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Contamination of arsenic, manganese and coliform bacteria in groundwater at Kushtia District, Bangladesh: human health vulnerabilities

Aminur Rahman and Hafezur Rahaman

ABSTRACT

Safe water is essential for life. Consumption of arsenic and manganese contaminated water poses a range of health effects to humans. Physico-chemical and bacteriological characteristics of groundwater at five administrative upazillas in Kushtia District, Bangladesh, have been studied to evaluate the potability of water for drinking purpose from 32 randomly selected tube wells (TWs). APHA (2012) standard analytical methods were applied for analyses of the physico-chemical and bacteriological parameters of the water samples. Arsenic, iron, and manganese content were analyzed by atomic absorption spectroscopy (AAS). The investigated parameters of water samples were found as pH 6.81–8.12, electrical conductivity (EC) 520–1,995 μs/cm, total dissolved solids (TDS) 357.8–1,372.6 mg/L, chloride 10–615 mg/L, total hardness 285–810 mg/L, arsenic (As) 0.001–0.098 mg/L, iron (Fe) 0.04–1.45 mg/L, manganese (Mn) 0.01–6.32 mg/L. About 56.25% of TWs were highly contaminated with fecal coliform (FC) and 68.75% were found to be contaminated with total coliform (TC). Results were compared with World Health Organization (WHO) and Bangladesh Drinking Standards (BDS). The concentrations of water quality parameters are much higher as compared to WHO and BDS standards. This may cause acute public health risks and make water unsuitable for direct human consumption without treatment.

Key words | contamination, groundwater, physico-chemical and bacteriological characteristics, public health, water quality

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INTRODUCTION

Water is the most fundamental commodity to the survival of life (WHO 2011a). Therefore, major requirements are not only to have sufficient supply, but also to have quality water that must be considered safe for human consumption (Amanatidou *et al.* 2007). This is a vital promise for public health and also essential to environmental security and sustainable development certainty (Eze & Madumere 2012). Groundwater is the world's largest source of fresh potable water (Howard 1997). Worldwide it provides an estimated 1.5 billion people everyday (DFID 2005) and is a fundamental resource for meeting rural water demand (MacDonald & Davies 2002; Harvey 2004). With ever-increasing water demand, the preference for most people in rural areas of Bangladesh is for groundwater and to abstract water through tube wells (TWs) for industrial, agricultural, and domestic use. However, the quality of groundwater resources varies from place to place, sometimes depending on seasonal changes (Trivede *et al.* 2010; Vaishali & Punita 2013; Juwarkar 2015) and the types of soils, rocks, and surfaces through which it flows (Thivya *et al.* 2014). As groundwater flows through sediment metals from different sources can be dissolved and may later be found in high concentrations in the groundwater (Moyo 2013). Human activities can influence the composition of groundwater with the use of

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chemical fertilizer and microbial substances on the land surface and into soils, or through injection of wastes directly into groundwater. Industrial discharges (Govindarajan & Senthilnathan 2014) and urban activities can affect groundwater quality. Thus, pesticides and fertilizers applied to lawns and crops can coagulate and migrate to water tables which affect the physical, chemical, and bacteriological quality of water.

In rural areas, the familiar type of sanitation, pit latrines, pose a great risk to the bacteriological quality of groundwater. A septic tank can introduce bacteria into water. Poor sanitary completion of TWs may lead to contamination of groundwater. Proximity of some TWs to solid waste dumpsites and animal droppings being littered around them (Bello *et al.* 2013) could also contaminate the quality of groundwater.

Residents, especially in rural areas, depend on groundwater resources. The quality of water from these sources is unpredictable; usually in some areas it may contain high quantities of arsenic (Von Brömssem *et al.* 2014) which is of particular concern (Van Vuuren 2013) to us. In some articles, high levels of iron, manganese and hardness problems in groundwater elsewhere have also been reported (Rahman *et al.* 2016). As far as we are aware, no report has been published concerning the physico-chemical and bacteriological properties of these areas.

The objective of this research was to monitor the water quality of this area for human potability concerning physico-chemical and bacteriological contaminants and possible impact on human health.

MATERIALS AND METHODS

Study area

Kushtia district is located in the Khulna administrative division of the western part of Bangladesh. It is bordered by the mighty Padma River to the north, Jhenaidah district to the south, Rajbari district to the east, Meherpur, Chuadanga districts and Nadia and Murshidabad districts of West Bengal (Indian State) to the west. The latitude (N) and longitude (E) position of each location was confirmed by GPS Meter (Garmin eTrex 10) reading which is given in Table 1.

Sampling and preservation

The drinking water samples from 32 randomly selected TWs (a tube well consists of a long pipe drilled subsurface or deep aquifer into the earth, with a hand pump attached at the top to obtain water) were collected for physico-chemical analyses in prewashed (with detergent, de-ionized water, diluted HNO_3 and completely de-mineralized water, respectively) high density polyethylene (HDPE) bottles from 32 different sources in the region of Kushtia district. All 32 water samples were collected within a week (third week of September 2017). During sampling the weather conditions were dry (temperature was about 25–27 °C). The sampling locations are shown in Figure 1. The water samples were collected in sterilized sample bottles for bacteriological analyses (fecal coliform (FC) and total coliform (TC)) carried out within 4 h after sampling.

Reagent and solutions

Analytical grade reagent chemicals were applied for the preparation of all solutions. Freshly prepared double de-ionized distilled water was used in all experiments. 5.0 M Hydrochloric acid (Sigma-Aldrich, USA), 0.6% sodium borohydride solution (Sigma-Aldrich, USA) reagent, 20% potassium iodide (Sigma-Aldrich, USA) solution as a reductant, inert gas argon (as a carrier gas) for HVG system (determination of As), air-acetylene as a fuel gas for direct flame system (determination of Fe and Mn), commercial grade standard solutions (CRM) of As, Fe, Mn solutions (Fluka-Analytical, Switzerland) were employed during the experiments.

Physico-chemical analyses

The physico-chemical water quality was measured in terms of pH, electrical conductivity (EC), total dissolved solids (TDS), chloride, total hardness, arsenic (As), iron (Fe), and manganese (Mn). All examinations were conducted according to American Public Health Association *Standard Methods* (APHA 2012).

The pH and EC of water were determined on-site using a multimeter (Model HQ 40d, HACH, USA). The meter was calibrated initially by using two buffer solutions at

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Table 1 | Location, latitude, longitude, and sample ID of the sampling points

Sl. no.	Upazilla	Union	Village	Latitude (N)	Longitude (E)	Sample ID	Sample collection date
1	Kushtia sadar	Jhaudia	Ashtanagar	23°46′58″	89°04′47″	D-1	17/09/2017
2	Kushtia sadar	Jhaudia	Badunathpur Matpara	23°45′58″	89°04′25″	D-2	17/09/2017
3	Kushtia sadar	Alampur	Kathulia	23°50′44″	89°05′36″	D-3	17/09/2017
4	Kushtia sadar	Alampur	Alampur Karigar Para	23°49′43″	89°05′52″	D-4	17/09/2017
5	Kushtia sadar	Barakhada	Mangalbaria	23°55′03″	89°06′48″	D-5	17/09/2017
6	Kushtia sadar	Barakhada	Mongolbaria	23°55′02″	89°06′57″	D-6	17/09/2017
7	Kumarkhali	Chandpur	D-Chandpur	23°45′56″	89°11′16″	D-7	18/09/2017
8	Kumarkhali	Chandpur	Jongoli	23°45′27″	89°09′02″	D-8	18/09/2017
9	Kumarkhali	Jagannathpur	Doyrampur	23°53′30″	89°15′30″	D-9	18/09/2017
10	Kumarkhali	Kaya	Baniapara	23°55′15″	89°’09′35″	D-10	18/09/2017
11	Kumarkhali	Panti	Krishnopur	23°47′32″	89°’13′43″	D-11	18/09/2017
12	Kumarkhali	Chapra	Varora	23°51′00″	89°12′07″	D-12	18/09/2017
13	Khoksha	Khoksha	Rotonpur	23°49′17″	88°16′27″	D-13	20/09/2017
14	Khoksha	Osmanpur	Komorvog	23°46′31″	89°15′29″	D-14	20//09/2017
15	Khoksha	Osmanpur	Komorvog	23°46′55″	89°16′09″	D-15	20//09/2017
16	Khoksha	Janipur	Biharea	23°45′33″	89°18′50″	D-16	20//09/2017
17	Khoksha	Ambaria	Ambaria	23°52′30″	89°20′30″	D-17	20//09/2017
18	Khoksha	Gopagram	Khoddosadhua	23°51′20″	89°18′09″	D-18	20/09/2017
19	Khoksha	Gopagram	Boroiechara	23°51′03″	89°18′40″	D-19	20//09/2017
20	Khoksha	Samaspur	Poddojani	23°49′49″	89°18′35″	D-20	20//09/2017
21	Mirpur	Amla	Kuhahbaria	23°53′23″	88°56′42″	D-21	22/09/2017
22	Mirpur	Chithulia	Dhubail	23°58′07″	88°58′54″	D-22	22/09/2017
23	Mirpur	Bahalbaria	Sahabnoger	23°58′06″	89°02′24″	D-23	22/09/2017
24	Mirpur	Bahalbaria	Khadempur	23°58′43″	89°01′11″	D-24	22/09/2017
25	Mirpur	Fulbaria	Mirpur	23°56′03″	88°59′59″	D-25	22/09/2017
26	Mirpur	Poradaha	Ahmmedpur	23°53′19″	88°03′45″	D-26	22/09/2017
27	Mirpur	Kursha	Kursha	23°50′16″	88°56′59″	D-27	23/09/2017
28	Mirpur	Kursha	Essalmaria	23°49′37″	88°57′13″	D-28	23/09/2017
29	Mirpur	Kursha	Essalmaria	23°49′15″	88°57′11″	D-29	23/09/2017
30	Bheramara	Dharampur	S.bhabanipur	23°00′58″	88°57′40″	D-30	23/09/2017
31	Bheramara	Mokarimpur	Fokerabad	24°04′49″	88°58′57″	D-31	23/09/2017
32	Bheramara	Junaidaha	Juniadaha	24°05′27″	88°55′56″	D-32	23/09/2017

pH = 4.01 and pH = 7.0 followed by rinsing thoroughly using de-ionized water. The meter was verified after measuring five samples. For EC determination, the meter was calibrated by using standard 1,000 μS/cm NaCl solution and verified after five measurements. pH and EC of the samples were measured while collecting the samples. In the case of TDS measurement, the multimeter (Sension-156, HACH, USA) was calibrated by 1,000 mg/L TDS standard and measured with the same method as EC measurement.

Chloride was analyzed by the standard titrimetric (Argentometric) method (APHA 2012). Here, silver nitrate (BDH, UK) solution (0.0141N) was used as titrant and potassium chromate (K_2CrO_4) used as an indicator. NaCl was used for the determination of strength of silver nitrate. pH

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Figure 1 | Location map of Kushtia, Bangladesh.

of water was adjusted so that it would fall within 7 to 10 pH units, and 1 mL of K_2CrO_4 (BDH, UK) indicator solution was added. Then, the obtained solutions were titrated with standard $AgNO_3$ to a pinkish yellow end point. The titrant was standardized and reagent blank value was established (APHA 2012).

Hardness was analyzed by standard ethylene diamine tetra-acetic acid (EDTA) (Merck, Germany, 0.01 M) titration method (APHA 2012). Erichrome Black T (Merck, Germany) was used as a indicator. 25 mL of the samples were diluted to 50 mL by distilled water, and 1 mL of buffer solution ($pH = 10$) was added in a conical flask, as well as two drops of indicator solution. Then, the solution was titrated with EDTA, until the last reddish tinge disappeared (the solution is normally blue) (APHA 2012).

Arsenic, iron, and manganese were analyzed by atomic absorption spectrophotometric (AAS) method (APHA 2012). First, preparation of calibration curve was done by using working standard solutions of different concentrations from certified reference material (CRM). As (V) is reduced to As(III) using potassium iodide and sodium borohydride reagent to form arsine vapor by the use of carrier gas

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argon and detect the total arsenic at 193.7 nm wavelength. This process is called hydride vapor generation (HVG). Iron and manganese is analyzed by atomization process (direct flame) creating a flame by the combustion of air and acetylene gas (flame temperature nearly about 2,200 °C) at 248.3 and 279.5 nm wavelength, respectively.

Bacteriological analyses (FC and TC)

Water samples were analyzed immediately after collection for the presence of fecal coliforms and total coliforms using membrane filtration method (APHA 2012). 100 mL from each water sample was filtered through 0.45 μm pore size filter papers. The filters were placed on mFC agar and mENDO agar and plates were incubated aerobically at 45 °C and 37 °C, respectively, for 21 ± 3 h. Blue and metallic sheen (golden red) colonies on MFC agar and mENDO agar plates were purified and used for bacteria identification tests. For all the assays, positive and negative controls were performed (ISO 1986).

Data analysis

Data for physico-chemical and bacteriological contaminants in drinking water samples were recorded and analyzed for pH, EC, TDS, chloride, hardness, As, Fe, Mn, FC, and TC. Mean and standard deviations were calculated from the results of the analysis of the three samples per sampling point. Errors were calculated to ±5%. Results were compared with the Department of Environment (Environment Conservation Rules 1997), Bangladesh and the WHO drinking water standards.

Water quality index (WQI)

WQI indicates the quality of water in terms of index number which represents overall quality of water for any intended use. It is defined as a rating reflecting the composite influence of different water quality parameters taken into consideration for the calculation of WQI. The indices are among the most effective ways to communicate information on water quality trends to the general public or to policy-makers and in water quality management. Mostly, it is considered from the point of view of its suitability for human consumption. In this study, the weighted arithmetic mean method is used for the determination of WQI.

Weighted arithmetic WQI method

The weighted arithmetic WQI method (Yisa & Jimoh 2010; Tyagi *et al.* 2014; Akter *et al.* 2016) was applied to assess water suitability for drinking purposes. In this method, water quality rating scale, relative weight, and overall WQI were calculated as per Equations (1)–(3) respectively.

$$Q_i = \left(\frac{C_i}{S_i}\right) \times 100 \tag{1}$$

where Q_i, C_i, and S_i indicate quality rating scale, experimental concentration of I parameter, and standard value of i parameter, respectively.

Relative weight was calculated by Equation (2):

$$W_i = \frac{1}{S_i} \tag{2}$$

where the standard value of the i parameter is inversely proportional to the relative weight.

Finally, overall WQI was calculated according to Equation (3):

$$\mathrm{WQI} = \frac{\sum W_i Q_i}{\sum W_i} \tag{3}$$

RESULTS AND DISCUSSION

Physico-chemical characteristics

The results of physico-chemical analysis are summarized in Table 2. According to Bangladesh Drinking Standards (BDS), pH of water should be 6.5 to 8.5. Thus, as shown in Table 2, all the water samples are slightly alkaline and in the range of 7.11 to 8.12 except that for sample no. D-1 (6.91) and D-5 (6.81). Hence, the pH of the water in the study area could be classified as suitable for drinking purposes. However, these values do not compromise groundwater quality in terms of human consumption, as

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Table 2 | Physico-chemical analyses of groundwater samples

Sample ID	pH	EC (μs/cm)	TDS (mg/L)	Cl (mg/L)	Hardness (mg/L)	As (mg/L)	Fe (mg/L)	Mn (mg/L)
D-1	6.91	710	488.5	55	290	0.003	0.04	0.09
D-2	7.11	560	385.3	18	340	0.02	0.04	0.11
D-3	7.13	612	421.1	97	355	0.001	1.45	0.11
D-4	7.10	490	337.1	10	423	0.064	0.11	1.94
D-5	6.81	704	484.3	30	462	0.028	0.16	6.32
D-6	7.20	690	474.7	48	485	0.079	0.04	0.98
D-7	7.81	750	516	20	398	0.016	0.1	0.87
D-8	7.93	620	426.6	19	295	0.004	0.05	0.31
D-9	7.85	670	461	21	440	0.098	0.05	0.34
D-10	7.87	720	495.4	24	390	0.001	0.61	0.09
D-11	7.67	840	578	22	430	0.011	0.39	0.59
D-12	7.49	1,830	1,259	490	690	0.006	0.07	0.12
D-13	7.81	960	660.5	55	485	0.005	0.04	0.09
D-14	7.92	780	536.6	20	392	0.002	0.10	0.09
D-15	7.73	770	529.8	40	410	0.013	0.05	0.30
D-16	7.81	800	550.4	58	350	0.005	0.04	0.12
D-17	7.83	840	578	40	425	0.009	0.05	0.30
D-18	7.66	890	612.3	30	440	0.02	0.52	4.72
D-19	7.82	840	578	20	435	0.027	0.04	3.64
D-20	7.82	830	571	65	410	0.022	0.75	4.93
D-21	8.11	580	399	20	290	0.001	0.09	0.01
D-22	7.92	680	467.8	22	395	0.001	0.42	0.01
D-23	7.54	1,590	1,094	335	740	0.001	0.09	0.01
D-24	7.48	1,230	846.2	202	505	0.007	0.22	0.01
D-25	7.85	550	378.4	30	403	0.02	0.09	0.01
D-26	7.91	520	357.8	21	285	0.007	0.92	0.18
D-27	7.72	700	481.6	20	401	0.024	0.49	4.05
D-28	7.63	1,995	1,372.6	615	810	0.002	0.04	0.20
D-29	7.91	700	481.6	50	380	0.001	0.04	0.01
D-30	7.72	894	615.1	110	545	0.003	0.81	1.02
D-31	7.91	660	454.1	20	360	0.022	0.04	0.01
D-32	8.12	910	626.1	70	392	0.006	0.04	0.10
WHO (2011a)	6.5–8.5	–	–	250	500	0.01	0.3	0.5
Environment Conservation Rules (ECR 1997)	6.5–8.5	–	1,000	600	500	0.05	1.0	0.1

they only reflect the geological composition of the ground (Trivede *et al.* 2010). Extreme values of pH may result in irritation of the eyes, mucous membranes, and skin (WHO 1996). No health-based guideline value is proposed for pH (WHO 1996).

The amount of dissolved mineral salts in water determines the EC and is dependent on the concentration, mobility, and valence of the present ions. From the conductivity investigation, it is observed that the water from almost of all the TWs has some dissolved mineral content. From

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convention, drinking water has been categorized into: (i) good drinking water for humans (EC <800 μS/cm), (ii) can be consumed by humans (EC <800–2,500 μS/cm), and (iii) not recommended (EC >2,500 μS/cm). It is seen that 59.37% of TWs (19 out of 32) supply good drinking water and at the same time 40.63% of TWs (13 out of 32) supply drinking water that can be consumed by humans. These results clearly indicate that water in the study areas was considerably ionized and has a higher level of ionic concentration activity due to excessive dissolved solids (USEPA 2012). It is said that drinking water of higher conductivity is not always safe for regular drinking as it may be the cause of hypertension, kidney failure, and stone deposition in the intestines. According to the Drinking Water Inspectorate (2005), drinking water with conductivity higher than 2,500 μS/cm at 20 °C is not recommended for human consumption. The highest EC, 1,995 μS/cm, was found in sample no. D-28 and may be due to high concentration of ionic constituents present in the water bodies.

EC level can be used as an indirect measurement of TDS (Bityukova & Petersell 2010) that represent the amount of inorganic salts, such as calcium, magnesium, sodium, potassium, carbonate, chloride, sulfate, or nitrate, and organic matter present in water (WHO 2011a). According to WHO (2011a), in terms of palatability, water can be categorized according to the level of TDS value as excellent (<300 mg/L), good (300–600 mg/L), fair (600–900 mg/L), poor (900–1,200 mg/L) and unacceptable (>1,200 mg/L). From the investigation it is seen that no tube well is in the excellent category on the basis of TDS rating. There are 24 out of 32 (75%) TWs providing good quality of water. From the results it is noted that 15.62% and 3.13% of TWs are fair and poor categories, respectively. Only two TWs (6.25%) provide unacceptable water. According to BDS and the WHO standard value level of TDS in water, <1,000 mg/L is acceptable and >1,000 mg/L is unacceptable for drinking purposes. 90.62% (29 out of 32) of TWs are within the acceptable limit while 9.38% (D-12, D-23, and D-28) exceed the limit.

Chloride may present naturally in groundwater and also originate from dissimilar sources such as weathering, leaching of sedimentary rocks, percolation of seawater, etc. Chloride concentration should not surpass 250 mg/L according to the WHO. It produces a brackish taste at between 250 mg/L and 500 mg/L (Trivedy & Goel 1984), which makes it obnoxious for human consumption. It is seen from Table 2 that 29 out of 32 TWs, i.e., 90.62% of TWs, provide chloride up to 250 m/L. It means that 9.38% of the total TWs exceeded the WHO standard for chloride content. It is also observed that although the WHO standard value for chloride is ≤250 mg/L that for BDS value is ≤600 mg/L. From the results 31, i.e., 96.87% of TWs meet the BDS value and the rest, i.e., 3.13% (only one) exceeded the allowable limit, hence unsuitable for drinking. Many of salts, especially NaCl, are present in dissolved state in groundwater for tube well D-28. People consuming highly chloride contaminated water have a risk of heart and kidney diseases (WHO 1997). Chloride toxicity has been observed in those cases where it is impaired with sodium (WHO 1978). When excess chloride concentration is present with excess sodium, it may cause congestive heart failure hypertension (ISO 1989).

Hardness (TH) is composed by both temporary and permanent hardness and symbolizes the water dissolved calcium and magnesium salts due to water contact with ground rocks (APHA 2012). These salts are very acerbic and deposit scale in different types of boilers. McGowan (2000) and WHO (2011b) categorized water as soft, moderately hard, hard, and very hard when its hardness levels are 0–60 mg/L, 61–120 mg/L, 121–180 mg/L, and >180 mg/L, respectively. Hardness of water is primarily due to the presence of salts of calcium and magnesium and also increases the boiling point of the water (Murhekar 2011). In our study, no samples are soft, moderately soft, or hard on the basis of TH. All of the samples were very hard, reflecting the geological composition of the area, i.e., Kushtia is limestone ground (WHO 2011a). This parameter does not cause harmful health effects (Leurs *et al.* 2010; Ahmed *et al.* 2015); however, the recommended values in the BDS range from 200 to 500 mg/L (ECR 1997). The obtained results clearly indicate that 84.37% of water samples presented lower values than permissible limits and 15.63% of TWs exceeded the limits that are very harmful for humans.

Arsenic is widely distributed throughout Earth's crust and is usually present in the form of compounds with sulfur and many metals such as copper, cobalt, lead, and zinc. Major sources of arsenic exposure to the environment

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are food, water, soil, and air. The universally reported symptoms of arsenic exposure are skin lesions, developmental effects, cardiovascular disease, melanosis, keratosis, ulcer, gangrene, lung disease, kidney failure, liver failure, neurotoxicity, and arsenicosis (FAO UNICEF, WHO & WSP 2010). There are 18 TWs, 56.25% of the total, that provide almost arsenic-free (0.001–0.01 mg/L) water. These TWs are within both BDS (0.05 mg/L) and WHO (0.01 mg/L) permissible limits. In the investigation there are 11 TWs (34.37%) that provide water of As content 0.001–0.05 mg/L, higher than the WHO guideline but within the BDS limit. Three TWs were found (D-4, D-6, and D-9) where arsenic level exceeded 0.05 mg/L which is unsafe for humans. A number of mechanisms regarding the release of arsenic into the environment have been proposed by different scientists at different times. The pyrite oxidation hypothesis suggests that pyrite and arsenopyrite are deposited as pockets in aquifer sands and are oxidized and released into the groundwater. The oxidation is initiated by the entry of air into the aquifer due to lowering of the water table, which occurs because of the large abstraction of groundwater for irrigation. In this hypothesis, the oxidation of pyrite and arsenopyrite may increase the concentration of sulfate along with the arsenic in a few cases at our study area.

Iron is found as the iron Fe^{2+} and Fe^{3+} ions which combine with oxygen and sulfur containing compounds to form oxides hydroxides, carbonates, and sulfides (Elinder 1986). Large amounts of iron in drinking water can give an objectionable metallic taste. It can also promote the growth of iron bacteria and make the water distasteful (Yagoub & Ahmed 2009). There are 23 TWs containing iron, 71.87% of the total provide water below the WHO standards (<0.30 mg/L) and comply with both BDS (0.30–1.0 mg/L) and WHO permissible limits. In this investigation, there are eight TWs (25%) that provide water of iron content 0.30–1.0 mg/L, within BDS permissible limit but exceeding the WHO guideline value. This reveals that water of 31 TWs is safe from iron concentration according to BDS guideline value. There is only one TW (3.13%) that provides water with iron content higher than BDS (>1.0 mg/L) guideline value. It is seen from Table 2, that the highest value is 1.45 mg/L found in sample no. D-3, which may be produced from iron oxides that occur in groundwater with other elements, e.g., Mn, As, etc. A few scientists have suggested that the presence of iron in underground drinking water could be due to its percolation from granitic and metamorphosed rocks into groundwater, i.e., water–rock interaction. Iron is an essential element in human nutrition, required for hemoglobin to transport oxygen from the lungs to the cells or it can be a dangerous toxin. The health effects of iron in drinking water may include warding off fatigue and anemia.

Manganese is a mineral that naturally occurs in rocks and soil, usually with iron. The central nervous system is the chief target of Mn toxicity, especially causing neurological disorders in children (ATSDR 2000). Manganism originates from exposure to excessive levels of manganese and is characterized by a ‘Parkinson-like syndrome’ (Mergler *et al.* 1994). Concentration of Mn in water up to 0.5 mg/L is the WHO standard whereas BDS maximum permissible limit is 0.1 mg/L. When Mn concentration exceeds 0.5 mg/L in water it becomes a health risk. There are 12 TWs (37.5%) providing water that contains manganese <0.1 mg/L and complying with both BDS (0.1 mg/L) and WHO (0.5 mg/L) permissible limits. In this investigation, there are 20 TWs (62.5%) that provide water of manganese concentration higher than 0.1 mg/L, which means that the water supplied by these wells exceeds the BDS standard guideline value and is thus unsuitable for drinking purposes, but according to the WHO standard (0.5 mg/L), the water of ten TWs may be drinkable. Like iron, it is suggested that manganese is most probably produced from different ores that are soluble in groundwater. In other words, the presence of manganese in underground drinking water could be due to its percolation from granitic and metamorphosed rocks into groundwater, i.e., water–rock interaction. In fact, manganese occurs naturally in ores that may erode into groundwater sources.

Bacteriological analysis

In our investigated areas, groundwater is the principal source of drinking water and the major problem in water potability is microbiological contamination (WHO 2011a), mostly associated with fecal contamination from wastewater or landfills (Al-Khatib & Arafat 2009). The results of the bacteriological analysis are shown in Table 3 and

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Table 3 | Results of bacteriological analyses of the studied groundwater samples

Sample ID	No. of TWs Fecal coliform, cfu/100 mL	Total coliform, cfu/100 mL
D-1	4	23
D-2	7	34
D-3	0	13
D-4	19	67
D-5	0	0
D-6	2	11
D-7	13	45
D-8	1	8
D-9	0	5
D-10	33	>100
D-11	7	31
D-12	1	5
D-13	0	0
D-14	2	7
D-15	3	12
D-16	0	2
D-17	0	0
D-18	0	0
D-19	3	15
D-20	1	9
D-21	0	0
D-22	5	12
D-23	0	0
D-24	0	0
D-25	0	0
D-26	0	0
D-27	0	2
D-28	11	52
D-29	3	11
D-30	13	62
D-31	0	0
D-32	3	14
WHO (2011a)	0 cfu/100 mL	0 cfu/100 mL
Environment Conservation Rules (ECR 1997)	0 cfu/100 mL	0 cfu/100 mL

cfu = colony forming unit.

Table 4 | Number of TWs contaminated with FC and TC

Category cfu/100 mL	No. of TWs Fecal coliform	Total coliform	% Fecal coliform	Total coliform	Type of risk
<1	14	10	43.75	31.25	Safe
1–10	13	7	40.62	21.88	Low
11–50	5	11	15.63	34.37	Intermediate
51–100	–	3	–	9.37	High
>100	–	1	–	3.13	Very high

the contamination of fecal and total coliform in our investigated drinking water sources and type of risk are shown in Table 4. From the table, it is clearly seen that 14 TWs (43.75%) provide FC-free water, hence safe for drinking purposes, whereas ten TWs (31.25%) supply TC-free water, hence also suitable for drinking. On the other hand, the remaining 18 out of 32 TWs (56.25%) contain FC and 22 out of 32 TWs (68.75%) (Table 5) contain TC organisms. This indicates that a large proportion of water sources in our studied area contain FC and TC. Thirteen TWs are at low risk type from FC and seven from TC contamination. In addition, there are five TWs at intermediate risk type from FC but 11 TWs from TC contamination. Again, it is observed that no TWs contain higher than 50 cfu/100 mL or 100 cfu/mL FC. At the same time, three TWs contain higher than 50 cfu/100 mL total coliform that could be harmful for humans especially for children as well as older people.

Only one TW has higher than 100 cfu/100 mL of TC, which is ruinous to health (very high risk condition). Here, it is mentioned that drinking water must be FC and/or TC free according to BDS and WHO standards. However, in our investigated area, people are drinking water in low or intermediate ranges habitually due to unavailability of fresh water, ignorance, or convenience. Interestingly, little trouble is observed. This may be because inhabitants in this area have adapted or become used to this type of water and developed immunity to that amount of bacteria. It is also seen from this study that the people who drink water which contains a high range of bacteria often suffer various diseases like dysentery, hepatitis, typhoid fever, cholera, gastroenteritis, abdominal cramping, vomiting, nausea, headaches, fatigue, and diarrhea, possibly leading to severe dehydration, malnutrition, kidney failure, and death. Most people in this area are illiterate or have no idea regarding water quality or the reason behind the diseases talked

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Table 5 | Comparison of water samples with its recommend standard quality

			Water quality standard		No. of samples exceeding water quality standard		% of samples exceeding water quality standard	
Sl no.	**Parameters**	**Unit**	**WHO (2006)**	**Environment Conservation Rules (ECR 1997)**	**WHO (2006)**	**Environment Conservation Rules (ECR 1997)**	**WHO (2006)**	**Environment Conservation Rules (ECR 1997)**
1	pH	–	6.5–8.5	6.5–8.5	–	–	–	–
2	EC	μS/cm	–	–	–	–	–	–
3	TDS	mg/L	1,000	1,000	3	3	9.38	
4	Chloride	mg/L	250	600	3	1	9.38	3.13
5	Hardness	mg/L	500	500	5	5	15.63	15.63
6	Arsenic	mg/L	0.01	0.05	14	3	43.75	9.38
7	Iron	mg/L	0.3	0.3–1.0	9	1	28.12	3.13
8	Manganese	mg/L	0.5	0.1	10	20	31.25	62.5
9	Fecal coliform	cfu/100 mL	0	0	18	18	56.25	56.25
10	Total coliform	cfu/100 mL	0	0	22	22	68.75	68.75

about. At the same time, they have no capacity to buy fresh/safe water or other alternatives. From our study, it is calculated that FC and TC may enter the water sources mainly because of the distance between latrines and TWs. Latrines are sometimes very close to the TWs. Moreover, a few TWs are dug close to the sewerage line or kacca drain, and contamination of FC and TC may result from this. It was also seen that all the TWs are unprotected from excreta of birds, like crows, sparrows, magpies, martins, etc.

Table 6 | Water quality parameters, standard values and their relative unit weights

Parameter	Min.	Max	Mean	WHO Standard (2011a) (Si)	Bangladesh Standards (ECR 1997)	Relative unit weight based on (WHO 2011a) (Wi = 1/Si)	Reason for not establishing a guideline value (WHO 2011a)
pH	6.81	8.12	7.66	8.5	8.5	0.12	–
EC (μS/cm)	520	1,995	841.09	–	–	–	Not of health concern at levels found in drinking-water. No health-based guideline value is proposed
TDS (mg/L)	357.8	1,372.6	578.68	-	1,000	0.002	Not of health concern at levels found in drinking-water. No health-based guideline value is proposed. 600 mg/L is used for palatability
Chloride (mg/L)	10	615	84.28	250	600	0.004	–
Hardness (mg/L)	285	810	432.84	200	500	0.005	–
Arsenic (mg/L)	0.001	0.098	0.017	0.01	0.05	100	–
Iron (mg/L)	0.04	1.45	0.25	0.3	1.0	3.33	–
Manganese (mg/L)	0.01	6.32	0.99	0.4	0.1	2.5	–
Fecal coliform (cfu/100 mL)	0	33	4	0	0	–	–
Total coliform (cfu/100 mL)	0	>100	14	0	0	–	–
						$\sum Wi = 105.96$	

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Table 7 | Water quality index (WQI) and status of the investigated groundwater samples

Sample ID	pH			Chloride			Hardness			As			Fe			Mn					Grading of water quality
	Conc.	**Qi**	**WiQi**	**Conc.**	**Qi**	**WiQi**	**Conc.**	**Qi**	**WiQi**	**Conc.**	**Qi**	**WiQi**	**Conc.**	**Qi**	**WiQi**	**Conc.**	**Qi**	**WiQi**	**∑WiQi**	**WQI = ∑WiQi/ ∑Wi**	
D-1	6.91	81.29	9.75	55	22	0.09	290	145	0.72	0.003	30	3,000	0.04	13.33	44.39	0.09	22.5	56.25	3,111	29.36	B
D-2	7.11	83.65	10.04	18	7.2	0.03	340	170	0.85	0.02	200	2,000	0.04	13.33	44.39	0.11	27.5	68.75	2,124	20.04	A
D-3	7.13	83.88	10.07	97	38.8	0.15	355	177	0.88	0.001	10	1,000	1.45	483	1,608.4	0.11	27.5	69	2,688	25.36	B
D-4	7.1	83.53	10.02	10	4	0.02	423	211	1.05	0.064	640	64,000	0.11	36.67	122.11	1.94	485	1,212.5	65,346	616.70	E
D-5	6.81	80.12	9.61	30	12	0.05	462	231	1.15	0.028	280	28,000	0.16	53.33	177.59	6.32	158	395	28,583	269.75	E
D-6	7.2	84.7	10.16	48	19.2	0.08	485	242	1.21	0.079	790	79,000	0.04	13.33	44.39	0.98	245	612.5	79,668	751.87	E
D-7	7.81	91.88	11.03	20	8	0.03	398	199	0.99	0.016	160	16,000	0.1	33.33	110.99	0.87	217	542.5	16,666	157.28	E
D-8	7.93	93.29	11.19	19	7.6	0.03	295	147	0.73	0.004	40	4,000	0.05	16.67	55.51	0.31	77.5	194	4,261	40.21	B
D-9	7.85	92.35	11.08	21	8.4	0.03	440	220	1.1	0.098	980	98,000	0.05	16.67	55.51	0.34	85.5	214	98,282	927.54	E
D-10	7.87	91.88	11.03	24	9.6	0.04	390	195	0.97	0.001	10	1,000	0.61	203.3	676.99	0.09	22.5	56.25	1,745	16.47	A
D-11	7.67	90.23	10.83	22	8.8	0.03	430	215	1.07	0.011	110	11,000	0.39	130	432.9	0.59	147	367.5	11,812	111.48	E
D-12	7.49	88.11	10.57	490	196	0.78	690	345	1.72	0.006	60	6,000	0.07	23.33	77.69	0.12	30	75	6,166	58.19	C
D-13	7.81	91.88	11.03	55	22	0.09	485	242	1.21	0.005	50	5,000	0.04	13.33	44.39	0.09	22.5	56.25	5,113	48.25	B
D-14	7.92	93.18	11.18	20	8	0.03	392	196	0.98	0.002	20	2,000	0.1	33.33	110.99	0.09	22.5	56.25	2,179	20.56	A
D-15	7.73	90.94	10.91	40	16	0.06	410	205	1.02	0.013	130	13,000	0.05	16.67	55.51	0.3	75	187.5	13,255	125.09	E
D-16	7.81	91.88	11.03	58	23.2	0.09	350	175	0.87	0.005	50	5,000	0.04	13.33	44.39	0.12	30	75	5,131	48.42	B
D-17	7.83	92.12	11.05	40	16	0.06	425	212	1.06	0.009	90	9,000	0.05	16.67	55.51	0.3	75	187.5	9,255	87.34	D
D-18	7.66	90.12	10.81	30	12	0.05	440	220	1.1	0.02	200	20,000	0.52	173.3	577.1	4.72	1,180	2,950	23,539	222.15	E
D-19	7.82	92	11.04	20	8	0.03	435	217	1.08	0.027	270	27,000	0.04	13.33	44.39	3.64	910	2,275	29,332	276.82	E
D-20	7.82	92	11.04	65	26	0.1	410	205	1.02	0.022	220	22,000	0.75	250	832.5	4.93	1,232	3,080	25,925	244.67	E
D-21	8.11	95.41	11.45	20	8	0.03	290	145	1.22	0.001	10	1,000	0.09	30	99.9	0.01	2.5	6.25	1,119	10.56	A
D-22	7.92	93.18	11.18	22	8.8	0.04	395	197	0.98	0.001	10	1,000	0.42	140	466.2	0.01	2.5	6.25	1,485	14.01	A
D-23	7.54	88.71	10.64	335	134	0.54	740	370	1.85	0.001	10	1,000	0.09	30	99.9	0.01	2.5	6.25	1,119	10.56	A
D-24	7.48	88	10.56	202	80.8	0.32	505	252	1.26	0.007	70	7,000	0.22	73.33	244.18	0.01	2.5	6.25	7,263	68.54	C
D-25	7.85	92.35	11.08	30	12	0.05	403	201	1	0.02	200	20,000	0.09	30	99.9	0.01	2.5	6.25	20,118	189.86	E
D-26	7.91	93.06	11.17	21	8.4	0.03	285	142	0.71	0.007	70	24,000	0.92	306.7	1,021.3	0.18	45	112.5	25,146	237.32	E
D-27	7.72	90.82	10.89	20	8	0.03	401	201	1	0.024	240	24,000	0.49	163.3	543.78	4.05	1,012	2,530	27,086	255.62	E
D-28	7.63	89.76	10.77	615	246	0.98	810	405	2.02	0.002	20	2,000	0.04	13.33	44.39	0.2	50	125	2,183	20.60	A
D-29	7.91	93.06	11.17	50	20	0.08	380	190	0.95	0.001	10	1,000	0.04	13.33	44.39	0.01	2.5	6.25	1,063	10.03	A
D-30	7.72	90.82	10.89	110	44	0.18	545	272	1.36	0.003	30	3,000	0.81	270	899.1	1.02	255	637.5	4,549	42.93	B
D-31	7.91	93.06	11.17	20	8	0.03	360	180	0.9	0.022	220	22,000	0.04	13.33	44.39	0.01	2.5	6.25	22,063	208.22	E
D-32	8.12	95.53	11.46	70	28	0.11	392	196	0.98	0.006	60	6,000	0.04	13.33	44.39	0.1	25	62.5	6,119	57.75	C

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Some TWs have good platform conditions whereas others have not. Thus, FC and TC contamination is mostly affected by location of latrines, dustbins, drains, sewerage lines, conditions of platforms, i.e., broken, unhealthy, apron constructions of the TWs (Rahman *et al.* 2015).

Water quality index

Relative unit weights of each water quality parameter (Wi), rating of WQI, and status of the investigated groundwater samples are shown in Tables 6 and 7, respectively. The overall suitability of drinking water was assessed using a combined measure of water quality parameters: the WQI. The physico-chemical parameters (pH, chloride, hardness, arsenic, iron, and manganese) of water samples were used to calculate the WQI value at each sample site. We applied the weighted arithmetic WQI method (Yisa & Jimoh 2010; Tyagi *et al.* 2014; Akter *et al.* 2016) to calculate WQI values. In this method, the permissible WQI value for drinking purposes is considered to be 100, the water quality being considered unsuitable for drinking if the value exceeds 100. According to Chatterji & Raziuddin (2002), in terms of suitability, water can be categorized as excellent (WQI = 0–25, grading A), good (WQI = 26–50, grading B), poor (WQI = 51–75, grading C), very poor (WQI = 76–100, grading D), and unsuitable (WQI >100, grading E), respectively.

Comparison with another study in this region

Bangladesh is divided into four major geological regions, i.e., tableland, flood plain, deltaic region including coastal belt and hill tract (Chakraborti *et al.* 2010). The study area, Kushtia, is situated in the deltaic region where Holocene sediment is usually present, and this region is one of the highly arsenic contaminated areas in Bangladesh. From the literature, it appears that a large scale screening for arsenic in water samples ($n = 2{,}065$) was conducted in this district and 47.6% samples had As above the WHO guideline value (10 μg/L), which is very similar to our study (43.75% samples exceeded 10 μg/L). However, the previous study (Chakraborti *et al.* 2010) did not consider other water quality parameter such as pH, EC, TDS, chloride, total hardness, arsenic, iron, manganese, total coliforms, and fecal coliforms which provide a complete scenario of water contaminants.

CONCLUSIONS AND RECOMMENDATIONS

From the above discussions we can conclude that the health of the people of Kushtia district in Bangladesh is vulnerable to the effects of drinking water. A large number of the households consumed water of an unsuitable quality (43.75%) according to WQI values which could result in several waterborne diseases. Hence, we need to adopt steps to control the problems. As responsible citizens of Bangladesh, we should make other residents aware of the adverse effects of arsenic, manganese, and coliform bacteria present in groundwater and motivate people in the community to share safe drinking water. The unsafe TWs must be sealed, and new TWs installed in those places where access to safe drinkable water can be ensured. Otherwise, the contaminated tube well water requires treatment for further human consumption. The Department of Public Health Engineering (DPHE) is the national lead agency and exclusively responsible for provision of safe drinking water supply, sanitation facilities, and waste management in the country. DPHE and other non-government organizations (NGOs) combined can take some steps such as installation of treatment plants for mitigating the risks in our investigated area.

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