Rajshahi University journal of science and engineering **ISSN 2309-0952 (Print)**
Vol. 46-53 (2018-2025), pp 11-25 **ISSN 2408-8803 (Online)**
DOI: https://doi.org/10.64102/rujse.0759

Concentration and human health risk assessment of heavy metals in groundwater from around the area of Ruppur Nuclear Power Plant, Pabna district, Bangladesh

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Abstract

Ruppur nuclear power plant (RNPP) is under construction in the study area (Ruppur, Pabna, Bangladesh), which has schedule for power production in 2023. Most of the local people generally consume groundwater from hand-tube wells, and groundwater also is used for cultivation. Therefore, this study has been designed to collect ground water samples from twelve different sampling points surrounding RNPP site for determining the present status of heavy metals concentration in groundwater and to assess human health risk related to heavy metals contamination in groundwater. The concentrations of Pb, Cd, Cr, Fe, Mn, As, Ni, Cu, and Zn in the groundwater samples were determined using Atomic Absorption Spectrometer (GTA 120-AA240Z, Varian, Australia) at Bangladesh Council of Scientific and Industrial Research (BCSIR). This study revealed that the concentrations of heavy metals in groundwater samples for this study area in decreasing order was as follows: manganese > iron > lead > chromium > cadmium respectively. As, Ni, Cu, and Zn concentrations in the water samples were found to be below detection level. The level of target hazard quotient (THQ) in ingestion in the study area followed the order: Mn > Cr > Pb > Cd > Fe respectively. Subsequently, this study revealed that THQ values for Mn were lower than 1 in five sampling points but higher than one in seven sampling points, which indicating that the adverse health effects on human body and potential non carcinogenic concern for manganese via ingestion water except all other studied metals. THQ values of dermal for all the heavy metals were less than 1. However, this study also revealed that the HI ingestion values for Pb, Cd, Cr, and Fe were higher than 1 for all sampling points, which indicating the adverse health effects on human body and potential non carcinogenic concern via ingestion of water. On the other hand, the HI dermal values for Pb, Cd, Cr, Fe and Mn are smaller than 1 indicating that there is no adverse health effects on human body and potential non carcinogenic concern via dermal adsorption of water.

Keyword: Ruppur Nuclear Power Plant, heavy metals, target hazard quotient, hazard index

1. Introduction

Water is an essential element for life. It is the soul of nature and hope of future. Without water nothing is possible. It is the most useful natural resource on earth and is needed in

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every phase and stage of our life. Fresh water comprises 3% of the total water on earth. For human use only 0.01% of this freshwater is available [1]. Drinking water contains small amounts of heavy metals that helps in normal functioning of the human body but excess can be toxic to human health. These heavy metals reach the human systems through ingestion in from water [2]. Heavy metals enter the human body through several pathways such as food chain, direct ingestion, dermal contact, fume inhalation, and particles through mouth and nose. In several regions of the developing world, groundwater pumped from hand tube wells is directly used for domestic purpose, including drinking. This poses a great threat in a rapidly urbanizing world and results in serious concerns on the quality of water resources. In developing countries such as India, people depend on groundwater and surface water resources for domestic use, including drinking, as piped water supply is limited [3].

Groundwater contamination may occur naturally from normal geological phenomena such as ore formation, weathering of rocks and leaching or due to increased population, urbanization, industrial activities, agricultural practices, exploration and exploitation of natural resources [4]. Anthropogenic activities, like industrial production and unsafe disposal of industrial wastes agricultural wastes and domestic sewage, release heavy metals into the environment [5]. Heavy metal contamination is potentially a significant problem in several community and agricultural areas [6] because agrochemicals, including plant nutrients and fertilizers, can lead to dramatic increases in the concentrations of heavy metals in the water. These heavy metals have the potential to reach levels in the surface and groundwater that are adverse to human health [7, 8]. As heavy metals are subject to environmental toxicity, abundance, and persistence, the contamination by these metals in the aquatic environment becomes a global concern [9]. Health effects of heavy metals have attracted attention to water quality studies. Iron and manganese are naturally available in many geological formations and can change the taste and odor of water according to the reports published by the United States Environmental Protection Agency (USEPA). They can restrict domestic and industrial usage of waters [10]. In drinking water sources, salts of Fe(II) are unstable and typically precipitate as iron hydroxide, but groundwater, which are kept in anaerobic conditions, may contain some iron when discharged out (WHO 1996). Manganese is also a trace element in the earth crust which mainly originates from weathering. Health impacts and side effects of water contaminated with manganese, such as neurological symptoms, have been proved [11]. Chromium is available in various oxidation states, mainly Cr (III) and Cr (VI). Depending on the oxidation, its biological activity is different. The toxicity of Cr (VI) is about 100 to 1000 times higher than that of Cr (III) [12]. Chromium in the sixth oxidation state, as CrO_4^{2-} and $HCrO_4^{-}$, has high mobility in the environment. On the other hand, Cr (VI) is a carcinogenic substance as well. In reduced condition, Cr (VI) is converted to Cr (III) that is insoluble in the aquifers and bind to solid particles, thus it has low toxicity. Copper is an essential element for life, however at higher levels can cause anemia and destroys kidney and liver tissues [13]. The copper content of the earth crust ranges from 25 to 75 mg/kg. Organic matters in the soil have a high affinity for copper and can reduce the binding of copper to solid particles. High concentrations of copper have been found in groundwater in area with mining or metal smelting activities. Since this element has low mobility in soil, it may reach high levels in some regions [14]. Heavy metals usually occur in small amounts in groundwater around industrial areas that use variety of chemicals in the manufacture of batteries, paints, pharmaceutical products, leather processing, agrochemicals, etc. Contamination of groundwater has gained international attraction of numerous researchers to estimate the quality of groundwater from different corners of the world [15,16,17]. With a motive of sustaining the groundwater quality, regular monitoring of groundwater has been performed in various cities from different corners of the world such as; USA, China, Mexico, Korea, India and Iran [18]. In China, it was reported that contamination of groundwater with heavy metals could lead to non-carcinogenic health impacts on local community [19]. These industries dispose the treated/partially treated wastewater that do not meet the standards in the surface water bodies such as rivers, lakes, ponds and into the sea in coastal areas. Contamination due to suite of heavy metals is also commonly reported around landfills [20]. The other important contamination route is through excessive application of agrochemicals that are retained in the unsaturated zone and reach groundwater through irrigation return flow [21]. Accumulation of the bio-toxic heavy metals in crops and subsequent transport in the food chain pose potential risk to human health. Hence, several studies have been conducted on these lines [22,23] by different researchers. But unfortunately very limited research works have been done in the study area. Therefore, the main objectives for this research are : (1) determination of the heavy metals (Pb, Cd, Cr, Fe, Mn, As, Ni, Cu, and Zn) concentration in the groundwater samples collected from different sampling points surrounded Ruppur Nuclear Power Plant (RNPP) site, and (2) determination of the possible human health risks assessment of local dwellers through ingestion, inhalation and adsorption of the water.

2. Materials and methods

2.1 Materials

All reagents were analytical grade (AR) and purchased from Merck, Germany. A calibrated electrical balance (GR-200, A&D Company Limited, Tokyo, Japan) with high precession was used for weighing purpose. Calibrated glass wares including pipette and volumetric flask were used for sample preparations. They were soaked in 10% (v/v) HNO_3 overnight and rinsed with deionized water and dried prior using.

2.2 The study area description

The study area is situated at the Ruppur Nuclear Power Plant (RNPP) site, which is under construction and has been scheduled for power production in 2023. This study area is 200 km north-west of Dhaka, at Paksey union on the bank of Padma River, Pabna District, Bangladesh. It is located at 24°3′36″N, 89°2′24″E. The groundwater samples were collected from the 12 different sampling points of Ruppur Nuclear Power Plant area, which is shown in Fig. 1. For all locations, three consecutive water samples were collected.

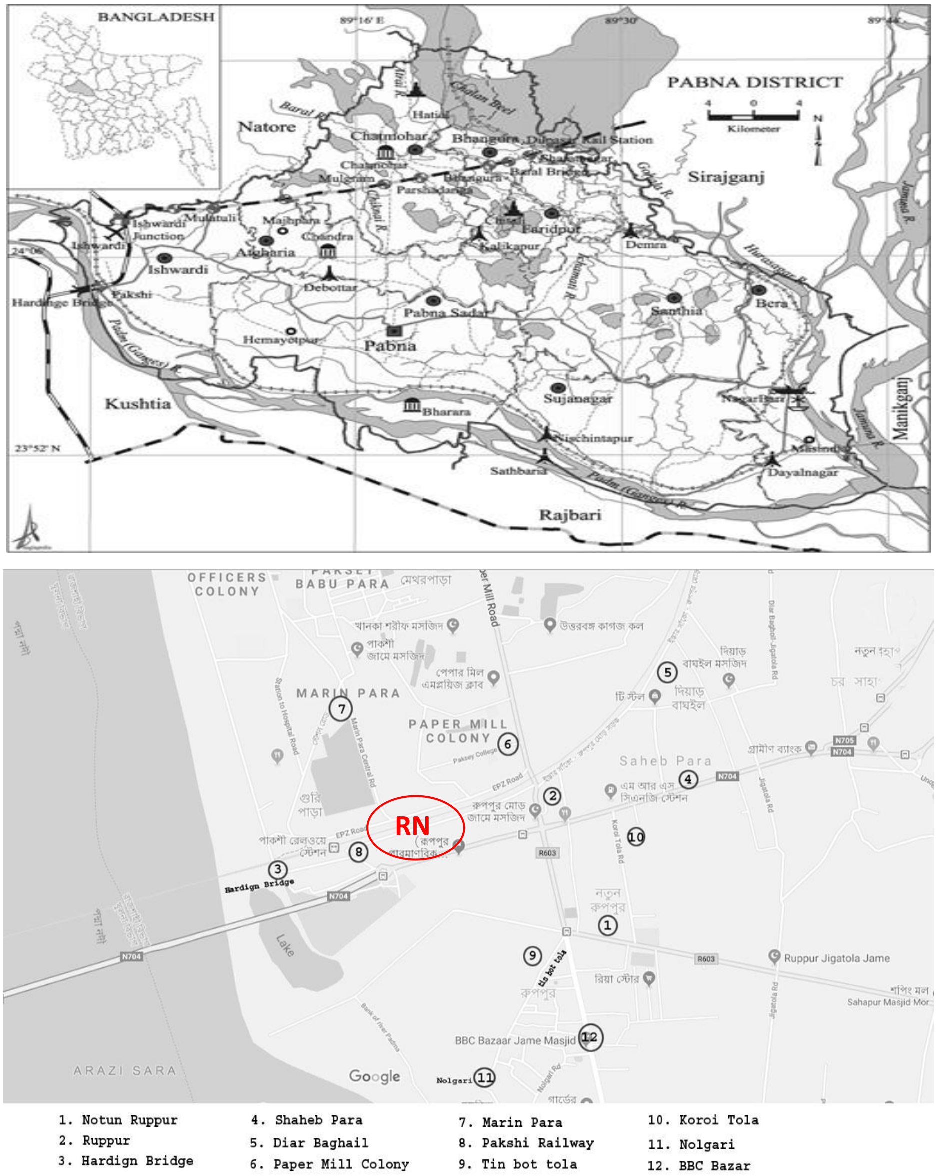

Fig. 1. Location of sampled points on the map of the study area

2.3 Collection and preparation of groundwater sample

Clean and dry plastic containers were used to get groundwater for sampling. Before sampling, the bottles were cleaned with detergent and then treated with 10% (v/v) nitric acid (HNO_3) solution overnight. Then they were washed several times with deionized water until free from acid and dried in air. Before collecting the groundwater samples, the tube-wells were pumped 5/6 minutes, the bottles were washed at least three times with sample water. However, the samples bottles were sealed and labeled properly for avoiding exposure to air and were transferred immediately to the laboratory. The samples for heavy metal analysis were acidified immediately with 2 mL of concentrated HNO_3 per liter of water to prevent the loss of metals by precipitation, absorption and ion exchange with the walls of the sample containers. All the collected samples were then brought to the laboratory with care by ice carrier and preserved in the refrigerator at 4 °C for the analysis in the laboratory [24].

2.4 Sample preparation and analysis

100 mL of each water sample was taken in a 250 mL cleaned glass beaker by using a calibrated pipette and acidified with about 4-5 mL of concentrated HNO_3. The beakers containing the samples were then heated on a hot plate at about 150-180 °C for digestion and volume reduction to about 25-30 mL. After proper digestion, the cooled sample was taken in a 100 mL cleaned and calibrated volumetric flask rinsing the beaker several times with deionized water and finally, the flask was made up to the mark. Then it was filtered with a Whatman TM qualitative 1 filter paper and preserved in a previously cleaned and dried 250 mL nontransparent plastic bottle with a label for the determination of heavy metals concentration. A sample blank was also prepared following the same procedure. However, the heavy metals (Pb, Cd, Mn, Ni, Zn, Fe, Cu, As and Cr) concentrations in the prepared groundwater samples were analyzed using Zeeman Atomic Absorption Spectrometer (Model: GTA 120-AA240Z with PSD 120 auto sampler, Varian, Australia) at ISO/IEC 17025 accredited laboratory of Institute of National Analytical Research and Service (INARS), Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka, Bangladesh. Hg concentration of the samples were analyzed using cold vapor hydride generation technique in AAS (Model: AA240 FS with VGA-77, Varian, Australia), and the concentration of arsenic in the samples were determined using electric hydride vapor generation technique in AAS (Model: SpcetrAA 220 with an electrothermal temperature controller (ETC)-60 and VGA-77, Varian, Australia).

2.5 Quality Control and data analysis

During analysis, accuracy and precision were verified by using reference materials from Fluka Analytical, Sigma-Aldrich. For analytical quality control, standard solution after each five samples and a reagent method blank after each ten samples were determined. A calibration curve was prepared for all metals by running different concentrations of working standard solutions prepared from CRM (Fluka Analytical, Sigma-Aldrich). The concentrations of heavy metals of the samples were determined against the prepared calibration curve. Average values of three consecutive replicates were taken for each determination. All stock standard solutions of physicochemical parameters, anions and heavy metals were 1000 ± 4 mgL^{-1} as traceable to National Institute of Standards and Technology (NIST) and measured against CRM produced and certified in accordance with ISO/IEC 17025 and ISO guide 34. For all locations, three consecutive samples were collected, analyzed and finally their average values were taken.

2.6 Human health risk assessment

Human exposure to heavy metals may occur via three main pathways including direct ingestion, inhalation through the mouth and nose, and dermal absorption through exposed skin. For metals in a water environment, ingestion and dermal adsorption play the most important role [25]. Considering these two pathways, the average daily dose was calculated using Equations (1) and (2). Assessment of risk is defined as the processes of estimating the probability of occurrence of any given probable magnitude of adverse health effects over a specified time period and is a function of the hazard and exposure. Non-carcinogenic risk of some trace metals in water was predicted from their target hazard quotient (THQ) and hazard index (HI) indices [26,27]. The potential exposure pathways of metal in environment are through ingestion and dermal contact. Exposure doses through ingestion and dermal pathways were calculated by the following equations [28].

Average daily intake via ingestion:

$$ADIi = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

where, ADI_i is the average daily intake via ingestion (mg/kg-day), C is the concentration of the chemical, IR is the intake rate (2 L per day for water), BW is the body weight of the exposed person (70 kg for normal adult), EF is the exposure frequency (365 days/year), ED is the exposure duration over a life time (70 years), AT is the averaging time in days (70 years x 365 days/year).

Average daily intake via dermal pathway:

$$ADId = \frac{C \times EF \times ED \times SA \times Kp \times ET \times CF}{BW \times AT} \quad (2)$$

where ADI_d is the average daily intake via dermal pathway (mg/kg-day), C is the concentration of the metal in water (mg/l), SA is the drinking water exposed skin area (cm^2) = 28000, Kp is the dermal permeability coefficient (cm/hr), ET is the exposure time during bathing and shower (hr/day) = 0.6, EF is the exposure frequency (days/year) = 365, ED is the exposure duration (year) = 70 years, BW is body weight (kg) = 70 kg, AT is the averaging time (days) = 25550 days, CF is the unit conversion factor (L/cm^3) = 0.001.

Target hazard quotient for oral THQi route was calculated by the flowing equations (Eq. (3)) [29]

$$THQi = \frac{ADIi}{RfD} \quad (3)$$

RfD = oral reference dose of the contaminant (mg/kg/day).

Target hazard quotient for dermal pathway THQ_d route was calculated as the following equation (Eq. (4))

$$THQd = \frac{ADId}{RfDdermal} \quad (4)$$

RfD dermal = dermal reference dose of the contaminant (mg/kg/day).

$$HI = THQ(toxicant\text{-}1) + THQ(toxicant\text{-}2) + THQ(toxicant\text{-}3) \quad (5)$$

In this case, the hazard index HI or total THQ is treated as the arithmetic sum of the individual metal THQ values [30].

3. Results and Discussion

3.1 Heavy metal concentration in water samples

The metal concentration in 12 groundwater samples were analyzed by AAS at ISO/IEC 17025 accredited laboratory of Institute of National Analytical Research and Service (INARS), Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka, Bangladesh; and the statistical analysis for the studied metals in indoor water samples is presented in (Table 1). This study revealed the order of dominance of these heavy metals following manganese > iron > arsenic > lead > chromium > cadmium respectively. Three metals (i.e., nickel, zinc and cupper) were found to be the below detection limit (BDL) for this study. Most heavy metals are required within the recommended limits in the human body for the smooth functioning of metabolic activities. Some of the beneficial health effects and negative consequences due to ingestion of heavy metals monitored in this study are compiled from United States Environmental Protection Agency [31] and Agency for Toxic Substances and Disease Registry [32]. However, our results were compared with the criterion continuous concentration (CCC), criteria maximum concentration (CMC) values of water quality criteria (USEPA, 2009), World health organization (WHO, 1993), Bangladesh drinking water standards (ECR, 1997) and Background concentrations, world average [33], which is presented in (Table 2).

Lead (Pb) is very toxic and serious cumulative body poison, which can affect every organ and system in the body. Exposure to its high levels can severely damage the brain, kidneys and ultimately cause death [34]. The concentrations of lead in the study area are varied from 0.011 – 0.041 ppm, which were below than that of the Chinese drinking water standard value (0.4 ppm) [35]. It is obvious that, the concentrations of lead in water samples are lower than the standard value. This study revealed that Pb concentration for this study was higher than the recommended value of criterion continuous concentration (CCC), world health organization (WHO, 1993)[36] but lower than the criteria maximum concentration (CMC) values of water quality criteria (USEPA, 2009) [37], Bangladesh drinking water standards (ECR, 1997). ANOVA study (Table 3) revealed that Pb concentration in different sampling points are significantly different, which is consistent with the percentage of relative standard deviation (%RSD) value (29.93%). Therefore, it has been suggested that sources of lead in the study area might be anthropogenic.

Though cadmium (Cd) is not yet proved to be either biologically essential or beneficial, it is suspected to cause renal arterial hypertension. At higher levels, cadmium can affect the liver and kidney severely. The concentrations of cadmium (Cd) in the study area are varied from 0.0011 – 0.005 ppm. This study revealed that Cd concentration in water samples was lower than that of the recommended values of world health organization (WHO, 1993) and Bangladesh drinking water standards (ECR, 1997)[38], which suggested that this water is safe for drinking purpose in terms of Cd concentration. However, Cd concentration in the water samples was higher than the recommendation value of criterion continuous concentration (CCC), and the criteria maximum concentration (CMC) values of water quality criteria (USEPA, 2009).

Chromium (Cr) is a widely reported pollutant around tanning industries [39] and known to cause allergic dermatitis. But, chromium (III) is required by the human body for insulin secretion that helps to maintain normal glucose metabolism in the human body. The concentrations of chromium (Cr) in the study area are varied from 0.007 – 0.04 ppm. This study revealed that Cr concentration in water samples was higher compared to the recommended value of the criteria maximum concentration (CMC) values of water quality criteria (USEPA, 2009), criterion continuous concentration (CCC), world health organization (WHO, 1993) and Bangladesh drinking water standards (ECR, 1997). This study also revealed that the percentage of relative standard deviation (%RSD) value (65.523%) was very high (Table 1), which indicated the sources of Cr in the water samples might be industrial (Table 2).

Black stains on porcelain, enamel, and fabrics are also caused by manganese contamination. The concentrations of manganese (Mn) in the study area water are varied from 0.599 – 1.595 ppm. This study revealed that Mn concentration in water samples was higher compared to the recommended values set by the world health organization (WHO, 1993) and Bangladesh drinking water standards (ECR, 1997).

Iron (Fe) is an essential component of hemoglobin and myoglobin play a major role in carrying oxygen from lungs to the tissues. Use of iron is disagreeable in food and beverage processing and additionally causes stains in laundry and utensils. The concentrations of iron (Fe) in the study area are varied from 0.051 – 3.072 ppm. The standard value of Fe is 0.3 ppm (WHO, 1993) and our average value (0.856 ppm) was higher than that of the recommended value. It was also observed that the concentrations of Fe in six water samples were higher than the standard value and six water samples are lower than standard value. This study also revealed that the %RSD value for iron was found to be very high (130.26%)

Table 1. Concentration (mg/L) of heavy metals of water from RNPP site, Pabna, Bangladesh

Sample	Heavy metal concentration in water samples (mg/L)				
ID	Pb	Cd	Cr	Fe	Mn
S-1	0.020	0.002	0.011	0.621	1.595
S-2	0.021	0.001	0.015	0.090	0.988
S-3	0.011	0.001	0.030	2.415	0.629
S-4	0.031	0.004	0.032	2.496	0.599
S-5	0.030	0.004	0.015	3.072	0.633
S-6	0.033	0.004	0.038	0.488	1.332
S-7	0.031	0.004	0.018	0.226	1.323
S-8	0.040	0.003	0.040	0.052	0.770
S-9	0.030	0.004	0.009	0.051	0.827
S-10	0.041	0.005	0.007	0.272	1.065
S-11	0.040	0.006	0.006	0.051	0.416
S-12	0.031	0.005	0.008	0.434	0.941
Min	0.011	0.001	0.006	0.051	0.416
Max	0.041	0.006	0.040	3.072	1.595
Ave	0.030	0.004	0.019	0.856	0.927
Stdev	0.009	0.002	0.013	1.115	0.353
%RSD	29.93	43.54	65.52	130.26	38.07
GM	0.028	0.003	0.016	0.333	0.865

Table 2. The heavy metal concentration in water and comparison with water quality guidelines (ppm).

Exp. and recommended data	Concentration of heavy metal (mg/kg)								References
	Pb	Cd	Ni	Cr	Cu	Zn	Mn	As	
This study	0.030	0.004	< BDL	0.019	< BDL	< BDL	0.927	< BDL	RNPP Site
CCC (Criterion continuous concentration)	0.0025	0.00025	0.052	0.011	0.009	0.12	NG	0.15	USEPA (2009)
CMC (Criteria maximum concentration)	0.065	0.002	0.47	0.016	0.013	0.12	NG	0.34	USEPA (2009)
World health organization	0.01	0.003	0.02	0.05	2	3	0.5	0.01	WHO (1993)
Bangladesh drinking water standards	0.05	0.005	0.1	0.05	1	5	0.1	0.05	ECR (1997)
Background concentrations, world average	0.0002	0.00002	0.0003	NG	0.001	0.01	0.006	NG	Klavins et al. (2000)

N.G. Not Given

Table 3. ANOVA test for heavy metal concentration in different water sampling sources

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Among sampling points	2.311	11	0.210	3.726	0.007	2.014
Among different metals	11.023	4	2.756	9.528	0.000	2.584
Error	12.726	44	0.289			
Total	26.060	59				

This study also revealed that As, Ni, Zn and Cu were found to be below the detection level for this study.. Considering this value we conclude that the water samples are free from cadmium, chromium, nickel, zinc and cupper contamination. Arsenic, lead are slightly contaminated and iron, manganese are contaminated in water samples from the proposed site of RNPP.

3.2 Health risk assessment

The levels of target hazard quotient (THQ) of selected heavy metals in water by ingestion from RNPP site are summarized in (Table 4). This study reveals that the THQ values are found to be in between 0.075 to 0.29 for Pb, 0.03 to 0.14 for Cd, 0.07 to 0.38 for Cr, 0.002 to 0.13 for Fe, and 0.71 to 1.89 for Mn respectively. THQ values for all the heavy metals were in between 0.002 to 1.89. The decrease in the level of THQ in the study area followed the order: Mn > Cr > Pb > Cd > Fe respectively. The target hazard quotient values for Pb, Cd, Cr, and Fe through ingestion are smaller than 1, which indicates that there is no significant non carcinogenic risk in the water samples in the study area. On the other hand, target hazard quotient values for Mn in six sampling points are lower than 1 but greater than one in half of the sampling points. That indicates the adverse health effects in human body and potential non carcinogenic concern via ingestion water for manganese **[40]**. Therefore, it has been suggested that Mn is the largest contributors among studied metals to non-carcinogenic risk exposure via ingestion of water from the RNPP site.

Table 4. Target hazard quotient and hazard index of heavy metals via ingestion of water from RNPP site.

Sample Code	Target hazard quotient (THQ) via ingestion					HI
	Pb	Cd	Cr	Fe	Mn	
S-1	0.143	0.060	0.095	0.025	1.892	2.214
S-2	0.150	0.032	0.142	0.004	1.173	1.500
S-3	0.075	0.031	0.285	0.098	0.747	1.236
S-4	0.220	0.093	0.304	0.102	0.711	1.429
S-5	0.213	0.121	0.142	0.125	0.752	1.352
S-6	0.230	0.117	0.271	0.020	1.582	2.220
S-7	0.218	0.114	0.128	0.009	1.571	2.040
S-8	0.285	0.086	0.380	0.002	0.914	1.667
S-9	0.213	0.119	0.085	0.002	0.982	1.401
S-10	0.291	0.143	0.066	0.011	1.265	4.398
S-11	0.287	0.178	0.057	0.002	0.494	1.018
S-12	0.216	0.146	0.076	0.018	1.117	1.573
Min	0.075	0.031	0.057	0.002	0.494	1.018
Max	0.291	0.178	0.380	0.125	1.892	4.398
Ave	0.212	0.103	0.169	0.035	1.100	1.837
Stdev	0.064	0.045	0.110	0.045	0.418	0.891
%RSD	30.275	43.891	65.121	130.485	38.047	48.473

The levels of target hazard quotient (THQ) of selected heavy metals in water by dermal adsorption are summarized in (Table 5). THQ values are found to be in between 0.00148 to 0.00303 for Pb, 0.0104 to 0.06009 for Cd, 0.0384 to 0.25600 for Cr, 0.000087 to 0.005266 for Fe, 0.104 to 0.39875 for Mn respectively. THQ values for all the studied heavy metals were between less than one, which is consistent with the reported result in literature [41]. However, this study suggested that the adverse non carcinogenic concern via dermal adsorption are very negligible as well as THQ values for all studied metals are significantly lower than one.

Table 5. Target hazard quotient and hazard index of heavy metals via dermal adsorption of water from RNPP site.

Sample Code	Target hazard quotient (THQ) via dermal adsorption					HI
	Pb	Cd	Cr	Fe	Mn	
S-1	0.001	0.020	0.071	0.001	0.399	0.492
S-2	0.002	0.011	0.096	0.000	0.247	0.355
S-3	0.001	0.010	0.192	0.004	0.157	0.355
S-4	0.002	0.034	0.205	0.004	0.150	0.395
S-5	0.002	0.041	0.096	0.005	0.158	0.302
S-6	0.002	0.040	0.243	0.001	0.333	0.619
S-7	0.002	0.038	0.115	0.000	0.331	0.487
S-8	0.003	0.029	0.256	0.000	0.193	0.480
S-9	0.002	0.040	0.058	0.000	0.207	0.307
S-10	0.003	0.048	0.045	0.000	0.266	0.363
S-11	0.003	0.060	0.038	0.000	0.104	0.206
S-12	0.023	0.049	0.051	0.001	0.235	0.359
Min	0.001	0.010	0.038	0.000	0.104	0.206
Max	0.023	0.060	0.256	0.005	0.399	0.619
Ave	0.004	0.035	0.122	0.001	0.232	0.393
Stdev	0.006	0.015	0.080	0.002	0.088	0.110
%RSD	149.16	43.54	65.52	130.33	38.08	27.97

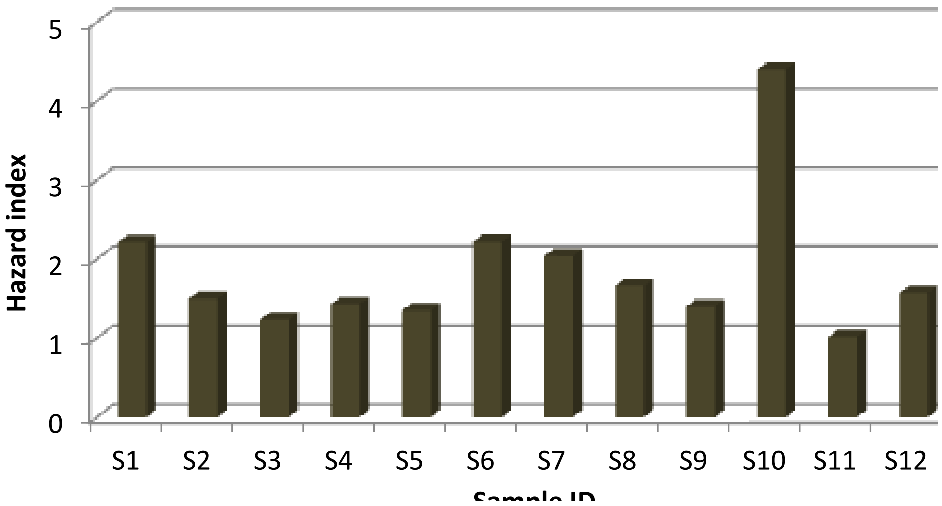

Fig. 2. Hazard index (HI) of heavy metals via ingestion in different water sample analyzed.

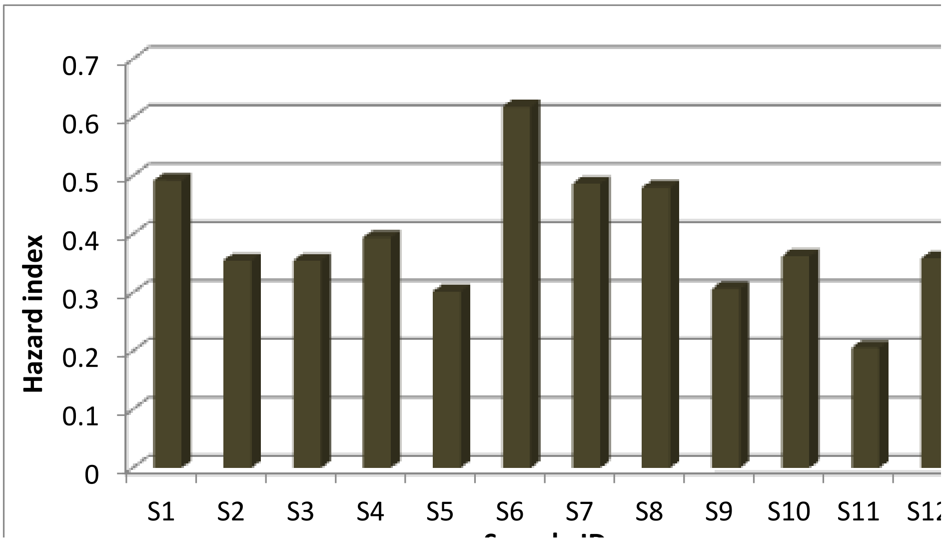

Fig. 3. Hazard index (HI) of heavy metals via dermal in different water sample analysed.

The hazard index (HI) values for heavy metals in drinking water through ingestion are shown in (Fig. 2). This study revealed that the HI values for Pb, Cr, Cd, Mn, Fe through ingestion in all locations are higher than one. Therefore, it has been suggested that there might be adverse health effects in human body as well as there is potential non-carcinogenic concern via daily oral intake ($HI_{ingestion} > 1$). Reversely, **t**he hazard index (HI) values for heavy metals by dermal adsorption are shown in (Fig. 3). This study revealed that the HI values through dermal adsorption for Pb, Cr, Cd, Mn and Fe in all locations are lower than one ($HI_{dermal\ adsorption} < 1$), which indicates that there is no significant adverse health effects in human body due to dermal adsorption.

Table 6. Reference dose and dermal permeability coefficient for the investigated heavy metals **[28]**

Reference dose	Pb	Cd	Cr	Ni	Fe	Zn	Cu	Mn
Oral reference dose (mg/kg/day)	4.0×10^{-3}	1.0×10^{-3}	3.0×10^{-3}	2.0×10^{-2}	7.0×10^{-1}	3.0×10^{-1}	4.0×10^{-2}	2.4×10^{-2}
Dermal reference dose (mg/kg/day)	4.0×10^{-4}	2.5×10^{-5}	7.5×10^{-5}	8.0×10^{-4}	1.4×10^{-1}	6.0×10^{-2}	8.0×10^{-3}	9.6×10^{-4}
Dermal permeability coefficient (cm/hr)	1.3×10^{-4}	1.0×10^{-3}	2.0×10^{-3}	2.0×10^{-4}	1.0×10^{-3}	6.0×10^{-4}	1.0×10^{-3}	1.0×10^{-3}

4. Conclusion

The heavy metals concentration in water samples collected from the Ruppur Nuclear Power Plant area followed the trend: manganese > iron > arsenic > lead > chromium > cadmium respectively. This study revealed that the concentration of Fe, Pb and Mn in water samples were higher than that of the recommended values set by world health organization (WHO) and Bangladesh drinking water standard (BDW). However, reverse trend was observed for Cr and Cd in the same water samples. This study also revealed that three metals (i.e., nickel, zinc, and cupper) were found to be below the detection limit for this study. The level of target hazard quotient (THQ) in ingestion in the study area followed the order: Mn > Cr > Pb > Cd > Fe respectively. Subsequently, this study revealed that THQ values for Mn were lower than 1 in five sampling points but higher than 1 in seven sampling points, which indicates the adverse health effects on human body and potential non carcinogenic concern for manganese via ingestion water except all other studied metals. THQ values of dermal for all the heavy metals were less than 1. However, this study also revealed that the HI ingestion values for Pb, Cd, Cr, and Fe were higher than 1 for all sampling points, which indicates the adverse health effects on human body and potential non carcinogenic concern via ingestion of water. On the other hand, the HI dermal values for Pb, Cd, Cr, Fe and Mn are smaller than 1 indicating that there is no adverse health effects on human body and potential non carcinogenic concern via dermal adsorption of water.

5. Acknowledgement

The authors deeply thankful to the laboratory of Bangladesh Atomic Energy Commission, 4 Kazi Nazrul Islam Avenue, Dhaka, and Bangladesh Council of Scientific and Industrial Research (BCSIR), Dhaka for providing all necessary research facilities.

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