Heavy Metal Intake from Meat and Poultry Consumption and Potential Human Health Risk Assessment in Noakhali, Bangladesh

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Abstract

Heavy metal contamination poses a significant food safety risk for human health in developing countries like Bangladesh. This study examined the quantities of heavy metals (Cd, Cr, Pb, Ni, Fe, and Cu) in commercially accessible meat, poultry, and game products in Noakhali, Bangladesh, and their carcinogenic and non-carcinogenic effects. Atomic Absorption Spectrophotometry was used to analyze heavy metals, and the health risk assessment was based on Estimated Daily Intake (EDI), Targeted Hazard Quotient (THQ), Total THQ, and Total Carcinogenic Risk (TCR). Most samples exceeded Maximum Allowable Concentrations (MAC) for heavy metals. The EDI value of Cd, Pb, and Cr for duck liver, goat liver, and pigeon brain, were higher than the Maximum Tolerable Dietary Intake (MTDI). Children had 1.28 times higher HI values than an adult. The calculation of THQ of all elements in adults and children was in the order of Cu > Pb > Ni > Cr > Cd > Fe. The calculated TTHQ values were in the range of 0.051 to 1.988 and 0.047 to 3.975 for adults and children, respectively. The TCR values for Cd in poultry liver, brain, and meat, Sonali chicken, cow, pigeon, duck, and goat liver were higher than the reference value for adults and children, suggesting a potential cancer risk.

Introduction

Heavy metal contamination is a global food safety concern, as it can occur in a variety of food products, including meat, fish, dairy, fruits, and vegetables [1, 2]. Dietary heavy metal exposure can have negative impacts on human health [3]. Heavy metals such as lead, cadmium, and mercury can accumulate in the body over time [4, 5], and exposure to high levels can lead to developmental delays, behavioral and learning problems, kidney damage, cancer, osteoporosis, and damage to the nervous, immune, and cardiovascular systems [5–7].

Heavy metal contamination in meat and poultry in Bangladesh is a concern. The primary sources of heavy metal contamination in meat and poultry in Bangladesh are believed to be from the feed, as well as from the environment. Contaminated feed can be a result of the use of pesticides, fertilizers, and industrial waste in agriculture, and also from contaminated water used to grow crops [8, 9]. The environment, including the soil, air, and water, can also be contaminated with heavy metals due to industrial activities, mining, and inadequate waste management [10]. However, even though animal meat supplies 30–40% of the country's protein needs [11], there is a paucity of published material in Bangladesh on the topic of heavy metals and the associated health risk in meat. Studies have found that meat and poultry products in the country can contain elevated levels of heavy metals. One study found that the levels of lead, cadmium, and chromium in chicken samples were higher than the permissible limits set by the World Health Organization (WHO) [12]. Another study reported that the higher levels of copper, cadmium, and chromium were higher in cattle and chicken [13]. There is no other study has been conducted to determine the heavy metal content and associated health risks through the consumption of spices in the coastal Noakhali region of Bangladesh.

The Noakhali region of Bangladesh is prone to heavy metal contamination due to a combination of factors. One primary reason is the widespread use of pesticides and fertilizers in agriculture, which can contaminate soil and water with heavy metals such as cadmium and lead [14]. Additionally, the region is known for its large shrimp farming industry, and the use of antibiotics and other chemicals in shrimp ponds can contribute to heavy metal contamination in the surrounding areas [15]. Furthermore, the Noakhali region is near the coast, making it vulnerable to sea level rise, salinity intrusion, and coastal erosion, which can contaminate the soil and water with heavy metals [16].

The objective of this study was to determine the levels of Cd, Cr, Pb, Ni, Fe, and Cu in Fresh meat, poultry, and game collected from the Noakhali district and assess the carcinogenic and non-carcinogenic effects of these metals from dietary intake.

Methods

Sample collection:

A total of 63 samples, specifically animal tissues (brain, muscle, and liver) from 7 varieties of animals, were collected from three different local markets of the Noakhali district of Bangladesh, namely Majidee Bazar, Pouro bazaar, and Sonapur Bazar. The global positioning system was used to map the sampling positions using QGIS software (v.3.10.2) (Fig. 1).

Heavy Metal Analysis:

Wet digestion of the collected sample was carried out using a 1:4 concentrated mixture of HNO3 (69% conc.) and H2SO4 (97% conc.). The mixture was heated with 0.5 g dehydrated homogenized sample from 130°C to 170°C using a thermostat-controlled heating block. The pre-digested samples were further digested by adding 2ml of H2O2 (30% conc.) and heated again to ensure organic matters free solutions. This step was replicated unless a colorless solution was generated. Following filtration, the clear solution was transferred to a 50 ml volumetric flask tube and topped up to the maximum with deionized water.

The heavy metal determination was performed with a PerkinElmer Inc. PinAAcleTM 900H Atomic Absorption Spectrometer (AAS) with a single beam and deuterium background correction. Limits of Detection and instrumental conditions during heavy metals analysis were calculated by following European Commission Guidelines (Supplementary table 1) [17]. Pb, Cd, Cr, and Ni were quantified by graphite furnace, while Fe and Cu were quantified by flame technique. The results of the validation of procedures were summarized in supplementary table 2. The mean recoveries of heavy metals were found in the range of 91.7-101.5%, and the correlation coefficient (R2) of metals ranged from 0.995 to 0.998.

Health risk assessment
The Health risk associated with heavy metal-contaminated meat consumption was assessed in terms of Estimated Daily Intake (EDI) of metals, Target Hazard Quotients (THQ), Hazard Index (HI), and Target Cancer Risk (TR) according to the standards of The US Environmental Protection Agency [18].

**Estimated daily intake (EDI)**

EDI is measured in mg/kg body weight/day [19]. To estimate EDI, the average metal content in each sample was calculated and multiplied by the respective consumption rate. Daily intake rate was determined by the following Eq. (1)

\[
\text{EDI} = \frac{MC \times IR}{BW}
\]

Where MC is the metal concentration in the meat, liver, and brain (mg/kg wet weight), and IR (kg/day/person) is the ingestion rate of the sample, which is taken as 7.54 g/day for beef, 0.55 g/day for mutton, 17.33 g/day for chicken/duck/others (quail, pigeon), for an adult individual of 60 kg (adult) body weight respectively according to "Report of the household income and expenditure survey 2016 [20]. For children, the average body weight was 30 kg [21], and the ingestion rate is 3.1g/day for beef, 0.3g/day for mutton, 8.3g/day for chicken, 1.7g/day for duck, quail, and pigeon [11]. The Bangladeshi population commonly consumes the liver of animals, especially children, and so, for accurate estimation, the ingestion rate of liver tissue and brain of animals was estimated as 3 g/day/BW [21].

**Non-carcinogenic risk:**

**Target Hazard Quotient (THQ)**

THQ is an estimation of the risk level (non-carcinogenic) due to pollutant exposure (Eq. 2). THQ was calculated as per USEPA Region III Risk-based Concentration Table [22] and in Wang et al. [23].

\[
THQ = \frac{EF \times ED \times FIR \times CM}{BW \times AT \times RfD} \times 10^{-3}
\]

Where EF is the exposure frequency (365 days/year), ED is the exposure duration (70 years for non-cancer risk in this study), as used by [24], FIR is the food ingestion rate (g/person/day) (BBS, 2016), CM is the heavy metal concentration in meat, liver, and brain (mg/kg, w/w), BW is the average body weight (bw) (adult: 60 kg and children: 30 kg) and AT is the average exposure time for non-carcinogens (EF×ED) (365 days/year for 70 years (i.e. AT = 25,550 days). The oral reference dose (RfD) of the metal (an estimate of the daily exposure to which the human population may be continuously exposed over a lifetime without an appreciable risk of deleterious effects) are based on 0.001, 0.003, 0.04, 0.02, and 0.004 (mg/kg-BW/day) for Cd, Cr, Cu, Ni, and Pb, respectively [22, 25, 26]. According to the guidelines of the Chinese Nutrition Society (CNS), the RfDs for Fe is 0.667 mg/kg-BW/ day [27, 28].

**Total Target Hazard Quotient (TTHQ)**

TTHQ for an individual from THQs is expressed as the sum of the hazard quotients (Eq. 3) [24].

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

**Hazard Index (HI)**

HI is assessed to estimate the overall potential for non-carcinogenic health risks from consuming more than one metal.

\[
HI = TTHQ (food_1) + TTHQ (food_2) + \ldots \ldots + TTHQ (food_{23})
\]

**Target Cancer Risk (TCR)**

TCR was used to indicate carcinogenic risks. The method to estimate TCR is also provided in USEPA Region III Risk-Based Concentration Table [24]. The model for estimating TCR was shown as follows (Eq. 4)

\[
TCR = \frac{EF \times ED \times FIR \times CM \times CPSo}{BW \times TA}
\]

Where CM is the metal concentration in meat (mg/kg), FIR is the meat ingestion rate (g/day), CPSo is the carcinogenic potency slope for oral route of 0.0085 (mg/kg bw/day)^{-1} for Pb, 6.3 (mg/kg bw/day)^{-1} for Cd, and 0.5(mg/kg bw/day)^{-1} for Cr and TA is the averaging time of carcinogens (365 days/year for 70 years), as used by USEPA (2011) [24, 28, 29].

**Statistical Analysis:**
Data collected were presented as mean and standard deviation and were subjected to one-way analysis of variance (ANOVA) (p < 0.05) to assess whether heavy metals varied significantly between animals. Pearson correlation and Principal Component Analysis (PCA) were performed to get detailed information about the distribution of heavy metals and their similarities and dissimilarities in the samples. All statistical calculations were performed with SPSS 23.0 Inc., Chicago, IL, USA, for Windows.

Results And Discussion

Concentration of heavy metals in commonly consumed animal tissues:

The concentrations of heavy metals (Cd, Cr, Pb, Ni, Fe, and Cu) from different varieties of animal tissues are presented in Table 1. The differences in heavy metals concentrations with other studies of Bangladesh and other countries were presented in supplementary table 4.

Cadmium is one of the most common toxic metals that occurs naturally in soil and is transmitted to food via soil-plant-animal or soil-water-animal routes [30]. A statistically significant difference (p<0.05) in Cd levels was found between meat and liver as well as between brain and liver in this study (Supplementary table 3). The highest Cd concentration in an animal's brain was found in a cow's brain and lowest in a quail brain which is higher than some reported studies [31, 32]. In the case of muscle, the concentrations of Cd were higher than MAC except for the Sonali chicken muscle (Table 2). The results of Cd levels in meat in this study were higher than those found in [32-39] and lower than those obtained in [31, 40-43]. Cadmium levels in different animals’ livers were also higher than previously reported findings [31, 34, 37, 39-44] (Supplementary table 4).

Chromium is an essential metal for our diet as it helps to maintain the blood glucose level of our body by making the function of insulin efficient [45]. However, Cr toxicity affects the function of different enzymes like catalase, peroxidase, and cytochrome oxidase [46]. There were significant differences observed amongst brain, meat, and liver for Cr concentrations (Supplementary table 3). The highest mean concentration of Cr levels was observed in the pigeon brain (4.8 mg/kg/fw), and the lowest was found in poultry muscle (0.46 mg/kg/fw). The observed concentrations of Cr among the maximum food samples were higher than MAC level (Table 1). The higher level of Cr in poultry muscle may be due to the use of feed from tannery waste which contains an elevated level of Cr [47]. However, these concentrations of Cr were lower than some of the previous literature [12, 31, 35, 41] (Supplementary table 4).

Heavy metals accumulate in the brain, especially Pb, which easily pass the blood-brain barrier and accumulate, leading to damage to the central nervous system. In the present study, the highest concentration of lead (Pb) was found in the poultry brain (7.54±2.54) and lowest in the quail brain (0.04±0.023). The concentration of Pb in different animals’ brains and muscle were higher than MAC (Table 1) and other reported studies [13, 31-41]. However, the concentrations of Pb found in goat and duck muscle were lower than in some studies [42, 48]. The concentration of Pb in animal’s liver was in order pigeon > quail > Sonali chicken > cow > duck > poultry > goat, and the concentrations of Pb were higher than other studies report [31, 32, 34, 39-43, 48] (Supplementary table 4).

Nickel, the metallic element mostly used for industrial purposes, can show some adverse health effects like immunologic, neurologic, reproductive, carcinogenic, and allergic reactions depending on the route of exposure (inhalation, oral or dental) [49]. The mean concentration of nickel in the analyzed animal’s foodstuffs was in order brain > muscle > liver. The highest mean concentration was found in cow liver (41.42 mg/kg fw), and the lowest Ni level was found in pigeon liver (2.71 mg/kg fw). All of the mean Ni concentrations among animal’s brains, muscles, and liver were higher than MAC (Table 1) and the findings of previously reported literature [12, 13, 32, 34, 35, 41] and lower than those found in [40] (Supplementary table 4).

Iron is the most crucial element for living creatures due to its support in the respiratory process [50]. The free radical formation is most common due to iron toxicity that may cause DNA damage leading to initiate cancer [51]. In the present study, the highest mean concentration of Fe was found in pigeon liver, followed by the descending order of duck liver > goat liver > quail liver > cow liver > Sonali chicken liver > pigeon muscle > Sonali chicken brain > pigeon brain > poultry brain > goat muscle > duck brain > Sonali chicken muscle > cow muscle > quail brain > goat brain > duck muscle > cow brain > poultry liver > quail muscle > poultry muscle. There was a statistically significant difference (p<0.05) observed between meat and liver and brain and liver (Supplementary table 3). There is no MAC value for Fe in foods. However, the concentration of Fe found in the present study was higher than those reported by [32-34] and lower than those reported by [41, 48] (Supplementary table 4).

The highest mean concentration of trace element Cu was found in goat liver (473.99 mg/kg fw), and the lowest concentration of Cu was in poultry liver (77.51 mg/kg fw). Statistically significant differences (p<0.05) among brain, muscle, and liver for Cu concentrations were found in the present study (Supplementary table 3). The mean concentrations of Cu in the muscle, liver, and brain were much higher than in MAC. The concentrations of Cu in these foodstuffs were also higher than some previously reported findings [12, 13, 31, 32, 35-37] (Supplementary table 4). However, the concentrations of Cu in duck liver, cow liver and goat meat were lower than the findings reported in previous studies [34, 43, 48] (Supplementary table 4).

Table 1: Concentrations of heavy metals in foodstuffs (meat, brain, and liver) commonly consumed by Bangladeshi populations
<table>
<thead>
<tr>
<th>Foodstuffs</th>
<th>Scientific name</th>
<th>Heavy Metals (mg/kg fw)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cd</td>
</tr>
<tr>
<td>Brain</td>
<td>Poultry <em>Gallus gallus domesticus</em></td>
<td>0.40±0.024</td>
</tr>
<tr>
<td>Cow</td>
<td><em>Bos primigenius</em></td>
<td>0.46±0.019</td>
</tr>
<tr>
<td>Sonali Chicken</td>
<td><em>Gallus gallus domesticus</em></td>
<td>0.39±0.021</td>
</tr>
<tr>
<td>Pigeon</td>
<td><em>Columba livia</em></td>
<td>0.19±0.047</td>
</tr>
<tr>
<td>Quail</td>
<td><em>Coturnix cotunix</em></td>
<td>0.04±0.023</td>
</tr>
<tr>
<td>Duck</td>
<td><em>Anas platyrhynchos</em></td>
<td>0.28±0.019</td>
</tr>
<tr>
<td>Goat</td>
<td><em>Capra aegagrus hircus</em></td>
<td>0.26±0.021</td>
</tr>
<tr>
<td>Muscle</td>
<td>Poultry <em>Gallus gallus domesticus</em></td>
<td>0.16±0.005</td>
</tr>
<tr>
<td>Cow</td>
<td><em>Bos primigenius</em></td>
<td>0.48±0.005</td>
</tr>
<tr>
<td>Sonali Chicken</td>
<td><em>Gallus gallus domesticus</em></td>
<td>0.06±0.021</td>
</tr>
<tr>
<td>Pigeon</td>
<td><em>Columba livia</em></td>
<td>0.13±0.022</td>
</tr>
<tr>
<td>Quail</td>
<td><em>Coturnix cotunix</em></td>
<td>BDL</td>
</tr>
<tr>
<td>Duck</td>
<td><em>Anas platyrhynchos</em></td>
<td>0.11±0.022</td>
</tr>
<tr>
<td>Goat</td>
<td><em>Capra aegagrus hircus</em></td>
<td>0.31±0.025</td>
</tr>
<tr>
<td>Liver</td>
<td>Poultry <em>Gallus gallus domesticus</em></td>
<td>0.65±0.017</td>
</tr>
<tr>
<td>Cow</td>
<td><em>Bos primigenius</em></td>
<td>2.40±0.008</td>
</tr>
<tr>
<td>Sonali Chicken</td>
<td><em>Gallus gallus domesticus</em></td>
<td>1.45±0.007</td>
</tr>
<tr>
<td>Pigeon</td>
<td><em>Columba livia</em></td>
<td>0.69±0.075</td>
</tr>
<tr>
<td>Quail</td>
<td><em>Coturnix cotunix</em></td>
<td>0.78±0.023</td>
</tr>
<tr>
<td>Duck</td>
<td><em>Anas platyrhynchos</em></td>
<td>15.98±0.87</td>
</tr>
<tr>
<td>Goat</td>
<td><em>Capra aegagrus hircus</em></td>
<td>1.81±0.024</td>
</tr>
</tbody>
</table>

MAC  0.1\(^a\)  1\(^a\)  0.1\(^a\)  0.5\(^a\) NA  0.1\(^b\)

Cd, Cadmium; Cr, Chromium; Pb, Lead; Ni, Nickel; Fe, Iron; Cu, Copper; BDL, below detection limit; MAC, maximum allowable concentration

\(^{a}\) JECFA 2005 [52]

\(^{b}\) JECFA 2012 [53]

**Multivariate analysis:**

By calculating a summary index, the Pearson correlation coefficient is a potential tool for assessing the strength of linear association between the pairs of variables [54]. Consequently, the Pearson product-moment correlation coefficients for the metal-to-metal correlation data that were significant at the 99% and 95% confidence levels were assessed and given in Supplementary table 5. At a 99% confidence level, the pairs of Fe-Cr (0.523) and Pb-Cu (0.889) displayed strong and significant correlations, and the pairs of Cd-Fe (0.382), Pb-Cr (0.327) and Cr-Cu (0.358) showed weak and significant correlations, while Cu displayed a weak correlation with Fe (0.268) at 95% confidence level. The strong connections provided evidence in favor of the theory that the sources of the metals might be comparable.

**Principal component analysis:**

For factor loadings in each metal, the principal component analysis (PCA) utilizing varimax-normalized rotation was performed. A large number of variables are reduced into a new set of reduced variables based on their mutual dependence, which is the PCA’s most significant contribution. A significant number of PCs was observed using a scree plot depicted in Figure 1. According to the results, three eigenvalues greater than one account for 78.95% of the total variance. **Supplementary Table 6** includes the computation of commonalities, percent of the total variance, and cumulative percent of the variance. While PC2
accounted for 20.75% of the total variation and exhibited the highest loadings for Fe, Cd, and Cr, indicating that they originated from the same origins. PC1 revealed the highest loadings for Cu and Pb, explaining more than 40.7% of the total variance. With a variance of 17.42%, the final significant factor revealed that Ni had the highest loadings among the materials with different sources. To understand the relationship among metals, a three-dimensional plot of the PCA loadings was presented in Figure 2.

Health risk assessment:

1. Estimated daily intake (EDI)

The health risk assessment of the population was estimated by the value of EDI for both adults and children and depicted in Figure 3. The EDI of trace elements (Cd, Cr, Pb, Ni, Fe, and Cu) was compared with maximum tolerable daily intake (MTDI) (Figure 3a, 3b, 3c, 3d, 3e, 3f), which indicates no adverse health effects after consuming foods [55]. The EDI of adults from consuming different animal muscles, liver, and brain were shown in the descending order of Fe > Cu > Ni > Pb > Cr > Cd, and for children, it was of Fe > Cu > Pb > Ni > Cr > Cd. The value of Cd and Pb through consumption of duck liver and goat liver, respectively, were above the permissible limit for both adults and children, whereas the levels of Pb and Cr from the consumption of sonali chicken brain and pigeon brain respectively, were also above the MTDI value for children.

2. Targeted Hazard quotient (THQ) and total targeted Hazard quotient (TTHQ):

The non-carcinogenic health risk was assessed in terms of targeted hazard quotients (THQ), and total targeted hazard quotients (TTHQ), summarized in Table 2. The estimated THQ value of Cd was greater than 1 for children through consuming duck liver, whereas the THQ value of Pb was above 1 for both adults and children and for Cu for child through the consumption of goat liver. Furthermore, the THQ in adults and children found that Cu > Pb > Ni > Cr > Cd > Fe. However, the value of THQ does not provide a quantitative probability of experiencing adverse health effects. It only indicates the level of risk due to exposure [13]. Considering all elements, the TTHQ value was estimated in the range of 0.051 to 1.988 and 0.047 to 3.975 for adults and children, respectively. The value of TTHQ is helpful to assess and understand the combined risk of different foods for human health. In the present study, TTHQ in children was almost two times higher than in adults, especially relating to poultry brain and liver, cow muscle and offal, Sonali chicken liver, pigeon muscle, and liver, and brain and liver of duck, goat, quail likely due to children consuming comparatively more muscle and edible offal than adults.

The hazard index (HI) was calculated to assess the non-carcinogenic risk of multiple elements by consuming one or more food items (Table 2). HI values by consuming foodstuffs were 13.22 and 17.005 for adults and children, respectively. The contribution of Cu to HI value was the highest for both adult and child.

Table 2: Non-carcinogenic (THQ and TTHQ) health risks of trace elements due to consumption of brain, muscle, and liver in Bangladesh
### Conclusion

The target carcinogenic risks (TCRs) derived from Cr, Cd, and Pb consumption was calculated because ingestion of these compounds may result in both non-carcinogenic and carcinogenic consequences depending on the exposure amount (Figure 4). The TCR values from exposure of Cd were found in the range of 9.46E-05 to 7.59E-04 and 2.06E-05 to 9.75E-03, whereas for Cr, it was 1.4E-05 to 3.3E-04 and 1.5E-05 to 2.04E-04, and for Pb, it was 1.3E-07 to 4.05E-05 and 1.37E-07 to 8.1E-05, for adults and children, respectively (Figure 4a, 4b, 4c, 4d, 4e, 4f, 4g). In general, TCR values below 1.0E-06 are regarded as negligible, those above 1.0E-04 are unacceptable, and those falling between 1.0E-06 and 1.0E-04 are considered as falling within an acceptable range [56, 57]. The estimation showed that the carcinogenic risk (TCR) of Pb due to consumption of muscle, liver, and brain was within the negligible range (<1.0E-4) to the acceptable range (1.0E-6 to 1.0E-4), whereas the TCR of Cd for both adult and children were within unacceptable range (>1.0E-4) due to consumption of liver, brain, and muscle of poultry, Sonali chicken, cow as well as liver of pigeon, duck, and goat. In the present study, it was suggested that children are more susceptible to toxic elements from dietary intake of foods.
The article focused on the levels of heavy metals in commonly consumed animal’s edible tissues (muscle, brain, and liver) and determined the health risk in terms of EDI, THQ, TTHQ, and TCR. The maximum edible tissues contained heavy metals that exceeded the maximum allowable concentrations (MAC) and indicated potential health risks. However, a maximum of edible tissues had low EDI than MTDI values. PCA and multivariate analysis showed that heavy metals in food were contributed by anthropogenic activities and a strong correlation between the metals. In terms of health risk assessment, the present study found that children are more susceptible to developing cancer compared with adults. This study suggested that the Government of Bangladesh routinely monitors the contamination levels of hazardous heavy metals and metalloids in its citizens’ daily diets to enforce regulatory limits and assess the risk of long-term exposure. Determination of the effects of the geographical distribution of heavy metals and feedings practices in meat and edible organs, including assessment of hazardous elements in feeds and foodstuffs, is also recommended.

Declarations

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Submission declaration and verification: The study was reported in accordance with ARRIVE guidelines. The Authors hereby consent to publish this research article. This article has not been published or submitted elsewhere for publication. The authors also declare that this work does not libel anyone or violate anyone’s copyright or common law rights.

Statement of Competing Interests: The authors have declared no conflict of interest.

Ethics approval: The study was classified as exempt according to the institutional ethics committee of the Noakhali Science and Technology University. All methods were performed in accordance with the relevant guidelines and regulations.

Availability of data and material: The datasets generated during this study are available from the corresponding author at a reasonable request.

Authorship contributions: MRA has conceptualized the study, acquired the funding, performed the statistical analysis, interpreted the data, and revised the manuscript critically for important intellectual content. AIC participated in the literature review, sample collection, and laboratory analysis and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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Figures

Figure 1

Map of the study area, Noakhali, Bangladesh
Figure 2

Principal component analysis (PCA) of heavy metals by scree plot and a three-dimensional plot showing loadings for heavy metals.

Figure 3

(a) Ca, (b) Cr, (c) Mn, (d) Ni, (e) Fe, (f) Cu.
Estimated Daily Intake (EDI) of Cd (a), Cr (b), Pb (c), Ni (d), Fe (e), Cu (f) from commonly consumed brain, meat, and liver according to maximum tolerable dietary intake (MTDI) based on the data established by WHO/FAO joint committee for food additives and JECFA

**Figure 4**
Calculation of total carcinogenic risk (TCR) in meat, liver, and brain by consumption of heavy metals according to USEPA. (a) Poultry, (b) Cow, (c) Sonali chicken, (d) pigeon, (e) Quail, (f) Duck, and (g) Goat.

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