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Exposure of Trace Metals and Their Effects on Human Health: A Case Study for Groundwater in Part of the Ganges Basin Areas

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Abstract: As technology continues to develop, the level of trace metals present in potable groundwater is still not within the standard guidelines as set by the monitoring authorities. The overall objective of this study was to assess the degree of metal pollution and human health risk for the exposure of trace metals through drinking raw groundwater. A total of 40 groundwater samples were collected and analyzed for some trace metals by the atomic absorption spectrophotometer. The study evaluated the degree of trace metal contamination with carcinogenic and non-carcinogenic risks through computed well-recognized methods. The metal pollution index illustrated that about 75% of the samples fell under a category of a high degree of contamination. The results showed that the carcinogenic risk values of Pb, Cd, Cr and Ni were found to be 1.51E-06 to 1.07E-04, which were within the acceptable range of 1.0E-06–1.0E-04. The non-carcinogenic hazard quotient (HQ) of the adult group exceeded the limit (HQ_{total}>1) for the metals of Mn and Co. But the quotient value was found higher for metals Mn, Co, Pb, Cd and Cu in the child group. The values of the total non-carcinogenic hazard index (HI_{total}) in 90% of sampling sites for the adult group were below 1, but, for the child group, the value was found higher than 1 with an average value of 4.25. Among the analyzed trace metals, the concentration of Fe, Mn, Pb and Ni in 50-100% of water samples crossed the global and national guideline limit. The study observed that the total hazard index value for the child was nearly 5-fold higher than the adult group. Hence, the child group posed a serious health risk than the adult group.

Key words: Carcinogenic Risk · Drinking Water · Metal Pollution Index · Non-Carcinogenic Risk · Trace Metal Toxicity

INTRODUCTION

Metal contaminated groundwater has delirious effects on the human body of causation acute and chronic toxicities. This water is an important natural resource for domestic, industrial and irrigation purposes. Safe drinking water is essential for healthy living. About 90% of the population of a developing country, like Bangladesh, has access to drinking water from shallow tube wells [1, 2]. Now a day, metal pollution in the groundwater has concerned global attention due to its abundance, serious toxicity and persistence. Several pollution sources, including, industrial effluents, mining and smelting, urban waste, atmospheric depositions in soil and agrochemicals are degrading the groundwater through their growing activities [3-5]. The presence and circulation of trace metals in soils are influenced mainly by the parent material, soil properties, metal speciation and climatic conditions. The toxic trace metals can affect the mental and central nervous system, blood composition, lungs, kidneys, liver and other important organs in the human body [5]. To keep good human health, the US-EPA [6], WHO [7] and PHED [8] have settled standard values for adaptable the maximum threshold levels (MTLs) in drinking water for trace metals. Also, health risk assessment (HRA) and several models were recognized by local and global authorities for the intake of trace metals through water consumption.

Several studies have explored the incidence of trace metals in the groundwater of Bangladesh. Mostafa *et al.* [2], Sarkar *et al.* [9]; and Saha and Zaman [10] measured the excess lead (Pb) in groundwater in the northern part of the country. Except for coastal areas, a higher concentration (over 5 mg/L) of iron (Fe) in potable and irrigation water is the greatest environmental threat of almost the entire country [11-14]. Other trace metals like

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manganese (Mn) and arsenic (As) were observed with higher levels than the guideline value in the selected area's groundwater [4, 15-18]. Except those, other trace metals concentration was almost within the safe ranges in the countrywide groundwater [18, 19].

Numerous water quality indices such as heavy metal pollution index (HMPI), degree of contamination (C_d) and heavy metal evaluation index (HMEI) have been projected for the assessment of water quality considering trace metal parameters [14, 20-22]. This study was considered those indices as supporting factors for the evaluation of the health risk assessment (HRA) of groundwater in the study region. The HRA is well-defined as a procedure used to estimate health effects over time that might result from the intake of toxic substances. It is classically achieved in 4 steps: risk findings, assessment of toxicity (dose-response), exposure evaluation and risk categorizations. The major ways for heavy metal consumption in the human body are oral, dermal and nasal through drinking water, foodstuff and dust in which ingestion and dermal absorption are common pathways [6]. The stage of hazard identification is used to establish a connection between the identification of carcinogenic and non-carcinogenic substances and their health impacts on inhabitants in the investigation area. Exposure assessment is used to evaluate the category and degree of exposure from the substances of probable concern that are permanently present or migrated from other locations. To measure the exposure, it is essential to estimate the chronic daily intake (CDI) of toxic chemicals via the drinking groundwater paths. Toxicity evaluation (dose-response) offered the connection between the degree of exposure and opposing health effects. For non-carcinogens, the dose-response calculation, reference doses (RfDs) were computed and for carcinogens, incremental slope factors (ISFs) were determined by the risk assessment information system (RAIS) [23]. The risk classification step creates all the info met in the 3 prior steps to calculate the likelihood that a theoretical exposure may harmfully influence human health. After computing the HRA, the results were then compared with the output of several recent investigations on that topic [e.g., 5, 24-28] which were conducted in various regions of the world.

The present study zone was part of the Ganges River basin, located in the middle-west zone of Bangladesh. The source of drinking water in this region is mostly raw groundwater [29]. In the Ganges River basin, the groundwater quality is poor in some areas due to pollution with high mineralization and the presence of some toxic elements [14, 30]. Therefore, suitable evaluation and reporting of groundwater quality are vital issues in the study area. The study provides vital information for groundwater quality indices and HRA that support the sustainability of drinking water management considering water demand and the safe environment.

MATERIALS AND METHODS

Sampling Station and Analysis: The sampling stations in the study area are located between north latitudes of 23°42' and 24°12' and east longitudes of 89°20'. The whole area of sampling places was 1652 km^2 and enclosed by the Padma River (Ganges River) and the extra three-branch rivers formed a large deltaic plain (Fig. 1). The total population of the study area is approximately two million and the groundwater is the single largest source of drinking and domestic purposes [14, 31]. This area is shielded by a subtropical climate with hot, rainy and humid summer seasons and distinct dry weather in the winter. A total of 1168 mm/y rainfall is received by the area [32].

Around the river basin areas, an overall of 40 sampling sites in the north-western part of Bangladesh (Fig. 1) was selected for collecting the samples through pre- (PRM) and post-monsoon (POM) time of year. As stated by the typical technique [31], pre-cleaned high-density polyethylene (HDPE) plastic flasks were used for the collection of shallower groundwater samples after pumping 3-5 min and preserved as per the recognized procedure. Trace metals were analyzed by an Atomic Absorption Spectrophotometer (Perkin-Elmer, Model 3110) and the US-APHA [33] procedures were followed at each stage of all the quantitative investigates. It was ensured the quality control in all analyses as specified by separate instruction manuals and more than 95% in confidence interval (*CI*) with the correlation factor, $r = \sim 1$ of individual calibration curves. The dataset of trace metals was used to evaluate the water suitability for drinking purposes through the following methods as concisely as possible.

Heavy Metal Pollution Indices: Three recognized methods, heavy metal evaluation index (HMEI), heavy metal potential index (HMPI) and degree of contamination (C_d) was assessed for their suitability for pollution monitoring of groundwater in parts of middle-east Bangladesh. The HMEI model gives the overall quality of the drinking groundwater concerning trace heavy metals [20] and it was computed by the Equation of (1):

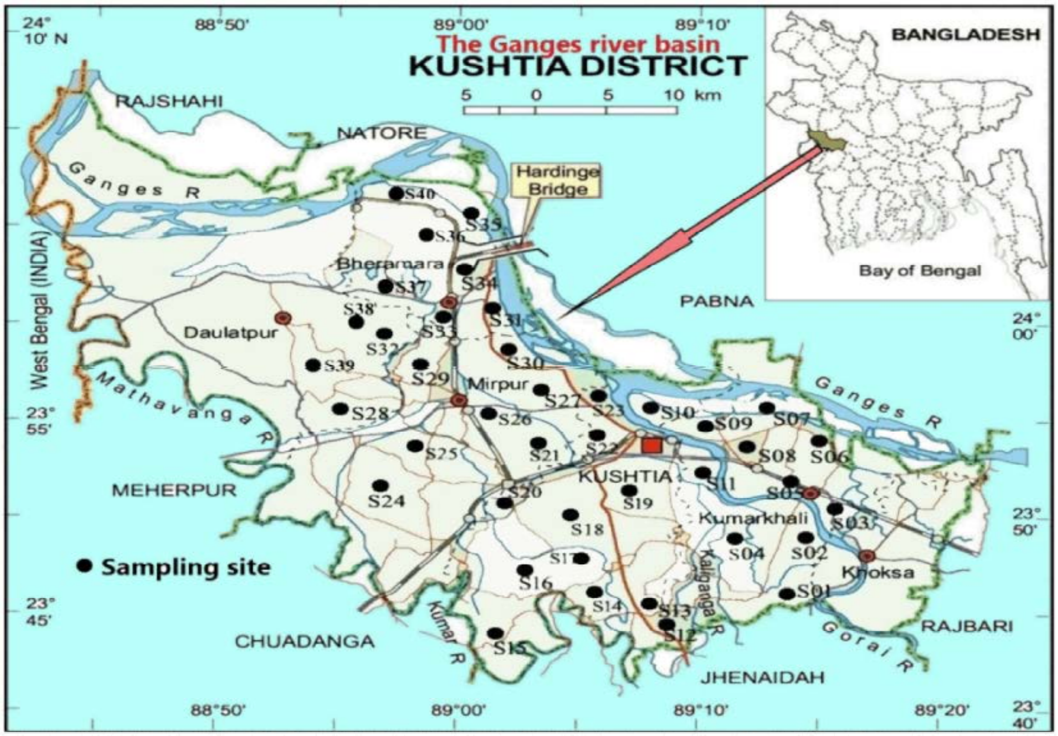

Fig. 1: Map of the sampling stations

$$HMEI = \sum_{i=1}^{n} \frac{H_m}{H_{MPC}} \tag{1}$$

where H_m is the measured value (mg/L) and H_{MPC} is the maximum permissible concentration (MPC) of ith metal parameters. The MPC values for analyzed metals were listed in Table 1. HMPI has been recognized by conveying the weightage (W_i) for the designated parameter and choosing the groundwater metal parameter on which the index must be based [29]. The score is closely 0 to 1 and its range exposes the consequence of individual water quality parameters. HMPI calculated by Equation (2) as follows:

$$HMPI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i} \tag{2}$$

The Q_i (sub-index value) is calculated by this Equation 3:

$$Q_i = \sum_{i=1}^{n} \frac{|Q_i - I_i|}{(S_i - I_i)} \times 100 \tag{3}$$

Here, S_i, O_i and I_i provided for the standard value, observed value and the ideal value (Table 1) of the ith metal parameter respectively. Lastly, the degree of contamination (C_d) model [34] was calculated with the following equation of 4:

Table 1: Standard values (S_i), Ideal values (I_i) and Max. admissible concentration (all are in mg/L) for the analyzed metals

Metal	W_i	S_i	I_i	MPC
B	0.000852	2.4	1.0	2.4
Fe	0.001855	1.0	0.3	1.0
Mn	0.005958	0.3	0.1	0.3
Cr	0.039977	0.05	0	0.05
Pb	0.202634	0.01	0	0.01
Co	0.045677	0.05	0	0.05
Ni	0.022053	0.1	0.07	0.1
Cd	0.674379	0.003	0	0.003
As	0.005260	0.01	0	0.01
Cu	0.001023	2.0	0.5	2.0
Zn	0.000682	3.0	0.5	3.0
	$\Sigma W_i = 1$			

$$C_d = \sum_{i=1}^{n} \frac{C_{ai}}{C_{ni}} - 1 \tag{4}$$

Here, $[(C_{ai}/C_{ni}) - 1]$ was denoted contamination factor in which C_{ai} and C_{ni} were the analyzed concentration and the maximum permitted concentration (MPC) of the ith parameter respectively.

Health Risk Assessment (HRA) for Human: Human health risk assessment is a multiple-step process counting collection and assessment of dataset, valuation of exposure, estimation of toxicity and risk classification.

Table 2: Key parameters for computing the health risks through oral and dermal pathways

Symbol	Exposure Route/Exposure Factor	Value	Reference/Source
IRW_a	Water ingestion rate for adult	2 L/day	Rani *et al.* [39]
IRW_c	Water ingestion rate for child	1 L/day	Harries and Harper [37]
IRW_{adj}	Age-adjusted water ingestion rate	2.229 L-year/kg-day	Eqn. 7
C_w	Contaminant conc. of each metal	(mg/L)	-
EF	Exposure frequency	365 days/year	Duggal *et al.* [5]
ED_a	Exposure duration for adult	70 year	Harries and Harper [37]
ED_c	Exposure duration for child	6 year	Harries and Harper [37]
BW_a	Bodyweight for adult	70 kg	Rani *et al.* [39]
BW_c	Bodyweight for child	15 kg	Harries and Harper [37]
AT_a	Average time for adult	25550 days	AT = EF × ED
AT_c	Average time for child	2190 days	AT = EF × ED
ET_a	Absorbed dose per event	0.58 hour/day	Eqn. 6
ET_c	Exposure time for child	1 hour/day	US-EPA [6]
ET_{adj}	Age-adjusted exposure time	0.616 hour/day	Eqn. 8
EV_a	Event frequency for adult	1 event/day	US-EPA [6]
EV_c	Event frequency for child	1 event/day	US-EPA [6]
SA_a	Skin surface area for adult	18000 cm^2	US-EPA [6]
SA_c	Skin surface area for child	6600 cm^2	US-EPA [6]
SA_{adj}	Age-adjusted skin surface area	19097 cm^2-yr/kg-day	Eqn. 8
CF	Conversion factor	0.001 L/cm^3	1L = 1000 cm^3
K_p	Permeability coefficient for each metal	COPC-specified (see Table 3)	USDOE [23]

Table 3: Values of RfD_{oral}, CSF_{oral} and GI_{ABS} for analyzed metals (US-DOE [23]; US-EPA (40])

Element	RfD_{oral} (mg/kg/day)	K_p (cm/hour)	CSF_{oral} (mg/kg/day)	Gastro-intestinal absorption factor (GI_{ABS})
B	2.00E-01	0.002	-	1
Fe	7.00E-01	0.005	-	1
Mn	4.60E-02	0.003	-	4.00E-02
Cr	1.50	0.002	4.10E-02	1.30E-02
Pb	3.50E-03	0.001	8.50E-03	1
Co	3.00E-04	0.001	-	1
Ni	2.00E-02	0.002	8.60E-04	4.00E-02
Cd	5.00E-04	0.001	6.10E-03	5.00E-02
Cu	4.00E-02	0.001	-	1
Zn	3.00E-01	0.006	-	1
As	3.00E-04	0.002	-	5.00E-01

In this study, the carcinogenic and non-carcinogenic hazards through oral and dermal pathways were evaluated distinctly. The dose acknowledged (chronic daily intake, $CDI_{nc\text{-}ca}$) was calculated by the Equations (5) to (8) which was taken from US-DOE Risk Assessment Information System [23] and US-EPA [35, 36] for two sub-resident groups of adults and children. Here, we stated only the calculated form of relevant equations and avoided any description or equation which have already been published.

For non-carcinogenic (nc) risk calculation;

$$CDI_{oral-nc} = \frac{C_w \times IRW \times EF \times ED}{BW \times AT} = C_w \times Factor\ A_{adult/child}\ mg/k/day \qquad (5)$$

where the calculated values of Factor A_{dult} and A_{child} are 0.0286 and 0.0667, respectively.

$$CDI_{derm-nc} = \frac{K_p \times C_w \times ET_a \times CF \times SA \times EF \times ED \times EV}{BW \times AT} = K_p \times Cw \times Factor\ B_{adult/child}\ mg/kg/day \qquad (6)$$

where the calculated values of Factor B_{adult} and B_{child} are 0.000149 and 0.00044, respectively (Table 2). The K_p values of each metal are recorded in Tables 3.

For carcinogenic (ca) risk calculation;

$$CDI_{oral-nc} = \frac{C_w \times IRW_{adj} \times EF}{AT} = C_w \times Factor\ C_{adult/child}\ mg/kg/day \qquad (7)$$

where water ingestion rate (age-adjusted), $IRW_{adj} = 2229\ L.\frac{yr}{kg}.day$ and, the calculated values of Factor C_{adult} and Factor C_{child} are 0.0318 and 0.2048, respectably (calculated by Table 2).

$$CDI_{derm-ca} = \frac{K_p \times C_w \times ET_{adj} \times CF \times SA_{adj} \times EF}{AT}$$
$$= K_p \times C_w \times Factor\ D_{adult/child}\ mg/kg/day \qquad (8)$$

were skin surface area (age-adjusted), SA_{adj} =19097.2 cm^2.day.yr/kg; and exposure time, ET_{adj} = 0.615 $hr.day^{-1}$. The calculated values of Factor D_{adult} and Factor D_{child} are 0.0002 and 0.002, respectively (calculated by Table 2). All factors/parameter values (Equation 5 to 8) are composed of the literature of Duggal *et al.* [5, 38]; US-EPA [6]; Harries and Harper [37]; and Rani *et al.* [39]. Assessing the hazard quotient (HQ) was used for the evaluation of non-carcinogenic risks. To get the HQ_{oral} and HQ_{derm} values, the assessed CDIs for individual metal were divided by the own reference dose (RfD); and RfD with gastro-intestinal absorption factor (GI_{ABS}), respectively (Table 3).

In the human body, a combination of non-carcinogenic risks across diverse intake pathways can be got from the total HQ value of an individually contact way for a trace metal to yield the screening level hazard index (HI) (Equation 9).

$$HI = \sum_{i=1}^{n} HQ_i \qquad (9)$$

The potential incremental lifetime cancer risks (ILCRs) for oral and dermal water exposure of Cr, Pb, Ni and Cd were calculated by Equations 10 and 11 with the equivalent cancer slope factors (CSFs) at a 95% confidence limit [23, 40, 41]. The prescribed CSF value of these metals was included in Table 2. Lastly, the total incremental lifetime cancer risks ($ILCR_{total}$) were considered by adding the ILCRs through oral and dermal absorption routes.

$$ILCR_{oral} = CDI_{oral-ca} \times CSF_{oral} \qquad (10)$$

$$ILCR_{derm} = CDI_{derm-ca} \times \frac{CSF_{oral}}{GI_{ABS}} \qquad (11)$$

RESULTS AND DISCUSSION

Generally, the local geology, atmospheric deposition, agrochemicals leaching, overexploitation, etc., were the major causes of toxic metals in groundwater [42, 43]. The concentration of eleven (11) trace elements in shallow groundwater and their respective guideline values were stated in Table 3. The average concentrations of Fe (7.645 mg/L) and Mn (2.885 mg/L) exceed in 87.5% and 82.5% of samples from the WHO guideline value 0.3 and 0.4 mg/L respectively. Another two metals Pb and Ni crossed the standard concentration in 50% of samples (Table 4). The concentration of other metals (B, Cr, Co, Cd, As, Cu and Zn) is within the safe ranges in an average of 80% of samples. So, regarding trace metal content, the quality of groundwater for drinking purposes is not enough good. Previous studies [14, 31, 44] were showed that the maximum water samples in the study area are acidic (pH<7), it is one of the major causes of excess dilution of those metals containing mixed rocks such as (Fe, Ni)O(OH), (Co, Fe)AsS, $ZnCrO_4$, $CuFeS_2$, $(Fe, Zn)_6Sb_2S_9$, etc. in aquifer basement [45]. The same studies revealed that the metal concentration mostly depends on the water depth and the concentrations of maximum trace metals in shallower levels are containing higher concentrations than the deeper aquifers.

The elevated loads of metals in groundwater depend on various physical, lithological, chemical and bacteriological factors in sedimentary levels in aquifers. Several reports showed that metal ions in aquifers may be derived from the mineral and soils [18, 30]. The study area was an agrarian zone and heavily irrigated using groundwater. There was no industrial plant is situated in the study area or neighboring areas. So, no industrial source was available but agrochemicals were the only anthropogenic cause of trace metal contamination in the groundwater of the study area. Besides, several studies assumed that the trace metal loading in aquifers occurred by local geogenic activities, which are positively influenced by heavy water mining [19, 47-49]. Also, based on the geological formation of the study area, it contains the coarse sandy alluvial lithology and the deltaic flood plain land. So it was thought to be porous and permeable enough to permit the passageway of the trace metal-laden water into the aquifer basement [50]. Therefore, the geogenic source is the key factor to increase the trace metal concentration in groundwater aquifers except for very few anthropogenic sources.

Heavy Metal Pollution Indices: Some water quality indices were driven by trace metal load in water like heavy metal pollution index (HMPI), heavy metal evaluation index (HMEI) and degree of contamination (C_d) was computed of forty (40) groundwater samples and the values of these indices are shown in Table 5. The study considered the average value of metal concentration in both pre-monsoon and post-monsoon periods. Regarding these documentation methods, the results of Table 5 revealed

Table 4: Statistics of trace metal composition in groundwater during the PRM and POM seasons and respective guideline value

	Pre-monsoon, PRM (*n* = 40)		Post-monsoon, POM (*n* = 40)						
Parameter*	Mean	±SD	Mean	±SD	Av. value of both seasons	%Samples exceed the WHO std.	WHO (2011)	USEPA (2011)	DPHE[a] (2017)
B	0.202	0.314	0.223	0.343	0.213	0	2.4	None	1.0
Fe	7.18	2.57	8.11	3.12	7.645	87.5	0.3	0.3	0.3-1.0
Mn	2.66	0.59	3.11	0.61	2.885	82.5	0.4	0.05	0.1
Cr	0.05	0.09	0.05	0.08	0.050	25	0.05	0.1	0.05
Pb	0.08	0.03	0.07	0.04	0.075	52.5	0.01	0.015	0.05
Co	0.05	0.05	0.06	0.07	0.055	30	0.05	None	None
Ni	0.183	0.01	0.191	0.01	0.187	57.5	0.1	0.1	0.1
Cd	0.01	0.02	0.012	0.019	0.011	22.5	0.003	0.005	0.003
Cu	0.91	0.99	0.88	1.11	0.895	20	2.0	1.3	1.0
Zn	1.44	1.87	2.01	2.43	1.725	27.5	3.0	5.0	5.0
As	0.015	0.011	0.016	0.010	0.0155	12.5	0.01	0.01	0.05

*All parameters unit are in mg/L except EC in µS/cm and pH

[a] Bangladesh guideline

Table 5: Summarized result of heavy metal pollution indices

Parameter (1)	Average (2)	Minimum (3)	Maximum (4)	Category/Degree of pollution (5)
HMPI	654.0	18.44	2141.42	<45: Low (20%) 45-90: Medium (2.5%) >90: High (77.5%) (Raja *et al.* [66])
HMEI	38.30	5.61	79.51	<10: Low (5%) 10–20: Medium (12.5%) >20: High (82.5%) (Wagh *et al.* [64])
C_d	34.27	1.43	73.51	<10: Low (17.5%) 10–20: Medium (20%) >20: High (62.5%) (Edet and Offiong [51])

Average (column 5) Low pollution level in samples: (20+5+17.5)% = 42.5; average: 14.18%
Medium pollution level in samples: (2.5+12.5+20)% = 35; average= 11.67%
High pollution risk of the samples: (77.5+82.5+62.5)% = 222.5%; average 74.15%

that an average of 75% of samples fell in a 'high' degree of pollution caused by trace metals. It is a great threat to the gross public health of the study area. The C_d values were showed a significant correlation with HMEI but the values of HMPI was showed abnormal results concerning C_d and HMEI. Edet and Offiong [51] was demonstrated the same relation between those three indices for the surface water of Nigeria. The higher loaded Fe, Mn, Pb and Ni in the groundwater samples were responsible for this type of result. The average values of HPI, HEI and C_d were found 654.0, 38.30 and 34.27 respectively in the present study. Besides, Bodrud-Doza *et al.* [20] and Bhuiyan *et al.* [52] conducted two separate investigations in different Districts like Faridpur and Lakshimpur in the country.

The first reported values for the HMPI, HMEI and C_d were 46, 8.55 and 7.52, respectively and the second ones for the same indices were 26.12, 7.44 and 11.2, respectively achieved of the groundwater samples. These results were found good enough compared to this present study. The study assumed that trace metals are considered to cause toxic effects by altering the mechanisms of the biochemical functions of the exposed people of the study area. As stated by numerous reports, trace metals are known to fix the protein sites by shifting the required metal complexes or cause oxidative decline, leading to the malfunctioning of the human body cells [53]. On the other hand, toxic metals can replace the hydrogen from S–H bonds of enzyme groups and metal ion forms a complex with enzyme resulting in breaking the essential enzymes of the human body [54]. So, without the removal of elevated loaded metals in groundwater, it should not use for drinking or other household purposes.

Table 6: Non-carcinogenic health risks of trace metals by oral and dermal pathways

	Hq_{oral}		Hq_{derm}		$HI = \Sigma HQ_{oral/derm}$	
Element	Adult	Child	Adult	Child	Adult	Child
B	3.03E-02	7.08E-02	3.17E-04	9.35E-04	3.06E-02	7.17E-02
Fe	3.12E-01	7.28E-01	8.14E-03	2.40E-02	3.20E-01	7.52E-01
Mn	1.79E+00	4.18E+00	7.01E-01	2.07E+00	2.49E+00	6.25E+00
Cr	9.50E-05	2.22E-03	7.64E-04	3.81E-07	8.59E-04	2.22E-03
Pb	6.12E-01	1.43E+00	3.19E-03	5.15E-04	6.15E-01	1.43E+00
Co	5.24E+00	1.22E+01	2.73E-02	8.07E-02	5.27E+00	1.23E+01
Ni	2.67E-01	6.23E-01	6.97E-02	3.29E-04	3.37E-01	6.23E-01
Cd	6.29E-01	1.47E+00	6.56E-02	4.84E-04	6.95E-01	1.47E+00
As	1.48E+00	3.45E+00	3.08E-05	2.27E-05	1.48E+00	3.45E+00
Cu	6.39E-01	1.49E+00	3.33E-03	9.85E-03	6.42E-01	1.50E+00
Zn	1.64E-01	3.83E-01	5.14E-03	1.52E-02	1.69E-01	3.98E-01

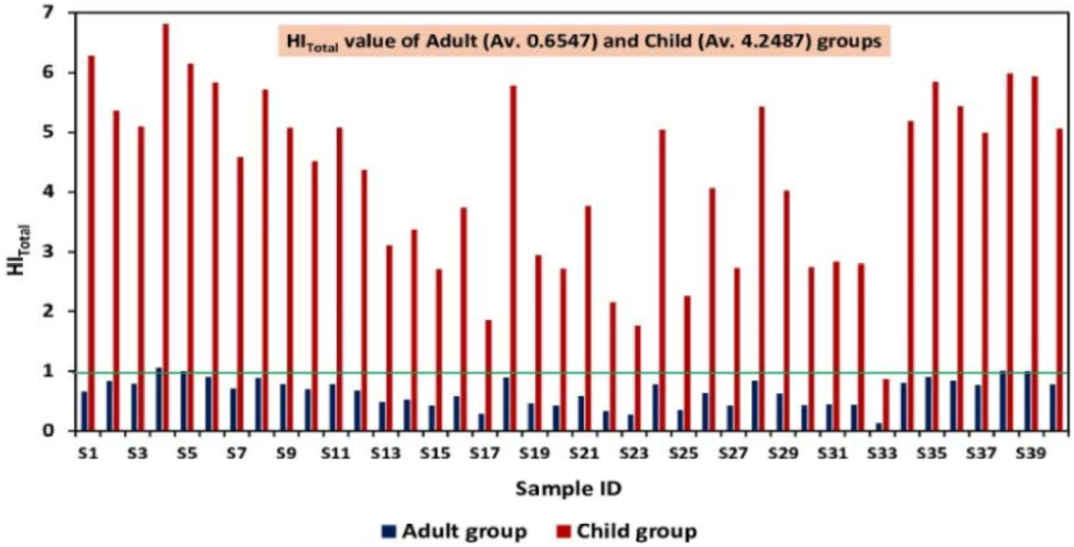

Fig. 2: Sample-by-sample HI_{total} values for adult and child groups

Health Risk Assessment (HRA) for Human: Human HRA is defined as the determination of the characteristics and degree of opposing health effects in humans who may be exposed to toxic chemicals in a polluted situation. The health risk assessment model is the most effective tool for computing the carcinogenic and non-carcinogenic health risks for separate age groups [55, 56]. These types of risks were computed for the trace metals of B, Fe, Mn, Cr, Co, Cd, Pb, Ni, As, Cu and Zn. The level of metals in water samples was used to measure human exposure through oral consumption and dermal absorption route. Two age groups viz adults and children were considered. Table 6 and Figs. 2 and 3 present the HQ, HI and ILCR values assessed for local peoples based on the oral intake and dermal absorption of water.

Non-Carcinogenic Risk Analysis (HQs and His): The study carried out the health exposure and risk calculations based on the US-EPA procedure. Human intake to trace metals primarily occurred via paths of potable water, foodstuff, inhaled aerosol and dust particles [24, 57]. The potentiality of toxicity of trace metals to human physiology is directly associated with their everyday consumption. Though, oral via potable water and dermal adsorption were taken into account in this study for risk calculation. The non-carcinogenic risk analysis was the cunning of the values of chronic daily intake (CDI) (Equations 5-8 in the Method section). Table 5 shows the calculated mean values of HQ_{oral} and HQ_{derm} in the study areas were detected in the order of Co>Mn>Cd>Cu>Pb>Ni>Fe>Zn>B>Cr and Co>Mn>Cu>Cd>Pb>Fe>Ni>Zn>B>Cr, correspondingly for the adult and child groups. The Table also shows that the total HQs of the heavy metals were below 1 in the adult group except for Mn and Co. Besides, the HQ_{total} values for Mn, Pb, Co, Cd and Cu have higher than 1 (HI_{total}>1) for the child group. The results showed that the Hi_{total} value of all metals for the child group was almost double of the adult group (Table 5). So, the children are more vulnerable to the non-carcinogenic health risk than the adult group. The study of Duggal *et al.* [5], Ukah *et al.* [25] and Tian *et al.* [56] in different regions of the world were given the same findings as to the present study.

Hazard index via oral (HI_{oral}) and dermal absorption (HI_{derm}) were measured to each sampling spot to evaluate the complete non-carcinogenic risk through toxic metals. The dataset of the computed HI_{total}, the sum of HI_{oral} and HI_{derm}, for the adults and children of each sample is presented in Fig. 2 and a summary of the results is shown in Table 7. For adults, sample by sample results of the HI_{total} was ranged from 0.1341 to 1.054 with an average value of 0.6547 indicating low chronic risk (Table 7). Out of the total 40 samples, the HI_{total} value of the samples S4, S5, S38 and S39 were higher than 1 (HI>1) and 6 samples were closed in 1 (HI>0.8) illustrating that the trace metals might cause for opposing health effects and non-carcinogenic health risks to the respective inhabitants (Fig. 2). However, the same Figure revealed that the value of HI_{total} of all the samples for the child group was higher than 1 (HI>1) except for the sample S33. Estimation showed the HI_{total} values in the child group were varied from 0.8668 to 6.8159 with an average of 4.2487. So, the child group was the more vulnerable to non-carcinogenic health risks in the study area (Table 7). Calculation showed that the mean values of HI_{derm} at all the sampling sites for both groups were much below 1 indicated that the metals would not illustrations at all health risks to the consumers over dermal absorption. The computed results showed that the HI_{total} was mostly attributed to the oral route.

Carcinogenic Risk Analysis: Heavy metals can boost the risk of cancer in human body organs [56, 57]. As stated by the International Agency for Research on Cancer [58, 59], Cr, Mn, Pb, Cu, Zn, Cd, etc., were observed as non-cancer consequence metals, whereas Co, Ni, Cr and Cd were considered as having possible cancer effect. Continuing exposure to less concentration of toxic trace metals could, then, result in many types of carcinogens. Next stated Equation 10 and 11 (Method section) were used to calculate the incremental lifetime cancer risk (ILCR) by using the values of CSF, K_p and GIABS which are itemized in Table 7 [59]. The cancer slope factors (CSFs) value was not existing for all toxic metals, this is a big problem to calculate the total carcinogenic risk. In this study, using only Ni, Cr, Pb and Cd as carcinogens, the total intake of the populaces was measured the ILCR based on the calculated CDIs values. Table 3 showed that the Cr cancer risk was higher than Ni, Cd and Pb for the water consumption through the oral and dermal absorption pathways. The carcinogenic risk assessment (ILCR) for the adult group is shown in Fig. 3.

For a single trace metal, an incremental lifetime cancer risk (ILCR) is lower than 1×10^{-6} considered unimportant and the cancer risk can be neglected; although an ILCR is above 1×10^{-4} considered as injurious and the risk of cancer is worrying. For the total of toxic metal overall exposure pathways, the satisfactory level is 1×10^{-5} [56, 60, 61]. Mohammadi *et al.* [24] stated that among the toxic metals, Cr has the maximum chance of cancer risks and Ni has the lowermost chance of cancer risk. The oral route donated more notably to the $ILCR_{total}$ than the dermal absorption. As together exposure paths, the $ILCR_{total}$ was computed in the range of 1.51E-06 to 1.07E-04 with an average value of 2.51E-05 and dependent on the sampling station. Thus, the value of $ILCR_{total}$ of metals exposure (fall between 10^{-6} to 10^{-4}) in the investigating zone was the adequate lifetime risks for carcinogens in consumption water. Spatial variation of carcinogenic and non-carcinogenic risk in the study zone was observed from both Figs. 2 and 3. The variation trends of sample-by-sample results of both risks value are almost the same.

Comparison of carcinogenic and non-carcinogenic risk values of the present investigation with previous studies of some countries are shown in Table 8. The Table illustrated that the measured values of the human health risks were not uniform among these countries. The values of the HQ_{total} for both adult and child groups for the groundwater intake of North China is higher compared to the results of India and this study. Like this present study, both the HQ_{total} and HI_{total} values for the child group are much greater than the adult group in all the studies of Table 8. The carcinogenic risk of the water samples of Tamil Nadu (India) and Lagos (Nigeria) is quite higher than the other studies.

The study followed the widely used HRA methods highlighted by the WHO, US-EPA, IRAC and other literature, but these methods have some uncertainties for risk calculation [5, 23, 56, 63]. Doubts have on the values of some procedural factors such as permeability constant (K_p), variations in intake conditions due to dissimilar ages and consumers and spatiotemporal differences in metal concentrations in samples [63-65]. In the recognized non-carcinogenic HRA method, given the same emphasis for all metals that is another drawback for the risk calculation. Moreover, exposure parameters used in the investigation were from the IRAC, RAIS, US-EPA, or WHO, which might not be exact to all places in the world.

Table 7: Summary result of non-carcinogenic classification based on HI_{total} (Ukah *et al.* [25]; US-EPA [40])

			% Samples in the category	
Risk level	HI_{total}	Chronic risk	Adult	Child
1	> 0.1	Negligible	0	0
2	$\geq 0.1<1$	Low	90	2.5
3	$\geq 1< 4$	Medium	4	37.5
4	≥ 4	High	0	60

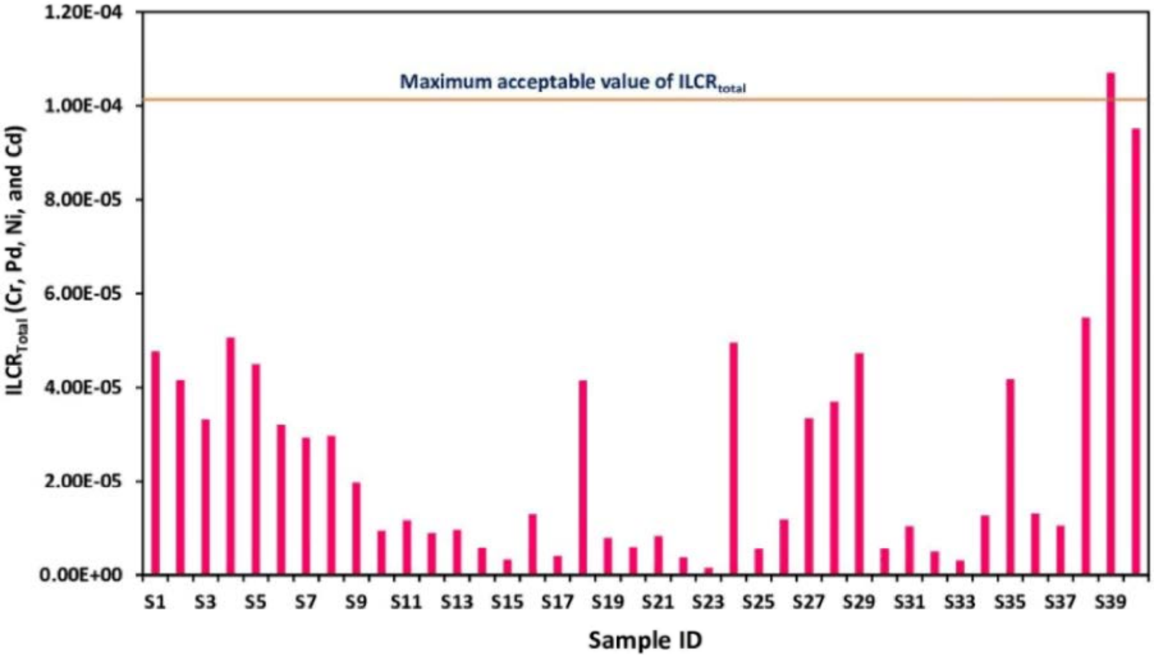

Fig. 3: $ILCR_{total}$ values for Cr, Ni, Ca and Pb metals

Table 8: Comparison of carcinogenic and non-carcinogenic risk values of the present study with previous studies in some countries

	Hq_{total}		Hi_{total} (mean)		Cancer risk (mean)	
Study area	*Adult*	*Child*	*Adult*	*Child*	*$ILCR_{total}$*	Reference
North Rajasthan, India	$HQ_{total}<1$, for all used metals	$HQ_{total}<1$, in all samples	7.32E-01	1.72E+00	5.15E-05	Duggal *et al.* [5]
Tamil Nadu, India	$HQ_{total}<1$, for all metals, except Pb	-	-	-	2.41E-03	Raja *et al.* [66]
Lagos, Nigeria	-	-	3.62E+00	12.38E+00	1.31E-03	Ukah *et al.* [25]
Lianhuashan District, China	$HQ_{total}<1$, for all metals, except Pb, As, Mn and Mo.	$HQ_{total}<1$, for all metals, except Fe, Co, Ni, Pb, As, Mn and Mo.	3.50E-01	1.53E+00	3.25E-05	Tian *et al.* [56]
Khorramabad, Iran	$HQ_{total}<1$, for all used metals	-	1.10E-04	-	5.05E-04	Mohammadi *et al.* [24]
Northwest China	$HQ_{total} = 2.6666$ (mean)	$HQ_{total} = 5.8013$ (mean)	-	-	-	Zhang *et al.* [62]
North China Plain	$HQ_{total}>1$, except Cd	-	-	-	4.23E-06	Liu and Ma [28]
This study	$HQ_{total}<1$, for all metals, except Mn and Co.	$HQ_{total}>1$, for Mn, Co, Pb, Cd and Cu. $HQ_{total}<1$, for B, Fe, Ni, Cr and Zn.	6.55E-01	4.25E+00	2.51E-05	-

How many metals or what types of elements are needed to risk calculation for a better result, yet now it was not prescribed by any authority or researcher. On the other hand, everyday water consumption amount and body weight are not the same around the world so, it was needed to specify these values regionally for a better estimation of the risk. Thus, additional accurate risk classification should be defined and health risk evaluation approaches may be improved considering the above-mentioned uncertainties.

CONCLUSIONS

The study focused on the extent of trace metal contaminations in water, choosing metal pollution indices and assessing human health risks associated with the ingesting of groundwater in the Ganges River basin area of Bangladesh. According to the findings of this investigation, among the analyzed trace metals, Fe, Mn, Pb and Ni are the most prevalent and 50-100% of samples contained those metals over than global and national guideline value. Based on the water quality indices (HMPI, HMEP and C_d), about 75% of the samples were of a high degree of trace metal pollution. The results revealed that $HQ_{total}>1$ for Mn and Co were the potential non-carcinogenic risk than other heavy metals from the adult group and $HQ_{total}>1$ for Mn, Co, Pb, Cd and Cu in the case of the child group. All HQ_{total} values of the child group are greater than doubled from the adult group for all metals. So, children are more unprotected from non-carcinogenic chronic health risks than the adult group. The values of HI_{total} of the adult group in 36 of the total 40 sampling sites are below unity. It also revealed that the HI_{total} values of the adult group crossed the unity of 90% samples, whereas the child group crossed the unity of all samples with an average value of 4.25. The results showed that the HI_{total} value of the child was almost 5-fold higher than the adult group. Therefore, the child group was fallen into serious health risk in the study area. Besides, $ILCR_{total}$ (carcinogenic) values for Cr, Ni, Ca and Pb in all samples were observed within the safe limits. The non-carcinogenic risk values showed that the opposing effect of the toxic metals on the organs and systems of children is more than that of adults. The study suggests drinking the water after necessary treatment for removing trace metal from the potable water. Further study could use sophisticated investigative approaches considering more parameters over a wide area.

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