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A comprehensive review on heavy metal contamination in the urban river Buriganga Bangladesh: restoration perspectives

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Abstract

Dhaka, one of the megacities in the world is situated at the bank of the Buriganga River. This river is flowing along the southeastern part of the megacity. The Buriganga River had a large contribution as an alternative source of water for the capital city of Bangladesh. But, at present the river water becomes polluted through various means viz. chemical wastes discharging, untreated industrial effluents disposal, human activities, sewage disposal and other solid wastes and consequently, it has been treated as a dead river. Rapid industrialization, urbanization and climate changes have put a negative impact on the soil, water and sediment quality of the Buriganga river for multifarious purposes. Typical researches on heavy metals contamination on the effluent of tannery, textile and dye industries, status and health risk assessment of heavy metals in water, sediment and fishes of Buriganga River, show that concentration of heavy metal is increasing day by day, especially in industrial areas. The heavy metals that are polluting the water of the Buriganga river are Chromium (Cr), Copper (Cu), Arsenic (As), Nickel (Ni), Lead (Pb), Cadmium (Cd), Manganese (Mn), Cobalt (Co), Zinc (Zn) and Iron (Fe). This review aims to represent the remarkable findings of metal pollution (exceeding water and sediments quality parameters as well as detrimental ecotoxicological threats and potential health risks) from the previously conducted researches on this critical urban river in this field and to make the dedicated researchers conscious about the present heavy metal's contamination background of the Buriganga River.

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Introduction

Water is one of the most essential elements of this planet for all kinds of living organisms and plants. River water plays an important role to develop a country like Bangladesh by supplying water to all kinds of industries and civilizations. Bangladesh is a land of rivers and it has about 700 hundred rivers and tributaries (Tamim *et al*., 2016) which flow all over the country. Buriganga is one of them. The capital city of Bangladesh is Dhaka which stands on the bank of the Buriganga River. The city has about 12 million people of which about less than 25% are served by sewage treatment facilities (Ahmad *et al*., 2010). Most of the industries of the city are located along the river or very close to the river system. About 249 factories are situated along the river which was identified by the department of environment (DoE) Bangladesh (Sarker, 2005). The Buriganga River is that the major source of water supply for the city. That is why the river is economically important for Bangladesh by supplying water to industry, agriculture, and livestock. It is also important for the transportation facilities of the country because it provides river connection through launches and boats.

The Buriganga River is situated near the confluence of the Padma (Ganges) river within the central region of Bangladesh (Kamal *et al*., 1999). It was known by the old Ganges in the past. The south-western part of Dhaka city is surrounded by the Buriganga River. It originates from the Dholeshwori River near Kalatia from the north of the Dhaka city and flows through the Dhaka city and it is joined with Turag River at

Kamrangirchar is a place of Dhaka city where the main flow of the river originates. The entire length of the river is around 27 km and the average depth and width are around 10m and 400m respectively (Tamim *et al*., 2016). Nowadays, heavy metal contamination of river water is one of the intense environmental problems globally within most developing countries (Wu *et al*., 2011). The sources of heavy metals originate from numerous urban and industrial effluents, agricultural activities, landfill, mining, tanning, textile, traffic emissions, terrestrial runoff, and brick kilns which are varied in these countries (Ahmad *et al*., 2010; Bhuiyan *et al*., 2011). Among these, industrial effluent and sewage are the major sources of environmental toxicity that may cause the deterioration of water quality and endanger the aquatic biota (Sinha and Paul, 2012). Due to the discharging of a huge amount of untreated wastes into the river daily, the Buriganga river has become the foremost polluted river in Bangladesh as well as in South Asia (Nouri *et al*., 2009). It has been assessed that every day it takes up to 40,000 tons of tannery waste along with sewage from Dhaka city dwellers (Anonymous, 2003). Thus, the water of the Buriganga River is contaminated by toxic chemicals and heavy metals like Fe, Cd, Zn, Pb, As, and so on. The presence of a high concentration of heavy metals can form many harmful complex compounds which pose a serious threat to different biological function (Rajbanshi, 2009). Due to their long-term persistence, bioaccumulation and biomagnifications in the food chain, they pose serious potential risks to human and ecological health as well by continuously entering the aquatic environment (Rahman *et al*., 2013a; Sin *et al.,* 2001). In the meantime, heavy metals contamination is growing to be much more concern because they are not easily bio-degradable or metabolized thus it exists in nature for a long time and affects the biological system like humans, animals and plants (Yoon, 2003; Sheikh *et al*.,2007; Zvinowanda et al., 2012). Yoon **KP.** 2003. Construction and characterization of multiple heavy metal-resistant phenol-degrading pseudomonads strains. Journal of microbiology and biotechnology **13(6),** 1001-1007.

In this particular review, by using the findings of various literature to review the possible sources of heavy metals contamination, associated with ecotoxicology and human health risk, the status of heavy metals in water and sediment and possible restoration step to minimize the river contamination are presented. Thus, this review will be more helpful for the new researchers as well as the Government to decide for remedial and take necessary steps to prevent the river contamination.

Sources of heavy metals

The combined term "Heavy Metals" is referred to like all the metals having densities above 5 gm/cm^3 and that are located in groups 3 to 16 of 4th period or higher in the periodic table (Hawkes, 1997). Heavy metals contamination is not an ignorable concern that has been continued from the very beginning of the chemical extraction (Renberg and Persson, 1994). Heavy metals arise in the earth's crust as natural elements of the environment and as well as the results of human activities which is raising due to the rapid industrialization and revolutionary uprise of the civilization (Mohammed *et al.*, 2011). Inundation, river erosion, weathering comprises natural sources and anthropogenic sources both are the main pathways for the accumulation of heavy metals in river systems (Levin *et al.*, 1989; Brookes, 1995; Blaser *et al.*, 2000; Gupta *et al.*, 2008; Sheykhi and Moore, 2016).

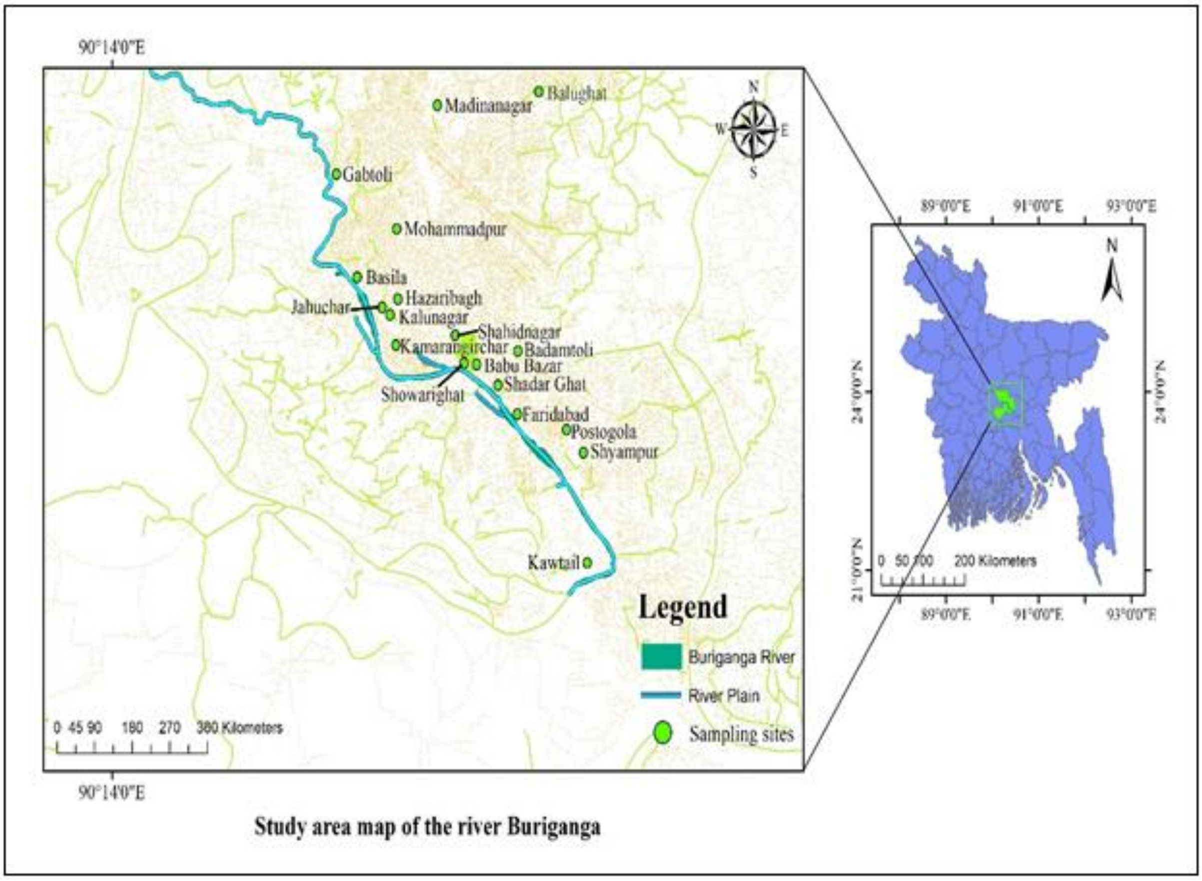

Fig. 1. Location map of the Buriganga river

Anthropogenic sources are predominated over natural origins including industrial discharges, agricultural runoffs, municipal waste disposals, various mining-smelting processes, domestic effluents that are responsible for the long-term presence of heavy metal residuals in river water (Majumder *et al.*, 2015). Heavy metals are deposited to the sediment via bedrock weathering and as well as the precipitation of metal- (sulfides, carbonates, and hydroxides) compounds of heavy metals (Pongratz and Heumann, 1999). Diverse industries around the river that are directly/indirectly contributing heavy metals into the river are steel industries, shipbreaking industries, tanneries, dye and paints industry, paper mills, rayon mills, liquor shops, textile mills, fertilizer manufacturing industries as well as insecticides enriched with heavy metals (Bhuiyan *et al.*, 2010; Bhuyan *et al.*, 2017; Boamponsem *et al.*, 2010; Dan'Azumi and Bichi, 2010; Islam *et al.*, 2014d; Islam *et al.*, 2015; Islam *et al.*, 2018a; Rahman *et al.*, 2012; Salati and Moore, 2010; Shikazono *et al.*, 2012; Sinha *et al.*, 2011). The presence of heavy metals in water above a certain limit can affect the water quality for drinking and other purposes as well as detrimental to aquatic bodies (Bodrud-Doza *et al.*, 2020).

Heavy metals and their harmful effects

Permissible limits of heavy metals in drinking water provided by World Health Organization (WHO, 2008), Environment Conservation Rules (ECR, 1997), Bureau of Indian Standards (BIS, 2012), US Environmental Protection Agency (USEPA, 2006), Council of the European Union (EU, 1998) and Ministry of Health of China (China, 2006) are given in the data table 1. The most abundant heavy metals found in water that cause water pollution are Fe, Cu, Zn, Cd, Pb, Cr, Ni, Mn, Hg and As. Some of these are (Fe, Cu, Zn, Ni and Mn) essential elements for human as well as plant growth and nutrients in a trace amount even in higher concentration they are toxic and others (Cd, Pb, Cr, Hg and As) are also a toxic element for human, plants and animals even in lower concentration (Dudka and Adriano, 1997; Sa'idi, 2010). Humans are exposed to heavy metals in three ways; ingestion, inhalation and dermal absorption (Muhammad *et al.*, 2011; Rahman *et al.*, 2019). The long-term persistence of heavy metals through polluted water in the human body may cause carcinogenic as well as non-carcinogenic diseases. Due to their toxicity, they become the significant environmental pollutants that create an adverse effect on different biological functions of the human body which have been reported by various authors.

Arsenic: Arsenic is the most common heavy metal found in drinking water. Kumar and Puri, 2012 reported that due to the drinking of arsenic-contaminated water early acute intoxication found in the human body includes abdominal pain, vomiting, diarrhea, muscular pain, and flushing of the skin.

He also added that long-term exposure to arsenic-contaminated water causes chronic diseases to include dermal lesions, peripheral neuropathy, skin cancer, and peripheral vascular disease. Saha *et al.*, 1999 reported that the major dermatological signs are melano-keratosis, melanosis, spotted and diffuse keratosis, leukokeratosis, and dorsal keratosis. Accumulation of As by aquatic biota can cause bioaccumulation in aquatic biota like liver lesions, decreased fertility, cell and tissue damage, and cell death.

Lead: Moore, 1998 reported that lead is used as a universal heavy metal found in household plumbing systems in which the pipes, solder, fittings, or service connections to homes. Drinking water is contaminated by lead not only from natural dissolution but also from household plumbing systems. Lead is a cumulative toxic element that causes several health diseases to include encephalopathy, peripheral neuropathy, central nervous disorders, anemia and reproductive effects (Mahurpawar, 2015). The toxicological effect of lead on an aquatic organism can cause metamorphosis, neurology and other developmental progressions.

Iron: A joint report of FAO/WHO, 1998 revealed that Iron is an essential element for both humans, animals and plants. It plays an important role in the oxygen transport system in the blood of all vertebrates and some invertebrate animals. The two forms of Iron (Ferrous Fe^{2+} and ferric F^{3+}) have a little bit of health concern for aquatic life beyond a certain limit.

Mercury: Mercury is referred to as one of the most toxic heavy metals in the environment which causes neurological poison in fish, wildlife, and humans. Exposure to elevated levels of metallic mercury can damage the brain, kidney and developing fetus (Alina *et al.*, 2012).

The adverse effects of exposure to metallic mercury in a short time include lung damage, vomiting, diarrhea, nausea, skin rashes, increased heart rate or blood pressure with increasing the exposure of mercury can alter brain functions and lead to shyness, tremors, memory problems, irritability, and changes in vision or hearing (Jaishankar *et al.*, 2014).

Cadmium: Cadmium is toxic to plants, animals and micro-organisms. High exposure to cadmium causes adverse effects on the growth and reproduction of an aquatic organism. Cadmium can cause both acute and chronic toxicity in the human body (Chakraborty *et al*., 2013). Long-time exposure can cause kidney disease, fragile bones and lung damage (Bernard, 2008) even in a lower concentration. High exposure to cadmium can cause premature birth and reduce birth weights during human pregnancy (Henson and Chedrese, 2004).

Chromium: Chromium is an essential nutritional element for both humans and plants. Exposure to Chromium in the human body can cause an ulcer, perforation of the nasal septum, respiratory cancer (Mahurpawar, 2015). The high exposure of chromium in the human body can reduce the capacity of methemoglobin to hemoglobin (Koutras *et al*., 1965; Schlatter and Kissling, 1973) as well as the aquatic organism.

Zinc: Zinc is a relatively nontoxic element in the environment, but the high amount has an adverse effect on the human body. Duruibe *et al.* in 2007 have been reported that the symptoms of zinc toxicosis include vomiting, diarrhea, bloody urine, liver failure, kidney failure and anemia.

Table 1. Permissible limits of Heavy Metals (mg/L) in water.

Fe	Cu	Zn	Cd	Pb	Cr	Hg	As	Mn	Ni	Reference
NGV	2	NGV	0.003	0.01	0.05	0.006	0.01	0.4	0.07	WHO, 2008
0.3-1.0	1	5	0.005	0.05	0.05	0.001	0.05	0.1	0.1	ECR, 1997
0.3	0.05	5	0.003	0.01	0.05	0.001	0.01	0.1	0.02	BIS, 2012
	1.3		0.005	0.015	0.1	0.002	0.01			USEPA, 2006
	2		0.005	0.01	0.05	0.001	0.01		0.2	EU, 1998
	1	1	0.005	0.01	0.05		0.01		0.2	China, 2006

NGV- No guideline value; WHO- World Health Organization; ECR- Environment Conservation Rules; BIS - Bureau of Indian Standards; USEPA- United States Environmental Protection Agency; EU- Council of the European Union.

Manganese: The drinking water with Manganese exposure to elevated levels can attack the nervous system of the body and causes hepatic encephalopathy (Beckman *et al*., 1985).

Nickel: Mahurpawar, 2015 reported that nickel occurs in the environment at very low levels. Exposure to nickel can cause the death of animals, fish and retardation of plant growth. He also added that uptake of small quantities of nickel is essential but large quantities are a danger for human health viz, higher chances of development of lung cancer, nose cancer, larynx cancer, lung embolism, birth defects, asthma and chronic bronchitis, skin rashes and heart disorders.

Pollution status of heavy metals in water and sediment of Buriganga river

Numerous studies in order to evaluate the heavy metals contamination in the Buriganga river have been conducted by various researchers. Islam *et al*., 2014a assessed the trace metal contamination in water and sediment of some rivers in Bangladesh. The sample was collected from three rivers (Buriganga, Turag and Shitalakkha) along with the Dhaka city with seasonal variation. Results show that most of the heavy metals with high concentration were found in Buriganga river water and sediment especially in the Hazaribagh area because of the effects from tannery and dyeing industries of this site. The authors concluded that the metals were highly concentrated in winter compared to the summer season. Decreasing order of concentration of metals in water and sediment were Cr> Cu>As>Ni>Pb>Cd and Cr>Pb>Ni>Cu>As>Cd respectively. Mokaddes *et al*., 2013 studied the status of heavy metal contaminations of river water of Dhaka metropolitan city. According to their study, the levels of Mn and Cd of Buriganga river water and especially, As the concentration of Hazaribagh area water exceeded the WHO permissible limits due to the discharging of heavy industrial effluents. The authors concluded that the water was suitable for irrigation not for drinking purposes. Baki *et al*., 2019 studied some heavy metal concentrations in Buriganga and Turag river water systems and assessed the health risk on the accumulation of different heavy metals by some fish species. According to them the metal concentration of the two-study point (Babu Bazar of Buriganga river and Ashulia Ltd. Station of Turag river) were found below the detection limit. They added that *Puntius ticto* had the highest potential hazard because of the accumulation of high concentration of metals in their liver which causes carcinogenic and non-carcinogenic effects. Bhuiyan *et al.*, 2014 studied the status of heavy metals in water and sediment of the Buriganga river and their source apportionment in different locations. Results show that the concentration of heavy metals in both water and sediment exceeded the permissible limit due to the discharging of a huge amount of sewage from textile, tanneries, industrial effluents, etc. The authors also added that the Cr, As, Cd and Pb were exceeded the critical limits and the water of the Buriganga river was unsafe for Drinking. Khan *et al.*, 2014 studied the contamination status and health risk assessment for the presence of trace elements in foodstuffs collected from the Buriganga river embarkments near the Hazaribagh area. According to them the concentrations of heavy metal of Hazaribagh area water were found below the safe limit for irrigation purposes except for Fe and Mn. The metal concentration was varied due to the discharging of treated or untreated industrial wastewater into the Buriganga river. Mohiuddin *et al.*, 2011 assessed the heavy metal contamination in water and sediment of 20 different locations of the Buriganga river with seasonal variation. The metal concentrations were varied from location to location due to the variation of sewage discharging from the different industries along the river as well as anthropogenic causes. The authors concluded that the overall metal concentration was higher in the winter season than in summer because of the dilution effect that arises in the water level in summer. Real *et al.*, 2019 studied some selected heavy metals contamination in environmental compartments of the Buriganga River in Dhaka city. The results reveal that the concentration of Cr exceeds the toxicity reference value set by USEPA in both water and sediment in the Hazaribagh area. The high concentration of Cr was found high due to the discharging of untreated Cr from leather industries into the river. The authors outlined that the metal concentration in water was less than the toxicity reference value for safe water except for Cr and Pb. Sarkar *et al.*, 2015 studied the hydrochemistry and pollution status of tannery effluent as well as Buriganga river water. According to their study, the concentration of Cr in the Postagola and Hazaribagh area water exceeded the WHO permissible limits because the cooling tower additives of different industries near the Postagola sampling area and the tannery effluent of the tanneries near Hazaribagh sampling area were mixed with river water. The concentration of Ni was exceeding the WHO permissible limit in Postagola, Sadarghat and Hazaribagh area water because there have been some paper mills and constructed dockyards situated at the bank of the Buriganga River which might be the source of Ni. The authors manifested that the water of the all-sampling station was unsafe for drinking. Mohiuddin *et al.*, 2015a assessed the physicochemical properties and metallic constituent load in the water samples of the Buriganga river. The water of the 10-sampling areas was slightly acidic out of 14 dues to the presence of the higher amount of industrial waste and the water was unsuitable for long-term irrigation uses. The authors concluded that the average concentration of Cr, Pb and Cu of all the sampling areas of the Buriganga river was about 10 times less than the same river water sample cited by Mohiuddin *et al.*, 2011 in previous. The Cr concentration was thirteen to twenty times higher than the reference value cited by USEPA for freshwater standard because a huge amount of Cr containing tannery wastes discharged in the river. Sikder and Islam, 2016 assessed the heavy metal contamination of Buriganga river bed sediment. In accordance with their study, the sediment quality of the all-sampling areas was highly concentrated for Cu and Zn, unpolluted to moderately polluted for Pb, moderately to highly polluted for Cr compared with the USEPA sediment quality guideline values.

Table 2. Concentrations of heavy metals in Buriganga River water of diverse sampling locations.

Study areas	Concentrations of Heavy Metals in water (mg/L)										
	Fe	Co	Cd	As	Zn	Cr	Pb	Ni	Mn	Cu	Reference
Hazaribagh			0.0198		0.3021	7.7656		0.207		0.0304	Sarkar *et al.*, 2015
		0.0967	0.14	0.2567	0.25	2.31	0.57	0.17		1.82	Mohiuddin *et al.*, 2011
		0.1	0.22	0.5	0.21	2.27	0.21	0.17		2.72	
	31.019	0.014			0.234				0.156	0.058	Khan *et al.*, 2014
			0.0005		0.114	0.136	0.014	0.024			Real *et al.*, 2019
			0.0115	0.03	0.0098		0.0023		0.0273	0.0115	Mokaddes *et al.*, 2013
	1.549		BDL		0.239	0.13	BDL		0.276	0.197	Mohiuddin *et al.*, 2015a
			0.017			0.23	0.002		0.061	0.012	Hoque and Deb, 2016
Sadarghat			0.0162		0.1544	0.143		0.2486		0.0238	Sarkar *et al.*, 2015
		0.09	0.15	0.22	0.26	0.88	0.51	0.14		1.74	Mohiuddin *et al.*, 2011
		0.11	0.22	0.43	0.21	1.88	0.32	0.16		2.75	
	0.363		BDL		0.522	0.194	0.82		0.041	0.236	Mohiuddin *et al.*, 2015a
			0.009	0.001	0.008		0.0018		0.0246	0.0017	Mokaddes *et al.*, 2013
Kamrangirchor		0.08	0.18	0.22	0.24	1.72	0.5	0.13		1.76	Mohiuddin *et al.*, 2011
		0.1	0.21	0.45	0.2	1.88	0.17	0.14		2.75	
	0.44		BDL		0.78	0.203	BDL		0.175	0.223	Mohiuddin *et al.*, 2015a
			0.016	0.002	0.0079		0.0043		0.0445	0.009	Mokaddes *et al.*, 2013
Shawaryghat	0.363		BDL		0.566	0.162	BDL		0.167	0.226	Mohiuddin *et al.*, 2015a
			0.00845			0.60587	0.07109	0.00852		0.13218	Ahmad *et al.*, 2010
			0.00708			0.55716	0.06236	0.00905		0.20129	
			0.01233			0.57825	0.06528	0.00715		0.19382	
		0.09	0.17	0.23	0.26	0.93	0.52	0.16		1.68	Mohiuddin *et al.*, 2011
		0.11	0.22	0.2	0.21	1.88	0.21	0.16		2.72	
Postagola			0.0148		0.0878	0.2163		0.2294		0.0142	Sarkar *et al.*, 2015
		0.1	0.16	0.22	0.27	0.88	0.5	0.15		1.64	Mohiuddin *et al.*, 2011
		0.1	0.22	0.29	0.21	1.87	0.19	0.16		2.75	
Badamtali	0.347		BDL		0.594	0.181	0.023		0.198	0.23	Mohiuddin *et al.*, 2015a
		0.1	0.14	0.26	0.29	0.99	0.45	0.13		1.74	Mohiuddin *et al.*, 2011
		0.11	0.22	0.46	0.21	1.88	0.29	0.16		2.74	
Gabtoli			0.02			0.07	0.002		0.06	0.014	Hoque and Deb, 2016
Basila			0.0005		0.065	0.018	0.009	0.017			Real *et al.*, 2019
Modinanagar			0.009		0.2948	0.0453		0.0834		0.016	Sarkar *et al.*, 2015
Babu Bazar			0.0007		0.037	0.02	0.009	0.015			Real *et al.*, 2019
Kawtail			0.0018		0.1471	0.0306		0.0663		0.0112	Sarkar *et al.*, 2015
Foridabad			0.01003			0.61325	0.05817	0.00896		0.13565	Ahmad *et al.*, 2010
			0.01015			0.61325	0.07245	0.01032		0.18765	
			0.00925			0.60434	0.06315	0.00843		0.18957	
Balughat			0.00921			0.64526	0.06234	0.01005		0.14503	Ahmad *et al.*, 2010
			0.00819			0.58627	0.06405	0.00762		0.10738	
			0.00905			0.60513	0.07019	0.00913		0.17527	

* * BDL – Below Detectable Limit.

Results show that the sediment of the Badamtali ghat area was highly concentrated by Cu and Zn and the concentration exceeded the USEPA sediment quality guideline values. Tamim *et al.*, 2016 studied the elemental distribution of the heavy metals in Buriganga river sediment. Results show that about 27 elements were found in the 9-sediment samples of the Hazaribagh sampling area. The sediment of the sampling area was highly concentrated by Cr because of the number of lather industries were situated at the bank of the sampling area which discharging a high amount of Cr content sewage into the river. The authors concluded that the metal concentration was decreased with increasing the sampling depth. There have also been several researchers who have been carried out extensive research works to evaluate the status of heavy metals in water and sediment from different locations of the Buriganga river. Mohiuddin *et al.*, 2015b studied the level of Cr, Pb, Cd, Ni, Zn, Cu, Fe and Mn concentrations in the Buriganga river and elucidated that all the samples were exceeded the permissible PLI (Pollution Load Index) values and among them, Cr, Cd, Zn, Pb and Cu were the major contaminants responsible for the higher PLI values founded in the river. The river water was badly polluted through these pollutants. Islam *et al.*, 2017 investigated the contamination extent for Chromium, Nickel, Copper, Arsenic, Cadmium and Lead metals in the Buriganga river surface sediments and stated that Pb (lead) and Cd (Cadmium) were possessed higher ecological hazard among all the examined heavy metals for almost all sampling locations. Whitehead *et al.*, 2019 modelled following heavy metals Cd, Pb, Cu and Cr in terms of INCA-modeling (Integrated Catchment) for Buriganga river to illustrate the impacts of tannery pollution control and suggested that the replacement of Hazaribagh tannery industries to Savar would not only be the way for gaining the cherished goal of reaching national water standards as well as attaining 6.3 SDGs for Bangladesh, but more comprehensive effluent treatment would also be needed. Majumder *et al.*, 2015 studied the heavy metals contamination of Buriganga bottom sediments and reported that the concentrations of Co, Ni, Cu, Cd and As metals were observed higher than the threshold average values of Canadian Sediment quality indices and were the major contaminants. Rampley *et al.*, 2019 assessed river toxicity with the help of Molecular Biosensors for the Turag, Balu and Buriganga rivers and outlined that the levels of ten heavy metals viz. Cr, Cu, Li, Ni, Se, Al, Cs, Rb, Zn and Sn concentrations among all quantified metals were increased in January 2018 than the values observed in December 2017, although the overall heavy metal concentrations were not exceeded the permissible limits.

Table 3. Concentration of heavy metals in Buriganga river sediment of divers sampling locations.

Study areas	Heavy metal concentrations in sediments (mg/Kg)										
	As	Cd	Cr	Cu	Co	Fe	Mn	Ni	Pb	Zn	Reference
Balughat.		3.87	218.39	23.18				147.06	77.13		Ahmad *et al.*, 2010
		3.26	203.17	21.75				199.28	72.45		
		2.83	201.15	32.54				187.65	66.23		
Shawaryghat	NA	0.8	275.1	419.3		13722	3157	128.5	16.7	413.1	Mohiuddin *et al.*, 2015b
	15	4.1	151	158	37			186	501	663	Mohiuddin *et al.*, 2011
	19	9.5	294	318	49			198	858	917	
Foridabad		4.05	168.53	27.25				258.17	68.07		Ahmad *et al.*, 2010
		2.54	118.63	31.15				212.08	65.18		
		4.25	167.43	30.45				193.35	71.05		
Badamtoli Ghat	NA	1.6	139.6	346	NA	NA	NA	NA	105.6	984.9	Saha and Hossain, 2011
	NA	1.2	108.4	336.9	NA	11943	3672	233.0	23.5	480.0	Mohiuddin *et al.*, 2015b
Badamtoli bridge	13	4.4	154	144	47			176	368	445	Mohiuddin *et al.*, 2011
	11	8.3	149	459	46			186	938	1199	
Sadarghat	NA		45.18	192.03				55.11	35.51	152.04	Sikder and Islam, 2016
	10	4.1	51	248				135	96		Islam *et al.*, 2017
	18	5.7	78	260				154	113		
		0.5	126.1	140.0		12842	4193	147.7	25.1	317.3	Mohiuddin *et al.*, 2015b
	9	4.1	105	191	48			153	753	288	Mohiuddin *et al.*, 2011
	17	8.5	190	354	58			202	976	1432	
Shyampur	19.90	5.50	1313	57.80	46.20	11,590	560	49.11	74.40	53.40	Bhuiyan *et al.*, 2014
Postogola	7.6	12	17	115				110	2252		Islam *et al.*, 2017
	17	16	22	170				123	2678		
Sahidnagar	21	5.8	433	250	27			137	460	2163	Mohiuddin *et al.*, 2011
	20	4.6	390	363	39			142	429	1873	
Hazaribagh	17.90	4.68	1178	83.80	46.50	11480	587	49.51	64.33	49.45	Bhuiyan *et al.*, 2014
Jahuchar, Hazaribagh	10	4.2	2017	345	33			160	567	476	Mohiuddin *et al.*, 2011
	9	4.4	4249	109	27			92	147	466	
Kalunagar, Hazaribagh	11	4.1	1456	242	27			68	171	357	Mohiuddin *et al.*, 2011
	12	4.8	2910	119	34			94	115	580	
Mohammapur	11.82	5.25	1535	39.00	45.30	12045	494	35.21	55.43	53.20	Bhuiyan *et al.*, 2014
Kamrangirchor	20.50	9.58	1565	85.20	48.50	13782	639	53.41	65.50	58.25	Bhuiyan *et al.*, 2014

* NA – Not Available.

It would keep rising during the Bishwa Ijtema and dry season particularly. Islam *et al.*, 2014b studied heavy metal contamination based on food consumption of Hazaribagh tannery areas as well as the Buriganga river water and reflected that all quantified heavy metals were exceeded the allowable concentrations of various guidelines with the exception for Cd (Cadmium) and among all the detected metals, Cr (Chromium) was beyond of all which led to acting as the major pollutant. A relevant study as before was reported regarding the effect of tannery effluent loads on the Buriganga river aquatic systems by Assaduzzaman *et al.*, 2014. Islam *et al.*, 2014c examined the heavy metals including Pb, Cd, Ni, Cu, Cr and Zn in sediments, water and fishes for the rivers Shitalakhya and Buriganga and found that three out of six heavy metals viz. Pb, Cu and Ni were present excessively high in both the water and sediments. Ahmad *et al.*, 2010 manifested based on their conducted study that the Buriganga river sediments, water and fishes were mostly unsafe for human health as well as for the ecosystem and that situation might be enhanced in the future through industrialization, untreated sewage disposals and other harmful practices. Several studies regarding water quality and metal contamination in fishes and water of Buriganga river were also reported by a group of researchers (Islam *et al.*, 2018b; Islam *et al.*, 2019; Ahmed *et al.*, 2011; Reza and Yousuf, 2016; Ahmed *et al.*, 2015; Ahmed *et al.*, 2016). Hoque and Deb, 2016 assessed the concentration of several selected heavy metals as well as Buriganga river water quality and recounted that Cr content at Hazaribagh and Cd content at Gabtoli areas were found to present 5 times and 4 times higher from the recommended limits respectively. The presence of heavy metals in effluents including textile and tannery as well as in the rivers adjacent to the capital city Dhaka was determined by Das *et al.*, 2011 and the study demonstrated that heavy metal concentrations viz. Zn, Cr, Ni, Cd, Cu, As and Pb were found to exist higher in the dry season than in the rainy season and among them, Cr and Cu extent were above the DoE (Department of Environment) guidelines. Rahman *et al.*, 2013b investigated the heavy metals concentration for several rivers flowing through the capital city Dhaka and reported that the level of Lead (Pb) was obtained higher than other selected metals including Cr, Cd, Ni and Zn which made the water of those examined rivers unsuitable for various purposes. Fatema *et al.*, 2018 assessed the Buriganga river water quality via heavy metal contents and described based on their analysis that the river water was not safe. All the heavy metal contents present in the water and sediments are mentioned in Tables 2 and 3 respectively.

Restoration steps through minimizing the river contamination

Since the Buriganga River is one of the most significant lifelines for the capital city Dhaka and the main alternative source of water that make the river heavy metals pollution a national concern which has influenced the consideration of many concerned researchers so far. River pollution is affected human health, society and especially biodiversity. This pollution has resulted from the various wastes, effluents and other domestic wastes disposal into the river. The industrial waste-effluents causing river pollution can be reduced only by inhibiting these waste-effluents disposals at the root level. Improvement of waste treatment facilities will be mandatory to get the desired water quality and endeavors ought to be provided to ascertain the implantation of clean up processes as well as regulatory improved monitoring has become a dire necessity for the river restoration (Rampley *et al.*, 2019; Whitehead *et al.*, 2019; Ahsan, 2019; Fatema *et al.*, 2018). As the river is the main source of water supply for Dhaka city so, its pollution has become a headache for the city dwellers as well as the government. The river is continuously polluting and turning into a dead river day by day. The total pollution has been come around 60% from the industrial wastes on the contrary 30% from the Wasa (Water and sewerage authority) and city corporations and 10% from domestic wastes reported by Bapa (Bangladesh Poribesh Andolan). Public awareness is the first and foremost way to prevent river pollution because every day the Dhaka city dwellers discharge huge amounts of untreated domestic sewage into the river through the drains. The government should take strict rules for the industries to prevent sewage disposal. It should be recycled again to minimize the heavy metal concentration in the sewage. It is beneficial for the industrial economy as well as the environment. Almost all industries did not have their Etps (Effluent treatment plants) according to Poba (Poribesh Bachao Andolan). So, all the industries should be installed effluent treatment plants which will reduce the environmental contaminant just before the discharging of sewage into the river. In this regard, the government of Bangladesh was done a central effluent treatment plant (CEPT) in 2006, which was under the recommendation of a task force on Buriganga formed in 2003 (Kibria *et al.*, 2015). Till March 2019, total 1765 ETPs were implanted in and 450 ZDPs ("Zero Discharge Plan" for recycling the various wastes) were also approved for all industries having effluent disposal issues by the Department of Environment (DoE), Bangladesh (Ahsan, 2019). According to the Department of Environment (DoE), the water quality of the Buriganga river has slightly improved following the relocation of the tannery industries, Hazaribagh to Heymayetpur, Savar where the all-industrial effluents will be discharged through the central effluent treatment plant (CEPT) which will minimize the contaminant. It will also be an effective way to prevent pollution if the dying industries at Shyampur on the bank of the river relocate to another place. According to (Kibria *et al.*, 2015) Bangladesh Inland Water Transport Authority (BIWTA) and Dhaka City Corporation should work combinedly to prevent sewage disposal into the river. The BIWTA should dig the river in a regular manner, it will also be an effective way to control river pollution. The authors also said that if the water flow of the river is continuous then the river water quality may improve that is why they have suggested that the Buriganga river should be connected with the Jamuna river for continuous flow in the dry season. It is also beneficial for agricultural irrigation and fisheries. The presence of heavy metals in Buriganga river water and sediment creates an adverse effect on aquatic biota and plants which was studied by very few researchers in the past (Choudhury *et al.*, 2015). The fish species of the river can accumulate heavy metals from water and sediment and cause a reduction of growth. These contaminated fishes enter our food chain and cause several health diseases. If the government should not take any strict steps to prevent the Buriganga river pollution it will be a great threat to the city dwellers. Although the replacement of tannery industries to another place in the city and remarkable rainfall were improved the water quality of the Buriganga river to is shorter extent according to DoE but this is not enough to achieve the standards (Whitehead *et al.*, 2019). Since around 60% of the total pollution has come from the industrial wastes reported by Bapa (Bangladesh Poribesh Andolan). So, waste management processes should be implemented in all industries that are situated at the Buriganga riverbanks and concerned should enforce strict law to remove the hidden pipelines to the river which are carrying the wastewater from different industries. In addition, the practice of three Rs (Reduce, Reuse and Recycle) waste management needs to be provided more insistence and the waste must be treated at the initial steps to reduce the possibility of accumulation as well as the hazardous effects. The Buriganga Action Plan (BAP) must be implemented as the major concern for the river and continuous efforts certainly be given to prevent the river endangerments. So that the Government should take crucial managements to ensure the complete treatment of waste-effluents before discharging them (Complete ETPs Implantation) and should create standard platforms or criteria to reward the industries for their better waste management that will encourage the industry owners towards less pollution. In the end, people around and the industries, shops should abide by all the enforced laws regarding the Buriganga river pollution and public awareness should be boosted.

Conclusion

This particular review article reflects the current background of heavy metals contamination associated with water and sediments of the Buriganga river. Numerous studies on the heavy metal contamination in the Buriganga river reveal that all the physico-chemical parameters of water and sediments determined from different study areas were gone beyond all the standard ranges. Considering the previously conducted numerous studies regarding this, the river water and sediments are no longer suitable for human health as well as the aquatic life systems. As heavy metals are not easily degradable substances as well as having hazards like biomagnification and bioaccumulation, therefore pose serious threats to the human and biodiversity. If we do not take any fruitful effort yet to control the metalloids and heavy metal pollution in the Buriganga River, this can be a permanent disaster for the water, sediment and living organisms in the Buriganga River. Therefore, crucial remedial measures must be taken to reduce the pollution load that is resulted from the untreated domestic and industrial wastes execution into the river Buriganga. Based on the findings of dedicated researchers, this study suggested that regulatory monitoring should be maintained to sustain the standard water quality such as treatment of effluents need to be improved and minimization of various wastes disposal into the river.

References

Tamim U, Khan R, Jolly YN, Fatema K, Das S, Naher K, Islam MA, Islam SMA, Hossain SM. 2016. Elemental distribution of metals in urban river sediments near an industrial effluent source. Chemosphere **155,** 509-518. http://dx.doi.org/10.1016/j.chemosphere.2016.04.099.

Ahmad MK, Islam S, Rahman S, Haque M, Islam MM. 2010. Heavy metals in water, sediment and some fishes of Buriganga River, Bangladesh. International Journal of Environmental Research (IJER) **4(2),** 321-332. https://doi.org/10.22059/IJER.2010.24.

Sarker MAK. 2005. Study on the accumulation and seasonal variation of trace metals in water, sediment and some fishes of the Buriganga River. PhD dissertation, M Sc thesis (1998-1999), Department of Zoology, Dhaka University, Dhaka, Bangladesh,1-4.

Kamal MM, Malmgren-Hansen A, Badruzzaman ABM. 1999. Assessment of pollution of the River Buriganga, Bangladesh, using a water quality model. Water Science and Technology **40(2),** 129-136. https://doi.org/10.1016/S0273-1223(99)00474-6.

Wu S, Zhou S, Li X. 2011. Determining the anthropogenic contribution of heavy metal accumulations around a typical industrial town: Xushe, China. Journal of Geochemical Exploration **110 (2),** 92-97.

Bhuiyan MAH, Suruvi NI, Dampare SB, Islam MA, Quraishi SB, Ganyaglo S, Suzuki S. 2011. Investigation of the possible sources of heavy metal contamination in lagoon and canal water in the tannery industrial area in Dhaka, Bangladesh. Environmental Monitoring and Assessment **175(1-4),** 633-649. https://doi.org/10.1007/s10661-010-1557-6

Sinha SN, Paul D. 2012. Detoxification of heavy metals by biosurfactants. Bulletin of Environmental and Scientific Research **1(3-4),** 1-3. http://besr.org.in/index.php/besr/article/view/31.

Nouri J, Fatemi MR, Danekar A, Fahimi FG, Karimi D. 2009. Determination of environmentally sensitive zones along Persian Gulf coastlines through geographic information system. J of Food, Agriculture and Environment **7(2),** 718-725.

Anonymous. 2003. Diffuse Pollution Conference Dublin. Institute for Environment and Development Studies, Aquatic ecology and dangerous substances: Bangladesh perspective. **8** Ecology, 65-66. http://www.ucd.ie/dipcon/docs/theme08/theme08_12.PDF

Rajbanshi A. 2008. Study on heavy metal resistant bacteria in Guheswori sewage treatment plant. Our nature **6(1),** 52-57. https://doi.org/10.3126/on.v6i1.1655.

Rahman MM, Asaduzzaman M, Naidu R. 2013a. Consumption of arsenic and other elements from vegetables and drinking water from an arsenic-contaminated area of Bangladesh. Journal of hazardous materials **262,** 1056-1063. https://doi.org/10.1016/j.jhazmat.2012.06.045.

Sin SN, Chua H, Lo W, Ng LM. 2001. Assessment of heavy metal cations in sediments of Shing Mun River, Hong Kong. Environment international **26 (5-6),** 297-301. https://doi.org/10.1016/S0160-4120(01)00003-4

Sheikh MA, Noah NM, Tsuha 2K, Oomori T. 2007. Occurrence of tributyltin compounds and characteristics of heavy metals. International Journal of Environmental Science & Technology **4(1),** 49-59. https://doi.org/10.1007/BF03325961

Yoon KP. 2003. Construction and characterization of multiple heavy metal-resistant phenol-degrading pseudomonads strains. Journal of microbiology and biotechnology **13(6),** 1001-1007.

Zvinowanda CM, Okonkwo JO, Shabalala PN, Agyei NM. 2009. A novel adsorbent for heavy metal remediation in aqueous environments. International Journal of Environmental Science & Technology **6(3),** 425-434. https://doi.org/10.1007/BF03326081

Hawkes SJ. 1997. What is a" heavy metal"? 1997. Journal of Chemical Education **74(11),** 1374. https://doi.org/10.1021/ed074p1374

Renberg I, Persson MW, Emteryd O. 1994. Pre-industrial atmospheric lead contamination detected in Swedish lake sediments. Nature **368(6469),** 323-326. https://doi.org/10.1038/368323a0

Mohammed AS, Kapri A, Goel R. 2011. Heavy metal pollution: source, impact, and remedies. In Biomanagement of metal-contaminated soils, p 1-28. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-1914-9_1

Blaser P, Zimmermann S, Luster J, Shotyk W. 2000. Critical examination of trace element enrichments and depletions in soils: As, Cr, Cu, Ni, Pb, and Zn in Swiss forest soils. Science of the Total Environment **249(1-3),** 257-280. https://doi.org/10.1016/S0048-9697(99)00522-7

Brookes PC. 1995. The use of microbial parameters in monitoring soil pollution by heavy metals. Biology and Fertility of soils **19(4),** 269-279. https://doi.org/10.1007/BF00336094

Gupta A, Rai DK, Pandey RS, Sharma B. 2009. Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad. Environmental monitoring and assessment **157(1-4),** 449. https://doi.org/10.1007/s10661-008-0547-4

Levin SV, Guzev VS, Aseeva IV, Bab'eva IP, Marfenina OE, Umarov MM. 1989. Heavy metals as a factor of anthropogenic impact on the soil microbiota. Microorganisms and Soil Conservation, 5-46.

Sheykhi V, Moore F. 2016. Environmental risk assessment of heavy metals pollution in aquatic ecosystem—A case study: Sediment of Kor River, Iran. Human and Ecological Risk Assessment: An International Journal **22(4),** 899-910. https://doi.org/10.1080/10807039.2015.1118677

Majumder RK, Faisal BMR, Zaman MN, Uddin MJ, Sultana N. 2015. Assessment of heavy metals pollution in bottom sediment of the Buriganga River, Dhaka, Bangladesh by multivariate statistical analysis. International Research Journal of Environmental Sciences **4(5),** 80-84.

Pongratz R, Heumann KG. 1999. Production of methylated mercury, lead, and cadmium by marine bacteria as a significant natural source for atmospheric heavy metals in Polar Regions. Chemosphere **39(1),** 89-102. https://doi.org/10.1016/S0045-6535(98)00591-8

Bhuiyan MAH, Islam MA, Dampare SB, Parvez L, Suzuki S. 2010. Evaluation of hazardous metal pollution in irrigation and drinking water systems in the vicinity of a coal mine area of northwestern Bangladesh. Journal of hazardous materials **179(1-3),** 1065-1077. https://doi.org/10.1016/j.jhazmat.2010.03.114

Bhuyan MS, Bakar MA, Akhtar A, Hossain MB, Ali MM, Islam MS. 2017. Heavy metal contamination in surface water and sediment of the Meghna River, Bangladesh. Environmental nanotechnology, monitoring & management **8,** 273-279. https://doi.org/10.1016/j.enmm.2017.10.003

Boamponsem LK, Adam JI, Dampare SB, Nyarko BJB, Essumang DK. 2010. Assessment of atmospheric heavy metal deposition in the Tarkwa gold mining area of Ghana using epiphytic lichens. Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms **268(9),** 1492-1501. https://doi.org/10.1016/j.nimb.2010.01.007

Dan'Azumi S, Bichi MH. 2010. Industrial Pollution and Heavy Metals Profile of Challawa River in Kano, Nigeria. Journal of Applied Sciences in Environmental Sanitation **5(1).**

Islam MS, Ahmed MK, Habibullah-Al-Mamun M, Islam KN, Ibrahim M, Masunaga S. 2014d. Arsenic and lead in foods: a potential threat to human health in Bangladesh. Food Additives & Contaminants: Part A **31(12)**, 1982-1992. https://doi.org/10.1080/19440049.2014.974686

Islam MS, Ahmed MK, Habibullah-Al-Mamun M, Hoque MF. 2015. Preliminary assessment of heavy metal contamination in surface sediments from a river in Bangladesh. Environmental earth sciences **73(4),** 1837-1848. https://doi.org/10.1007/s12665-014-3538-5

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

Rahman MS, Molla AH, Saha N, Rahman A. 2012. Study on heavy metals levels and its risk assessment in some edible fishes from Bangshi River, Savar, Dhaka, Bangladesh. Food chemistry **134(4),** 1847-1854. https://doi.org/10.1016/j.foodchem.2012.03.099

Salati S, Moore F. 2010. Assessment of heavy metal concentration in the Khoshk River water and sediment, Shiraz, Southwest Iran. Environmental monitoring and assessment **164(1-4),** 677-689. https://doi.org/10.1007/s10661-009-0920-y

Shikazono N, Tatewaki K, Mohiuddin KM, Nakano T, Zakir HM. 2012. Sources, spatial variation, and speciation of heavy metals in sediments of the Tamagawa River in Central Japan. Environmental geochemistry and health **34(1),** 13-26. https://doi.org/10.1007/s10653-011-9409-z

Sinha SN, Biswas M, Paul D, Rahaman S. 2011. Biodegradation potential of bacterial isolates from tannery effluent with special reference to hexavalent chromium. Biotechnology Bioinformatics and Bioengineering **1(3),** 381-386.

Bodrud-Doza M, Didar-Ul Islam SM, Rume T, Quraishi SB, Rahman MS, Bhuiyan MAH. 2020. Groundwater quality and human health risk assessment for safe and sustainable water supply of Dhaka City dwellers in Bangladesh." Groundwater for Sustainable Development, 100374.
https://doi.org/10.1016/j.gsd.2020.100374

WHO. Geneva. 2011. Guidelines for drinking-water quality. World Health Organization **216,** 303-304.

ECR (The Environment Conservation Rules). 1997. Department of Environment, Government of the People's Republic of Bangladesh. Poribesh Bhaban E-16, Agargaon, Shere Bangla Nagar Dhaka 1207, Bangladesh, 179-226.

BIS. 2012. Indian Standard Drinking Water Specification. "Bureau of Indian Standards." New Delhi, 2-3.

EPA U. 2006. "Edition of the drinking water standards and health advisories." US Environmental Protection Agency, Washington, DC.

EU. (European Union).1998. Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption.

China. 2006. Standards for Drinking Water, National Standard of the People's Republic of China. Ministry of Health of China GB, 5749-2006.

Dudka S, Adriano DC. 1997. Environmental impacts of metal ore mining and processing: a review. Journal of environmental quality **26(3),** 590-602.
https://doi.org/10.2134/jeq1997.00472425002600030003x

Sa'idi M. 2010. Experimental studies on effect of heavy metals presence in industrial wastewater on biological treatment. International journal of environmental sciences **1(4)**, 666-676.

Muhammad S, Shah MT, Khan S. 2011. Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. Microchemical journal **98(2),** 334-343.
https://doi.org/10.1016/j.microc.2011.03.003

Rahman MS, Khan MDH, Jolly YN, Kabir J, Akter S, Salam A. 2019. Assessing risk to human health for heavy metal contamination through street dust in the Southeast Asian Megacity: Dhaka, Bangladesh. Science of The Total Environment **660,** 1610-1622.
https://doi.org/10.1016/j.scitotenv.2018.12.425

Kumar M, Puri A. 2012. A review of permissible limits of drinking water. Indian journal of occupational and environmental medicine **16(1),** 40.
10.4103/0019-5278.99696

Saha JC, Dikshit AK, Bandyopadhyay M, Saha KC. 1999. A review of arsenic poisoning and its effects on human health. Critical reviews in environmental science and technology **29(3),** 281-313.
https://doi.org/10.1080/10643389991259227

Moore MR. 1988. Haematological effects of lead. Science of the total environment **71(3)**, 419-431.
https://doi.org/10.1016/0048-9697(88)90214-8

Mahurpawar M. 2015. Effects of heavy metals on human health. International Journal of Reseacrh-Granthaalayah, ISSN-23500530, 2394-3629.
http://www.granthaalayah.com.

World Health Organization. 1988. Requirements of Vitamin A, Iron, Folate, and Vitamin B12: Report of a Joint FAO/WHO Expert Consultation. No. 23. Food & Agriculture Organization.

Alina M, Azrina A, Yunus ASM, Zakiuddin SM, Effendi HMI, Rizal RM. 2012. Heavy metals (mercury, arsenic, cadmium, plumbum) in selected marine fish and shellfish along the Straits of Malacca. International Food Research Journal **19(1),** 135–140.

Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. 2014. Toxicity, mechanism and health effects of some heavy metals. Interdisciplinary toxicology **7(2),** 60-72. https://doi.org/10.2478/intox-2014-0009

Chakraborty S, Dutta AR, Sural S, Gupta D, Sen S. 2013. Ailing bones and failing kidneys: a case of chronic cadmium toxicity. Annals of Clinical Biochemistry **50(5),** 492-495. https://doi.org/10.1177/0004563213481207

Bernard A. 2008. Cadmium & its adverse effects on human health. Indian Journal of Medical Research **128(4),** 557. http://hdl.handle.net/2078.1/35901.

Henson MC, Chedrese PJ. 2004. Endocrine disruption by cadmium, a common environmental toxicant with paradoxical effects on reproduction. Experimental biology and medicine **229(5),** 383-392. https://doi.org/10.1177/153537020422900506

Koutras GA, Schneider AS, Hattori M, Valentine WN. 1965. Studies on chromated erythrocytes. Mechanisms of chromate inhibition of glutathione reductase. British Journal of Haematology **11(3),** 360-369. https://doi.org/10.1111/j.1365-2141.1965.tb06596.x

Schlatter C, Kissling U. 1973. Acute fatal bichromate poisoning. Beitrage zur gerichtlichen Medizin **30,** 382-388.

Duruibe JO, Ogwuegbu MOC, Egwurugwu JN. 2007. Heavy metal pollution and human biotoxic effects. International Journal of physical sciences **2(5),** 112-118. https://doi.org/10.5897/IJPS.9000289

Beckman RA, Mildvan AS, Loeb LA. 1985. On the fidelity of DNA replication: manganese mutagenesis in vitro. Biochemistry **24(21),** 5810-5817. https://doi.org/10.1021/bi00342a019

Islam MS, Han S, Ahmed MK, Masunaga S. 2014a. Assessment of trace metal contamination in water and sediment of some rivers in Bangladesh. Journal of Water and Environment Technology **12(2),** 109-121. https://doi.org/10.2965/jwet.2014.109

Mokaddes MAA, Nahar BS, Baten MA. 2012. Status of heavy metal contaminations of river water of Dhaka Metropolitan City. Journal of Environmental Science and Natural Resources **5(2),** 349-353. https://doi.org/10.3329/jesnr.v5i2.14842

Baki MA, Shojib MFH, Sehrin S, Chakraborty S, Choudhury TR, Bristy MS, Ahmed MK, Yusoff SB, Khan MF. 2020. Health risk assessment of heavy metal accumulation in the Buriganga and Turag River systems for Puntius ticto, Heteropneustes fossilis, and Channa punctatus. Environmental geochemistry and health **42(2),** 531-543. https://doi.org/10.1007/s10653-019-00386-4

Bhuiyan MAH, Dampare SB, Islam MA, Suzuki S. 2015. Source apportionment and pollution evaluation of heavy metals in water and sediments of Buriganga River, Bangladesh, using multivariate analysis and pollution evaluation indices. Environmental monitoring and assessment **187(1),** 4075. https://doi.org/10.1007/s10661-014-4075-0

Khan FE, Jolly YN, Islam GMR, Akhter S, Kabir J. 2014. Contamination status and health risk assessment of trace elements in foodstuffs collected from the Buriganga River embankments, Dhaka, Bangladesh. International Journal of Food Contamination **1(1),** 1. https://doi.org/10.1186/s40550-014-0001-z

Mohiuddin KM, Ogawa Y, Zakir HM, Otomo K, Shikazono N. 2011. Heavy metals contamination in water and sediments of an urban river in a developing country. International journal of environmental science & technology **8(4),** 723-736. https://doi.org/10.1007/BF03326257

Real MIH, Redwan A, Shourov MMR, Azam H, Majed N. 2017. Heavy Metal Contamination in Environmental Compartments of Buriganga River in Dhaka City. In Global Civil Engineering Conference, p 1455-1466. Springer, Singapore. https://doi.org/10.1007/978-981-10-8016-6_105.

Sarkar M, Rahman AKML, Islam JB, Ahmed KS, Uddin MN, Bhoumik NC. 2015. Study of hydrochemistry and pollution status of the Buriganga river, Bangladesh. Bangladesh Journal of Scientific and Industrial Research **50(2),** 123-134. https://doi.org/10.3329/bjsir.v50i2.24353

Mohiuddin KM, Alam MM, Ahmed I, Zakir HM, Chowdhury AK. 2015a. Physicochemical Properties and Metallic Constituent Load in the Water Samples of the Buriganga of Bangladesh. Journal of Environmental Science and Natural Resources **8(2),** 141-146. https://doi.org/10.3329/jesnr.v8i2.26881

Sikder D, Islam MS. 2016. HEAVY METAL CONTAMINATION ASSESSMENT OF THE BURIGANGA RIVER BED SEDIMENT.". Proceedings of 3rd International Conference on Advances in Civil Engineering, 21-23 December 2016, CUET, Chittagong, Bangladesh, 37-42.

Mohiuddin KM, Alam MM, Ahmed I, Chowdhury AK. 2015b. Heavy metal pollution load in sediment samples of the Buriganga river in Bangladesh. Journal of the Bangladesh Agricultural University **13(2),** 229-238. https://doi.org/10.3329/jbau.v13i2.28784.

Islam MS, Proshad R, Saad Ahmed S. 2018. Ecological risk of heavy metals in sediment of an urban river in Bangladesh. Human and ecological risk assessment: an international journal **24(3),** 699-720. https://doi.org/10.1080/10807039.2017.1397499

Whitehead PG, Bussi G, Peters R, Hossain MA, Softley L, Shawal S, Jin L. Rampley CPN, Holdship P, Hope R, Alabaster G. 2019. Modelling heavy metals in the Buriganga River system, Dhaka, Bangladesh: impacts of tannery pollution control. Science of the Total Environment **697,** 134090. https://doi.org/10.1016/j.scitotenv.2019.134090

Rampley, CPN, Whitehead PG, Softley L, Hossain MA, Jin L, David J, Shawal S, Das P, Thompson IP, Huang WE, Peters R, Holdship P, Hope R, Alabaster G. 2020. River toxicity assessment using molecular biosensors: Heavy metal contamination in the Turag-Balu-Buriganga river systems, Dhaka, Bangladesh. Science of the Total Environment **703,** 134760. https://doi.org/10.1016/j.scitotenv.2019.134760

Islam GMR, Khan FE, Hoque MM, Jolly YN. 2014b. Consumption of unsafe food in the adjacent area of Hazaribag tannery campus and Buriganga River embankments of Bangladesh: heavy metal contamination. Environmental monitoring and assessment **186(11),** 7233-7244. https://doi.org/10.1007/s10661-014-3923-2

Asaduzzaman M, Hasan I, Rajia S, Khan N, Kabir KA. 2016. Impact of tannery effluents on the aquatic environment of the Buriganga River in Dhaka,

Bangladesh. Toxicology and Industrial Health **32(6),** 1106-1113.
https://doi.org/10.1177/0748233714548206

Islam MM, Rahman SL, Ahmed SU, Haque MKI. 2014c. Biochemical characteristics and accumulation of heavy metals in fishes, water and sediments of the river Buriganga and Shitalakhya of Bangladesh. Journal of Asian scientific research **4(6),** 270.

Islam MM, Karim M, Zheng X, Li X. 2018b. Heavy metal and metalloid pollution of soil, water and foods in Bangladesh: A critical review. International Journal of Environmental Research and Public Health **15(12),** 2825.
https://doi.org/10.3390/ijerph15122825

Islam MS, Afroz R, Mia MB. 2019. Investigation of surface water quality of the Buriganga river in Bangladesh: Laboratory and spatial analysis approaches. Dhaka University Journal of Biological Sciences **28(2),** 147-158.
https://doi.org/10.3329/dujbs.v28i2.46501

Ahmed K, Das M, Islam MM, Akter MS, Islam S, Al-Mansur MA. 2011. Physico-chemical properties of tannery and textile effluents and surface water of River Buriganga and Karnatoli, Bangladesh. World Applied Sciences Journal **12(2),** 152-159.

Ahmed MK, Baki MA, Islam MS, Kundu GK, Habibullah-Al-Mamun M, Sarkar SK, Hossain MM. 2015. Human health risk assessment of heavy metals in tropical fish and shellfish collected from the river Buriganga, Bangladesh. Environmental science and pollution research **22(20),** 15880-15890.
https://doi.org/10.1007/s11356-015-4813-z

Ahmed MK, Baki MA, Kundu GK, Islam MS, Islam MM, Hossain MM. 2016. Human health risks from heavy metals in fish of Buriganga river, Bangladesh. SpringerPlus **5(1),** 1-12.
https://doi.org/10.1186/s40064-016-3357-0

Reza A, Yousuf TB. 2016. Impacts of waste dumping on water quality in the Buriganga River, Bangladesh and possible mitigation measures. Journal of the Environment **11(1),** 35-40.
https://www.researchgate.net/publication/309310989.

Hoque MMM, Deb PP. 2016. Assessment of Physicochemical Water Quality Parameters and Heavy Metals Concentration in Water Samples from Buriganga River Adjacent to Dhaka City. Journal of Environmental Science and Natural Resources **9(2),** 97-104.
https://doi.org/10.3329/jesnr.v9i2.32164

Das M, Ahmed MK, Islam MS, Islam MM, Akter MS. 2011. Heavy metals in industrial effluents (Tannery and Textile) and adjacent rivers of Dhaka city, Bangladesh. Terrestrial and Aquatic Environmental Toxicology **5(1),** 8-13.

Khan MT, Biswas S. 2013. Investigation of heavy metal pollution in peripheral river water around Dhaka city. Pensee **75(10).**

Fatema K, Begum M, Al Zahid M, Hossain ME. 2018. Water quality assessment of the river Buriganga, Bangladesh. Journal of Biodiversity Conservation and Bioresource Management **4(1),** 47-54.
https://doi.org/10.3329/jbcbm.v4i1.37876

Ahsan SN. 2019. State of Water Pollution from Industrial Effluents in Bangladesh. Department of Environment, Bangladesh.

Kibria MG, Kadir MN, Alam S. 2015. Buriganga river pollution: its causes and impacts. In International conference on recent innovation in civil engineering for sustainable development, p 323-328.
https://www.researchgate.net/publication/287759957.

Choudhury MR, Islam MS, Ahmed ZU, Nayar F. 2016. Phytoremediation of heavy metal contaminated buriganga riverbed sediment by Indian mustard and marigold plants. Environmental Progress & Sustainable Energy **35(1),** 117-124. https://doi.org/10.1002/ep.12213

Saha PK, Hossain MD. 2011. Assessment of heavy metal contamination and sediment quality in the Buriganga River, Bangladesh. In 2nd international conference on environmental science and technology, IPCBEE, Singapore, p 26-28.