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RESEARCH ARTICLE

Risk assessment of heavy metals in marine fish and seafood from Kedah and Selangor coastal regions of Malaysia: a high-risk health concern for consumers

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Abstract

The heavy metals namely Fe, As, Cu, Cd, and Pb were investigated in two marine fishes silver pomfret (*Pampus argentus*) and torpedo scad (*Megalaspis cordyla*), and three seafoods sibogae squid (*Loligo sibogae*), Indian white prawn (*Fenneropenaeus indicus*), and mud crab (*Scylla serrata*) by using inductively coupled plasma spectrophotometer (ICP-MS) from two renowned fish harvesting coastal area of Malaysia named as Kedah and Selangor. Among the target heavy metals, highest mean concentration of As and Fe were found in *Scylla serrata* (72.14±7.77 μg/g) in Kedah and *Megalaspis cordyla* (149.40±2.15 μg/g) in Selangor. Pearson's correlation results showed As-Fe-Cd-Cu originated from the same source. Maximum estimated daily intake (EDI) values of *Scylla serrata* were found 175.25 μg/g/day and 100.81 μg/g/day for child in both Kedah and Selangor areas respectively. Hazard quotient (HQ) and hazard index (HI) results revealed that local consumers of Kedah and Selangor will face high chronic risk if they consume *Scylla serrata*, *Fenneropenaeus indicus*, and *Megalaspis cordyla* on regular basis in their diet. Carcinogenic risk results suggested that all the studied species pose very high risk of cancer occurrences to the consumers in both areas. Therefore, it could be recommended that consumers should be aware when they are consuming these marine species since they can pose serious health risk associated with prolonged consumption.

Keywords Heavy metal concentration · Marine fishes and seafoods · Hazard quotients (HQ) · Hazard index (HI) · Carcinogenic risk (CR)

Introduction

Marine fish and seafood consumption have been steadily increased over the last decades worldwide due to its health-promoting benefits (Rak et al. 2020; He et al. 2010). Nutritionists considered marine fish and shellfish species as a vital source of high-quality proteins (17% animal protein of which 6% constitute total human intake), minerals, and essential fatty acids like omega-3 (Salam et al. 2019; Guérin et al. 2011; Ersoy and Çelik 2010; Zalloua et al. 2007). However, on the contrary side of these health benefits of eating marine species, trace elemental contamination in marine fish and seafood create potential health effects particularly to the frequent marine species consumers (Domingo 2007; Martorell et al. 2011; Rajeshkumar et al. 2018). Toxicologists stated that marine fish species (salmon, chinook, etc.) and seafoods (squid, prawn, etc.) are some of the primary vectors of toxic substances like heavy metals (Guérin et al. 2011). Due to natural and anthropogenic emissions like industrial, agricultural, and mining activities,

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heavy metals have been considered as toxic pollutants that are assimilated and bioaccumulated in marine species, creating a potential health risk to the consumers (Ersoy and Çelik 2010; Sarmiento et al. 2011). The pathway of heavy metal contamination in the marine ecosystem is like the following order: industry-atmosphere-soil-water-phytoplankton-zooplankton-fish-human. Marine species can be weighted by heavy metals through respiration via gills, adsorption, and ingestion and eventually to the human body by oral intake (Mendil et al. 2010). In Malaysia, population density is very high in the coastal area; increased urbanization, petroleum industries, tourism, and abnormal precipitation as well as other business activities have posed numerous environmental and ecological imbalances like beach erosion, resource depletion, environmental degradation, and destruction of natural habitats (Cicin-Sain and Knecht 1998; Alina et al. 2012). Heavy metal pollution creates even worse conditions by bioaccumulation and biomagnification occurrences in marine fish species and seafoods of Malaysian coastal areas (Aweng et al. 2020; Alina et al. 2012; Kannan et al. 2007; Chary et al. 2008; Ahmad et al. 2016; Salam et al. 2019). These biological processes tend to create the metallic concentration normal to a toxic level in marine species and consequently to human beings. Several studies claimed that the persistent nature of heavy metal poses long-term effects, even the discharges are stopped (Rosli et al. 2018; Sharif et al. 2016; Hossen et al. 2015; Tavares and Carvalho 1992).

Metals may react with diffusing ligands and macromolecules that create bioaccumulation and biomagnification incidence in the marine food chain which become persistent in the environment creating anomalies in consumer metabolism. The availability of Fe concentration in the ocean is not rich when compared with other elements. The major source of Fe in the marine environment are mainly diverse population of phytoplankton like photosynthetic microalgae, cyanobacteria, and organic matter chelation from sediment (Rue and Bruland 1995). Presence of Cu in marine species might be originated from both human and natural sources. Some of the anthropogenic sources are mining, refining, and coal-based industries that may leach to the environment through direct deposition to the aquatic body and ultimately to the sea (CCREM 1987). As is a ubiquitous element with metalloid properties. As enters the marine environment both from natural and artificial diffuse. Natural sources of As are like igneous and sedimentary rocks (Tourtelot et al. 1960; Gulbrandsen 1966). Pb contamination in marine species may be attributed to atmospheric deposition, Pb mineralization, metal processing and manufacturing, sewage, sludge, petroleum burning, etc. (Renberg et al. 2000; Nriagu and Pacyna 1988; WHO 1995). Weathering and sedimental erosion, non-ferrous metal mines, smelting of non-ferrous metal ores, and manufacture of phosphate fertilizer can be responsible for Cd level in the marine environment (Nriagu and Pacyna 1988; Johnson and Eaton 1980; GESAMP 1997).

Several analytical methods have been established for the analysis of trace metals in food including marine fish and seafood. Among the analytical methods, the ion coupled plasma–mass spectrometry (ICP-MS) method easily determines the heavy metals in marine fish and seafood species. The main advantages of ICP-MS over FAAS (flame atomic absorption spectrometry), GF-AAS (graphite furnace atomic absorption spectrometry), and ICP-AES (inductively coupled plasma–atomic emission spectrometry) are that ICP-MS can detect multi-element at a time. It also has a low detection limit, wide linear range, simpler spectral interpretation, and fewer matrix interferences (Nardi et al. 2009). Considering the public health and food safety aspects, quantification of heavy metal concentration and evaluation of risk assessment in marine fish and seafood have become a great concern. Health risk assessment can be defined as the process of determining the occurrence probability of any given magnitude of adverse health effects over a specified time period on the basis of hazardous chemical exposure (USEPA 2009). Some studies claimed that elevated concentrations of As, Cu, Cd, and Pb were detected in marine fish (*Megalapis cordyla*) and seafood species (*Amusium pleuronectes* and *Polymesoda expansa*) in local fish markets at Kudat area in Sabah and Pantai Remis area and Kampung Pasir area in Malaysia (Rosli et al. 2018; Sharif et al. 2016; Hossen et al. 2015). To the best of our knowledge, there was no study conducted in Kedah and Selangor coastal regions of Malaysia facing towards the South China Sea to look at the heavy metals' concentration in marine species and quantify the public health hazard status of local consumers. Therefore, the main objectives of this study were set to determine heavy metal concentrations in studied marine fish and seafood species and the health risk assessment like hazard quotient (HQ), hazard index (HI), and carcinogenic risk (CR) vulnerability for consumers, which provides recommendation for local consumers whether they are below or at risk level for chronic or acute exposure of heavy metals prior to further step of risk management.

Materials and methods

Sampling site

The study was conducted in two coastal regions of Malaysia that are renowned for marine fish harvesting area. These coastal regions are facing towards the South China Sea. Consequently, the pollution phenomenon is a prime concern for ensuring the sound health of the residents in these areas. Thus, two sampling sites were selected at Kuala Kedah in Kedah and Tanjung Sepat, Hulu Langat in Selangor, Malaysia (Fig. 1). The geographical coordinates of Kuala

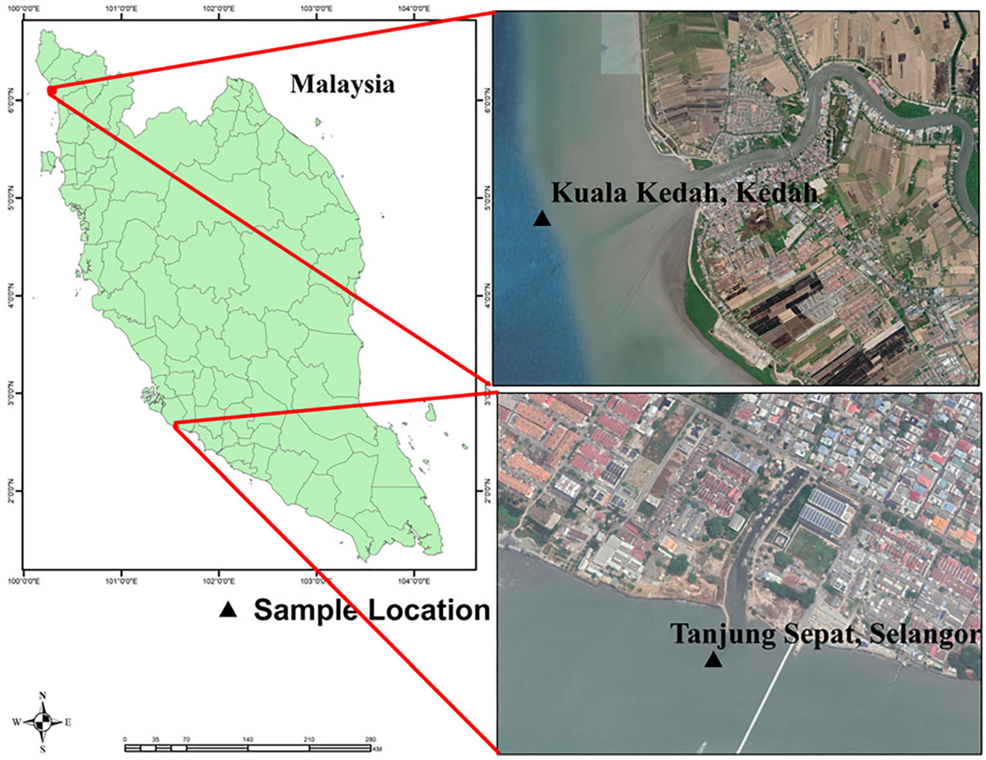

Fig. 1 Location of marine fish and seafood sample collection point at Kedah and Selangor areas of Malaysia

Kedah are 6° 6′ 0″ N and 100° 18′ 0″ E. This area is popular for catching fish that meets the Andaman Sea and the strait of Melaka. Again, Tanjung Sepat Selangor is situated in 2° 39′ 28″ N and 101° 33′ 49″ E. This area was also primarily known as fishing town and near to the straits of Melaka.

Sample preparation

Physical features of marine species like habitat, feeding, weight, length, and number of sample size of each species from each area are placed in Table 1. The samples were thawed and washed thoroughly with tap water before dissection. Using a sterilized knife, the collected marine species were cut into smaller pieces and stored at −20° C for 24 h in a glass bottle (Kamaruzzaman et al. 2011). Then, these samples were dried at −47° C for 24 h by a freeze dryer and blended homogeneously into powdered form and packed in a polythene bag (Kumar and Achyuthan 2007).

Sample extraction

Approximately 0.5 g of prepared dry samples placed in 50-mL beaker and analytical grade (Merck, Darmstadt, Germany), 65% concentrated HNO_3 (6 mL), and 30% H_2O_2 (2 mL) were added into it. Then, these beakers were heated for 2 h at 60° C to ensure complete digestion of all organic matters (Chi et al. 2007). After cooling down, these digested solutions were filtered through 0.45-μm Whatman filter paper to a falcon tube. The filtrates were then made up to 30 mL by adding Milli-Q deionized water (Jamil et al. 2014). After this, 1 mL solution from the filtrate was again transferred into a test tube and diluted for up to 10 mL by Milli-Q deionized water (Taweel et al. 2013).

Table 1 List of samples with narrow range of weight and length

Local name	Common name	Scientific name	Habitat	Feeding	Number of species sampled (each area)	Weight (g) (min–max)	Length (cm) (min–max)
Bawal putih	Silver pomfret	*Pampus argenteus*	Pelagic	Omnivores	8	90–120	15–18
Cencaru	Torpedo scad	*Megalaspis cordyla*	Pelagic	Carnivores	7	120–150	28–30
Sotong jarum	Sibogae squid	*Loligo sibogae*	Neritic	Carnivores	14	7–9	8–10
Udang putih	Indian white prawn	*Fenneropenaeus indicus*	Demersal	Omnivores	14	10–13	7–9
Ketam bangkang	Mud crab	*Scylla serrata*	Neritic	Omnivores	10	50–70	10–12

Instrumentation and quality control

Total five heavy metals Cd, Fe, Cu, As, and Pb were measured by inductively coupled plasma–mass spectrometry (ICP-MS) (ELAN 9000, Perkin Elmer ICP-MS, USA) at Nuclear Malaysia Center, Selangor for speciation. The precision of this applied analytical method was validated through accurate analysis of standard reference material (SRM 2976, freeze-dried muscle tissue, National Institute of Standards and Technology, NIST, USA). The average recovery was 96.5%, 103.7%, 105.1%, 104.9%, and 105% for Fe, Cu, As, Cd, and Pb respectively.

Health risk assessment

To determine the human health risk associated with heavy metal contamination of marine species inhabited in Kedah and Selangor area, estimated daily intake (EDI), hazard quotient (HQ), hazard index (HI), and carcinogenic risk (CR) were calculated for both adult and child.

Estimated daily intake (EDI)

The EDI of trace metals in marine species depends on metal concentration and daily consumption rate as well as the average body weight. EDI was calculated by the following Eq. 1 for both areas (Salam et al. 2019).

$$\mathrm{EDI} = \text{metal concentration} \times \text{consumption rate}/\text{body weight} \quad (1)$$

Here, the consumption rates of marine species for adults and children are 169 g/day and 85 g/day respectively. The considered body weight for an adult was 70 kg and for a child was 35 kg.

Chronic risk estimation

Health risks of adult and child due to marine species intake were determined in relation to its chronic effects based on the following Eq. 2 (Bortey-Sam et al. 2015).

$$\mathrm{HQ} = \mathrm{EDI}/\mathrm{RfD} \quad (2)$$

Here, HQ stands for the hazard quotient and RfD for the oral reference dose. RfDs of Fe, Cu, As, Cd, and Pb are 70, 40, 30, 10, and 4 μg/kg/day respectively (USEPA 2010).

When considering different elements, HQ can be combined to form hazard index (HI) that is shown in Eq. 3.

$$\mathrm{HI} = \mathrm{HQ}_1 + \mathrm{HQ}_2 + \mathrm{HQ}_3 + \ldots\ldots \mathrm{HQ}_n \quad (3)$$

If the calculated HQ/HI values exceed 1, there could be a potential chronic risk to human health. For example, HQ/HI $\geq 0.1 < 1$ = low, HQ/HI $\geq 1 < 4$ = medium, and HQ/HI ≥ 4 = high (USEPA 1999).

Carcinogenic risk assessment

Carcinogenic risks for adult and child due to potential risk on individual developing cancer over a lifetime were calculated by the following Eq. 4 (USEPA 2006).

$$\mathrm{CR} = \mathrm{EFr} \times \mathrm{ED} \times \mathrm{EDI} \times \mathrm{CSF}_0 \times 10^{-3}/\mathrm{AT} \quad (4)$$

Here, EFr = exposure frequency (350 days/year), ED = exposure duration (30 years), AT = average time for carcinogens (365 days/year×70 years), CSF_0 = oral carcinogenic slope factor (USEPA 2010). CSF_0 for As, Cd, and Pb are 1500, 380, and 8.5×10^{-3} μg/kg/day respectively (OEHHA 2009; USEPA 2015).

Statistical analysis

The data of the present study was analyzed by using the statistical package for the social sciences (SPSS) software version 20. The correlation of different heavy metals is calculated using the $p<0.05$ value. The data are expressed as mean ± standard deviation (SD) and calculated by using Microsoft Excel 2010.

Results and discussion

Heavy metal concentration in marine fishes and seafoods

Mean concentrations (μg/g) of Fe, Cu, As, Cd, and Pb were determined for *Pampus argenteus, Megalaspis cordyla*, *Loligo sibogae*, *Fenneropenaeus indicus*, and *Scylla serrata* in both Kedah and Selangor area which are presented in Table 2. The calculated mean concentrations were also compared with FAO/WHO (1984) standard and the Malaysian Food Regulation (1985). In the coastal area of Kedah, mean Cu and Cd concentrations (μg/g) were found higher than both standards in *Loligo sibogae* (Cu: 11.35 ±0.86, Cd: 0.80±0.02), *Fenneropenaeus indicus* (Cu: 25.37 ±0.62, Cd: 0.80±0.01), and *Scylla serrate* (Cu: 34.00±2.80, Cd: 5.11±0.62). High Pb concentration 1.93±0.90 μg/g was found in *Fenneropenaeus indicus* that exceeded the FAO/WHO (1984) standard. Mean As concentrations (μg/g) were found to be of higher amounts in all studied species that crossed both the standard limit. Therefore, in Table 2, the Kedah area suggested that maximum mean concentration (μg/g) of Fe (60.59±3.44), Cu (34.00±2.80), As (72.14 ±7.77), and Cd (5.11±0.62) were found in seafood *Scylla serrata*.

The maximum mean concentration of Pb (μg/g) was found in seafood *Fenneropenaeus indicus* (1.93±0.90). Again, considering Selangor area mean concentration of Cu (μg/g) was greater than FAO/WHO 1984 standard found in *Megalaspis cordyla* (25.69±2.04), *Loligo sibogae* (21.01±6.03), *Fenneropenaeus indicus* (12.70±0.23), and in *Scylla serrata* (14.83±0.12). The elevated mean concentration of Cd (μg/g) compared with FAO/WHO 1984 was found in *Megalaspis cordyla* (0.43±0.01), *Loligo sibogae* (0.471±0.01), and in *Scylla serrata* (0.97±0.02) while the elevated mean concentration of Pb (μg/g) was found in *Megalaspis cordyla* (1.64 ±0.53) and *Fenneropenaeus indicus* (2.83±0.23). As mean concentrations (μg/g) were found beyond all standards in all the studied marine species.

In Table 2, the Selangor area depicted that the maximum mean concentrations (μg/g) of As (41.45±0.26) and Cd (0.97 ±0.02) were found in seafood *Scylla serrata* while the maximum mean concentrations (μg/g) for Cu (25.69±2.04) and Fe (149.40±2.15) were found in marine fish *Megalaspis cordyla* and maximum mean Pb concentration (μg/g) was found in seafood *Fenneropenaeus indicus*.

The concentration of Fe in all studied marine fish and seafood species was found to be below the FAO/WHO 1984 standard in both studied areas. A very high concentration of Cu was found in all seafood species of the Kedah area. In the Selangar area, a high concentration of Cu was found in both marine fish and seafood except for *Pampus argentus*. Similar kinds of highly Cu and Cd contaminated different marine fish and seafood species were also determined by Bashir et al. (2013), Mustafa et al. (2013), and Kamaruzzaman et al. (2012) in different coastal areas of Malaysia. The concentration of As was found to be highly threatening in all the seafood species of the Kedah area while a very high concentration of As was found to be highly threatening in all the studied samples of the Selangar area. Again, an elevated concentration of Cd was found for all species in Kedah whereas one marine fish (*Megalaspis cordyla*) and two seafood species (*Loligo sibagae* and *Scylla serrata*) exceeded the FAO/WHO 1984 standard. The elevated concentration of Pb was found significantly for *Fenneropenaeus indicus* in both Kedah and Selangor. *Megalaspis cordyla* fish in the Selangor area also showed elevated Pb concentration. The result of our research is similar to the findings of Kamaruzzaman et al. (2012) who stated that the high concentration of Pb in *Scylla serrata* due to crab shell has a high tendency to accumulate metal while Mustafa et al. (2013) found a low concentration of Pb in *Acetes* shrimp that could occur due to the variation of sampling time.

High concentrations of heavy metals in marine food species pose serious health risks. For example, high exposure of Fe intake by humans can cause nausea, vomiting, loose stools, neurodegenerative disorders, and multi-organ failure that can lead to even death in extreme conditions (Mills and Curry 1994; Thompson et al. 2001). However, the health effects of Cu exposure are largely unknown. Some studies revealed that acute Cu exposure could induce toxic effects on gastrointestinal tract like nausea, cramping, vomiting and even lead to death, if oral exposure occurred for >1 g Cu concentration (Pandit and Bhave 1996; NRC 2000). The health effects of As are quite large. High exposure to As may lead to respiratory effects (laryngitis, bronchitis), cardiovascular effects, gastrointestinal effects (nausea, vomiting, diarrhea), kidney damage, and dermal effects as well as carcinogenic effects (Lee-Feldstein 1983; Morton and Caron 1989; Sunderman 1986). Cd is considered to be another carcinogenic hazardous element (Luevano and Damodaran 2014). Along with

Table 2 Heavy metal concentration (μg/g) found in different marine fish and seafood species collected from Kedah and Selangor areas of Malaysia

Area	Heavy metal (μg/g)	Marine fish species		Seafood species			FAO/WHO 1984	Malaysian Food and Regulations 1985
		Pampus argenteus	*Megalaspis cordyla*	*Loligo sibogae*	*Fenneropenaeus indicus*	*Scylla serrata*		
Kedah	Fe	24.09±0.17	28.57±2.43	12.99±1.30	29.19±0.47	60.59±3.44	300	-
	Cu	1.84±0.23	3.36±0.34	11.35±0.86	25.37±0.62	34.00±2.80	10	30
	As	4.17±0.17	3.54±0.65	7.40±0.02	26.28±0.74	72.14±7.77	5	1
	Cd	0.16±0.03	0.04±0.01	0.80±0.02	0.80±0.01	5.11±0.62	0.2	1
	Pb	1.49±0.01	0.81±0.08	0.81±0.14	1.93±0.90	1.46±0.46	1.5	2
Selangor	Fe	11.68±1.73	149.40±2.15	24.73±0.35	23.47±0.270	27.35±1.89	300	-
	Cu	2.07±0.99	25.69±2.04	21.01±6.03	12.70±0.23	14.83±0.12	10	30
	As	6.38±0.73	23.52±0.09	9.51±0.52	9.04±0.07	41.51±0.26	5	1
	Cd	0.03±0.01	0.43±0.01	0.471±0.04	0.09±0.01	0.97±0.02	0.2	1
	Pb	0.81±0.07	1.64±0.53	1.23±0.29	2.83±0.23	0.58±0.05	1.5	2

cancer, excessive Cd exposure can cause cough, dryness and irritation of nose, headache, dizziness, chest pain, pneumonitis, and pulmonary edema (Roy et al. 2013; Marmar and Benoff 2005). Elevated Pb contamination can cause neurological damage (cognition, decreased IQ), kidney disease, endocrine disorder, elevated blood pressure, decreased total sperm count, and increase abnormal sperm frequencies and cancer (Cecil et al. 2008; Han et al. 2008; Vaziri and Gonick 2008).

Correlation analysis

Correlation analysis was performed to delineate the extent of the relationship between the studied heavy metals in both Kedah and Selangor (Table 3) areas. In Kedah, significant correlations are observed between As-Fe (r = 0.922), As-Cu (r = 0.914) Cd-Fe (r = 0.891), and Cd-As (r = 0.971) while only Cd-As (r = 0.905) shows strong association in the Selangor area. These types of associations suggested that all these elements possessed similar origins. As-Fe-Cu-Cd is the dominating heavy metal associations that create pollution in marine water bodies of Kedah. This kind of result may be associated with the activities like excessive agricultural practice and metal industries (Rahman et al. 2018). In Selangor, As-Cd shows a strong association. This might have happened due to rapid industrialization and hazardous chemical discharges from industries into the sea. For both areas, heavy metal pollution in the sea occurred mainly because of chemical discharge from industrial activities that go directly into the river and so do to the sea that causes marine aquatic species to bioaccumulate heavy metals into their bodies and shells (Salam et al. 2019). Therefore, the consumption of fish and food species possess a high potential health risk in both areas.

Table 3 Pearson correlation between in fish and seafood samples from Kedah and Selangor areas of Malaysia

Area	Heavy metals	Fe	Cu	As	Cd	Pb
Kedah	Fe	1				
	Cu	0.731	1			
	As	0.922*	0.914*	1		
	Cd	0.891*	0.829	0.971*	1	
	Pb	0.388	0.552	0.444	0.260	1
Selangor	Fe	1				
	Cu	0.716	1			
	As	0.270	0.330	1		
	Cd	0.124	0.454	0.905*	1	
	Pb	0.156	0.186	−0.427	−0.529	1

"*" shows correlation is significant ($p<0.05$)

Estimated daily intake (EDI)

EDI was calculated and compared with permissible value (PV) for both Kedah and Selangor areas (Table 4). Permissible value for Fe, Cu, As, Cd, and Pb are 40,000 μg, 30 μg, 10 μg, 46 μg, and 210 μg respectively (FAO/WHO 2002; JECFA 2003). Results from Table 4 revealed that all the heavy metals excluding As were found to be within daily permissible consumption value percentages. Similar kinds of studies were also described by Salam et al. 2019 and Anita et al. 2010. However, As concentration in *Megalaspis cordyla* marine fish at Kedah was found below the permissible value percentages. The descending order of As contamination in studied marine species of Kedah is like *Scylla serrata* > *Fenneropenaeus indicus* > *Loligo sibogae* > *Pampus argenteus* > *Megalaspis cordyla*. Again, the descending order of As contamination in studied marine species of Selangor area is like *Scylla serrata* > *Megalaspis cordyla* > *Loligo sibogae* > *Fenneropenaeus indicus* > *Pampus argenteus.*

Chronic risk estimation

Hazard quotient (HQ) is an important tool to determine chronic health risk by establishing the hazard index (HI) (JECFA 2003). Chronic risk results of HQ and HI due to marine species consumption by adults and children for both Kedah and Selangor areas are displayed in Table 5. The following order is found in respect of HQ (>1) in Kedah for both adults and children—Pb>As>Fe>Cd>Cu. For Selangor, the HQ (>1) order is followed by Fe >As>Pb>Cu>Cd for both adults and children. A similar kind of investigation was also done by Keshavarzi et al. (2018) and Azmi et al. (2019). Hazard index results from the Kedah area showed that *Pampus argenteus*, *Loligo sibogae*, and *Megalaspis cordyla* possessed medium chronic risk while *Scylla serrata* and *Fenneropenaeus indicus* possessed high chronic risk. Again, for Selangor area, *Loligo sibogae* and *Pampus argenteus* were characterized by medium chronic risk while *Megalaspis cordyla*, *Scylla serrata*, and *Fenneropenaeus indicus* showed high chronic risk. It is obvious from Table 5 that *Scylla serrata* seafood possessed maximum chronic risk (Adult: 12.06, Child: 12.13) in the Kedah area and *Megalaspis cordyla* marine species possessed maximum chronic risk (Adult: 9.69, Child: 9.75) in the Selangor area.

Carcinogenic risk

Carcinogenic risk results of As, Cd, and Pb for both adults and children are presented in Table 6 (Kedah and Selangor area). Very high carcinogenic risks were found for all of these studied elements among the adult and children in Kedah and Selangor areas. In the Kedah area, the highest carcinogenic risks for As, Cd, and Pb were found in *Scylla serrata* (adult:

Table 4 Estimated daily intake (EDI) of adults (A) and children (C) calculated for Kedah and Selangor areas of Malaysia

Area	Species	Estimated daily intake (μg/kg/day)									
		Fe		Cu		As		Cd		Pb	
		A	C	A	C	A	C	A	C	A	C
Kedah	*Pampus sp.*	58.16	58.50	4.44	4.47	10.07	10.13	0.38	0.39	3.60	3.62
	Contribution to PV %	0.14	0.15	0.15	0.15	100.7	101.3	0.83	0.85	1.71	1.72
	Megalaspis sp.	68.98	69.38	8.11	8.16	8.55	8.60	0.09	0.090	1.94	1.96
	Contribution to PV %	0.17	0.17	0.27	0.27	85.5	86.0	0.19	0.19	0.92	0.93
	Loligo sp.	31.36	31.55	27.40	27.56	17.84	17.95	1.94	1.95	1.95	1.96
	Contribution to PV %	0.07	0.07	0.91	0.92	178.4	179.5	4.26	4.24	0.93	0.93
	Fenneropenaeus sp.	70.47	70.89	61.25	61.61	63.45	63.82	1.92	1.93	1.92	1.93
	Contribution to PV %	0.17	0.17	2.04	2.05	634.5	638.2	4.17	4.19	0.91	0.92
	Scylla sp.	146.20	147.20	82.08	82.57	174.20	175.20	12.34	12.40	12.34	12.41
	Contribution to PV %	0.36	0.37	2.74	2.75	1742.2	1752.0	26.83	26.95	5.87	5.91
Selangor	*Pampus sp.*	28.20	28.37	5.00	5.03	15.40	15.49	0.08	0.08	1.96	1.97
	Contribution to PV %	0.07	0.07	0.16	0.17	154.0	154.9	0.17	0.17	0.93	0.94
	Megalaspis sp.	360.60	362.80	62.02	62.39	56.78	57.12	1.04	1.04	3.96	3.98
	Contribution to PV %	0.90	0.91	2.07	2.08	567.8	571.2	2.26	2.27	1.88	1.89
	Loligo sp.	59.71	60.06	50.72	51.02	22.96	23.10	1.14	1.14	2.96	2.97
	Contribution to PV %	0.14	0.15	1.69	1.70	229.6	231.0	2.47	2.48	1.40	1.41
	Fenneropenaeus sp.	56.66	56.99	30.66	30.84	21.83	21.95	0.21	0.21	6.83	6.86
	Contribution to PV %	0.14	0.14	1.02	1.03	218.3	219.5	0.45	0.45	3.25	2.26
	Scylla sp.	66.03	66.42	35.80	36.02	100.20	100.81	2.34	2.35	1.40	1.41
	Contribution to PV %	0.16	0.17	1.19	1.20	1002.0	1008.1	5.08	5.11	0.66	0.67

PV permissible value (μg/day)

107.38×10^{0}, child: 108.0×10^{0}), *Loligo sibogae* (adult: 302.98×10^{-3}, child: 304.52×10^{-3}), and *Scylla serrata* (adult: 43.10×10^{-3}, child: 43.35×10^{-3}) respectively. Again, considering the Selangor area, the highest carcinogenic risk of As, Pb, and Cd were found for *Scylla serrata* (adults and children: 62.14×10^{0}), *Fenneropenaeus indicus* (adult: 23.85×10^{-3}, child: 23.96×10^{-3}), and *Scylla serrata* (adult: 364.96×10^{-3}, child: 367.14×10^{-3}) respectively. Therefore, *Scylla serrata*

Table 5 Chronic risk of adults (A) and children (C) calculated for Kedah and Selangor areas of Malaysia

Area	Species	Hazard quotients (HQ)										Hazard index (HI)		Chronic risk	
		Fe		Cu		As		Cd		Pb					
		A	C	A	C	A	C	A	C	A	C	A	C	A	C
Kedah	*Pampus sp.*	0.83	0.84	0.11	0.11	0.33	0.34	0.04	0.04	0.89	0.90	2.23	2.23	Medium	Medium
	Megalaspis sp.	0.98	0.99	0.20	0.20	0.28	0.27	0.008	0.009	0.48	0.49	1.96	1.97	Medium	Medium
	Loligo sp.	0.45	0.45	0.68	0.69	0.59	0.59	0.19	0.19	0.48	0.49	2.40	2.42	Medium	Medium
	Fenneropenaeus sp.	1.00	1.01	1.53	1.54	2.11	2.12	0.21	0.21	6.83	6.86	6.03	6.04	High	High
	Scylla sp.	2.08	2.10	2.05	2.06	5.80	5.84	2.34	2.35	1.40	1.41	12.06	12.13	High	High
Selangor	*Pampus sp.*	0.40	0.40	0.12	0.13	0.51	0.52	0.007	0.008	0.49	0.49	1.54	1.55	Medium	Medium
	Megalaspis sp.	5.15	5.18	1.55	1.56	1.89	1.90	0.10	0.10	0.99	0.99	9.69	9.75	High	High
	Loligo sp.	0.85	0.86	1.26	1.27	0.76	0.77	0.11	0.11	0.74	0.74	3.74	3.76	Medium	Medium
	Fenneropenaeus sp.	0.80	0.81	0.76	0.77	0.73	0.73	0.02	0.021	1.70	1.71	4.03	4.05	High	High
	Scylla sp.	0.94	0.95	0.89	0.90	3.34	2.36	0.23	0.23	0.35	0.35	5.76	4.79	High	High

Table 6 Carcinogenic risk (CR) calculated for adults (A) and children (C) in Kedah and Selangor areas of Malaysia

Area	Species	As		Cd		Pb		CR
		Adult	Children	Adult	Children	Adult	Children	
Kedah	*Pampus sp.*	6.20×10^{0}	6.25×10^{0}	59.34×10^{-3}	60.9×10^{-3}	12.57×10^{-3}	12.64×10^{-3}	Very high
	Megalaspis sp.	5.27×10^{0}	5.30×10^{0}	14.05×10^{-3}	14.05×10^{-3}	6.77×10^{-3}	6.84×10^{-3}	Very high
	Loligo sp.	10.99×10^{0}	11.06×10^{0}	302.98×10^{-3}	304.52×10^{-3}	6.81×10^{-3}	6.84×10^{-3}	Very high
	Fenneropenaeus sp.	39.11×10^{0}	39.34×10^{0}	299.83×10^{-3}	301.39×10^{-3}	6.7×10^{-3}	6.74×10^{-3}	Very high
	Scylla sp.	107.38×10^{0}	108.0×10^{0}	192.70×10^{-3}	193.60×10^{-3}	43.10×10^{-3}	43.35×10^{-3}	Very high
Selangor	*Pampus sp.*	9.49×10^{0}	9.54×10^{0}	12.33×10^{-3}	12.49×10^{-3}	6.84×10^{-3}	6.88×10^{-3}	Very high
	Megalaspis sp.	35.0×10^{0}	35.30×21^{0}	162.09×10^{-3}	163.03×10^{-3}	13.83×10^{-3}	13.90×10^{-3}	Very high
	Loligo sp.	14.15×10^{0}	14.23×10^{0}	177.55×10^{-3}	178.65×10^{-3}	10.33×10^{-3}	10.37×10^{-3}	Very high
	Fenneropenaeus sp.	13.45×10^{0}	13.53×10^{0}	32.48×10^{-3}	32.63×10^{-3}	23.85×10^{-3}	23.96×10^{-3}	Very high
	Scylla sp.	62.14×10^{0}	62.14×10^{0}	364.96×10^{-3}	367.14×10^{-3}	4.90×10^{-3}	4.93×10^{-3}	Very high

seafood was found to possess maximum carcinogenicity characteristics. Similar kinds of studies were stated by Alam et al. (2015) and Botrey-Sam et al. (2015).

Conclusion

Assessment of heavy metals' presence in marine fish and seafood is pivotal since the resulting data could suggest the consumption acceptability of these species. The maximum average level of heavy metals recorded in studied marine species are As followed by Fe, Cu, Cd, and Pb. Considering EDI calculation, *Scylla serrata* was found mostly contaminated with all the studied heavy metals that significantly contribute to the daily metal consumption percentages. The high chronic risk was heavily posed by seafood *Scylla serrata*, *Fenneropenaeus indicus* in the Kedah area, and marine fish *Megalaspis cordyla* in the Selangor area. All species were found very highly carcinogenic in both areas. It is obvious from this study that the most contaminated marine fish was *Megalaspis cordyla* and the least contaminated was *Pampus argentus*. Again, the most contaminated seafood was *Scylla serrata* while the least contaminated was *Loligo sibogae*, but the health risk of adults and children are very high through the consumption of marine fishes and seafoods. Thus, this study could be used as an important health impact outline to the marine fish and seafood consumers of Kedah and Selangor areas of Malaysia. Further investigation is needed in near future to other coastal regions of Malaysia under in holistic approach.

Availability of data and materials Not applicable

Author contributions The study was designed by Mohammed Abdus Salam. Shalini Rajeswara Dayal, Sadia Afrin Siddiqua, and Md. Iftakharul Muhib performed the experiments and analyzed and interpreted the data. The analysis was done by Shuva Bhowmik and Mohammad Mahbub Kabir, and the manuscript was written by Mohammed Abdus Salam, Md. Iftakharul Muhib and Shuva Bhowmik corrected by Aweng A/L Eh Rak and George Srzednicki.

Declarations

Ethical approval Not applicable

Consent to participate Not applicable

Consent for publication Not applicable

Conflict of interest The authors declare that there is no conflict of interest.

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