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Food Adulteration and Bio-Magnification of Environmental Contaminants: A Comprehensive Risk Framework for Bangladesh

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This article thoroughly investigates the severity of the prevailing environmental conditions and evaluates the resulting threats to food intake and public health in Bangladesh by establishing relationship among different contaminant transfer mechanisms to human. It describes the potential of certain contaminants to get bio-magnified through the food chain. A database was prepared on a number of contaminants in the study area that are responsible for rendering different foods vulnerable to produce long term or short-term health effects. Contaminants that have been identified in the food sources were categorized in a continuum based on their allowable daily intake. A protocol has been developed which will enable the assessment of the potential of a contaminant to bio-magnify through food chain to understand the contribution of a contaminant on different levels of food chain. The study also provides a detailed assessment of the public health risks associated with direct ingestion of adulterated foods and intake of contaminants through food chain or water intake. Their intake to human body was quantified, which provides an indication of the toxicity level of the contaminants and possible impact on human health. The traditional four steps of risk assessment technique have been employed for some model contaminants (including metals, organic contaminants, and food adulterants). Additionally, existing rules and regulations of Bangladesh were identified with possible limitations that can play significant role in controlling the food adulteration practices and concentration of contaminants in the environment and human body. Finally, a holistic approach to necessary interventions has been prescribed at policy, treatment and evaluation level to prevent the water pollution and food adulteration. Thus, a much-needed comprehensive framework is prescribed in this study to promote safety in food handling, preserve environment and improve health-based strategies in Bangladesh.

Keywords: adulteration, contamination, bio-magnification, public health, risk assessment, regulatory framework, Bangladesh

INTRODUCTION

Bangladesh experiences heavy water pollution due to the poor regulation and improper waste disposal/discharge practices. In addition, deteriorating public health situation can be attributed to food adulteration practices. The contaminants become part of the food chain due to poor control of effluent treatment plants of textiles, tanneries, and pharmaceuticals industries as well as open dumping of toxic/solid waste and wastewater (Amin et al., 2011; Chakraborty et al., 2013). The prevalent food adulteration practices are contributing to abating public health to a larger extent especially for the wide-spread use of contaminants such as formalin, artificial color, toxic chemicals etc., (Labu et al., 2011; Ali, 2013a). First level of pollution occurs through the direct exposures to contaminants from the discharge of both point sources and non-point sources. Point sources, mainly, refer to untreated effluent discharge from different industries and non-point sources refer to the agricultural run-off. Second level of pollution of human induced adulteration constitutes the addition of ripeners, preservatives, and food enhancers etc. for increasing shelf lives of the food items and making them more appealing. As a result, the toxic chemicals affect food consumers and travel across food chains producing an effect known as bio-magnification. Bio-magnification process describes how the tissue concentrations of a contaminant increase as it moves up the food chain through two or more trophic levels (Nowell et al., 1999). It is a result of, for instance, contamination due to heavy metal or other persistent contaminants, which cannot be decomposed by environmental processes. The contaminant's low rate of internal excretion or degradation is another reason for bio-magnification (Bacaksızlar and Önsel, 2013). Both carcinogenic and non-carcinogenic substances could be bio-magnified in this process. Clear understanding of the bio-magnification health effects in Bangladesh would immensely contribute toward assessing the human vulnerability to toxic pollutants such as DDTs, pesticides, heavy metals, toxic dyes etc. There is no major study conducted in Bangladesh looking into the effects of human health affected through bio-magnification. Compilation of a protocol to quantify the bio-magnification induced effect would therefore facilitate the development of regulatory actions to combat food contamination.

Extensive studies on food adulteration confirm that ∼50% of the food is either adulterated or contaminated with toxic compounds (DDTs, formalin, textile dyes) or disease causing microorganisms (Dawlatana et al., 2008; Bhuiyan et al., 2009a; Uddin et al., 2011; Naser et al., 2012; Ali, 2013a; Nasreen and Ahmed, 2014). Several laws have been promulgated in Bangladesh over the years looking into food safety, nutrition and public health issues in Bangladesh such as BSTI Ordinance, 1985; Fish and Fish Products Rules, 1997; Bangladesh Pure Food Ordinance, 1959 etc. Though adulteration has been reported and investigated extensively by researchers recently, the scale, level and spread of the different types of adulteration together with its effects and risks on human health have not been investigated holistically to address its public health impacts in Bangladesh. Furthermore, the aspect of food contamination through bio-magnification has not been incorporated in the paradigm. A proper understanding of the complex relationship and contribution of the two aspects (adulteration and contamination through bio-magnification) on food quality in the context of malnutrition and public health can provide significant regulatory guidelines. Additionally, identification and detailed performance analysis of different interventions (such as regulation, enforcement mechanisms, natural alternatives, preventive measures, frequency, and amount of daily intake) can provide specific measures to control food adulteration. While on the water pollution side, identification, and performance analysis of existing regulations, mechanisms of enforcement, treatment techniques and hygiene/healthy habits can provide appropriate measures to reduce the accumulation of water pollutants in humans through direct exposure or bio-magnification.

Transport of variable amounts of contaminants to human body through various exposure routes needs temporal estimation. It is also important to understand how much total intake and health risk can be reduced if control is set, even on a single source. Unfortunately, mere presence of contaminants in edible foods has been identified so far whereas sufficient and accurate information on the concentration levels of toxic substances in food is very limited. Proper and regular laboratory assessment of the three mechanisms discussed as well as development of laboratory and evaluation protocols for such complex and interconnected pathways of contamination/human exposure are urgently required.

The risk for carcinogenic and non-carcinogenic effects associated with the exposure to contaminants through three specific mechanisms (e.g., water pollution, food adulteration and bio-magnification) can be variable depending on the types of contaminants, their respective properties and natural attenuation or digestive mechanisms. The multivariate presence, transfer, and effects of contaminants in human health, thus require a comprehensive risk based approach to select and recommend proper regulation, control, treatment techniques, and health care strategies. Such a risk-based approach to control and regulate contamination is not adequately addressed in Bangladesh. Intake and associated risks via water pollution and food-adulteration need to be quantified and effects of bio-magnification, potential degradation, and relevant other exposure pathways are required to be addressed in a broader scale. This necessitates the assessment and characterization of the risks to obtain a comprehensive protocol specific for a developing country like Bangladesh so that pro-active measures could be taken in handling further detrimental effects on national health.

The transition of Bangladesh's status from "Developing Countries" to "Lower middle income Countries" (The World Bank, 2015) necessitates further major investigation and evaluation of food adulterants and aquatic contaminants in Bangladesh. Thus, this research can provide significant guidelines to determine necessary steps for Bangladesh at regulatory and intervention levels (Department of Environment, Ministry of Health, Ministry of Science of Technology, Department of public health Engineering as well as private sector stakeholders). When the health impacts of those

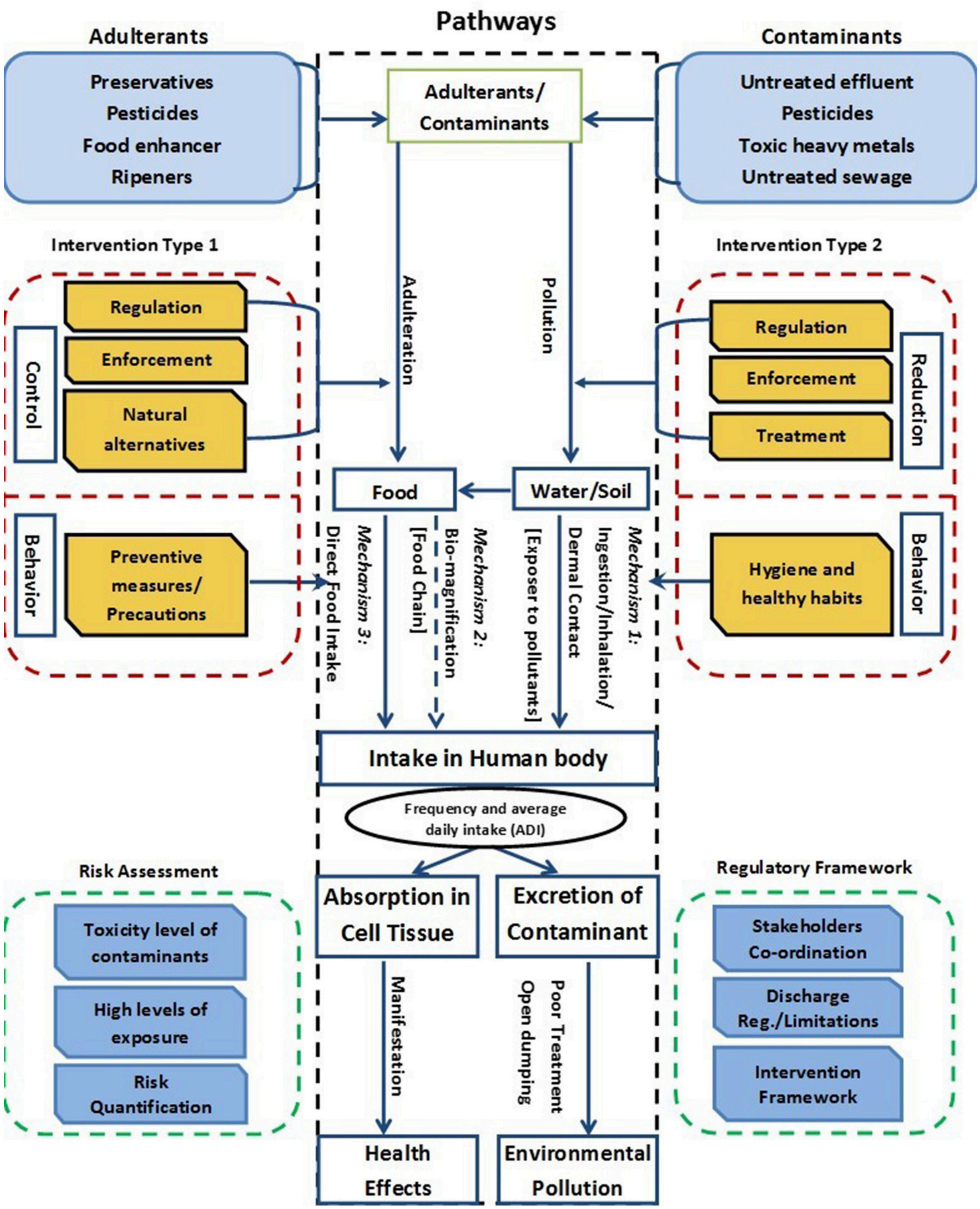

FIGURE 1 | Flow chart of human exposure to contaminant pathways and associated mechanisms involved and framework for interventions.

contaminants on specific class or vulnerable groups of people could be very serious and detrimental, a much-needed comprehensive framework has been developed in this study to promote safety in food handling, preserve environment and thus improve health-based strategies in Bangladesh.

SCOPE AND OBJECTIVES OF THE STUDY

This article mainly investigates and analyzes different aspects of human exposure to water/food contaminants found and adulterants used in Bangladesh. Thus the objectives of this review study are:

TABLE 1 | Common contaminants found in different categories of food in Bangladesh.

Type and names of the contaminants		Chemical formula	Effects	Food categories
Preservative	Formalin	CH_2O	Toxic, allergenic, carcinogenic, tumor development, asthma, skin disease	Fish, fruit, milk, meat, apple
	Coal Tar	NA*	Toxic and carcinogenic	Sweetmeats, ghee, condensed milk, khoa, milk powder
	DDT	$C_{14}H_9C_{l5}$	Persistent organic pollutant, causes infertility and birth defect, toxic and carcinogenic	Dried fish
	Burnt engine oil	NA*	Damages nervous and gastrointestinal system	Jilapi
	Sulfuric acid	H_2SO_4	Damages cardiac system	Milk
Ripener	Ethephon	$C_2H_6ClO_3P$	Dermally corrosive, toxic, irritates skin and eye	Mango, tomato, pineapple
	Ethelyne Oxide	C_2H_4O	Respiratory and eye irritation, skin sensitization, vomiting, and diarrhea	Papayas, bananas
	Calcium carbide	CaC_2	Liver failure, ulcer, cancer	All fruits
Adulterant	Brick dust	$C_3H_6N_6$	Cancer, asthma, allergic alveolitis	Chilli powder, mango juices
Flavor enhancer	Monosodium glutamate	$C_5H_8NO_4Na$	Causes nervous system disorder and depression	Chinese foods
Food enhancer	Sodium cyclamate	$C_6H_{12}NNaO_3S$	Causes cancer, kidney, and liver failures	Beverage and soft drinks, syrup, cake, canned fruit, preserved fruit, ice cream
	Toxic colors/Textile dyes	NA*	Sleeping disorder, asthma, indigestion, allergies, diarrhea, neurological disease	Sweets, chilli powder, jilapi, beguni, piyaju
	Artificial sweetener	NA*	Maintain reduced energy intake, body weight, lower risk of type-2 diabetes and coronory heart diseases	Sweetmeats
Filler	Saw dust	NA*	Stomach problem	Loose tea, mango juices, chilli powder
Additive	Hormone	NA*	Causes infertility in women	Beef, dairy product
	Melamine		Causes illness and death	Powdered milk
Pesticide	Heptachlor	$C_{10}H_5Cl_7$	Human carcinogen, changes in nervous system and immune function	Fish
Fertilizer	Urea	CH_4N_2O	Agricultural, industrial and medical application, carcinogenic, causes ulcer, damages nervous system	Puffed rice/muri, milk
Heavy Metal	Cadmium	Cd	Carcinogenic, kidney failure, environmental hazard	Milk, rice, eggplant
	Chromium	Cr	Lead to cancer	Milk, chicken, bone and liver
	Lead	Pb	Cardiac problem	Street foods (Fuchka, chotpoti, bhelpuri etc.)
	Arsenic	As	Carcinogenic, cardiovascular disease	Rice, potato, eggplant, spinach, green banana

NA, Not available.*

(1) Description of the transport mechanisms of contaminants/adulterants between environment and human.
(2) Identification of major pollutants/adulterants of concern in Bangladesh, a detailed scenario analysis with nutritional need/existing health problems and categorization of food adulterants and contaminants based on their allowable daily intake.
(3) Compilation of a protocol for the assessment of bio-magnification potential of a particular contaminant in the food chain based on its flow/transport across different levels of food chain.
(4) Application of the traditional risk assessment techniques for certain model contaminants (such as metals, organic contaminants, and food adulterants) and determination of the public health risks (e.g., toxicity scores, hazard index) associated with their direct/indirect intake through food chain or environmental exposure.
(5) Identification of possible limitations in the existing rules and regulations that can play significant role for controlling the

TABLE 2 | Food categories arranged according to the number of contaminants involved.

Milk	Fruits	Fish	Vegetables	Sweetmeats	Meat	Rice	Powdered Milk	Puffed rice
^	^	^	^	^	^	^	^	^
Formalin	Formalin	Formalin	Cadmium	Artificial Sweeteners	Formalin	Cadmium	Melamine	Urea
DDE	Calcium Carbide	Chlordane	Arsenic	Coal tar	Hormone	Arsenic	Coal tar	
Urea	Sodium Cyclamate	Heptachlor	Chromium	Toxic color				
Sulfuric Acid	Ethylene Oxide	DDT	Pesticides					
Cadmium	Ethephon							

TABLE 3 | Basic components of nutrition and their sources in food types found in Bangladesh.

Components	Sources in Bangladesh	Daily Requirements/RNI/RDA/RDI (Adults)
Carbohydrates	Mushrooms, rice, wheat, wheat flour, potato, maize, millet, barley (whole-grain, raw), biscuit (sweet), bread (bun/roll; white/for toasting), semolina, vermicelli, starchy roots, sorghum	270–450 g/day
Fat	Soybean, mustard and rice bran oil, whole cream milk, butter, ghee, egg, meat, shrimp, prawn, animal skin, coconut oil, fish oil, palm oil	Visible fat: 30 g/day Cholesterol: 300 mg/day
Protein	Soybean, red kidney bean, Bengal gram, black gram, green gram, red gram, lentil, pea, meat, fish, poultry, egg, legumes and pulses, lean meat	33–66 g/day
Vitamins	Sea fish, pulses, legumes, dark green leafy vegetables, yellow-orange vegetables, fruits, peas, beans, brinjal, cabbage, cauliflower, carrot, cucumber, agathi, dock leaves, beet greens leaves, colocasia (kochu) weed, alligator weed, amaranth	Vit-A: 500–600 μg/day Thiamine: 1.1–1.2 mg/day Riboflavin: 1–1.3 mg/day Vit-B12: 2.4 μg/day Folic acid: 400 μg/day Vit-C: 40 mg/day
Minerals	Wheat, meat and poultry, pulses and legumes, cow milk, goat milk, buffalo milk, colocasia (kochu), potato tuber, blackberry, gourd, cauliflowers, lalshak, stem amaranth, spinach, custard apple, pomegranate, pear, pineapple, kolmishak, kochushak, drumstick leaves	Calcium: 1000–1300 mg/day Phosphorus: 700 mg/day Iron: 9.1–58.8 mg/day Sodium: 1902–2092 mg/day Potassium: 3225–3750 mg/day Magnesium: 190–260 mg/day Iodine: 150 μg/day Zinc: 3–14 mg/day
Water	Sweet potato leaves, water spinach, watercress, sugarcane	1.5–3.5 liters/day

RNI, Recommended Nutrient Intake; RDA, Recommended Dietary Allowances; RDI, Reference Daily Intake.

food adulteration practices and contaminant levels in the environment and human body.

(6) Finally, development of a comprehensive framework in order to promote safety in food handling, preserve environment, and thus improve health-based strategies in Bangladesh.

FOOD CONTAMINATION AND BIO-MAGNIFICATION OF CONTAMINANTS—THE OVERALL MECHANISM

The overall picture of food contamination, adulteration, and bio-magnification starting from the sources, pathways, intake and the effects is shown in a simplified flow chart in **Figure 1**. A contaminant becomes a part of the environmental medium (water, air or soil) through variety of anthropogenic activities. Water pollution from point sources (e.g., discharge of untreated effluent and toxic heavy metals from sewers and industries) and non-point sources (e.g., agricultural runoff of pesticides) give rise to contaminant transport into aquatic sources of food such as different aquatic species. Aquatic species (e.g., fishes) and other types of foods of nutritional importance (e.g., milk, meat, vegetables) get contaminated for human malpractice/adulteration through the use of preservatives, food enhancers, ripeners etc., to increase their shelf lives and make them appear fresh. Thereby, the contaminants enter the food chain through different types of foods and end up in human body with harmful concentration levels based on the intake rate. Zenker et al. (2014) stated that, chemical risk assessment methods for substances found in food and drinking water involve establishing an acceptable daily intake (ADI) or tolerable daily intake (TDI) based on a variety of calculations (e.g., from extrapolations applications of uncertainty factors) from toxicological and epidemiological databases.

If the intake of a contaminated food in human body results in the concentration level of the contaminant to be within the allowable daily intake value for that contaminant (specified by WHO), excretion or degradation of the contaminant is still a possibility leaving limited or zero detrimental effect on health.

TABLE 4 | Toxicity continuum ranked from the most harmful to the least harmful contaminants based on their respective allowable/total daily intake (ADI/TDI) values.

Contaminant		Concentration in food, C_{food}	Concentration in water, C_{water}	ADI	Chronic reference dose, RfD
		mg/kg	mg/l	mg/kg	mg/kg-day
Aldrin	High value	0	0.0009	0.00003 (mg/l)	0.00003
		Rahman and Alam, 1997	Ghose et al., 2009	WHO, 2003a	US EPA, 2012
	Low value	0	0.002	0.00003 (mg/l)	0.00003
		Rahman and Alam, 1997	Ghose et al., 2009	WHO, 2003a	US EPA, 2012
Cadmium	Mean value	0.033	0.018	0.0001	0.0005
		Khan et al., 2010	Shamsuzzoha, 2002	WHO, 1972	US EPA, 2012
Heptachlor	High value	0.005464	0.00524	0.0001	0.0005
		Bhuiyan et al., 2009b	Chowdhury et al., 2012	WHO, 2006	US EPA, 2012
	Low value	0.000682	0.00524	0.0001	0.0005
		Bhuiyan et al., 2009b	Chowdhury et al., 2012	WHO, 2006	US EPA, 2012
Chlordane	High value	NA*	NA*	0.0002 (mg/l)	0.0005
				WHO, 2003b	US EPA, 2012
	Low value			0.0002 (mg/l)	0.0005
				WHO, 2003b	US EPA, 2012
Arsenic	High value	0.309	0.3	0.002	0.0003
		Khan et al., 2010	Smith et al., 2000	Seiler and Sigel, 1998	US EPA, 2012
	Low value	0.036	0.05	0.002	0.0003
		Khan et al., 2010	Smith et al., 2000	Seiler and Sigel, 1998	US EPA, 2012
DDT	High value	0.874966	0.00829	0.02	0.006
		Bhuiyan et al., 2009b	Chowdhury et al., 2012	WHO, 2006	Cabral et al., 1982
	Low value	0.003038	0.002595	0.02	0.006
		Bhuiyan et al., 2009b	Chowdhury et al., 2012	WHO, 2006	Cabral et al., 1982
DDE	High value	0.025	0.0041	0.03	0.04
		Hussain, 2013	Chowdhury et al., 2012	Gatrell et al., 1986	Valvi et al., 2012
	Low value	NA*	0.002	0.03	0.04
			Chowdhury et al., 2012	Gatrell et al., 1986	Valvi et al., 2012
Lead	Mean value	0.326	0.47	0.05	NA*
		Islam et al., 2014	Shamsuzzoha, 2002	FAO/WHO, 1987	
Formalin	High value	140	NA*	0.2	0.2
		Uddin et al., 2011		US EPA, 1997	US EPA, 2012
	Low value	1	NA*	0.2	0.2
		Uddin et al., 2011		US EPA, 1997	US EPA, 2012
Melamine	Mean value	NA*	NA*	0.2	NA*
				WHO, 2008	

NA, Not available.*

Whereas, if the contaminant turns out to be in concentration levels higher than the allowable daily intake value, it gets absorbed in cell tissue and depending on the toxicity level (toxicity continuum), exposure level and risk associated, minor to major health effects could be observed.

Thus, **Figure 1** explains the various pathways that human health can be potentially exposed to the contaminants/adulterants found and used in the environment. The routes of exposure to the contaminants in a given environmental reservoir give a clear identification of the bioaccumulation phenomenon that can occur. When this exposure route involves food chain, then the contaminant could potentially bio-magnify depending on the contaminant properties and the ingestion routes. Thus, (a) bio-concentration occurs when dermal ingestion or absorption process works for the intake of contaminants inside the body while (b) bio-magnification occurs when the contaminant is transported through food inside the body and the concentration in the body is found in elevated magnitude in comparison to that in the food source. When the contaminant is excreted out in the environment, it contributes to environmental pollution again if not managed or treated properly again becoming an environmental contaminant. In **Figure 1**, interventions that should be adopted in order to control adulteration are listed in "Type I" box and the ones to reduce pollution are listed in "Type II" box. Preventive measures also include behavioral

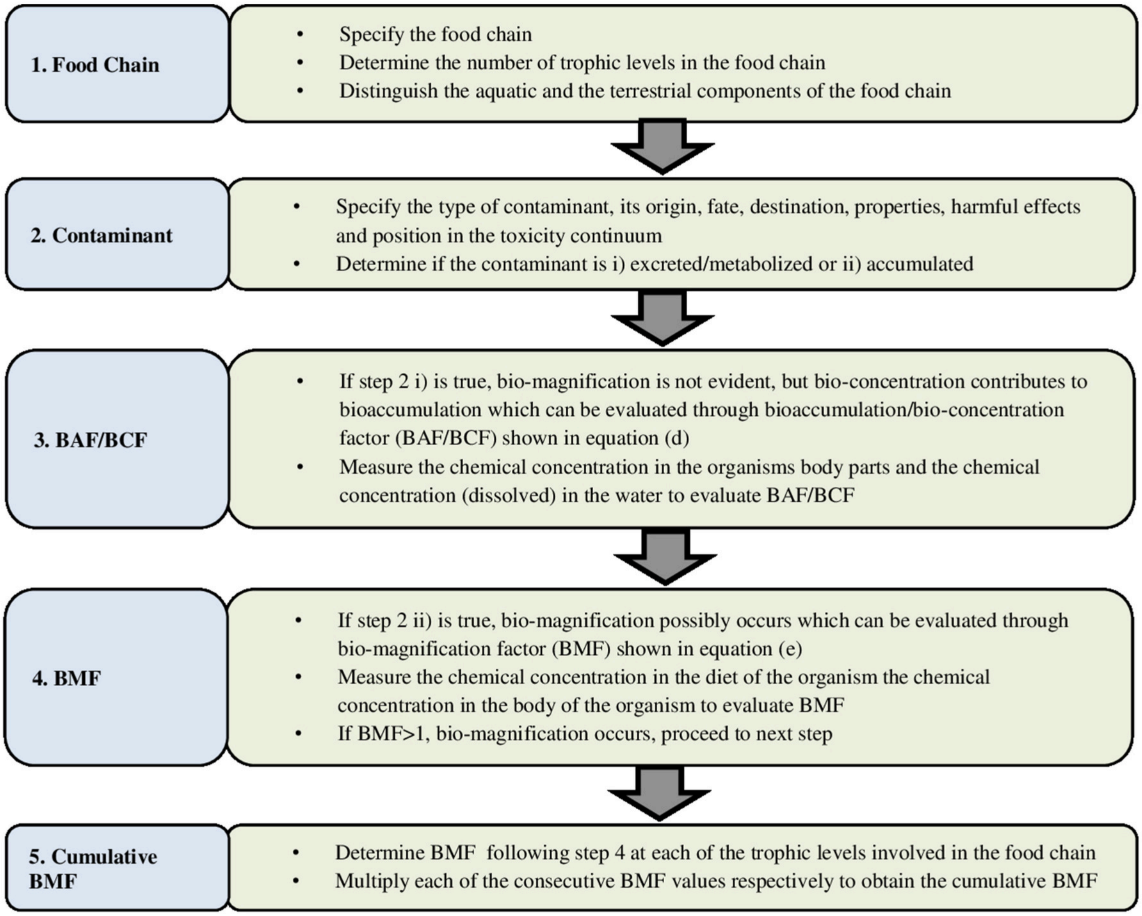

FIGURE 2 | Protocol to evaluate bio-magnification.

practices of the consumers in general. Based on the exposure level and the toxicity level of the contaminants, overall risk on public health can be quantified (Dumitrescu et al., 2012) as shown in the risk assessment box. Finally, a proper regulatory framework will address the proper coordination among the stakeholders and implement the intervention strategies to reduce food adulteration and water pollution. All the above-mentioned processes and relevant pathways will be elaboratedin the subsequent sections with appropriate case studies relevant to Bangladesh.

TOXIC CHEMICALS IN WATER BODIES IN DHAKA CITY AND THEIR EFFECTS ON AQUATIC FOOD SOURCES

Major contaminants from the different industries (e.g., alkali, chromium and chlorine from textile industry; chromium, and other heavy metals from fertilizer companies and tanneries; mercury and phenols from pulp and paper industry, refineries, pharmaceuticals, and paint industries) significantly affect the fish and consequently impart water induced health effects (Alam et al., 1998). Quantitatively, these pollutants affect the fishing industries through affecting the natural productivity of fisheries and qualitatively they affect the values of such aquatic species as an important food source. Thus, human health is endangered accordingly.

A recent study investigating the water quality parameters discharged from seven textile dyeing industries at Konabari in Gazipur region of Bangladesh reported the harmful effects of effluents on the surrounding environment (Munnaf et al., 2014). The study concluded that the volume of wastewater discharged from the studied industries often exceeds acceptable standards set by Department of Environment (DOE). The textile dyeing industries in the Gazipur area discharge large quantities of effluent with significant higher levels of physicochemical pollutants than the discharge limits for water quality parameters regulated for Bangladeshinland surface waters. These exclude certain industries that have active wastewater treatment plants. Now arises the concern, how these contaminants are becoming parts of our food.

Fishes constitute important aquatic sources of food in Bangladesh. The major bulk of fish comes from the catch and aquaculture of the rural poor although they are rarely able to

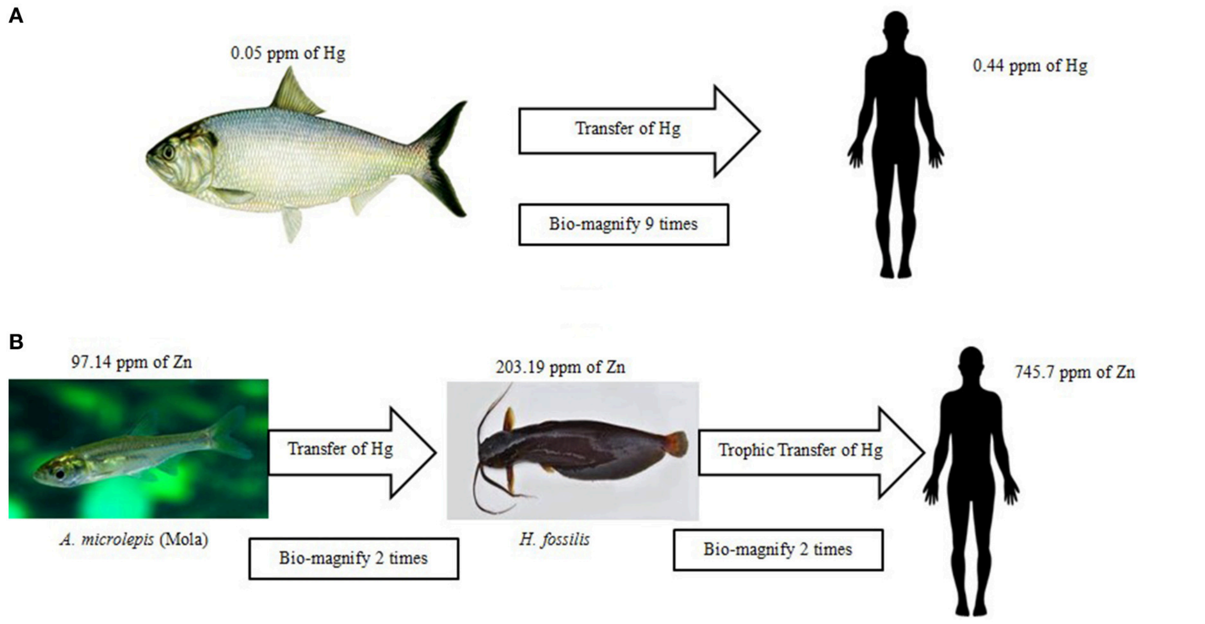

FIGURE 3 | Bio-magnification of (A) Hg and (B) Zn at different trophic levels.

consume their products (Rahman and Ali, 1986; Nuruzzaman, 1993). Aquaculture activities in urban areas in Bangladesh have not been developed in commercial levels because of higher densities of population and scarcity of land areas. This is particularly true for Dhaka City. However large amounts of fish are marketed and distributed in the city every day. There are large areas of low-lying land encompassing the city that takes the form of vast floodplains during the monsoon. Hundreds of hectares of these floodplains are fed by three big rivers namely, Buriganga, Shitalakhya, and Turag (Ali, 1991; Tsi and Ali, 1997). But the major sources of fish are not those rivers rather the fish distribution channel is dependent upon the ponds or open waters from nearby districts, which are shipped to consumers. Fish marketing channel in Dhaka City are almost entirely conducted, financed and regulated by traditional, hardworking, and skilled middlemen. The market chain from farmers/fishermen to consumers passes through a number of intermediaries. This system includes four stages such as (a) primary market, (b) secondary market, (c) higher secondary market, and (d) consuming market. Fish distribution channel in Dhaka City is also involved with inadequate facilities and ill control of the intermediaries. Thus, it is apparent that the transport of fishes from the production zones of the country and the fish distribution path in Dhaka City is complex.

Thus, adulteration of fish is hard to control. Nevertheless, the contamination and pollution of water bodies and their tributaries continue to pose threat on the overall aquaculture practices. Meanwhile, the edible parts of the fish species are important sources of protein, vitamin A and calcium. So, the sources of these important species need to be conserved and kept contamination free.

Five freshwater species (from Bangshi River in Savar, Dhaka District) were analyzed for lead, manganese, nickel, zinc, copper, and iron by atomic absorption spectrophotometry (AAS) to investigate the adsorption of heavy metals in the fish muscles (Amin et al., 2011). The reported contaminants concentration detected in the fish samples indicates the possibility of contaminants transport in the food chain, which were discharged in the water bodies via toxic industrial effluents. Apart from the main sources of fish, the aquatic ecosystems consist of different forms of phytoplanktons and zooplanktons that can be affected by pollution. Phytoplanktons and zooplanktons could become part of human food chain eventually, as aquatic herbs are edible and easily available for floating/poor people. Furthermore, animals and people living nearby water bodies also get exposed to the untreated water from these polluted sources.

FOOD CHAIN AND BIO-MAGNIFICATION

Food chain is a linear network of links of the food web starting from the producer organisms and ending at apex predator species or decomposer species and thus, clearly shows how the organisms/animals/human are related with each other by the food they consume. Bio-magnification, a potential pollutant pathway to human, refers to the tendency of pollutants to concentrate as they move from one trophic level to the next (Mader, 1996). The bio-magnified pollutant should have different intrinsic properties such as (a) the pollutant has to be long-lived, otherwise it will be broken down or degraded very easily; (b) it should be mobile so that organisms can easily take it up; (c) it has to be soluble in fats and that is why it may be retained for a long time, water soluble compounds are excreted easily which

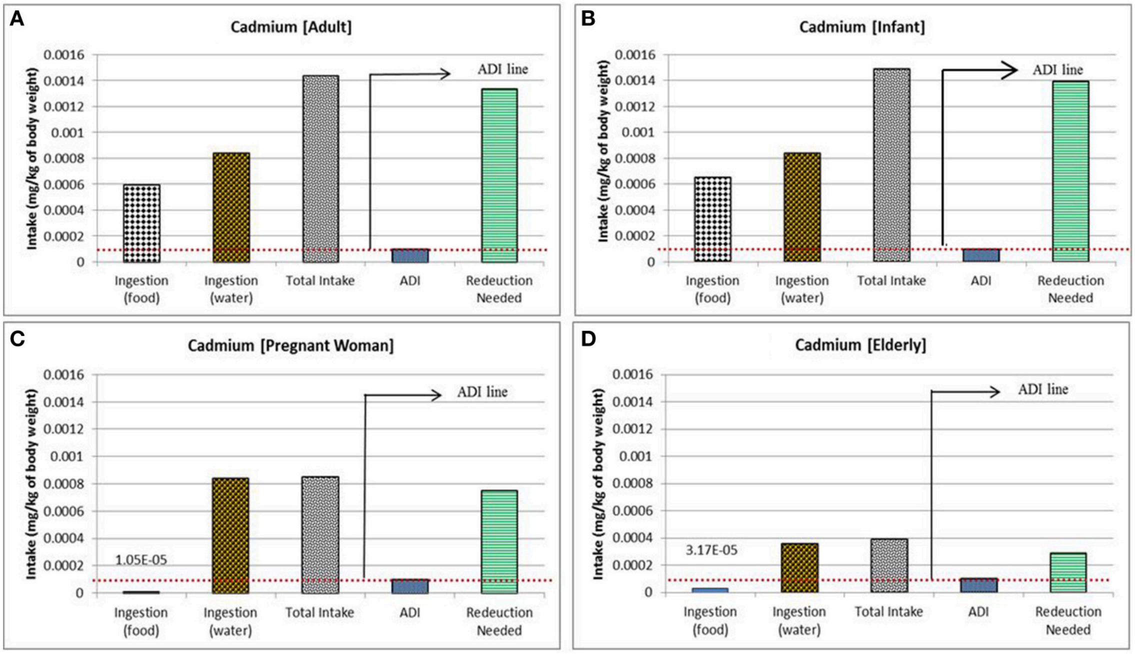

FIGURE 4 | Intake of cadmium to (A) Adult, (B) Infant, (C) Pregnant woman, and (D) Elderly people with necessary reduction needed.

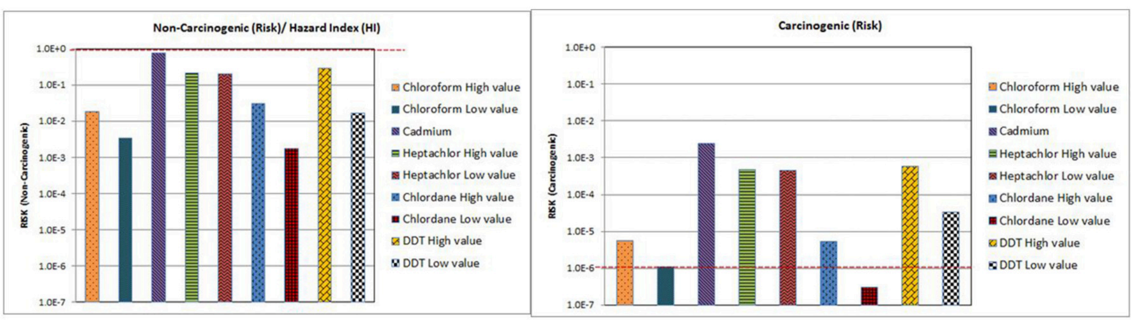

FIGURE 5 | Non-carcinogenic and carcinogenic toxicity scores of different contaminants/adulterants.

do no cause bio-magnification, and (d) the pollutant has to be biologically active to cause bio-magnification.

Mercury based compounds are bio-magnifiable pollutants that are toxic and can be very dangerous at low levels both at aquatic and terrestrial ecosystems. Mercury being a persistent substance, can build up or bio-accumulate in living organisms. In the environment, mercury can be converted to a highly toxic organic compound called methyl mercury. Methylmercury biomagnifies through the food chain as predators eat other organisms and absorb the contaminants contained in their food sources. Over time, predator organisms/species (e.g., an individual) consume plants or prey on contaminated organisms with methylmercury will acquire greater levels methylmercury than in either its habitat or its food (Environment Canada website[1]). DDT is another toxic substance, which along with its derivatives were found in each food web compartment (i.e., water, sediment, aquatic plant, plankton, fish, and invertebrates) and bio-magnification potentially occurred from the lowest up to the highest trophic level (Siriwong et al., 2009). This is because there are an increasing number of toxic substances that are being added to the environment every day as the development progresses from different anthropogenic sources. Except for DDT and mercury, there are other compounds that could be biomagnified such as polychlorinated biphenyls (PCB's), polynuclear aromatic hydrocarbons (PAH's, petroleum products), cyanide, selenium, other heavy metals such as copper, cadmium, chromium, lead, zinc, nickel, and tin (Mader, 1996).

The nature and effect of each of the contaminants would be very different and in order to assess those effects, it is necessary to learn what contaminants are likely to become part of our nutrition. It is worth mentioning that certain

[1] https://www.ec.gc.ca/mercure-mercury/default.asp?lang=En&n=D721AC1F-1 (Accessed June 20, 2015).

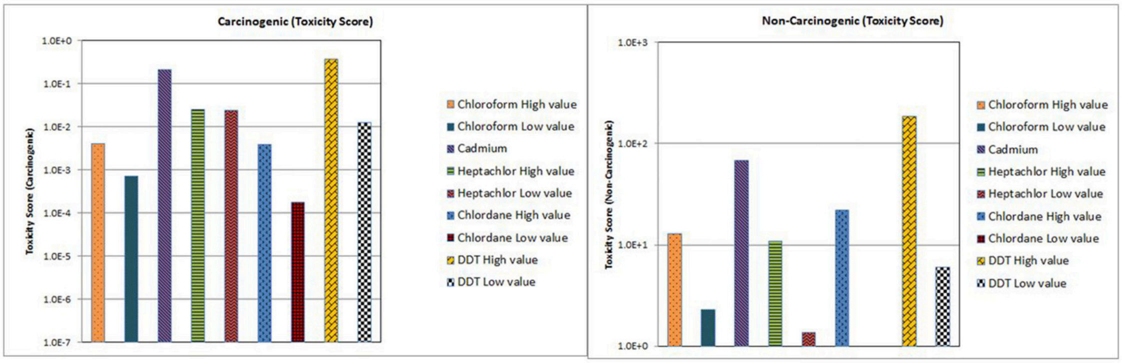

FIGURE 6 | Non-carcinogenic and carcinogenic risk values of different contaminants/adulterants.

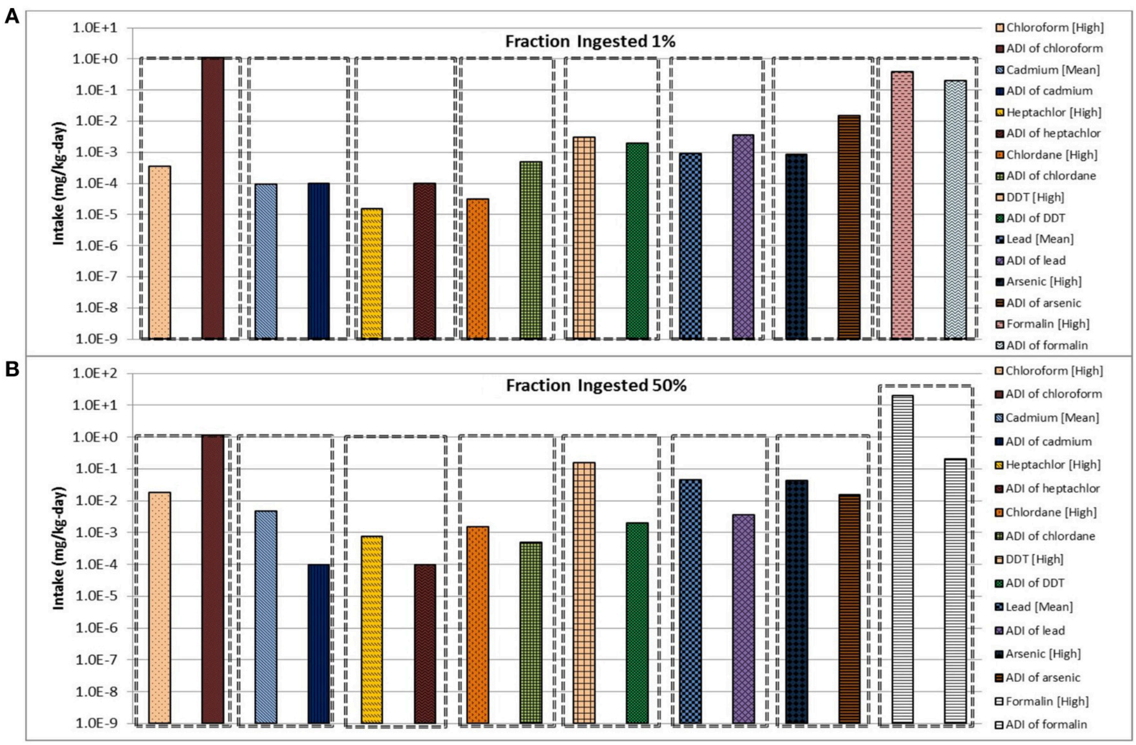

FIGURE 7 | Intake of different contaminants/adulterants via food ingestion for (A) 1% and (B) 50% of the adulterated food ingested for adults.

toxic chemicals are dermally ingestible and thus can be absorbed through human skin in addition to being ingested directly through water or inhaled though air for contaminants, which are volatile. Aquatic lives are important to humans in terms of food resources. Humans are located in a fairly high position on the aquatic food chain. Thus they tend to eat from higher trophic levels such as predatory fishes. These might store highest concentrations of chemicals that can potentially bio-magnify through eating other fishes and relevant phytoplanktons/zooplanktons. Many popular fish are also rich in fat and fish oils where many toxins could be stored. Exposure to toxic chemicals can be minimized by eating species from lower trophic levels and by avoiding aquatic food from polluted sources.

FOOD CONTAMINANTS: THEIR USES AND SEVERITY

According to the flow chart shown in **Figure 1**, there are various ways a contaminant can get accumulated inside the food. Pollutants in water bodies enter food chain through aquatic sources of food; pesticides also enter food chain through crop production etc. Finally, the most direct pathway of contaminant

TABLE 5 | Natural alternatives for certain food adulterants, contaminants and pesticides.

Index	Name of contaminants	Alternative sources	Other information	References
1	Formalin	1. Carosafe 2. Formalternate	1. A safer, far less toxic substitute 2. Recommended for storage of preserved specimens	Environmental Health and Safety Office (EHSO), 2012
2	DDT	1. Environmental management 2. Non-chemical personal 3.Protection biological control	1. Water management through land leveling, filling depressions, covering water pools, irrigation management and vegetation management 2. House improvement contribute 3. Fish, the bacterial pathogens and some plants (neem, citronella or pyrethrum)	Laumann, 2012
3	Calcium carbide	1. 1-methylcyclopropene (1-MCP), 2. Powdered ethylene	1.1-MCP has been accepted as being safe for use in agriculture in 34 countries 2. Non-carcinogenic and safe for human	Dhingra and Hendrickson, 2014
4	Artificial sweetener	1. Honey 2. Agave 3. Stevia	1. Same relative sweetness as granulated sugar 2. Has a low glycemic index 3. Stevia is 200 times sweeter than table sugar.	Panchal et al., 2014
5	Heptachlor	1. Deltamethrin 2. Dichlorvos 3. Bifenthrin 4. Chlorpyrifos 5. Cypermethrin	1. One of the safest classes of pesticides: synthetic pyrethroids 2. It behaves as a fast-acting neurotoxin in insects	Alvarenga et al., 2012
6	Sodium glutamate	1. Soy 2. Tomato 3.Mushrooms 4. Herbs	1. Often used for their high levels of protein 2. Provides a natural umami flavor 3. Appealing taste for protein with high umami-related compounds 4. Can stimulate the taste buds and enhance the flavor of foods	Dreifke, 2015
7	Chlordane	Introduction of beneficial pest species through integrated pest management and integrated vector controlled technique	Integrated Pest Management or IPM is an approach to pest control that utilizes regular monitoring to determine if and when treatments are needed. IPM employs physical, mechanical, cultural, biological, and educational tactics to keep pest numbers low enough to prevent intolerable damage	Edwards and Ford, 1992
8	Sodium benzoate	Natamax	A natural antimycoticpolyene macrolide produced by fermentation of Streptomyces natalensis bacteria	Oostendorp, 1981
9	Burnt Engine oil	Alcohol, cotton oil	Less expensive than olive oil or canola oil	Jones and King, 1996
10	Pesticide	1. Different cultivation methods 2. Using biological controls 3. Reproductive controls, 4. Different pheromones 5. Quarantine	1. Plants can be developed stronger and more naturally resistant, and also predators of pests can be brought into the crop fields. 2. Naturally occurring disease organisms, parasites or predators to control pests 3. Reduce the pest population by sterilizing some of its members 4. Natural substances produced by animals to stimulate a response in other members of the species usually used to attract individuals for mating	Raven et al., 2012
11	Toxic color	Turmeric, spinach, strawberry, raspberry, blueberry	A safer substitute that has no toxicity.	Klein, 2015

ingestion occurs via adulterated foods, which are preserved or artificially made of enhanced quality through utilization of adulterants, preservatives, artificial ripeners, food enhancers, or food additives etc. These contaminants are mixed with the food or are used to process the food to increase their shelf lives or make them more appealing.

In order to study the food adulteration scenario, database was prepared on how many contaminants in the study area are responsible for rendering one food vulnerable to produce long term or short-term health effects. **Table 1** shows the contaminants and adulterants that have been observed or found in different food sources consumed generally by people living in Dhaka city. These information have been collected from certain recent studies that were conducted to expose the severity of the situation that urban dwellers in Bangladesh are facing through intake of adulterated food (Uddin et al., 2011; Al-Rmalli et al., 2012; Naser et al., 2012; Nasreen and Ahmed, 2014). Some common impacts or functions of the contaminants are also described in **Table 1**. It has been shown that one specific kind of contaminant can be associated with different kinds of foods thereby signifying the frequency of the contaminant to be found in the food ingredients.

The risk index will have a higher number for those food elements which are the most vulnerable to get adulterated or the foods that are contaminated with multiple types of contaminants at multiple stages in different ways. This important observation is shown in **Table 2** where foods are categorized and arranged in an order from left to right with foods exposed to increased number

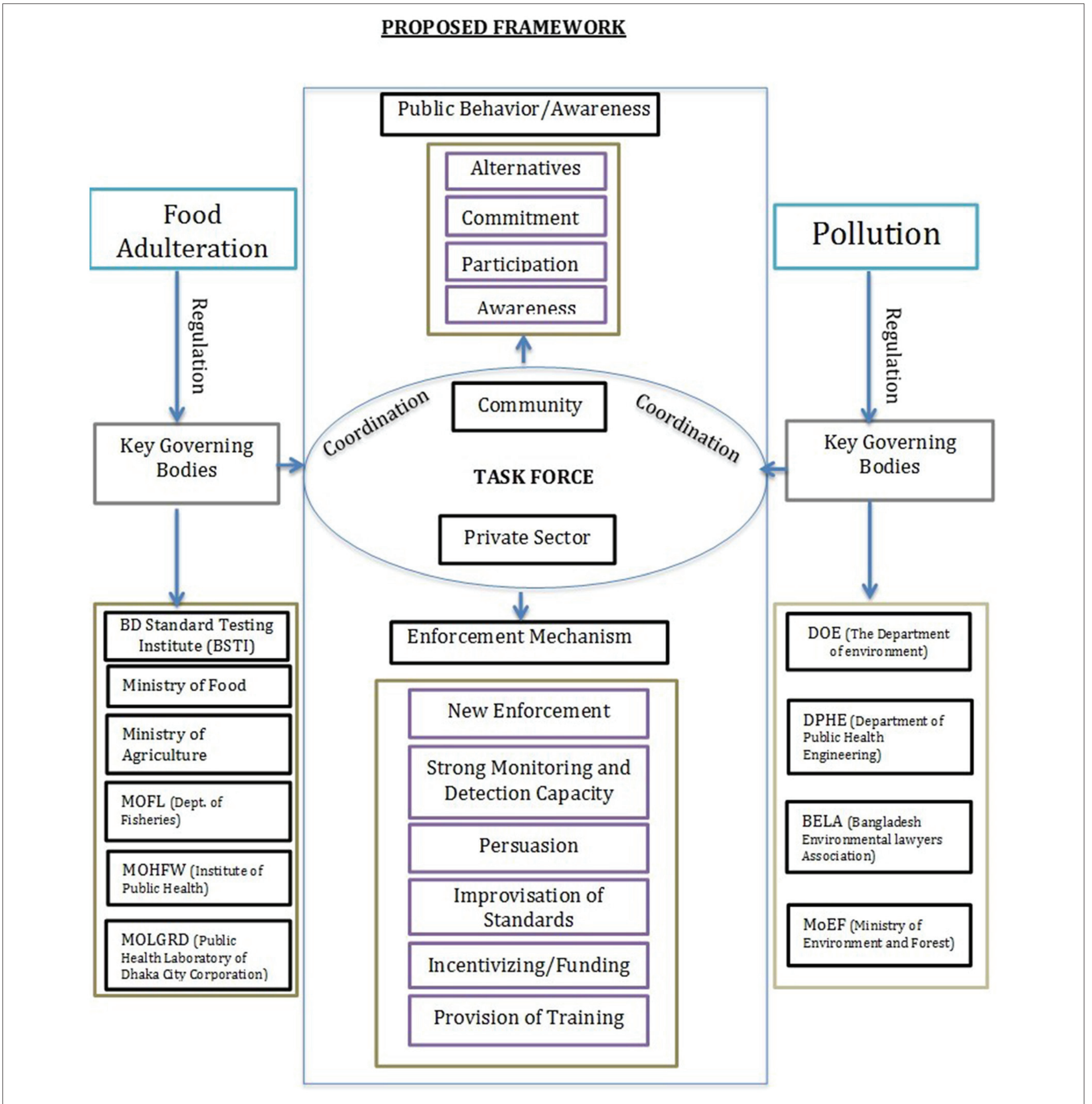

FIGURE 8 | Proposed regulatory framework addressing food adulteration and aquatic pollution issues.

of contaminants. Milk and fruits were found to be associated with maximum number of adulterants (up to five different contaminants), which are used to either preserve them, increase their shelf lives or to enhance their processing. Toxic pesticides, heavy metals or preservatives mainly contaminate Fishes and vegetables. Thus, the food items shown in **Table 2** (milk, fruits, fish, vegetables, sweetmeats, meat, rice, puffed rice, etc.) should be carefully evaluated by the consumers as well as frequently tested by regulators in different markets of Bangladesh.

Concentration ranges have been reported only for limited number of contaminants due to inadequacy of skilled systems or lack of detection methods. Cadmium and chromium (heavy metals) have been detected at levels ranging from 0.34 to 0.58 and 4.81 to 6.8 μg/g, respectively (Naser et al., 2012). Levels of heptachlor (pesticides) have been detected in fish samples at ranges of 0.4–2.5 μg/g (Bhuiyan et al., 2009b). Most of the other contaminants present in different types of food and its ingredients are either known to be involved in the adulteration process or certain contaminated food are devoid of the expected nutrition values due to the adulteration. The detection methods of most of the contaminants or adulterants are mainly qualitative. Thus, establishing statistical relationship between emergence of contaminants or level of contamination and specific impact on public health still remains a challenge.

NUTRITION AND STATUS OF NUTRITIONAL SITUATION IN BANGLADESH

Nutrition is the processes of nourishing and interprets the interaction of nutrients and other valuable substances in food (e.g., phytonutrients, anthocyanins, tannins, etc.) in relation to maintenance, growth, reproduction, health and disease of an organism, animal or plant (NIH, 2014). Thus, the nutrition is the intake of food, considered in relation to the body's dietary needs. Poor nutrition can lead to reduced immunity, increased susceptibility to disease, impaired physical and mental development, and reduced productivity (WHO, 2015). **Table 3** summarizes the six basic components of human nutrition, the sources of these requirements in Bangladesh and the daily requirements based on dietary guidelines (Nahar et al., 2013; Shaheen et al., 2013).

It has been clearly shown before that the nutritional values of aquatic sources such as fish are severely affected by aquatic pollution in Bangladesh. On the other hand, **Table 2** shows that fishes are also affected through adulteration with formalin, heptachlor and other pesticides. Thus, a very important source of protein is at risk due to aquatic pollution and food adulteration practices. Roos et al. (2003) documented the nutritional values in the indigenous fish species such as protein content of fish range from 14 to 18 g/100 g raw edible parts; vitamin A content of fish range from $<100\,\mu g$ RE (Retinol equivalents) in most species to $>1500\,\mu g$ RE in certain fishes like mola (as high as $2680\,\mu g$ RE). Among minerals, iron content of fish ranges from 1.8 mg to 12 mg/100 g edible parts whereas calcium content range from 476 mg to 1171 mg/100 g edible parts (Roos et al., 2003). Thus it is obvious that bioavailability of calcium from whole small fish (mola) is as high as that from milk. In humans, the fractional calcium absorption is found to be 24 $\pm$ 6% from small fish and 22 $\pm$ 6% from milk (Larsen et al., 2000).

In addition, data shown in **Tables 1–3** show that foods belonging to all the essential dietary nutrition values are being adulterated in Bangladesh currently. People will be devoid of one or more essential dietary nutrition if they avoid the adulterated foods. Major sources of carbohydrates such as rice and potato are being adulterated which are also the major food components of the necessary daily dietary intake (**Tables 1, 3**). In the same way, milk powder, ghee etc are being adulterated which are the sources of fat; all kinds of fruits are being contaminated which are the sources of vitamins and minerals; poultries, meat, and liquid milk going through adulteration that constitute important sources of minerals etc. The risk assessment section will elaborate on the danger on public health that is happening everyday in Bangladesh of which most of the victims or users are not aware.

PUBLIC HEALTH PERSPECTIVE: TOXICITY CONTINUUM

Table 1 lists the impact on health or possible negative effects on health and disease risks on humans due to the ingestion of specific contaminants directly from food or indirectly through food chain. WHO reveals that unsafe foods can be significant reasons of many chronic and non-chronic diseases including but not limited to diarrhea, different types of cancer, heart diseases, various kidney diseases, and birth defects (Ali, 2013b). Clear positive correlation between mercury level in human hair and fish consumption patterns (daily methylmercury intake from commonly eaten fish) has been documented in Bangladesh (Holsbeek et al., 1996). Different health problems could result from one specific contaminant and also different contaminants could give rise to the frequency of occurrence of one specific disease or health disorder (**Table 1**). Thus it is expected that occurrence of diseases that are direct results of the ingestion of the contaminants above allowable daily intake (ADI) are expected to increase with the increased occurrence of food contamination or food adulteration.

The pattern of disease is changing in Bangladesh, which is recently observed by medical doctors of Dhaka Medical College, and they predicted that recent increase in number of patients suffering from cancer, diabetes and kidney diseases are significantly affected by widespread food adulteration (Daily Star News, 2011). Additionally, International Centre for Diarrheal Disease Research, Bangladesh (ICDDR,B) reported that everyday more than 500 people visit hospitals in Bangladesh for diarrheal disease caused by unsafe foods (Ali, 2013b). This long diarrheal disease problem, related to food safety, persists and it has been a significant cause of malnutrition in Bangladesh for the last couple of decades. A comprehensive analysis of cancer situation in Bangladesh revealed that about 2 lakh (0.2 million) patients are diagnosed with cancer each year (Hussain, 2013). Change of dietary habit and reduced food adulteration are among the most important preventive measures identified in the study to reduce the increased occurrence of cancer. Among the adulterants/contaminants that are listed in **Table 1**, the main carcinogenic or cancer causing agents are formalin, coal tar, DDT, calcium carbide, sodium cyclamate, urea, cadmium, chromium, and arsenic. All of these contaminants or adulterants have been detected or reported to be present in different types of food in recent studies (Bhuiyan et al., 2009a; Uddin et al., 2011; Al-Rmalli et al., 2012; Naser et al., 2012; Mahfuz and Mahin, 2014; Nasreen and Ahmed, 2014). Occurrence of diarrhea has increased from 11 to 14% from 2011 to 2014 which could be attributed to increased water pollution and increased presence of diarrhea causing adulterants in foods such as ethylene oxide, saw dust, toxic colors shown in **Table 1** (Khan, 2004; Health Bulletin, 2013/2014; Farooque, 2014).

National Institute of Kidney Disease and Urology (NIKDU) reported the increase of the kidney disease in Bangladesh by 6.8% from 2012 to 2013 (Health Bulletin, 2013/2014). 3.48% of total deaths in Bangladesh were associated with kidney problem during the year 2014 (World Health Ranking, 2014). Intake of sodium cyclamate and cadmium with adulterated food could result to kidney failure (Naser et al., 2012; Nasreen and Ahmed, 2014; **Table 1**).

Around 13% increment of Asthma patients and 14% increment in yearly mortality rate due to respiratory problems have been observed recently (Health Bulletin, 2013/2014). These problems can potentially arise due to intake of foods adulterated with formalin, toxic colors, brick dust etc. (**Table 1**) as those were widely reported and detected in recent studies on food adulteration (Farooque, 2014; Mahfuz and Mahin, 2014; Nasreen and Ahmed, 2014). There are various other health problems that are occurring in increased frequency due to the food adulteration practices and also due to ingestion of aquatic sources of food that are contaminated with toxic substances. Though there is clear evidence of food adulteration related health impacts, establishing a direct statistical correlation between the events of adulteration/contamination and their effects on public health warrants laboratory and field level quantitative analysis of the suspected adulterants both in the foods and also in human subjects who are diagnosed with the health problems.

Contaminants that are responsible for different kinds of health hazard can be tracked in the environment such as food chain and the different transport media. Contaminants that have been identified in the food sources in Dhaka city were categorized in **Table 4** based on their concentrations in water and food, allowable intakes and their reported chronic reference doses (RfD), which provides an indication of the toxicity level of the specific contaminant. Contaminants with higher concentrations in the food and water together with lower allowable daily intake values and lower reported RfDs are considered highly toxic and should be prioritized for potential measures by regulatory bodies. Heavy metals such as cadmium (ADI = 0.0001), arsenic (ADI = 0.0002 mg/Kg), and lead (ADI = 0.05 mg/Kg) are highly toxic and known contaminants affecting human health. Pesticides such as Aldrin (ADI = 0.03 mg/Kg), chlordane (ADI = 0.0005 mg/Kg), and heptachlors (ADI = 0.0001 mg/Kg) are also very toxic at very slow concentrations. The food adulterants such as formalin (ADI = 0.0001 mg/Kg), have significant potential of affecting human health in Bangladesh as it is widely used in different types of food. Characterization of toxic dye and melamine has not been reported in Bangladesh, which warrants introduction of new analysis to be conducted by BSTI. Additionally, the allowable water concentration reported in the **Table 4** is not based on Bangladesh standard rather tabulated based on standards reported by Environmental Protection Agency (US EPA, 2012). This table also emphasizes the need for revising the environmental conservation rules promulgated in Bangladesh through addition of new compounds as well as lower allowable concentrations for several chemicals.

ASSESSMENT OR QUANTIFICATION OF BIO-MAGNIFICATION

Two main groups of chemicals, toxic metals and persistent halogenated organic compounds, have potential to bio-magnify. They are lipophilic and not easily degradable. Microorganisms, plants, animals, and humans lack previous exposure to novel organic substances known as persistent organic pollutants (POPs; Voutsas et al., 2002). Thus they do not have well developed specific detoxification and excretion mechanisms for that particular contaminant. There has been no selection pressure from the contaminants and hence living organisms/human does not easily degrade those. Additionally, the metals are not degradable because they are mainly elements. However, organisms subjected to naturally high levels of exposure to metals developed mechanisms to sequester and excrete metals. When organisms are exposed to higher concentrations than their allowable limit, then they cannot excrete rapidly enough to prevent significant effects (Suedel et al., 1994). As discussed and shown in this study, several of the toxic metals and POPs are prevalent in the contaminated water bodies and adulterated food found in Bangladesh.

Previous studies have investigated the potential of contaminants to bio-magnify in aquatic ecosystems (Suedel et al., 1994; Cardwell et al., 2013). Most metal and organic contaminants have low potential for trophic transfer and are therefore not likely to bio-magnify in aquatic food webs, but DDT, DDE, PCBs, toxaphene, total and methyl mercury, and arsenic have the potential to bio-magnify (Dillon et al., 1995). Recently reported bio-magnification factors varied up to 2 to 3 orders of magnitude for arsenic, zinc, methyl mercury, and cadmium (Dillon et al., 1995; Cardwell et al., 2013). Fate, transport, and bio-magnification potentials for five inorganic metals (viz., cadmium, copper, lead, nickel, and zinc) in aquatic food webs had been assessed recently (Cardwell et al., 2013). The magnitude of single and multiple trophic transfers in food chains utilizing different assessment techniques such as laboratory experiments, bio-kinetic modeling, and field studies indexed bio-magnification potentials. Trophic transfers, a widely used terminology in bio-magnification, explain the passage of a contaminant through food chains as a result of uptake only from water (bio-concentration), only from diet (dietary accumulation), or from a combination of these (bioaccumulation) (Davis and Foster, 1958; Macek et al., 1979; Biddinger and Gloss, 1984; Suedel et al., 1994; Cardwell et al., 2013). Trophic transfer factors (TTF) are analogous to bioaccumulation (accumulation) factors, the original terms used to describe steady-state tissue residues in an organism resulting from both water and dietary uptake pathways (Boroughs et al., 1957). TTFs are the same as bio-magnification factors and also meet the definition of bio-magnification when TTFs exceeding 1.0 are observed through three or more trophic levels as a result of at least two trophic transfers (Biddinger and Gloss, 1984; Cardwell et al., 2013).

Results indicated that Cd, Cu, Pb, and Zn generally do not bio-magnify in food chains that consist of primary producers, macro-invertebrate consumers, and fish occupying trophic levels 3 and higher. However, bio-magnification of Zn (trophic transfer factors of 1–2) is possible when dietary Zn concentrations are below those required for metabolism. Cd, Cu, Ni, and Zn may bio-magnify in specific marine food chains (Cardwell et al., 2013). To understand the magnitude of contribution of a contaminant on different levels of food chain, a protocol has been compiled to utilize in Bangladesh in this current study. This will enable the assessment of a contaminant in general and elucidate its potential to bio-magnify through food chain. The protocol will also evaluate the threshold concentrations of the contaminants, which can prevent adsorption/ingestion in aquatic species. **Figure 2** shows the assessment steps for determining the bio-magnification potential of an environmental contaminant.

The important parameters and relationships of bio-magnification are shown below for better interpretation of the subsequent flow chart or protocol:

(a) Bioaccumulation = Bio-concentration + Bio-magnification
(b) Bio-concentration = Effect from absorption into body—exposure through water for phytoplankton and zooplankton,
(c) Bio-magnification = Effect from concentrating via food chain—exposure through food only for zooplankton and mammals
(d) BAF/BCF (L/kg)

$$= \frac{\text{Chemical concentration in the organism, Cb}}{\text{Freely dissolved chemical concentration which is biologically available in water, Cd}}$$

(e) BMF (unit less)

$$= \frac{\text{Chemical concentration in the organism, Cb}}{\text{Concentration of the chemical in the dietof the organisms, Ca}}$$

(f) Cumulative BMF = $BMF_1 * BMF_2 * \ldots\ldots\ldots\ldots *BMF_i$

where 1, 2,….. i etc. represents the different trophic levels.

The protocol in **Figure 2** provides steps to determine BAF, BCF, and BMF values considering three different equations into account. The measurements of all the variables are not also straight forward and careful interpretation is needed for applying those variables in the context of Bangladesh. The following facts are summarized to provide guidelines for determining those factors in Bangladesh. Certain simplifications and certain complexities are listed below for applying the protocol especially in context to Bangladesh:

- A number of studies have reported that BCF values for hydrophobic organic compounds are correlated with octanol water partitioning coefficients (K_{ow}) which represents the hydrophobicity of organic compounds (Neely et al., 1974; Meylan et al., 1999). Mackay and Fraser (2000) suggested a continuum of log Kow in their review of bioaccumulation models in order to realize the possibility of bioaccumulation for a particular contaminant. The study reported that appreciable bioaccumulation occurs when the log Kow is within the range of 5–10. Substances with lower Kow are unlikely to accumulate in aquatic systems and those with higher log Kow values require further evaluation.
- Compounds for which approximation of bioaccumulation through Kow values would be inadequate, kinetic coefficients have to be computed in order to assess BAF to include the processes of uptake, back diffusion, excretion, growth, metabolism, and finally ingestion of the contaminants in the aquatic system (Mackay and Fraser, 2000). Then, steady state and time-variable concentrations should be evaluated.
- BAFs for the metals examined in earlier studies may not be an inherently useful predictor of potential hazard (i.e., toxic potential) to aquatic organisms (Cardwell et al., 2013). For a potential detailed study in Bangladesh, zinc, cadmium, chromium, chromium, mercury metals could be good candidate for extensive bio-magnification study.
- For the food chains having greater than three trophic levels, the possibility of a specific contaminant to bio-magnify would be dependent on the metabolism processes of the individual species involved. The specific contaminant would bio-magnify across the food chain only if the species involved do not have any detoxification (they cannot metabolize or biodegrade) mechanism for that particular contaminant (Sørmo et al., 2006).
- BAF and BCF values would provide estimation for target concentration ranges for a water body in order to keep the concentration of the contaminant in the edible portion of the aquatic food source below acceptable/tolerable daily intake.

A specific example is elucidated below for the overall evaluation of bio magnification potential in context to Bangladesh. Considering two cases of toxic substances that have potential to bio-magnify such as Mercury (Hg) and Zinc (Zn). Mercury (Hg) has been found in mean concentration of 0.03 mg/l in Turag River as a pollutant and was also found in traces in different fishes (Shamsuzzoha, 2002). The relevant mean concentration found in tissues of fishes was 0.05 mg/kg and that in human body was 0.44 mg/kg (Holsbeek et al., 1996) where intake of Hg of Bangladeshi people is 0.0035 mg/day.Hg can potentially bio-magnify in human body up to 9 times utilizing the BMF equations (e) and (f).

Similarly, Zinc (Zn) had been found in mean concentration of 2.0 mg/l in Turag River (Shamsuzzoha, 2002). In the study, different fishes were analyzed and found to be contaminated as well. Concentration of zinc found in tissues of a small fish, *A. Microlepis* (Mola), was 97.14 mg/kg (Rahman et al., 2012), and in a bigger fish *H. fossilis*(Shing) was 203.19 mg/kg (Rahman et al., 2012). In a trophic level where *A. Microlepis* is prey and *H. fossilis* is predator, BMF data strongly suggest that Zn biomagnifies in *H. fossilis* muscle upto 2 times. Now, when humans consume the *H. fossilis* fish, it turns to prey from predator and humans become final predator. No information was obtained on concentration of Zn in humans in Bangladesh; but Zn has been measured in human tissue in a study at Krakow, Poland, which was reported as 745.7 mg/kg (Baran and Wieczorek, 2013). For the evaluation of BMF in this upper trophic level (humans), the reported concentration values were used and it is found that Zn can potentially bio-magnify in human body up to four times. The above-mentioned cases of bio-magnification are elucidated in **Figure 3**.

So, it could be concluded that both Hg and Zn have potential to bio-magnify. As Zn is transferred in two trophic levels, the cumulative BMF of Zncan be calculated as 8. Now, if these concentrations are toxic to human and in order to prevent the effects or manifestations, the diet has to be restricted. So we have to restrict the concentration of Hg and Zn in fishes by restricting Hg and Zn concentration in the surrounding water body or have to ensure adequate water treatment targeting those compounds before consumption. From the data mentioned above, we can predict the concentration of Hg and Zn in fishes should not be more than 0.0044 mg/kg and 54.5 mg/kg, respectively to prevent the effects when humans are final predators.

RISK ASSESSMENT OF CONTAMINANTS AND ADULTERANTS

Availability of wide variety of environmental contaminants and uncontrolled use of different adulterants in all types of food warrants careful evaluation of the risk associated with the processes to estimate human related risks and help in allocating scarce resources to intervention and control/treatment mechanisms in developing countries such as Bangladesh. Apart from assessing health risks for adult human being, extensive risk associated with three types of vulnerable groups (e.g., infants, pregnant women, and elderly people) was assessed. Risk assessment can significantly affect identification of important chemicals of interest, waste treatment/disposal options, remediation of contaminated water/site, minimization, and public awareness build-up on food safety/adulterants use, immediate enforcement of law and treatment/intervention of high risk contaminants etc. Four steps method for risk analysis have been followed in the study: (a) hazard identification, (b) exposure assessment, (c) toxicology assessment, and (d) risk characterization. Ingestion of aquatic contaminants and food adulterants has been calculated and were compared with allowable daily intake (ADI) to determine risk reduction strategies (LaGrega et al., 2010; Dumitrescu et al., 2012). The intake of contaminants via inhalation and dermal contact were estimated (data not shown) to be negligible and were not reported in this study. Reference values of chronic reference dose (RfD) and slope factors (SF) based on reported literature were investigated for different contaminants and adulterants for risk calculation. The following intake formula was used for determination of daily intake of contaminants and adulterant in both healthy and vulnerable population (Dumitrescu et al., 2012; LaGrega et al., 2010). Separate ingestion formula was used for water and food intake of contaminants/adulterants to determine severity of the different pathways.

(a) Ingestion Intake through drinking water, $I_{Ingestion,\ water} = (CW * CR * EF * ED)/(BW * AT)$, where, CW = concentration in water (mg/L); CR = contact rate (e.g., L/day); EF = exposure frequency (day/year); ED = exposure duration (yr); BW = body weight (kg) and AT = average time (days).
(b) Ingestion Intake through food, $I_{Ingestion,\ food} = (CF * IR * FI * EF * ED / (BW * AT)$, where, CF = concentration in food (mg/kg); IR = Ingestion Rate (kg/meal); FI = Fraction ingested from the contaminated sources (unitless); EF = exposure frequency (day/year); ED = exposure duration (yr); BW = body weight (kg) and AT = average time (days).

The ingestion intakes were used to determine the carcinogenic and non-carcinogenic toxicity scores and risk using the following formula: non-carcinogenic toxicity score, TS = C/RfD; carcinogenic toxicity score, TS = SF * C; non-carcinogenic risk, HI= I/RfD and carcinogenic risk= I*SF. The intake of contaminants/adulterant classified through different exposure routes and need for reduction comparing with allowable daily intake (ADI) have been shown in the following (**Figures 4–7**) for healthy adult, infants, pregnant women and elderly people. Additionally, the present levels of contamination/adulteration of food are not known/well documented and thus, this review paper showed change in contaminant intake by varying the adulterated fractions of the food due to human practice.

Ingestion of contaminants through water, food and their total intake in human body were compared with allowable daily intake for different groups of people. **Figure 4** shows detailed comparison of intake and reduction needed for cadmium. Though it shows clearly that ingestion through water is contributing higher compared to food intake, nevertheless intake via food has significant contribution. It is important to mention that it was assumed that 10% of the total food ingested are contaminated or adulterated whereas it has been reported that 50% of the total food ingested could be contaminated and adulterated (Khan, 2004; Bhuiyan et al., 2009a; Uddin et al., 2011; Naser et al., 2012; Ali, 2013a; Nasreen and Ahmed, 2014). Additionally, this analysis approximated that water with the contaminants found in the river/water sources are minimally treated and normally drank by the common people. The capital of Bangladesh, Dhaka has water treatment plant though no extensive study is known investigating the fate, transport and removal of those contaminants in any treatment systems of Bangladesh. For cadmium, daily intake of both food and water are significantly higher than allowable daily intake of 0.0001 mg/kg of body weight for adult, infant, pregnant woman and elderly people. In case of adults, ingestion through food was 0.0006 mg/Kg of body weight and ingestion through water was 0.00085 mg/kg of body weight, which corresponds to 41 and 59% of the total intake, manifested by food and water. For heptachlor (plot/data not shown), the total intake for infants is much higher compared to ADI where as pregnant woman and elderly people normally have heptachlor intake lower than ADI. The total daily intake of heptachlor for infant was 0.00061 mg/kg of body weight, which is significantly higher than ADI value of 0.0001 mg/kg of body weight. Again, the heptachlor intake via food is ∼16.67% compare to 83.33% through water of the total daily intake. For healthy adults, though the intakes through food and water are individually below the ADI, the combined total intake is 0.00019 mg/kg of body weight compared to ADI value of 0.0001 mg/kg of body weight. Similar findings were reported for DDT (plot/data not shown), total daily intake is higher for adult, infant and elderly people. Thus, it is clear that the people of Bangladesh are ingesting higher concentrations of different contaminants compared to allowable limits. Though detailed investigation is needed for other contaminants, it is expected that the contaminant ingestion scenario will not be different than the present findings for other food contaminants. The recent increase in different possible toxic metals or organic chemicals induced diseases in Bangladesh demonstrates the impact of these higher levels of ingestions (Health Bulletin, 2013/2014; Hussain, 2013).

Additionally, toxicity scores and associated risks have been determined both at non-carcinogenic and carcinogenic levels for cadmium, high/low concentrations reported for heptachlor, chlordane, chloroform and DDT (**Figures 5**, **6**). Though non-carcinogenic risks reported for all the contaminants are below allowable non-carcinogenic risk values of 1, the carcinogenic risks for all the contaminants are much higher than allowable carcinogenic risks (1.0 E-06). Furthermore, the intakes of wide variety contaminants could be increased significantly if the percentages of contaminated/adulterated food are increased from 1% to as high as 50% (**Figure 7**). Though not shown in this present study, the possibility of higher intake of contaminants via food could significantly increase the overall carcinogenic risks for the people of Bangladesh. These findings clearly show that the regulatory bodies and all other stake holders of food industry need to take immediate actions to control the open dumping of industrial waste/wastewater and adulteration of food.

INTERVENTION AT CRITICAL STEPS—REGULATORY APPROACH

It is shown clearly that the public health is under severe risk of food adulteration and contamination in Bangladesh. Thus, it is important to contemplate different intervention and appropriate regulation for these emerging problems. Intervention, with effective and adequate combination of program elements or strategies, could be designed to produce behavior changes or to improve health status among different food related stakeholders or the entire population in Bangladesh. Interventions may include educational programs, new or stronger policies, improvements in the environment, public sector-private section partnership, proper allocation of resources, community based services, or a health promotion campaign. Additionally, proper enforcement of the existing food safety laws and new standards for emerging contaminants and its proper implementation mechanisms are vital for the improvement of the situation.

In order to address the prevailing food contamination and aquatic contamination issues that result to significance deterioration of public health in Bangladesh, the identified interventions required are shown in a flow chart (**Figure 1**). Different control mechanisms need to be implemented to disrupt the two major flow paths that the contaminants travel through from the environment to the human body. The existing regulations on food contamination, contaminants discharge in water bodies, policies involved, limitations in the policies, and requirement of new strategies are discussed and proposed for Bangladesh.

Food Safety Regulations and Limitations

Myriad types of enactments and governmental bodies govern the existing food safety legal and regulatory regime of Bangladesh (Ali, 2013a). The legal framework of food safety in Bangladesh includes fifteen laws that are implemented by several ministries and their subordinate bodies. A proper co-ordination among the key public sector stakeholders and mechanisms of implementation of the existing laws are clearly missing. After enactment of the law by the Bangladesh parliament, the ministries such as Ministry of health and welfare (MOHFW), Ministry of Agriculture (MOA), Ministry of Local Government, Rural Development, and Co-operatives (MOLGRD), Ministry of Industry (MOI), Ministry of Fisheries and Livestock (MOFL), Ministry of Commerce (MOC), Ministry of Establishment (MOE), and Ministry of Home Affairs (MOHA) are responsible for enforcement, regulation, making standards, implementing, and administering the laws. The associated bodies that are principally responsible for regulatory activities are Bangladesh Standard Testing Institute (BSTI), National Consumer Rights Protection Council (NCRPC), Directorate of National Consumer Rights Protection (DNCRP), Directorate General of Health Services (DGHS), National Food Safety Advisory Council (NFSAC), Local Government Bodies, Bangladesh Police, and Executive Magistrate.

Given such a well-numbered key bodies and 15 laws governing the current legal framework of food safety in Bangladesh, total food industries have been ignoring the existing food regulations in Bangladesh. The reasons for ineffective food safety rules and regulations in Bangladesh are multiplicity of laws, non-coordination and overlapping of regulatory bodies, transparency, autonomy and bureaucracy issues, inadequacy of penalties, enforcement problems etc. (Ali, 2013a). Persuasive tools and highest penalties for the wrongdoers along with the awareness from the users' end have been recommended. There is clear indication of resources allocation and proper planning issues in the public/government sectors, and missing active and organized participation of private sectors stakeholders as well as community involvement in the overall food safety paradigm.

Discharge Regulations and Limitations

In an attempt to recover the water bodies that are subject to heavy pollution from industrial and domestic waste discharge practices, discharge regulations have been established on the maximum concentration of relevant contaminants that should be obtained when the water quality is analyzed for the respective water body. There is a standard guideline of water discharge quality, which is regulated by Ministry of Environment. Through careful analysis of parameters, units & the allowable limits of discharge limits, it could be concluded that there are certain compounds found in Bangladesh with potential to bio-magnify through food chain. Several compounds are also hazardous to aquatic lives such as mercury, selenium, zinc etc. Although the list cannot be considered complete, as it does not include certain hazardous compound such as DDT, dieldrin, polychlorinated biphenyls (PCBs) etc. which are also harmful and have significant potential to bio-magnify (Biddinger and Gloss, 1984; Kay, 1984). Nevertheless, the problems regarding pollution do not cease to exist because of non-compliance with the regulations from the users' end and lack of enforcement mechanisms, lack of monitoring, and supervision from the key governing bodies' end. Lack of commitment and awareness from both the users and the enforcement authorities' ends also exist.

Alternatives for Contaminants

As there are specific functions for each of the food adulterants and contaminants, the possibility should be explored that the same functions could be accomplished by harmless alternatives. Such alternatives are listed in **Table 5** for the food contaminants, certain industrial pollutants, and pesticides. Completely different chemicals or elements are suggested as alternatives for certain contaminants such as formalin, cadmium, calcium carbide, artificial sweetener, lead, burnt engine oil, coal tar, etc. For proper pest control, instead of pesticide, biological control, integrated paste management, special cultivation methods, quarantine etc. have been suggested some of which are already in practice. Food adulterators and farmers should be made aware of these alternatives which they can apply and obtain the same functions as they are used to obtain with the harmful contaminants. There must be an active program for performing premarket safety reviews of food and color additives with effective evaluation process for legalizing the use of alternatives proposed in this study.

Proposed Framework of Intervention

The existing regulatory frameworks to ensure food safety, contamination/adulteration, and the existing discharge guidelines to protect the water bodies have become ineffective in protecting public health. This can be attributed to the fact that proper enforcement and compliance of these existing regulations is practically non-existent. In the existing regulatory framework, private sector involvement and community level active participation are clearly lacking. In order to ensure coordination between the key governing bodies and the general consumers, it is imperative that persuasive tools are utilized to exhibit zero tolerance toward non-compliance through highest possible penalties. Furthermore, the users have to adjust their compromising attitude toward food adulteration (Sobhani, 2015).

First of all, the government should mandate resource-intensive method of food safety regulation and allocate adequate resources. It should also establish and enforce regulations governing food levels in different sectors and types of food with provision for inspection. The regulatory bodies by partnering with private sector stakeholders should focus on persuasion, enforcement, improvisation of standards, and incentivizing the compliant behaviors, training programs, course development for knowledge dissemination etc. The public, the consumers should be encouraged to participate in the regulatory program and made knowledgeable about the food adulteration and water pollution scenario so that they are committed toward protecting the water bodies and avoid practices of food adulteration. The existing infrastructure of different well-established private sector organization could be utilized within the existing mechanisms of the government under the leadership of a new public-private TASK force on food safety representing different ministries and directorates of the government, private sectors, food retailers, communities, and consumers. This task force can work closely with the retailers and private organization, to convince them to use the natural alternatives instead of food additives, food enhancers, or preservatives in order to protect the public health. This task force should work on developing a national policy, platform, and mechanisms for controlling food contamination and adulteration.

The government and private sectors spent and allocated very limited amount of money so far for field inspection, research and analysis of wide variety of adulterants used in Bangladesh. Furthermore, there should be a clear mechanism how food adulteration issues could be controlled at the grass root levels. It has been shown in this study that contaminant/adulterant ingestion via water could have significant impact on public health and safety. So, all kinds of anthropogenic sources of water pollution should be controlled through proper environmental education and awareness, commitment and providing adequate means for integrated waste management and discharge. There should be a "new branch" of enforcement agencies at local and national level ensuring the regulation as the adulteration often originates at local levels. In technical side, well-equipped laboratory services are essential to detect the most important and frequently involved contaminants such as DDT, formalin, carbide, toxic colors etc. with reasonable accuracy. Skilled personnel should also be engaged in order to keep the laboratories running in all the districts all over Bangladesh (Sobhani, 2015). Proper environmental monitoring should be ensured utilizing tools such as Geographic Information System (GIS), remote sensing and environmental impact assessment. At the end, a comprehensive risk based analysis and prioritization of enforcement as well as subsequent risk based framework can ensure proper focus of effort and improvement for the food contamination/adulteration scenario. The proposed regulatory framework addresses these issues as shown in **Figure 8**. Food adulteration and water pollution as the imminent threats to public health are shown in both sides of the center box which direct toward the key governing bodies that list the relevant government departments in Bangladesh responsible for the enactment of laws and regulatory enforcement. The concentric circle shows the task force that needs to be established to ensure proper coordination among community, private sectors and key governing bodies. As specified earlier, the community participation has to be in the form of behavioral modification and awareness building up whereas the private sector should engage all kinds of mechanisms to ensure enforcement of standards and regulations. This framework clearly connects all stakeholders and provides a broad spectrum of actions to be undertaken in order to combat the negative impacts of the environmental contaminants.

CONCLUSIONS

A comprehensive investigation was carried out in this study analyzing the prevailing aquatic pollution and food adulteration situation in Bangladesh. Detailed assessment of the bio-magnification potential of the different toxic compounds and public health risks associated with the direct/indirect exposure to the adulterants/contaminants were attempted in a step-by-step approach. Finally, a regulatory framework has been proposed addressing the limitations in the existing guidelines and adequate intervention strategies. The outcomes of the study are summarized below:

(1) Major adulterants/pollutants have been identified that are frequently becoming part of the regular diets and the consumers are unaware of the fact in many cases. The broader categories include preservatives, ripeners, food enhancers, additives, pesticides, fertilizers and heavy metals.
(2) The staple food items that are at risk include rice, fruits, vegetables and fish, which are the major sources of nutrition. Obsoleting staple foods for adulteration/contamination would deprive the users of essential dietary nutrition such as carbohydrates, proteins, vitamins, minerals, and water.
(3) The frequently identified adulterants and contaminants have been categorized based on their allowable daily intake values to highlight the relative severity of exposure to each of those. The outcome suggested that the most toxic contaminants are the pesticides and the heavy metals as those are harmful at a very low concentration of ingestion (<0.001 mg/kg body weight).
(4) The contaminants that travel across food chain from environmental reservoirs (water or soil) could potentially bio-magnify and a detailed protocol has been summarized to evaluate the extent of bioaccumulation and the possibility of bio-magnification in Bangladesh. Elevated concentration of a contaminant at subsequent trophic levels of different food chains in Bangladesh indicates the effects of bio-magnification in the contaminant transport and human health.
(5) An extensive risk analysis has been performed for certain identified adulterants/contaminants. Intake of these elements have been classified through various exposure routes and calculated for healthy adults as well as for infants, pregnant woman and elderly people. Quantification of risks showed clearly that that the people of Bangladesh are ingesting higher levels of multiple contaminants compared to their allowable limits which would significantly increase the overall carcinogenic risks for the people of Bangladesh.
(6) The redundancy of the existing and lack of relevant regulations, absence of commitment, co-ordination and competence among the different enforcing organizations and non-compliance among the users/consumers are mainly responsible for the existing severity of the contamination and adulteration situation in Bangladesh. Participation of the users have to be ensured through making them aware of the harmful effects of the contaminants and encouraging the use of natural alternatives instead of the adulterants. A comprehensive regulatory framework has been suggested addressing the proper intervention strategies to obstruct the pathways of the contaminants/adulterants into food chain thereby protecting the public health.

FUTURE CHALLENGES

Certain challenges have been identified in this study that need to be acknowledged and investigated into so that further studies could be carried out in a broader scale toward solving the imminent public health problems:

(1) Sufficient documentation and extensive analysis of levels of different contaminant concentrations in the food items need to be worked out and carried out with accuracy.
(2) Quantification of the contaminant concentrations in the staple food items requires utilization of state of the art technologies that are lacking in Bangladesh. Adequate skill, well-developed laboratories and relevant tools/protocols for quantification need to be developed and made available for disposal accordingly.
(3) Inefficient and inadequate standardization of the regulatory guidelines for protecting the surface water bodies is noticeable. These need to be updated in frequent intervals to address the emergence of the contaminants and their severity in the environment.
(4) Lack of partnership/communication among the food retailers, food handlers and the food standardizing institutions is severe. This creates difficulty in getting accurate information to establish relationship between contamination and health effect. All the stakeholders and key governing bodies need to cooperate in abridging this communication gap.

AUTHOR CONTRIBUTIONS

NM, Formulated the topic/idea, collected information, initiated and carried out research, wrote and compiled article. MR, Collected information, assisted in research, crosschecked information. MA, Collected information, assisted in research. HA, conceived the idea, collected and cross checked information, carried out research, wrote and edited the article.

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