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ORIGINAL ARTICLE

# Water quality index and health risk assessment for heavy metals in groundwater of Kashiani and Kotalipara upazila, Gopalganj, Bangladesh

Molla Rahman Shaibur[1] · Masum Howlader[1] · Ishtiaque Ahmmed[1] · Sabiha Sarwar[1] · Abul Hussam[2]

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## Abstract

The groundwater quality of the Gopalganj district in Bangladesh was not well documented. Therefore, this research was done to determine the groundwater quality in the study area. The water quality index and the human health risk for heavy metal ingestion were used to describe the water quality. The water quality was performed through the estimation of turbidity, pH, electrical conductivity, total dissolved solids, and concentration of sodium, potassium, ammonium, nitrate, iron, manganese, zinc, copper, and arsenic. The mean turbidity, pH, and total dissolved solids in the two upazila were within the permissible limit. However, the electrical conductivity in both the upazila was higher than the WHO-prescribed value in which the higher concentration was in Kotalipara. Excess concentrations of iron and arsenic were found in the Kashiani upazila, but these were below the detection limit in Kotalipara upazila. The water quality index revealed that roughly 61.0% of samples of Kashiani upazila were of poor quality. However, about 96.0% of samples of Kotalipara upazila were of excellent quality. Chronic health risks due to the revelation of drinking have also been determined by assessing the hazard quotient and hazard index. In Kashiani, almost 85.0% of samples were elevated chronic risks for adults and 100.0% of the samples were very high chronic risks for children. In Kotalipara, all the samples (almost 100%) were suggested to have a lower chronic risk for adults and children. The results suggested that the carcinogenic risk of arsenic via oral exposure was very high for both adults and children in Kashiani upazila.

**Keywords** Groundwater · Hazard index · Hazard quotient · Health risk · Heavy metals · WQI

## Abbreviations

| | |
|---|---|
| AR | Analytical reagent |
| As | Arsenic |
| BBS | Bangladesh Bureau of Statistics |
| BDL | Below detection limit |
| BNDWQS | Bangladesh National Drinking Water Quality Survey |
| CDI | Chronic daily intake |
| CERCLA | Comprehensive Environmental Response, Compensation and Liability Act |
| CR | Carcinogenic risk |
| Cu | Copper |
| DNA | Deoxyribonucleic acid |
| EC | Electrical conductivity |
| Fe | Iron |
| GW | Groundwater |
| HI | Hazard index |
| HMs | Heavy metals |
| HRA | Health risk assessment |
| HQ | Hazard quotient |
| KaU | Kashiani upazila |
| KoU | Kotalipara upazila |
| Mn | Manganese |
| NTU | Nephelometric turbidity unit |
| RfD | Reference dose |
| SF | Slope factor |
| TDS | Total dissolved solids |
| USEPA | US Environmental Protection Agency |
| WHO | World Health Organization |
| WQ | Water quality |

✉ Molla Rahman Shaibur
shaibur75@just.edu.bd; shaibur75@yahoo.com

[1] Laboratory of Environmental Chemistry, Department of Environmental Science and Technology, Jashore University of Science and Technology, Jashore 7408, Bangladesh

[2] Department of Chemistry and Biochemistry, George Mason University, Fairfax, VA, USA

WQI Water quality index
Zn Zinc

## Introduction

Water is one of the fundamental compounds essential to maintain every type of living beings (Al-Jlil 2017; vanLoon and Duffy 2017; Roy et al. 2018; Yesmin et al. 2022; Adimalla and Qian 2022; Rahman et al. 2023). About 97.0% of the water on earth is somewhat saline, while just 3.0% is fresh (Rahman et al. 2021; Hossain et al. 2022; Hosseininia and Hassanzadeh 2023). Of which (freshwater), more than 67.0% is frozen in ice caps and glaciers, 30.0% is thawed as GW and only 3% is in surface water (Al-Barakah et al. 2017; Mina et al. 2018; Lahkar and Bhattacharyya 2019; Ofosu et al. 2021). Groundwater is an important source of drinking water and one-third of the world's population needs to rely on it for ingestion (Xing et al. 2013; Bashir et al. 2017; Emenike et al. 2017; Adimalla et al. 2022; Piyathilake et al. 2022).

The standard of public health of a community depends on the availability and purity of drinking water (Khan et al. 2011; Ewaid 2017; Fathi et al. 2018; Shaibur et al. 2019b; Hossain et al. 2024). Drinking water is water that is safe to drink or use for cooking without any health risks (Sardar et al. 2017; Shaibur et al. 2021a, c). It is also known as potable water (Sardar et al. 2017; Shaibur 2022; Shaibur and Das 2022). Safe drinking water is very scarce in most developing countries including Bangladesh (Shaibur et al. 2022a). Many people drink tainted water which may be responsible for lots of diseases (Adimalla et al. 2020). Heavy metal-containing water could be purified with the process of gas-sparged dialysis (Al-Jlil and Hardi 2014) or adsorption processes (Shaibur et al. 2022b). Ingestion of tainted water is accountable for 80.0% of all diseases in developing countries and hence causes one-third of deaths (Adimalla et al. 2020). Perilous drinking water causes about 34.0 million deaths every year all over the world and fatalities mostly go to children (Hrudey and Hrudey 2007). The safety and quality of drinking water is the vital public health concern, as the contagion of potable water is responsible for the transmission of diseases and serious illnesses throughout the globe (Marshall et al. 2006; Adimalla and Qian 2021).

The Southern part of Bangladesh is exposed to intense weather events (Shaibur et al. 2017a, b, c), and the excellence of the GW of this region is being deteriorated recurrently (Shaibur et al. 2019g; Shaibur et al. 2021b, c). Groundwater has been the foremost source of untainted water used in the Indian sub-continent for farming, engineering, and drinking purposes (Hamzaoui-Azaza et al. 2011; Shaibur et al. 2023). South-Central parts of Bangladesh face lessening of GW due principally to poor river flow, lack of upholding, climatic factors (Shaibur et al. 2019f, g; Das et al. 2021a, b), and anthropogenic activities (Shaibur 2023). Both surface and GW experiencing increased demand and pollution (Sikder et al. 2013; Islam et al. 2017). Some researchers have inveterate that the lofty salinity of surface water in adjoining areas near the coast (Shammi et al. 2017; Shaibur et al. 2019a, b, c, d, e, f, g; Das et al. 2021a, b; Shaibur et al. 2021c) as well as coastal districts such as Khulna (Shammi et al. 2016; Das et al. 2021b; Shaibur et al. 2021c), Gopalganj (Shammi et al. 2012, 2016), and Barguna and Patuakhali (Islam et al. 2017; Shamsuzzoha et al. 2019). Gopalganj district is vital in Bangladesh and is situated in the South-Center part. Though Gopalganj is not incredibly close to the coastlines, salinity has freshly been observed in some parts of the surface water systems (Shammi et al. 2012, 2016; Shaibur and Howlader 2020).

Arsenic, Fe, Mn, Zn, and Cu are the most recurrent heavy metals to which humans are exposed (Shaibur et al. 2019a, c, d, f, g). They are among the top priority pollutants on the basis of the 2007 CERCLA of perilous substances precedence list (Tapase and Kodam 2018). Arsenic is the fatal element (Lindsay and Maathuis 2017) documented by WHO as the group 1 carcinogenic element (Driscoll et al. 2004). Arsenic contamination is a severe threat to drinking water in Bangladesh. Long-term exposure to As not only raises the probability of diseases such as cancer of the lungs, renal, or skin, but also creates an age group known as As-orphans (Flanagan et al. 2012). Iron and Mn are the most widespread and often present in GW due to large deposits on the earth's surface (Edet et al. 2011; Islam et al. 2017). Too much Fe in GW is responsible for an unusual metallic taste and can cause disease if ingested beyond the acceptable limits (Rahman and Gagnon 2014; Ahmed et al. 2019). Ingestion of Fe accounts for the most toxic effects, as Fe is rapidly absorbed in the gastrointestinal tract. Iron exposure to high concentrations has detrimental effects on target organs such as the kidneys, livers, and cardiovascular systems (WHO 2011), but Mn may cause different neurological disorders (WHO 2011). Manganese is also liable for hurt to DNA and chromosomal changes that aggravate toxic effects on embryos and fetuses (Gerber and Grove 2002). In addition, Zn can be migrated to GW by ordinary processes or by discharge from human activities and creates an unwanted astringent taste if it exceeds 3.0 mg $L^{-1}$ (Bodrud-Doza et al. 2019). In addition, dreadfully elevated levels of Cu are noxious and can cause vomiting, diarrhea, loss of strength, and liver cirrhosis. The blue-green color appears in water if corroded Cu comes out from inside of the pipes and appears as a precipitate in the water (Georgopoulos et al. 2001; Chiarugi et al. 2002).

Some reports reveal that the GW of the Gopalganj district is contaminated with As and other heavy metals (Shaibur 2019; Shaibur and Howlader 2020). Not only those, the

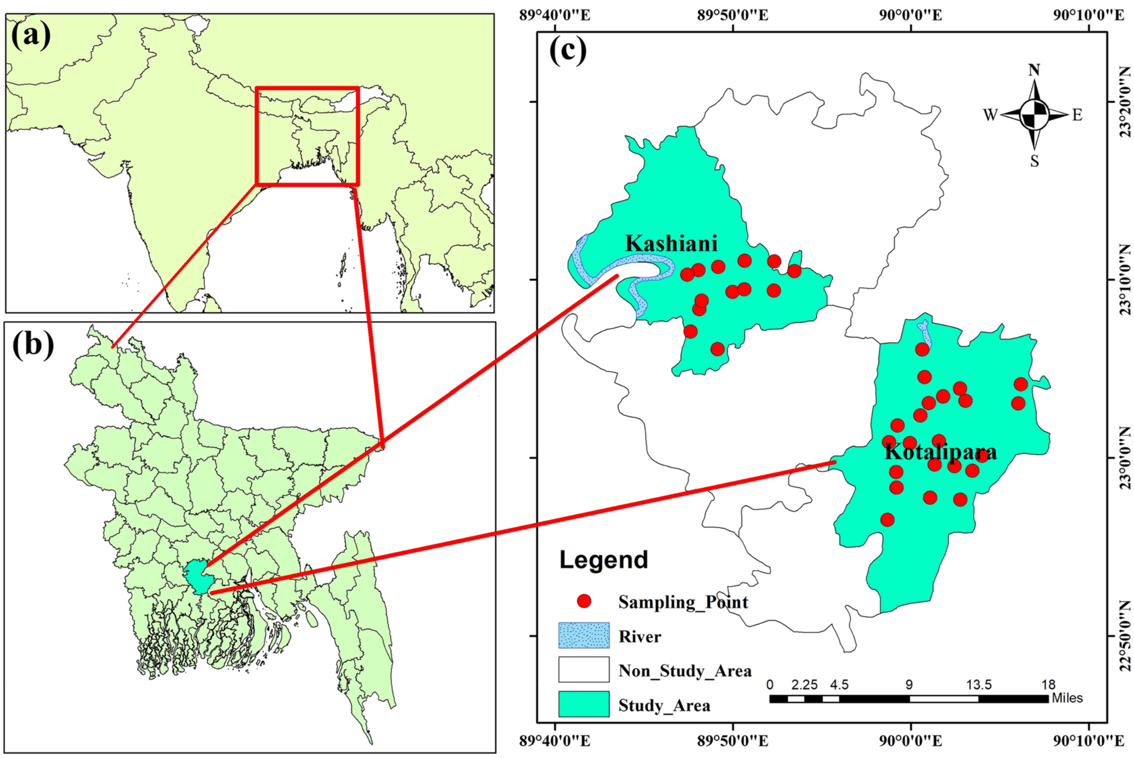


**Fig. 1** Map of the study area with sampling location. Pointing out the study area in the context of Bangladesh; (**a**) Map of Bangladesh (**b**) Map of Gopalganj district in Bangladesh (**c**) Map of Kashiani upazila and Map of Kotalipara upazila. The maps were created by using Arc Map GIS 10.5

salinity and WQ are also the problem in Gopalganj (Shammi et al. 2012, 2016, 2017). The WQI is considered to be the most operative technique for measuring WQ. A number of WQ parameters need to be included in the mathematical equation for the assessment of WQ, which determines the aptness of water for drinking purposes (Ochuko et al. 2014).

The WQI provides a comprehensive picture of the quality of exterior and GW for most household uses (Mostafa et al. 2017). The WQI is termed as the score that reflects the merged pressure of diverse WQ parameters on the overall excellence of water for consumption (Sahu and Sikdar 2008). It is the central index for assessing WQ and its correctness for drinking purposes (Mishra and Patel 2001; Naik and Purohit 2001; Avvannavar and Shrihari 2008; Pawar et al. 2014; Boateng et al. 2016). The WQI is the solitary value of the expression that numerically summarizes various WQ parameters. It is premeditated from the point of view that the lower value of it signifies the lesser quantity of discrepancy from the suggested values of the parameters included and more good quality water for human consumption or vice versa. The WQI is very much interrelated with human health.

The estimation of human health risks to GW is crucial and considered to be a proposed approach to link environmental pollution to human health (Zhang et al. 2016; Rahman et al. 2018; Singh et al. 2018). Human risks were estimated from different parts of the world including Bangladesh, but there were few or no reports regarding the WQI of Kashiani and Kotalipara upazila of Gopalganj district. Therefore, this research was conducted to uncover the GW quality in the composed samples of Kashiani and Kotalipara upazila. The main objectives of this study were (1) to calculate the WQI by determining the physicochemical properties of GW to confirm its fitness for human consumption, and (2) to evaluate potential human health risks associated with exposure to heavy metals in the GW through HI and CR assessments. The research findings will be an essential reference for local policymakers as well as planners in decision-making, monitoring, and reducing polluting activities in the study area.

## Materials and methods

### Description of the study area

Gopalganj is positioned in the Dhaka division of Bangladesh at 23°20′ to 22°50′ North and 90°05′ to 89°40′ East (Banglapedia 2006; BBS 2014), consisting of five upazilas (Fig. 1). Historically, Kashiani and Kotalipara upazila were awfully significant for the reason that the famed river Madhumati passes beside the Kashiani upazila and the Ghaggar river passes through the Kotalipara upazila. There are 14 unions in Kashiani upazila and 12 unions in Kotalipara. The geological location of Kashiani and Kotalipara upazila is between 23.2167°N and 89.7000°E and 22.9833°N to 89.9917°E, correspondingly (BBS 2011). The meticulous explanation of the study area has been described as a different place (Shaibur et al. 2019e).

This location has a tropical climate due to the Indian Ocean's Southwest monsoon season (Islam et al. 2018). Weather vacillations affect GW's existence and transportation. In this region, there were three primary weather seasons: hot summer (March–May), monsoon or wet season (June–October), and mild winter (November–February). As described in earlier studies, the rainy season runs from May to October, with the maximum rainfall in July. The summer is largely dry (Iftakher et al. 2015; Islam et al. 2017). The Gopalganj district has an average annual precipitation of approximately 1620 mm, with temperatures ranging from 9 to 30 °C. The region is also affected by natural phenomena such as storm surges, tidal flooding, and salinity (BBS 2011). Four rivers flow through the district, namely the Gorai, Madhumati, Kaliganga, and Ghaggar, with a complex combination of freshwater and tidal flows in the Southern region (Rahman et al. 2018). River pathways transport stormwater runoff to the Bay of Bengal while also serving as drainage systems for rainfall and tidal currents (Islam et al. 2018). The aquifers in the study area are multilayered and range from unconfined to confined, with GW levels rising during the rainy season and replenished by rainwater, rivers, streams, and ponds (Uddin and Lundberg 1998). The elevation of the lower shallow aquifer morphology varies from 10 to 50 m in the Holocene coastal plain deposition, primarily comprising tidal deltaic sediments and marshland peat covered by thick sandy clay deposition (Khan et al. 2011). The GW piezometric volume declines during the dry period due to over-exploitation for crop production but is replenished during the rainy season (Islam et al. 2018). Gopalganj district has an apparent magnitude of fewer than 2.0 m above sea level. Gopalganj is made up of 30% active low Ganges River floodplain, 5% Ganges Floodplain, 23% Old Meghna Floodplain, 41% Gopalganj-Khulna Beels, and 1% others. The GW of this area is heavily polluted with As (Shaibur 2019; Shaibur and Howlader 2020).

## Sample collection and analysis

A sum of 35 (13 from Kashiani upazila and 22 from Kotalipara upazila) water samples were collected from hand tube wells (Fig. 1). The designed samples were collected from 10.00 a.m. to 6.00 p.m. on August 12–14, 2019 at a depth of 100–1200 ft (Shaibur and Howlader 2020). This time was chosen because the peoples of the households were the most available. The August month of the year is the post-monsoon in Bangladesh which represents both rainy and dry seasons. Therefore, this time was chosen for representative sample collection. Samples were put in 250 mL untainted and dry screw-capped polystyrene bottles. All analyses were performed by following the regular guiding principle (APHA 2005; Shaibur et al. 2012, 2019a; Islam et al. 2017; Shammi et al. 2017). The bottles were prewashed with 0.1 N $HNO_3$ and rinsed four times with distilled water before sampling. The samples were composed after pumping the wells for 15–20 min. This was done to achieve the condition of the samples to be steady state. Some parameters, e.g., turbidity, pH, EC, and TDS, were determined instantly at the sampling points. Prior to storing the samples in the refrigerator, $NO_3^-$ and $NH_4^+$ were quantified in the laboratory. After that acidification was performed with concentrated $HNO_3$ (AR grade; 60–61% and density; 1.38 kg $L^{-1}$) to protect the samples from being complexes of trace metals. Finally, the acid-treated samples were stored at 4° C in the refrigerator placed in the laboratory. Later on, the Na, K, Fe, Mn, Cu, Zn, and As were determined at the laboratory. The in-depth methodologies of sample analysis were freshly described somewhere else (Shaibur et al. 2012; Shaibur et al. 2019a, c, f; Sarwar et al. 2020). The customary method of sample analysis is mentioned in Table 1. The maps were created by using Arc Map GIS 10.5. Data entry and analysis were done by using computer software packages e.g., MS Word and Excel-2010 (Model 2010, Microsoft Word, USA).

## Accuracy of data analysis

Uncertainties sources of errors in water quality determination, sampling technique, and instrumental accuracy were performed where it was needed. The repetition of a standard solution was performed after the analysis of 7–8 samples each to find out the accuracy of the instrument. In every case, the analytical grade standard solution was used. Deionized water was used as blank control. Detailed information on the sample's location and depth of DTW was recently reported (Shaibur and Howlader 2020).

## Estimation of human health risks

The estimation of human health risks includes evaluating risk indices of prospective sources of risk, estimating risk indices, and quantifying the health effects of exposure (Ni et al. 2010). Usually, four steps, i.e., (1) hazard identification, (2) dose–response assessment, (3) exposure assessment, and (4) risk characterization was repeatedly used to recognize human health risks (Ma et al. 2007; Rahman et al. 2018). Up to now, numerous scientists have tried to build up a wide range of WQI for the assessment of GW quality in different parts of the world (Bodrud-Doza et al. 2015; Mostafa et al. 2017; Mohammadi

**Table 1** Methods and instruments used for the determination of parameters of water samples. The water samples were collected from the unions of Kashiani and Kotalipara upazila, Gopalganj, Bangladesh

| Parameters | Unit | Methods/instruments | References |
|---|---|---|---|
| Turbidity | NTU | HACH Model DR 2100Q Portable Turbidimeter | APHA (1995) Shaibur et al. (2012) Shaibur et al. (2019a) |
| pH | | Digital pH meter (EZDO < Model: 6011) | |
| EC | $\mu S\ cm^{-1}$ | EC meter (Model: HANNA Instrument, HI (98,312) | |
| TDS | $mg\ L^{-1}$ | | |
| $Na^+$ | $mg\ L^{-1}$ | Flame Method (JENWAY PFP7 Flame Photometer) | |
| $K^+$ | $mg\ L^{-1}$ | | |
| $NH_4^+$ | $mg\ L^{-1}$ | UV–visible spectrophotometer (HACH DR 3900 Spectrophotometer) | |
| $NO_3^-$ | $mg\ L^{-1}$ | | |
| Fe | $mg\ L^{-1}$ | Atomic Absorption Spectrophotometer (AAS, Model: AA-7000; Shimadzu, Japan City) | |
| Mn | $mg\ L^{-1}$ | | |
| Cu | $mg\ L^{-1}$ | | |
| Zn | $mg\ L^{-1}$ | | |
| As | $mg\ L^{-1}$ | | |

et al. 2019; Karimi et al. 2020; Mahmud et al. 2020; Shams et al. 2020). But this type of research was not done yet for the study area, Kashiani and Kotalipara upazila of Gopalganj district.

## The calculation for the water quality index

To compute the WQI, the previously mentioned 13 physicochemical parameters were used. The mentioned parameters were used because those were the most common and important characteristics of water quality. The WQI was calculated step by step. Firstly, relative weight (*Wi*) was calculated to determine the hazardous effects of the parameters on human health or WQ . The parameters which have the foremost impacts on water excellence are- TDS, $NH_4^+$, $NO_3^-$, and As. These parameters were assigned to the top weight of 5.0 due to their major importance in WQ assessment. Other parameters such as turbidity, pH, EC, Na, K, Fe, Mn, and Cu were assigned a weight between 2.0 and 4.0 depending on their magnitude on the whole of water quality. The *Wi* is then obtained by using Eq. 1 (Chatterjee and Raziuddin 2002):

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \tag{1}$$

where "*Wi*" is the relative weight of the "*i*th" parameter, "*wi*" is the weight of the individual parameter, and "*n*" is the number of parameters. The assigned weight, BNDWQS standard value, and calculated *Wi* are mentioned in Table 2. The quality rating degree for a specific parameter was deliberated by using Eq. 2 (Batabyal and Chakraborty 2015):

$$qi = \frac{Ci}{Si} \times 100 \tag{2}$$

where $q_i$ is the quality rating of a specific parameter, $C_i$ is the concentration ($mg\ L^{-1}$) of the measured parameter or value of the specific parameter, and $S_i$ is the BNDWQS standard of the targeted parameter.

For computing the WQI, the sub-index (SI) was obtained for the respective parameter by using Eq. 3, and the WQI is then obtained by using Eq. 4 (Batabyal and Chakraborty 2015):

$$\mathrm{SI} = Wi \times qi \tag{3}$$

where SI is the sub-index of the *i*th parameter.

$$\mathrm{WQI} = \sum \mathrm{SI} \tag{4}$$

Bodrud-Doza et al. (2016) have categorized the water quality as (1) excellent, (2) good, (3) poor, (4) very poor, and (5) unsuitable for human consumption on the basis of WQI values as mentioned in Table 3.

## The calculation for chronic daily intake assessment

This is done for chronic risk assessment. The HRA of heavy metals or metalloids is habitually based on quantification of the risk intensity and is articulated in terms of non-carcinogenic and or carcinogenic health risk (USEPA 2009). The two principal toxicity risk factors evaluated are the RfD for non-carcinogen risk characterization and the SF for carcinogen risk categorization (Lim et al. 2008). The oral exposure trail was considered for the estimation and the CDI of elements via oral trail was estimated by using Eq. 5 (USEPA 1989; Karim 2011).

$$\mathrm{CDI_{oral}} = C \times \frac{\mathrm{IR} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \tag{5}$$

**Table 2** Relative weight ($Wi$) of physical and chemical parameters

| Parameters | Unit | BNDWQS standard | Weight ($w_i$) | Relative Weight (Wi) = $\frac{Wi}{\sum_{i=1}^{n} Wi}$ |
|---|---|---|---|---|
| Turbidity | NTU | 10.00 | 2.0 | 0.0425 |
| pH | | 8.50 | 4.0 | 0.0851 |
| EC | $\mu S\ cm^{-1}$ | 2000.00 | 4.0 | 0.0851 |
| TDS | $mg\ L^{-1}$ | 1000.00 | 5.0 | 0.1063 |
| $Na^+$ | $mg\ L^{-1}$ | 200.00 | 4.0 | 0.0851 |
| $K^+$ | $mg\ L^{-1}$ | 12.00 | 2.0 | 0.0425 |
| $NH_4^+$ | $mg\ L^{-1}$ | 0.50 | 5.0 | 0.1063 |
| $NO_3^+$ | $mg\ L^{-1}$ | 10.00 | 5.0 | 0.1063 |
| Fe | $mg\ L^{-1}$ | 0.30 | 4.0 | 0.0851 |
| Mn | $mg\ L^{-1}$ | 0.10 | 4.0 | 0.0851 |
| Cu | $mg\ L^{-1}$ | 1.00 | 2.0 | 0.0425 |
| Zn | $mg\ L^{-1}$ | 5.00 | 1.0 | 0.0212 |
| As | $mg\ L^{-1}$ | 0.05 | 5.0 | 0.1063 |
| | | | $\sum wi = 47$ | $\sum Wi = 0.9994$ |

NB: BNDWQS = Bangladesh National Drinking Water Quality Survey; EC = Electrical Conductivity; NTU = Nephelometric Turbidity Unit; TDS = Total Dissolved Solids

**Table 3** Water quality classification for drinking purposes based on the water quality index (WQI) values

| WQI range | Type | Grading |
|---|---|---|
| < 50 | Excellent | A |
| 50–100 | Good | B |
| 100.1–200 | Poor | C |
| 200.1–300 | Very poor | D |
| > 300 | Unsuitable for ingestion | E |

Source: Bodrud-Doza et al. (2016)

**Table 4** Toxicity response of trace metals for the RfD and SF

| Parameters | Oral RfD ($mg\ Kg^{-1}\ day^{-1}$) | SF ($mg\ Kg^{-1}\ day^{-1}$) |
|---|---|---|
| As | $3 \times 10^{-4}$ | 1.5 |
| Cu | $4 \times 10^{-2}$ | n.d |
| Fe | $3 \times 10^{-1}$ | n.d |
| Mn | $2 \times 10^{-2}$ | n.d |
| Zn | $3 \times 10^{-2}$ | n.d |

NB: n.d. = Not Determined; RfD = Reference Dose; SF = Slope Factor; (Source: Wongsasuluk et al. 2014; USEPA 2011)

where $CDI_{oral}$ reveals the exposure dose ($mg\ Kg^{-1}\ day^{-1}$) via oral ingestion. The "$C$" represents the concentration of trace elements in GW ($mg\ L^{-1}$), and IR is the water ingestion rate. In this study, $IR_{adult} = 2.2\ L\ Day^{-1}$ and $IR_{child} = 1.0\ L\ Day^{-1}$ (USEPA 2004; Wu et al. 2009). The ED is the exposure duration (70 years for an adult and 10 years for a child; Wu et al. 2009), EF is the exposure frequency (365 days' $year^{-1}$; Karim 2011), BW is the average body weight (70.0 kg for adult and 15.0 kg for children; Rahman et al. 2018; USEPA 2004), and AT is the average time for non-carcinogenic expressed as AT (days) = ED × 365; Wu et al. 2009; USEPA 2004; Rahman et al. 2018). The detailed information is presented in Table 4.

## The calculation for non-carcinogenic risk assessment

The HQ and HI are essential to evaluate human health risks. The HQ is an essential tool to estimate non-carcinogenic health risks by calculating related to HI.

## Hazards quotient assessment

The HQ is typically used to express the non-carcinogenic risk, which is computed as the ratio of CDI and RfD for specified elements (USEPA 1989) by using Eq. 6:

$$HQ = \frac{CDI}{RfD} \tag{6}$$

where HQ = hazard quotient, CDI = chronic daily intake, and RfD = reference dose. The toxicity responses of trace metals for the RfD are presented in Table 4. For non-carcinogenic risk assessment, the HI value is obtained by combining the individual values of HQs. If the values of HQ and HI are > 1 individually, then the elements have potentially non-carcinogenic effects on human health, while the value < 1 indicates no risk to health (USEPA 1989).

### Hazards index assessment

The HI is the magnitude that takes into account the joint involvement of intake where HQ is unit less. The RfD is the reference dose of mg $Kg^{-1}$ $day^{-1}$ that originates from the risk-based concentration table (USEPA 2001). To appraise the overall potential for non-carcinogenic effects caused by multiple chemicals, the HQ intended for individual chemicals are summed and articulated as HI (USEPA 1989) by using the Eq. 7:

$$HI = HQ1 + HQ2 + \ldots\ldots + HQn \quad (7)$$

Previously chronic risk assessment was conducted by some well-known researchers (Simeonov et al. 2003; Muhammad et al. 2011). They pointed out the categories as (1) Negligible Risk: where the HI or HQ is $< 0.1$, (2) Low Risk: where the HI or HQ is $\geq 0.1$–$< 1.0$, (3) Moderate Risk: where the HI or HQ are $\geq 1.0$–$< 4.0$ and finally (4) High Risk: where the HI or HQ is $\geq 4.0$ (Table 5).

### The calculation for carcinogenic risk assessment

The carcinogenic risk was anticipated as the incremental probability of individual cancer over a lifetime as the result of experiencing a prospective carcinogen (Rahman et al. 2018; Bodrud-Doza et al. 2019). The linear dose carcinogenic risk equations, e.g., Eqs. 8 and 9, were used for individual exposure routes (USEPA 1989).

$$\text{Low - Dose Exposure Risk} = CDI \times SF \quad (8)$$

$$\text{High - Dose Exposure Risk} = 1 - exe^{(-CDI \times SF)} \quad (9)$$

where risk stood for cancer risk and SF was the slope factor of contaminants (mg $Kg^{-1}$ $day^{-1}$). Toxicity responses of trace elements for the oral, RfD, and oral SF are presented in Table 4. If the obtained value is $> 0.01$, only then the Eq. (9) is considered. The acceptable stage was considered at $\leq 1 \times 10^{-6}$, which means on average, the probability is that approximately 1 person in 1,000,000 will develop cancer as the result of exposure (Lim et al. 2008). Risk in the range of $1 \times 10^{-6}$–$1 \times 10^{-4}$ is considered acceptable (USEPA 2004; Fakhri et al. 2018). Chronic and carcinogenic risk assessment scales are presented in detail in Table 5.

## Results and discussion

### General characteristics of groundwater

In Kashiani upazila, the turbidity assorted from 0.45 to 4.73 NTU of which the mean value was 1.58 NTU, indicating that the GW of Kashiani upazila was transparent in nature and the water was apposite for ingestion. The Bangladesh and WHO suggested turbidity values were 10.0 and 5.0 NTU, correspondingly (WHO 2011; Table 6). The EC values are assorted from 490.0 to 3060.0 µS $cm^{-1}$ of which the mean value is 941.54 µS $cm^{-1}$. The suggested tolerable limit value of EC in drinking water is 300.0–1500.0 µS $cm^{-1}$ and 750.0 µS $cm^{-1}$ for BNDWQS and WHO (WHO 2011), correspondingly. Considering the Bangladesh-prescribed value, the GW was in safe hands, but if we reflect on the WHO (2011) suggested value then the GW was not in safe hands for drinking. It meant that even if the value was within the recommended limit, it was in an ominous condition. The pH assorted from 7.20 to 7.74, and the mean value was 7.47. Therefore, considering the pH, the collected samples were safe for consumption. The Gopalganj district is closer to the coastal region. Maybe this is the reason for the alkaline tendency of pH in the research area. The lowest TDS value was 240.0 mg $L^{-1}$, and the uppermost value was 1530.0 mg $L^{-1}$, and the mean value was 473.07 mg $L^{-1}$. Considering the TDS, the water could be consumed because the WHO (2011) and Bangladesh's recommended value is 1000.0 mg $L^{-1}$. The lower concentration of TDS in the sampling point was most probably due to the presence of lower dissolved elements in the GW. Nitrate concentration in the water samples varied from 0.20 to 1.3 mg $L^{-1}$, and the mean value was 0.60 mg $L^{-1}$. Similarly, $NH_4^+$ concentration varied from 0.21 to 1.28 mg $L^{-1}$ with a mean value of

**Table 5** Scales for chronic and carcinogenic risk assessment

| Risk level | HQ/HI | Chronic risk | Calculated cancer occurrence | Cancer risk |
|---|---|---|---|---|
| 1 | $< 0.1$ | Negligible | $< 1$ per 1000,000 ($10^{-6}$) | Very Low |
| 2 | $\geq 0.1$ to $< 1$ | Low | $> 1$ per 1000,000 ($10^{-6}$)<br>$< 1$ per 100,000 ($10^{-5}$) | Low |
| 3 | $\geq 1$ to $< 4$ | Medium | $> 1$ per 100,000 ($10^{-5}$)<br>$< 1$ per 10,000 ($10^{-4}$) | Medium |
| 4 | $\geq 4$ | High | $> 1$ per 10,000 ($10^{-4}$)<br>$< 1$ per 1000 ($10^{-4}$) | High |
| 5 | - | - | $> 1$ per 1000 ($10^{-4}$) | Very High |

N.B.: HQ = Hazard Quotient; HI = Hazard Index. Source: USEPA (1999), Bodrud-Doza, et al. (2019)

**Table 6** Descriptive statistics of physical and chemical parameters of water samples. Samples were collected from Kashiani upazila (KaU) and Kotalipara upazila (KoU) of Gopalganj district

| Parameter | Unit | Min | Max | Mean | Med | SD | Standard value | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | WHO (2011) | BNDWQS (2011) |
| Turbidity | NTU | 0.23 | 4.73 | 0.94 | 0.63 | 0.911 | 5.00 | 10.00 |
| pH | | 7.20 | 8.20 | 7.62 | 7.64 | 0.210 | 6.5–8.5 | 8.50 |
| EC | $\mu Scm^{-1}$ | 280.00 | 3060.00 | 1300.57 | 1370.00 | 595.472 | 750.00 | 2000.00 |
| TDS | $mg\ L^{-1}$ | 240.00 | 1700.00 | 668.00 | 680.00 | 308.343 | 500.00 | 1000.00 |
| $Na^+$ | $mg\ L^{-1}$ | 31.00 | 317.00 | 100.14 | 88.00 | 57.00 | 200.00 | 200.00 |
| $K^+$ | $mg\ L^{-1}$ | 5.00 | 30.00 | 15.57 | 15.00 | 7.151 | 30.00 | 12.00 |
| $NH_4^+$ | $mg\ L^{-1}$ | 0.12 | 1.28 | 0.47 | 0.38 | 0.323 | 1.5 | 0.50 |
| $NO_3^-$ | $mg\ L^{-1}$ | 0.00 | 1.30 | 0.59 | 0.60 | 0.2862 | 50.00 | 10.00 |
| Fe | $mg\ L^{-1}$ | 0.02 | 2.95 | 0.56 | 0.08 | 0.857 | 0.01 | 0.30 |
| Mn | $mg\ L^{-1}$ | BDL | BDL | BDL | BDL | BDL | 0.10 | 0.10 |
| Cu | $mg\ L^{-1}$ | BDL | BDL | BDL | BDL | BDL | 2.00 | 1.00 |
| Zn | $mg\ L^{-1}$ | BDL | BDL | BDL | BDL | BDL | 3.00 | 5.00 |
| As | $mg\ L^{-1}$ | 0.024 | 0.428 | 0.191 | – | 0.107 | 0.01 | 0.05 |

**NB:** BDL = Below Detection Limit; BNDWQS = Bangladesh National Drinking Water Quality Survey; EC = Electrical Conductivity; NTU = Nephelometric Turbidity Unit; SD = Standard Deviation; TDS = Total Dissolved Solids

0.74 mg $L^{-1}$. Considering $NO_3^-$ and $NH_4^+$ (similar comment as previous) concentrations, the water was out of harm for consumption. The low concentrations of $NO_3^-$ and $NH_4^+$ in the GW were most probably due to the fact that there were not many industries present in Kashiani and Kotalipara upazila releasing N components in the GW. Sodium and K concentrations seemed to be within the permissible limit of drinking water quality. The concentrations of Mn, Cu, and Zn were lower than the detection limit in all the samples collected. However, the concentration of Fe in the GW of Kashiani ranged from 0.14 to 2.95 mg $L^{-1}$ in which the mean value was 1.22 mg $L^{-1}$. The Bangladesh permissible limit value of Fe in drinking water is 0.30 –1.0 mg $L^{-1}$, and WHO (2011) permissible border value is 0.30 mg $L^{-1}$. Therefore, it was assured that most of the water sources contained higher concentrations of Fe than the permissible stage. Nearly all universal sources of Fe in GW are naturally occurring, e.g., from weathering of Fe-bearing minerals and rocks (Edet et al. 2011). Industrial effluent, sewage, landfill leachate, and acid-mine drainage possibly will also add Fe to the GW of Kashiani. However, we suspect that the higher concentration of Fe in GW was mostly due to the geographical position of Kashiani upazila, though this supposition needs to be established with the experimental result. High concentration of Fe in drinking water may be responsible for gastric and dysentery. Iron plaque on teeth may also generate due to the presence of higher Fe in drinking water. Reports showed that an extensive series of public health tribulations, e.g., gastrointestinal bleeding, vascular disease, hypertension, restrictive lung disease, cancer, reproductive effects, and neurological disorder can occur if trace metal contaminated water is consumed frequently (Belabed and Soltani 2018; Nkpaa et al. 2018).

The hostile result was that a lofty concentration of As was recorded in Kashiani upazila and the content ranged from 0.024 to 0.428 mg $L^{-1}$ in which the mean value was 0.191 mg $L^{-1}$. The BNDWQS tolerable limit value of As is 0.05 mg $L^{-1}$, and the WHO (2011) tolerable limit value is 0.01 mg $L^{-1}$ (Table 6). It was believed that the Ganges River may bring dissolved As from the Fe-mine of West Bengal, India. Then, the As containing water might be transported by the branch river Madhumati, and As might be deposited beside the bank of the Madhumati river or might be distributed by overflowing during flooding. The Kashiani upazila is situated on the bank of the Madhumati River (BBS 2011). The above perception is only a presumption and needs to be demonstrated.

In Kotalipara upazila, the turbidity was assorted from 0.23 to 0.86 NTU with a mean value of 0.56 NTU, indicating that the turbidity was in safe hands. The lowest EC value was 280.0 μS $cm^{-1}$, the highest EC was 2830.0 μS $cm^{-1}$, and the mean value was 1512.73 μS $cm^{-1}$. It meant that the average EC value was more than the permissible limit of Bangladesh and WHO (WHO 2011). This outcome indicated that the EC value in Kotalipara was the warning of salinity intrusion. It is an alarming condition for the people of Kotalipara. The lowest pH in the water sample was 7.35, the highest was 8.20, and the mean value was 7.70. Thus, similar to EC, the pH also showed an insignificant increase in inclination which was also the signal of salinity intrusion. The lowest limit of TDS was 560.0 mg $L^{-1}$, the highest limit was 1700.0 mg $L^{-1}$ and the mean value was 783.18 mg $L^{-1}$, indicating that the ranged values were within the permissible boundary. The $NO_3^-$ and $NH_4^+$ concentrations were less than or within the tolerable limit assigned by BBS and WHO (WHO 2011). The average concentrations of Na, K, and Fe were also within the brackets suggested by BBS and WHO (WHO 2011). The remarkable fallouts were that no one of the samples in Kotalipara contained a few measurable amounts of Mn, Cu, Zn, and As. Therefore, it was definite that in the majority of the cases, the GW of the Kotalipara upazila was superior to the Kashiani upazila. However, a sign of salinity intrusion was intimidation in the case of Kotalipara upazila. It was definite that the symptom of salinity intrusion was missing in Kashiani upazila.

## WQI for drinking purposes

Bangladesh standard values (BNDWQS 2011) are applied in Eqs. 1–4 to verify the appropriateness of the GW quality for drinking purposes, and the results are presented in Table 7. The WQI values ranged from 28.33 to 213.76 with a mean value of 71.69 (Table 7). The end result showed that about 61% of samples (KaU-1, KaU-3, KaU-6, KaU-7, KaU-8, KaU-11, KaU-12, and KaU-13) exhibited poor water quality ("C" grade) in Kashiani upazila. Similarly, good water quality that is "B" grade was about 31% of the water. Among the samples of Kashiani, the KaU-10 was a very poor quality type of water for drinking purposes (Table 7). The poor quality of water was mostly due to a higher concentration of Fe and As. The unwarranted concentration of Fe and As in drinking water might be responsible for hypertension, neurological disorder, skin cancer, renal cancer, and lung cancer (Flanagan et al. 2012; Belabed and Soltani 2018).

On the contrary, about 96% of the samples (KoU-14–KoU-34) pertained to excellent drinking water quality in Kotalipara upazila. There was only one sample (KoU-35) that showed poor water, i.e., a "C" grade (Table 7). The difference in poor quality (Fig. 2) of water was mostly due to the differences in the geographical position of the two upazila. Kashiani upazila is beside the Madhumati River, and it is very near to the Padma river as compared to the Kotalipara upazila. The other cause was mostly the agricultural practices which are extensive in Kashiani upazila (BBS 2014). The Kotalipara is basically a low land area and lies under the water for the maximum time of the year. This is only speculation that needs to be proved with research. A report from the Khulna City of Bangladesh showed that the WQI values varied from 40.11 to 454.37 with a midline value of 108.94. Among the samples, almost 8.47% of the samples were unfit, 1.69% of the samples were very poor, 23.73% were poor, 54.24% were good, and only 11.86% of samples were excellent for drinking purposes (Mahmud et al. 2020). The differences in WQI values were governed by As in Kashiani upazila but in Khulna, the responsible factors were other elements other than As (Mahmud et al. 2020).

## Non-carcinogenic risk assessment

### Chronic risk assessment

Two health indices were used to evaluate the non-carcinogenic health risk of metals or metalloids on human health. In this report, HQ and HI were used for calculating the impacts

**Table 7** Calculated Water Quality Index (WQI) and their classification. Water samples were collected from Kashiani upazila (KaU) and Kotalipara upazila (KoU) of Gopalganj district

| Sample ID | WQI Value | Water Type | Grade | Sample ID | WQI Value | Water Type | Grade |
|---|---|---|---|---|---|---|---|
| KaU-1 | 122.46 | Poor | C | KoU-19 | 36.86 | Excellent | A |
| KaU-2 | 87.28 | Good | B | KoU-20 | 33.36 | Excellent | A |
| KaU-3 | 154.58 | Poor | C | KoU-21 | 40.72 | Excellent | A |
| KaU-4 | 68.74 | Good | B | KoU-22 | 33.85 | Excellent | A |
| KaU-5 | 75.34 | Good | B | KoU-23 | 28.33 | Excellent | A |
| KaU-6 | 134.69 | Poor | C | KoU-24 | 42.74 | Excellent | A |
| KaU-7 | 123.85 | Poor | C | KoU-25 | 39.56 | Excellent | A |
| KaU-8 | 131.39 | Poor | C | KoU-26 | 38.34 | Excellent | A |
| KaU-9 | 81.43 | Good | B | KoU-27 | 42.84 | Excellent | A |
| KaU-10 | 213.76 | Very poor | D | KoU-28 | 56.34 | Excellent | A |
| KaU-11 | 167.34 | Poor | C | KoU-29 | 44.56 | Excellent | A |
| KaU-12 | 111.34 | Poor | C | KoU-30 | 32.65 | Excellent | A |
| KaU-13 | 145.83 | Poor | C | KoU-31 | 38.34 | Excellent | A |
| KoU-14 | 32.56 | Excellent | A | KoU-32 | 36.86 | Excellent | A |
| KoU-15 | 32.68 | Excellent | A | KoU-33 | 33.58 | Excellent | A |
| KoU-16 | 34.59 | Excellent | A | KoU-34 | 34.48 | Excellent | A |
| KoU-17 | 32.45 | Excellent | A | KoU-35 | 37.62 | Excellent r | A |
| KoU-18 | 31.64 | Excellent | A | | | | |

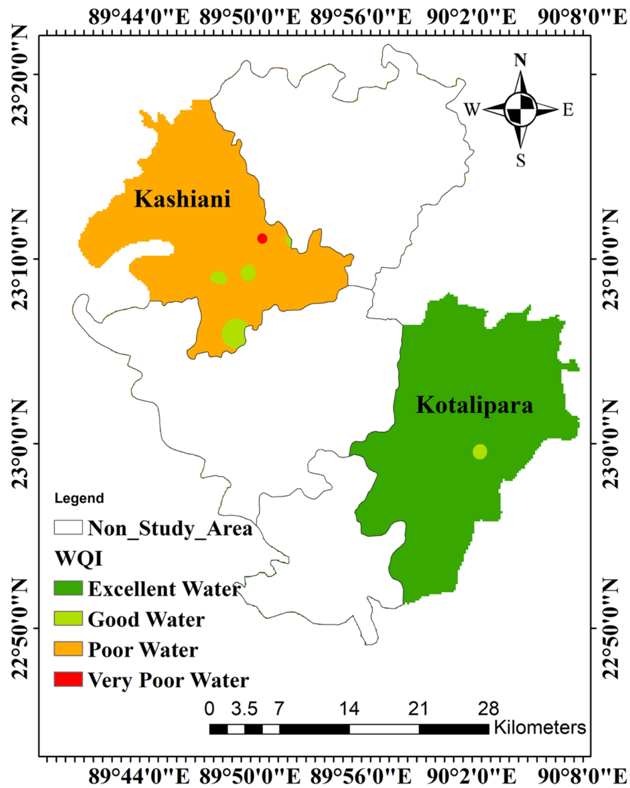


**Fig. 2** Water Quality Index maps of Kashiani and Kotalipara upazila. Most of the water samples from Kotalipara upazila are excellent and most of the water samples from Kashiani upazila are poor quality

of Fe, Mn, Cu, Zn, and As on health and are presented in Tables 8 and 9. Oral intake pathway for adults and children showed high HQ values for As compared to Fe. The order for HQ and HI values was As > Fe both for adults and children.

### Regarding adults

Chronic health risks, e.g., HQ and HI of GW through the introduction of oral consumption for adults, are presented in Table 8. The HQ values for Mn, Cu, and Zn were found to be BDL for adults in the Kashiani and Kotalipara upazila, indicating that these elements were not related to any hazard. The HQ values for Fe were found to be less than 1, indicating that Fe poses a low degree of hazards (Giri and Singh 2015; Bodrud-Doza et al. 2019). On the other hand, the utmost HQ values for As was found in the Kashiani upazila and the values ranged from 2.62 to 44.89 for adult (Table 8). According to USEPA (2004), for As, the majority of the samples of Kashiani upazila were within the high group of chronic risk, but in Kotalipara upazila the values were no chronic risk (Table 8). This was because the As concentration was BDL in Kotalipara. The results of HI for adults were also presented in Table 8. Nearly, 85% of samples were recognized as having high chronic risks in Kashiani upazila, however, in Kotalipara upazila nearly 100% of samples showed a minor level of chronic risk. In Kashiani upazila, the maximum chronic risk was established at sampling point KaU-10, while the least potential chronic risk was recorded at sampling point KaU-4 (Table 8). The high chronic risk in Kashiani upazila for As was most probably due to the fact that the water samples were collected from a shallow depth and the Kashiani upazila was situated on the bank of the Madhumati river (Shaibur 2019; Shaibur and Howlader 2020). On the other hand, the water samples of Kotalipara upazila were collected from a depth of 750–1200 ft (Shaibur and Howlader 2020). Moreover, Kotalipara is far from the Madhumati River. The depth of the water sources and the physiographic positions of the samples might play an important role in the occurrence of high concentrations of As (Shaibur and Howlader 2020). The difference in chronic risks for adults between the two upazila is presented in Fig. 3.

### Regarding children

Similar to adults, the HQ and HI values for children are outlined in Table 9. The Mn, Cu, and Zn were not related to any hazard considering HQ values, because the concentrations of these elements were BDL both in Kashiani and Kotalipara upazila (Table 9). But the HQ values for Fe were found to be less than 1, indicating that similar to adults, Fe poses a low degree of hazards for children (Giri and Singh 2015; Bodrud-Doza et al. 2019). For children, the greater HQ values for As were found in Kashiani upazila and the values ranged from 5.58 to 95.12 (Table 9). Considering As, the majority of the samples in Kashiani upazila were within the very high group of chronic risk for children, but in Kotalipara upazila, there was no chronic risk (USEPA 2004; Table 9). The HI values showed that about 100% of samples were recognized as the high chronic risks for children in Kashiani upazila. But in Kotalipara upazila, about 100% of samples showed a negligible level of chronic risk (Table 9).

In Kashiani upazila, both adults and children were under the maximum chronic risk level at sampling point KaU-10, while the least potential chronic risk was recorded at sampling point KaU-4 (Tables 8 and 9). In Kashiani upazila, nearly 85% of water samples were at high chronic risk and the remaining 15% of samples were at medium chronic risk for adults (Table 8). However, nearly 100% of water samples were high chronical risk for children (Table 9). On the contrary, the GW of Kotalipara is chronical risk-free both for adults and children. A recent report showed that almost 75.76% of water samples were in high non-carcinogenic risk levels and 19.19% were in medium non-carcinogenic risk for adults in Singair of Manikganj district, the central part of Bangladesh. But for children, the values were nearly 83.84% and 11.11%, respectively. For both categories, about

**Table 8** Hazard quotient (HQ) and hazard index (HI) value for adult through dermal exposure pathway

| Sample ID | HQ Adult | | | | | HI Adult | Chronic risk |
|---|---|---|---|---|---|---|---|
| | Fe | Mn | Cu | Zn | As | | |
| KaU-1 | 0.126 | BDL | BDL | BDL | 20.00 | 20.13 | VH |
| KaU-2 | 0.020 | BDL | BDL | BDL | 21.05 | 21.07 | VH |
| KaU-3 | 0.309 | BDL | BDL | BDL | 14.24 | 14.55 | VH |
| KaU-4 | 0.052 | BDL | BDL | BDL | 2.57 | 2.62 | Medium |
| KaU-5 | 0.015 | BDL | BDL | BDL | 16.03 | 16.04 | VH |
| KaU-6 | 0.071 | BDL | BDL | BDL | 24.82 | 24.89 | VH |
| KaU-7 | 0.192 | BDL | BDL | BDL | 15.71 | 15.90 | VH |
| KaU-8 | 0.141 | BDL | BDL | BDL | 21.75 | 21.89 | VH |
| KaU-9 | 0.099 | BDL | BDL | BDL | 2.83 | 2.92 | Medium |
| KaU-10 | 0.055 | BDL | BDL | BDL | 44.84 | 44.89 | VH |
| KaU-11 | 0.261 | BDL | BDL | BDL | 28.96 | 29.22 | VH |
| KaU-12 | 0.177 | BDL | BDL | BDL | 17.07 | 17.24 | VH |
| KaU-13 | 0.131 | BDL | BDL | BDL | 30.89 | 31.02 | VH |
| KoU-14 | 0.005 | BDL | BDL | BDL | BDL | 0.005 | Negligible |
| KoU-15 | 0.023 | BDL | BDL | BDL | BDL | 0.023 | Negligible |
| KoU-16 | 0.023 | BDL | BDL | BDL | BDL | 0.023 | Negligible |
| KoU-17 | 0.005 | BDL | BDL | BDL | BDL | 0.005 | Negligible |
| KoU-18 | 0.003 | BDL | BDL | BDL | BDL | 0.003 | Negligible |
| KoU-19 | 0.005 | BDL | BDL | BDL | BDL | 0.005 | Negligible |
| KoU-20 | 0.013 | BDL | BDL | BDL | BDL | 0.013 | Negligible |
| KoU-21 | 0.008 | BDL | BDL | BDL | BDL | 0.008 | Negligible |
| KoU-22 | 0.023 | BDL | BDL | BDL | BDL | 0.023 | Negligible |
| KoU-23 | 0.005 | BDL | BDL | BDL | BDL | 0.005 | Negligible |
| KoU-24 | 0.005 | BDL | BDL | BDL | BDL | 0.005 | Negligible |
| KoU-25 | 0.005 | BDL | BDL | BDL | BDL | 0.005 | Negligible |
| KoU-26 | 0.016 | BDL | BDL | BDL | BDL | 0.016 | Negligible |
| KoU-27 | 0.010 | BDL | BDL | BDL | BDL | 0.010 | Negligible |
| KoU-28 | 0.005 | BDL | BDL | BDL | BDL | 0.005 | Negligible |
| KoU-29 | 0.007 | BDL | BDL | BDL | BDL | 0.007 | Negligible |
| KoU-30 | 0.003 | BDL | BDL | BDL | BDL | 0.003 | Negligible |
| KoU-31 | 0.005 | BDL | BDL | BDL | BDL | 0.005 | Negligible |
| KoU-32 | 0.005 | BDL | BDL | BDL | BDL | 0.005 | Negligible |
| KoU-33 | 0.005 | BDL | BDL | BDL | BDL | 0.005 | Negligible |
| KoU-34 | 0.003 | BDL | BDL | BDL | BDL | 0.003 | Negligible |
| KoU-35 | 0.069 | BDL | BDL | BDL | BDL | 0.069 | Negligible |

N.B: BDL = Below Detection Limit; KaU = Kashiani Upazila; KoU = Kotalipara Upazila; USEPA = US Environmental Protection Agency; VH = Very High

5.05% of the samples were low non-carcinogenic risk levels (Rahman et al. 2020). The results proved that both adults and children showed high non- CR effects in the study area. The difference in chronic risks for children between the two upazila is presented in Fig. 4.

## Carcinogenic risk assessment

Both for adults and children, the CR of As via oral intake was determined, and the value is presented in Table 10. It was found that in Kashiani upazila, all most all the samples were at very high CR (USEPA 2004). All the sampling points in Kashiani upazila were habitually intimidated, and the cancer risk values were higher for children than adults (Table 10). The outcome demonstrated that the children were more vulnerable to potential cancer risk in the study area due to oral consumption of GW. A recent report showed that a high level of As in GW was accountable for higher CR to children ($1.94 \times 10^{-3}$) as compared to adults ($9.20 \times 10^{-4}$) in Singair, Manikganj, the central part of Bangladesh (Rahman et al. 2020). Another study from Khorramabad, Iran showed that the total HQ

**Table 9** Hazard quotient (HQ) and hazard index (HI) value for children through dermal exposure way

| Sample ID | HQ children | | | | | HI Children | Chronic risk |
|---|---|---|---|---|---|---|---|
| | Fe | Mn | Cu | Zn | As | | |
| KaU-1 | 0.267 | BDL | BDL | BDL | 40.00 | 40.26 | VH |
| KaU-2 | 0.042 | BDL | BDL | BDL | 44.67 | 44.72 | VH |
| KaU-3 | 0.656 | BDL | BDL | BDL | 30.23 | 30.88 | VH |
| KaU-4 | 0.111 | BDL | BDL | BDL | 5.47 | 5.58 | VH |
| KaU-5 | 0.031 | BDL | BDL | BDL | 34.00 | 34.03 | VH |
| KaU-6 | 0.151 | BDL | BDL | BDL | 52.67 | 52.82 | VH |
| KaU-7 | 0.407 | BDL | BDL | BDL | 33.34 | 33.74 | VH |
| KaU-8 | 0.300 | BDL | BDL | BDL | 46.24 | 46.54 | VH |
| KaU-9 | 0.121 | BDL | BDL | BDL | 6.00 | 6.12 | VH |
| KaU-10 | 0.118 | BDL | BDL | BDL | 95.12 | 95.23 | VH |
| KaU-11 | 0.553 | BDL | BDL | BDL | 60.89 | 61.44 | VH |
| KaU-12 | 0.376 | BDL | BDL | BDL | 36.23 | 36.60 | VH |
| KaU-13 | 0.278 | BDL | BDL | BDL | 65.56 | 65.83 | VH |
| KoU-14 | 0.011 | BDL | BDL | BDL | BDL | 0.011 | Negligible |
| KoU-15 | 0.004 | BDL | BDL | BDL | BDL | 0.004 | Negligible |
| KoU-16 | 0.004 | BDL | BDL | BDL | BDL | 0.004 | Negligible |
| KoU-17 | 0.011 | BDL | BDL | BDL | BDL | 0.011 | Negligible |
| KoU-18 | 0.007 | BDL | BDL | BDL | BDL | 0.007 | Negligible |
| KoU-19 | 0.011 | BDL | BDL | BDL | BDL | 0.011 | Negligible |
| KoU-20 | 0.027 | BDL | BDL | BDL | BDL | 0.027 | Negligible |
| KoU-21 | 0.018 | BDL | BDL | BDL | BDL | 0.018 | Negligible |
| KoU-22 | 0.004 | BDL | BDL | BDL | BDL | 0.004 | Negligible |
| KoU-23 | 0.011 | BDL | BDL | BDL | BDL | 0.011 | Negligible |
| KoU-24 | 0.004 | BDL | BDL | BDL | BDL | 0.004 | Negligible |
| KoU-25 | 0.011 | BDL | BDL | BDL | BDL | 0.011 | Negligible |
| KoU-26 | 0.033 | BDL | BDL | BDL | BDL | 0.033 | Negligible |
| KoU-27 | 0.022 | BDL | BDL | BDL | BDL | 0.022 | Negligible |
| KoU-28 | 0.004 | BDL | BDL | BDL | BDL | 0.004 | Negligible |
| KoU-29 | 0.016 | BDL | BDL | BDL | BDL | 0.016 | Negligible |
| KoU-30 | 0.007 | BDL | BDL | BDL | BDL | 0.007 | Negligible |
| KoU-31 | 0.004 | BDL | BDL | BDL | BDL | 0.004 | Negligible |
| KoU-32 | 0.011 | BDL | BDL | BDL | BDL | 0.011 | Negligible |
| KoU-33 | 0.004 | BDL | BDL | BDL | BDL | 0.004 | Negligible |
| KoU-34 | 0.007 | BDL | BDL | BDL | BDL | 0.007 | Negligible |
| KoU-35 | 0.629 | BDL | BDL | BDL | BDL | 0.629 | Low |

N.B: BDL = Below Detection Limit; KaU = Kashiani Upazila; KoU = Kotalipara Upazila; USEPA = US Environmental Protection Agency; VH = Very High

and HI values for GW were within acceptable limits both for adults and children (Mohammadi et al. 2019). However, the children of Dhaka city are under health risk from the consumption of contaminated GW for a long time (Bodrud-Doza et al. 2020). Cancer risk for the existence of As in drinking water can be a provision because arsenical skin diseases have previously been reported in Bangladesh (Shaibur 2019; Shaibur and Howlader 2020; Rahman et al. 2020) where both the adults and children were affected equally by As contaminated drinking water (Das et al. 2009). Luckily almost 100% of samples of Kotalipara were free from the effect of As CR.

The current study is characterized by a lofty concentration of As in GW of Kashiani. The mean concentration of As exceeded the suggested value of BNDWQS or WHO (BNDWQS 2011; WHO 1984). This is because the potential source of As in the Bengal basin is geogenic (Das et al. 2009; Rahman et al. 2016) as well as anthropogenic (Kundu et al. 2008). Arsenic in GW is associated with cancer, the circulatory system, or with skin damage (Bodek et al. 1988).

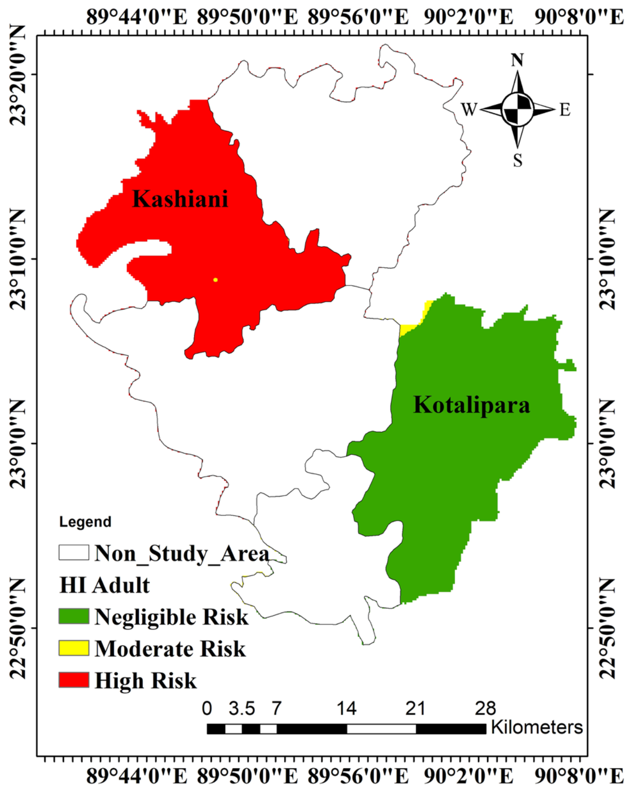


Fig. 3 Hazard index for adults. Most of the water samples from Kotalipara upazila are negligible risks for adults and most of the water samples from Kashiani upazila are high risks

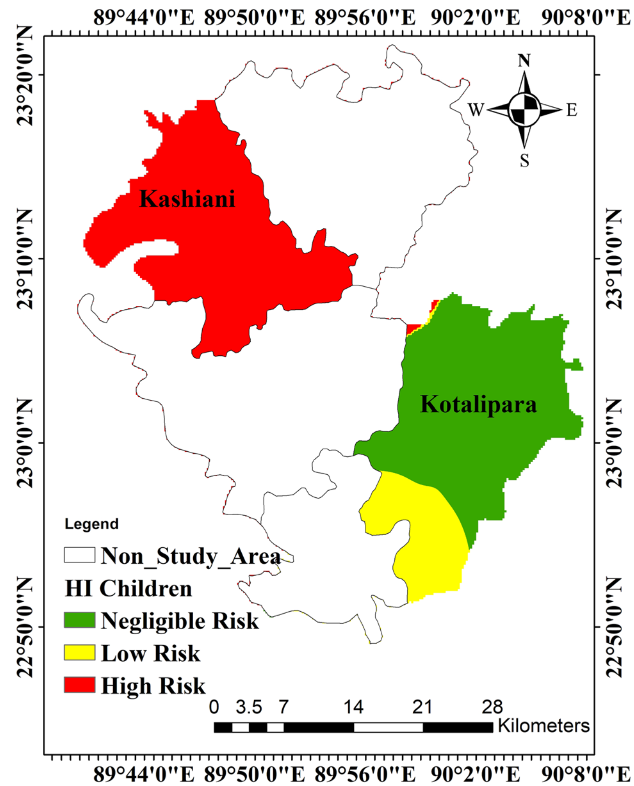


Fig. 4 Hazard Index for children. Most of the water samples from Kotalipara upazila are negligible risks and some were under low risks for children. On the contrary, most of the water samples from Kashiani upazila are high risks for children

In the present research, the CR of As for oral ingestion was higher for children than adults (Table 10). Similarly, the high CR for child and adults were reported in Gopalganj (Rahman et al. 2018). People exposed to As with drinking water are associated with heart (Chen et al. 2011) and skin (Das et al. 2009) diseases. Furthermore, enhance risks at low concentrations of As exposure cause the death of cardiovascular disease, cancer as well as various infectious disease in Bangladesh (Sohel et al. 2009). A recent report showed that about 95% of samples exhibited pollution for Cd and 75% of pollution took place for Ni (Bodrud-Doza et al. 2019).

## Conclusions

Concentrations of Mn, Zn, and Cu were below the detection limit in both upazila. Additionally, As concentration was also below the detection limit in the Kotalipara upazila. The WQI suggested that about 61% of samples of Kashiani upazila belonged to poor WQ. On the contrary, about 96% of samples of Kotalipara upazila pertained to excellent WQ. The uppermost HQ and HI related to drinking water values of Fe and As were obtained from Kashiani upazila. In the case of oral exposure, nearly 85% of the samples were ascribed to high chronic risks for adults, and 100% of the samples were referred to high chronic for children in

**Table 10** Cancer risk of As among the adult and children for verbal exposure way

| Sample ID | Cancer risk | | Carcinogenic risk (USEPA 1999) | |
|---|---|---|---|---|
| | Adult | Children | Adult | Children |
| KaU-1 | $9.0\times10^{-2}$ | $1.2\times10^{-2}$ | VH | VH |
| KaU-2 | $9.4\times10^{-3}$ | $2.01\times10^{-2}$ | VH | VH |
| KaU-3 | $6.4\times10^{-3}$ | $1.36\times10^{-3}$ | VH | VH |
| KaU-4 | $1.11\times10^{-3}$ | $2.46\times10^{-3}$ | VH | VH |
| KaU-5 | $7.21\times10^{-3}$ | $1.53\times10^{-2}$ | VH | VH |
| KaU-6 | $1.12\times10^{-2}$ | $2.73\times10^{-2}$ | VH | VH |
| KaU-7 | $7.07\times10^{-3}$ | $1.5\times10^{-2}$ | VH | VH |
| KaU-8 | $9.8\times10^{-3}$ | $2.08\times10^{-2}$ | VH | VH |
| KaU-9 | $1.27\times10^{-3}$ | $2.7\times10^{-6}$ | VH | VH |
| KaU-10 | $2.02\times10^{-2}$ | $4.2\times10^{-2}$ | VH | VH |
| KaU-11 | $1.29\times10^{-2}$ | $2.74\times10^{-2}$ | VH | VH |
| KaU-12 | $7.68\times10^{-3}$ | $1.63\times10^{-3}$ | VH | VH |
| KaU-13 | $1.39\times10^{-2}$ | $2.954\times10^{-2}$ | VH | VH |
| KoU-14 | BDL | BDL | NR | NR |
| KoU-15 | BDL | BDL | NR | NR |
| KoU-16 | BDL | BDL | NR | NR |
| KoU-17 | BDL | BDL | NR | NR |
| KoU-18 | BDL | BDL | NR | NR |
| KoU-19 | BDL | BDL | NR | NR |
| KoU-20 | BDL | BDL | NR | NR |
| KoU-21 | BDL | BDL | NR | NR |
| KoU-22 | BDL | BDL | NR | NR |
| KoU-23 | BDL | BDL | NR | NR |
| KoU-24 | BDL | BDL | NR | NR |
| KoU-25 | BDL | BDL | NR | NR |
| KoU-26 | BDL | BDL | NR | NR |
| KoU-27 | BDL | BDL | NR | NR |
| KoU-28 | BDL | BDL | NR | NR |
| KoU-29 | BDL | BDL | NR | NR |
| KoU-30 | BDL | BDL | NR | NR |
| KoU-31 | BDL | BDL | NR | NR |
| KoU-32 | BDL | BDL | NR | NR |
| KoU-33 | BDL | BDL | NR | NR |
| KoU-34 | BDL | BDL | NR | NR |
| KoU-35 | BDL | BDL | NR | NR |

N.B: BDL = Below Detection Limit; KaU = Kashiani Upazila; KoU = Kotalipara Upazila; NR = No Risk; USEPA = US Environmental Protection Agency; VH = Very High

Kashiani upazila. On the contrary, about 100% of the samples in Kotalipara upazila recommend a lower chronic risk both for adults and children. The carcinogenic risk of As via oral exposure pathway indicates that all samples of Kashiani upazila were high risk for both adults and children, whereas children were more susceptible.

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## Declarations

**Conflict of interest** We do not have any conflict of interest. Authors are responsible for any errors.



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