Research Journal of

Environmental Toxicology

ISSN 1819-3420

Academic
Journals Inc.

www.academicjournals.com

OPEN ACCESS Research Journal of Environmental Toxicology

ISSN 1819-3420
DOI: 10.3923/rjet.2018.18.23

Research Article
Carcinogenic and Non-carcinogenic Human Health Risk from Exposure to Heavy Metals in Surface Water of Padma River

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Abstract
Background and Objective: Surface water of Bangladeshi is now in a great concern through the contamination with heavy metals. Therefore, characterization of carcinogenic and non-carcinogenic health risk due to the use of this water is a demand of time. This study aimed to determine levels of heavy metals in surface water of Padma river (Northwestern Bangladesh) and to estimate human health risk associated with the use of water from this River via. ingestion and dermal exposure. **Materials and Methods:** 4 study sites in Padma river were selected for sampling during 3 study seasons (summer, monsoon and winter). The concentration of heavy metals (Cr, Pb, Ni, Cd, As, Cu and Zn) of the water samples were determined by Flame Atomic Absorption Spectrometer. **Results:** The mean concentration of metals investigated during the study period was Cr (0.038 mg L^{-1}), Pb (0.009 mg L^{-1}), Ni (0.004 mg L^{-1}), Cd (0.005 mg L^{-1}), As (0.003 mg L^{-1}), Cu (0.012 mg L^{-1}) and Zn (0.030 mg L^{-1}). The Hazard Quotient (HQ) and Hazard Index (HI) for both the child and the adult via. ingestion and dermal contact were less than one except for the child, whereas HI value via. ingestion was greater than one indicating an unacceptable risk of non-carcinogenic effects on health. Carcinogenic Risk (CR) due to use of water of Padma river ranged between 4.63×10^{-7} (Pb) to 1.75×10^{-4} (Cd) and 4.96×10^{-7} (Pb) to 1.87×10^{-4} (Cd) for the child and the adult, respectively. The cumulative cancer risk for both the child and the adult indicates medium-high risk for the studied metals according to the Delphi method. **Conclusion:** The health risk assessment of the heavy metals content in Padma river indicating minor adverse health risk effects but suggests caring about the risk status and to its remediation process.

Key words: Heavy metals, surface water, human health risk, Padma river, carcinogenic risk

Citation: Md. Ayenuddin Haque, Md. AbuSayed Jewel, Zannatul Ferdoushi, Moni Begum, Md. Iqbal Husain and Subrata Mondal, 2018. Carcinogenic and non-carcinogenic human health risk from exposure to heavy metals in surface water of Padma river. Res. J. Environ. Toxicol., 12: 18-23.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Metals have a serious toxic effect on human health and their long-term persistence in the aquatic environment make it more hazardous for local inhabitants[1]. Only trace concentrations of heavy metal sometimes known to cause a carcinogenic and non-carcinogenic effect in the human body[2]. Carcinogenic risks are expressed as the probability that an individual will develop cancer over a lifetime of exposure, wherein non-carcinogenic risk body can sometimes able to cope with or recover from the exposure[3]. Arsenic, cadmium, chromium, copper, lead, nickel and zinc are the most frequent heavy metals found in the surface water of rivers[4]. These metals come from industrial effluents, urban run-off, sewage discharge and insect or disease control agents and from many others sources[5]. Zhang *et al*.[6] revealed that these toxicants from river water can entire into the nearby groundwater recharge system and can cause potential health risk through ingestion, inhalation and dermal contact. Therefore, assessment and management of such risk due to exposure to such contaminants needs to be provided with the greatest priorities for sustainable development of health status of local communities.

The Padma river, which flows along the side of Rajshahi city (where it is known as Padma river) is very important for its multidimensional use as fishery, domestic and recreational activities[7]. A large number of fishermen and local inhabitants use the water of the river for various domestic purposes and sometimes for drinking and bathing. However, in recent years, the continuous increase of urbanization makes the aquatic ecosystem of this river frequently an ultimate recipient of pollutants. As Rajshahi city does not possess any sewerage system, the surface run-off drains essentially act as a reservoir which taking the overflow from septic tanks and other waste from other commercial units and ultimately discharged these into this river. Therefore, the water quality deterioration due to contamination of heavy metals is a common phenomenon in this river[8].

However, there is no data available on the severity of heavy metal contamination and the extent of the associated health risk in the surface water of Padma river (Northwestern Bangladesh). Therefore, this paper studied the influence of heavy metal contamination on fishermen communities and other local people inhabiting along the river bank to assess the non-carcinogenic and carcinogenic risk.

MATERIALS AND METHODS

Sampling and analytical method: A total of 12 water samples were collected from 4 study sites (T-dam, Padma garden, I-dam and Talaimari point from latitude of N-24°21'42.41" to N-24°21'29.30" and longitude of E-88°34'31.18" to E-88°37'30.55") in Padma river (Fig. 1) during 3 study seasons (summer, monsoon and winter) from March, 2017 to February, 2018. After collecting the samples from 10 cm below the water surface it was stored in 100 mL polyethylene bottles. About 10% HNO_3 was used to soak the sampling bottles prior to use these bottles for sample collection. This soaking was due to avoid precipitation of heavy metals in the bottles. An icebox was used to bring the samples to the laboratory, where they were stored at 4°C in a refrigerator for further analysis. A freshly prepared aqua regia (1:3 HNO_3: HCl) was used for the wet digestion of the samples. The digestion of samples was carried out in a block digester. The determination of heavy metals (Cr, Pb, Ni, Cd, As, Cu and Zn) concentration in the water samples were carried out by the use of Flame Atomic Absorption Spectrometer (Shimadzu, AA-6800) in the central laboratory of University of Rajshahi, Rajshahi, Bangladesh.

Human health risk assessment indices: Human health risk assessment indices were calculated for both non-cancer and cancer risks from ingestion and absorption of studied metals for the child and the adults. The Average Daily Dose (ADD) intake was calculated according to Iqbal and Shah[9] following the Eq. 1 and 2:

$$ADD_{ingestion} = C_w \times IR \times ED \times EF/BW \times AT \quad (1)$$

where, $ADD_{ingestion}$ (mg kg^{-1} day^{-1}) represents the exposure dose through ingestion, C_w is the mean concentration of the trace elements in water (mg L^{-1}); IR is both direct and indirect intake rate of drinking water (1 L day^{-1} for the child and 2 L day^{-1} for the adult), ED is the exposure duration (6 years for the child and 30 years for the adult), EF is the exposure frequency to pollutants (365 days/year), BW represents the total body weight (15 kg for the child and 70 kg for the adult), AT is equal to ED$\times$365 for non-carcinogenic risk, which is 2190 and 10950 for the child and the adult, respectively. For carcinogenic risk, AT is the average life expectancy of people, which is 70$\times$365 = 25550 for both the child and the adult:

$$ADD_{dermal} = C_w \times SA \times Kp \times ET \times EF \times ED \times CF/BW \times AT \quad (2)$$

where, ADD_{dermal} (mg kg^{-1} day^{-1}) is the average daily dose of heavy metal through dermal absorption. SA is the exposure area of skin (6600 cm^2 for the child and 18,000 cm^2 for the adults); Kp is the dermal permeability coefficient of pollutants in water (cm h^{-1}) in this study, 0.002 cm h^{-1} for Cr, 0.0001 cm h^{-1} for Pb, 0.0002 cm h^{-1} for Ni, 0.001 cm h^{-1} for

Fig. 1: Location of the study area
Source: Modified from Google Earth-2017

Cd, As and Cu and 0.0006 cm h^{-1} for Zn; ET is the exposure time (h day^{-1}), in this study, ET is 0.6 h day^{-1}; CF is unit conversion factor 0.001 L cm^{-3} [10].

The health risk from river water ingestion and dermal absorption was assessed in relation to its non-carcinogenic hazard quotient effects based on the Eq. 3:

$$\text{Hazard quotient } (HQ_{ingestion/dermal}) = \frac{ADD_{ingestion/dermal}}{RfD_{ingestion/dermal}} \tag{3}$$

where, $ADD_{ingestion/dermal}$ and $RfD_{ingestion/dermal}$ are in mg kg^{-1} day^{-1}. RfD (reference dose) was taken from the United States Environmental Protection Agency, The Integrated Risk Information System[11]. According to Lim *et al.*[12] HQ value greater than 1.0 indicates an unacceptable risk of adverse non-carcinogenic effects and HQ value less than 1.0 indicates an acceptable level of risk for human health. However, the potential risk to human health through the mixture of all chemicals was assessed by[13] Eq. 4:

$$\text{Hazard index}(HI_{ingestion/dermal}) = \sum_{i=1}^{n} HQ_{ingestion/dermal} \tag{4}$$

where, $HI_{ingestion/dermal}$ is potential hazard through ingestion and dermal absorption of heavy metals, $HQ_{ingestion/dermal}$ is the hazard quotient through ingestion or dermal absorption, i is the pathways of exposure; n is the kinds of trace elements; HI>1 means an unacceptable risk and HI<1 means an acceptable level of risk of non-carcinogenic effects on health[12].

The carcinogenic risk is the multiplication of ADD (mg kg^{-1} day^{-1}) and Cancer Slope Factor (CSF) (mg kg^{-1} day^{-1}). Cancer risk due to ingestion of contaminated water with heavy metals was calculated according to Wongsasuluk *et al.*[14] following the Eq. 5:

$$CR_{ingestion} = ADD_{ingestion} \times CSF \tag{5}$$

where, $CR_{ingestion}$ is cancer risk through ingestion of heavy metals contaminated water, $ADD_{ingestion}$ is average daily dose (mg kg^{-1} day^{-1}) of heavy metals and CSF is cancer slop factor (mg kg^{-1} day^{-1}). During the present study, the carcinogenic risk values were calculated for Cr, Pb and Cd according to Masok *et al.*[15], Ni according to Koki *et al.*[16] and As according to USEPA[17]. Risks values rated as 7 levels based on the Delphi method according to the study of Li *et al.*[18] are shown in Table 1.

Statistical analysis: The calculation of risk indices was done by Microsoft Office Excel, version 2010 and descriptive statistics was performed by IBM SPSS software package (version 20.0, USA).

RESULT AND DISCUSSION

Concentration of heavy metals in surface water: Descriptive statistics of heavy metals in surface water of Padma river is shown in Table 2. The average concentration of studied metals followed the decreasing order of: Cr (0.038 mg L^{-1})> Zn (0.030 mg L^{-1})>Cu (0.012 mg L^{-1})>Pb (0.009 mg L^{-1})> Cd (0.005 mg L^{-1})>Ni (0.004 mg L^{-1})>As (0.003 mg L^{-1}). Therefore, it was observed that Cr is the most concentrated

Table 1: Levels and values of assessment standards according to Li *et al.*[18]

Risk grades	Range of risk value	Acceptability
Grade I (Extremely low risk)	$<10^{-6}$	Completely accept
Grade II (Low risk)	10^{-6}, 10^{-5}	Not willing to care about the risk
Grade III (Low-medium risk)	10^{-5}, 5×10^{-5}	Do not mind about the risk
Grade IV (Medium risk)	5×10^{-5}, 10^{-4}	Care about the risk
Grade V (Medium-high risk)	10^{-4}, 5×10^{-4}	Care about the risk and willing to invest
Grade VI (High risk)	5×10^{-4}, 10^{-3}	Pay attention to the risk and take action to solve it
Grade VII (Extremely high risk)	$>10^{-3}$	Reject the risk and must solve it

Table 2: Descriptive statistics of heavy metals (mg L^{-1}) in surface water of Padma river

					Sample over standard (%)		Standard/guidelines	
Metals	Min	Max	Mean	SD	DWSB	WHO	DWSB	WHO
Cr	0.002	0.102	0.038	0.043	25.00	25.00	0.05	0.05
Pb	0.001	0.025	0.009	0.009	0.00	0.00	0.05	0.07
Ni	ND	0.006	0.004	0.002	0.00	0.00	0.10	0.01
Cd	ND	0.014	0.005	0.004	33.33	50.00	0.01	0.00
As	ND	0.006	0.003	0.002	0.00	0.00	0.05	0.01
Cu	ND	0.045	0.012	0.013	0.00	0.00	1.00	2.00
Zn	ND	0.110	0.030	0.035	0.00	0.00	5.00	0.50

Min: Minimum, Max: Maximum, SD: Standard deviation, ND: Note detected, DWSB: Drinking water standard of Bangladesh, WHO: World Health Organization

metal in the surface water of the Padma river. According to Eastmond *et al.*[19] high concentration of Cr (III) in the cell can cause DNA damage; therefore, a long-term drinking of Cr contaminated water of the Padma River can be a threat to human health. During the study period, Zn was found to be the second most abundant metal of the samples of surface water studied. Prasad[20] stated that acute adverse effects of high intake of zinc include nausea, vomiting, loss of appetite, abdominal cramps diarrhea and headache, while Hambidge and Krebs[21] considered Zn as an essential mineral for biological and public health organisms. The high contamination of Cr and Zn observed in this river water may be attributed to contaminants from household activities and other small industries located in the Rajshahi city area. However, the average concentrations of all the studied metals were lower than the Drinking Water Standard of Bangladesh (DWSB) (DoE)[22,23] and World Health Organization (WHO)[24,25]. During the study period, among the 12 water samples, only 25.00% of samples exceeded DWS Bstandard of DoE[22,23] and WHO[24,25] for Cr. While for Cd, 33.33% samples exceeded the drinking water standard of DoE[22,23] and 50.00% for WHO[24,25].

Human health risk assessment to heavy metals in surface water: The carcinogenic and non-carcinogenic health risk owing to ingestion and dermal exposure to the studied heavy metals for both the child and the adult are shown in Table 3 and 4, respectively. Average levels of non-carcinogenic risk (HQ) in surface water were observed in the descending order of: Cr>Cd and As>Pb>Cu>Ni>Zn via. ingestion and Cr>Cd>As >Pb>Cu>Zn>Ni via. dermal contact for the child (Table 3). In case of the adult, this trend was Cd and As>Pb>Cu>Ni>Zn>Cr via. ingestion and Cr>Cd>As>Pb>Cu>Zn>Ni via. dermal contact (Table 4). According to Liang *et al.*[26] the heavy metal pollutant can pose potential adverse health effects when the HQ value of a metal is higher than 1. In the present study, the HQ values for each metal were all lower than 1. Therefore, the result of the present study indicates that, the studied metals were not capable individually to pose any adverse health effect through ingestion or bathing in the water of Padma river. Hazard index (HI) of selected heavy metals was above 1 for the child via. ingestion pathway (2.65), therefore the studied metals have a cumulative potential to cause adverse health to the child through direct ingestion of water. The HI value obtained via. dermal contact (0.32) for the child (Table 3) and via. ingestion (0.39) and dermal contact (0.19) for the adult were below the risk value (1) (Table 4). Lifetime cancer risk calculated during the present study through ingestion of Cr, Pb, Ni, Cd and As was 1.09×10^{-4}, 4.63×10^{-7}, 3.89×10^{-5}, 1.75×10^{-4} and 2.57×10^{-5} for the child (Table 3) and 1.17×10^{-4}, 4.96×10^{-7}, 4.17×10^{-5}, 1.87×10^{-4} and 2.76×10^{-5} for the adult (Table 4), respectively. The cumulative cancer risk of studied metals was 3.49×10^{-4} for the child and 3.74×10^{-4} for the adult. These results indicated higher cancer risks for the adults than the child. The evaluation of cancer risks from exposure to Cr, Cd and cumulative cancer risk value in the present study were found to be above the acceptable[17] cancer health risk range of 1.00×10^{-6} to 1.00×10^{-4} (i.e., 1 case of cancer per every 1,000,000 to 1 case of cancer per every 10,000). According to Pawelczyk[27] a risk of 1.00×10^{-3} indicated the risk will absolutely require protective

Table 3: Hazard Quotient (HQ) Hazard Index (HI) and Cancer Risk (CR) of heavy metals for the child in surface water from Padma river

				Exposure assessment: $ADD_{ingestion}$			Non-carcinogenic risk assessment			
Metals	$RfD_{ingestion}$ (mg kg^{-1} day^{-1})	RfD_{dermal} (mg kg^{-1} day^{-1})	$CSF_{ingestion}$ (mg kg^{-1} day^{-1})	Non-cancer	Cancer	ADD_{dermal}	$HQ_{ingestion}$	Hq_{dermal}	Cancer risk assessment	Risk grades
Cr	3.00×10^{-3}	7.50×10^{-5}	0.500	2.53×10^{-3}	2.17×10^{-4}	2.01×10^{-5}	8.43×10^{-1}	2.68×10^{-1}	1.09×10^{-4}	Grade-V
Pb	1.40×10^{-3}	4.20×10^{-4}	0.009	6.00×10^{-4}	5.14×10^{-5}	2.38×10^{-7}	4.29×10^{-1}	5.67×10^{-4}	4.63×10^{-7}	Grade-I
Ni	2.00×10^{-2}	5.40×10^{-3}	1.700	2.67×10^{-4}	2.29×10^{-5}	2.11×10^{-7}	1.34×10^{-2}	3.91×10^{-5}	3.89×10^{-5}	Grade-III
Cd	5.00×10^{-4}	2.50×10^{-5}	6.100	3.33×10^{-4}	2.86×10^{-5}	1.32×10^{-6}	6.67×10^{-1}	5.28×10^{-2}	1.75×10^{-4}	Grade-V
As	3.00×10^{-4}	2.85×10^{-4}	1.500	2.00×10^{-4}	1.71×10^{-5}	7.92×10^{-7}	6.67×10^{-1}	2.78×10^{-3}	2.57×10^{-5}	Grade-III
Cu	4.00×10^{-2}	6.00×10^{-3}	-	8.00×10^{-4}	6.86×10^{-5}	3.17×10^{-6}	2.00×10^{-2}	5.28×10^{-4}	-	
Zn	3.00×10^{-1}	6.00×10^{-2}	-	2.00×10^{-3}	1.71×10^{-4}	4.75×10^{-6}	6.67×10^{-3}	7.92×10^{-5}	-	
							HI = 2.65	HI = 0.32	$\Sigma CR = 3.49\times10^{-4}$	Grade-V

Table 4: Hazard Quotient (HQ) Hazard Index (HI) and Cancer Risk (CR) of heavy metals for the adult in surface water from Padma river

				Exposure assessment: $ADD_{ingestion}$			Non-carcinogenic risk assessment			
Metals	$RfD_{ingestion}$ (mg kg^{-1} day^{-1})	RfD_{dermal} (mg kg^{-1} day^{-1})	$CSF_{ingestion}$ (mg kg^{-1} day^{-1})	Non-cancer	Cancer	ADD_{dermal}	$HQ_{ingestion}$	HQ_{dermal}	Cancer risk assessment	Risk grades
Cr	1.50	7.50×10^{-5}	0.500	5.42×10^{-4}	2.33×10^{-4}	1.17×10^{-5}	3.61×10^{-4}	1.56×10^{-1}	1.17×10^{-4}	Grade-V
Pb	1.40×10^{-3}	4.20×10^{-4}	0.009	1.29×10^{-4}	5.51×10^{-5}	1.39×10^{-7}	0.92×10^{-1}	3.30×10^{-4}	4.96×10^{-7}	Grade-I
Ni	2.00×10^{-2}	5.40×10^{-3}	1.700	5.71×10^{-5}	2.45×10^{-5}	1.23×10^{-7}	2.86×10^{-3}	2.28×10^{-5}	4.17×10^{-5}	Grade-III
Cd	5.00×10^{-4}	2.50×10^{-5}	6.100	7.14×10^{-5}	3.06×10^{-5}	7.71×10^{-7}	1.43×10^{-1}	3.08×10^{-2}	1.87×10^{-4}	Grade-V
As	3.00×10^{-4}	2.85×10^{-4}	1.500	4.29×10^{-5}	1.84×10^{-5}	4.63×10^{-7}	1.43×10^{-1}	1.62×10^{-3}	2.76×10^{-5}	Grade-III
Cu	4.00×10^{-2}	6.00×10^{-3}	-	1.71×10^{-4}	7.35×10^{-5}	1.85×10^{-6}	4.28×10^{-3}	3.08×10^{-4}	-	
Zn	3.00×10^{-1}	6.00×10^{-2}	-	4.29×10^{-4}	1.84×10^{-4}	2.78×10^{-6}	1.43×10^{-3}	4.63×10^{-5}	-	
HI							HI = 0.39	HI = 0.19	$\Sigma CR = 3.74\times10^{-4}$	Grade-V

measures and therefore, compared to the above range of risk, the results of the present study implies that a lifetime exposure to present heavy metal concentration poses cancer risks for both the child and the adults. The risk grade of studied metals was fall in grade-V for Cr and Cd, grade-I for Pb and grade-III for both Ni and As for both the child and the adult. However, the cumulative cancer risk grade was V for both the child and the adult too.

CONCLUSION

Now-a-days, an important issue in environmental studies is heavy metal pollution. A significant amount of metal-containing drinking water might be harmful to human health and results in several types of cancers indeed. According to health risk assessment of the heavy metals content in Padma river, HQ value of seven kinds of heavy metal was less than 1 indicating no health risk effects, while according to cancer risk standard, the river water was fall in the medium-high risk category. Data of the present study will be valuable for management of the sustainable use of water of Padma river regarding maintenance of public health.

SIGNIFICANCE STATEMENT

The study showed the effect of contaminated surface water with heavy metals on carcinogenic and non-carcinogenic human health risk of Padma river. Although several studies have been conducted on contamination of surface water with heavy metals in Bangladesh, the human health risk assessment for evaluating the relationship between the environment and public health are still lacking. It is hoped that this study will provide a platform for researchers to evaluate the health risk of human contaminated by heavy metal polluted surface water of the river.

ACKNOWLEDGMENT

The authors would like to thank Government of the People Republic of Bangladesh for providing available funding through National Science and Technology (NST) (Grand No. 39.00.0000.012.20.004.16-439) fellowship for Master's Thesis work and Department of Environmental Science, University of Rajshahi for approving this study.

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