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Research Article

Human health risk status of groundwater in slum areas located in Dhaka-Narayanganj city of Bangladesh

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ABSTRACT

Deterioration of groundwater (GW) quality due to natural and anthropogenic activities remains a critical concern in the Dhaka-Narayanganj city of Bangladesh because it is the primary drinking water (DW) source for millions of slum dwellers, and comprehensive health risk assessments integrating advanced pollution indices (PIs) and Carcinogenic Risk (CR) evaluation remain limited. Here, GW quality with heavy metal (HM) contamination and associated human health risks were assessed in 23 slum areas across the Dhaka-Narayanganj city by measuring physicochemical parameters along with concentration of nutrients and HMs. Furthermore, the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) and multiple PIs based on the obtained concentration of HMs were evaluated. Most of the physicochemical parameters and concentration of nutrients were within the World Health Organization (WHO) limit of DW, and the order of nutrient levels was nitrate > phosphate > ammonia. Among all HMs, Fe was the principal aesthetic concern (176 - 470 µg/L), with 4 stations exceeding the limit of WHO (300 µg/L) and As, Cr, Hg, Mn, and Pb being below health-concern limits. PIs classified 87 % of stations as *low* contamination, while CCME-WQI categorized 82.6 % as "*good*," 13 % as "*excellent*," and one as "*fair*." However, CR assessment identified that 5 stations (21.7 %) in Narayanganj and Shiddhirganj industrial areas pose "*unacceptable*" lifetime CR ($>1\times10^{-4}$) due to continuous ingestion and dermal contact with As-contaminated GW over many years. Standard water quality indices underestimate chronic health risks, so carcinogenic assessments must be added to regular GW monitoring to protect vulnerable slum communities.

Introduction

Groundwater (GW) constitutes a critical component of the hydrological cycle of the Earth, serving as a vital and renewable resource that is significantly linked to surface water (SW) systems across diverse environments (Lachassagne, 2020; Sophocleous, 2002; Winter et al., 1998). In a riverine nation like Bangladesh, SW from major transboundary rivers significantly contributes to GW recharge (Rahman and Habiba, 2023; Shamsudduha et al., 2011). However, the quality of these water resources is increasingly threatened by a complex interplay of geological factors, anthropogenic activities, and

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ecosystem dynamics (Shukla and Saxena, 2020). This challenge is acutely faced in Dhaka city, where a severe decline in both the availability and quality of drinking water (DW) is in progress. The situation is particularly dire in its slum settlements, home to approximately one-third of the population of the city, where residents face disproportionately greater hardships compared to formal residential areas (Kashem et al., 2023).

Previous research has extensively documented the degradation of GW of Bangladesh by a huge number of heavy metals (HMs). Nationwide, As contamination of natural and anthropogenic origin affects over 20 million people, with concentrations exceeding national limits (Jiang et al., 2013; Chakraborti et al., 2015; Shankar et al., 2014). Furthermore, the presence of other HMs: Pb, Cd, and Mn is frequently reported (Ganguli et al., 2021; Bodrud-Doza et al., 2016). Specifically, in the slums of Dhaka city, studies have linked the reliance on tube-well water, exacerbated by high population density and poor sanitation, to a high frequency of diseases such as diarrhea and skin conditions (Bhuyan et al., 2017).

Although water quality indices (WQIs) and health risk assessment models are established tools for evaluating water potability and health impacts, a focused, multi-index investigation combining these approaches has not been systematically applied to the sources of GW serving slum communities in Dhaka. Thus, this study is designed to assess GW quality in these underserved areas through measurement of some key physicochemical parameters: pH, dissolved oxygen (DO), total dissolved solids (TDS), total suspended solids (TSS), turbidity, and concentration of some hazardous HMs: As, Cr, Hg, Mn, Pb, and Fe. However, multiple WQIs like the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI), Heavy Metal Pollution Index (HPI), Contamination Index (CI), Heavy Metal Evaluation Index (HEI), and Nemerow's Pollution Index (NI) were calculated through observed physicochemical parameters and concentration of HMs to classify the GW quality and identify pollution hotspots. Additionally, various human health risk assessment models including Hazard Quotient (HQ), Hazard Index (HI), and Carcinogenic Risk (CR) were applied to quantify the non-carcinogenic and carcinogenic risks for the consuming population (Prasad and Bose, 2001; Edet and Offiong, 2002; EPA, 2011). The results will be judged against national and international standards (World Health Organization (WHO) and Bangladesh) to determine GW quality and mark priority contaminants. By connecting conventional WQIs with advanced pollution indices (PIs) and quantified health risks, this research aims to inform policymakers, water authorities, and development organizations about the pollution status of GW in slum areas of Dhaka-Narayanganj city. Ultimately, this work seeks to contribute to improved water security, enhanced public health resilience, and more equitable development for vulnerable communities in one of the most densely populated and environmentally challenged megacities of the world (Nahar et al., 2014).

Table 1. Local names of the sampling stations from where GW were collected.

Station No.	Location Name
1	Shyampur, Dhaka
2	Rasulpur Dhaka
3	Hasnabad, Dhaka
4	Keraniganj, Dhaka
5	Lalbagh, Dhaka
6	Tarabo, Narayanganj
7	Rupganj, Narayanganj
8	Shiddhirganj Housing
9	Shimrail, Shiddhirganj
10	Adamjee Geneva Camp, Narayanganj
11	Mirpur Eastern Housing, Dhaka
12	Mirpur 1, Dhaka
13	Hemayetpur, Dhaka
14	Savar
15	Kunipara, Dhaka
16	Korail, Mohakhali, Dhaka
17	Kalshi, Dhaka
18	Mirpur 12, Dhaka
19	Basila, Mohammadpur, Dhaka
20	Geneva Camp, Dhaka
21	Hazaribagh, Dhaka
22	Kamarpara, Dhaka
23	Tongi, Dhaka

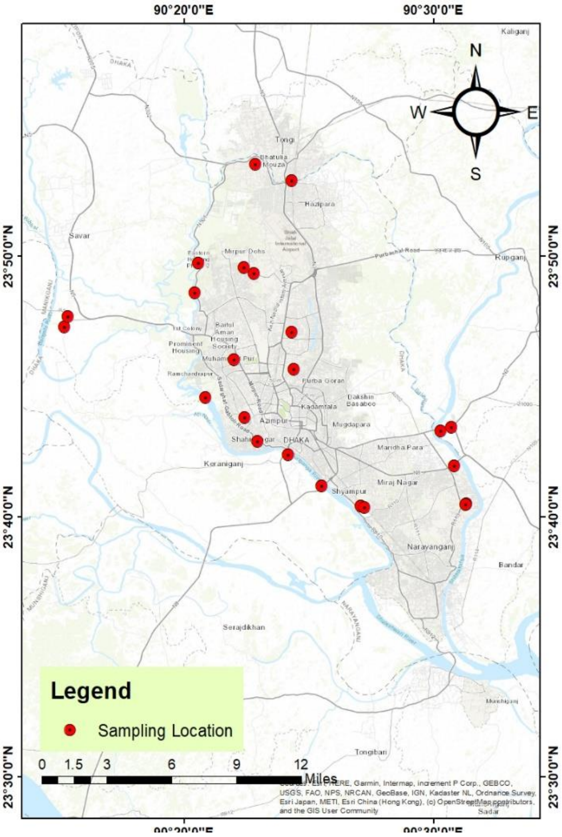

Fig. 1. Geographical coordinates of study area covering Dhaka-Narayanganj city of Bangladesh.

Materials and Methods

Study areas

The study was conducted within informal settlements ("slums") in Dhaka city, one of the most densely populated megacities of the world, located in central Bangladesh between latitudes 23°42' and 23°54' N and longitudes 90°20' and 90°28' E. The hydrogeological setting is characterized by the Pleistocene Madhupur Clay terrace and Holocene alluvial deposits of the Bengal Delta Plain (BDP), with the shallow and deep aquifers serving as the primary sources of water supply for the residents of the city (Shamsudduha et al., 2011). Water samples were preselected from both GW and SW sources, primarily tube wells and taps used for drinking and domestic purposes. This approach was designed to capture potential exposure pathways and environmental contamination profiles relevant to the resident communities, aligning with hazard-identification principles outlined in WHO guidance of DW (WHO, 2017). A total of 23 GW samples were collected across 21 distinct slums in Dhaka-Narayangonj city (Table 1 and Fig. 1).

Collection of samples

The sampling strategy was purposive rather than probabilistic, designed to include multiple slum localities and representative water source types. At each station, GW was collected in clean, appropriately labeled 500 mL polyethene (PE) plastic containers. Before collection, each tube well was flushed for 3-5 mins to ensure representative GW samples were obtained. GW samples for HM analyses were collected separately in 250 mL PE bottles and acidified with conc. HNO_3 to pH < 2 for preservation, following Environment Protection Agency (EPA) method 200.8 specifications (USEPA, 1994).

Questionnaire survey

A structured questionnaire survey was conducted to collect data about the GW consumption and potential exposure pathways in the selected slum area of the Dhaka-Narayanganj region. The survey was designed to collect data about the demographic breakdown of respondents, primary source of DW, consumption rate, water treatment practice, and water-related health issues. Approximately 7 to 8 families from every slum were randomly selected for the questionnaire survey. Adult members of each family, both male and female, who had been living in those slums at least for 10 years were considered for the survey. Information on health-related issues was obtained through respondents' self-reports during face-to-face interviews, where common health issues like diarrhea, skin disease, and itching were both diagnosed and self-observed based on respondents' personal experiences.

Analysis of physicochemical parameters

In situ physicochemical parameters: pH, DO (mg/L), TDS (ppm), and turbidity (NTU) were measured immediately after sample collection using a calibrated Hanna multiparameter meter (HI9829). TSS was measured by gravimetric method (US EPA, 2009) using 47 mm diameter and 45 µm nominal pore size Whatman filter paper and a vacuum pump. TSS was calculated with the equation TSS (mg/L) = (W_f - W_0) × 1000/V, where W_0 = initial wt. of filter paper (mg), W_f = mass of dried residue and filter paper (mg), and V = volume of sample water taken (mL).

Analysis of concentration of nutrients

Nutrient concentrations were analyzed using a HACH DR3900 UV-Vis spectrophotometer (Hansen and Koroleff, 1999) following standard operation methods. Phosphate, nitrate, and ammonia were measured using the USEPA PhosVer 3 (Ascorbic Acid) method (suitable for orthophosphate levels in the range of 0.02-2.50 mg/L), the cadmium reduction method (applicable for concentrations of 0.3-30.0 mg/L), and the USEPA Nessler method (effective for concentrations ranging from 0.02-2.50 mg/L in SW), respectively.

Analysis of concentration of heavy metals

Concentrations of six HMs: As, Cr, Hg, Fe, Mn, and Pb were measured using an Inductively Coupled Plasma Mass Spectrometer (ICP-MS). EPA method 200.8 for trace element determination by ICP-MS was followed (USEPA, 1994) for sample preparation, preservation, and acid digestion.

Statistical analysis

Descriptive statistics (mean, standard deviation, minimum, maximum, median) were analyzed for all water quality parameters. Correlation analysis was performed using Pearson's correlation coefficient to identify relationships between various HMs. All statistical analyses were performed using Python and Microsoft Excel 2019.

Determination of water quality indices

14 water quality parameters (pH, DO, turbidity, TDS, TSS, with concentration of phosphate, ammonia, nitrate, As, Fe, Pb, Hg, Mn, and Cr) were selected to calculate CCME-WQI using equation (CCME, 2001): $WQI = 100 - [\sqrt{(F1^2 + F2^2 + F3^2)}/1.732]$, where F1 (scope) = % of parameters that exceed guidelines, F2 (frequency) = % of failed tests, and F3 (amplitude) = extent by which failed tests exceed guidelines. CCME-WQI values were classified as *excellent* (95-100), *good* (80-94), *fair* (65-79), *marginal* (45-64), and *poor* (0-44). HPI was calculated using the weighted arithmetic quality rating method (Prasad and Bose, 2001) as $HPI = \Sigma(Wi \times Qi)/\Sigma Wi$, where Wi is the unit weight of the i-th parameter (inversely proportional to its permissible standard Si) and Qi is the quality rating calculated with $Qi = 100\times[(Mi-Ii)/(Si-Ii)]$, where Mi is the monitored concentration, Ii is the ideal value (0 for toxic metals), and Si is the permissible standard. HPI values were classified as *low* (HPI < 15), *medium* ($15 \leq HPI < 30$), and *high* ($HPI \geq 30$). NI (Nemerow, 1974) was calculated using $NI = \sqrt{[(\bar{P}^2 + Pmax^2)/2]}$, where $\bar{P}$ is the mean contamination factor of all metals and Pmax is the maximum contamination factor. NI values were classified as *clean* (NI < 0.7), *no pollution* ($0.7 \leq NI < 1.0$), *warm* ($1.0 \leq NI < 2.0$), and *polluted* ($NI \geq 2.0$). CI and HEI were calculated as follows (Edet and Offiong, 2002): $CI = \Sigma [(Mi/Si)-1]$ and $HEI = \Sigma (Mi/MAC)$, where MAC is the maximum admissible concentration for DW. CI values were classified as *low* (CI < 1), *medium* ($1 \leq CI < 3$), and *high* ($CI \geq 3$). HEI values were classified as *low* (HEI < 10), *medium* ($10 \leq HEI < 20$), and *high* ($HEI \geq 20$).

Assessment of human health risk

A health risk assessment was conducted following the USEPA method (USEPA, 1989, 2011) to evaluate both non-carcinogenic and CR associated with HM exposure through DW. Chronic daily intake (CDI) of HMs through oral ingestion was calculated as $CDI = (C \times IR \times EF \times ED)/(BW \times AT)$; here, C = metal concentration in water (mg/L), IR = ingestion rate (2 L/day for adults), EF = exposure frequency (365 days/year), ED = exposure duration (70 years for CR, 30 years for non-carcinogenic risk), BW =

average body weight (70 kg for adults), and AT = averaging time (ED × 365 days for non-carcinogenic; 70 × 365 days for carcinogenic). Non-carcinogenic risk: HQ and HI, where HQ was calculated as HQ = CDI/RfD, and RfD is the oral reference dose for each HM (EPA, 2011). HI was calculated as the sum of HQs for all HMs: $HI = \Sigma HQi$, and $HI < 1$ indicates *no significant* non-carcinogenic risk, while $HI \geq 1$ indicates *potential adverse* health effects. CR for individual HM was evaluated as follows: CR = CDI × SF; SF is the oral slope factor $(mg/kg/day)^{-1}$. Total CR was calculated as the sum of CR values of individual HM. Risk levels were classified as *tolerable* ($CR \leq 1 \times 10^{-4}$) and *unacceptable* ($CR > 1 \times 10^{-4}$) (USEPA, 2011).

Results and Discussion

Physicochemical parameters

pH distribution was approximately normal, although a slightly acidic GW was found at stations 16, 17, and 18, introducing a minor negative skew (Fig. 2a) which can enhance corrosion of plumbing materials and potentially mobilize trace metals (WHO, 2021). 19 water samples out of 23 stations fell within the guideline of WHO, 2021 (Table 2) and the observed range of pH is consistent with values reported for GW of Dhaka (Hasan et al., 2019). DO variation was distinctly nonnormal and bimodal (Fig. 2b): most stations (1-18) had DO < 2 mg/L, characteristic of anoxic GW, while stations 19-23 showed DO >7.5 mg/L, suggesting recent recharge or mixing with oxygenated SW (Meybeck and Helmer, 1996). This bimodality indicates that the sampled aquifers belong to two different hydrochemical environments, and changes of TSS were heavily skewed by two extreme outliers: station 5 (21 mg/L) and 16 (23 mg/L) (Fig. 2c) likely resulting from poor well casing or recent disturbance, allowing particulate matter to enter the sample (Rice et al., 2017). Most water samples, however, had TSS ≤ 1 mg/L, indicating generally clear GW in the slums of the Dhaka-Narayangonj city. Furthermore, TDS displayed the greatest variability among all physicochemical parameters with a strong positive skew (Fig. 2d). Most water samples were < 400 ppm, but station 6 reached 804 ppm, indicating localized mineralization. All values were less than the Bangladesh standard of 1000 ppm (Table 2). Turbidity values show a positively skewed pattern (Fig. 2e) where the majority of stations were indicating clear water conditions with lower values, whereas a small number of higher turbidity values exceeding 7 NTU create a long tail and contribute to noticeable variability in the dataset. These observational values show occasional spikes in turbidity, which may indicate localized disturbances, including sediment resuspension, runoff, or anthropogenic inputs.

Concentration of nutrients

Nitrate concentrations showed only mild right skew (Fig. 3a) and all water samples were well below the WHO guideline (Table 2) and the Bangladesh standard of 45 mg/L. Moderate values reflect limited anthropogenic input, although the presence of nitrate even at low levels indicates some influence from wastewater or fertilizer runoff (WHO, 2021). Phosphate levels varied with a mild right skew (Fig. 3b), and while it is not a direct health hazard at these observed concentrations, its presence signals possible contamination from sewage, detergents, or organic waste. Elevated values at stations 8 (0.72 mg/L) and 5 (0.33 mg/L) may indicate localized pollution sources. Ammonia showed a strong right-skewed distribution (Fig. 3c) with most values near zero but two pronounced hotspots: station 10 (0.72 mg/L) and 6 (2.03 mg/L). Station 6 exceeded the WHO guideline (Table 2) indicating fresh organic contamination, likely from sewage or industrial effluent. The isolated nature of these hotspots suggests that ammonia contamination is highly localized.

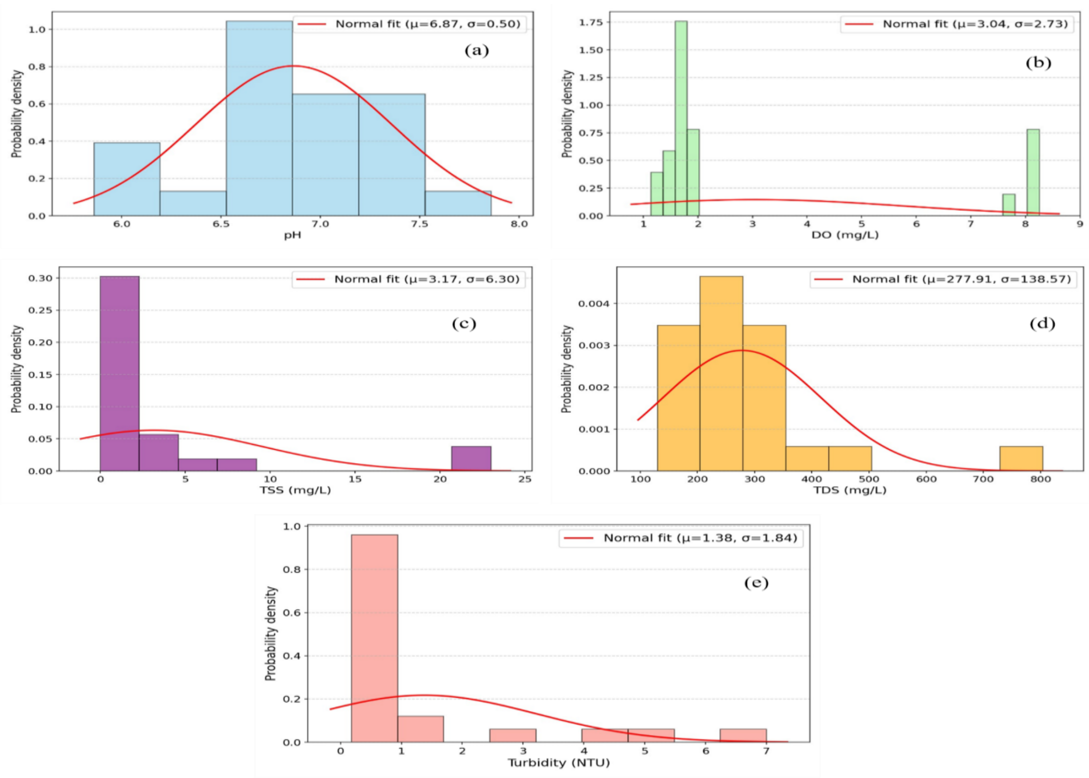

Fig. 2. Distribution curve of (a) pH (b) DO (c) TSS, (d) TDS and (e) turbidity of GW collected from different slums of the Dhaka-Narayanganj city of Bangladesh.

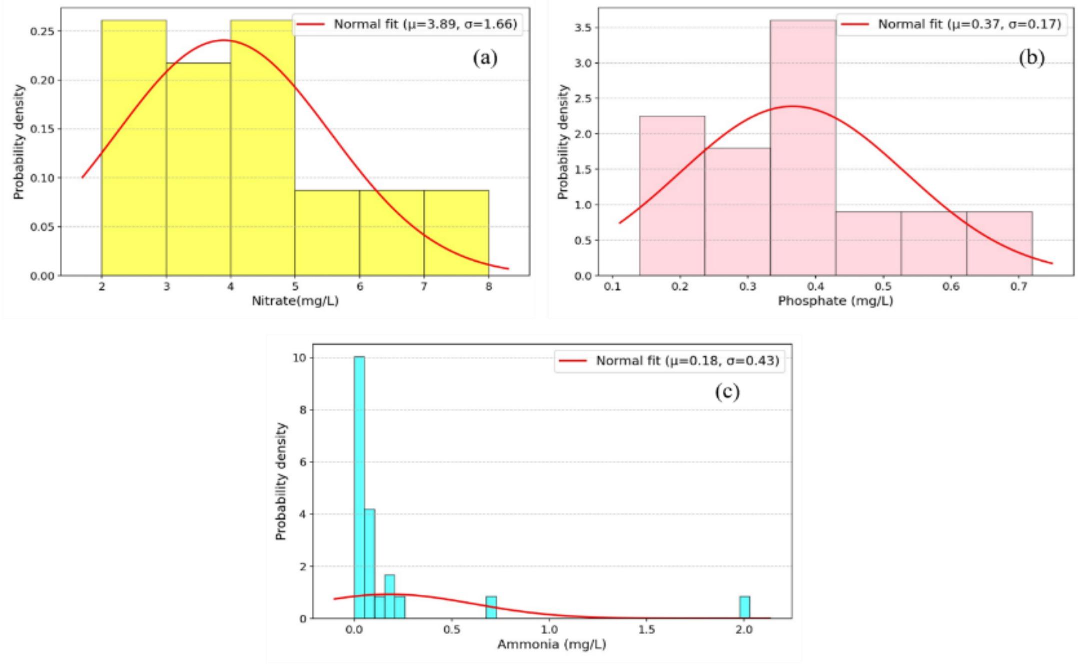

Fig. 3. Distribution curve of concentration of (a) nitrate, (b) phosphate and (c) ammonia in GW collected from different slums of the Dhaka-Narayanganj city of Bangladesh.

Concentrations of heavy metals

Maximum and minimum concentrations of As were observed at stations 8 and 13, respectively (Fig. 4a) and all water samples have levels of As below the WHO guideline (Table 2). Highest concentrations occurred in the Shiddhirganj industrial area, suggesting a possible anthropogenic contribution in addition to natural geogenic sources. Although below the instantaneous safety threshold, chronic exposure even at these levels contributes to cumulative CR (Flanagan et al., 2012). Observed concentrations of Cr in all water samples were far below the WHO guideline (Table 2): lowest in station 7 and highest in station 22 (Fig. 4b). Peak levels at station 22 (Kamarpara) may reflect local industrial activity (tanneries, electroplating) or natural ultramafic sources (International Agency for Research on Cancer, 2012). Concentration of Hg was highest in station 8 and lowest in station 22 (Fig. 4c) although in all water samples, Hg levels were below the limits of WHO (Table 2). Elevated value at station 8 (Shiddhirganj) is consistent with industrial discharge; Hg is also known to accumulate from atmospheric deposition (Futsaeter and Wilson, 2013).

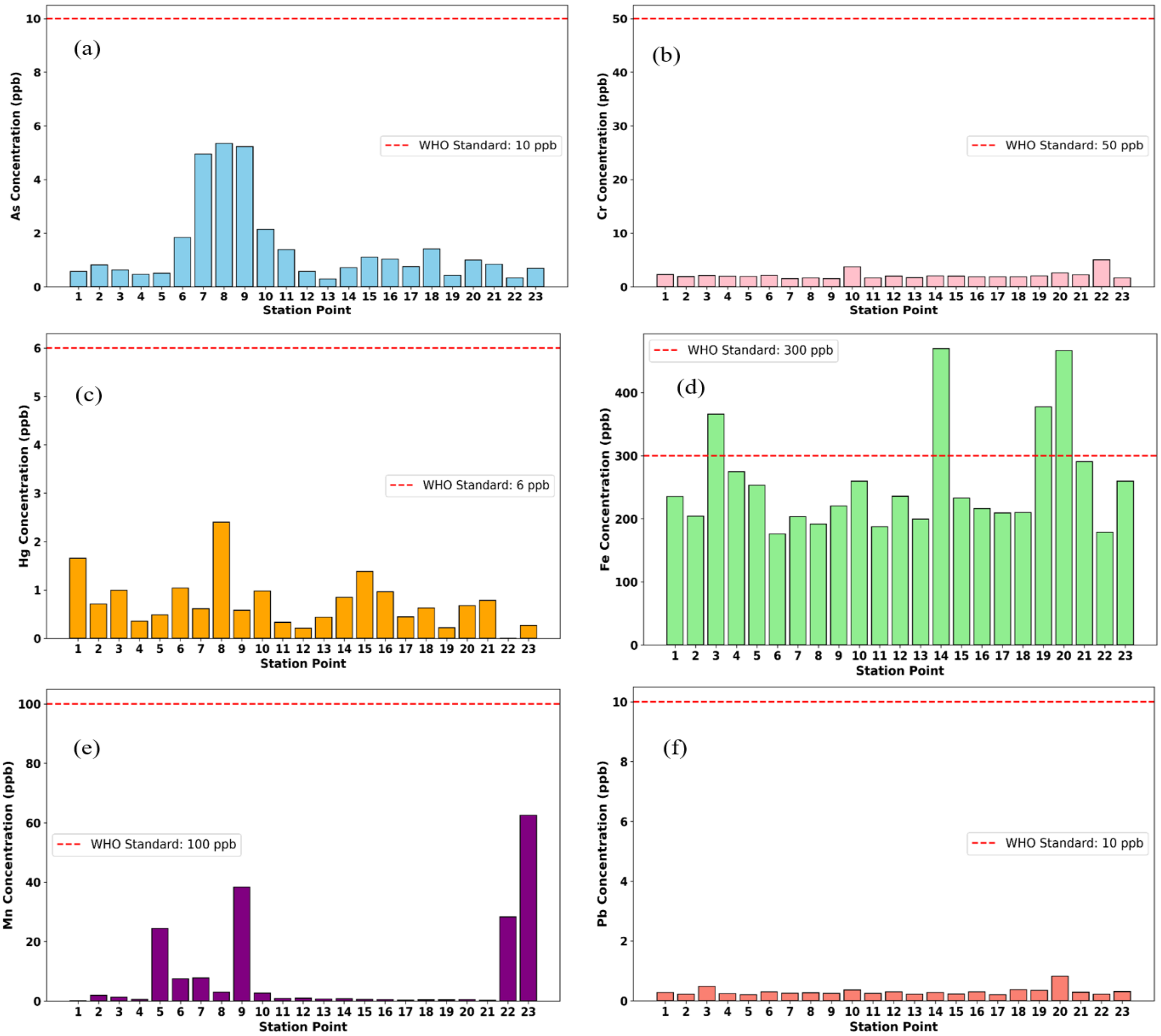

Fig. 4. Variation in concentration of (a) As (b) Cr (c) Hg (d) Fe (e) Mn and (f) Pb in GW collected from different slums of the Dhaka-Narayanganj city of Bangladesh.

Among all HMs, Fe was the dominant one, where the highest and lowest levels were found at stations 14 and 6, respectively (Fig. 4d). Stations 3, 14, 19, and 20 exceeded the WHO aesthetic guideline (Table 2) containing 365.8, 470.0, 377.4, and 466.7 ppb, respectively, as high levels of Fe are common in Bangladeshi GW for reducing conditions that favor Fe(II) dissolution (Hasan et al., 2019). While not a direct health risk, elevated Fe causes discoloration, metallic taste, and staining, reducing consumer acceptability (WHO, 2021). Although concentrations of Mn (Fig. 4e) in all GW samples were below the WHO health guideline (Table 2), indicating safe levels. But stations 5, 9, 22, and 23 showed comparatively elevated levels where these stations approached a higher aesthetic threshold than others and may be considered potential localized hotspots of contamination. Furthermore, concentrations of Pb were uniformly low: lowest at station 5 and highest at station 20 (Fig. 4f). All values were far below the WHO limits of DW (Table 2), indicating minimal contamination from Pb plumbing or industrial sources.

Statistical analysis

Descriptive statistics of the physicochemical parameters, concentration of nutrients as well as HMs in GW of the Dhaka-Narayangonj city of Bangladesh are summarized in Table 2.

Table 2. Statistical summary of physicochemical parameters, concentration of nutrients as well as HMs in GW of the Dhaka-Narayangonj city of Bangladesh with WHO (n = 23).

Parameter	Unit	Min	Max	Mean	SD	Median	Permissible Limits of DW According to WHO
pH	–	5.86	7.86	6.80	0.57	6.84	6.5 - 8.5
DO	mg/L	1.14	8.26	2.98	2.68	1.72	-
TDS		93	804	270.2	140.7	238.5	No strict health limit (usually <1000 recommended)
TSS		0	23	3.04	6.20	0.5	1
Turbidity	NTU	0.18	7	1.38	1.82	0.67	≤1
Nitrate	mg/L	2.0	8.0	3.94	1.64	4.0	50
Phosphate		0.14	0.72	0.37	0.16	0.36	6
Ammonia		0.00	2.03	0.17	0.42	0.05	0.5
As	ppb	0.296	5.350	1.63	1.26	2.82	10
Cr		1.544	5.021	2.26	0.87	3.28	50
Hg		0.002	2.400	0.73	0.60	1.20	10
Fe		176.0	470.0	256.4	73.5	323.0	< 300
Mn		0.142	62.51	8.47	15.59	31.33	100
Pb		0.203	0.824	0.32	0.16	0.51	50

Heavy metal abundance and hotspots

The overall abundance pattern based on mean concentrations of various HMs was Fe > Mn > Cr > As > Hg > Pb indicates the dominance of lithogenic elements (Fe and Mn) over trace metals of anthropogenic origin, corresponding with the BDP, where Fe-bearing minerals are prevalent in aquifer sediments (Hasan et al., 2019; Hasan et al., 2022). HM pollution is site-specific rather than uniform, as observed in varying HM distribution of the study areas, which implies a complex interaction of anthropogenic and geogenic influences. Multivariate statistical studies in Bangladesh consistently identify three dominant source categories: geogenic sources (~54-60%), primarily controlling Fe, Mn, and baseline concentrations through dissolution of Fe/Mn-bearing minerals in the reducing aquifer conditions typical of the BDP (Hasan et al., 2022; Hossain et al., 2025); anthropogenic sources (~20–25%), dominating Cr, Hg, Pb, and hotspot As signatures through industrial effluents (tanneries, steel, battery, and paint industries), sewage discharge, and solid waste leachate (Ariyan et al., 2025; Basir et al., 2025; Islam et al., 2025) and mixed sources (~15–25%) where natural processes and human activities intersect: industrial zones overlying geogenically enriched aquifers (Khan et al., 2020); (Zahid et al., 2006). Most alarming HMs profiles were found at stations 8 (Shiddhirganj), 22 (Kamarpara), and 20 (Mohammadpur Geneva Camp) due to this tripartite source apportionment and show an intersection of favorable geochemical conditions (reducing aquifers, Fe/Mn-rich sediments) with intense anthropogenic pressure (industrial activity, high population density, and inadequate waste management). Thus, the study highlights the fact that the GW vulnerability in slums of the Dhaka-Narayanganj city is not only a result of background geology but is also significantly increased by localized human activity, especially in areas where uncontrolled urban development and industrial discharge coexist with abundant metal mobility (Jubairul et al., 2025). Table 3 summarizes the possible hotspots of HMs with their probable sources.

Table 3. Hotspots of HMs and their probable sources in GW of the Dhaka-Narayangonj city of Bangladesh.

Station No.	Location	Elevated Metals	Probable Source(s)	Ref
8	Shiddhirganj	As, Hg	Industrial discharge (steel, battery, paint industries); mixed anthropogenic sources	(Ariyan et al., 2025; Basir et al., 2025)
22	Kamarpara	Cr	Tannery waste; industrial effluent	(Khan et al., 2020; Zahid et al., 2006)
14 and 20	Savar, Mohammadpur	Fe	Geogenic (dissolution of Fe-bearing minerals); possible industrial overlay	(Hasan et al., 2019; Basir et al., 2025)
23	Tongi	Mn	Reductive dissolution of Mn-oxides in reducing aquifer conditions; potential industrial mixing	(Jubairul et al., 2025; Hossain et al., 2025)
20	Mohammadpur Geneva Camp	Pb	Battery recycling/manufacturing; industrial waste	(Ariyan et al., 2025;Islam et al., 2025)

Correlation analysis

The Pearson correlation between various HMs showed that a strong positive correlation (Fig. 5) between Fe and Pb ($r = 0.65$) suggests a common geological source, probably weathering of Fe-bearing minerals that also contain trace Pb. A moderate correlation between As and Hg ($r = 0.42$) may indicate similar geochemical mobilization conditions or a shared industrial source. Other HMs show weak correlations, implying diverse origins.

Pollution indices and classification of water quality

CCME-WQI (Fig. 6) integrates the measured values of various physicochemical parameters and concentrations of HMs in GW (Table 2) collected from different slums of the Dhaka-Narayangonj city, and water quality varied in different areas (Table 4). Station 6 (Tarabo) had the lowest WQI (79.7) due to high levels of ammonia, turbidity, and As.

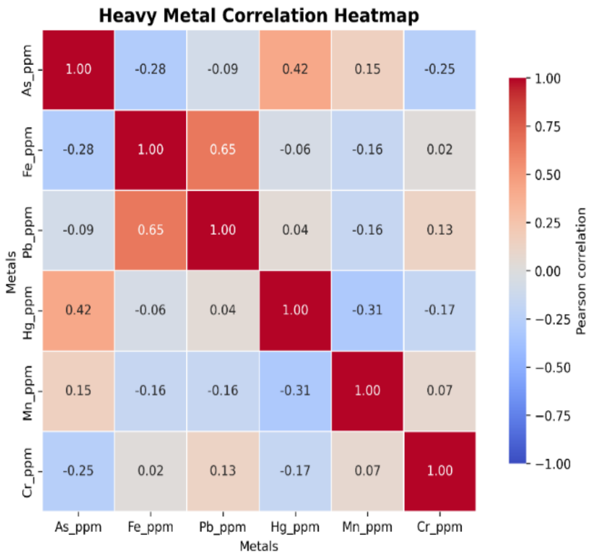

Fig. 5. Pearson correlation between concentration of HMs observed in GW collected from different slums of the Dhaka-Narayanganj city of Bangladesh.

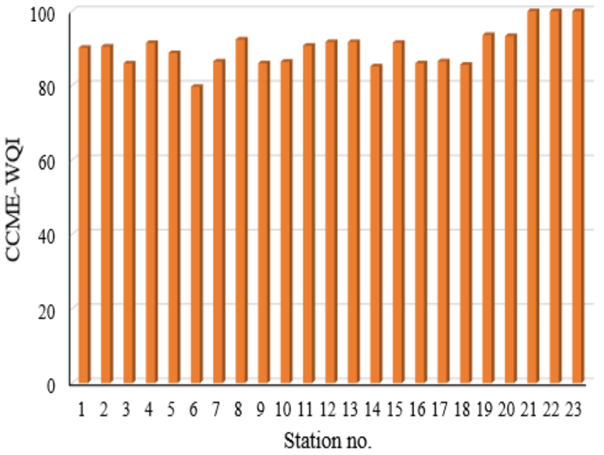

Fig. 6. CCME-WQI of GW collected from different slums of the Dhaka-Narayanganj city of Bangladesh.

Calculated CI values ranged from -5.178 to -4.097 (Fig. 7) and all 23 stations were classified as *low* contamination with HMs and reflect that most concentrations of HMs are below their respective background references. HEI ranged from 0.822 to 1.903 (Fig. 7) with all stations falling into the *low* pollution category, and confirms that the cumulative HM load is generally low across the study areas. NI provided a more discriminating assessment: *clean* ($NI < 0.7$) for 12 stations, *no pollution* ($0.7 \leq NI < 1.0$) for 6 stations, *warm* ($1.0 \leq NI < 2.0$) for 3 stations (3, 19, and 21), and *polluted* ($NI \geq 2.0$) for 2 stations (14 and 20) (Fig. 7). Stations 14 and 20, both with very high levels of Fe, were classified as *polluted*, highlighting Fe as the main contributor to the NI. HPI values ranged from 2.48 to 32.02 (mean 10.62): *low pollution* ($HPI < 15$) in 20 stations, *medium pollution* ($15 \leq HPI < 30$) in stations 7 (18.31) and 9 (18.86), and *high pollution* ($HPI \geq 30$) in station 8 (32.02). Station 8, with elevated As and Hg, emerged as the most significant HM hotspot (Table 3). Approximately 83.3 % of water bodies in the divisions of Dhaka, Chittagong, and Mymensingh have HPI values greater than 100 (Proshad et al., 2018).

Table 4. Water quality status of GW collected from different slums of Dhaka-Narayanganj city of Bangladesh based on CCME-WQI values.

Serial No.	WQI Range	Status	Possible Use	Represent Station
1	95 - 100	Excellent	Suitable for drinking, aquatic life, irrigation, recreation, and industrial use without treatment	21, 22, 23
2	80 - 94	Good	Suitable for drinking, irrigation, fisheries, and recreation.	1 - 5, 7 - 20
3	65 - 79	Fair	Can be used for irrigation and some industrial uses, but drinking requires proper treatment.	6

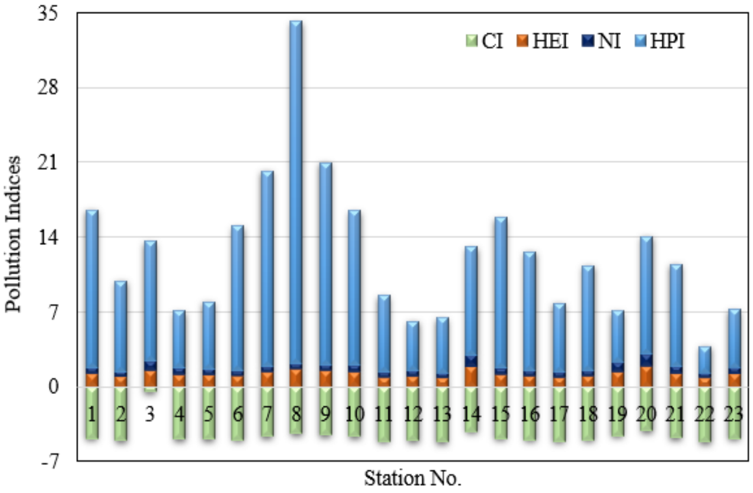

Fig. 7. Various pollution indices based on observed concentration of HMs in GW collected from different slums of the Dhaka-Narayanganj city of Bangladesh.

Human health risk assessment

Non-carcinogenic risk

HQ for individual HMs and the summed HI are presented in **Error! Reference source not found.** 8a, where HI values ranged from 0.095 (station 22) to 0.765 (station 8), with a mean of 0.234. All stations had HI < 1, classified as "*no significant risk*" for non-carcinogenic effects.

Carcinogenic risk

CR was calculated for As and Cr (Fig. 8b) with established slope factors (EPA, 2011). Total CR values ranged from 3.70×10^{-5} to 2.53×10^{-4}, where *tolerable* risk ($\leq 1\times10^{-4}$) for 18 stations and *unacceptable* risk ($> 1\times10^{-4}$) for station 6 (Narayanganj), 7 (Rupganj), 8 and 9 (Shiddhirganj), and 10 (Adamjee Genevacamp). Highest total CR occurred at station 8 (2.53×10^{-4}), followed by stations 9 (2.46×10^{-4}) and 7 (2.34×10^{-4}). Even though concentrations of As at these stations were below the guideline of WHO, they still pose an *unacceptable* lifetime CR when there is continuous ingestion and dermal contact with As-contaminated GW over many years (Abdelhalim et al., 2023). Thus, compliance with single-parameter benchmark values does not automatically imply absence of chronic health risks. Although conventional PIs suggested generally *low* contamination, CR assessment identified a localized cluster of *unacceptable*-risk stations, especially around stations 6-10 and most critically station 8 (Shiddhirganj).

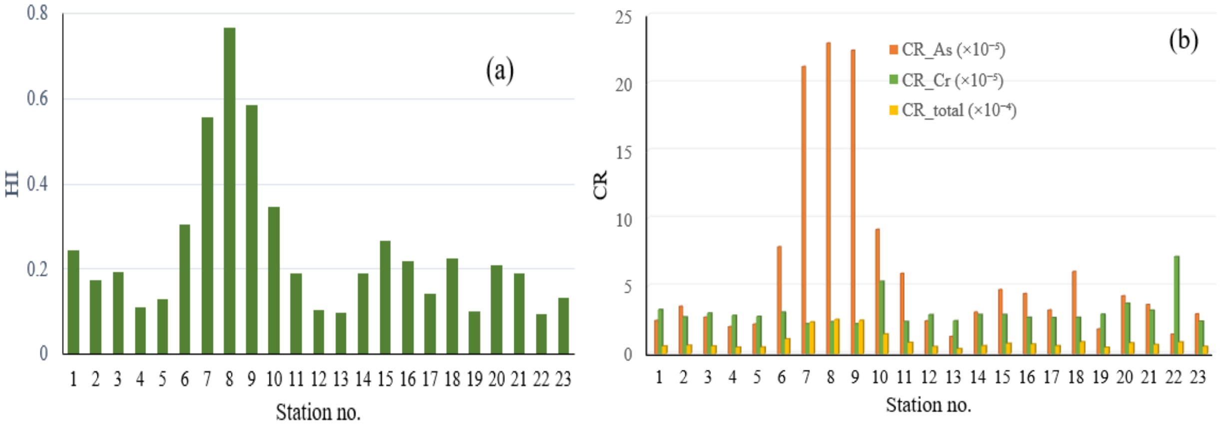

Fig. 8. HI and CR based on observed concentration of HMs in GW collected from different slums of the Dhaka-Narayanganj city of Bangladesh.

According to the questionnaire survey during sample collection from various slums of the Dhaka-Narayanganj city, the overall result shows (Fig. 9) a significant proportion of respondents (45%) reported no specific disease, which suggests that not all exposed populations immediately exhibit visible health effects. However, among the reported health problems, skin diseases were the most common (23%), and the relatively high occurrence of skin-related issues indicates possible contamination of collected GW with irritants or HMs, like the As, which commonly affect the skin upon prolonged exposure.

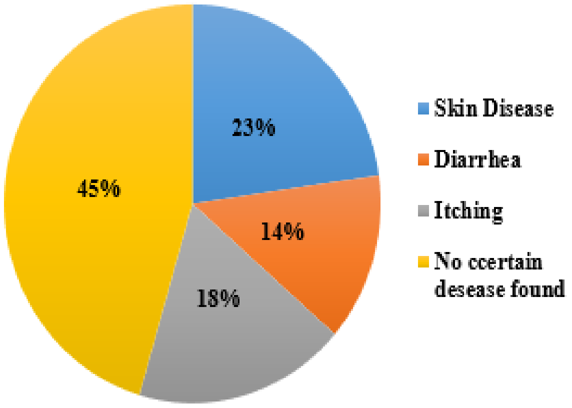

Fig. 9. % of health-risk issues using contaminated GW for domestic purpose in different slums of the Dhaka-Narayanganj city of Bangladesh.

Conclusions

This study comprehensively assessed the groundwater (GW) quality in 23 slum areas across the Dhaka-Narayangonj city, Bangladesh, through analysis of physicochemical parameters, heavy metal (HM) concentrations, nutrient levels, multiple pollution indices and human health risk assessment. The integrated approach showed that the GW in these low-income, densely populated areas exhibits unique hotspot behavior with important public health implications rather than severe widespread contamination. Most physicochemical parameters remained within acceptable limits, generally conforming to WHO guidelines; however, moderate levels of nitrate and phosphate suggested anthropogenic influences, while DO, TDS, TSS, and ammonia showed skewed distribution, reflecting localized rather than widespread contamination. Tarabo, Narayanganj, emerged as a pollution hotspot with elevated ammonia, TDS, and turbidity, resulting in the lowest CCME WQI score among all stations. HM analysis identified Fe as the principal aesthetic concern at several stations exceeding the WHO guideline of 300 ppb. An abundance of HMs was found as Fe > Mn > Cr > As > Hg > Pb, which reflects the dominance of lithogenic elements typical of the Bengal Delta Plain aquifer system.

Even though other HMs remained below health-based guidelines, their cumulative effects indicated critical insights through advanced indexing. Pollution indices revealed subtle assessments; while the Contamination Index and Heavy Metal Evaluation Index classified all stations as "*low*" contamination and the Heavy Metal Pollution Index (HPI) placed 87% of stations in the "*l*ow" category, Nemerow's Pollution Index identified Savar and Mohammadpur Geneva Camp as polluted, while HPI classified the areas of Rupganj and Shiddhirganj of Narayanganj as *medium*- to *high*-pollution zones and HM hotspots with the highest As and Hg concentrations that reflect the convergence of industrial discharge and favorable geochemical conditions. Although most stations were rated “*good*” and “*excellent*” by the CCME-WQI, suggesting generally acceptable water quality. Five stations were found to pose an *unacceptable* lifetime cancer risk, mainly due to As exposure (continuous ingestion and dermal contact with As-contaminated GW) over many years, even when its concentration remained below standard guideline limits of WHO. This suggests that simply meeting regulatory thresholds does not always ensure long-term safety for communities. However, multivariate source apportionment studies from Bangladesh consistently identify geogenic sources controlling Fe and Mn; anthropogenic sources dominating Cr, Hg, Pb, and hotspot As signatures through industrial effluents, sewage discharge, and solid waste leachate; and mixed sources where natural processes and human activities intersect. Therefore, the findings highlight the need to go beyond conventional water quality indices and incorporate health risk assessments to uncover hidden threats and develop more effective and protective water management strategies for vulnerable urban populations.

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Authors contribution

Syeda Jasia Firdaws: Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Visualization, Investigation, Writing - original draft; Rafia Karim: Software, Validation, Visualization, Investigation, Writing - original draft; Ferdousi Begum: Supervision, Conceptualization, Data curation, Methodology, Investigation, Validation, Writing - review and editing; Rakibul Hasan Rabbi: Software, Validation, Visualization; Khandakar Akhter Hossain: Conceptualization, Visualization; Mohammad Moniruzzaman: Formal analysis, Investigation, Methodology, Validation; Md. Abu Bin Hasan Susan: Writing - review and editing.

Declaration

The first and second author declare that they carried out the experimental works in BCSIR and Chemistry and Chemical Oceanography Laboratory (BMU) and the corresponding author certifies that the contents of this paper have not been published before in any journal. The co-authors have edited the paper and consented to the article being considered by the Editorial Board for publication in the Journal of Bangladesh Academy of Sciences.

Conflicting of interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

References

Abdelhalim A, Howard G, Howden NJ, Ahmed M, and Ismail E. Carcinogenic and non-carcinogenic health risk assessment of heavy metals contamination in groundwater in the west of Minia area, Egypt. *Hum Ecol Risk Assess Int J* 2023; 29(2): 571–596.

Rice EW, Baird RB, and Eaton AD, eds. *Standard Methods for the Examination of Water and Wastewater* (23rd ed.). Washington, DC: American Public Health Association, American Water Works Association and Water Environment Federation; 2017.

Ariyan TN, Quraishi SB, Nur E Alam M, Khan MSR, Faria FF, and Kabir A. Comprehensive analysis and human health risk assessment of tap water quality in Dhaka City, Bangladesh: Integrating source identification, index-based evaluation, and heavy metal assessment. *J. Hazard. Mater.*, 2025; 485: 136837.

Basir MS, Anik AH, Siddique MAB., Ikbal Q, and Muktadir MG. Hydrochemical and contamination dynamics of groundwater in relocated tannery area, Dhaka, Bangladesh: Impacts of tannery relocation and preliminary health risks. *Results Eng.* 2025; 26: 105512.

Bhuyan MS, Bakar MA, Akhtar A, Hossain MB, Ali MM, and Islam MS. Heavy metal contamination in surface water and sediment of the Meghna river, Bangladesh. *Environ. Nanotechnol. Monit. Manag.*, 2017; 8: 273–279.

Bodrud-Doza M, Islam ARMT, Ahmed F, Das S, Saha N, and Rahman MS. Characterization of groundwater quality using water evaluation indices, multivariate statistics and geostatistics in central Bangladesh. *Water Sci.*, 2016; 30(1): 19–40.

Canadian Council of Ministers of the Environment. Canadian Water Quality Guidelines for the Protection of Aquatic Life: CCME Water Quality Index 1.0, User’s Manual. Winnipeg, Manitoba: Canadian Council of Ministers of the Environment; 2001.

Chakraborti D, Rahman MM, Mukherjee A, Alauddin M, Hassan M, Dutta RN, Pati S, Mukherjee SC, Roy S, Quamruzzman Q, Rahman M, Morshed S, Islam T, Sorif S, Selim M, Islam MR, and Hossain MM. Groundwater arsenic contamination in Bangladesh-21 Years of Research. *J. Trace Elem. Med. Biol.*, 2015; 31: 237–48.

Edet AE and Offiong OE. Evaluation of water quality pollution indices for heavy metal contamination monitoring. A study case from akpabuyo-odukpani area, lower cross river basin (southeastern Nigeria). *GeoJournal*, 2002; 57(4): 295–304.

Environmental Protection Agency (EPA). Drinking Water Standards and Health Advisories, 820-R-11-002, 2011.

Flanagan S, Johnston R, and Zheng Y. Arsenic in tube well water in Bangladesh: Health and economic impacts and implications for arsenic mitigation. *Bull. World Health Organ.*, 2012; 90(11): 839–846.

Futsaeter G and Wilson S. The UNEP global mercury assessment: sources, emissions and transport. In: *E3S Web of Conferences*. Les Ulis, France: EDP Sciences; 2013. p. 36001.

Ganguli S, Rifat MAH, Das D, Islam S, and Islam MN. Groundwater pollution in Bangladesh: A review. *GJNR*, 2021; 4 (4): 115–145.

Hansen HP and Koroleff F. Determination of nutrients, Chapter 10. In: *Methods of Seawater Analysis*, 3rd ed. Grasshoff K, Kremling K, Ehrhardt M, eds., Weinheim, Germany: Wiley-VCH; 1999; pp. 159–228.

Hasan M, Islam MA, Alam MJ, Rahman M, and Hasan MA. Hydrogeochemical characterization and quality assessment of groundwater resource in savar - An industrialized zone of Bangladesh. *Environ. Monit. Assess.*, 2022; 194(8): 549.

Hasan MK, Shahriar A, and Jim KU. Water pollution in Bangladesh and its impact on public health. *Heliyon*, 2019; *5*(8).

Hossain MI, Alam MM, Tasnim SM, Chowdhury TA, Rahaman M, Aldalbahi A, and Hasnat MA. Hydrogeochemical investigation of the groundwater quality controlling processes involved in north-western Bangladesh using statistical approaches. *Appl. Water Sci.*, 2025; 15(7): 164.

International Agency for Research on Cancer. *A Review of Human Carcinogens: Arsenic, Metals, Fibres, and Dusts: Chromium (VI) Compounds*. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol. 100C. Lyon, France: International Agency for Research on Cancer; 2012.

Islam M, Anannya A, Rahman MS, and Rahman MM. (2015). Present situation of water supply and sanitation at Karail Slum Dhaka. *J. Environ. Sci. Nat. Resour.*, 8(1): 161–163.

Islam N, Reza AHMS, Rahman MA, and Rahman MS. Comprehensive assessment of trace element pollution and its distribution in surface and groundwater around the Ishwardi export processing zone, Bangladesh. *J. Trace Elem. Miner.*, 2025; 2(2): 100238.

Jiang JQ, Ashekuzzaman SM, Jiang A, Sharifuzzaman SM, and Chowdhury SR. Arsenic Contaminated Groundwater and Its Treatment Options in Bangladesh. *Int. J. Environ. Res. Public Health,* 2013; 10 (1): 18–46.

Jubairul H, Raisul HM, Newaz CA, Varner Thomas S, Hasan TM, Nur Alam LM, Parvin S, Dewan AT, and Mesbah UBM. Pollution metrics and health implications of heavy metals in coastal groundwater systems in Bangladesh. *China Geol.* 2025; 9.

Kashem S, Tahsin N, Subah Z, Murshed SB, Nowreen S, and Mondal MS. Assessing the right to water of the urban poor in Dhaka City. *GeoJournal*, 2023; 88(3): 3183–3204.

Khan A, Michelsen N, Marandi A, Hossain R, Hossain MA, Roehl K E, Zahid A, Hassan MQ, and Schüth C. Processes controlling the extent of groundwater pollution with chromium from tanneries in the Hazaribagh area, Dhaka, Bangladesh. *Sci. Total Environ.*, 2020; 710(2): 136213.

Lachassagne P. What Is Groundwater? How to manage and protect groundwater resources. *Ann. Nutr. Metab.*, 2020; 76: 17–24.

Meybeck M and Helmer R. Introduction. In: D. Chapman [Ed.] Water Quality Assessments. A Guide to the use of Biota, Sediments and Water in Environmental Monitoring. 2nd edition. In *Chapman & Hall, London,* 1996.

Nahar MS, Zhang J, Ueda A and Yoshihisa F. Investigation of severe water problem in urban areas of a developing country: the case of Dhaka, Bangladesh. *Environ. Geochem. Health.* 2014; 36(6): 1079–1094.

Nemerow NL. *Scientific stream pollution analysis. McGraw-Hill,* 1974.

Prasad B and Bose JM. Evaluation of the heavy metal pollution index for surface and spring water near a limestone mining area of the lower Himalayas. *Environ. Geol.*, 2001; 41(1-2): 183–188.

Proshad R, Kormoker T, Mursheed N, Monirul MI, Bhuyan MI, Islam MS and Mithu, TN. Heavy metal toxicity in agricultural soil due to rapid industrialization in Bangladesh: A Review. *Int. J. Adv. Geosci.*, 2018; 6(1): 83–88.

Rahman MA and Habiba U. Groundwater quality evaluation and pollution source apportionment using multivariate statistical analyses in Chuadanga Municipality, Bangladesh. *HydroResearch*, 2023; 6: 166–176.

Shamsudduha M, Taylor RG, Ahmed KM and Zahid A. The impact of intensive groundwater abstraction on recharge to a shallow regional aquifer system: Evidence from Bangladesh. *Hydrogeol. J.*, 2011; 19(4): 901–916.

Shankar S, Shanker U, and Shikha. Arsenic contamination of groundwater: A review of sources, prevalence, health risks, and strategies for mitigation. *Sci. World J.,* 2014; 2014, 1–18.

Shukla S and Saxena A. Groundwater quality and associated human health risk assessment in parts of Raebareli District, Uttar Pradesh, India. *Groundwater Sust. Dev.*, 2020; 10: 100366.

Sophocleous M. Interactions between groundwater and surface water: The state of the science. *Hydrogeol. J.*, 2002; 10(1): 52–67.

United States Environmental Protection Agency. Method 200.8: Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma-Mass Spectrometry, Revision 5.4. Cincinnati, OH: United States Environmental Protection Agency; 1994.

United States Environmental Protection Agency. Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual. Washington, DC: United States Environmental Protection Agency; 1989.

Winter TC, Harvey JW, Franke OL, and Alley WM. Ground water and surface water - A single resource - U.S. geological survey circular 1139. 1998, *USGS Publications*.

World Health Organization (WHO), Guidelines for Drinking-Water Quality, 2017.

World Health Organization (WHO). Guidelines for Drinking-Water Quality, 4th ed., Incorporating the 1st addendum (chapters). In *World Health Organization* (Number April 2017), 2021.

Zahid A, Blke KD, Hassan MQ, and Flegr M. Evaluation of aquifer environment under hazaribagh leather processing zone of Dhaka City. *Environ. Geol.*, 2006; 50(4): 495–504.