Assessment of Human Health Risks Associated with Heavy Metals Accumulation in the Freshwater Fish *Pangasianodon hypophthalmus* in Bangladesh

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Abstract
In this study, pangas and feed samples were analyzed to estimate the levels of metallic elements and to profile the human health risks due to consumption of contaminated fish. This investigation confirmed significant variations in heavy metal concentrations among different tissues of pangas in the order of Ni > Cu > Pb > Cd > Cr in pre-monsoon and Ni > Cd = Cu > Pb = Cr in post-monsoon. Considerably higher concentrations of Pb, Cu, and Cr were estimated in liver; and Cd and Ni were detected in muscle than in other organs (p > 0.05). Statistically significant higher amounts of Cd, Ni, and Cu were observed in pre-monsoon than in post-monsoon. Furthermore, three metal pairs showed significant association (Pb–Ni and Pb–Cu involved positively; Cd–Ni acted negatively). In pre-monsoon, Cd, Pb, Ni, and Cu concentrations of feed significantly differed than those of pangas contents, whereas only Cu varied during the post-monsoon. Regression analysis revealed the significant effect of Ni content in feed on the Cu deposition of pangas (p-value 0.027, that was < 0.05). For the assessment of potential human health risk of the studied metals, estimated daily intake (EDI), target hazard quotient (THQ), hazard index (HI), and carcinogenic risk (CR) indices were calculated. Studied EDI indicated that an average adult ingested a higher amount of Ni and Cu than the recommended intake limit. Nevertheless, only the higher EDI of Ni increases the value of THQ and HI than standard limit indicates adverse non-carcinogenic risk. However, lower CR of Pb confirmed no serious health hazard due to the ingestion of pangas. Factor analysis through principal component and cluster analysis suggested that higher concentrations of Pb and Ni may be regulated by the feed used, geochemical properties, or rapid industrialization in the study area. A proper monitoring for controlling the quality of fish feed with sustainable planning for industrialization could secure the booming of pangasius aquaculture in Bangladesh.

Keywords *Pangasianodon hypophthalmus* · Heavy metals · THQ · Hazard Index · Bioaccumulation

Introduction
Aquatic environment has become polluted with heavy metals day by day which acts like a global issue of scientific concern, because these metals are indestructible and most of them have toxic effects on organisms (Islam et al. 2017). Literally, heavy metals can be explained as any metal element which contains a comparatively higher density with toxigenic impact on living organism even at a lower exposure dose (Fergusson 1990; Duffus 2002). On the other hand, metal could be considered heavy metal if it has an atomic number of > 20, density exceeding 5 g cm\(^{-3}\)or carrying a density relatively greater than water (Barakat 2011; Walker et al. 2012; Ali and Khan 2017). In that sense, cadmium (Cd), lead (Pb), nickel (Ni), chromium (Cr), mercury (Hg),
and arsenic (As) are all listed as the most toxic members of heavy metal (Tchounwou et al. 2012). Actually, the nature of non-biodegradability, persistence, and bioaccumulation triggered the metals to show poisonous effects on the health of animals and humans (Duman et al. 2007). Heavy metals contamination of aquatic ecosystems is becoming an alarming issue for public health as its potential bioaccumulation mechanism from fish to finally human (Le and Ngo 2013). Heavy metal contamination in water and its uptake by fishes could be a direct consequence of urban and industrial pollution (Türkmen et al. 2005). Acute and prolonged exposure or contact to metallic elements lead to extreme toxicity, renal and hepatopancreatic dysfunction, even carcinogenicity of the brain, prostate gland, and other organs of a human being (Vannooft and Thomson 2005; Gray et al. 2005; García-Lestón et al. 2010). So far, several criteria of the toxic elements, viz., the dose of metal exposure, their route, and the chemical properties, along with exposed one’s details, including age, gender, genetic behaviors, and nutritional deficiency, actively regulate the level of toxicity (Tchounwou et al. 2012). Specifically, long-term exposure to Cd contents in high doses could deal with renal dysfunction, osteomalacia, and even increase the vulnerability to prostate cancer (Vannoort and Thomson 2005; Gray et al. 2005). Studies confirmed brain and kidney infection due to Pb exposure for an extended period (García-Lestón et al. 2010). The higher concentration of Cu in fish indicated these values could increase the chances of adverse risks of kidney and liver damage (Ikem and Egiebor 2005).

Ingestion of metal elements through dietary substance could be a direct exposure route for the majority of the people (Loutfy et al. 2006). In the aquatic food chain, fishes ranked on the top and hence accumulated a significant amount of metals (Hodson 1988) that contributed as the cause of toxic metal contamination for consumers. Generally, in any locality, fish consumed as a cheaper and the best supplier of protein and polyunsaturated fatty acids (PUFA). American Heart Association (AHA) suggested intake of fish two times a week for the fully grown person, which helps control the history of heart attack and stroke (Stone 1996).

Like other species of fish, cultured striped catfish Pangasianodon hypophthalmus (locally known as “Pangas” in Bangladesh) offers easy digestibility of protein with low-fat substance (Økland et al. 2005; Orban et al. 2008). However, in the last two decades, Bangladesh has experienced the overgrowing establishment of urbanization and industrialization (Siddiqy 2017). Literature confirmed the origin of metal contamination in an aquaculture system, including untreated industrial and agricultural dumping in the natural water resources (Zhang et al. 2010; Islam et al. 2018), air pollution (EMEP 2015), aquatic environment pollution through washout of monsoon or for flooding (Islam et al. 2018), erosion, atmospheric accumulation in the aqueous ecosystem (Baki et al. 2018), and natural geochemical characteristics (Islam et al. 2018). This situation extensively controls the increased nature of toxic metals on fish or pangas. Eating fish (pangas) with deposited toxic elements could enhance the highly critical health issues of a human being (Mansour et al. 2009).

Several works have been published on bioaccumulation of heavy metals in pangas all over the world (Elnimr 2011; Hossain et al. 2016; Duarte et al. 2019; Milenkovic et al. 2019). This is a concerning issue as it is directly related to human health when it crosses the acceptable limit. For fish feed, FAO/WHO (1984), EC (2003), WHO (1985) and for pangas, MOFL (2014), FAO/WHO (1989), USFDA (1993), and WHO (2011) have published minimum acceptable level for each metal (like Cd, Pb, Ni, Cu, Cr, and others).

Muktagacha, Trishal, and Bhaluka sub-districts of Mymensingh district are the familiar commercial freshwater fish farming zone of Bangladesh, especially for pangas farming. Geological features of this district have a remarkable blessing of nature, including suitable water sources, average annual rainfall, and better water quality parameters (Ahmed 2009; FAO 2000). These criteria strongly have influenced on the introduction of highly active and economically significant aquaculture business. Therefore, fish produced in the farms of Mymensingh, specifically in the sub-districts, viz., Trishal, Mymensingh Sadar, Phulpur, Bhaluka, and Muktagacha, have been circulated throughout Bangladesh. Unfortunately, in a couple of years, rapidly growing industrialization immensely influence the environmental pollution of the area where all the factories discharge their untreated effluents directly into the canals and then the dumping spread over agricultural lands. Furthermore, several studies reported on heavy contamination of metals (As, Zn, Cr, Cd, Pb, Sr, Ni, Li, Ag, Hg, Co, and Se) in the dumping grounds of almost 300 different industries distributed in Mymensingh district where every day a significant amount of textile dyes, plastics, metal fabricates, diesel, and leather tanners are being discharged into the local agricultural areas (Islam et al. 2015; Ahmed et al. 2012; Al Zabir et al. 2016). However, metal contamination of marketed or farmed fish and their diets of Mymensingh has already been examined (Hossain et al. 2016; Al Zabir et al. 2016; Akter et al. 2020), but no systematic comparison of metal contents in pangas and their feeds with the seasonal variation was reported yet. In Bangladesh, pangas has been included in a regular diet of mass people, especially in a low-income section of the society; it is a highly concerning issue where those consumers could be a target group of potential health hazards due to the biomagnification of toxic elements in the food chain. Therefore, this research work was aimed to quantify the accumulation of the metals in pangas and fish feed during pre- and post-monsoon, collected from three economically important aquaculture locations of Mymensingh.
region. Besides, estimation of the potential human health risk because of the ingestion of contaminated pangas, was another substantial objective of the present investigation.

**Materials and Methods**

**Sampling Area**

In this study, fish feed and fish samples were purchased from Muktagacha (24°45'57.66" N to 90°15'22.09" E), Trishal (24°34'53.97" N to 90°23'41.46" E), and Bhaluka (24°24'28.54" N to 90°23'11.79" E) regions of Mymensingh district (Fig. 1). The abundance of fish farms in these areas is praiseworthy. Pangas (*P. hypophthalmus*) is cultured on a large scale in that area. Household effluents, feed, industrial pollution, and consequently heavy metal released into water bodies of study areas can bioaccumulate in pangas and could transfer into the food chain. The feed that was used to feed pangas was collected from farms of Muktagacha, Trishal, and Bhaluka for this study.

**Fish Feed and Pangas Sampling**

During pre-monsoon and post-monsoon of 2017, fish feed and pangas samples were collected from three regions of Mymensingh district. In pre-monsoon, a total of 27 adult freshwater pangas (*P. hypophthalmus*) ranged between 900 and 1200 g in weight were collected from nine pangas farms (three fish from each farm) and used fish feeds as well from all farms. However, in post-monsoon, a total of nine adult pangas were collected from nine pangas farms (one fish from each farm). All fishes were washed with deionized-distilled water, took in sterile plastic bags, and stored frozen in an icebox. Finally, three organs of pangas (gill, liver, and muscle) were dissected and taken for the further preparation. However, in post-monsoon, each organ sample (viz., a gill/liver/muscle) of three farms of each sampling site was

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**Legend**

- Sampling sites
- Bhaluka
- Muktagacha
- Trishal

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**Fig. 1** Map representing the sampling sites of the present study (created by ArcGIS v. 10.7.1)
pooled and considered as a representative organ sample (viz., a gill/liver/muscle) for each region. Before digestion, all organ and feed samples were dried at 60 °C for 48 h and ground them completely.

**Chemicals and Reagents**

Throughout this study, all reagents and solutions were used with analytical grade (Merck, India). Digestion was maintained with deionized double distilled water, 68% nitric acid (HNO₃), and 70% perchloric acid (HClO₄). Atomic absorption spectrometer (AA-7000, Shimadzu, Japan) equipped with a single element hollow cathode lamp was used for the determination of five heavy metals (Cd, Pb, Ni, Cu, and Cr). In this process, fish samples were dried in a hot air oven where digestion done by a fume hood (EFD-481, ESCO, USA). For this experiment, all operating parameters considered for the quantification of each metal and their recovery percentages are listed in Table 1. Calibration graph of the correlation coefficient of respective elements were prepared to calculate standard deviation. The accuracy of data was validated for all the elements by certified reference material supplied by Sigma-Aldrich, Germany. To assure the accuracy, sensitivity, and precision of the analytical procedure of AAS, SRM 2976-Mussel tissue was analyzed as certified reference material from the national institute of standards (NIST). The limits of detection (LOD) of AAS system for Cd, Pb, Ni, Cu, and Cr were 0.003, 0.01, 0.02, 0.01, and 0.01 ppm, respectively.

**Assessment of Heavy Metals**

To estimate metal accumulation in the studied samples, 0.5 g of dried samples was mixed in 10 ml HNO₃ with blank which kept aside for overnight due to analyze the presence of contamination in the sample before digestion. During digestion, the mixture was digested, grinded for 2 h, and reheated for 60°–80 °C, until the mixture turns to gel. This gel was cooled in 5–10 min, then 5 ml HClO₄ in each sample was added and digested one more time. After that, the cooled gel solution was filtered and was made to 25 ml solution with distilled water and kept in the marked plastic bottle. The total digestion procedure followed the methodology developed by Huq and Alam (2005). Concentrations of metal elements were quantified as mg/kg dry weight for tissues. The following formula developed by Huq and Alam (2005) was considered to determine metals concentration. So, studied metals concentration was calculated by the following formula: Where, primary dilution factor (PDF) = volume/weight of sample and secondary dilution factor (SDF) = secondary volume/secondary weight of sample.

\[
\text{Concentration of heavy metals} = (\text{Reading} - \text{Blank reading}) \times \text{PDF} \times \text{SDF},
\]

**Measurement of Human Health Risk**

**Estimated Daily Intake (EDI)**

Estimated daily intake (EDI) of studied metals in pangas was measured by a metal concentration in pangas, average daily consumption of an adult, and average body weight. The equation described by Shaheen et al. (2016) was followed for EDI quantification. Estimated daily intake (EDI) = \( \frac{\text{FIR} \times C}{\text{BW}} \), where FIR = Fish/Pangas ingestion rate; on average an adult FIR is 49.5 g/person/day (BBS 2015); C = Heavy metal concentration in pangas (mg/kg, dry weight); and BW = Average body weight (60 kg).

**Target Hazard Quotient**

Target hazard quotient (THQ) is health risk estimation of non-carcinogenic due to heavy metals exposure. As per the explanation of USEPA (1989), amount of metals consumption and their absorbed dose is similar which was not affected by cooking. This research work assessed the non-carcinogenic health risks that related to the intake of pangas by the adult fish consumers based on the target hazard quotients (THQs). THQ values were calculated using the USEPA standard assumption: THQ = \( \frac{\text{EFr} \times \text{ED} \times \text{FIR} \times C}{\text{RfD} \times \text{BW} \times \text{AT} \times 10^{-3}} \), where THQ is the target hazard quotient, EFr = Exposure frequency (365 days/year), ED = Exposure duration (70 years), FIR = Fish/Pangas ingestion rate (on average adult consumption rate 49.5 g/person/day), C = Heavy metal concentration in pangas (mg/kg), BW = Average body weight (60 kg), AT = average exposure time for non-carcinogens (EFr×ED) (365 days/year for 70 years), RfD = The oral reference doses were 0.001, 0.0035, 0.02, 0.04, and 1.5 mg/kg/day for Cd, Pb, Ni, Cu, and Cr, respectively (USEPA 2020).

| Heavy metals | Wave length (nm) | Lamp intensity (mA) | Slit intensity (nm) | Recovery percentage (%) |
|--------------|-----------------|---------------------|---------------------|------------------------|
| Cd           | 228.8           | 4                   | 0.5                 | 98                     |
| Pb           | 217.3           | 10                  | 1                   | 109                    |
| Ni           | 232             | 4                   | 0.2                 | 97                     |
| Cu           | 324.8           | 4                   | 0.5                 | 106                    |
| Cr           | 357.9           | 7                   | 0.2                 | 101                    |
Hazard index (HI) is a mathematical calculation where all the THQ values of the studied fish were added together, and this value reflects the effect of non-carcinogenic risk: 

\[ HI = THQ(Cd) + THQ(Pb) + THQ(Ni) + THQ(Cu) + THQ(Cr) \]

The value of HI > 10; in that situation, the higher non-carcinogenic risk is considered for the exposure group of people (USEPA 2011).

### Carcinogenic Risk (CR) Analysis

According to USEPA (1989), carcinogenic health risks were quantified as the probable raise of a metal that developing cancer over a long-time contamination to that potential carcinogen. Carcinogenic risk (CR) was determined by considering the following equation:

\[ CR = \frac{EF \times ED \times FIR \times C \times CSF}{BW \times AT} \times 10^{-3}, \]

where CSF is the oral carcinogenic slope factor and CSF of Pb is \(8.5 \times 10^{-3}(mg/kg/day)^{-1}\) (CEPA 2009). As per USEPA (2010), the safe range of CR is \(10^{-4}\) to \(10^{-6}\), which means when CR goes to more than \(10^{-4}\), that could increase the chance of carcinogenic risk impact.

### Statistical Analysis

Statistical testing of the studied quantitative data was conducted by SPSS 20.0 (SPSS, USA), and the graphs were prepared using MS Excel 2019. Violin plot was made by GraphPad Prism version 8.4.2. The data are presented here as mean ± SEM (due to the lack of replications in post-monsoon samples, standard deviation was used with mean). Multiple comparisons with a 5% level of significance were applied for Tukey’s post hoc tests (ANOVA, \(p < 0.05\)) and one-way ANOVA for the multivariate analysis. Multiple linear regression analysis was used to determine the effect of the feed elements on the metal contents of pangas (Alizada et al. 2020). Effects testing were completed at a 5% level of significance, where season and location-based effects were not considered. Paired sample t-test was performed (t-test, \(p < 0.05\)) to find out any impact on the heavy metal concentrations due to seasonal changes. 2-tailed Mann–Whitney U-test (\(p < 0.05\)) was done to validate the relationship between metals seasonal variations in each sampling area. Bivariate Pearson’s correlation test was conducted to check the association among metals in each site.

For the factor analysis, the principal component analysis (PCA) was applied to confirm the distribution of the metals, which helped in the identification of the origin of the studied metals (Islam et al. 2018; Milenkovic et al. 2019). Besides, cluster analysis (CA) performed by Ward’s linkage method that aided to identify similar distribution group of the metals against different sampling locations (Islam et al. 2018; Milenkovic et al. 2019; Ahmed et al. 2019). All multivariate analyses, like PCA and CA, were performed by JMP version 15.1 (SAS Institute Inc., USA).

### Results and Discussion

#### Concentration of Heavy Metals in Pangas Organs

Table 2 illustrates the average metal concentrations with SEM of pangas organs in studied sampling sites during pre- and post-monsoon of the year 2017. In pre-monsoon, the order of metals in tissues of pangas was Ni > Cu > Pb > Cd > Cr. On the other hand, in the post-monsoon, the sequence was Ni > Cd = Cu > Pb = Cr.

During pre-monsoon of 2017, pangas liver of Muktagacha contained the highest amount of cadmium, Cd (0.0933 mg/kg), whereas the lowest value of Cd was recorded in gill sample of Muktagacha and Trishal (0.03 mg/kg). In contrast, during post-monsoon, the highest concentration of Cd was recorded in the muscle sample of Trishal and the lowest in the liver sample of Bhaluka. Table 2 also describes the total concentration of metals present in the pangas of each sampling site. Cd concentration of studied pangas, which brought from each sampling area of Mymensingh district, significantly varied within seasonal changes. Furthermore, for Cd, no significant relation observed among gill, liver, and muscle within each sampling region (\(p > 0.05\)) in both pre- and post-monsoon.

During pre-monsoon, the highest level of Pb in pangas gill was observed in Trishal (0.6517 mg/kg) and the lowest in Muktachaga (0.11 mg/kg). In the liver, higher concentration was documented in Muktachaga (2.15 mg/kg) and lower in the Trishal region (0.0 mg/kg). However, in muscle, the highest level of Pb was 1.1917 mg/kg in Trishal and the lowest in the farms of Bhaluka (0.0 mg/kg). This experiment confirmed the significant level of Pb composition in liver samples of Muktachaga rather than the gill and muscle samples of this region (\(p < 0.05\)). In the post-monsoon season, the concentration of lead (Pb) in the pangas organ estimated below the detection limit (BDL). Table 2 indicates that pangas of Muktachaga contained more Pb contents in pre-monsoon time than post-monsoon.

In the pre-monsoon period, the highest and lowest recorded nickel concentration was 120.78 mg/kg and 22.4367 mg/kg in muscle samples of Muktachaga and Bhaluka. There were no significant differences found among gill, liver, and muscle within the region (\(p > 0.05\)) (Table 2). During post-monsoon, farms of Muktachaga and Trishal showed the decreased value of Ni concentration in pangas organs and followed the sequence gill > liver = muscle. Nevertheless, in the farms of Bhaluka, the sequence

\[ EF \times ED \times FIR \times C \times CSF \]

\[ BW \times AT \]
was followed as muscle > liver > gill. The average Ni concentration of gill, liver, and muscle of pangas was insignificant within study areas (p > 0.05). Additionally, in pre-monsoon, pangas of Trishal carried a significant amount of Ni than samples of Muktagacha and Bhaluka. Even Ni contents of Trishal and Bhaluka showed significantly higher accumulation in the pre-monsoon period than in the post-monsoon (Table 2).

Copper (Cu) concentration of liver samples of Muktagacha, Trishal, and Bhaluka showed significant variation in comparison to gill and muscle samples, in the pre-monsoon season (Table 2). On the other hand, during post-monsoon, copper accumulation in different organs of Muktagacha was in the order of gill = muscle > liver, whereas in Trishal, the order was muscle > liver > gill and in Bhaluka that was muscle > gill > liver. In the pangas of Muktagacha zone, a higher amount of Cu concentration was estimated in pre-monsoon than in post-monsoon. Besides, no significant variation was observed in Cu values among three sampling sites within each sample collection period (Table 2).

In the pre-monsoon time, the highest recorded concentration of chromium (Cr) in gill was 0.0933 mg/kg in Trishal, and the lowest value was 0.0 mg/kg in Muktagacha. In pangas liver, the highest concentration observed in Trishal (0.1567 mg/kg) and BDL (below detection level) in Muktagacha and Bhaluka. In muscle samples, higher concentration estimated in Muktagacha (0.0933 mg/kg) and BDL in Bhaluka and Trishal. Moreover, Cr content was nil/below the detection limit in post-monsoon time. In both pre- and post-monsoon periods, there were no significant differences found among organs within each region (p > 0.05). Similarly, pangas of sampling sites did not show any significant relation in seasonal variations (Table 2).

Table 2 Metal concentrations (mg/kg, dry weight ± SEM) in pangas organs of three sampling sites of this study where n defines number of samples (n = 9 in pre-monsoon and n = 3 in post-monsoon)

| Sampling site | Organ of pangas | Sampling season | Cd     | Pb     | Ni       | Cu       | Cr       |
|---------------|----------------|----------------|--------|--------|----------|----------|----------|
| Muktagacha    | Gill           | Pre-monsoon    | 0.03 ± 0.02a | 0.11 ± 0.06a | 23.35 ± 3.26a | 1.33 ± 0.14a | 0.00 ± 0.00a |
|               |                | Post-monsoon   | 0.73 ± 0.00a | 0.00 ± 0.00a | 3.79 ± 0.00a  | 0.73 ± 0.00a | 0.00 ± 0.00a |
|               | Liver          | Pre-monsoon    | 0.09 ± 0.05a | 2.15 ± 0.18b | 62.37 ± 17.45a | 35.47 ± 9.51b | 0.00 ± 0.00a |
|               |                | Post-monsoon   | 0.62 ± 0.00a | 0.00 ± 0.00a | 0.00 ± 0.00a  | 0.62 ± 0.00a | 0.00 ± 0.00a |
|               | Muscle         | Pre-monsoon    | 0.05 ± 0.01a | 0.24 ± 0.24a | 60.5 ± 31.94a | 1.03 ± 0.24a | 0.09 ± 0.09a |
|               |                | Post-monsoon   | 0.73 ± 0.00a | 0.00 ± 0.00a | 0.00 ± 0.00a  | 0.73 ± 0.00a | 0.00 ± 0.00a |
| Total pangas contain | Pre-monsoon | 0.06 ± 0.02a | 0.83 ± 0.34a | 48.74 ± 12.32a | 12.61 ± 6.34a | 0.03 ± 0.03a |
|               |                | Post-monsoon   | 0.69 ± 0.04a | 0.00 ± 0.00a | 1.26 ± 1.26a  | 0.69 ± 0.04a | 0.00 ± 0.00a |
| Trishal        | Gill           | Pre-monsoon    | 0.03 ± 0.02a | 0.65 ± 0.57a | 36.60 ± 13.75a | 1.50 ± 0.19a | 0.09 ± 0.09a |
|               |                | Post-monsoon   | 0.51 ± 0.00a | 0.00 ± 0.00a | 6.32 ± 0.00a  | 0.51 ± 0.00a | 0.00 ± 0.00a |
|               | Liver          | Pre-monsoon    | 0.05 ± 0.01a | 0.00 ± 0.00a | 47.70 ± 12.51a | 43.30 ± 8.76a | 0.16 ± 0.08a |
|               |                | Post-monsoon   | 0.73 ± 0.00a | 0.00 ± 0.00a | 0.00 ± 0.00a  | 0.73 ± 0.00a | 0.00 ± 0.00a |
|               | Muscle         | Pre-monsoon    | 0.03 ± 0.02a | 1.19 ± 0.67a | 102.78 ± 37.12a | 0.60 ± 0.31a | 0.00 ± 0.00a |
|               |                | Post-monsoon   | 0.79 ± 0.00a | 0.00 ± 0.00a | 0.00 ± 0.00a  | 0.79 ± 0.00a | 0.00 ± 0.00a |
| Total pangas contain | Pre-monsoon | 0.04 ± 0.01a | 0.61 ± 0.31a | 62.36 ± 15.76a | 15.13 ± 7.48a | 0.08 ± 0.04a |
|               |                | Post-monsoon   | 0.68 ± 0.09a | 0.00 ± 0.00a | 2.11 ± 2.11a  | 0.68 ± 0.09a | 0.00 ± 0.00a |
| Bhaluka        | Gill           | Pre-monsoon    | 0.05 ± 0.01a | 0.24 ± 0.24a | 39.91 ± 16.69a | 1.62 ± 0.20a | 0.03 ± 0.03a |
|               |                | Post-monsoon   | 0.62 ± 0.00a | 0.00 ± 0.00a | 0.00 ± 0.00a  | 0.62 ± 0.00a | 0.00 ± 0.00a |
|               | Liver          | Pre-monsoon    | 0.06 ± 0.01a | 1.92 ± 1.58a | 37.70 ± 14.21a | 45.94 ± 4.58a | 0.00 ± 0.00a |
|               |                | Post-monsoon   | 0.45 ± 0.00a | 0.00 ± 0.00a | 1.27 ± 0.00a  | 0.45 ± 0.00a | 0.00 ± 0.00a |
|               | Muscle         | Pre-monsoon    | 0.04 ± 0.04a | 0.00 ± 0.00a | 22.44 ± 3.45a | 0.74 ± 0.23a | 0.00 ± 0.00a |
|               |                | Post-monsoon   | 0.68 ± 0.00a | 0.00 ± 0.00a | 8.22 ± 0.00a  | 0.68 ± 0.00a | 0.00 ± 0.00a |
| Total pangas contain | Pre-monsoon | 0.05 ± 0.01a | 0.72 ± 0.23a | 48.15 ± 7.21a | 14.61 ± 3.98a | 0.04 ± 0.02a |
|               |                | Post-monsoon   | 0.58 ± 0.07a | 0.00 ± 0.00a | 3.16 ± 2.55a  | 0.58 ± 0.07a | 0.00 ± 0.00a |
| Standard permissible limit | For fish     | 0.5§          | 0.5§          | 80‡          | 0.05†         |

**Notes:**
- a,b Illustrates (in column) significant differences among different organs in each region (ANOVA, p < 0.05); a and b represent (in column) seasonal variations in each sampling site (U test, p < 0.05); x and y denote (in row) significant variations among sampling sites in each sampling season (ANOVA, p < 0.05)
- § FAO/WHO (1989), ‡USFDA (1993), † WHO (2011)
Cd contents of post-monsoon samples of pangas tissues exceed the permissible limit of FAO/WHO (1989). Even Pb concentrations in pangas of three locations during pre-monsoon crossed the acceptable limit established by FAO/WHO (1989). A pre-monsoon muscle sample of Trishal contained an extreme amount of Ni that also flips the permissible limit. Also, all tested pre-monsoon liver samples of Mymensingh observed higher values of Cu contamination, which exceed the standard limit of FAO/WHO (2011) except in Bhaluka. The standard level of heavy metals in fish prepared by Bangladesh government are as follows: Cd ≤ 0.25 mg/kg, Pb = 0.30 mg/kg, Ni not defined, Cu = 5 mg/kg, and Cr = 1 mg/kg (MOFL 2014). According to this standard, total Cd contents in pangas during post-monsoon and Pb and Cu values exceeded permissible limit. On the contrary, Cr did not surpass this maximum acceptable level.

Several studies are summarized in Table 3 those worked on heavy metals contamination in different pangas species. In comparison with the present study, Hossain et al. (2016), Das et al. (2017), Duarte et al. (2019), Milenkovic et al. (2019), and Strungaru et al. (2020) confirmed a high concentration of Cd, Pb, Ni, and Cr in different organs of pangas, which exceeds the permissible level of intake. Besides, Kamruzzaman et al. (2018) studied the muscle of Pangasius sutchi collected from Messua Bazar of Mymensingh town, Bangladesh, in which the estimated values of Cd and Cr were lower than this research work. Another study on Pangasius pangasius muscle sampled from the agro-ecological zones of Bangladesh confirmed the similar lower loads of Cd, Pb, Ni, and Cu except Cr (Ahmed et al. 2015). On the other hand, higher Cd and Ni contents (0.616 and 231.50 mg/kg) in the liver of Pangasius hypophthalmus were reported by Hossain et al. (2016), this work validated the present investigation. The fish samples of Hossain et al. were collected from different fish markets of Dhaka city. Liver tissue is one of the indicators of environmental pollution due to the physiological role of this organ, where it acts as a significant deposition area of metals in the fish body (Henry et al. 2004). Higher copper contamination in liver tissue dealt with by Kim and Kang (2004), this study strongly justifies the situation of this research. In this experiment, the pangas muscle contained a significant amount of Ni rather than other fish tissue; this statement was partially supported by Mwakalapa et al. (2019). Ali and Khan (2018) assessing the concentration of Cr, Ni, Cd, and Pb in different

| Pangas species | Sampling sites | Organ type | Heavy metals | References |
|---------------|---------------|------------|--------------|------------|
| P. hypophthalmus | Mymensingh, Bangladesh | Muscle | <0.05 | Duarte et al. (2019) |
| P. hypothalas | Mymensingh, Bangladesh | Muscle | <0.05 | Strungaru et al. (2020) |
| P. pangasius | Bangladesh | Head | 0.01 ± 0.00 | Ahmed et al. (2015) |
| P. hypothalas | Dhaka city, Bangladesh | Muscle | 0.641 | Hossain et al. (2016) |
| P. hypothalas | Noakhali districts, Bangladesh | Muscle | 0.16 | Das et al. (2017) |
| P. sutchi | Imported from Vietnam for Brazilian supermarket | Edible part | 0.01 | Milenkovic et al. (2019) |
| P. sanitwongsei | Imported from Vietnam for Serbian supermarket | Edible part | 0.83 | - |
| P. hypophthalas | Imported from Vietnam for Romanian supermarket | Muscle | 0.0027 | - |
freshwater fish species of River Kabul, Pakistan found the average concentrations of Cr, Ni, Cd, and Pb in muscle samples of fish ranged from 12.3 to 33.0, 33.2 to 109.2, 0.98 to 1.5, and 13.9 to 29.6 mg/kg wet weight, respectively.

Research work on three cultured fish species [grass carp (Ctenopharyngodon idella), silver carp (Hypophthalmichthys molitrix), and mrigel (Cirrhinus cirrhosis)] of Muktagacha and Trishal fish farms ensured the higher accumulation of Cd (1.127 µg/g), Pb (18.98 µg/g), Ni (0.688 µg/g), Cu (15.197 µg/g), and Cr (15.097 µg/g) in the fish samples which were quite similar to the present experiment except for loads of Ni and Cr (Akter et al. 2020). However, a study to evaluate heavy metals soil pollution in Bhaluka region by Al Zabir et al. highlighted the devastating condition of that particular zone due to the on-growing industrialization and unplanned urbanization (Al Zabir et al. 2016).

Previous studies indicated several causes behind the excessive value of metals in fish, such as different anthropogenic ingredients (boating, use of antifouling paint, oil dropping, fishing, agrochemicals, etc.), overgrowing unbalance industrialization, natural geochemical properties, etc. (Al Zabir et al. 2016; Islam et al. 2018; Rajeshkumar and Li 2018; Hossain et al. 2018). Studies on heavy metals accumulation in fish farms pointing the source of contamination could be from sharing one-way waste discharge system of every pond in the farm area, a habitat of the farm, farm ecosystem condition, water quality issues of the farm system, and excessive use of growth supplements as feed additives (Ali and Amaal 2005; Li et al. 2010; Nofal et al. 2019).

Seasonal Comparison of Metal Contents in Pangas of Mymensingh District

Paired sample t-test of pre- and post-monsoon pangas sample of three studied areas in Mymensingh district is illustrated in Fig. 2. This figure showed statistically significant variations between studied seasons in each metal. Cd, Ni, and Cu contents were significantly higher in pre-monsoon than post-monsoon (Fig. 2). Additionally, in pre-monsoon of 2017, pangas samples contained a higher value of Pb (pre-monsoon = 0.72 ± 0.23 and post-monsoon = 0.00 ± 0.00 mg/kg), Ni (pre-monsoon = 48.15 ± 7.21 and post-monsoon = 2.18 ± 1.06 mg/kg), Cu (pre-monsoon = 14.61 ± 3.98 and post-monsoon = 0.65 ± 0.04 mg/kg), and Cr (pre-monsoon = 0.04 ± 0.02 and post-monsoon = 0.00 ± 0.00 mg/kg) except in the Cd (pre-monsoon = 0.05 ± 0.01 and post-monsoon = 0.65 ± 0.04 mg/kg). Figure 2 also defines that the total amount of each metal loads in pangas samples of Mymensingh always remained below the acceptable limit. Pal and Maiti (2018) observed the higher concentration of Cd, Pb, and Cr during the pre-monsoon season; their findings are consistent with present experiment. Similar observations obtained by Saha et al. (2016) agreed with this investigation where they worked on the pangas sample. Worldwide several studies established seasonal effects on metal deposition in fish (Gu et al. 2017; Rajeshkumar and Li 2018; Sow et al. 2019; Sunjog et al. 2019. Besides, higher cadmium loads in Panulirus homarus during post-monsoon were also observed by Mahdi Abkener et al. (2018) that has similar situation with this study. In Bangladesh, after the heavy rainfall in monsoon, washout of agricultural effluents, industrial wastages, batteries, and alloys directly come to add in the open water supply system that could be a great source of Cd contamination during post-monsoon period. Association between effluent dumping with potential toxic substance availability into aquatic biota was described by Baeyens et al. (1998); Wang and Wang (2016).
Association Between Heavy Metals Within Each Sampling Sites

During pre- and post-monsoon, association between heavy metals differed within each sampling area, which presented in Tables 4 and 5 with star signs (Pearson’s correlation test, 1 and 5% significance level). During pre-monsoon, only Pb (0.83 mg/kg) and Cu (12.61 mg/kg) contents of Mukttagacha pangas were in a strong positive linear association between these metals. On the other hand, the post-monsoon concentration of Cd and Cu in every studied site showed an entirely positive linear correlation between them. However, the p-value of Cd, Pb, and Cu was < 0.05 in every season; consequently, it could determine that there was a linear association among metals in each sampling site (Tables 4 and 5). On the other hand, Table 6 suggests the correlated metals of pangas in Mymensingh districts, and the positively related pairs were like Pb–Ni (0.44), Pb–Cu (0.36), Ni–Cu (0.146), Ni–Cr (0.025), and Cu–Cr (0.175), respectively. Besides, three pairs showed significant association where two pairs (Pb–Ni and Pb–Cu) were positively involved and one negatively (Cd–Ni), Girgis et al. (2019) confirmed a positive association with the level of metallothionein (MT) and loads of Pb and Cu across seasonal changes.

Analysis of Metal Accumulation in Feed and Pangas

Figure 3i–v represents an average accumulation of Cd, Pb, Ni, Cu, and Cr in feed and pangas collected from farms of Mukttagacha, Trishal, and Bhaluka regions of Mymensingh district during pre-monsoon.

In feed samples, the highest concentration of cadmium (Cd) was recorded in Bhaluka (0.8967 mg/kg) and the lowest in Mukttagacha (0.3767 mg/kg), whereas in pangas samples, the concentration of Cd was the highest in Mukttagacha (0.0589 mg/kg) and the lowest in Trishal (0.0372 mg/kg). Besides, feed and pangas of Mukttagacha
and Bhaluka contained a significantly higher level of Cd than Trishal (p < 0.05, Fig. 3 i). On the other hand, Fig. 3 (ii) shows the higher level of lead (Pb) in feed samples of Muktagacha (0.1867 mg/kg) and BDL in Bhaluka and Trishal. In pangas, the concentration of Pb was the highest in Muktagacha (0.8317 mg/kg) and the lowest in Trishal (0.6145 mg/kg). Similarly, Pb content in feed and pangas of Muktagacha and Trishal was significantly higher than that

Fig. 3 (i–v) Mean (± SEM) concentration of the Cd, Pb, Ni, Cu, Cr in feed and pangas collected from farms of Muktagacha, Trishal, and Bhaluka of Mymensingh district during pre-monsoon. Bars with stars are significantly different within feed and pangas (ANOVA, p < 0.05). Red disconnected lines with values indicate maximum permissible limit of the studied metals where superscripts a, b, c on feed values represent FAO/WHO (1984), EC (2003), WHO (1985), respectively, similarly, on pangas define FAO/WHO (1989), USFDA (1993), WHO (2011), respectively.
of Bhaluka (p < 0.05, Fig. 3ii). The highest value of nickel (Ni) was recorded in Muktagacha feed sample (684.30 mg/kg) and the lowest concentration was found in feed of Bhaluka (207.27 mg/kg), whereas pangas of Trishal region contained higher amount of Ni (62.3578 mg/kg) than that of Muktagacha and Bhaluka (48.7411 mg/kg and 33.3467 mg/kg). Nickel concentration in feed and pangas of Muktagacha significantly differed from other studied regions (p < 0.05, Fig. 3iii). Figure 3iv shows the higher value of copper (Cu) in feed of Bhaluka (5.88 mg/kg) and the least concentration observed in feed of Muktagacha (5.18 mg/kg). In pangas sample, the concentration of Cu was the highest in Bhaluka (16.1 mg/kg) and the lowest in Muktagacha (12.6067 mg/kg). Cu contents significantly varied in Trishal and Bhaluka with respect to Muktagacha (p < 0.05, Fig. 3iv). However, chromium concentrations in feed samples were below detection level (BDL) for all sampling sites, whereas pangas samples contained the highest Cr value in Trishal (0.0833 mg/kg) and the lowest in Bhaluka (0.0111 mg/kg). There were no significant differences among feed and pangas within the studied sites (p > 0.05, Fig. 3v).

Figure 4i–iv explains the mean heavy metal composition of Cd, Pb, Ni, and Cu in feed and pangas samples, collected from farms of Muktagacha, Trishal, and Bhaluka of Mymensingh region during post-monsoon.

Figure 4i describes that in Muktagacha, the concentrations of cadmium (Cd) in pangas and their feed were 0.6933 mg/kg and 0.3769 mg/kg, respectively. However, in Trishal, the accumulation of cadmium in pangas and their feeds was 0.675 mg/kg and 0.4233 mg/kg, respectively. In Bhaluka, the concentration of Cd in pangas (0.5817 mg/kg) was lower than their feed (0.8967 mg/kg). On the other hand, Fig. 4 (ii) shows that in Muktagacha, the concentration of lead (Pb) in pangas was BDL, but their feed had 0.1867 mg/kg. No trace of Pb was confirmed in pangas and feed samples, which were collected from Trishal and Bhaluka.

Fig. 4 (i–iv) Mean (± SD) concentration of the Cd, Pb, Ni, and Cu in feed and pangas collected from farms of Muktagacha, Trishal and Bhaluka upazilas of Mymensingh district during post-monsoon. Bars with stars are significantly different within feed and pangas (ANOVA, p < 0.05). Red disconnected lines with values indicate maximum permissible limit of the studied metals where superscripts a, b on feed values represent FAO/WHO (1984), EC (2003), respectively, similarly, on pangas define FAO/WHO (1989), USFDA (1993), respectively.
Bhaluka. In Muktagacha, the concentration of Ni in pangas (1.2633 mg/kg) was too lower than their feed Ni concentration (684.3 mg/kg) (Fig. 4iii). In Trishal, this value was 2.1067 mg/kg in pangas, which was too lower than their feed concentration (454.333 mg/kg). In Bhaluka, the concentration of Ni in pangas (2.1067 mg/kg) was also lower than their feed (207.27 mg/kg). Figure 4i–iii shows there are no significant differences in Cd, Pb, and Ni composition in feed and pangas (p > 0.05). Nevertheless, copper concentration significantly varied in all feed and pangas samples of studied areas (p < 0.05) (Fig. 4iv). Cu content was lower in the Muktagacha pangas sample (0.6933 mg/kg) than in their feed sample (5.1883 mg/kg). Also, in Trisha and Bhaluka region, the estimated concentration of Cu in the pangas feed sample was higher than that in the pangas sample. In this study, any contamination due to the presence of chromium was not recorded both in feed and pangas of the studied regions during post-monsoon.

Furthermore, this study confirmed the effect of feed metal contents in the variation of metal loads in pangas (Table 7). A multiple linear regression model was used to find out the effect and the final regression model for this study was $Y$ (metals in pangas) = $\alpha$ (intercept of unstandardized co-efficient) + $\beta_1 \times (X_1 = \text{Cd in feed}) + \beta_2 \times (X_2 = \text{Pb in feed}) + \beta_3 \times (X_3 = \text{Ni in feed}) + \beta_4 \times (X_4 = \text{Cu in feed}) + \beta_5 \times (X_5 = \text{Cr in feed})$ for the estimation; all the required values are listed in Table 7. Among all the relation-establishment testing of feed metal contents on metal accumulation in pangas, only feed contaminated with Ni significantly contributed to the Cu deposition in pangas ($p$-value 0.027, which was < 0.05). Table 7 determines that the estimated $\alpha$ of the tested model was -14.783, which defines on average the change of Cu in pangas was 14.783% when the feed sample was 0.009, which explained the effect of a 1% change of Ni loads in feed could change 0.009% of the Cu feed sample was 0.009, which explained the effect of a 1% change of Ni loads in feed could change 0.009% of the Cu concentration in pangas. Besides, in this situation, $R^2$ was 0.907 which implies that 90.7% of the total variation of Cu contents in pangas can be explained by the regression model or by the variation of feed with Ni loads (Table 7).

Different works have been done on heavy metals contamination in fish feed samples (Fallah et al. 2011; Anhwange et al. 2012; Saha et al. 2018; Sabbir et al. 2018; Mo et al. 2019; Ali et al. 2019). In this study, Ni contents of feed samples in the studied locations exceed the permissible levels of EC (2003). Other metal loads positioned below the acceptable limits of FAO/WHO (1984), WHO (1985). The Cd and Cu concentrations of the tested feed were found to show similar patterns as described by Saha et al. (2018) (listed in Table 8). Lower values of Pb and Cr in the studied fish feeds were supported by Mo et al. (2019), Anhwange et al. (2012), Fallah et al. (2011). In the manufacturing of fish feed, Cu is one of the essential growth enhancers used as feed additives, which could be the cause of higher accumulation of copper in pangas (Burridge et al. 1999). The extreme contamination of nickel in the fish feed samples was observed in the present study where this high value may enter the fish feed through the raw materials (Saha et al. 2018).

**Evaluation of Human Health Risk**

**Estimation of Daily Intake of Metals**

Figure 5i–iv demonstrates the estimated daily intake (EDI) (mg/day) of heavy metals due to their intake by pangas. In 2017, pangas of Mymensingh district followed a descending order for EDI of each metal through the consumption of this fish and the order was Ni (58.2986 mg/day) > Cu (17.1353 mg/day) > Pb (1.5813 mg/day) > Cd (0.5720 mg/day) > Cr (0.1540 mg/day). Figure 5i presents the EDI distribution against studied metal concentrations of Muktagacha, where nickel contents of pangas showed the maximum EDI value of 47.806 mg/day and minimum Ni value of 1.0422 mg/day. On the other hand, in that region, the lowest daily consumption of heavy metal of average adults was chromium (max. 0.5720 mg/day and min.nil). Similarly, Trishal and Bhaluka exhibited the same pattern described above. Furthermore, this study confirmed an average adult of Mymensingh ingested a higher amount of Ni and Cu in contrast to the recommended intake limit of JECFA (2019) (Fig. 5i–iv).

**Non-carcinogenic Risk Estimation**

The boxplots of heavy metals displayed the range of non-carcinogenic risk in Fig. 6i–iv. Through the consumption of pangas of the experimented sites could be the key route of Ni intake in the body of an adult. The range of THQ of Ni was 0.052–2.915, in which the THQ value exceeds the acceptable threshold 1 (USEPA 2011). Besides this, other metals, viz., Cd (0.017–0.572), Pb (nil—0.452), Cu (0.012–0.428), and Cr (nil—1.03E – 4), occupied the below acceptable threshold. Overall, the highest Ni THQ recorded in Trishal and the lowest in tested pangas of Muktagacha. Therefore, the order of non-carcinogenic risk of tested metals in 2017 was Ni > Cd > Pb > Cu > Cr. Risk level of Ni could contribute to the serious concerning issue for residents of Trishal as well as for the human health of Mymensingh even in all over Bangladesh.

Additionally, the order of HI (Hazard Index) in the sampling areas was $HI_{\text{Trishal}} (9.837) > HI_{\text{Muktagacha}} (8.184) > HI_{\text{Bhaluka}} (6.375)$ (Table 9). If we considered the individual sampling sites, no one crosses the acceptable limit of hazard index suggested by literature (Lei et al. 2015; Dadar et al.
Table 7  Multiple regression model results for testing the effect of changing different feed heavy metals concentrations on studied pangas metal compositions used for their feeding in farms of Mymensingh

| Response variable | Intercept/ α | Predictors in the model | Estimated β value | SE   | P value of t-test | P value of F-test | F ratio | R2   | Adjusted R2 |
|-------------------|--------------|--------------------------|-------------------|------|------------------|------------------|---------|------|-------------|
| Cd in Pangas      | −0.089       | Cd in Feed β1            | −0.011            | 0.041| 0.807            | 0.4433           | 1.164   | 0.538| 0.076 |
|                   |              | Pb in Feed β2            | 0.116             | 0.06 | 0.127            |                  |         |      |             |
|                   |              | Ni in Feed β3            | 2.940E−6          | 3.174E−5| 0.931          |                  |         |      |             |
|                   |              | Cu in Feed β4            | 0.0241            | 0.019| 0.282            |                  |         |      |             |
|                   |              | Cr in Feed β5            | 0                 | 0    |                  |                  |         |      |             |
| Pb in Pangas      | −0.287       | Cd in Feed β1            | −0.819            | 1.317| 0.568            | 0.9425           | 0.171   | 0.146| -0.709 |
|                   |              | Pb in Feed β2            | 0.630             | 1.930| 0.761            |                  |         |      |             |
|                   |              | Ni in Feed β3            | −0.001            | 0.01 | 0.634            |                  |         |      |             |
|                   |              | Cu in Feed β4            | 0.299             | 0.621| 0.655            |                  |         |      |             |
|                   |              | Cr in Feed β5            | 0                 | 0    |                  |                  |         |      |             |
| Ni in Pangas      | 54.92        | Cd in Feed β1            | −42.676           | 27.1704| 0.1914         | 0.5114           | 0.9699  | 0.492| −0.015 |
|                   |              | Pb in Feed β2            | 0.122             | 39.833| 0.998           |                  |         |      |             |
|                   |              | Ni in Feed β3            | −0.0087           | 0.021| 0.6985           |                  |         |      |             |
|                   |              | Cu in Feed β4            | 3.820             | 12.814| 0.7804          |                  |         |      |             |
|                   |              | Cr in Feed β5            | 0                 | 0    |                  |                  |         |      |             |
| Cu in Pangas      | −14.783      | Cd in Feed β1            | 3.146             | 3.337| 0.399            | **0.0244**       | 9.7486  | 0.907| 0.814 |
|                   |              | Pb in Feed β2            | −10.984           | 4.892| 0.088            |                  |         |      |             |
|                   |              | Ni in Feed β3            | 0.009             | 0.003| **0.027**        |                  |         |      |             |
|                   |              | Cu in Feed β4            | 4.361             | 1.574| 0.0503           |                  |         |      |             |
|                   |              | Cr in Feed β5            | 0                 | 0    |                  |                  |         |      |             |
| Cr in Pangas      | 0.109        | Cd in Feed β1            | −0.227            | 0.102| 0.091            | 0.3097           | 1.701   | 0.6298| 0.2596|
|                   |              | Pb in Feed β2            | −0.252            | 0.1495| 0.167           |                  |         |      |             |
|                   |              | Ni in Feed β3            | −8.464E−5         | 7.879E−5| 0.343          |                  |         |      |             |
|                   |              | Cu in Feed β4            | 0.0205            | 0.048| 0.692            |                  |         |      |             |
|                   |              | Cr in Feed β5            | 0                 | 0    |                  |                  |         |      |             |

Bold values represent their significance at 5% level.
confirmed less non-carcinogenic risk effects due to the ingestion of pangas.

**Carcinogenic Risk Calculation**

The present study found that the estimated value of lead (Pb), tested from all sites of Mymensingh in pre-monsoon season, was between $10^{-4}$ and $10^{-6}$; this posed the tolerable and negligible cancer-causing hazard risk. Figure 7 shows the carcinogenic risk (CR) of Pb due to the ingestion of pangas of the tested sites. In post-monsoon, the carcinogenic risk (CR) was not estimated because the concentration of Pb was below the detection limit (BDL). The highest CR of Pb detected from pangas of Muktagacha (0.00384), then Trishal (0.00214) and Bhaluka (0.00156). The descending order of the median CR of Pb was Muktagacha (5.832E $-06$) > Bhaluka (5.03E $-06$) > Trishal (4.309E $-06$). According to USEPA (2010), when the CR value lies under $10^{-6}$ that could be considered as negligible risk due to exposure of an average adult but when this condition turns into more than $10^{-4}$ that reach to the serious cancer risk. Figure 7 clearly depicts the actual scenario of the studied location and confirms the tolerable health issues due to the consumption of Pb contained pangas. This situation was also supported by Baki et al. (2018) and Ahmed et al. (2019) where the range of carcinogenic risk value of Pb was 7.99E $-07$ to 1.24E $-05$ and 8.48E $-08$ to 1.79E $-05$ in a studied fish species collected from Saint Martin Island and Karnaphuli river of Bangladesh. Pal and Maiti (2018) confirmed their estimated CR of Pb contents suspended on the acceptable limit in cultured *Labeo rohita* and *Labeo bata*. However, Ahmed et al. (2015) worked on Rui (*Labeo rohita*), Pangas (*Pangasius pangasius*) and Tilapia (*Oreochromis mossambicus*) collected from markets of 30 agro-ecological zones in Bangladesh and found an acceptable carcinogenic value.

**Table 8** Metal contents (mg/kg) in different feeds of fish and crustacean measured by several researchers in their studies

| Feed types  | Sampling sites                        | Details                                      | Heavy metals | References          |
|-------------|---------------------------------------|----------------------------------------------|--------------|---------------------|
| Fish feed   | Mymensingh, Bangladesh                | 3 commercial pangas feeds                    |              | Present study       |
|             |                                       | Feed 1:                                      | Pb: 0.18±0.13 | Feeds 1: 0.18±0.13 |
|             |                                       | Feed 2:                                      | Pb: 0.0±0.0  | Feeds 2: 5.19±0.38  |
| Shrimp feed | Bangladesh                            | 12 feeds                                     | Pb: 0.0±0.0  | Feeds 2: 5.67±0.25  |
| Fish feed   | Chaharmahal va Bakhtiari province, Iran| Commercial rainbow trout feed                | Pb: 0.0±0.0  | Feeds 2: 5.88±0.03  |
| Fish feed   | Makurdi metropolis, Nigeria           | Synthetic 2 feeds                            |              | Anhwange et al. (2012) |
| Fish feed   | South western region, Bangladesh      | Local fish feeds                             |              | Saha et al. (2018)  |
| Fish feed   | Hongkong, China                       | Fermented 2 diets (Nile tilapia &Jade perch) |              | Sabbir et al. (2018) |
| Fish feed   | UAE                                   | 3 types of pellet diets                      |              | Mo et al. (2019)    |

and confirmed less non-carcinogenic risk effects due to the ingestion of pangas.
of Pb which was $3.9 \times 10^{-6}$. This study also agreed with the present investigation.

### Metal Distribution in Pangas of Mymensingh Region by PCA and Cluster Analysis

Figure 8 displays a data reduction method, principal component analysis (PCA), used in this study to identify two principal factors/components that described 62.18% of the data variance. PCA analysis extracted two significant components (PC1 and PC2) from the dataset that hold eigenvalues more than 1 (Table 10). Component 1 stood with 40.4% of the metal values and exhibited the highest eigenvalue of 2.020, which explained that the PC1 shared the highest partition of the total variances in the multivariate dataset. On the other hand, the second-higher percentage of variance defined as PC2 that contains the eigenvalue of 1.088. Besides eigenvalue, drastic changes in the slope of the scree plot (Fig. 8) considered confirming the first two factors represented most of the variances of the dataset.

From the rotated component matrix and the biplot of Fig. 8 depicting the first component, PC1 shared the highest positive relation with Pb (0.787) and Ni (0.805) as well as the highest negative association with Cd. On the contrary, the second component, PC2, dealt with the maximum association with the contents of Cu (0.472) and Cr (0.910). The positively associated PC1 loads of Pb and Ni could consider as group1 that ensured their most probable common origin from Trishal. Nevertheless, without any substantial observations, this would not be assumed (Ashaiekh et al. 2019).

Higher concentrations of Pb and Ni indicate that maybe their presence was regulated by the feed used in the respective

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**Fig. 5** Boxplots representing estimated dietary intake (EDI) (mg/day) of studied metals from Muktagacha, Trishal, and Bhaluka (i–iii) and Mymensingh district (iv) in 2017 calculated from studied pangas sample. Red disconnected lines with values indicate a tolerable daily intake limit of studied metals where superscripts a, b, c denote provisional tolerable monthly intake (JECFA 2019), provisional tolerable weekly intake (JECFA 2019; Lin et al. 2004), provisional tolerable daily intake (FAO 2006), respectively
studied location or by the parameters of the geochemical properties of the area or because of the rapid industrialization in the study area (Hossain et al. 2015; Nguyen et al. 2020), whereas Cu and Cr contents could be accumulated from feed supplied in the studied area.

The present study also conducted cluster analysis (CA) on the estimated data, which helped group sampling sites that ensured similar share values across the different estimated metals. In row-wise consideration of Fig. 9, cluster 1

Table 9 Hazard index of studied heavy metals for average adult pangas consumer in Mymensingh district

| Sampling sites | HI   | Recommended HI (Lei et al. 2015)     |
|---------------|------|-------------------------------------|
| Muktagacha    | 8.184| HI ≤ 1 obvious adverse impact       |
| Trishal       | 9.837| HI > 1 most probable adverse impact  |
| Bhaluka       | 6.375| HI > 10 high or chronic of acute impact |

Fig. 6 Boxplots depicting target hazard quotients (THQ) of studied metals from Muktagacha, Trishal, and Bhaluka (i–iii) and Mymensingh district (iv) in 2017 calculated from the metal concentrations of studied pangas sample. Red dashed line indicates benchmark of non-carcinogenic hazardous condition (USEPA 2011)
exhibited the group of similar concentrations of metals than cluster 2 and so on. Every cluster indicated an individual common dataset among other clusters. The mean concentration of cluster 3 was the highest and the lowest mean observed in cluster 1. In cluster 2, most of the metal concentrations were found from two farms of Trishal, whereas in cluster 3, most values come from all three farms of Bhaluka.

On the contrary, in cluster 1, all the values represented an equal number of distributions in each site. Additionally, Fig. 9 reflects the highest number of variables lay in cluster 3 and the lowest in cluster 2. However, farms of Trishal contain the highest concentrations of Cd, Ni, Cu, and Cr in which the highest load of Pb observed in one farm of Bhaluka. The rapidly growing industrialization of Bhaluka region indicates an alarming scenario of the
polluted environment described by Al Zabir et al. (2016). Pb, Cu, Cr, and Cd contributed to this extreme situation in Bhaluka as well as in total Mymensingh district where industrial effluents or anthropogenic origins act as the primary source (Al Zabir et al. 2016; Hossain et al. 2015).

On the column of the dendrogram, distances between clusters helped understand the typical pattern between metals. Here, Fig. 9 confirms four clumps of the metals that contributed to four individually similar patterns in sampling sites but highly distinct among each other. The order of the clusters presented here based on the distance between clusters, like Pb–Ni (4.427, cluster 1) < Pb–Cu (5.323, cluster 2) < Pb–Cr (6.133, cluster 3) < Cd–Pb (7.470, cluster 4) (Fig. 9). Low distance between metals indicates their higher association or similar pattern of the data. Similarly, high distance reflects a lower association between metals or different patterns of the values. In this study, the Cd and Pb association of cluster 4 detects alternative data levels, like in post-monsoon, higher Cd

**Table 10** Rotated component matrix and total explained variance of metals of pangas in Mymensingh district where extraction method was principal component analysis and rotation method was varimax with Kaiser normalization

| Variable (PC) | Cd  | Pb  | Ni  | Cu  | Cr  | Eigenvalue | Variance % | Cumulative % |
|---------------|-----|-----|-----|-----|-----|------------|------------|--------------|
| Factor 1 (PC1)| −0.635 | 0.787 | 0.805 | 0.457 | −0.109 | 2.0204 | 40.408 | 40.408 |
| Factor 2 (PC2)| −0.402 | −0.064 | 0.0 | 0.472 | 0.910 | 1.0884 | 21.768 | 62.176 |

Rotation converged in 3 iterations

![Biplot of tested heavy metals in pangas of studied areas by principal component analysis (PCA). Right-bottom corner of this figure displays the scree plot of this PCA with two drastic slopes and eigenvalues](image-url)
concentrations were recorded from sampling locations but the lowest loads were estimated for Pb content.

Eventually, PCA and CA analyses depicted in Figs. 8 and 9 represented a similar pattern of data distribution and became useful to make decisions in the formation of groups among common sampling areas and to find out the origin of the metals (Simeonov et al. 2000).

**Conclusion**

Heavy metal contamination in food items, like fish, made this topic the most concerning issue as for the extreme health hazards. Keeping the alarming situation in mind, the present study was designed on the cultured pangas of Mymensingh to highlight the distribution of the metals in fish and the pattern of their risk on an adult human after consumption. Comprehensively shocking findings documented in this write-up is that a significantly higher deposition of Cd, Pb, Ni, and Cu was observed in pangas tissues in each tested site. Therefore, eating contaminated fish liver and muscle could be dangerous for human health. To seek out the source of metals accumulation, pangas and their feed samples were tested in which significant variations were observed in each study area. However, seasonal variations interfered changing the pattern of metals distribution, which was established in this study. Besides, in this investigation, elements with significant positive (between Pb–Ni and Pb–Cu) and negative (Cd–Ni) associations were recorded among sampling sites. Daily higher intake of Mymensingh

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**Fig. 9** Two-way cluster analysis of metal contents in pangas among sampling sites during pre- and post-monsoon of 2017, where yellow color indicates the lowest concentrations of each metal and dark blue represents the highest concentrations. Color palette from yellow to dark blue represents increasing trends of metal concentrations. The rightmost corner of the figure indicates the distance graph that plotted distances beneath the dendrogram. Each farm with three values represents three tested tissue samples (gill, liver, and muscle).
of metals crosses the recommended line that influenced the higher effects on non-carcinogenic health hazards. The highly adverse hazard index indicated the chronic risk of intake of pangas of studied sites. However, no carcinogenic risk was observed due to the lower CR value of lead. Thus, considering all the issues, the present study strongly recommended several strategies such as the incorporation of good quality fish feed in the farm, controlling the discharge of the industrial pollutants and other anthropogenic ingredients directly into the natural waterways, and the proper purification of the source water for aquaculture would be helpful to resolve this severe threat imposed on the human health, thereby sustaining the pangasius aquaculture in Bangladesh. In this study, we could not collect enough fish samples during the post-monsoon period. In the future work plan, the sample size of fish, water, and soil needs to be increased.

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Data Availability The data that support the findings of this study are available on request from the corresponding author.

References

Ahmed N (2009) Revolution in small-scale freshwater rural aquaculture in Mymensingh, Bangladesh. World Aqua 40:31–35
Ahmed G, Miah MA, Anawar HM, Chowdhury DA, Ahmad JU (2012) Influence of multi-industrial activities on trace metal contamination: An approach towards surface water body in the vicinity of Dhaka Export Processing Zone (DEPZ). Environ Monit Assess 184:4181–4190. https://doi.org/10.1007/s10661-011-2254-9
Ahmed MK, Shaheen N, Islam MS, Habibullah-al-Mamun M, Islam S, Mohiduzzaman M, Bhattacharjee L (2015) Dietary intake of trace elements from highly consumed cultured fish (Labeo rohita, Pangasius pangasius and Oreochromis mossambicus) and human health risk implications in Bangladesh. Chemosphere 128:284–292. https://doi.org/10.1016/j.chemosphere.2015.02.016
Ahmed ASS, Sultana S, Habib A, Ullah H, Musa N, Hossain MB, Rahman MM, Sarker MS (2019) Bioaccumulation of heavy metals in some commercially important fishes from a tropical river estuary suggests higher potential health risk in children than adults. PLoS ONE. https://doi.org/10.1371/journal.pone.0219336
Akter M, Zakir HM, Sharmim S, Quadir QF, Mehrin S (2020) Heavy metal bioaccumulation pattern in edible tissues of different farmed fishes of Mymensingh Area, Bangladesh and health risk assessment. Adv Res 21:44–55. https://doi.org/10.9734/air/2020/v21i430200
Al Zahir A, Zaman MWU, Hossen MZ, Uddin MN, Islam MS, Islam MS (2016) Spatial dissemination of some heavy metals in soil adjacent to Bhaluka industrial area, Mymensingh, Bangladesh. Am J Appl Sci Res 2:38–47
Ali MIH, Amaal MA (2005) Studies of some heavy metals in water, sediments, fish and fish diets in some fish farms in EL-Fayoum province. Egypt Egypt J Aquat Res 31:261–273
Ali H, Khan E (2017) What are heavy metals? Long-standing controversy over the scientific use of the term ‘heavy metals’—proposal of a comprehensive definition. Toxicol Environ Chem 100:6–19. https://doi.org/10.1080/02772272
Ali H, Khan E (2018) Assessment of potentially toxic heavy metals and health risk in water, sediments, and different fish species of River Kabul. Pakistan Hum Ecol Risk Assess 24:2101–2118. https://doi.org/10.1080/10807039.2018.1438175
Ali NAAH, Abu-Abdoulin II, Janaan AS, Hassan JH, Al Jeaidi MA (2019) Investigation of selected heavy metals concentration in animal feeds in United Arab Emirates. Chem Sci Int J 28:1–6. https://doi.org/10.9734/CSI/2019/v28i30139
Alizada N, Malik S, Muzaffar SB (2020) Bioaccumulation of heavy metals in tissues of Indian anchovy (Stolephorus indicus) from the UAE coast. Arabian Gulf Mar Pollut Bull 154:111033. https://doi.org/10.1016/j.marpollbul.2020.111033
Anhwange BA, Asemave K, Kim BC, Nyaatagher DT (2012) Heavy metals contents of some synthetic fish feeds found within Makurdi metropolis. Int J Food Saf Nutr Publ Health 2:55–61
Ashaikehr MA, Eltabey MAH, Ali AH, Ebrahim AM, Salih I, Idris AM (2019) Spatial distribution of total and bioavailable heavy metal contents in soil from agricultural, residential, and industrial areas in Sudan. Toxin Rev 38:93–105. https://doi.org/10.1080/15569543.2017.1419491
Baeyens W, Parmentier K, Goeyens L, Ducastel G, DeGietter M, Leermakers M (1998) The biogeochemical behaviour of Cd, Cu, Pb and Zn in the Scheldt estuary: results of the 1995 surveys. In: Baeyens WFI (ed) Trace metals in the Westerschelde Estuary: a case-study of a polluted, partially anoxic estuary. Hydrobiologia, vol 366. Springer, Dordrecht, pp 45–62
Baki MA, Hossain MM, Akter J, Quraishi SB, Haque Shojib MF, Atique Ullah AKM, Khan MF (2018) Concentration of heavy metals in seafood (fishes, shrimp, lobster and crabs) and human health assessment in Saint Martin Island. Bangladesh Ecotoxicol Environ Saf 159:153–163. https://doi.org/10.1016/j.ecoenv.2018.04.035
Barakat MA (2011) New trends in removing heavy metals from industrial wastewater. Arab J Chem 4:361–377. https://doi.org/10.1016/j.arabjc.2010.07.019
BBS (2015) Government of the People’s Republic of Bangladesh. Bangladesh Bureau of Statistics Ministry of Planning, Dhaka Burridge LE, Haya K, Zitko V, Waddy S (1999) The lethality of Salmonos (Azamethiphos) to American lobster (Homarus americanus) larvae, postlarvae, and adults. Ecotoxicol Environ Saf 43:165–169. https://doi.org/10.1006/eesa.1999.1771
CEPA (2009) Technical Support Document for Cancer potency Factors: Methodologies for derivation, listing of available values and adjustments to allow for early life stage exposures. https://oehha.ca.gov/media/downloads/crnr/tsdcancerpotency.pdf.
Dadar M, Adel M, Nasrollahzadeh Saravi H, Fakhri Y (2017) Seasonal variability of heavy metals in surface sediment of Lake Sapanca, Turkey. Environ Monit Assess 133:277–283. https://doi.org/10.1007/s10661-006-9580-3

EC (2003) Opinion of the scientific committee on animal nutrition on undesirable substances in feed. EC, Brussels

Elnimr T (2011) Evaluation of some heavy metals in fillets of Pangasius hypophthalmus (Sauvage, 1878), Panga, imported from Vietnam. Int J Fish Res 9:30181–30186

Duffus JH (2002) “heavy metals”—a meaningless term? (IUPAC technical report), Pure Appl Chem 74:793–807. https://doi.org/10.1351/pac200274050793

Duman F, Aksoy A, Demirezen D (2007) Seasonal variability of heavy metals in surface sediment of Lake Sapanca, Turkey. Environ Monit Assess 133:277–283. https://doi.org/10.1007/s10661-006-9580-3

FAO/WHO (1989) Evaluation of certain food additives and the contaminants by the Joint Food Additives, Codex Alimentarius Commission. FAO/WHO, Rome

FAO/WHO (1984) List of maximum levels recommended for contaminants by the Joint FAO/WHO. Codex Alimentarius Commission. FAO/WHO, Rome

FAO/WHO (1989) Evaluation of certain food additives and the contaminants mercury, lead and cadmium. WHO Technical Report, Series No. 505. FAO/WHO, Rome

Ferguson JE (1990) The heavy elements: chemistry, environmental impact and health effects. Pergamon Press, Oxford

García-Lestón J, Méndez J, Pásaro E, Laforn B (2010) Genotoxic effects of lead: an updated review. Environ Int 36:623–636. https://doi.org/10.1016/j.envint.2010.04.011

Girgis SM, Mabrouk DM, Hanna MI, ElRaouf AA (2019) Seasonal variation of heavy metals in settling particulate matter (SPM) from a typical southern Chinese mariculture base. Mar Pollut Bull 123:404–409. https://doi.org/10.1016/j.marpolbul.2017.08.044

Gray MA, Harrins A, Centeno JA (2005) The role of cadmium, zinc, and selenium in prostate disease. In: Moore TA, Black A, Centeno JA, Harding JS, Trumm DA (eds) Metal contaminants in New Zealand: sources, treatments, and effects on ecology and human health. Resolutionz Press, Christchurch, pp 393–414

Gu YG, Ouyang J, An H, Jiang SJ, Tang HQ (2017) Risk assessment and seasonal variation of heavy metals in settling particulate matter (SPM) from a typical southern Chinese mariculture base. Mar Pollut Bull 123:404–409. https://doi.org/10.1016/j.marpolbul.2017.08.044

Henry F, Amara R, Courcot L, Lacouture D, Bertho ML (2004) Heavy metals in four fish species from the French coast of the Eastern English Channel and Southern Bight of the North Sea. Environ Int 30:675–683. https://doi.org/10.1016/j.envint.2003.12.007

Hodson PV (1988) The effect of metal metabolism on uptake, disposition and toxicity in fish. Aquat Toxicol 11:3–18. https://doi.org/10.1016/0045-6535(88)90003-3

Hossain MS, Zakir HM, Rahman MS, Islam MM (2015) Toxic metal contamination in wastewater of some industrial areas of Mymensingh town, Bangladesh. Adv Arch. City Environ 1:7–13

Hossain A, Saha B, Rahman MM, Moniruzzaman M, Begum M (2016) Heavy metal concentration and its toxicity assessment in some market fishes of Dhaka city. Int J Fish Aquat Stud 4:523–527

Hossain MB, Ahmed ASS, Sarker MSI (2018) Human health risks of Hg, As, Mn, and Cr through consumption of fish, Ticto barb (Puntius ticto) from a tropical river. Bangladesh Environ Sci Pollut Res 25:31727–31736. https://doi.org/10.1007/s11356-018-3158-9

Huq SML, Alam MD (2005) A handbook on analysis of soil, plant and water. Bangladesh-Australia Centre for Environmental Research (BACER-DU). University of Dhaka, Dhaka, pp 1–246

Ibekwe A, Egiebor NO (2005) Assessment of trace elements in canned fishes (mackerel, tuna, salmon, sardines and herrings) marketed in Georgia and Alabama (United States of America). J Food Comp Anal 18:771–787. https://doi.org/10.1016/j.jfca.2004.11.002

Islam S, Ahmed K, Habibullah-Al-Mamun M, Masunaga S (2015) Potential ecological risk of hazardous elements in different land-use urban soils of Bangladesh. Sci Total Environ 512–513:94–102. https://doi.org/10.1016/j.scitotenv.2014.12.100

Islam GMR, Habib MR, Wadl J, Rahman MS, Kabir J, Akter S, Jolly YN (2017) Heavy metal contamination of freshwater prawn (Macrobachium rosenbergii) and prawn feed in Bangladesh: a market-based study to highlight probable health risks. Chemosphere 170:282–289. https://doi.org/10.1016/j.chemosphere.2016.11.163

Islam MS, Hossain MB, Matin A, Islam Sarker MS (2018) Assessment of heavy metal pollution, distribution and source apportionment in the sediment from Feni River estuary, Bangladesh. Chemosphere 202:25–32. https://doi.org/10.1016/j.chemosphere.2018.03.077

JECFA (2019) Joint FAO/WHO Expert Committee on Food Additives. Food Contaminants. http://apps.who.int/foodadditives-contaminants-ts/jecefa-database/search.aspx Accessed 24 May 2020.

Kamruzzaman, Mahamud MA, Alim A, Hossen MS, Islam MA, Munir MA (2018) Study on heavy metal content of Oreochromis niloticus, Heteropeucese fossils and Pangasiusutchi collected from pond and open water. Res. Agric. Livest. Fish. 5:117–126. https://doi.org/10.3329/ralf.v5i1.36560

Kim SG, Kang JC (2004) Effect of dietary copper exposure on accumulation, growth and histological parameters of the juvenile rockfish, Sebastes schlegeli. Mar Environ Res 58:65–82. https://doi.org/10.1016/j.marenvres.2003.12.004

Le HT, Ngo HTT (2013) Cd, Pb, and Cu in water and sediments and their bioaccumulation in freshwater fish of some lakes in Hanoi. Vietnam Toxicol Environ Chem 95:1328–1337. https://doi.org/10.1016/j.tjoralf.2013.07.002

Lei M, Tie BQ, Song ZG, Liao BH, Lepo JE, Huang YZ (2015) Potential ecological risk of hazardous elements in different land-use urban soils of Bangladesh. Sci Total Environ 512–513:94–102. https://doi.org/10.1016/j.scitotenv.2014.12.100

Loutfy N, Fuerhacker M, Tundo P, Raccanelli S, El Dien AG, Ahmed MT (2006) Dietary intake of dioxins and dioxin-like PCBs, due to the consumption of dairy products, fish/seafood and meat from Ismailia city. Egypt Sci Total Environ 370:1–8. https://doi.org/10.1016/j.scitotenv.2006.05.012
Mahdi Abkener A, Yahyavi M, Bahri A, Jafaryan H (2018) Assessment of heavy metals pollution in muscle of sole (Cynoglossus arel), spiny lobster (Panulirus homarus) and sediments in the northern coasts of the Oman Sea during pre and post monsoon. Iran J Fish Sci. https://doi.org/10.22092/jfs.2018.124017.1006

Mansour SA, Belal MH, Abou-Arab AAK, Gad MF (2009) Monitoring of pesticides and heavy metals in cucumber fruits produced from different farming systems. Chemosphere 75:601–609. https://doi.org/10.1016/j.chemosphere.2009.01.058

Milenkovic B, Stajic JM, Stojic N, Pucarevic M, Strbac S (2019) Evaluation of heavy metals and radionuclides in fish and seafood products. Chemosphere 229:324–331. https://doi.org/10.1016/j.chemosphere.2019.04.189

Mo WY, Man YB, Zhang F, Wong MH (2019) Fermented food waste for cultivating Jade perch and Nile tilapia: growth performance and health risk assessment based on metal/loids. J Environ Manag 236:236–244. https://doi.org/10.1016/j.jenvman.2019.01.102

MOFL (2014) Bangladesh Gazette, Bangladesh Ministry of Fisheries and Livestock, SRO no. 233/Ayen

Mwakalapa EB, Simukoko CK, Mmochi AJ, MdegeLA RH, Berg V, Bjorge Müller MH, Lyche JL, Polder A (2019) Heavy metals in farmed and wild milkfish (Chanos chanos) and wild mullet ( Mugil cephalus) along the coasts of Tanzania and associated health risk for humans and fish. Chemosphere 224:176–186. https://doi.org/10.1016/j.chemosphere.2019.02.063

Nguyen BT, Do DD, Nguyen TX, Nguyen VN, Phuc Nguyen DT, Nguyen MH, Thi Truong HT, Dong HP, Le AH, Bach QV (2020) Seasonal, spatial variation, and pollution sources of heavy metals in the sediment of the Saigon River. Vietnam Environ Pollut 256:113412. https://doi.org/10.1016/j.envpol.2019.113412

Nofal MI, Zaki VH, Ahmed NAS (2019) Effects of heavy metal pollution on Nile tilapia in Manzala farm: oxidative stress biomarkers and histopathological findings. Int J Fish Aquat Stud 7:315–328

Okland HMW, Stoknes IS, Remme JF, Kjerstad M, Synnes M (2005) Seasonal, spatial variation, and pollution sources of heavy metals in the muscle from deep-sea teleosts and elasmobranchs. Comp Biochem Physiol B Biochem Mol Biol 140:437–443. https://doi.org/10.1016/j.cbpc.2004.11.008

Orban E, Nevgiato T, Di Lena G, Masci M, Casini I, Gambelli L, Caproni R (2008) New trends in the seafood market. Sutchi catfish ( Pangasius hypophthalmus) fillets from Vietnam: nutritional quality and safety aspects. Food Chem 110:383–389. https://doi.org/10.1016/j.foodchem.2008.02.014

Pal D, Maiti SK (2018) Seasonal variation of heavy metals in water, sediment, and highly consumed cultured fish (Labeo rohita and Labeo bata) and potential health risk assessment in aquaculture pond of the coastal city, Dhanbad (India). Environ Sci Pollut Res 25:12464–12480. https://doi.org/10.1007/s11356-018-1424-5

Rajeshkumar S, Li X (2018) Bioaccumulation of heavy metals in fish species from the Meiliang Bay, Taihu Lake, China. Toxicol Rep 5:288–295. https://doi.org/10.1016/j.toxrep.2018.01.007

Rani Das P, Hossain MK, Sarkar BS, Parvin A, Swarna D, Moniruzzaman M, Saha B (2017) Heavy metals in farm sediments, feeds and bioaccumulation of some selected heavy metals in various tissues of farmed Pangasius hypophthalmus in Bangladesh. Fish Aquac J. https://doi.org/10.4172/2152-3508.1000218

USEPA, 2020. Regional Screening Levels (RSL). Superfund Risk Assessment. https://epa-props.orl.gov/cgi-bin/chemicals/csi_search.pl. Accessed 19 Apr 2020

Sahib W, RahmanMZ, Khan MN, Sabir CW, Halder T, Ray S (2018) Assessment of heavy metal contamination in fish feed available in three districts of South Western region of Bangladesh. Int J Fish Aquat Stud 6:100–104

Saha N, Mollah MZI, Alam MF, Rahman MS (2016) Seasonal investigation of heavy metals in marine fishes captured from the Bay of Bengal and the implications for human health risk assessment. Food Control 70:110–118. https://doi.org/10.1016/j.foodcont.2016.05.040

Saha B, Mottalib MA, Al Razee ANM (2018) Assessment of selected heavy metals concentration in different brands of fish feed available in Bangladesh. J Bangladesh Acad Sci 42:207–210

Shahen N, Ahmed MK, Islam MS, Habibullah-Al-Mamun M, Tukkan AB, Islam S, Abu AT (2016) Health risk assessment of trace elements via dietary intake of “non-piscine protein source” food-stuffs (meat, milk and egg) in Bangladesh. Environ Sci Pollut Res 23:7794–7806. https://doi.org/10.1007/s11356-015-6013-2

Shamshad BQ, Shahidur RK, Tasrena RC (2009) Studies on toxic elements accumulation in shrimp from fish feed used in Bangladesh. J Food Ag-Ind 2:440–444

Siddiqi MR (2017) Urban environment and major challenges in sustain-able development: experience from Dhaka City in Bangladesh. South East Asia J Public Heal 7:12–16. https://doi.org/10.3329/seaiph.v7i1.34673

Simeonov V, Massart DL, Andreev G, Tsakovski S (2000) Assessment of metal pollution based on multivariate statistical modeling of “hot spot” sediments from the Black Sea. Chemosphere 41:1411–1417. https://doi.org/10.1016/S0045-6535(99)00540-8

Soy AW, Ismail A, Zulkifli SZ, Amal MN, Hambali K (2019) Seasonal variation of heavy metals and metallothionein contents in Asian swamp eels, Monopterus albus (Zuiew, 1793) from Tumpat, Kelantan. Malaysia BMC Pharmacol Toxicol 20:1–8. https://doi.org/10.1186/s40360-019-0286-x

Stone NJ (1996) Fish consumption, fish oil, lipids, and coronary heart disease. Circulation 94:2337–2340

Strungraru SA, Nicolaor M, Gorban CF, Paduraru E, Plavan GI (2020) Toxic metal contamination and total organic carbon content in the meat of the main fish species imported and sold in Romanian’s supermerkats. Survey Fish Sci 6:45–54

Sunjog K, Kolarević S, Kračun-Kolarević M, Višnjić-Jeftić Ž, Gačić Z, Lenhardt M, Vuković-Gačić B (2019) Seasonal variation in metal concentration in various tissues of the European chub (Squalius cephalus L.). Environ Sci Pollut Res 26:9232–9243. https://doi.org/10.1007/s11356-019-04274-3

Tchounwou PB, Yedjiou CG, Patlolla AK, Sutton DJ (2012) Molecular, clinical and environmental toxicology v3: environmental toxicology. Mol Clin Environ Toxicol 101:133–164. https://doi.org/10.1097/978-3-7643-8340-4

Türkmen A, Türkmen M, Tepe Y, Akyurt I (2005) Heavy metals in three commercially valuable fish species from Iskenderun Bay, Northern East Mediterranean Sea. Turkey Food Chem 91:167–172. https://doi.org/10.1016/j.foodchem.2004.08.008

USEPA (1989) Risk assessment guidance for superfund. Human Health Evaluation Manual. EPA/540/1-89/002. Office of Emergency and Remedial Response, v1, Washington, D.C.

USEPA (2010) Integrated Risk Information System (IRIS); United States Environmental Protection Agency: Washington, D.C., USA. http://www.epa.gov/ncea/iris/index.html. Accessed 1 May 2020

USEPA (2011) USEPA regional screening level (RSL) summary table: November 2011. https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables. Accessed 27 Apr 2020

USFDA (1993) Food and drug administration Guidance document for arsenic in shellfish. DHHS/PHS/FDA/CFSAN/Office of Seafood, Washington D.C.

Vannoor RW, Thomson BM (2005) 2003/04 New Zealand total diet survey—agricultural compound residues, selected contaminants and nutrients. https://www.mpi.govt.nz/dmsdocument/4004/direct t. Accessed 20 Aug 2020

Walker CH, Sibly RM, Hopkin SP, Peakall DB (2012) Principles of ecotoxicology, 4th edn. CRC Press, Boca Raton

Wang W, Wang WX (2016) Phase partitioning of trace metals in a contaminated estuary influenced by industrial effluent discharge.
Environ Pollut 214:35–44. https://doi.org/10.1016/j.envpol.2016.03.059

WHO (1985) Guidelines for drinking water quality. Recommendation
WHO, Geneva

WHO (2011) WHO guidelines for drinking water quality, 4th edn.
WHO Publications, Geneva, pp 307–340

Zhang H, Cui B, Xiao R, Zhao H (2010) Heavy metals in water,
soils and plants in riparian wetlands in the Pearl River Estuary.
South China Procedia Environ Sci 2:1344–1354. https://doi.org/10.1016/j.proenv.2010.10.145

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