (0.0)	5.373 (0.0)	0.001 (0.0)	1.419 (0.0)	0.347 (0.0)	0.158 (0.0)
3	*Selar crumenopthalmus*	Bigeye scad	1	0.738 (0.0)	0.029 (0.0)	0.017 (0.0)	0.426 (0.0)	5.743 (0.0)	0.000 (0.0)	3.860 (0.0)	0.114 (0.0)	0.229 (0.0)
4	*Atule mate*	Yellowtail scad	4	0.587 (0.11)	0.007 (0.0)	0.002 (0.0)	0.924 (0.0)	8.487 (4.0)	0.000 (0.0)	1.260 (0.0)	0.264 (0.0)	0.275 (0.0)
5	*Caranx sexfasciatus*	Bigeye trevally	1	0.598 (0.0)	0.013 (0.0)	0.019 (0.0)	0.698 (0.0)	9.491 (0.0)	0.001 (0.0)	2.282 (0.0)	0.335 (0.0)	0.198 (0.0)
6	*Seriola dumerili*	Greater amberjack	1	0.376 (0.0)	0.025 (0.0)	0.049 (0.0)	0.764 (0.0)	5.299 (0.0)	0.000 (0.0)	2.971 (0.0)	0.452 (0.0)	0.255 (0.0)
7	*Decapterus kurroides*	Redtail scad	4	0.756 (0.49)	0.038 (0.1)	0.009 (0.0)	0.873 (0.1)	8.505 (5.5)	0.001 (0.0)	1.614 (5.0)	0.237 (0.2)	0.216 (0.3)
8	*Decapterus muruadsi*	Round scad	7	0.822 (0.18)	0.023 (0.1)	0.012 (0.1)	0.892 (1.1)	8.109 (3.1)	0.000 (0.0)	1.932 (3.8)	0.148 (0.2)	0.181 (0.1)
9	*Decapterus russelli*	Slender scad	10	0.998 (0.39)	0.027 (0.0)	0.012 (0.0)	1.328 (0.4)	7.352 (3.0)	0.001 (0.0)	2.260 (2.9)	0.222 (0.2)	0.223 (0.1)
10	*Decapterus macrosoma*	Shortfin scad	1	1.075 (0.0)	0.079 (0.0)	0.017 (0.0)	0.877 (0.0)	15.961 (0.0)	0.005 (0.0)	1.317 (0.0)	0.258 (0.0)	0.273 (0.0)
11	*Megalaspis cordyla*	Torpedo scad	20	0.667 (0.2)	0.023 (0.0)	0.012 (0.0)	1.614 (1.6)	7.008 (3.1)	0.001 (0.0)	2.022 (1.9)	0.270 (0.1)	0.250 (0.2)
12	*Parastromateus niger*	Black pomfret	15	0.573 (0.2)	0.015 (0.0)	0.035 (0.0)	0.349 (0.5)	5.124 (2.1)	0.001 (0.0)	1.914 (2.7)	0.230 (0.2)	0.385 (0.4)
		Total	**80**	**0.668**	**0.025**	**0.018**	**0.824**	**7.804**	**0.001**	**2.053**	**0.258**	**0.233**
	***Scrombidae* (97)**											
13	*Rastrelliger kanagurta*	Indian mackerel	13	0.793 (0.2)	0.014 (0.0)	0.033 (0.1)	0.971 (0.4)	9.082 (5.6)	0.001 (0.0)	2.465 (3.1)	0.312 (0.4)	0.222 (0.2)
14	*Rastrelliger faughni*	Faughn's mackerel	6	0.832 (0.3)	0.030 (0.1)	0.041 (0.1)	1.281 (3.1)	9.531 (3.9)	0.000 (0.0)	1.608 (3.4)	0.297 (0.4)	0.428 (1.0)
15	*Rastrelliger brachysoma*	Indo-Pacific mackerel	3	0.726 (0.0)	0.010 (0.0)	0.034 (0.0)	0.908 (0.0)	9.554 (0.0)	0.001 (0.0)	1.367 (0.0)	0.165 (0.0)	0.177 (0.0)
16	*Scomber australasicus*	Blue mackerel	18	0.895 (0.3)	0.021 (0.0)	0.021 (0.0)	0.943 (0.7)	6.500 (3.1)	0.001 (0.0)	2.122 (2.6)	0.179 (0.1)	0.204 (0.2)
17	*Scomberomorus guttatus*	Indo-Pacific king mackerel	12	0.384 (0.1)	0.003 (0.0)	0.011 (0.0)	0.330 (0.1)	4.253 (1.0)	0.001 (0.0)	2.666 (3.5)	0.143 (0.1)	0.095 (0.1)
18	*Scomberomorus commerson*	Narrowbarred Spanish mackerel	14	0.530 (0.2)	0.006 (0.0)	0.017 (0.0)	0.301 (0.5)	4.69292. 3)	0.001 (0.0)	1.358 (2.0)	0.256 (0.2)	0.112 (0.2)

Continued

19	*Gymnosarda unicolor*	Dogtooth tuna	10	0.994 (0.66)	0.014 (0.0)	0.020 (0.0)	0.936 (1.6)	7.530 (9.3)	0.001 (0.0)	1.814 (1.1)	0.218 (0.1)	0.203 (0.1)
20	*Sarda orientalis*	Striped bonito	6	0.861 (0.4)	0.014 (0.0)	0.014 (0.0)	1.084 (0.8)	7.790 (5.8)	0.001 (0.0)	2.174 (1.8)	0.236 (0.3)	0.182 (0.2)
21	*Thunnus tonggol*	Longtail tuna	8	1.221 (0.3)	0.008 (0.0)	0.012 (0.0)	1.530 (0.7)	7.784 (5.0)	0.001 (0.0)	1.629 (2.4)	0.197 (0.2)	0.194 (0.1)
22	*Auxis thazard thazard*	Frigate tuna	2	0.931 (0.0)	0.012 (0.0)	0.007 (0.0)	1.046 (0.0)	6.944 (0.0)	0.000 (0.0)	0.986 (0.0)	0.147 (0.0)	0.125 (0.0)
23	*Euthymus affinis*	Kawakawa	5	0.779 (0.52)	0.007 (0.0)	0.021 (0.0)	0.941 (0.0)	9.550 (6.1)	0.001 (0.0)	1.325 (0.0)	0.300 (0.0)	0.160 (0.0)
		Total	**97**	**0.813**	**0.013**	**0.021**	**0.934**	**7.564**	**0.001**	**1.774**	**0.223**	**0.191**
		Total (pelagic fish)	**177**	**0.738**	**0.019**	**0.019**	**0.877**	**7.690**	**0.001**	**1.920**	**0.241**	**0.213**
	Demersal fish											
	Lutjanidae **(24)**											
24	*Lutjanus argentimaculatus*	Mangrove red snapper	3	0.361 (0.0)	0.002 (0.0)	0.011 (0.0)	0.185 (0.0)	4.347 (0.0)	0.004 (0.0)	1.167 (0.0)	0.200 (0.0)	0.095 (0.0)
25	*Lutjanus gibbus*	Humpback red snapper	1	0.514 (0.0)	0.002 (0.0)	0.011 (0.0)	0.183 (0.0)	3.149 (0.0)	0.001 (0.0)	1.304 (0.0)	0.203 (0.0)	0.184 (0.0)
26	*Lutjanus sebae*	Emperor red snapper	11	0.481 (0.2)	0.006 (0.0)	0.012 (0.1)	0.218 (0.2)	2.872 (2.3)	0.000 (0.0)	1.213 (2.0)	0.122 (0.1)	0.091 (0.1)
27	*L utjanus malabaricus*	Malabar blood snapper	5	0.430 (0.28)	0.004 (0.0)	0.009 (0.0)	0.268 (0.3)	3.028 (1.4)	0.000 (0.0)	1.903 (1.6)	0.200 (0.2)	0.114 (0.1)
28	*Lutjanus russellii*	John's snapper	4	0.510 (0.0)	0.004 (0.0)	0.021 (0.0)	0.246 (0.0)	4.764 (0.0)	0.002 (0.0)	1.219 (0.0)	0.318 (0.0)	0.147 (0.0)
		Total	**24**	**0.459**	**0.004**	**0.013**	**0.220**	**3.632**	**0.001**	**1.361**	**0.208**	**0.126**
	Latidae **(14)**											
29	*Lates calcarifer*	Giant sea perch	10	0.258 (0.1)	0.003 (0.0)	0.014 (0.0)	0.216 (0.0)	4.206 (1.2)	0.000 (0.0)	1.043 (1.3)	0.203 (0.2)	0.083 (0.1)
30	*Psammoperca waigiensis*	Waigeu sea perch	4	0.434 (0.3)	0.002 (0.0)	0.012 (0.0)	0.179 (0.0)	3.406 (2.1)	0.000 (0.0)	1.051 (0.0)	0.188 (0.0)	0.077 (0.0)
		Total	**14**	**0.346**	**0.002**	**0.013**	**0.197**	**3.806**	**0.000**	**1.047**	**0.195**	**0.080**
	Dasyatidae **(25)**											
31	*Himantura gerrardi*	Sharpnose stingray	10	0.666 (0.34)	0.008 (0.0)	0.057 (0.1)	0.570 (1.1)	6.282 (3.2)	0.001 (0.0)	4.128 (5.5)	0.214 (0.2)	0.390 (1.3)
32	*Neotrygon kuhlii*	Bluespotted stingray	7	0.867 (0.8)	0.011 (0.0)	0.036 (0.1)	0.418 (0.3)	3.697 (2.5)	0.001 (0.0)	1.837 (2.0)	0.166 (0.2)	0.230 (1.5)
33	*Dasyatis zugei*	Pale-edged stingray	5	0.559 (0.12)	0.013 (0.0)	0.038 (0.1)	0.335 (0.4)	5.108 (1.8)	0.001 (0.0)	3.251 (3.1)	0.250 (0.6)	1.542 (0.8)
34	*Himantura uarnak*	Honeycomb stingray	3	0.522 (0.0)	0.007 (0.0)	0.055 (0.0)	0.274 (0.0)	4.635 (0.0)	0.002 (0.0)	3.136 (0.0)	0.282 (0.0)	0.269 (0.0)
		Total	**25**	**0.653**	**0.010**	**0.047**	**0.399**	**4.930**	**0.001**	**3.088**	**0.228**	**0.608**
	Sciaenidae **(25)**											

Continued

35	*Chrysochir aureus*	Reeve's croaker	3	0.469 (0.0)	0.002 (0.0)	0.011 (0.0)	0.218 (0.0)	4.002 (0.0)	0.001 (0.0)	2.062 (0.0)	0.230 (0.0)	0.140 (0.0)
36	*Otolithoides ruber*	Tigertooth croaker	6	0.492 (0.1)	0.004 (0.0)	0.016 (0.0)	0.290 (0.3)	4.341 (3.8)	0.001 (0.0)	3.465 (3.6)	0.220 (0.5)	0.296 (0.3)
37	*Nibea soldado*	Soldier croaker	15	0.559 (0.1)	0.005 (0.0)	0.020 (0.0)	0.333 (0.2)	4.462 (1.0)	0.001 (0.0)	3.239 (2.1)	0.210 (0.2)	0.237 (0.3)
38	*Otolithoides biauritus*	Bronze croaker	1	0.074 (0.0)	0.001 (0.0)	0.005 (0.0)	0.039 (0.0)	2.300 (0.0)	0.000 (0.0)	0.283 (0.0)	0.016 (0.0)	0.065 (0.0)
		Total	**25**	**0.398**	**0.003**	**0.013**	**0.220**	**3.776**	**0.001**	**2.262**	**0.169**	**0.184**
	***Nemipteridae* (31)**											
39	*Nemipterus bathybius*	Yellowbelly threadfin bream	6	0.544 (0.4)	0.006 (0.0)	0.011 (0.0)	0.249 (0.1)	2.875 (1.2)	0.001 (0.0)	3.256 (2.1)	0.200 (0.1)	0.208 (0.1)
40	*Nemipterus japonicus*	Japanese threadfin bream	11	0.512 (0.1)	0.016 (0.0)	0.021 (0.0)	0.261 (0.4)	2.866 (1.7)	0.001 (0.0)	3.485 (2.0)	0.277 (0.7)	0.381 (0.3)
41	*Nemipterus furcosus*	Forktail threadfin bream	3	0.543 (0.0)	0.004 (0.0)	0.013 (0.0)	0.281 (0.0)	3.143 (0.0)	0.000 (0.0)	1.554 (0.0)	0.228 (0.0)	0.217 (0.0)
42	*Nemipterus thosaporni*	Threadfin bream	4	0.478 (0.0)	0.023 (0.0)	0.028 (0.0)	0.256 (0.0)	3.516 (0.7)	0.000 (0.0)	2.251 (0.0)	0.167 (0.0)	0.290 (0.0)
43	*Nemipterus tambuloides*	Fivelined threadfin bream	2	0.575 (0.0)	0.008 (0.0)	ND	0.188 (0.0)	3.933 (0.0)	0.000 (0.0)	5.717 (0.0)	0.132 (0.0)	0.280 (0.0)
44	*Nemipterus nematophorus*	Doublewhip threadfin bream	2	0.543 (0.0)	0.021 (0.0)	0.010 (0.0)	0.256 (0.0)	3.794 (0.0)	0.000 (0.0)	3.155 (0.0)	0.161 (0.0)	0.339 (0.0)
45	*Nemipterus marginatus*	Red filament threadfin bream	2	0.472 (0.0)	0.006 (0.0)	0.005 (0.0)	0.241 (0.0)	2.871 (0.0)	0.000 (0.0)	3.623 (0.0)	0.332 (0.0)	0.239 (0.0)
46	*Nemipterus nemurus*	Redspine threadfin bream	1	0.548 (0.0)	0.024 (0.0)	0.011 (0.0)	0.317 (0.0)	3.714 (0.0)	0.001 (0.0)	3.718 (0.0)	0.411 (0.0)	0.192 (0.0)
		Total	**31**	**0.527**	**0.013**	**0.012**	**0.256**	**3.339**	**0.000**	**3.345**	**0.238**	**0.268**
		Total (demersal fish)	**119**	**0.612**	**0.013**	**0.019**	**0.563**	**5.724**	**0.001**	**2.164**	**0.226**	**0.239**
		Overall (marine fish)	**296**	**0.496**	**0.008**	**0.019**	**0.262**	**3.796**	**0.001**	**2.481**	**0.214**	**0.265**

IQR: Interquartile range. ND: Not detected.

3.2. Risk Estimation

The estimated weekly intake (EWI) was presented in Table 3. The results were expressed as per unit body weight per week (ug/kg b.wt/week). Our results estimated that EWI for Cd consumption from Peninsular Malaysia ranged between 0.01 to 1.42 ug/kg b.wt/week. The estimated EWI of Cd in the study was far below the established PTWI of FAO/WHO JECFA (7 ug/kg b.wt/week). The calculated EWI of Pb from consumption of various fish species was between 0.03 and 1.02 ug/kg b.wt/week which was lower than PTWI guideline for Pb (25 ug/kg b.wt/week). The estimated EWI Cu ranged between 0.69 and 27.65 ug/kg b.wt/week, Zn ranging from 41.55 to 288.3 ug/kg b.wt/week and Sn were between 5.12 and 103.27 ug/kg b.wt/week. The results showed that the calculated EWI was below than established PTWI of Cu (3500 ug/kg b.wt/week), Zn (7000 ug/kg b.wt/week) and Sn (14,000 ug/kg b.wt/week). Therefore consumption of studied fishes was not considered to pose adverse effects to consumer based on FAO/WHO JECFA guidelines.

Table 3. Estimated weekly intake (EWI) of heavy metals from fish consumption.

No.	Groups/family/ species	Common name	EWI (ug/kg b.wt/week)								
			Se	Cd	Pb	Cu	Zn	Sb	Sn	Cr	Mn
	Pelagic fish										
	***Carangidae* (80)**										
1.	*Selaroides leptolepis*	Yellowstripe scad	7.92	0.34	0.25	9.03	130.08	0.02	32.32	3.90	2.85
2.	*Selar boops*	Oxeye scad	7.03	0.14	0.27	11.67	97.07	0.01	25.63	6.27	2.85
3.	*Selar crumenopthalmus*	Bigeye scad	13.33	0.52	0.30	7.70	103.75	0.00	69.73	2.06	4.14
4.	*Atule mate*	Yellowtail scad	10.60	0.13	0.03	16.69	153.32	0.01	22.77	4.76	4.97
5.	*Caranx sexfasciatus*	Bigeye trevally	10.80	0.23	0.35	12.60	171.45	0.01	41.22	6.06	3.57
6.	*Seriola dumerili*	Greater amberjack	6.79	0.45	0.88	13.80	95.72	0.01	53.66	8.16	4.61
7.	*Decapterus kurroides*	Redtail scad	13.66	0.69	0.16	15.77	153.65	0.01	29.15	4.28	3.91
8.	*Decapterus muruadsi*	Round scad	14.85	0.41	0.22	16.12	146.49	0.01	34.90	2.67	3.28
9.	*Decapterus russelli*	Slender scad	18.03	0.48	0.21	23.99	132.81	0.01	40.82	4.01	4.03
10.	*Decapterus macrosoma*	Shortfin scad	19.42	1.42	0.31	15.84	288.33	0.09	23.80	4.67	4.94
11.	*Megalaspis cordyla*	Torpedo scad	12.05	0.42	0.22	29.15	126.60	0.01	36.53	4.87	4.51
12.	*Parastromateus niger*	Black pomfret	10.36	0.27	0.64	6.30	92.55	0.02	34.57	4.15	6.95
	***Scrombidae* (97)**										
13.	*Rastrelliger kanagurta*	Indian mackerel	14.32	0.24	0.60	17.54	164.06	0.01	44.53	5.64	4.01
14.	*Rastrelliger faughni*	Faughn's mackerel	15.04	0.54	0.73	23.13	172.16	0.01	29.05	5.37	7.73
15.	*Rastrelliger brachysoma*	Indo-Pacific mackerel	13.12	0.19	0.61	16.39	172.59	0.01	24.70	2.98	3.19
16.	*Scomber australasicus*	Blue mackerel	16.17	0.37	0.38	17.04	117.41	0.01	38.33	3.23	3.68
17.	*Scomberomorus guttatus*	Indo-Pacific king mackerel	6.93	0.05	0.20	5.96	76.82	0.01	48.17	2.59	1.72
18.	*Scomberomorus commerson*	Narrowbarred Spanish mackerel	9.58	0.10	0.31	5.44	84.75	0.01	24.53	4.62	2.02
19.	*Gymnosarda unicolor*	Dogtooth tuna	17.95	0.24	0.35	16.91	136.02	0.01	32.77	3.95	3.67
20.	*Sarda orientalis*	Striped bonito	15.55	0.26	0.25	19.58	140.72	0.01	39.26	4.26	3.29
21.	*Thunnus tonggol*	Longtail tuna	22.05	0.15	0.21	27.65	140.61	0.01	29.42	3.55	3.51
22.	*Auxis thazard thazard*	Frigate tuna	16.81	0.21	0.13	18.90	125.44	0.01	17.81	2.65	2.26
23.	*Euthymus affinis*	Kawakawa	14.08	0.13	0.38	17.00	172.52	0.02	23.94	5.41	2.89
	Demersal fish										
	***Lutjanidae* (24)**										
24.	*Lutjanus argentimaculatus*	Mangrove red snapper	6.51	0.03	0.20	3.34	78.53	0.07	21.08	3.62	1.71
25.	*Lutjanus gibbus*	Humpback red snapper	9.28	0.04	0.20	3.30	56.89	0.01	23.55	3.66	3.32

Continued

26.	*Lutjanus sebae*	Emperor red snapper	8.69	0.11	0.22	3.94	51.88	0.01	21.92	2.20	1.65
27.	*L utjanus malabaricus*	Malabar blood snapper	7.77	0.08	0.16	4.83	54.71	0.01	34.37	3.61	2.06
28.	*Lutjanus russellii*	John's snapper	9.21	0.08	0.39	4.43	86.07	0.03	22.01	5.74	2.66
	Latidae **(15)**										
29.	*Lates calcarifer*	Giant sea perch	4.66	0.05	0.26	3.89	75.98	0.01	18.84	3.66	1.50
30.	*Psammoperca waigiensis*	Waigeu sea perch	7.84	0.03	0.22	3.24	61.53	0.01	18.98	3.40	1.39
	Dasyatidae **(25)**										
31.	*Himantura gerrardi*	Sharpnose stingray	12.03	0.14	1.02	10.29	113.47	0.02	74.57	3.87	7.04
32.	*Neotrygon kuhlii*	Bluespotted stingray	15.66	0.21	0.66	7.55	66.79	0.01	33.18	2.99	4.15
33.	*Dasyatis zugei*	Pale-edged stingray	10.09	0.24	0.69	6.04	92.27	0.02	58.73	4.52	27.86
34.	*Himantura uarnak*	Honeycomb stingray	9.42	0.13	0.99	4.94	83.72	0.04	56.65	5.09	4.85
	Sciaenidae **(25)**										
35.	*Chrysochir aureus*	Reeve's croaker	8.47	0.03	0.21	3.94	72.29	0.01	37.25	4.15	2.52
36.	*Otolithoides ruber*	Tigertooth croaker	8.88	0.07	0.29	5.24	78.41	0.01	62.59	3.97	5.35
37.	*Nibea soldado*	Soldier croaker	10.09	0.09	0.35	6.01	80.60	0.01	58.51	3.79	4.29
38.	*Otolithoides biauritus*	Bronze croaker	1.33	0.01	0.09	0.69	41.55	0.00	5.12	0.29	1.17
	Nemipteridae **(31)**										
39.	*Nemipterus bathybius*	Yellowbelly threadfin bream	9.83	0.12	0.19	4.51	51.93	0.01	58.82	3.61	3.76
40.	*Nemipterus japonicus*	Japanese threadfin bream	9.25	0.28	0.37	4.72	51.78	0.02	62.95	5.00	6.87
41.	*Nemipterus furcosus*	Forktail threadfin bream	9.80	0.08	0.23	5.08	56.78	0.01	28.07	4.11	3.92
42.	*Nemipterus thosaporni*	Threadfin bream	8.63	0.42	0.50	4.62	63.51	0.01	40.66	3.02	5.24
43.	*Nemipterus tambuloides*	Fivelined threadfin bream	10.38	0.14	NIL	3.39	71.05	0.00	103.27	2.38	5.05
44.	*Nemipterus nematophorus*	Doublewhip threadfin bream	9.81	0.37	0.18	4.62	68.53	0.01	57.00	2.90	6.12
45.	*Nemipterus marginatus*	Red filament threadfin bream	8.52	0.11	0.10	4.35	51.86	0.01	65.45	6.00	4.32
46.	*Nemipterus nemurus*	Redspine threadfin bream	9.89	0.44	0.20	5.73	67.10	0.01	67.15	7.42	3.46

PTWI values for Cd, Pb, Cu, Zn and Sn are 7, 25, 3500, 7000 and 14,000 ug/kg b.wt./week (FAO/WHO, 2004; 2011).

Table 4 showed the estimated hazard quotient (HQ) and hazard index (HI) for the consumption of fish for each species. Overall results showed the HQ and HI values were less than one indicated that exposure to the studied metals through ingestion is unlikely to result in adverse health effects. There was a significant discrepancy of HQ among different metals. HQ values of Se were the biggest ranging between 0.0365 (*Otolithoides biauritus*) and 0.6041 (*Thunnus tonggol*). *Decapterus macrosoma* demonstrated the highest HI value (0.8930) compare to other species while *Otolithoides biauritus* showed the lowest value of HI (0.0593).

Table 4. Health risk estimates for Se, Cd, Zn, Sb and Mn from consumption of marine fish samples in Peninsular Malaysia.

No.	Groups/family/species	Common name	n	HQ Se	HQ Cd	HQ Zn	HQ Sb	HQ Mn	HI
	Pelagic fish								
	***Carangidae* (80)**								
1.	*Selaroides leptolepis*	Yellowstripe scad	13	0.2169	0.0468	0.0594	0.0052	0.0028	0.3310
2.	*Selar boops*	Oxeye scad	3	0.1926	0.0190	0.0443	0.0039	0.0028	0.2625
3.	*Selar crumenopthalmus*	Bigeye scad	1	0.3651	0.0711	0.0474	0.0011	0.0041	0.4887
4.	*Atule mate*	Yellowtail scad	4	0.2905	0.0177	0.0700	0.0026	0.0049	0.3857
5.	*Caranx sexfasciatus*	Bigeye trevally	1	0.2958	0.0313	0.0783	0.0049	0.0035	0.4138
6.	*Seriola dumerili*	Greater amberjack	1	0.1859	0.0620	0.0437	0.0024	0.0045	0.2986
7.	*Decapterus kurroides*	Redtail scad	4	0.3742	0.0939	0.0702	0.0036	0.0038	0.5457
8.	*Decapterus muruadsi*	Round scad	7	0.4069	0.0557	0.0669	0.0028	0.0032	0.5355
9.	*Decapterus russelli*	Slender scad	10	0.4940	0.0664	0.0606	0.0039	0.0039	0.6289
10.	*Decapterus macrosoma*	Shortfin scad	1	0.5320	0.1946	0.1317	0.0299	0.0048	0.8930
11.	*Megalaspis cordyla*	Torpedo scad	20	0.3300	0.0571	0.0578	0.0041	0.0044	0.4534
12.	*Parastromateus niger*	Black pomfret	15	0.2838	0.0375	0.0423	0.0068	0.0068	0.3772
		Total	**80**						
	***Scrombidae* (97)**								
13.	*Rastrelliger kanagurta*	Indian mackerel	13	0.3924	0.0333	0.0749	0.0039	0.0039	0.5085
14.	*Rastrelliger faughni*	Faughn's mackerel	6	0.4120	0.0736	0.0786	0.0020	0.0076	0.5738
15.	*Rastrelliger brachysoma*	Indo-Pacific mackerel	3	0.3595	0.0255	0.0788	0.0047	0.0031	0.4716
16.	*Scomber australasicus*	Blue mackerel	18	0.4431	0.0510	0.0536	0.0033	0.0036	0.5546
17.	*Scomberomorus guttatus*	Indo-Pacific king mackerel	12	0.1899	0.0074	0.0351	0.0032	0.0017	0.2374
18.	*Scomberomorus commerson*	Narrowbarred Spanish mackerel	14	0.2625	0.0140	0.0387	0.0041	0.0020	0.3212
19.	*Gymnosarda unicolor*	Dogtooth tuna	10	0.4919	0.0334	0.0621	0.0038	0.0036	0.5948
20.	*Sarda orientalis*	striped bonito	6	0.4260	0.0352	0.0643	0.0035	0.0032	0.5322
21.	*Thunnus tonggol*	Longtail tuna	8	0.6041	0.0200	0.0642	0.0051	0.0034	0.6968
22.	*Auxis thazard thazard*	Frigate tuna	2	0.4606	0.0290	0.0573	0.0019	0.0022	0.5509
23.	*Euthymus affinis*	Kawakawa	5	0.3857	0.0180	0.0788	0.0056	0.0028	0.4909
		Total	**97**						
	Demersal fish								
	***Lutjanidae* (24)**								
24.	*Lutjanus argentimaculatus*	Mangrove red snapper	3	0.1784	0.0045	0.0359	0.0246	0.0017	0.2450
25.	*Lutjanus gibbus*	Humpback red snapper	1	0.2542	0.0055	0.0260	0.0041	0.0032	0.2930
26.	*Lutjanus sebae*	Emperor red snapper	11	0.2380	0.0144	0.0237	0.0017	0.0016	0.2795
27.	*L utjanus malabaricus*	Malabar blood snapper	5	0.2128	0.0109	0.0250	0.0023	0.0020	0.2531
28.	*Lutjanus russellii*	John's snapper	4	0.2524	0.0109	0.0393	0.0118	0.0026	0.3170
		Total	**24**						

Continued

	Latidae **(15)**								
29.	*Lates calcarifer*	Giant sea perch	11	0.1277	0.0066	0.0347	0.0025	0.0015	0.1730
30.	*Psammoperca waigiensis*	Waigeu sea perch	4	0.2148	0.0047	0.0281	0.0020	0.0014	0.2509
		Total	**15**						
	Dasyatidae **(25)**								
31.	*Himantura gerrardi*	Sharpnose stingray	10	0.3295	0.0187	0.0518	0.0062	0.0069	0.4131
32.	*Neotrygon kuhlii*	Bluespotted stingray	7	0.4291	0.0281	0.0305	0.0051	0.0041	0.4969
33.	*Dasyatis zugei*	Pale-edged stingray	5	0.2765	0.0326	0.0421	0.0061	0.0273	0.3845
34.	*Himantura uarnak*	Honeycomb stingray	3	0.2582	0.0172	0.0382	0.0139	0.0047	0.3322
		Total	**25**						
	Sciaenidae **(25)**								
35.	*Chrysochir aureus*	Reeve's croaker	3	0.2320	0.0043	0.0330	0.0032	0.0025	0.2751
36.	*Otolithoides ruber*	Tigertooth croaker	6	0.2434	0.0098	0.0358	0.0043	0.0052	0.2985
37.	*Nibea soldado*	Soldier croaker	15	0.2764	0.0127	0.0368	0.0040	0.0042	0.3342
38.	*Otolithoides biauritus*	Bronze croaker	1	0.0365	0.0017	0.0190	0.0009	0.0011	0.0593
		Total	**25**						
	Nemipteridae **(31)**								
39.	*Nemipterus bathybius*	Yellowbelly threadfin bream	6	0.2693	0.0159	0.0237	0.0032	0.0037	0.3157
40.	*Nemipterus japonicus*	Japanese threadfin bream	11	0.2533	0.0386	0.0236	0.0055	0.0067	0.3277
41.	*Nemipterus furcosus*	Forktail threadfin bream	3	0.2686	0.0104	0.0259	0.0027	0.0038	0.3115
42.	*Nemipterus thosaporni*	Threadfin bream	4	0.2364	0.0572	0.0290	0.0024	0.0051	0.3302
43.	*Nemipterus tambuloides*	Fivelined threadfin bream	2	0.2845	0.0186	0.0324	0.0012	0.0049	0.3417
44.	*Nemipterus nematophorus*	Doublewhip threadfin bream	2	0.2688	0.0507	0.0313	0.0028	0.0060	0.3595
45.	*Nemipterus marginatus*	Red filament threadfin bream	2	0.2335	0.0146	0.0237	0.0024	0.0042	0.2785
46.	*Nemipterus nemurus*	Redspine threadfin bream	1	0.2711	0.0599	0.0306	0.0039	0.0034	0.3689
		Total	**31**						

HQ - hazard quotient; HI - hazard index.

Significant variation of heavy metals concentrations, HQ and HI values for different factors were presented in Table 5. The median concentration of Cu, Se, Cd and Zn in pelagic fish were significantly higher compared to demersal fish ($p < 0.05$). Pb and Mn levels were significantly higher in herbivorous compared to the omnivorous and carnivorous (Pb, $p = 0.001$; Mn, $p < 0.05$). While Zn level was significantly higher ($p = 0.014$) in omnivorous compared to other feeding habits. Among family group, Pb and Mn levels were found to be higher in *Dasyatidae* compared to other family groups. Level of Se was higher in *Scrombidae;* Cu, Cd and Zn levels were higher in *Carangidae;* Sn level was higher in *Sciaenidae* compared to other family groups. Meanwhile, Cr and Sb levels showed no

Table 5. Comparison of heavy metals concentration (median; mg/kg, wet weight) and health risk estimates for marine fish at different factors.

Factors		Pb	Cu	Sn	Cr	Se		Cd		Zn		Sb		Mn		HI
		median	median	median	median	median	HQ	median	HQ	median	HQ	median	HQ	median	HQ	
Habitats	Pelagic	0.017	0.908	1.750	0.224	0.702	0.348	0.015	0.037	7.167	0.059	6.1E-04	3.8E-03	0.205	3.6E-03	0.451
	Demersal	0.018	0.269	2.278	0.203	0.511	0.253	0.006	0.016	4.019	0.033	6.5E-04	4.0E-03	0.217	3.8E-03	0.309
	p-value	0.356	0.000*	0.103	0.133	0.000*		0.000*		0.000*		5.5E-01		0.888		
Feeding habits	Herbivorous	0.034	0.417	1.721	0.229	0.573	0.284	0.015	0.037	5.298	0.044	7.7E-04	4.8E-03	0.325	5.8E-03	0.375
	Omnivorous	0.018	0.631	1.808	0.230	0.556	0.275	0.012	0.030	6.762	0.056	7.2E-04	4.4E-03	0.216	3.8E-03	0.369
	Carnivorous	0.016	0.625	1.865	0.204	0.594	0.294	0.009	0.023	4.951	0.041	5.7E-04	3.5E-03	0.193	3.4E-03	0.364
	p-value	0.001*	0.722	0.471	0.186	0.887		0.069		0.014*		1.4E-01		0.000*		
Family	Carangidae	0.016	1.046	1.674	0.248	0.621	0.307	0.021	0.051	7.167	0.059	6.4E-04	4.0E-03	0.229	4.1E-03	0.426
	Scrombidae	0.017	0.901	1.766	0.204	0.771	0.382	0.010	0.025	6.528	0.054	5.7E-04	3.6E-03	0.177	3.1E-03	0.467
	Lutjanidae	0.011	0.186	1.261	0.181	0.473	0.234	0.004	0.011	3.145	0.026	6.6E-04	4.1E-03	0.103	1.8E-03	0.277
	Latidae	0.012	0.191	1.013	0.197	0.294	0.145	0.002	0.006	3.848	0.032	3.2E-04	2.0E-03	0.080	1.4E-03	0.186
	Dasyatidae	0.050	0.392	2.993	0.213	0.644	0.319	0.012	0.029	5.269	0.043	9.7E-04	6.0E-03	0.355	6.3E-03	0.403
	Sciaenidae	0.017	0.329	3.073	0.220	0.543	0.269	0.004	0.011	4.451	0.037	6.4E-04	4.0E-03	0.237	4.2E-03	0.325
	Nemipteridae	0.011	0.279	2.755	0.223	0.516	0.256	0.008	0.020	3.236	0.027	4.5E-04	2.8E-03	0.275	4.9E-03	0.310
	p-value	0.000*	0.000*	0.000*	0.063	0.000*		0.000*		0.000*		7.5E-02		0.000*		
Origin	Local	0.017	0.642	1.865	0.220	0.586	0.290	0.011	0.027	5.402	0.045	6.5E-04	4.0E-03	0.210	3.7E-03	0.369
	Import	0.024	0.386	1.557	0.236	0.579	0.287	0.015	0.038	5.733	0.047	6.6E-04	4.1E-03	0.249	4.4E-03	0.380
	p-value	0.375	0.275	0.225	0.642	0.372		0.528		0.893		9.5E-01		0.118		
Coastal	West coast	0.016	0.555	1.598	0.192	0.552	0.273	0.010	0.025	5.122	0.042	6.8E-04	4.2E-03	0.210	3.7E-03	0.348
	East coast	0.018	0.563	1.921	0.226	0.624	0.309	0.011	0.027	5.698	0.047	5.5E-04	3.4E-03	0.204	3.6E-03	0.390
	South	0.015	0.707	2.540	0.243	0.567	0.281	0.012	0.030	6.380	0.053	5.7E-04	3.5E-03	0.212	3.7E-03	0.371
	p-value	0.380	0.780	0.414	0.002*	0.044*		0.320		0.236		0.022*		0.856		
Sampling points	LKIM fish landing complexes	0.017	0.500	1.756	0.201	0.611	0.302	0.010	0.026	5.568	0.046	6.5E-04	4.0E-03	0.205	3.6E-03	0.382
	Wholesale wet market	0.018	0.646	1.864	0.226	0.562	0.278	0.010	0.026	5.273	0.043	6.3E-04	3.9E-03	0.209	3.7E-03	0.355
	p-value	0.798	0.025*	0.000*	0.084	0.005*		0.000*		0.325		1.0E-01		0.132		
Sampling locations	Selayang	0.022	0.915	1.553	0.222	0.508	0.251	0.007	0.017	5.473	0.045	6.0E-04	3.7E-03	0.198	3.5E-03	0.321
	Klang	0.017	0.333	1.520	0.209	0.358	0.177	0.002	0.005	4.361	0.036	8.2E-04	5.1E-03	0.134	2.4E-03	0.225
	Kuala Pari	0.017	0.574	1.865	0.225	0.551	0.273	0.011	0.027	4.673	0.039	5.4E-04	3.3E-03	0.182	3.2E-03	0.345
	Bukit Mertajam	0.014	0.446	1.963	0.230	0.564	0.279	0.013	0.032	5.530	0.046	6.4E-04	4.0E-03	0.259	4.6E-03	0.365
	Kuala Perlis	0.196	0.467	2.631	0.259	0.591	0.292	0.013	0.033	4.906	0.040	9.8E-04	6.1E-03	0.217	3.8E-03	0.376
	Mergong	0.018	0.836	2.693	0.229	0.660	0.326	0.014	0.035	5.950	0.049	7.6E-04	4.7E-03	0.263	4.7E-03	0.420
	Kuala Besar	0.020	0.346	1.293	0.203	0.646	0.320	0.007	0.018	6.068	0.050	6.2E-04	3.8E-03	0.241	4.3E-03	0.396
	Pandan	0.015	0.707	2.540	0.243	0.567	0.281	0.012	0.030	6.380	0.053	5.7E-04	3.5E-03	0.212	3.7E-03	0.371

Continued

	Kuantan	0.015	0.467	3.910	0.190	0.614	0.304	0.015	0.037	5.276	0.044	5.7E-04	3.5E-03	0.178	3.1E-03	0.391
	Chendering	0.017	0.901	1.520	0.198	0.711	0.352	0.008	0.021	6.107	0.050	5.6E-04	3.5E-03	0.177	3.1E-03	0.430
	Pulau Kambing	0.014	0.692	1.304	0.161	0.542	0.268	0.011	0.028	5.574	0.046	3.4E-04	2.1E-03	0.205	3.6E-03	0.348
	p-value	0.798	0.025*	0.000*	0.084	0.005*		0.000*		0.325		1.0E-01		0.132		
Body length of fish	Body length < 20 cm	0.017	0.764	1.661	0.227	0.620	0.307	0.015	0.037	5.562	0.046	5.5E-04	3.4E-03	0.202	3.6E-03	0.396
	Body length ≥ 20 cm	0.017	0.496	2.008	0.210	0.562	0.278	0.010	0.024	5.108	0.042	6.7E-04	4.1E-03	0.208	3.7E-03	0.352
	p-value	0.746	0.173	0.661	0.726	0.127		0.025*		0.151		0.159		0.919		

*Significant different ($p < 0.05$).

significant difference between the family group. No significant differences were shown for heavy metals level between local and imported fish ($p > 0.05$). The coastal region showed significant differences for Cr, Se and Sb levels ($p < 0.05$). The highest concentrations of Cr were found on the south coast, Se in east coast while Sb in the west coast. The concentration of Cu, Sn, Se and Cd showed significant different ($p < 0.05$) between fish landing complexes and wholesale wet market. The levels of Cu, Sn, Se and Cd. Sn and Cd were found to be higher in Kuantan compared to other sampling location. Cu levels were higher from Selayang, and Se levels were higher from Chendering compared to other locations. Only Cd level was found significantly different ($p = 0.025$) for smaller fish compared to bigger fish.

4. Discussion

4.1. Evaluation of Heavy Metals Concentration in Marine Fishes

Study on heavy metal in fish has been reported in many studies in Malaysia. However, most of the study focused on the specific location, certain heavy metal and particular fish species. Up to our knowledge, this is first publishing in Malaysia with a high number of samples, representing each state throughout Peninsular Malaysia, and covered nine elements of heavy metals. The results indicated that Zn was the most abundant metal in the fish samples. Even though Zn is essential for human, excessive amount could cause a severe health problem. It is quite interesting to discuss on this topic regarding its source, safe daily intake and health risk of zinc exposure through consumption of fish. The data also showed that there were interspecific differences in heavy metals level for all metals. This paper discussed the differences based on several factors, *i.e.*, habitats, feeding habits, family, origin, coastal area, sampling points, sampling location and body length of fish. Each of these factors is discussed below.

Results of this study demonstrated Zn is the most accumulated metals in fish sample coincided with results reported in several studies conducted in Malaysia [9] [25] [26] [27] [37], which conducted the study in 6 coastal areas in Peninsular Malaysia found that Zn concentration in fish muscle relatively high among the studied elements (26.8 ug/g dry wt.). The study conducted by Bashir *et al.*, 2013 [9] reported Zn was the highest metal concentration in two fish species, namely *Arius thalassinus* and *Johnius belangeri*, ranged between 30.21 to 13.12 ug/g dry weights. Fathi *et al.*, 2013 [37] did a study in the eastern coast of Malaysia, recorded the highest mean concentration of Zn in *Arius thalassinus* (35.4 ug/g dry wt.), and the lowest mean concentration of Zn was in *Megalaspis cordyla* (17.54 ug/g dry wt.). Zn concentration in Ong *et al.*, 2016 [27] study was lower compared to our study, ranged between 11.172 ug/g dry wt. (*Thunnus sp.*) to 5.861 ug/g dry wt. (*Nemipterus sp.*). While Kamaruzzaman *et al.*, 2010 [26] study showed Zn range between 12 ug/g dry wt. (*Selaroides leptolepis*) to 25 ug/g dry wt. (*Rastrelliger kanagurta*) nearly equivalent to our study. The results indicated that bioaccumulation of Zn from water to muscle of fish is higher compared to other metals [27]. The source of Zn in natural water mostly from rock weathering process or human activities such as wastes water discharges from industrial. Even though Zn is an essential element for the human, higher concentration of Zn could cause health problems such as skin annoyances, stomach cramps, anaemia, vomiting and nausea. High levels of Zn could also cause damage to the pancreas and disturb the protein metabolism, and cause arteriosclerosis [38]. This study showed that *Decapterus macrosoma* recorded the highest concentration of Zn (63.013 ug/g dry wt.) and Cd (0.310 ug/g dry wt.). However, the levels were lower compared to a study conducted by Khalaf *et al.*, 2012 [3] (Zn 94.57 ug/g, Cd 2.32 ug/g dry wt.). Agusa *et al.*, 2005 [25], reported the much lower result of Zn (29.1 ug/g dry wt.) and Cd (0.162 ug/g dry wt.) in *Decapterus macrosoma* sample. Elements such as Pb, Cd, and Cr were subject to many studies because of their toxicity [25] [39]. Pb is other known significant contaminants in the environment and occurs naturally in soils, sediments and hydrosphere. Pb is also widely used in industries which may contribute to pollution in the environment [7]. Cd levels in this study were significantly high in Kuantan area. Kuantan is an urban area and situated near to petrochemical industries, which might contribute to Cd pollution in the coastal area [40]. Burning of fossil fuels and municipal waste are known to be the largest sources of Cd release to the environment [38].

4.2. Health Risk Assessment

Generally, the EWIs obtained from this study did not exceed the standard PTWIs recommended by JEFCA for Cd, Pb, Cu, Zn and Sn. Nevertheless, the EWI results from our study were higher compared to study conducted by Zaza *et al.*, 2015 [21] in Italy, where EWI for Cd and Pb were 0.33 ug/kg/week and 0.49 ug/kg/week respectively. The study by Peycheva *et al.*, 2016 [20] in Bulgaria reported that the EWI of Cu were ranged between 0.480 to 1.279 ug/kg/week, which is about 25% lower than our study. While the EWI of Zn demonstrates significantly lower than our study (7.334 - 15.983 ug/kg/week). The calculated HQ and HI in this study demonstrated that HQ values were lower than 1, which implied that fish consumption from Peninsular Malaysia has low non-cancer risk towards the human. Similar to the findings by Storelli *et al.*, 2008 [2] showed HQ values lower than 1 for Cd. However, the values ranges were much lower compared to our study (HQ; 0.01 to 0.04). The study by Peycheva *et al.*, 2016 [20] also demonstrated that their HQ values for Zn (0.0005 to 0.0010) were lower compared to our study. Although the values of HQ and HI were much lesser than 1, the consumer should consider the daily intake of fish to ensure safe consumption of fish.

5. Conclusion

This study assessed the concentration of nine heavy metals in 46 species of commonly consumed marine fish in Peninsular Malaysia. The obtained data provided comprehensive information as a baseline reference for future studies concerning heavy metals contaminations in marine fish for the country. The results show that different heavy metals demonstrate different accumulation rates in different species. Further study on physiological and ecological factors is suggested to better understand the factors affecting the accumulation of heavy metal in fish species. Health risk assessment shows that the values for HQ and HI were lower than one, suggesting that these pollutants possibly pose a low non-cancer risk to the population. Even though the EWI of the population was lower than PTWI levels, the excessive consumption of fish could lead to adverse effects on human health. It is recommended that regular monitoring of heavy metal contamination of fish species should be carried out to ascertain the safety of consumption of fish.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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