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Spatial pattern of arsenic concentration and associated noncarcinogenic health risk assessment: a case study on Gangni Union of Chuadanga district of Bangladesh

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Abstract

Groundwater is one of the world's most important sources of fresh drinking water. Various contaminants mix with groundwater and alter its natural composition, such as arsenic. This study aimed to ascertain the present condition of arsenic concentration, its spatial pattern, and its relationship with tube well depth in the Gangni Union in the Chuadanga district of Bangladesh. Additionally, the study tried to assess the associated noncarcinogenic health risks imposed by oral ingestion of arsenic. Systematic sampling was used to collect water samples ($n = 100$) along with depth information from the sample tube wells. Water samples were analyzed with the pre-calibrated Hach EZ, Dual-Range Arsenic Test Kit (Range: 0.00–0.5 mg/l). Both geostatistical (spatial autocorrelation, Hotspot analysis, and IDW) and statistical (descriptive and correlation statistics) methods were used. The resultant arsenic content of the samples tested ranges from 0.0004 (mg/l) to 0.10 (mg/l). Arsenic levels in almost 42% of the samples exceeded the WHO standard, 21% exceeded the Bangladesh standard, and 37% were within the tolerable standard. Geostatistical analysis shows that approximately 63% of the total area is arsenic contaminated. Furthermore, hotspot analysis reveals that the northeastern and southeastern parts of the study area are more arsenic-contaminated than the other parts. Noncarcinogenic health risk assessment shows that children have a higher average daily dose (ADD) range (8.33E-06-0.00181) than adults (2.78E-06-0.0006). Similarly, the hazard quotient (HQ) value is also higher for children (0.0277–6.033) than for adults (0.0092–2.011). The result of Pearson's correlation coefficient, $r(98) = -0.7580$, $p = 0.000$, shows a negative linear relationship between concentration values and depth, meaning that increasing depth will reduce arsenic contamination from tube well water.

Keywords Groundwater, Arsenic contamination, Geostatistics, Hotspot analysis, Health risks

Introduction

Groundwater is frequently used by people in Bangladesh for drinking, cooking, and irrigation, so a significant amount of arsenic contamination can cycle through the ecosystem each year, causing a serious threat to public health and the environment (Sarkar et al. 2022; Safiuddin 2011). Arsenic (As, atomic number 33) is a common element that can be found in the Earth's crust (Bowell et al. 2014). It is the 20th most abundant natural resource and the 12th most abundant in the human body (Rahaman et al. 2022; Thakur et al. 2010). It is found throughout the world in both inorganic and organic forms of arsenic in water (Valiente-Diaz et al. 2023). The oxidation states of arsenic are As (arsenic), As^{V} (arsenate), and As^{III} (arsenite). Arsenic (arsenobetaine, AB, and arsenocholine, AC) and arsenosugar

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compounds are environmental concerns in addition to arsenite, arsenate, and their methylation derivatives (Ivy et al. 2023; Martena et al. 2010). Although the ultimate source of arsenic is geological, human activities such as mining, fossil fuel combustion, and pesticide application also contribute to contamination in groundwater (Yin et al. 2022; Das et al. 2009). Intake of arsenic-contaminated groundwater causes arsenic poisoning, which is one of the most serious issues in Bangladesh. It occurs when the amount of arsenic consumed in the human body surpasses the allowable limit (Schmidt 2014). According to the World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA), the maximum allowable level of arsenic in drinking water is 0.01 mg/l. The maximum allowable level of arsenic in drinking water in Bangladesh is 0.05 mg/l (SAYATO 1989; USEPA 1975). Long-term consumption of arsenic-contaminated water generally results in a variety of pathological conditions (Soria et al. 2021; Mohammed Abdul et al. 2015). Chronic exposure to arsenic causes arsenicosis and results in dermatological manifestations, noncommunicable diseases including cancer, adverse pregnancy outcomes, and decreased intelligence quotients among children (Ahmed et al. 2018).

The Department of Public Health Engineering (DPHE) of the Government of Bangladesh first detected arsenic pollution in the Chapainawabgonj district in 1993 (BICN 2002). In Bangladesh, the concentration of arsenic in groundwater from impacted areas ranges from 0.05 to 2500 g/l. Hossain et al. (2005) found that the arsenic concentration throughout Bangladesh ranges from 1–224 ppb at depths of 23–45 m. Another investigation by DPHE (2009) found arsenic levels above the Bangladesh arsenic threshold for drinking water in 12.6% of tested samples taken from tube wells in 13,423 households across the country (Ahmed et al. 2018). Arsenic pollution is more prevalent in shallow aquifers than in deeper aquifers, and it is mostly found in high concentrations at depths of 9 to 30 m (Tareq 2023; Sarkar et al. 2019). Arsenic-free groundwater can be found at depths of more than 150 to 200 m (Flanagan et al. 2012). Millions of men, women, and children living in arsenic-affected areas of the country's 59 districts out of 64 districts have been fighting to overcome the ongoing battle against the 'arsenic curse' (Tashdedul et al. 2022; Chakraborti et al. 2015). Several disasters struck the country during the twentieth century. Arsenic poisoning in Bangladesh, however, has cast a pall over them all, with over 75 million people at risk and countless having reached the point of no return (Faroque and South 2022). Of 5 million shallow tube wells in Bangladesh, arsenic contamination has polluted 3 million of them (Ahmad and Khan 2023; Shafiuddin and Karim 2003).

Despite its evident harmful effects on people and water quality, the remote part of Bangladesh still lags behind in terms of arsenic contamination-related research. Most previous studies lack an insufficient understanding of the spatial distribution of arsenic. Additionally, there is a limited investigation on the relationship between arsenic concentration and tube well depth. Moreover, preliminary health risk assessment with arsenic data is highly important for understanding the degree of vulnerability. An integrated study using a mixed approach can help to better understand the geospatial character of arsenic risk zones as well as possible health hazards and concentration-depth relationships. Therefore, this study has tried to determine the current state of arsenic concentration, its spatial distribution, its relationship with tube well depth and associated health risks in the Gangni Union in Alamdanga Upazila of Chuadanga district of Bangladesh.

Materials and methods

Study area sampling

Gangni is a Union in Alamdanga Upazila of Chuadanga District in the Khulna Division of Bangladesh. It covers an area of 20.06 km^2 and has a population of 14,426 as per the 2011 census (Bangladesh National Portal 2023). Using the Fishnet tool in ArcGIS 10.4.1, 100 predefined systematic sampling locations (Fig. 1) were selected to properly cover the whole study area. After that, each selected point was visited physically, and 100 ml samples were collected from tube wells in protected plastic bottles. To restrict sample contamination, strong surgical tape was additionally used. Before using these bottles, all of them were washed with distilled water to ensure that they were free of any other impurities. Personal conversations with the owners of the sample tube well sources allowed for the collection of the sources of groundwater depth. Details of the sample dataset is presented in Additional file 1: Appendix-A, Table 6.

Sample verification and analysis

The location of the groundwater samples was verified using a handheld GPS receiver, and arsenic concentrations were measured by the Hach EZ Dual-Range Arsenic Test Kit (detection limit: 0.00–0.5 mg/l). Standard safety precautions and protocols were used to examine the sample.

Statistical analysis

Microsoft Excel was used for descriptive statistical analysis. Whisker plots and correlation coefficients were generated using IBM SPSS Statistics version 26. SPSS was also used to

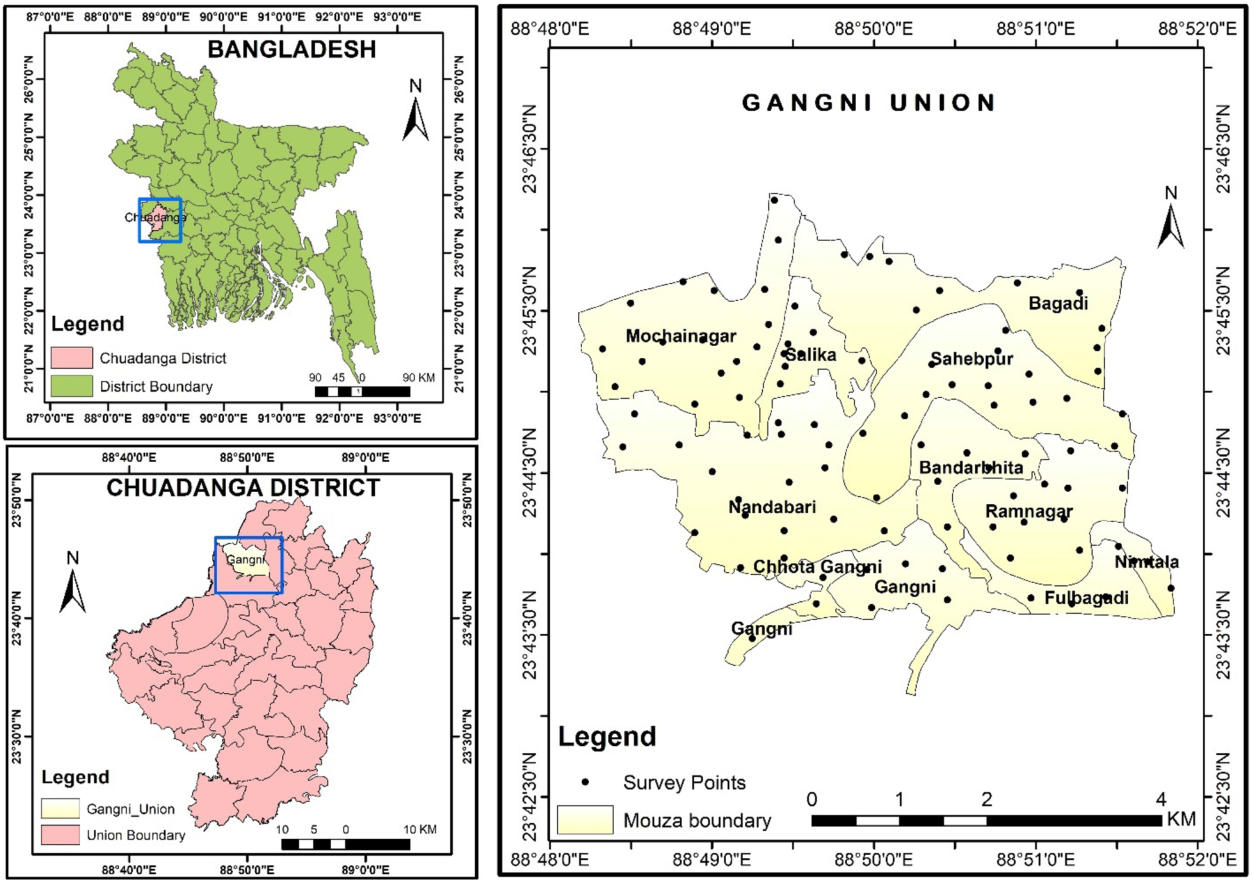

Fig. 1 Map showing the sampling locations in the study area

investigate the connection between the concentration level and the depth of the sample water source by correlation analysis. The value of the correlation coefficient (r) gauges how closely two variables are related. Both a positive or negative magnitude and direction are necessary for the correlation's r value. It may take on a spectrum of absolute, non-dimensional values with no units, ranging from −1 to +1 (Rahman et al. 2022; Biswas et al. 2011). For the two-sided test, a p-value of 0.05 or less was considered statistically significant. The nondimensional Pearson correlation coefficient is unaffected by the linear conversions of either variable (Rodgers and Nicewander 1988). The following formula (Asuero et al. 2006) can be used to calculate the correlation coefficient for two variables:

$$r = \frac{\sum\left(x - \bar{x}\right)\left(y - \bar{y}\right)}{\sqrt{\sum\left(x - \bar{x}\right)^2\left(y - \bar{y}\right)^2}} \quad (1)$$

Geostatistical analysis

Spatial autocorrelation

Spatial autocorrelation was observed by using Moran's I statistic in ArcGIS 10.8. Using the spatial autocorrelation (global Moran's I) numbers, it is possible to determine whether the arsenic levels in the research region were dispersed randomly, in clusters, or uniformly throughout. To assess spatial autocorrelation, Moran's I is a spatial statistics metric that makes use of the whole data set of arsenic to provide a single output value that ranges from 1 to +1 by using the distance threshold 780 m. Moran's I computes the spatial autocorrelation using attribute values and feature positions (Scott and Janikas 2010). Moran's I values near 1 denote a distributed concentration, whereas I values near +1 denote a clustered concentration and, when I value is zero, a randomly distributed concentration (Khosravi et al. 2018). An indication of the presence of the spatial autocorrelation is a statistically substantial Moran's I ($p < 0.01$) that leads to the denial of the null hypothesis (the arsenic level is randomly dispersed) and indicates the existence of spatial autocorrelation (Gu 2023; Xia et al. 2022; Waldhör 1996) and is defined by:

$$I = n/S_0 \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} \left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right) or$$

$$\sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2 S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij}$$

In this case, x_i,x_j stands for the rate of the measurement unit or area i, j, $\bar{x}$ for the average of the rates, n for the total number of spatial units, and w_{ij} is the i, jth portion of the weighting matrix W provided to the comparison between rate i and j and ought to represent the user's opinion of the relationship between the unit i and j.

Hotspot analysis

Hotspot analysis was also performed in ArcGIS 10.8 in a form of spatial analysis and mapping technique that uses the Getis-Ord Gi* statistic to locate clusters of spatial occurrences. It also determines how the spatial autocorrelation differs across the study area. By inputting the arsenic dataset in hotspot analysis, this statistic helps to determine statistically significant hot spots and cold spots by calculating the degree of suggestion that emerges from the concentration of weighted points (Getis and Ord 2010). High-value data points that cluster more strongly when there are positive Z values reflect hot spots (Hossain et al. 2023). Similarly, the lower the z-score for statistically significant negative z-scores, the more concentrated the cluster of low values (Xu et al. 2019), and values close to zero point to a random distribution of clusters with significance (Abdulhafedh 2017). According to Dadashi et al. (2021) and Al-Kindi et al. (2020), a statistical result with an elevated Gi* denotes a "hot spot," whereas a low GI* denotes a "cold spot". The Getis-Ord local statistic by (Getis et al. 2004) is defined as:

$$G_i^* \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{x}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \quad (3)$$

where n is the number of features, x_j is the attribute value for feature j, $w_{i,j}$ is the spatial weight between features i and j, and S is the standard deviation of all features.

Spatial interpolation

The continuous data for the unsampled areas in the study area can be identified with the spatial interpolation method based on the actual results (Hossain et al. 2023). It is an essential tool for spatial analysis and modeling, and a wide range of interpolation techniques are available depending on the characteristics of the data and the research question (Liang et al. 2017). The two primary kinds of spatial interpolation techniques are deterministic and stochastic. Deterministic methods rely on mathematical formulas that estimate values at unsampled sites using measured values at nearby places. IDW, kriging, and spline interpolation are a few examples of deterministic interpolation methods (Taheri and Mohamadi 2019). A well-liked technique for spatial interpolation is inverse distance weighting (IDW), which estimates values at unmeasured places from measured values at nearby locations. The interpolation calculation gives a known location more weight the closer it is to the unknown place (Gong et al. 2014). To illustrate the spatial distribution and perform hotspot analysis, IDW was used to predict the location's concentration using ArcGIS 10.8.

Health risk assessment

Average daily intake dose of arsenic (ADD)

In this study, only the noncarcinogenic health risk of oral ingestion was assessed. The USEPA's Integrated Risk Information System (IRIS): arsenic, inorganic, CASRN 7440-38-2, 1998, was used to create a health risk assessment model to estimate the noncarcinogenic and carcinogenic effects on persons who utilize groundwater as a source of drinking water (Phan et al. 2010).

$$ADD = \frac{\mathrm{IR} \times \mathrm{C} \times \mathrm{ED} \times \mathrm{EF}}{\mathrm{AT} \times \mathrm{BW}}$$

where C is the quantity of arsenic in groundwater (mg/l) and IR is the daily human water consumption in liters. The intake rate (IR) may range from 2 to 3 l (on average 2.5 l) daily (Proshad et al. 2017). The average body weight (BW) for adults was 60 kg, while for children, it was 20 kg. The other characteristics were derived using a mean lifetime of 12,705 days, (Proshad et al. 2017) and the average duration of exposure (ED) was 5.04 years using an exposure frequency (EF) calculated at 365 days per year, and (AT) is the averaging time.

Hazard quotient of arsenic (HQ)

Using the hazard quotient (HQ) (Thompson et al. 1992; Rapant et al. 2011), the possible exposure to human health from noncarcinogenic arsenic was calculated by Eq. (5). There is no significant physiological risk of noncarcinogenic consequences anticipated based on the HQ values if the HQ value is less than 1 (Muhammad et al. 2010; Yousefi et al. 2018). Whenever the HQ value exceeds one or HQ > 1, inhabitants are at risk for noncarcinogenic health problems (Khan et al. 2008). No significant health risk from noncarcinogenic effects is predicted based on the HQ values.

$$HQ = \frac{ADD}{RfD}$$

The EPA's suggested reference dosage for arsenic is RfD, which is 0.0003 mg/kg/day (Sharma 2020), and the daily average dose of arsenic (ADD) is determined by Eq. (4).

Methodological framework

The overall methodologies of this study are expressed by the following flowchart (Fig. 2).

Results

Summary statistics of arsenic

Figure 3 shows a summary of the arsenic concentration in the study area. The lowest recorded concentration is 0.00046, while the highest recorded value is 0.1. The mean concentration is approximately 0.035, while the median value is 0.0343, showing a fairly symmetrical data distribution. The variance and standard deviation are 0.001145539 and 0.03382566, respectively, indicating that the data are dispersed moderately around the mean. The interquartile range (IQR), which represents the middle 50% of the data, spans 0.04377, revealing information about the distribution of the central data points. Detailed statistical summary of this section is included in the Additional file 1: Appendix-B, Table 7–9, Figure 9–11.

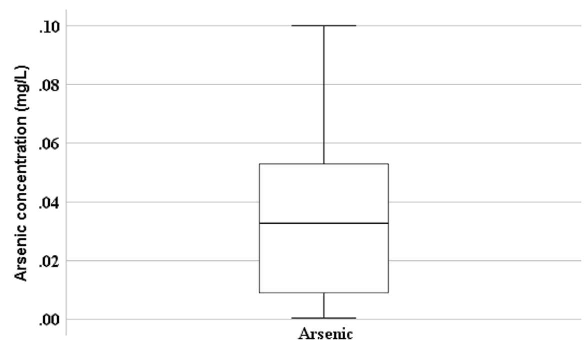

Fig. 3 Whisker plot showing arsenic concentration (mg/l)

A notched box plot ($n = 100$)depicting the arsenic contents in the water from tube wells is displayed. The top and bottom of the notch represent the median's 95% confidence interval (CI). Each data point is represented by a small disk.

Table 1 provides information on arsenic concentrations categorized as minimal (0–<0.01 mg/l), elevated (0.01–0.05 mg/l), and high (> 0.05 mg/l). The distribution shows that 37% of samples are Minimal, 42% are Elevated, and 21% are High in reference to WHO, JECFA and Bangladesh health ministry guideline. The mean concentrations for each category are minimal (0.006 mg/l), elevated (0.03 mg/l), and high (0.08 mg/l). The range varies from 0.0004 to 0.1 mg/l, with minimal ranging from 0.0004 to 0.01 mg/l, elevated ranging from 0.02 to 0.05 mg/l, and

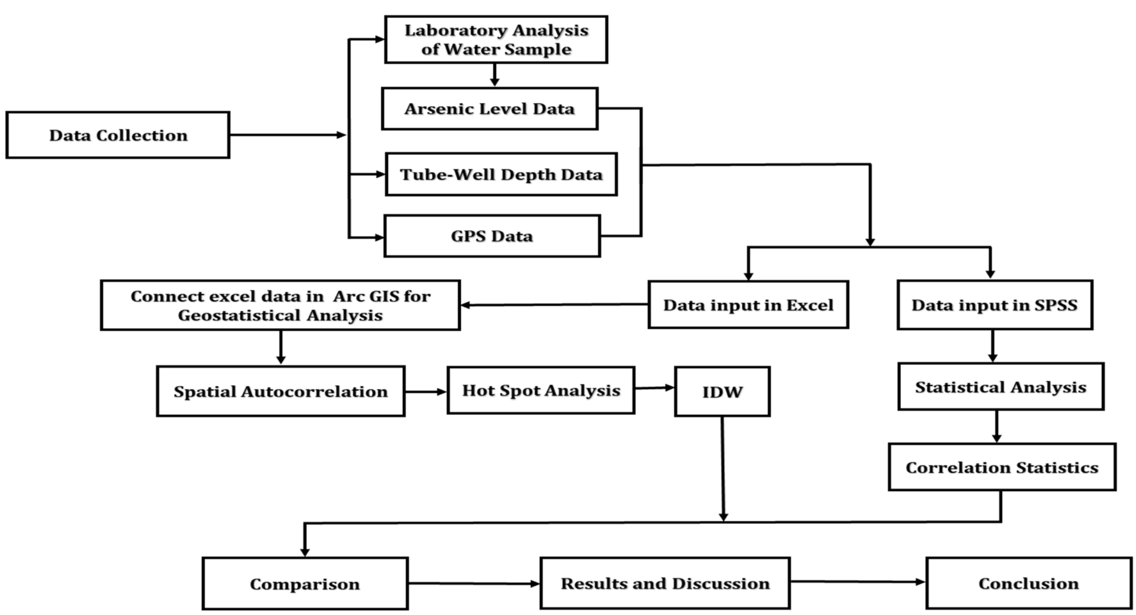

Fig. 2 Methodological flowchart

Table 1 Arsenic concentration distribution for 100 tube wells based on Bangladesh, WHO, and JECFA drinking water quality recommendations

	Category	N (%)	Mean	Min	Max	Median	IQR
Arsenic (mg/l)	Minimal (0–< 0.01[a])	37 (37%)	0.006	0.0004	0.01	0.004	0.001,0.01
	Elevated (0.01–0.05[b])	42 (42%)	0.03	0.02	0.05	0.03	0.03,0.05
	High (> 0.05[c])	21 (21%)	0.08	0.06	0.1	0.08	0.07,0.09

Drinking water standard for [a]WHO health-based value 0.01 mg/l (WHO 2011); [b]JECFA's proposed daily consumption limit for Arsenic in water 0.01–0.005 mg/l (World Health Organization 2004; World Health Organization 2011); [c]Bangladesh health-based value 0.05 mg/l (World Health Organization 2011)

Table 2 Summary statistics of the depth value of the study area

	Mean	Min	Max	Median	IQR	Q1	Q3	Low quartile	High quartile
Tube-well depth(m)	72.598	21	120	72.5	50.125	47.3	97.425	− 27.8875	172.6125

high ranging from 0.06 to 0.1 mg/l. The median concentrations were 0.004 mg/l for Minimal, 0.03 mg/l for Elevated, and 0.08 mg/l for High. The interquartile range (IQR) measures the spread of the middle 50% of data, with values of 0.001–0.01 mg/l for Minimal, 0.03–0.05 mg/l for Elevated, and 0.07–0.09 mg/l for High.

Summary statistics of depth

Table 2 presents the depth information of the sample tube wells. The average depth of the sample tube wells is 72.598 m, with minimum and maximum depths of 21 and 120 m, respectively. The dataset's interquartile range (IQR), which is determined by deducting the first quartile (Q1) from the third quartile (Q3), is 47.3 m. Q1 and Q3 have lengths of 97.425 and 50.125 m, respectively. The dataset's bottom and higher boundaries are represented by the low quartile values of −27.8875 and 172.6125 m, respectively.

Spatial autocorrelation

The distribution (on the right side) shows that there are high concentrations of arsenic present in the sample tube wells. The z value suggested a clustered pattern with less than 1% probability of occurring by chance. The vivid red and blue colors of the terminal tails suggested that the level of relevance increased (Fig. 4).

With a z-score of 3.07, the probability that this clustered pattern is the result of chance is less than 1%. Finally, it should be noted that certain of the research area's locations have been discovered to have high arsenic concentrations, which is known as a cluster pattern.

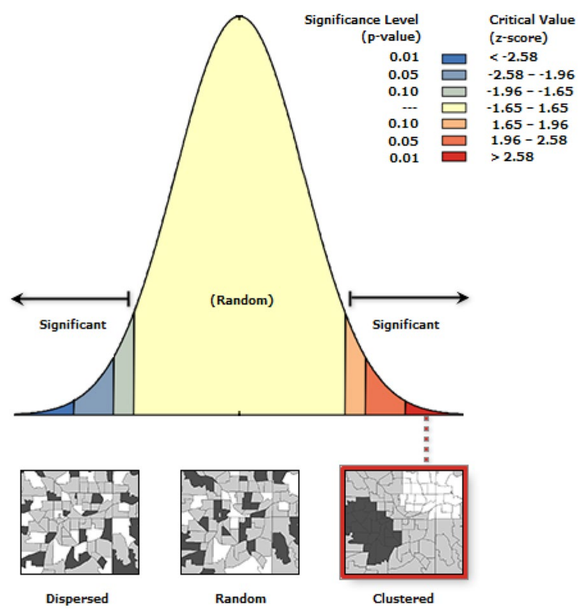

Fig. 4 The Moran's I spatial autocorrelation value of 0.16 is near + 1, which shows that values cluster together and indicates the spatial autocorrelation of the distribution, where a p-value of 0.00 denotes the statistically significant value of the cluster

Hotspot identification

Areas of the Gangni Union with a significant arsenic risk were found using hot spot analysis. The tourmaline green color denotes less risky areas for arsenic contamination and is seen in Nandabari and Mochainagar. The red color denotes major risk areas and is found in the central and SW parts of Ramnagar, the central parts of Sahebpur, northern Nimtala, the central Fulbagadi, Bagadi, and Gangni. Finally, the yellow color is considered not significant for arsenic contamination in the Gangni Union (Fig. 5).

The likelihood of arsenic exposure increased as we moved from the green to the red-colored areas. In the Gangni Union, red indicates high-risk locations for arsenic pollution, whereas green and light green indicate

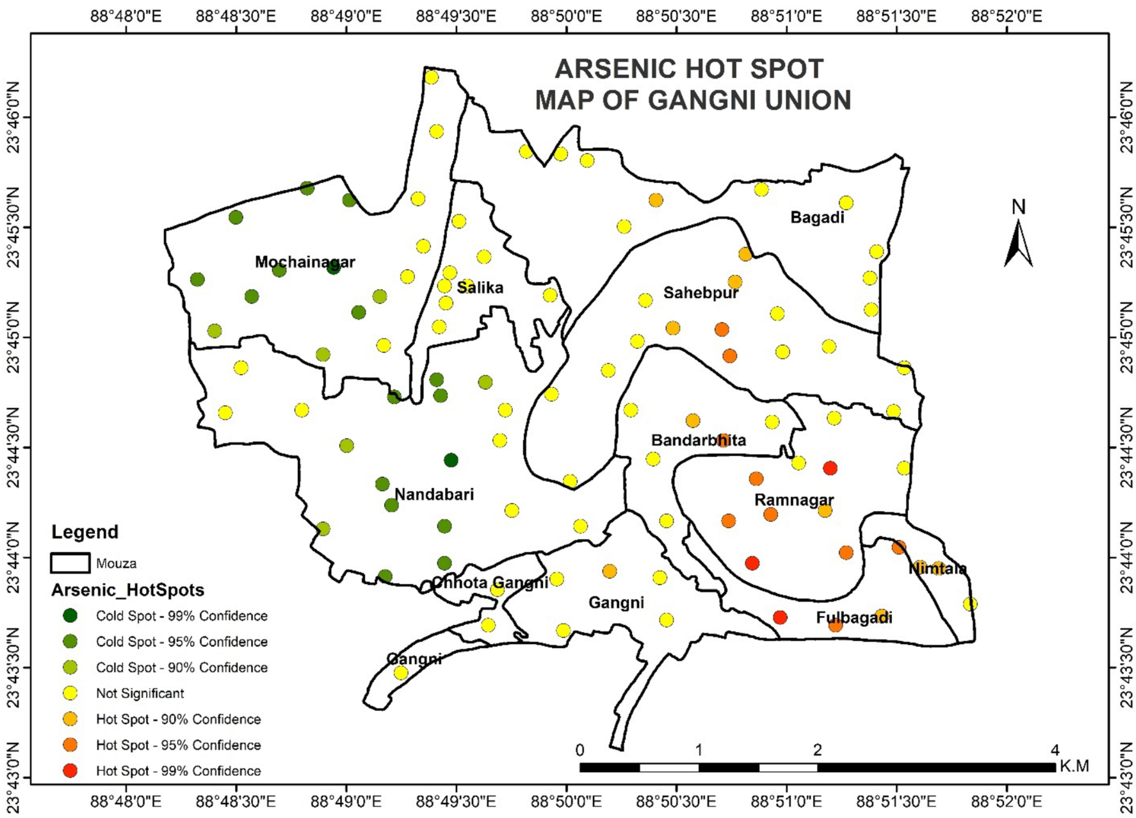

Fig. 5 Arsenic hotspots of Gangni Union

low-risk zones. In comparison to other locations, Ramnagar, Nimtala, Bagadi, Sahebpur, Salika, Gangni, Fulbagadi, and Bandarbhita were expected to be more dangerous. The green tint, on the other hand, denotes places with lower arsenic contamination risks, and it was found in Mochainagar, Soto Gangni, and Nandabari (Fig. 6).

Assessment of noncarcinogenic human health risk

Average daily intake dose of arsenic (ADD)

Table 3 shows the average daily dosage (ADD) of arsenic from oral intake. The estimated ADD of arsenic in Gangni ranged from 0.00031 to 0.00060 mg/l/day for adults and from 0.00093 to 0.00181 mg/l/day for children. Moving on to Chota Gangni, the estimated ADD for adults ranged from 9.29E−05 to 9.53E−05 mg/l/day, and for children from 0.00028 to 0.00029 mg/l/day. Arsenic ADD in Nandabari ranged from 6.33E−06 to 0.00031 mg/l/day for adults and 1.90E−05 to 0.00094 mg/l/day for children. Similarly, the estimated ADD in Bandarbhita ranged from 0.00012 to 0.00048 mg/l/day for adults and 0.00036 to 0.00145 mg/l/day for children. Furthermore, in Ramnagar, adults' estimated ADD ranged from 0.00047 to 0.00045 mg/l/day, while children's estimated ADD ranged from 0.00141 to 0.00136 mg/l/day. The estimated ADD varied from 5.83E−05 to 0.00017 mg/l/day for adults and from 0.00017 to 0.00051 mg/l/day for children in Mochainagar. Notably, the estimated ADD in Nimtala remained constant at 0.00024 mg/l/day for both adults and children. In Fulbagadi, however, the estimated ADD ranged from 0.00060 to 0.00051 mg/l/day for adults and from 0.00179 to 0.00154 mg/l/day for children. Moving on to Asmankhali, the estimated ADD for adults ranged from 0.00032 mg/l/day to 0.00021 mg/l/day, and for children from 0.00096 to 0.00062 mg/l/day. In Bagadi, adults had an estimated ADD of 0.00026 mg/l/day to 0.00031 mg/l/day, while children had an estimated ADD of 0.00078 mg/l/day to 0.00094 mg/l/day. Similarly, the estimated ADD in Salika ranged from 0.00021 to 0.0006 mg/l/day for adults and from 0.0006 to 0.0018 mg/l/day for children. Finally, the estimated ADD in Sahebpur ranged from 0.0006 to 0.00016 mg/l/day for adults and 0.0018 to 0.0004 mg/l/day for children.

In brief, the ADD range for adults varies from 2.78E−06 to 0.0006, and high ADD values are found in Gangni (0.0006), Salika (0.0006), Shahebpur (0.0006), Ramnagr (0.0056), Fulbagadi (0.0006) and Bagadi (0.00057) villages. In contrast, the ADD range for children varies from 8.33E-06-0.00181, which is comparatively higher than that for the adult group, and high ADDs are found in Gangni (0.00181), Nandabari (0.00096), Salika (0.0018),

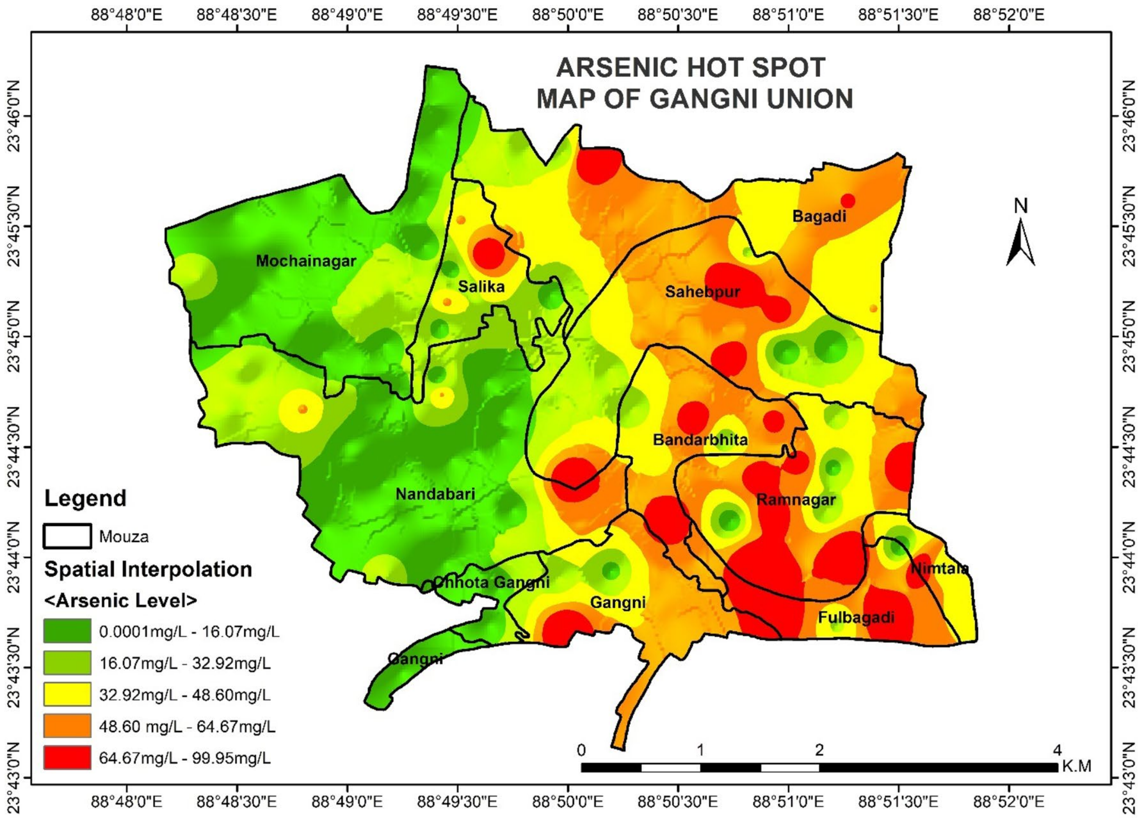

Fig. 6 Interpolation of the hotspots of the Gangni Union

Shahebpur (0.0018), Ramnagar (0.00177), Fulbagadi (0.00179), and Bagadi (0.00172).

Hazard quotient (HQ) of arsenic

The HQ values were calculated based on the ADD values, as shown in Table 4. The HQ values for arsenic exposure in different mouzas within the study area vary across the different areas. Adults in Gangni Mouza had HQ values ranging from 0.2373 to 2.011, while children had HQ values ranging from 0.7119 to 6.033. Adults in Sahebpur Mouza had HQ values ranging from 0.549 to 1.1281, while children had values ranging from 1.647 to 3.3845. Adults at Chota Gangni Mouza had HQ values ranging from 0.3096 to 0.3177, and children had values ranging from 0.929 to 0.9532. Moving on to Nandabari Mouza, adults had HQ values ranging from 0.0211 to 1.0457, while children had values ranging from 0.0633 to 3.137. Bandarbhita Mouza reported a range of HQ values for adults (0.4022 to 1.6088) and children (1.2066 to 4.8264). Adults in Ramnagar Mouza had HQ values ranging from 1.5685 to 1.5082, while children had values ranging from 4.7057 to 4.5247. Adults in Mochainagar Mouza had HQ values ranging from 0.1944 to 0.0384, while children had values ranging from 0.5833 to 0.1152. Adults reported HQ values ranging from 0.8003 to 0.808 for Nimtala Mouza, while children had values ranging from 2.4011 to 2.4252. Fulbagadi Mouza had an HQ value of 1.9909 for adults and 5.9727 for children. Adults in Asmankhali Mouza had HQ values ranging from 1.065 to 0.7078, while children had values ranging from 3.1975 to 2.1236. Adults in Bagadi Mouza had HQ values ranging from 0.864 to 0.1162, while children had values ranging from 2.5942 to 0.3487. Finally, in Salika Mouza, adults had HQ values between 0.7058 and 1.9104, while children had values from 2.1176 to 5.7314. The HQ values for arsenic in adults showed a broad range (0.009 to 2.01), having a median score of 0.658 and an interquartile range between 0.18 and 1.06. Detail result of descriptive statistical analysis of this section is presented in Additional file 1: Appendix-B, Table 10.

In summary, the HQ for adults ranges from 0.02 to 2.01, with 0.02, 2.01, 0.73, and 0.88 as the minimum, maximum, average, and IQR values, respectively. The HQ for children, on the other hand, continues from 0.02 to 6.03, with minimum, maximum, average, and IQR values of 0.02, 6.03, 2.20, and 2.64, respectively. The summary of the findings is shown in Fig. 7.

Table 3 Estimated daily average intake dose (ADD) of arsenic (mg/l/day) for both adults and children in the Gangni Union

Mouza name	Arsenic (mg/l/day)		Mouza name	Arsenic (mg/l/day)	
	Adult	Children		Adult	Children
Gangni	0.00031	0.00093	Sahebpur	0.00016	0.00049
	7.12E−05	0.00021		0.00034	0.00102
	0.00016	0.00049		0.00030	0.00090
	0.00031	0.00093		0.00060	0.00181
	0.00060	0.00181		0.00018	0.00054
Chota Gangni	9.29E−05	0.00028		0.00033	0.00100
	9.53E−05	0.00029		0.00030	0.00090
	2.78E−06	8.33E−06		0.00043	0.00130
Nandabari	6.33E−06	1.90E−05		0.00039	0.00117
	0.00020	0.00059		4.55E−05	0.00013
	2.46E−05	7.38E−05		9.05E−06	2.71E−05
	0.00031	0.00094		0.00030	0.00090
	7.90E−05	0.00024		0.00037	0.00112
	9.95E−05	0.00030	Bandarbhita	0.00012	0.00036
	6.76E−06	2.03E−05		0.00048	0.00145
	1.20E−05	3.60E−05		0.00013	0.00040
	9.65E−06	2.90E−05		0.00042	0.00127
	1.01E−05	3.02E−05		0.00024	0.00071
	7.12E−05	0.00021		0.00054	0.00163
	1.08E−05	3.24E−05	Ramnagar	0.00047	0.00141
	0.00031	0.00095		0.00045	0.00136
	5.47E−05	0.00016		1.10E−05	3.31E−05
	0.00019	0.00056		0.00048	0.00145
	0.00032	0.00096		0.00020	0.00060
	0.00018	0.00054		0.00020	0.00060
	1.10E−05	3.31E−05		0.00056	0.00168
	0.00017	0.00050		0.00059	0.00177
Mochainagar	5.83E−05	0.00017		0.00020	0.00061
	1.15E−05	3.46E−05		0.00046	0.00137
	0.00017	0.00051	Nimtala	0.00024	0.00072
	0.00017	0.00051		0.00024	0.00073
	0.00001	0.00004		7.06E−05	0.00021
	1.51E−05	4.54E−05	Fulbagadi	0.00060	0.00179
	1.93E−05	5.79E−05		0.00051	0.00154
	5.47E−05	0.00016		0.00018	0.00054
	2.21E−05	6.64E−05		0.00046	0.00139
	2.38E−05	7.10E−05	Asmankhali	0.00032	0.00096
	0.00021	0.0006		0.00021	0.00062
	2.48E−05	7.40E−05		0.00021	0.00062
	4.42E−05	0.0001		0.00021	0.00063
	2.38E−05	7.10E−05	Bagadi	0.00026	0.00078
	3.49E−05	0.0001		0.00031	0.00094
	2.43E−05	7.30E−05		9.95E−05	0.00029
Salika	0.00021	0.0006		0.00057	0.00172
	5.47E−05	0.0001		0.00033	0.00098
	0.0006	0.0018		0.00025	0.00076

Table 3 (continued)

Mouza name	Arsenic (mg/l/day)		Mouza name	Arsenic (mg/l/day)	
	Adult	Children		Adult	Children
	7.06E−05	0.0002		0.00040	0.00119
	4.42E−05	0.0001		0.00028	0.00083
Sahebpur	0.0006	0.0018		0.00028	0.00083
	0.00016	0.0004		0.00030	0.00090

Relationship between arsenic concentration and tube well depth

The strength of the linear association between the depth of the water sources and the concentration level was assessed using correlation coefficients. The Pearson correlation coefficient, r (98) = −0.758, p = 0.000 (Table 5), exhibits a significant negative linear relationship between depth and concentration level, as Xu et al. (2023) discussed that ranges between −0.6 and −0.8 represent a strong negative linear relationship, and it is statistically significant.

Figure 8 shows the association using a scatter diagram. The closer the points on a scatter plot are to a straight line, the stronger the linear relationship between two variables. (Bewick et al. 2003). Step by step procedure of this section is presented in Additional file 1: Appendix-B, Table 11–14.

Discussion

Approximately 37% of the tube well water surpassed the JECFA preliminary maximum tolerated daily intake for arsenic in water, of which 42% were classified as “elevated” and 21% as “high”. The term “elevated” (Malan and Sharma 2023; Cotruvo 2017; World Health Organization 2004, 2011) refers to water standards that fall below the Joint FAO/WHO Committee of Experts on Food Additives (JECFA) established limit (0.05 mg/l for arsenic). According to the JECFA limit, which is 0.03 mg of arsenic/kg of body weight and assumes a daily water intake of 2 l (World Health Organization 1985, 2004, 2011), the average body mass is 60 kg. Tube wells were considered to have “high” levels of arsenic if their respective arsenic concentrations exceeded 0.5 mg/l.

In this study, high concentrations of arsenic were observed in specific areas, prompting an investigation into the spatial pattern of contamination. Spatial autocorrelation analysis using Moran’s I revealed a positive spatial autocorrelation, indicating that locations with similar arsenic concentrations tend to cluster together in space. The calculated Moran’s I value of 0.16, close to +1, confirmed the existence of a clustered pattern in the distribution of arsenic. The statistical significance of the observed clustering was supported by a low p-value of

Table 4 Estimated hazard quotient (HQ) of arsenic for both adults and children in the Gangni Union

Mouza	Hazard quotient (HQ)		Mouza	Hazard quotient (HQ)	
	Adult	Children		Adult	Children
Gangni	1.0316	3.0949	Sahebpur	0.549	1.647
	0.2373	0.7119		1.1281	3.3845
	0.5409	1.6228		1.0055	3.0165
	1.0296	3.0889		2.011	6.033
	2.011	6.033		0.6033	1.8099
Chota Gangni	0.3096	0.929		1.106	3.3181
	0.3177	0.9532		1.005	3.0165
	0.0092	0.0277		1.439	4.3196
Nandabari	0.0211	0.0633		1.295	3.8852
	0.6535	1.9607		0.1518	0.4554
	0.082	0.2461		0.0301	0.0904
	1.0457	3.137		1	3.0165
	0.2634	0.7903		1.2468	3.7404
	0.3318	0.9954	Bandarbhita	0.4022	1.2066
	0.0225	0.0675		1.6088	4.8264
	0.04	0.12		0.4464	1.3393
	0.0321	0.0965		1.407	4.223
	0.0335	0.1007		0.7923	2.377
	0.2373	0.7119		1.8099	5.4297
	0.0359	0.1079	Ramnagar	1.5685	4.7057
	1.0577	3.1733		1.5082	4.5247
	0.1823	0.5471		0.036	0.1104
	0.6214	1.8642		1.6088	4.8264
	1.0618	3.1854		0.6636	1.9909
	0.6053	1.815		0.6656	1.9969
	0.0368	0.1104		1.8702	5.6107
	0.553	1.659		1.9707	5.9123
Mochainagar	0.1944	0.5833		0.6757	2.0271
	0.0384	0.1152		1.5263	4.579
	0.563	1.6892	Nimtala	0.8003	2.4011
	0.563	1.6892		0.808	2.4252
	0.0486	0.146		0.2352	0.7058
	0.0504	0.1514	Fulbagadi	1.9909	5.9727
	0.0643	0.193		1.7093	5.128
	0.1823	0.5471		0.6033	1.8099
	0.0738	0.2214		1.5484	4.6454
	0.0792	0.2377	Asmankhali	1.065	3.1975
	0.7078	2.1236		0.6857	2.0572
	0.0826	0.2479		0.6897	2.0693
	0.1472	0.4416		0.6978	2.0934
	0.0792	0.2377	Bagadi	0.864	2.5942
	0.1162	0.3487		1.0457	3.1371
	0.0808	0.2425		0.3318	0.9954
Salika	0.7058	2.1176		1.9104	5.7314
	0.1823	0.5471		1.085	3.2578

Table 4 (continued)

Mouza	Hazard quotient (HQ)		Mouza	Hazard quotient (HQ)	
	Adult	Children		Adult	Children
	2.011	6.033		0.8446	2.5338
	0.2352	0.7058		1.3272	3.9818
	0.1472	0.4416		0.921	2.763
Sahebpur	2.011	6.033		0.927	2.781
	0.5409	1.6228		0.9974	2.9923

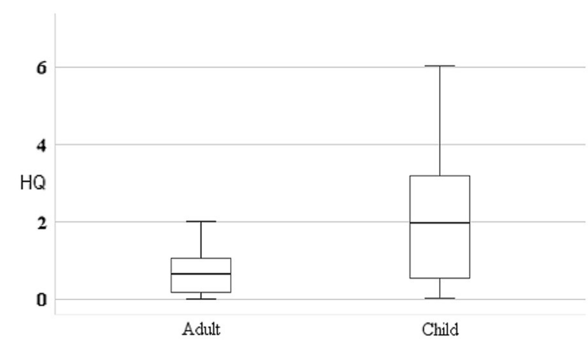

Fig. 7 The noncarcinogenic hazard quotient (HQ) of arsenic for multiple individuals shown in a box plot

Table 5 Correlations between the depth of the tube well and arsenic concentration

Correlations		
	Depth of tube-well	Arsenic concentration
Depth of tube-well		
Pearson correlation	1	−0.758**
Sig. (2-tailed)		0.000
N	100	100
Arsenic concentration		
Pearson correlation	−0.758**	1
Sig. (2-tailed)	0.000	
N	100	100

**Correlation is significant at the 0.01 level (2-tailed)

0.00, indicating that the likelihood of the clustered pattern occurring by chance alone is highly improbable. This strengthens the validity of the identified spatial clustering. Visual analysis of Fig. 4, which depicted vivid red and blue colors in the terminal tails, suggested an increased level of relevance. The distinct color representation visually reinforced the substantive nature of the observed pattern, indicating that it extends beyond random variation.

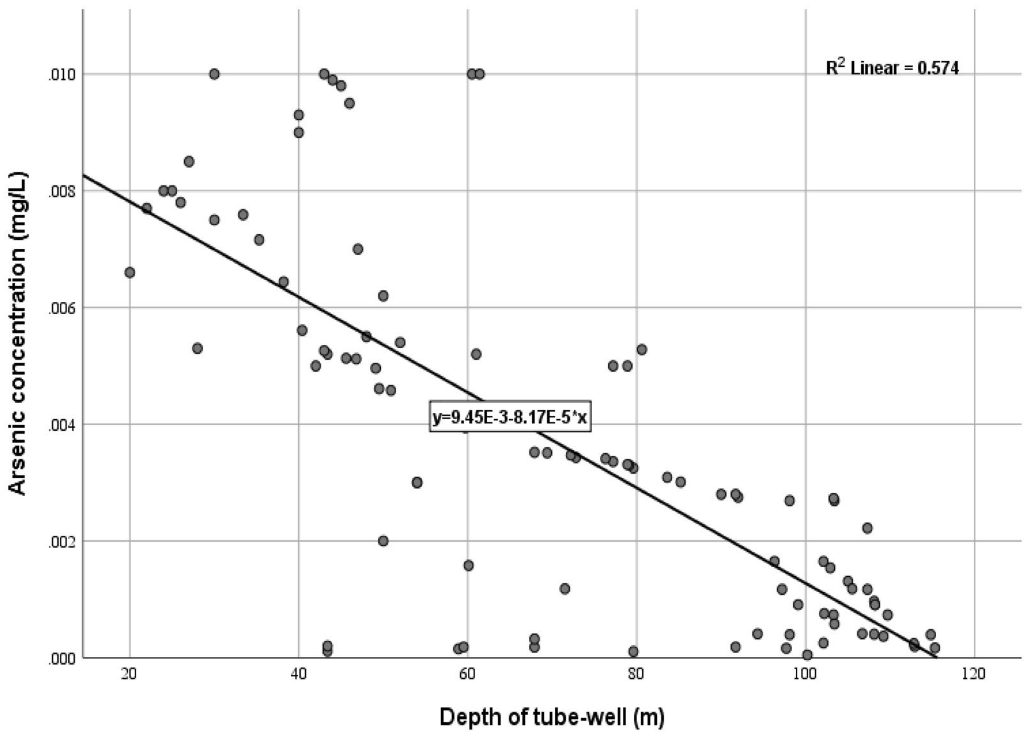

Fig. 8 Scatter plot showing the relationship between arsenic concentration and tube well depth

The z-score of 3.07 mentioned in the study indicated a significant deviation from the expected random pattern. With a z-score of this magnitude, the probability of the observed clustered pattern resulting from chance is less than 1%. This additional evidence further supports the argument that the clustering of high arsenic concentrations is highly unlikely to be a random occurrence.

Figure 5 shows the regional distribution of arsenic in the groundwater of the Gangni Union in the Chuadanga District according to health class boundaries. In the case of arsenic, "elevated" levels (0.01 to.05 mg/l) covered more than 42% of the entire surface area of groundwater, followed by "high" levels (>0.05 mg/l), which covered 21% of the total surface, and "minimum" levels (37%), which covered the remaining portion. The southeast and northeast are predominantly where the Gangni Union in the Chuadanga district has "high" quantities of arsenic. In Fig. 5, the hot spot analysis conducted in the Gangni Union is visually represented, highlighting different levels of arsenic contamination risk. The color-coded scheme in the figure provides crucial information regarding the potential health risks associated with arsenic exposure. The areas colored green in tourmaline, such as Nandabari and Mochainagar, indicate a lower risk for arsenic contamination. Residents in these areas are likely to face a reduced risk of exposure to arsenic and its related health hazards. Conversely, the red areas in Fig. 5 represent major risk zones. Locations such as the central and southwest parts of Ramnagar, the central parts of Sahebpur, northern Nimtala, the central Fulbagadi, Bagadi, and Gangni exhibit high levels of arsenic contamination. Urgent attention is needed in these hot spots, as residents are at a significantly higher risk of facing adverse health effects due to arsenic exposure. The yellow areas in Fig. 5 are considered not significant for arsenic contamination. Although these regions may have lower levels of arsenic, ongoing monitoring and caution are necessary to ensure that the risk remains under control. Figure 6 provides a comprehensive visual representation of the arsenic contamination risk in the Gangni Union, offering valuable insights into the spatial distribution of arsenic pollution and its potential health implications. The color-coded scheme in the figure allows for a clear understanding of varying risk levels associated with arsenic exposure. The transition from green to red areas in Fig. 6 signifies an increase in the likelihood of arsenic exposure. The red-colored locations, including Ramnagar, Nimtala, Bagadi, Sahebpur, Salika, Gangni, Fulbagadi, and Bandarbhita, are identified as high-risk areas for arsenic contamination. These areas are expected to pose a higher threat to residents in terms of potential health effects resulting from arsenic exposure. The presence of high-risk areas highlights the urgent need for targeted interventions and mitigation strategies to minimize exposure and protect the health of the affected population. Conversely, the green-tinted areas in the figure represent locations with lower arsenic contamination risks. Mochainagar, Soto Gangni, and Nandabari are identified as areas with a reduced likelihood of arsenic exposure. While residents in these areas may face relatively lower risks, it is crucial to maintain ongoing monitoring and preventive measures to ensure that the risk remains under control and prevent any potential escalation in arsenic contamination.

The ADD range for adults varied from 2.78E−06 to 0.0006, with several villages demonstrating relatively high levels. Gangni, Salika, Shahebpur, Ramnagr, Fulbagadi, and Bagadi exhibited the highest ADD values among adults, ranging from 0.0006 to 0.0056. In contrast, children exhibited a higher ADD range, varying from 8.33E−06 to 0.00181. Notably, Gangni, Nandabari, Salika, Shahebpur, Ramnagar, Fulbagadi, and Bagadi villages recorded significantly elevated ADD values for children, ranging from 0.00096 to 0.00181. The observed high ADD values in the selected villages, both for adults and children, indicate a significant health risk associated with arsenic exposure through oral ingestion. According to Table 4, adult HQ values of arsenic were higher than 1 in approximately 31% of tube wells (n = 31), indicating a negative impact on health, although arsenic levels in 42% of the tube wells were higher than the JECFA's provisional daily maximum intake for arsenic in water. In addition to a broad range (0.027 to 6.03), children's HQ values for arsenic also had a lower median (1.97) and interquartile range (0.547 to 3.19) than those for adults. Arsenic HQ values for kids were higher than 1 in almost 63% of cases, raising the possibility of non-cancerous health issues for kids. Arsenic HQ values for kids were less than 1 in 37% of cases, which suggests that kids do not have any noncarcinogenic health issues. Due to a potential link between excessive body arsenic and a number of chronic disorders, including cancer (Morales et al. 2000; Smith et al. 1992) and skin disease (Yu et al. 2006; Chowdhury et al. 2017), it may be important to be concerned about this issue.

Hossain et al. (2023) found a strong negative relationship between depth and iron concentration by using the Pearson correlation coefficient and concluded that increasing depth lowers the concentration of iron. The finding of the Pearson correlation coefficient of this study also indicates the same type of result and suggests that local people should increase the well depth, which will possibly decrease the arsenic concentration level.

Conclusion and recommendations

This study summarizes that the Gangni union of the Chuadanga district of Bangladesh is a highly arsenic-contaminated zone. Among 100 samples (n = 100), only 37 samples (n = 37) followed within the safe limits for arsenic under WHO and Bangladesh standards. The northeastern and southeastern parts of the study area are more arsenic-contaminated than the other parts. The calculated ADD range for adults is 2.78E-06-0.0006. In contrast, for the children, the ADD value ranged between 8.33E-06-0.00181. Moreover, the hazard quotient (HQ) value is higher (0.0277–6.033) for children than for adults (0.0092–2.011). The correlation analysis evaluates that the arsenic concentration shows a downward trend as the depth of the tube well increases; thus, tube well depth acts as a putative limiting factor of arsenic concentrations.

However, arsenic contamination is caused by various natural and man-made variables that were not considered in this study. Additionally, the spatial and seasonal fluctuations of arsenic contamination were not studied. An in-depth health risk assessment including carcinogenic exposure and other indirect health effects was also out of consideration. To better understand arsenic contamination, this study suggests future integrated research for examining natural and anthropogenic components of arsenic scientifically, seasonal and temporal fluctuations spatially, and health concerns with appropriate demographic evidence. This study can also guide professionals and policymakers to find a cost-effective way of monitoring arsenic contamination levels and evaluating the level of vulnerability. Additionally, the findings of this study can be a reference for future research exploring the critical sources of arsenic contamination and evaluating potential mitigation strategies (Additional file 1).

Supplementary Information

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Additional file 1: Raw Dataset and Details of Statistical Analysis.

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Author contributions

The authors confirm their contribution to the paper as follows: study conception and design: M. I Haque, M. N Islam; data collection: M. N Islam, M. A Hossain; analysis and interpretation of results: M. N Islam, M. I Haque, M. A Hossain; draft manuscript preparation: M. N Islam, M. A Hossain. Manuscript review and formatting for publication: M. I Haque; M. N Islam, M. A Hossain All authors reviewed the results and approved the final version of the manuscript.

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Declarations

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