Human Health Hazard due to Metal Uptake via Fish Consumption from Coastal and Fresh Water Waters in Eastern India Along the Bay of Bengal

Bhupander Kumar*, Virendra Kumar Verma1, Ashish Kumar Naskar1, Paromita Chakraborty1 and Rita Shah2

Abstract
Concentrations of copper, zinc, manganese, and iron were determined in muscle tissue of coastal fish (Pampus argenteus, Tenulosa ilisha and Rastreiliger kanagurta) and fresh water fish (Hypophthalmichthys molitrix and Cirrhinus mrigala) samples from West Bengal, India, for assessing the potential health risk to human population. The concentrations of Cu, Zn, Mn and Fe in coastal fish muscles were between 0.79-4.0 mg kg\(^{-1}\) dw, 5.29-9.5 mg kg\(^{-1}\) dw, 0.50-5.0 mg kg\(^{-1}\) dw and 20-75 mg kg\(^{-1}\) dw, respectively, and in fresh water fish, they were in the ranges of 5.0-28 mg kg\(^{-1}\) dw, 33-51 mg kg\(^{-1}\) dw, 2.0-6.0 mg kg\(^{-1}\) dw and 38-110 mg kg\(^{-1}\) dw, respectively. The pattern of metals accumulation was in order of Fe > Zn > Cu > Mn. The results showed that the concentrations of metals in studied fish muscles were all lower than recommended guideline values. Estimated daily intakes (DIs) and weekly intakes (WIs) of metals (Cu, Zn, Mn & Fe) from fish consumption were lower than stipulated reference dose (RfD) and provisional tolerable weekly intake (PTWI) for human population. Total health hazard, based on hazard quotients (HQ) for fish eating human population from studied metals was ranged between 0.027-0.13, which is much lower than safe limit of one (<1) suggesting negligible health risk.

Keywords
Fish muscle; Metals; Daily intake; PTWI, Health hazard quotient

Introduction
Fishes are important part of the majority of human diet [1,2]. Due to high content of omega-3 fatty acids, vitamins, minerals and low levels of saturated fats in fish [3], American heart association recommended their consumption at least two times a week [4]. There is evidence of beneficial relation between fish consumption and lower risk of prostate cancer [5], renal cell cancer [6] and coronary heart disease [7]. In contrast to beneficial effects, fish can also contribute significant dietary exposure to the chemical contaminants such as poerisistent organic pollutants and metals. The health benefits and risks of fish consumption are depend upon their species, size, and habitat, as well as the amount consumed by the humans.

Majority of fish are capable of accumulating metals from their environment such as food items, sediments, and water [8]. Fish may accumulate metals in different tissues depending upon the intake and the elimination from their body [9]. Exceeded levels of accumulated metals in fish could become a significant metal exposure pathway and a consequent health risk for fish consuming human population [10,11].

There is a growing concern that metals accumulated in fish tissues may represent a health risk, especially for high fish consuming population [12,13]. Metals like arsenic, cadmium, mercury and lead are toxic to biota, even in low concentrations, but other metals like Cu, Fe, Mn and Zn are required for physiological activities in biological species [14]. These metals required in biological systems can also produce toxic effects when taken excessively [15]. Cu, Fe and Mn have shown unpairing of electrons that allow their participation in redox reactions, thereby biological toxic effects of these metals can be explained by their capacity to catalyze the initiation of free radical reactions [16]. Therefore, several studies has been undertaken worldwide to assess the accumulation of these metals in edible fishes caught from fresh water and coastal waters [8,17-23].

In recent years, researchers are emphasizing globally on assessment of the health risk to human population from essential metals through fish consumption [24-28]. A very few studies were carried out in India on human health risk due to metals exposure through fish consumption [29-32].

Earlier studies conducted in this area were on non-essential metal. Therefore, in this study we have exclusively included essential metals with an aim to elucidate the levels of daily and weekly intake of Cu, Zn, Mn and Fe for human population through consumption of commonly available coastal and fresh water fishes. Additionally, potential health risk in terms of hazardous index (HI) for human population was evaluated. For this purpose, we have estimated lifetime average daily dose (LADD) of metals for human population in eastern India along the Bay of Bengal. The LADD is defined by US Environmental Protection Agency (USEPA) as the amount of a chemical intake and absorbed into the body over a long period of time. Intake may be either through inhalation, ingestion or dermal contact by a person’s per kg of body weight per day thereby adverse health effects may be suspect [33]. Hazardous index (HI), the non-carcinogenic health effects is the quantifiable magnitude of exposure potential for developing non-carcinogenic health effects after an averaged exposure period [34].

Materials and Methods
Sampling location and sample collection
During this study, coastal and fresh water fish samples were collected from Diamond Harbor and aquaculture ponds near eastern Kolkata (Figure 1). Diamond Harbor a picnic resort and fish landing station situated on the bank of Hugli (the lower stretch of River Ganges). Diamond Harbor is the gateway to world’s largest mangrove ecosystem, the Sundarban (World Heritage Site). It is one of major fish landing centre of Sundarbans fish catch. Aquaculture ponds, located at eastern part of Kolkata are well known for their multiple
uses of wastewater and cover an area of approximately 28.5 km². Presently, ~30 percent of generated wastewater per day from Kolkata Metropolitan City is flowing through a web of canals into these ponds for aquaculture and irrigation purposes. 

Selected fishes were among the most available, consumable and economically valued species for the fish eating population. 25 adult specimens of approximately similar size of each species were collected including three species of coastal fishes (Pomfret argentiata, Tenulosa ilisha and Rastrelliger kanagurta) and two species of fresh water fishes (Hypophthalmichthys molithrix and Cirrhinus mrigela). Fifteen coastal fish samples were collected from different counters of fish landing station at Diamond Harbor. However, ten fresh water fish samples were from different aquaculture fish ponds of Eastern Kolkata Wetlands. After collection, all samples were kept in separate prewashed polythene bags in ice boxes and transported to the main laboratory and stored at -20 °C till further treatment, digestion and analysis of the metals.

Sample processing

In the laboratory, fish samples were thoroughly washed with tap water and Milli-Q water. After removing the scales, fishes were dissected and approximately 100 g of muscle portion was taken for chemical treatment and analysis. Muscle portion was oven dried at 110 °C, powdered with mortar and pestle, and stored at -20 °C. Metals were analyzed after digesting the homogenized samples in a mixture of concentrated nitric acid and perchloric acid. 0.5 g of duplicate subsamples of the homogenized muscle tissue of each sample was digested in Teflon beaker with 10 ml mixture (1:5) of concentrate nitric acid (65%) and concentrated perchloric acid (70%) at 70 °C in a water bath for 12 hrs. During digestion, few drop of sodium chloride solution (30%) was added to develop free chlorine. Developed free chlorine helps to loosen the chemical bonds in complex compounds and gentle heating destroys the organic matter and the metals are released into the digesting solution. After digestion, solution was transferred to a volumetric flask and 0.01 N of nitric acid was added to make known volume of the digested solution. Final solutions were centrifuged and the supernatant was taken using clean pipette for metal content analysis.

Instrumental analysis and quality control

Concentration of copper, zinc, manganese and iron in digested solutions were determined using flame atomic absorption spectrometry (FAAS, Thermo, USA). Before analysis, standard reference solutions (Merck NJ, USA) were used to check the precision of the instrument and five level calibration curve preparation. Each sample was analyzed in triplicate. Average values of instrumental analysis were corrected for digestion volume, sample weight taken and used in final results. Obtained results were reported on dry weight basis as mg kg⁻¹ dw. The detection limit for Cu, Zn, Mn and Fe was 0.05, 0.01, 0.05 and 0.06 ppm, respectively. Procedural blank in duplicate was processed and analyzed as real samples to check any loss or cross contamination. A certified reference material (SW 8022) was processed along with samples to determine the accuracy of the method. The recovery of the studied metals was within acceptable ranges of 97-109 ± 2.9 percent. The average recovery for individual metals was 103% (± 3%), 111% (± 1%), 108% (± 8%) and 112% (± 12%), respectively for Cu, Mn, Zn and Fe. Additionally, this laboratory has been regularly participating in international proficiency testing (PT) exercises for metals with satisfactory performance scores.

Health hazard characterization

Risk assessment guidelines [33] were used for the assessment of lifetime average daily dose (LADD) and health risk for metals to human population from fish consumption. For this purpose, human health risk in terms of hazard quotient (HQ) was calculated by comparing the estimated average daily dose of the each metal with the reference dose (RfD) [38]. Reference Dose (RfD) is an amount of daily exposure to toxic compound that does not show the symptoms of toxic effects from the exposed organism. Where, HQ is known as the magnitude of quantifiable potential for developing non-carcinogen health effects after averaged exposure period. Total potential for non-cancer risk to humans was derived by summing the HQ values of metals. This total HQ is referred to as the Hazard Index (HI). It has been suggested that, if HQ is equal to or less than one (≤1) indicates no appreciable health risk. Hazard index or ΣHQs value of less than one (<1) suggests no risks either from any chemical alone or in combination with others. Following equations were used for estimating the LADD, HQ and HI:

\[
\text{LADD} (\mu g \text{ kg}^{-1} \text{ day}^{-1}) = (C_s \times IR \times EF \times ED)/(BW \times AT) \quad (1)
\]

\[
\text{Hazard Quotient (HQ)} = \text{LADD/RfD} \quad (2)
\]

\[
\text{Hazard Index (HI)} = \text{HQ}_{\text{Cu}} + \text{HQ}_{\text{Zn}} + \text{HQ}_{\text{Mn}} + \text{HQ}_{\text{Fe}} \quad (3)
\]

Where, C_s is the metal concentration in fish muscle tissue (mg kg⁻¹ dw), IR is the fish ingestion rate. An average Indian adult consumes fish approximately 19.5 g day⁻¹ [39] and this consumption rate was used in our health-risk assessment. EF is exposure frequency (5 days week⁻¹ or 240 days/year), ED is the life time exposure duration (70 years), BW is the body weight (70 kg), AT is the averaging time, non-carcinogens (EF × ED days) and RfD is the reference dose of individual metal (mg kg⁻¹ dwday⁻¹) [38].
Result and Discussion

Concentration of metals

Obtained results of metals in muscle tissue of fishes have been presented in Table 1. The average concentration of Cu, Zn, Mn and Fe in coastal fish muscle ranged between 5-28 mg kg\(^{-1}\) dw (mean, 16 ± 3 mg kg\(^{-1}\) dw), 33-51 mg kg\(^{-1}\) dw (mean, 44 ± 2 mg kg\(^{-1}\) dw), 2.0-6.0 mg kg\(^{-1}\) dw (mean, 4.2 ± 0.36 mg kg\(^{-1}\) dw) and 38-110 mg kg\(^{-1}\) dw (mean, 68 ± 7 mg kg\(^{-1}\) dw), respectively for Cu, Zn, Mn and Fe. Pattern of metal contamination in studied fish was observed in descending order of Fe > Zn > Cu > Mn.

It was observed that fish collected from aquaculture ponds had comparatively higher concentrations of metals than coastal fish (Figure 2). Copper, zinc, manganese and iron in ponds fish was 8.5, 3.5, 2.4 and 2.1 times higher when compared with coastal fish. However, contents of studied metal in muscle tissue of fish from aquaculture ponds were lower, when compared with levels reported in the past [40]. The sources of metal input to these aquaculture ponds is possible from the wastewater of industrial effluents and municipal wastewater throughout the year [35,36,41]. Due to this reason, elevated concentrations of heavy metals in water, sediments and biota from these aquaculture ponds have been reported by several workers [35,36,42-45]. Significant bioavailable fraction of heavy metals i.e. Mn (58%), Zn (63%), Cu (40%) and Fe (37%) in sediments was reported by Kumar et al. [45]. Chatterjee et al. [35] reported accumulation of Fe (188-8625 mg kg\(^{-1}\) dw), Zn (59-364 mg kg\(^{-1}\) dw), Cu (6.2-39 mg kg\(^{-1}\) dw) and Mn (87-364 mg kg\(^{-1}\) dw) in wetland plant species from these wetland area. However, elevated concentration of Zn (90.87-148.04 mg kg\(^{-1}\) dw) and Cu (15.26-32.11 mg kg\(^{-1}\) dw) was reported in vegetables from this area [46].

Fishes found at Diamond Harbor area usually comes from deltaic coast of Hugli estuary along the Bay of Bengal. Hugli estuary has been receiving discharges of agricultural runoff, storm water and wastewater containing appreciable amount of pollutants such as metals and organic pollutants. The surface runoff from the Ganga basin ultimately reaches to the Bay of Bengal and increases the load of pollutants laden suspended particulate matter and sediment. The estimated annual sediment load of Hugli estuary from natural weathering and anthropogenic sources was reported to be 520x10\(^6\) MT, which ultimately flows into the coastal water of Bay of Bengal [47,48]. Researchers reported that the discharge of metals into the coastal waters through estuaries resulted accumulation in the marine biota [49]. Therefore, significant concentration of heavy metals has been reported in aquatic biota including fish collected from Hugli estuary and Sundarbans in Bay of Bengal [50-55]. In other several studies anthropogenic influences have been suggested for the elevated concentrations of the metal in water and sediments of this estuarine zone including Sundarbans [51,56-61]. Concentration of Fe, Mn, Zn and Cu in surface water of Hugli River was reported in the ranges of 0.025-5.49 mg L\(^{-1}\), 0.025-2.72 mg L\(^{-1}\), 0.012-0.370 mg L\(^{-1}\) and 0.003-0.032 mg L\(^{-1}\), respectively [62]. Akter et al. [51] reported concentration of Cu and Zn in River water near Kolkata as 0.15 mg L\(^{-1}\) and 0.29 mg L\(^{-1}\), respectively. However, concentrations of metals in Sundarbans sediment ranged between 6231-30632 mg kg\(^{-1}\) dw, 3-42 mg kg\(^{-1}\) dw, 4-74 mg kg\(^{-1}\) dw and 114-583 mg kg\(^{-1}\) dw, respectively for Fe, Cu, Zn and Mn [47].

This study indicated that Cu, Zn and Fe levels in three coastal fish species and two fresh water fish species were lower than the permissible limit (Table 1). However, Mn concentration was higher than prescribed guideline limits [63]. Mn is essential element for

Table 1: Statistical calculated results (mg kg\(^{-1}\) dw) of metals in muscle tissue of analysed fish.

<table>
<thead>
<tr>
<th>Fish Species</th>
<th>Stat.</th>
<th>Copper</th>
<th>Zinc</th>
<th>Manganese</th>
<th>Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coastal fish</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. argentius</td>
<td>Mean</td>
<td>1.4</td>
<td>10</td>
<td>2.7</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>0.8-2.0</td>
<td>5-15</td>
<td>1.0-5.0</td>
<td>21-39</td>
</tr>
<tr>
<td></td>
<td>Std Err</td>
<td>0.3</td>
<td>2.1</td>
<td>0.7</td>
<td>3.1</td>
</tr>
<tr>
<td>T. ilisha</td>
<td>Mean</td>
<td>2.3</td>
<td>13</td>
<td>1.9</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>1.0-3.5</td>
<td>5-29</td>
<td>0.9-4.0</td>
<td>22-29</td>
</tr>
<tr>
<td></td>
<td>Std Err</td>
<td>0.6</td>
<td>4.3</td>
<td>0.6</td>
<td>1.5</td>
</tr>
<tr>
<td>R. kanagurta</td>
<td>Mean</td>
<td>2.2</td>
<td>16</td>
<td>0.8</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>1.0-4.0</td>
<td>12-19</td>
<td>0.5-1.0</td>
<td>20-75</td>
</tr>
<tr>
<td></td>
<td>Std Err</td>
<td>0.6</td>
<td>1.3</td>
<td>0.1</td>
<td>11</td>
</tr>
<tr>
<td>All samples</td>
<td>Mean</td>
<td>1.9</td>
<td>13</td>
<td>1.8</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>0.8-4.0</td>
<td>5-29</td>
<td>0.5-5.0</td>
<td>20-75</td>
</tr>
<tr>
<td></td>
<td>Std Err</td>
<td>0.3</td>
<td>1.7</td>
<td>0.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Fresh water fish</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H. molithrix</td>
<td>Mean</td>
<td>22</td>
<td>45</td>
<td>4.7</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>10-28</td>
<td>41-51</td>
<td>3.9-6.0</td>
<td>53-110</td>
</tr>
<tr>
<td></td>
<td>Std Err</td>
<td>3.4</td>
<td>1.6</td>
<td>0.4</td>
<td>11</td>
</tr>
<tr>
<td>C. mirgela</td>
<td>Mean</td>
<td>11</td>
<td>43</td>
<td>3.7</td>
<td>58</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>5-25</td>
<td>33-47</td>
<td>2.0-6.0</td>
<td>38-80</td>
</tr>
<tr>
<td></td>
<td>Std Err</td>
<td>3.7</td>
<td>2.5</td>
<td>0.6</td>
<td>7.1</td>
</tr>
<tr>
<td>All samples</td>
<td>Mean</td>
<td>16.4</td>
<td>44</td>
<td>4.2</td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>5-28</td>
<td>33-51</td>
<td>2-6</td>
<td>38-110</td>
</tr>
<tr>
<td></td>
<td>Std Err</td>
<td>3.0</td>
<td>1.5</td>
<td>0.4</td>
<td>6.9</td>
</tr>
<tr>
<td>Guidelines (WHO 1989)</td>
<td></td>
<td>30</td>
<td>100</td>
<td>1.0</td>
<td>100</td>
</tr>
</tbody>
</table>
humans, and is involved in the formation of bone and protein, lipid, and carbohydrate metabolism in biological system [64]. However, excess doses of Mn may lead to impaired neurological function, therefore, tolerable upper limit of dietary intake based on a "no observable adverse effect level" (NOAEL) of 11 mg day\(^{-1}\) of Mn was introduced for human adults [64]. Thus, we can conclude that Mn concentrations observed in this study is much lower than NOAEL and reference dose (Rd) for human adults, suggesting no harmful effects.

### Potential human health risk

Although metals are present in the aquatic environment at low levels, but their concentrations in aquatic organisms could be higher by bioconcentration and bioaccumulation processes, resulting in progressively higher concentrations of these pollutants higher trophic levels in the food chain. Therefore, human health can be at risk because of consumption of contaminated biota including edible fish. The life time average daily dose (LADD) calculations were made as per report of US EPA (1989) using the standard assumption for an integrated US EPA risk analysis, including exposure over an entire 70-year lifetime and to a 70-kg body weight for an average Indian adult (Table 2). Global average weight of human adult (>18 years) are being used 70 kg. The 50\(^{th}\) and 97\(^{th}\) percentile of Indian adults (>18 years) body weight ranged between 47-66 kg and 63-99 kg, respectively [65]. We assessed health risk, considering that the average fish consumption was 19.5 g day\(^{-1}\) for five days in a week during the life span of 70 years. Additionally, it was assumed that the ingested amount of metals is equal to the absorbed amount [33] and that cooking has no effect on the metals [66]. To evaluate the health risk to human population through consumption of coastal and fresh water fish, daily intake of metals was estimated on the basis of the concentrations of metals in muscle of fish and daily fish consumption. Metals intakes were compared with the reference dose of copper (4.0x10\(^{-3}\) mg kg\(^{-1}\) d\(^{-1}\)), zinc (3.0x10\(^{-3}\) mg kg\(^{-1}\) d\(^{-1}\)), manganese (1.4x10\(^{-3}\) mg kg\(^{-1}\) d\(^{-1}\)) and iron (7.0x10\(^{-3}\) mg kg\(^{-1}\) d\(^{-1}\)) established by the United States Environmental Protection Agency [38]. Hazard quotient was calculated using the average of each fish species divided by the reference dose of metal.

Estimated LADD, hazard quotient and hazard index for human adults from metal exposure through studied fish consumption has been presented in Table 3. Estimated LADD for total metals (Cu, Zn, Mn and Fe) from coastal and fresh water fish species was 8.83 µg kg\(^{-1}\) d\(^{-1}\) and 24.19 µg kg\(^{-1}\) d\(^{-1}\), respectively. Daily intake of Cu, Zn, Mn and Fe from coastal fish consumption was 0.35 µg kg\(^{-1}\) d\(^{-1}\), 2.31 µg kg\(^{-1}\) d\(^{-1}\), 0.33 µg kg\(^{-1}\) d\(^{-1}\) and 5.84 µg kg\(^{-1}\) d\(^{-1}\), respectively. However, average daily intake of metals from consumption of fresh water fish was 3.00 µg kg\(^{-1}\) d\(^{-1}\), 8.06 µg kg\(^{-1}\) d\(^{-1}\), 0.77 µg kg\(^{-1}\) d\(^{-1}\) and 12.36 µg kg\(^{-1}\) d\(^{-1}\), respectively for Cu, Zn, Mn and Fe. Therefore, it may be stated that total metal intakes by human populations from present fish consumption rate were 7.65 µg kg\(^{-1}\) d\(^{-1}\), 7.77 µg kg\(^{-1}\) d\(^{-1}\), 11.07 µg kg\(^{-1}\) d\(^{-1}\), 27.34 µg kg\(^{-1}\) d\(^{-1}\) and 21.04 µg kg\(^{-1}\) d\(^{-1}\), respectively for P. argentius, T. ilisha, R. kanagurta, H. molitrix and C. mrigela fish species. Estimated daily intake of metals through fish to human was lower than recommended reference dose of copper, zinc, manganese and iron [38]. The average contribution of daily metal intake to human beings from coastal and fresh water fish was 2.30-3.14 µg kg\(^{-1}\) d\(^{-1}\) and 9.53-15.46% (Table 3), respectively for respective daily reference doses.

Table 4 shows the estimated weekly intakes (EWIs) of Cu, Zn, Mn and Fe for the consumers along with their percentage with respect to provisional tolerable weekly intake (PTWI). EWI of the metals obtained from the study due to fish consumption by the surrounding population did not exceed the standard PTWI. Although, American Heart Association (AHA) has recommended the fish consumption twice a week, but, Food Safety Authority (FSA) of European countries has established safety guidelines regarding weekly intakes (WIs) of copper, iron and zinc from fish and shellfish [67]. It recommends a PTWI value of 1120 µg kg\(^{-1}\) w\(^{-1}\), 5600 µg kg\(^{-1}\) w\(^{-1}\) and 4900 µg kg\(^{-1}\) w\(^{-1}\), respectively for Cu, Zn and Mn. No PTWI for manganese from fish was available due to insufficient data [67]. Average WI of Cu, Zn, Mn and Fe estimated from this study was 1.76 µg kg\(^{-1}\) w\(^{-1}\), 11.56 µg kg\(^{-1}\) w\(^{-1}\), 1.64 µg kg\(^{-1}\) w\(^{-1}\) and 29.19 µg kg\(^{-1}\) w\(^{-1}\), respectively for coastal fishes. However, estimated WI of Cu, Zn, Mn and Fe from fresh water fishes was 14.98 µg kg\(^{-1}\) w\(^{-1}\), 40.31 µg kg\(^{-1}\) w\(^{-1}\), 3.87 µg kg\(^{-1}\) w\(^{-1}\) and 61.79 µg kg\(^{-1}\) w\(^{-1}\), respectively, EWI of sum of all the metals from coastal and fresh water fish, in this study accounted for 0.16-0.91 µg kg\(^{-1}\) w\(^{-1}\) and 1.34-3.26 µg kg\(^{-1}\) w\(^{-1}\),

### Table 2: Life time average daily dose (LADD) of metals for human population from fishes.

<table>
<thead>
<tr>
<th>Fish Sp.</th>
<th>LADD (µg kg(^{-1}) d(^{-1}))</th>
<th>Percent of Rd</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cu</td>
<td>Zn</td>
</tr>
<tr>
<td>Coastal fish</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P. argentius</td>
<td>0.3</td>
<td>1.8</td>
</tr>
<tr>
<td>T. ilisha</td>
<td>0.4</td>
<td>2.3</td>
</tr>
<tr>
<td>R. kanagurta</td>
<td>0.4</td>
<td>2.8</td>
</tr>
<tr>
<td>Average</td>
<td>0.4</td>
<td>2.3</td>
</tr>
<tr>
<td>Fresh water fish</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H. molitrix</td>
<td>4.0</td>
<td>8.3</td>
</tr>
<tr>
<td>C. mrigela</td>
<td>2.0</td>
<td>7.8</td>
</tr>
<tr>
<td>Average</td>
<td>3.0</td>
<td>8.1</td>
</tr>
</tbody>
</table>

*USEPA 2012 [38]
respectively to the PTWI. Thus, as shown in Table 3, EWI values for Cu, Zn, Mn, and Fe were much lower than PTWI concentrations, and suggested no risk for human health on weekly consumption of fish species included in this study.

In this study, human health risk was quantified as hazard quotient (HQ) for Cu, Zn, Mn, and Fe. The hazard Quotient is one of the measures of non-carcinogenic health effects of exposure to chemical contaminants. It is the ratio of an exposure level (amount kg⁻¹ d⁻¹) by contaminant (i.e. through inhalation, ingestion or dermal contact) to a reference dose (amount kg⁻¹ d⁻¹) for a particular chemical. If the exposure level is higher than the reference dose, then there is the potential of risk. HQ values of ≤1 indicate the daily oral exposure level for the receptor (particularly human population), is likely to be without an appreciable risk during a lifetime. The computed HQ for this study was presented in Table 4 and Figure 3. The estimated HQ from Cu, Zn, Mn, and Fe exposure to coastal fish species reported in this study is 8.8×10⁻³, 7.7×10⁻³, 2.4×10⁻³ and 8.3×10⁻³, respectively. However, HQ from Cu, Zn, Mn, and Fe exposure through fresh water fish consumption is 7.5×10⁻², 2.7×10⁻², 5.5×10⁻² and 1.8×10⁻², respectively. The total health hazard or hazard index (HI) to human population due to Cu, Zn, Mn, and Fe exposure, through coastal and fresh water fish intakes ranges between 2.3×10⁻² (P. argentius) to 3.1×10⁻² (R. kanagurta) and 9.5×10⁻² (C. mirgela) to 1.5×10⁻¹ (H. molithrix) with an average value of 2.7×10⁻² and 1.3×10⁻¹, respectively (Table 4, Figure 3). The observed ranges and average of hazard quotient (HQ) and hazard index (HI) is lower than the acceptable safe risk level (HI≤1) (Table 3). Therefore, our results infers that consumption of these fish species at the present rate might not be hazardous to human population with respect to observed levels of Cu, Zn, Mn, and Fe alone or in combination of each other.

Metal intake through fish and human health hazard reported in this study was compared with other studies around the world including India, and found lower than those reported from Mersing, Malaysia [24], Southwest India [31], Uttar Pradesh, India [32], Slovenia [68], Taiwan [13,69,70], Puerto Rico [28], Southeast Gulf of
Conclusion

The selected fish individuals from coastal and fresh water waters we analyzed reveal metals concentrations are within guidelines and may not be harmful to human population. Since their health risk for humans is given by the present consumption rate, hence data we obtained on ADD and EWI was lower than daily reference dose (RfD) and provisional tolerable weekly intake (PTWI) of metals for the surrounding human population within the limit of our study area. Furthermore, the estimated risk in terms of total hazard quotient (THQ) from the metal concentrations does not have risk to human health. However, it is just a selective fish investigation; metal contamination levels should be carefully monitored on a regular basis in more fish species, to detect the change in their accumulation patterns. It is well known that fishes can accumulate variety of toxic chemicals including persistent organic contaminants such as dioxins and chlorinated pesticides; hence similar study has to be conducted for such compounds.

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