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REVIEW ARTICLE

Heavy metals contamination and associated health risks in food webs—a review focuses on food safety and environmental sustainability in Bangladesh

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Abstract

Heavy metals occur naturally in very small amounts in living organisms, but exposure to their higher concentrations is hazardous. Heavy metals at hazardous levels are commonly found in foodstuffs of Bangladesh, mainly due to the lack of safety guidelines and poor management of industrial effluents. Several lines of evidence suggest that the level of heavy metals in foodstuffs of Bangladesh is higher than the acceptable limits set by World Health Organization/Food and Agriculture Organization. Literature survey revealed that the sources and transport pathways of heavy metals in the ecosystem and the abundance of heavy metals in the food products of Bangladesh are potential threats to food safety. However, an extensive assessment of the toxicity of heavy metals in food webs is lacking. Although widespread heavy metal contamination in various foodstuffs and environmental matrices have been summarized in some reports, a critical evaluation regarding multi-trophic transfer and the health risk of heavy metal exposure through food chain toxicity in Bangladesh has not been performed. This systematic review critically discussed heavy metal contamination, exposure toxicity, research gaps, existing legislation, and sustainable remediation strategies to enhance Bangladesh's food safety. In particular, this study for the first time explored the potential multi-trophic transfer of heavy metals via food webs in Bangladesh. Furthermore, we recommended a conceptual policy framework to combat heavy metal contaminations in Bangladesh.

Keywords Heavy metals · Food safety · Risk assessment · Exposure toxicity · Policy framework

Introduction

Heavy metals such as arsenic, lead, cadmium, and chromium are non-biodegradable hazardous substances derived from natural mineral sources or industrial discharges (Qin et al. 2020). The abundance of heavy metals in common foods,

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such as fresh vegetables and fruits, poses several human health risks including carcinogenesis, kidney dysfunction, immune system imbalance, and even death due to biomagnification and bioaccumulation (Islam et al. 2015a; Ahmed et al. 2019a; Shamsudduha et al. 2019). Heavy metals are the predominant contaminants in most ecosystems of Bangladesh including agricultural land, foodstuffs, suburban soil, and waterways (Ahmed et al. 2015a; Kibria et al. 2016; Proshad et al. 2020; Hasan et al. 2021). The presence of heavy metals in common agricultural products, including rice, vegetables, fruits, and fish, has been reported (Ahmed et al. 2019a). In addition, the World Health Organization (WHO) has already expressed concern about the presence of trace metals (arsenic, lead, cadmium, and chromium) in drinking water and their contamination in the ecosystems in many countries, including Bangladesh (WHO 2004, 2017). Consequently, heavy metal contamination in the drinking water of the Surma basin of Bangladesh, and coastal groundwater were reported with a potential risk prediction including carcinogenic and non-carcinogenic risks to adults and children (Ahmed et al. 2019b; Islam et al. 2020a). Therefore, common foodstuffs, food chains, and water samples (e.g., river water and groundwater) were considered the critical source and sink of heavy metals in Bangladesh.

Heavy metals have also been recently detected in major food items, such as rice, vegetables, and meat available in large markets of Bangladesh (Proshad et al. 2020; Zakir et al. 2020a). A large body of literature indicates that arsenic, zinc, cadmium, copper, chromium, and lead are present at higher concentrations than the maximum tolerable limits (MTLs) set by WHO (Islam et al. 2015a; Islam et al. 2018a). Heavy metal contamination has been attributed to the poor management of industrial effluents, improper application of metal-rich irrigation water, improper handling of trace metal additives to poultry and fish feed, and rigorous application of heavy metal–containing pesticides and fertilizers, which lead to high toxicity levels and further transfer of heavy metals into the food chain (Pourang and Noori 2012; Sarker et al. 2017; Zakir et al. 2020b).

Weak monitoring of entry routes, poor understanding of safety measurements, ignorance of regulatory guidelines, and poor management of industrial effluents are the major causes of environmental and food contamination by hazardous heavy metals in Bangladesh (Shamsudduha et al. 2019; Zakir et al. 2020a). However, regulatory weaknesses related to heavy metal contamination are not considered a priority in research in Bangladesh. Although a few reviews have discussed the occurrence and toxicity profile of heavy metals in the food chain, soil, water, and environment of Bangladesh (Hezbullah et al. 2016; Islam et al. 2018a), the key challenges with respect to risk factors, legislation, and research gaps have been poorly explored. Heavy metal contamination and related biogeochemistry are a vast research area with respect to exposure and health risks throughout the world. Furthermore, heavy metal contamination, exposure toxicity, research gaps, existing legislation, and remediation for increasing food safety in Bangladesh are rarely assessed in the existing literature. Therefore, we planned to use this broad research theme to focus the current review on the existing challenges of heavy metal contamination in the food webs of Bangladesh for reducing the potential redundancies of the well-known concept of a satisfactory research theme in the environmental pollution. This review attempts to update current knowledge and critically discusses research trends and risk factors of heavy metal contamination in Bangladesh to facilitate safety and quality evaluations of the domestic food chain and the associated health risks. Furthermore, this study also discusses the critical challenges of heavy metal toxicity through multi-trophic transfer and recommends a conceptual policy framework in Bangladesh for sustainable remediation of heavy metals contamination.

Review methodology

This study is dependent on the systematic and non-exhaustive literature survey for related published research articles, papers, and books concerning heavy metals contamination and related health risk in Bangladesh. A comprehensive literature bank (including both online and offline information) was collected by scrutinous web-surfing as well as comprehending printed materials for identifying the research questions and knowledge gap with respect to heavy metal contamination and its impact on food sate on environmental sustainability in Bangladesh. The review process involved the selection of thematic areas and narrowing down to well-suited keywords to extract contemporary information. For online materials, the popular academic search engines viz. Google Scholar, PubMed, Science Direct, Scopas, ResearchGate, Springer, as well as official websites were explored with selected keywords. The used keywords include “heavy metals in Bangladeshi foodstuffs”, “Heavy metal toxicity”, “Heavy metal contamination”, “Heavy metals in the food chain”, “Arsenic situation in Bangladesh”, “Regulation for a safe level of heavy metals in foodstuffs”, “Heavy metals pathways to food”, “Risk assessment for heavy metals in foods”, and “Removal of heavy metals”. The offline materials were obtained from the institutional library as well. At first, the abstract and major findings of secondary materials were critically overviewed to assess the relevancy to be included in the current study. Later on, the eligible materials were sorted (e.g., abstracts, full text, and salient findings) based on the research frame of the study. No specific timeline or verified methodology (e.g., PRISMA) was applied during selection and reviewing the information source. However, the screened references were scrutinized and summarized to build-up the story focusing on the presence of heavy metals in foodstuffs, the channel of contamination, associated health risk, and existing regulation to reduce the effect from Bangladesh's perspective. To avoid any potential redundancies, the data derived from previously published articles focusing on the abundance of heavy metals and salient features deciphering the resulting health risks were arranged in two separate tables to relate the heavy metal contamination in Bangladesh and its potential trophic transfer to affect the food chain. Finally, the research gap regarding the studied area and potential steps for alleviating the situation were suggested through rational exposition.

Current scenario of heavy metals contamination in Bangladesh

In Bangladesh, most arable land, edible crops (e.g., cereals and vegetables), fish, dairy products, and freshwater sinks, including urban rivers and lakes, are badly contaminated with heavy metals (Islam et al. 2018a). For instance, a research study on heavy metals in common vegetables and fruits collected from 30 agroecological zones of Bangladesh and the resulting risk assessment for human consumption showed that the concentrations of lead in mango and cadmium in tomatoes were above the MTL set by the WHO/United Nations Food and Agriculture Organization (FAO) (Shaheen et al. 2016). A similar study of cultured fish species commonly consumed in Bangladesh, namely rahu (*Labeo rohita*), tilapia (*Oreochromis mossambicus*), and pangas (*Pangasius pangasius*) (Ahmed et al. 2015b), demonstrated that tilapia contained a higher concentration (1.486 mg/kg) of arsenic than the other two fish species, suggesting the potential risk for carcinogenic and chronic toxicity due to the continuous consumption of these abundant and cheap fish species by inhabitants of contaminated areas. In addition, the accumulation of trace metals in common freshwater fish species (*Pangasianodon hypophthalmus*) and the potential health risk due to frequent consumption by a human are reported in a recent study (Maruf et al. 2021). Although the concentration of heavy metals was below the hazard level in the studied fish species, prolonged consumption of contaminated fish may lead to widespread chronic carcinogenesis and other health complexities (Hasan et al. 2020). In contrast, a hazardous concentration of copper was detected in giant freshwater prawns from the Buriganga River in Dhaka, the capital of Bangladesh (Ahmed et al. 2015a). Additionally, arsenic, chromium, cadmium, nickel, and lead concentrations above the safe MTLs were found in cereals, pulses, fruits, and vegetables grown in northern Bangladesh (Kormoker et al. 2020) posing a potential carcinogenic risk to residents and especially to children and infants that could be affected through the food webs (Table 1).

Heavy metals have been identified in various sources in Bangladesh such as agricultural soils near industries (Zakir et al. 2015; Proshad et al. 2020); groundwater samples (Shamsudduha et al. 2019); common foods, including cereals, vegetables, fruits, or other raw and fresh products (Ahmed et al. 2016a; Shaheen et al. 2016; Ahmed et al. 2019a); freshwater rivers; and fish species that inhabit the rivers (Ahmed et al. 2015a; Kibria et al. 2016; Hasan et al. 2021). Heavy metal toxicity was found in groundwater samples in Dhaka with lead (Pb) as the predominant toxic metal followed by arsenic (As) (Sharmin et al. 2020). The findings of that study indicate that water quality of Dhaka is unsuitable as per the guidelines of WHO (permissible value for As and Pb is set 0.01 mg/l concerning the drinking water quality assessment) (Sharmin et al. 2020). Based on risk factor analysis of the studied samples by Sharmin and coworker, adults and children in the central-western areas of Dhaka were warned of potentially carcinogenic and noncarcinogenic health risks. Similarly, the prevalence and potential risks of heavy metals were also assessed for water samples in the Jamalpur district of Bangladesh (Zakir et al. 2020b). Like Dhaka, 95% of the tested water samples from Jamalpur district were also unsuitable for drinking, whereas 18% of surface water and 25% of subsurface water samples were suitable only for irrigation as per WHO permissible limits of tested heavy metals (i.e., WHO permissible limit for total Cr 0.05 mg/l and Cd 0.003 mg/l) (Zakir et al. 2020b). However, the suitability test for water quality index was performed by the empirical equation termed heavy metal evaluation index (HMEI) as suggested by the earlier research (Singh et al. 2017). If the HMEI is greater than 1, the water quality is unsuitable in terms of heavy metal contamination. Thus, both adults and children in the examined district were warned of the potential carcinogenic and noncarcinogenic health risks from chronic exposure to those contaminated waters. In a contemporary study, heavy metals along with polycyclic aromatic hydrocarbons were detected in rooftop garden soils and corresponding cultivated vegetables (Tusher et al. 2020). Urban rooftop gardens are likely to be more polluted than the suburban rooftop gardens. The results of this study were particularly worrying in terms of food safety, as a considerable city dwellers rely on rooftop agricultural products as a source of fresh and toxin-free fruits and vegetables in Bangladesh. The urban agriculture based on rooftop gardening is a popular concept in the major cities of Bangladesh, where the soil may be considered as a hidden sink of many toxic pollutants including heavy metals due to lack of specific research data. There is an urgent need for a meticulous monitoring and policymaking approach toward quality assessment of the urban agricultural practices to combat the hidden threat of heavy metals and associated

Table 1 Trace metal contamination soil, sediment, river, marine ecosystem, and water samples in Bangladesh

Experimental site/sample	Experiment type/analytical method	Trace elements	Salient findings	References
Bay of Bengal, Bangladesh	EDX spectroscopy	Fe, Ca, K, Ti, Sr, Zr, Rb, Cu, Zn, Pb, As, Ni	Sediment samples followed the order of Fe > Ca > K > Ti > Sr > Zr > Rb > Cu > Zn > Pb > As > Ni, and water samples the order (μg/mL) of Fe > Ti > Ca > Co > Mn > Ni > Zn > Sr > Cu > As > Se.	Hossain et al. 2020a
Suburban farmland near Dhaka EPZ	Lab trial for assessment of HM in soils	As, Fe, Mn, Zn, Hg, Cu, Ni, Cr, Pb, Cd	All metals were found in higher concentrations than MDIL.	Rahman et al. 2012a, b
Surface sediment samples at Kutubdia Channel, Bangladesh	EDX spectroscopy	Cr, Mn, Cu, Zn, As, Pb, Br, Co, Fe, Sr, Rb, Zr	Surface sediment samples had higher concentrations in the post-monsoon than in the pre-monsoon season.	Hossain et al. 2020a
Feni River estuary	ICP–MS	Mn, Cr, Ni, Co, Ag, As, Hg	Study indicated that Ni and Cr concentrations were likely to have occasional adverse effects on the ecosystem.	Islam et al. 2018c
Meghna River	AAS	Zn, Al, Cd, Pb, Cu, Ni, Fe, Mn, Cr, Co	Fe, Ni, and Al exceed the tolerable limit in water. In sediment, all trace metals were below the limit compared to other scientific results.	Bhuyan et al. 2017
Sangu River estuary	ICP–MS	As, Cr, Cu, Cd, Pb, Ni, Zn	Sangu River estuary was not contaminated by studied metals except Pb.	Hossain et al. 2019
Buriganga River	Lab trial of collected water samples	Pb, Cd, Ni, Cu, Cr	Extremely risky HM concentration.	Ahmad et al. 2010
Karnaphuli River estuary	ICP–MS	As, Pb, Cd, Cr, Cu	All values were within the acceptable threshold for both adults and children.	Ahmad et al. 2019a
Salt marsh sediments, Chittagong	EDX spectroscopy	Fe > Ca > Ti > K > Sr > Rb > Zr > Zn > Cu > Pb	Fe was significantly enriched in the sediments. Ecological risk factors illustrated a pollution-free condition of the salt marsh ecosystem in Bangladesh.	Rakib et al. 2021a
Halda River, Bangladesh	EDX spectroscopy	Cd > Cr > Mn > Fe > Co > Cu > Zn > As> Pb > Hg	Arsenic for water ingestion and dermal pathways was the primary contributors to total health risk (HI/THI) indicated that As in surface water of the Halda River might pose health risks to residential users.	Rakib et al. 2021b
Mangrove Forest, (sediment) Sundarbans, Bangladesh	EDX spectroscopy	Fe, Mn, Sr, Zn, Cu, Co, and Pb	The human health hazard index (HI) values were 261, 20.6, and 20.6 for children, adult male and adult female, respectively, in Mn due to the inhalation process, indicating elevated health risk.	Hossain et al. 2021
Mangrove Forest, (water) Sundarbans, Bangladesh	EDX spectroscopy	Fe, Sr, Cu, Zn, Pb, Mn, and Co	Children can be at high risk due to manganese contamination by skin contact where HI = 2.18 × 10.	Hossain et al. 2021
Korotoa river, (water) Bangladesh	AAS	Cr, Cu, As, Ni, Pb, and Cd	Water samples followed the order: Cr > Cu > As > Ni > Pb > Cd	Islam et al. 2015b

Table 1 (continued)

Experimental site/sample	Experiment type/analytical method	Trace elements	Salient findings	References
Korotoa river, (sediment) Bangladesh	AAS	Cr, Ni, Cu, Pb, As, and Cd	Sediment samples followed the order: Cr > Ni > Cu > Pb > As > Cd.	Islam et al. 2015b

EDX spectroscopy energy-dispersive X-ray spectroscopy, *ICP-MS* inductively coupled plasma mass spectrometry, *AAS* atomic absorption spectrometry, *FAAS* flame atomic absorption spectrometry

toxins in the food system. Saha et al. (2016) noticed the transfer of six major trace metals (e.g., Cu, Ni, Cd, Pb, Cr, and Zn) from the soils to the mature plants and leaves of tobacco in Kushtia district of Bangladesh. Thus, heavy metals can be found in different environmental components and can be taken up by plants in fields near industrial and urban facilities (Table 2). However, the identification of the primary sources of heavy metal contamination in Bangladesh is sparingly studied (Islam et al. 2018a; Ratul et al. 2018; Zakir et al. 2020b), and further research is needed to determine the environmental fate and transport pathways of heavy metals at contaminated sites in Bangladesh. The environmental sustainability of the ecosystems of Bangladesh is largely dependent on the hidden threat and uncertainty of the heavy metals contamination and their potential toxicity through the food webs of Bangladesh. Meticulous synchronization of local studies with global contemporary legislation concerning heavy metals contamination is needed to be explored toward enhancement of food safety of Bangladesh.

Trophic transfer of heavy metals through food webs in Bangladesh

Heavy metal contamination is caused by natural and anthropogenic activities, polluting most components of ecosystems such as agricultural and suburban soils, urban waterways, and sediments (Islam et al. 2018b; Ratul et al. 2018; Kumar et al. 2019). Improper disposal of industrial effluents, application of heavy metal–containing agrochemicals (fertilizers, pesticides, etc.), mining, the release of heavy metals from poultry manure, and weathering of trace metal–rich rocks and minerals are considered the primary sources, and subsequent transport of heavy metals in the surrounding environments has been documented globally (Gupta et al. 2018; Kumar et al. 2019; Zakir et al. 2020a). Agricultural and suburban soils, freshwater rivers, and groundwater are the ecological components most affected by heavy metals in Bangladesh (Ahmad and Goni 2010; Islam et al. 2018a, 2018b). Although global studies have revealed the transport pathways of heavy metals in various environmental matrices (Gupta et al. 2018; Kumar et al. 2019), primary sources and transport pathways are not well studied in Bangladesh (Kibria et al. 2016; Islam et al. 2018a), which needs to be investigated to explore the trophic transfer of trace metals through the food chain of Bangladesh.

Arsenic in contaminated groundwater has extensively been studied in Bangladesh due to its acute and chronic toxicity that leads to severe health complications (Flanagan et al. 2012; Ahmad et al. 2018; Huq et al. 2020). Inorganic arsenic salts and toxic arsenate and arsenite derived from arsenic ores after natural or anthropogenic intervention (Chakraborti et al. 2015) have also been found in shallow

Table 2 Trace metal contamination in common foodstuffs such as fruits, vegetables, fish, and meat products

Experimental site/sample	Experiment type/ analytical method	Trace elements	Salient findings	References
Common vegetables/fish/dairy products	AAS	Cu, Zn, Pb, Cr, Cd, Fe, Ni	A higher concentration of HM was detected.	Ahmad et al. 2010
Markets fruits and vegetables	ICP–MS	As, Cd, Pb, Cr, Mn, Ni, Cu, Zn	Exceeding MTLs set by FAO/WHO for Pb in mango and Cd in tomato	Shaheen et al. 2016
Surrounding the Korotoa river (vegetables)	AAS	Cr, Ni, Cu, As, Cd, Pb	As, Cd, and Pb in some vegetable species exceeded the maximum allowable concentration.	Islam et al. 2015b
Surrounding of the Turag river (vegetables)	ICP–MS	Cr, Ni, Cu, Zn, As, Cd, Pb	Health risks were predicted for Cr, Cu, As, Cd, and Pb	Islam and Hoque 2014
Paksi (Pabna) (vegetables)	FAAS	Ni, Cd, Cr, Co, Pb, As, Hg, Zn, Cu	Pb was found above the tolerable limit	Tasrina et al. 2015
Dry fishes, Cox's Bazar, Bangladesh	EDX spectroscopy	Fe > Zn > Hg > Cu > Se > Cr > Mn > Co > Rb > Pb	Hazard index for Hg to children is higher than the standard	Rakib et al. 2021c
Buriganga River in Bangladesh (fishes)	AAS	Cd, As, Pb, Cr, Ni, Zn, Se, Cu, Mo, Mn, Sb, Ba, V, and Ag	The target cancer risk (TR) values indicated that Ni and As were carcinogenic.	Ahmed et al. 2016b
Dinajpur, Mymensingh, Bogra, Rajshahi, Patuakhali, Dhaka (vegetables)	AAS	Cd, As, Cr, Cu, Pb, and Ni	Both carcinogenic and non-carcinogenic health risk was predicted	Islam et al. 2018b
Shitalakhya river in Narayangonj, Bangladesh (vegetables)	FASS	Cu, Ni, Cd, Cr, Pb, and Zn	The health risk index (HRI) is 1, indicating that there is a relative absence of health risks.	Ratul et al. 2018
Vegetables grown around Hazaribagh leather industrial area (vegetables)	ICP-MS	Fe, Cr, Pb, Cu, Ni, As, and Cd	The concentration of Cr and Fe were extremely higher than the tolerance limit	Mottalib et al. 2016
Paira River (fishes)	AAS	Cu, Ni, Cr, Pb, As, and Cd	Trace elements were found slightly higher than the MTL in fish species and potential health impact was predicted	Islam and Habibullah-Al-Mamun 2017
Samta village, Bangladesh (vegetables)	ICP-AES	As, Cd, Pb, Cu, and Zn	Pb would be a health hazard for human consumption, followed by As in the diet.	Alam et al. 2003
Bogra District of Bangladesh (vegetables and fish)	AAS	Cr, Ni, Cu, As, Cd, and Pb	Cu, As, and Pb may lead to non-carcinogenic risk.	Islam et al. 2016
Chicken farms around Dhaka, Bangladesh	EDX spectroscopy	As, Ni, Cr, Hg, and Pb	Detected trace metals shown several times higher concentrations than the tolerable limit, in particular in the studied chicken livers	Haque et al. 2021

FAAS flame atomic absorption spectrophotometer, *ICP-AES* inductively coupled plasma emission spectrometry, *AAS* atomic absorption spectrophotometer groundwater. The irrigation with arsenic-contaminated groundwater and improper mining of arsenic ores have been shown to further facilitate arsenic transport to surrounding environment (Flanagan et al. 2012; McArthur et al. 2016). Arsenic pollution could affect the groundwater, farming land irrigated with polluted groundwater. The evidence of food web toxicity of human due to chronic exposure of arsenic-contaminated water and foodstuffs is well established (Islam et al. 2017a, b; Rahman et al. 2018; Huq et al. 2020; Mihajlov et al. 2020). Contamination with several heavy metals was also found in agricultural lands near the Dhaka export processing zone area (Rahman et al. 2012a, b; Hasnine 2017), and was mainly attributed to the release of untreated industrial effluents and their poor management. Similarly, heavy metals have been spread from industrial activities to suburban soils and nearby farmlands in large industrial cities in Bangladesh (Zakir et al. 2015; Begum and Huq 2016). Tanneries with lack of environmental treatment discharge a large amount of heavy metals through their effluents. In the Dhaka City, about 200 tanneries discharge nearly 95,000 l or 21,000 m^3 of untreated effluents along with 115 tons of solid wastes daily into the surrounding environment (Islam et al. 2021a). Earlier studies reported the transfer of heavy metals to surrounding soils through contaminated effluents derived from the leather industry in Dhaka (Mottalib et al. 2016), nearby groundwater through coal effluents derived from the coal mine of Barapukuria coal basin, Bangladesh (Habib et al. 2020). Thus, heavy metal–contaminated soils and groundwaters may act as the secondary sources of heavy metals, as their uptake by plants may cause food chain toxicity through the consumption of crops grown on contaminated arable land, posing a critical concern about the trophic transfer of heavy metals from primary sources through the human food chain in Bangladesh.

Freshwater rivers are another important sink of heavy metals in Bangladesh. Most urban rivers in Bangladesh are dumping sites for industrial, domestic, and agricultural waste, and are usually treated improperly (Islam et al. 2020b). As a result, almost all freshwater rivers are polluted with heavy metals from industrial effluents (Kibria et al. 2016). Among the studied rivers, Buriganga, a major river near Dhaka, was heavily polluted with heavy metals, followed by other urban rivers (e.g., Dhaleshwari River), while tracing elements accumulated in vegetables through irrigation with contaminated river water (Ratul et al. 2018; Hasan et al. 2020). Similarly, the variability of the water quality of other major rivers including transboundary streams of such as the Ganges for Indian subcontinents, and Halda for Bangladesh were also dominated by the abundance of toxic heavy metals (Bhuyan and Bakar 2017; Islam et al. 2020; Haque et al. 2020). However, the concentration of arsenic varied depending on the sampling site. For instance, shallow tubewells (STW) were found to be the main source of heavy metal contamination in agricultural land through irrigation by contaminated groundwater, while the distance of the sampling site from the STW was positively correlated with reduced heavy metal concentrations (Hossain et al. 2008). A confirmatory study documented heavy metal transfer from Barapukuria coal mine in northern Bangladesh to surrounding agricultural soils (Bhuiyan et al. 2010). Similarly, mining activities in central China were also identified as a potential source of heavy metal contamination (Fan et al. 2017). A recent study based on marine and freshwater aquatic species in South Indian aquatic ecosystems noticed the risky levels of mercury and the potential health risks due to human exposure (Subhavana et al. 2020). It is therefore clear that the cycling of heavy metals into the environment can be driven by urban rivers, industrial activities, improper management of industrial effluents, heavy metal–containing agrochemicals, mining, and other anthropogenic activities as described in the abovementioned tables were illustrated, accordingly (Fig. 1).

The trophic transfer of heavy metals from the primary source to surrounding ecosystems and food webs is a crucial concern for global food safety (Ali and Khan 2019; Kumar et al. 2019) and can be regulated by several transfer factors, such as bioaccumulation, defined as the ratio of metal concentration in an organism's tissue to that in an abiotic medium (Mortuza and Al-Misned 2015); biomagnification, defined as the ratio of metal concentration in an organism to that in the organism's diet (Yarsan and Yipel 2013); and bioconcentration, defined as the ratio of metal concentration in a studied organism to that in water (Chalkiadaki et al. 2014; Ali and Khan 2019). An earlier study focusing on the transfer of heavy metals through various terrestrial food web pathways highlighted the health risks that develop with biomagnification of transported heavy metals from the primary source to consumers (Gall et al. 2015). Moreover, heavy metals have been detected in raw cow milk, suggesting that the biomagnification and subsequent transfer of heavy metals from the primary source to cow milk through grazing is a global threat to the food chain for infants, children, and adults (Boudebbouz et al. 2021; Haakonde et al. 2021). Additionally, the risk of heavy metals through dietary exposure in the case of the Italian population was documented (Filippini et al. 2019). Hence, the transport of heavy metals through the food chain should be treated as a future threat to global food safety related to terrestrial and aquatic ecosystems.

Heavy metals have been detected in major food products of Bangladesh, including cereals, vegetables, fruits, water, or fish (Hezbullah et al. 2016; Islam et al. 2018a). A comparative study of common leafy vegetables collected from industrial and nonindustrial regions showed that nonessential heavy metals accumulated most in vegetables from the industrial regions of Bangladesh (Naser et al. 2018).

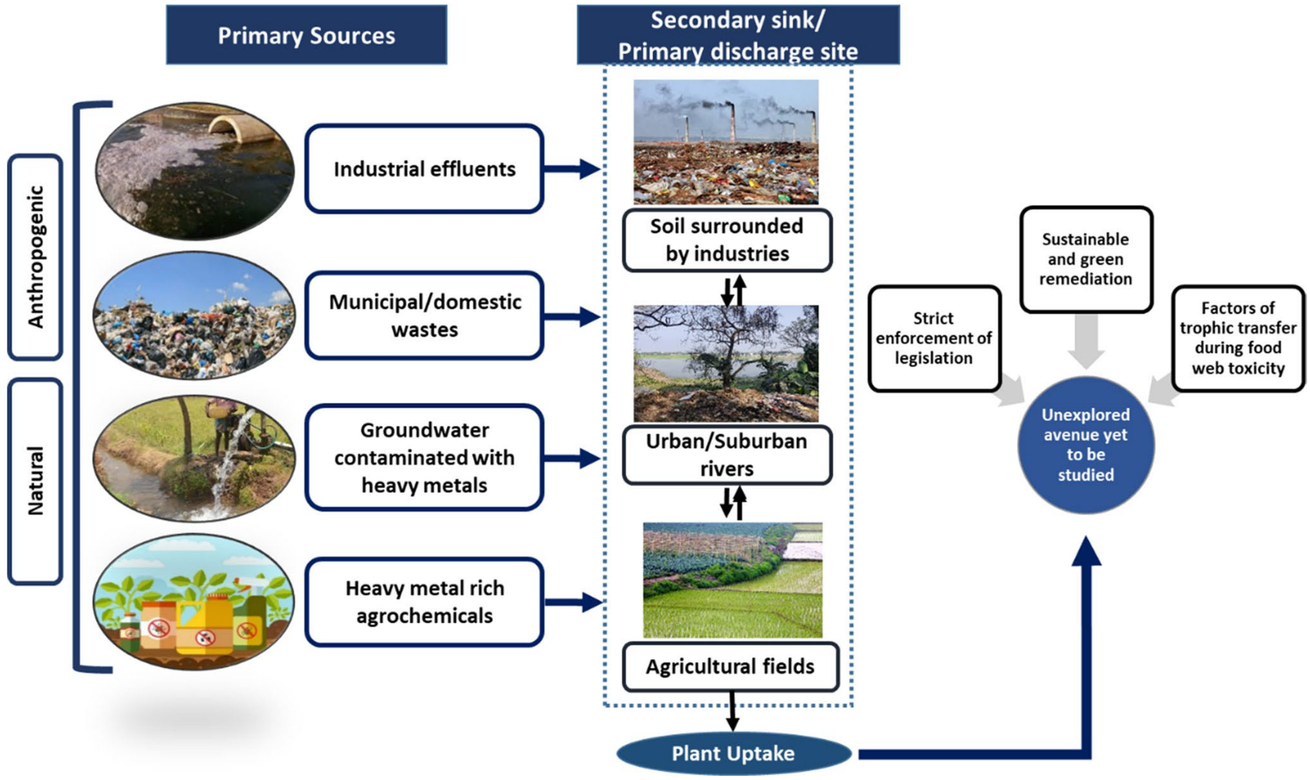

Fig. 1 Schematic presentation of existing situations (primary source, fate, etc.) of heavy metal pollution through food webs of Bangladesh. The sources including the natural and anthropogenic sources are considered. This figure is drawn by the author using symbolic image or photos from primary sources

Furthermore, the trophic transfer of heavy metals from rivers via human consumption of fish and other freshwater animals was confirmed in previous studies on urban rivers of Bangladesh (Rahman et al. 2012a, b; Ahmed et al. 2015a). Despite the numerous studies supporting the pervasive presence of heavy metals in common foodstuffs of Bangladesh (Shaheen et al. 2016; Zakir et al. 2020a), the bioconcentration and bioaccumulation of heavy metals during trophic transfer have been largely overlooked. Although several encouraging multivariate techniques and statistical modeling were attempted to explore the spatial distribution of trace metals and related co-contaminants in the drinking and groundwater (Islam et al. 2017a, b, 2019), the meticulous toxicity profile of heavy metal contamination and resulting health risk is not studied vastly. Similarly, the arsenic mobilization process was investigated through the hydrogeochemical evolution in Bangladesh (Saha et al. 2020), which may pose a potential health risk to the habitants through drinkable groundwater. As a consequence, the nutritional value of vegetables and fruits can be significantly reduced due to unexpected contamination (Khan et al. 2014) with essential trace metals introduced by fertilizer application and/or nonessential trace metals deposited due to poor management of municipal and industrial waste (Shaheen et al. 2016; Kumar et al. 2019). Therefore, further studies are needed to clarify the impact of bioaccumulation and biomagnification of heavy metals and to combat food adulteration and ensuring sustainable food safety in Bangladesh.

Uncertainty of health risks and legislation associated with heavy metals contamination in Bangladesh

Heavy metals are toxic to humans even in trace amounts after acute or chronic exposure, severely affecting the major organs of adults, such as the brain, kidney, central nervous system, heart, reproductive, and digestive systems as well as the physiology of children, including the nervous system, kidney, brain, and circulation (Gupta et al. 2018; Kumar et al. 2019). Oral ingestion of nonessential heavy metals (arsenic, lead, mercury, or cadmium) by humans or animals can cause chronic or acute toxicity manifested as nausea, vomiting, irregular bowel movements, motor neuron dysfunction, vision and hearing impairment, brain and heart damage, or hypertension, etc. (Jomova et al. 2011; Flora et al. 2012; Mari et al. 2018). Moreover, internal and cellular toxicity may lead to the disruption of nerve cells and

DNA structure and delay mitochondrial metabolic processes such as ATP synthesis and oxidative photophosphorylation (Rehman et al. 2018; Lai et al. 2018; Zafarzadeh et al. 2018; Kumar et al. 2019). A recent study noticed the bioavailability of heavy metals and toxic metalloids in the suspended particulate matter of air, which may pose a hidden threat to human health through inhalation of atmospheric air (Ren et al. 2021). Similarly, arsenic was detected in the air samples, and the studied urine samples were derived from the habitants of the copper smelter regions (Skoczynska et al. 2021). Therefore, in the global context, these severe complications along with constant exposure to the food product or environmental contamination with toxic heavy metals may even lead to death.

Although global research on heavy metal toxicity is advancing at the cellular and genomic level to clarify the effect of heavy metals on human metabolism (Renu et al. 2021), studies on heavy metal contamination and its health implications in Bangladesh are at a very early stage (Islam et al. 2018a). Several research projects have reported the occurrence of hazardous concentrations of heavy metals in common foods such as cereals, vegetables, fruits, and fish (Islam et al. 2015a; Ahmed et al. 2016b; Ratul et al. 2018; Proshad et al. 2020; Zakir et al. 2020a). However, the health risks of the identified heavy metals were expressed as a hazard index or hazard quotient of the estimated daily intake and acceptable daily intake parameters. In contrast, a contemporary study based in Kuwait reported the presence of heavy metals derived from the household dust of air filters, where, household heating, ventilation, and air-conditioner are considered the key point sources for those toxic metals and metalloids (Al-Harbi et al. 2021). Similarly, the topsoil-derived heavy metals and their potential exposure to health risks were reported in central China (Li et al. 2020a, b), where the untreated discharge from the factory was blamed for the potential source of heavy metal to the nearby arable soils. However, recent studies have noticed the considerable concentration of detected heavy metals in the school dust of Dhaka City and indoor dust samples derived from the Dhaka EPZ area of Bangladesh (Rahman et al. 2021a, 2021b), which are the critical risk during unconscious inhalation. Thus, in Bangladesh, there is an urgent need to expedite the potential airborne heavy metals, which may pose a hidden threat to critical respiratory complexities during this COVID 19 pandemic. In a recent study, salinity-induced dissolved organic materials (DOM) have been noticed to accelerate the co-contamination of heavy metals in the southern coastal region of Bangladesh (Kabir et al. 2021), which is a promising sector of future study regarding co-exposure toxicity and vector transport pathways of heavy metals with related emerging environmental pollutants. Moreover, to combat the hidden threat to food safety, the studies regarding complex metabolism and cellular toxicity of heavy metals in human health and their subsequent effects on food webs including terrestrial, aquatic, and air particulate samples should also be emphasized in Bangladesh (Fig. 2).

Advanced yet unnoticed approaches for remediation of heavy metals in Bangladesh

Advanced studies on heavy metal remediation have been a priority in the development of environmental strategies. Among them, microbial approaches and heavy metal–tolerant microbes have proven to be the most promising options (Rahman 2020). The complex mechanisms of microbial remediation, including chemical–microbial interactions, were recently elucidated (Yin et al. 2019; Islam et al. 2021b), while heavy metal–tolerant microbes were considered potential candidates for advanced genetic development for sustainable field applications. Nanotechnology-based approaches have also been adopted to recover heavy metals from contaminated sites (Kumar et al. 2019; Nasir et al. 2019), while phytoremediation, a comparatively cheaper plant-based technology, was used to clean heavy metal–contaminated areas based on mechanisms such as phytoaccumulation (Muthusaravanan et al. 2018). A novel arsenic-hyperaccumulating fern (*Pteris vittata*) is widely reported as a sustainable phytoremediation tool for reclamation of arsenic-contaminated soils (da Silva et al. 2018).

Carbon-based biochar is another ideal adsorbent for heavy metal reclamation from the contaminated sites (Mansoor et al. 2020). The variation of pyrolysis temperature, redox complexation, and addition of organics was identified as the key factors for effective sorption of heavy metals through modified biochar (Li et al. 2017). Therefore, several significant modifications of biochar were adopted for the innovative remediation of toxic metal–contaminated sites. A recent observation suggests a new "vermibiochar" through the activation of biochar by potential earthworms by the stimulation of exogenous enzyme activities to establish an efficient and cheap recovery tool for heavy metal remediation from the contaminated soil and water systems (Yuvaraj et al. 2021). Similarly, an innovative and cheap "hydrogel" derived from the food waste was utilized as the food waste valorization approach for simultaneous application of soil health improvement and effective remediation of heavy metal–contaminated soils (Zhou et al. 2021). This hydrogel was prepared by combining montmorillonite clay minerals with urea and poly(acrylic) acid. The multifaceted chemical properties of this hydrogel may be advantageous for improving the oxidation reduction of the heavy metal–contaminated sites along with increasing soil's physical and chemical properties toward fertility status of the soils. Thus, the modification of biochar- or carbon-based adsorbents, vermiremediation,

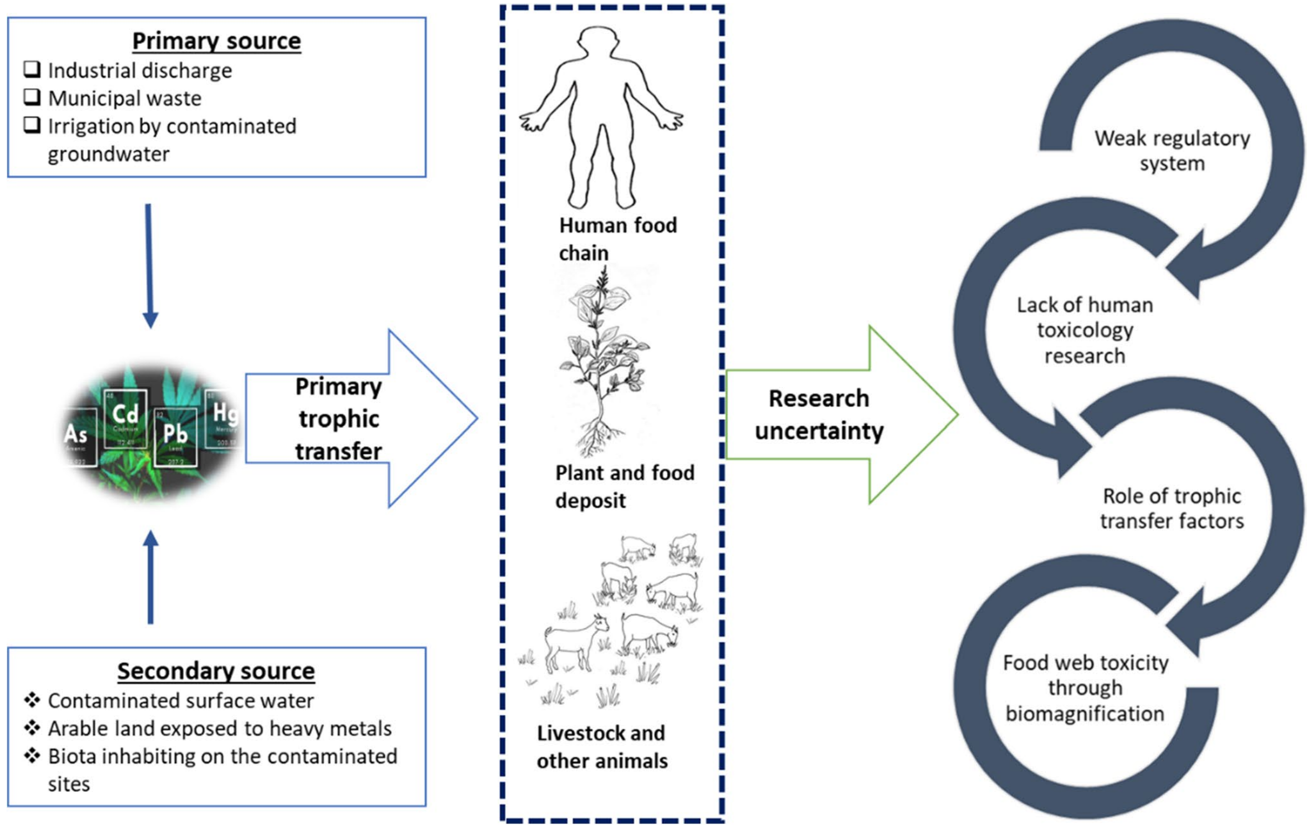

Fig. 2 Transport pathways, hidden threat, trophic transfer mediated by several transfer factors (e.g., biomagnification and biotransformation factors), and research uncertainty of heavy metal contamination in Bangladesh

and food waste–derived hydrogels are considered the sustainable approaches for heavy metal remediation due to the cost-effectiveness, and simplicity in applications. However, such sustainable techniques have not been widely applied in Bangladesh except for a recent study, which reported the potential use of a salt marsh macrophyte (*Porteresia* sp.) for the uptake and translocation of various toxic heavy metals (Hossain et al. 2021). Further adaptive investigations could be expanded to explore the cheap, sustainable, and innovative heavy metal remediation strategies in Bangladesh.

Challenges in environmental regulations for heavy metal pollution in Bangladesh

Heavy metal risk assessments in foodstuffs have been carried out in Bangladesh based on WHO and FAO safety standards (Islam et al. 2020a; Zakir et al. 2020b). Furthermore, while several studies have focused on estimating heavy metal levels in samples collected in Bangladesh, no integrated safety guidelines for assessing MTLs (maximum tolerable limits) have yet been established (Islam et al. 2018a, 2018b). It indicates a significant regulatory gap in heavy metal contamination in Bangladesh. There are several government entities such as Bangladesh Atomic Energy Commission (BAEC) and Bangladesh Standard and Testing Institute (BSTI) for controlling food safety including the contamination from the toxic heavy metals in the foodstuffs. The basic function of BAEC is to monitor the food and environmental samples with respect to the abundance of toxic heavy metals (Islam et al. 2015a; Islam et al. 2018a). In addition, recent findings on heavy metal contamination should be integrated to combat the prevailing research shortcomings in the food safety mission of the Bangladesh Food Safety Authority (BFSA 2017). The establishment of BFSA (based on Food Safety Act, 2013) ensures food safety in terms of toxins (heavy metals, pesticides, mycotoxins, etc.) in the common fresh and processed foodstuffs of Bangladesh. In addition, the National Food Safety Laboratory of Public Health Institution (PHI) has established a reference laboratory to monitor heavy metals and pesticides in the market available foodstuffs (BFSA 2017). The other regulatory bodies such as INARC (under the Institute of National Analytical Research and Services, BCSIR) are also fostering the food safety campaign by ensuring quality assessment of toxic heavy metals and related pollutants in the foodstuffs (INARS 2021). Despite several encouraging approaches acting to combat the heavy metal contamination in Bangladesh, several challenges such as poor enactment of the existing legislation due to ignorance among the stakeholders, lack of unified and reference analytical protocol for the comparative study of the toxic heavy metals in the common foodstuffs and environmental matrices, and adaptation of the green and sustainable management strategies for heavy metal polluted sites are considered as the bottlenecks of heavy metal research in Bangladesh.

In contrast, a recent review pointed out the heavy metal contamination in the farming land and following food chain toxicity toward food safety in China (Qin et al. 2020). Policymaking advocacy and sustainable remediation of heavy metal contamination were suggested to combat the heavy metals as a barrier to food safety in Chinese food webs. Similarly, a recent paper summarized the variations of bioaccessibility of heavy metals in the food webs through a comparison of in vitro and in vivo bioassay (Li et al. 2020a, b). The finding of that study indicates a significant variation of metal bioaccessibility due to various metabolic factors from source to sink pathways. However, Bangladesh is the worst victim of major environmental disasters, including heavy metal contaminations in the food webs. Thus, there is a need for the synchronization of global legislation and the health risks of heavy metals to foster the safety of foodstuffs in Bangladesh. The major institutions and their regulatory framework for addressing heavy metal contamination including related acts and legislations at global and at level of the government of Bangladesh are illustrated in Fig. 3.

Conceptual implication for management of heavy metal contamination in Bangladesh

During the last decade, heavy metal contamination in Bangladesh is studied extensively. Those earlier published reports have already noticed the abundance of heavy metals in the common foodstuffs (fruits, vegetables, and fishes), river and groundwater, and soils and sediments nearby the industries and suburban soils (Islam et al. 2018a; Habib et al. 2020). However, to date, the sustainable management of heavy metal contamination was not suggested precisely in Bangladesh's perspective. This study identified several untapped research themes and the possible holistic solution through a conceptual implication approach (Fig. 4), which is the pioneering step toward policy implication and prospective of heavy metal research in Bangladesh. The existing studies of heavy metals should be corroborated with the untapped research themes to overcome the current research uncertainties of heavy metal contamination in Bangladesh. Among the unveiled research avenue, unified strict enforcement of the existing regulatory framework with possible contemporary amendments will boost the current legislation of heavy metal contamination for improving local food safety in Bangladesh. In addition, the factors of trophic transfer of heavy metals in various ecosystems, and following food chain toxicity including bioaccumulation and biotransformation

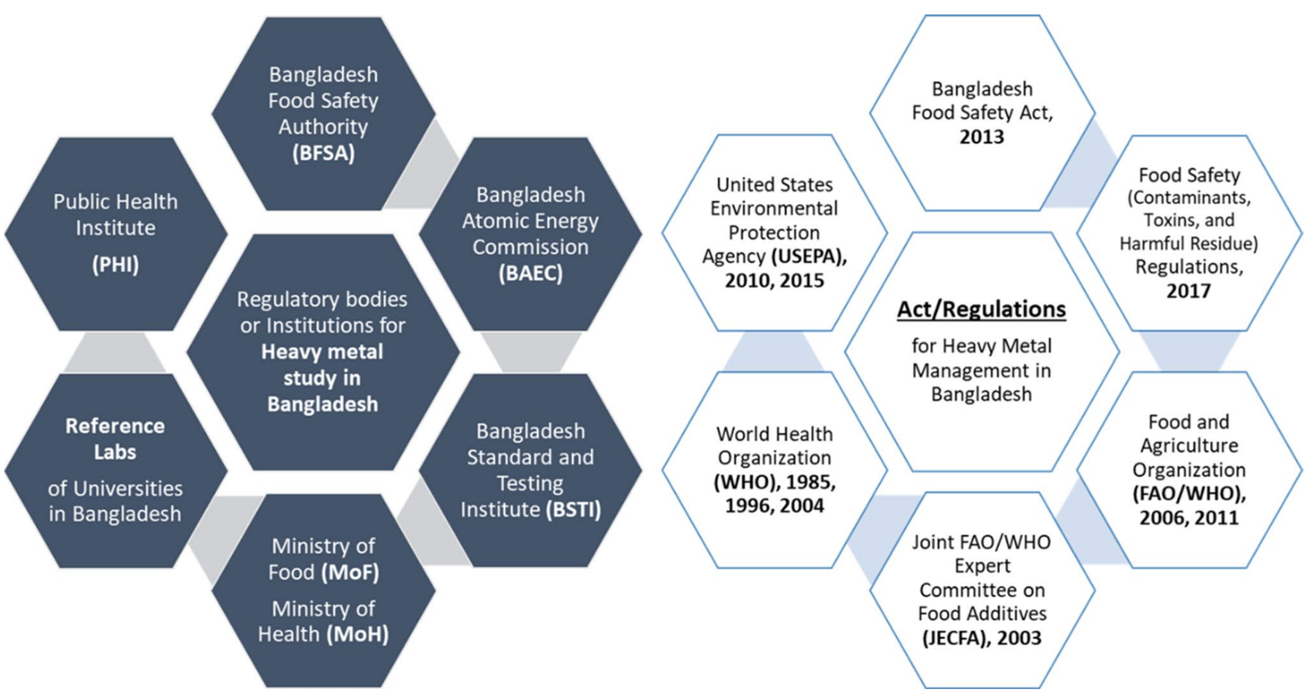

Fig. 3 National and global regulatory bodies and respective institutions involved in regulatory acts and legislative monitoring, and safety regulations of heavy metal contamination in Bangladesh

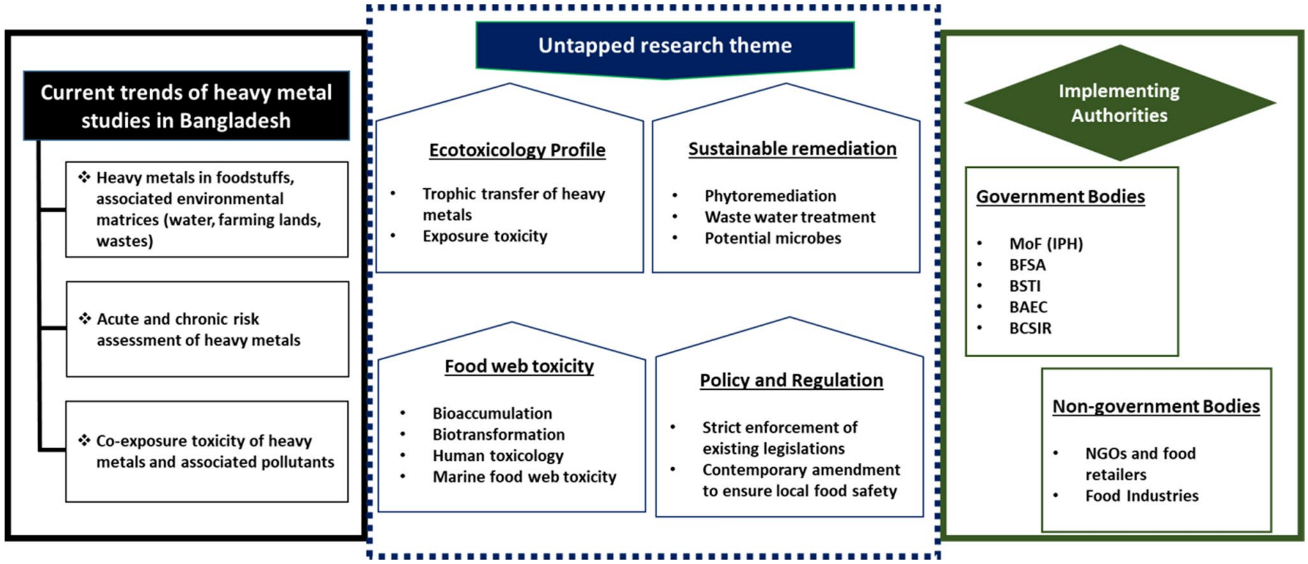

Fig. 4 Conceptual policy framework for sustainable management of heavy metal contamination in Bangladesh for fostering the food safety and environmental sustainability

should be investigated. Furthermore, economically viable and sustainable remediation of heavy metals from the contaminated matrix should be merged with advanced global remediation (e.g., phytoremediation, microbial remediation, and wastewater treatments). Another important sink of heavy metals and co-existence of other organic pollutants of Bangladesh in the Bay of Bengal (Hossain et al. 2020a, b, c), which is not studied meticulously for food webs transfer of heavy metals to the human food chain (Islam et al. 2021), except few empirical seafood heavy metals contamination studies (Baki et al. 2018; Biswas et al. 2021). Thus, a meticulous evaluation of existing research gaps and global policy synchronization should be implemented through a logical merger of all possible stakeholders (e.g., government bodies—Ministry of Food, Bangladesh Standard and Testing Institute-BSTI, Bangladesh Food Safety Authority-BFSA, and non-government stakeholders) for enhanced management of heavy metal contamination in Bangladesh.

Conclusion and research perspective

This review summarizes and updates scenarios of toxic heavy metal contamination and related health risk in food webs and associated environments in Bangladesh. It also explores the transformation of toxic trace metals into food webs in Bangladesh. Our literature survey revealed that current challenges of heavy metal contamination in the food chain are mainly caused by improper management of industrial discharge, poor enforcement of standard guidelines and regulations, unavailability of research data concerning sustainable management, and limited public awareness. These limitations ultimately pose a hidden threat to food safety in Bangladesh. Policy formulation in synchronicity with global regulatory policy and research efforts is therefore needed to overcome these bottlenecks for the mitigation of heavy metal contamination in Bangladesh. In addition, an extensive future investigation on the human and plant metabolism of heavy metals is needed. Regular monitoring of analytical findings from well-equipped unified laboratories is needed to ensure local food safety. Furthermore, potential health risks due to the exposure to hazardous heavy metals and molecular toxicology through clinical trials need to be explored. To sum up, strengthening sanitary systems and adopting contemporary remediation approaches (e.g., bioremediation, phytoremediation, nano-remediation, and advanced catalysis) are needed to sustainably combat heavy metal contamination to ensure food safety in Bangladesh. The existing challenges and possibilities of further toxic metal contamination in Bangladesh warrant future critical evaluation following the recommended conceptual policy frameworks.

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Author contribution Aniruddha Sarker and Jang-Eok Kim: conceptualization, methodology, data curation, and writing — review and editing. Abu Reza Md. Towfiqul Islam and Muhammad Bilal: conceptualization and writing — review and editing. Md. Refat Jahan Rakib and Mohammed M. Rahman: writing — original draft and visualization. Rakhi Nandi: methodology and writing — review and editing. Tofazzal Islam: conceptualization, methodology, writing — review and editing, and supervision.

Declarations

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