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Probabilistic human health risk assessment of commercially supplied jar water in Gopalganj municipal area, Bangladesh

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Every day, the amount of quality fresh water decreases notably due to contamination of drinking water. As a result, people use commercially supplied jar water in the southern part of Bangladesh as well as in the Gopalganj municipal area. This study aims to investigate the physicochemical parameters, trace elements, and microbial parameters for assessing human health risks from oral ingestion of these elements. This study gathered commercially supplied jar water samples from 15 companies in the Gopalganj municipal area during the post-monsoon season. Temperature, potential of hydrogen (pH), total dissolved solids (TDS), electrical conductivity (EC), and salinity showed significant variation among the samples, and the level was within the national and international standard limits. The concentrations of iron (Fe) and arsenic (As) were measured using a UV–VIS spectrophotometer and atomic absorption spectroscopy (AAS), respectively. The microbial analysis was conducted by the membrane filtration method. The study found that the water samples had an average concentration of 0.16mg/L in terms of Fe and 0.016mg/L in terms of As, with the mean value of As exceeding the standard limits. On the other hand, the mean Fe concentration value did not exceed the standards. Probable human health risk from heavy metal in the jar water was determined by hazard quotient (HQ), hazard index (HI), and carcinogenic risk (CR) assessments. A child (HI=3.5914) is more vulnerable to non-carcinogenic human health risks than an adult (HI=1.6931). Furthermore, pollution in water samples was found to pose a high carcinogenic risk, with children ($CR=1.6\times10^{-3}$) being more vulnerable to carcinogenic risk than adults ($CR=7.5\times10^{-4}$). In the microbial analysis, 100% of the samples exceeded the total coliform and fecal coliform standard limits, and 80% of the samples exceeded the *Escherichia coli* standard limits. Among the samples, 7% present high risk, around 47% present medium risk, 26% show low risk, and 20% show no risk based on the *E. coli* standard limits. This study did not find any samples that exceeded the extremely high limit for *E. coli* concentration. This study found that drinking jar water samples had inadequate quality, which may increase the risk of water-borne infections such diarrhea as well as heart disease, diabetes, and cancer. As a result, the manufacturer of drinking water in jars must carry out the essential quality control procedures, and the government should regularly monitor the procedures.

KEYWORDS

jar water, supplied water, trace elements, microbial contamination, *E. coli*, human health risks

1 Introduction

Water is an essential element that has allowed us to survive in the world (Hasan et al., 2019). However, human activity causes more water scarcity and puts risk on drinking water sources every day (Molden, 2020). Water scarcity affects two-thirds of the world's population at least once a year, and 1.6 billion people currently have an economic water deficit (Mekonnen and Hoekstra, 2016). Stress and the scarcity of water have both gotten worse in recent years. By 2025, more than 1.8 billion people worldwide may face a total water shortage (UNESCO World Water Assessment Programme, 2012). Global development, industrial activities, and climate change have contributed to the contamination of water bodies due to floating plastic bags, synthetic waste, heavy metals, and salinity intrusion (Nayak et al., 2023; Rahman et al., 2020; Sakamoto et al., 2019; Walker et al., 2019; Zamora-Ledezma et al., 2021). To overcome the problem, the United Nations proposed SDG 6.1, which states that "widespread and equal availability of safe and affordable drinking water for all by 2030" (UNICEF, 2019).

Over 97% of the people of Bangladesh, a developing nation in South Asia, have access to improved water supplies (UNICEF and WHO, 2015). However, inadequately managed water services serve less than 40% of the population. Furthermore, the World Bank (2018) discovered that hazardous bacteria, salt, or heavy metals had polluted about half of the delivered water. However, naturally occurring groundwater has significant levels of geogenic arsenic (As) (Saha et al., 2019). At least 59 out of 64 districts in Bangladesh have reported arsenic issues, exposing 30 million people to levels of arsenic above the national standard of 0.05 mg/L (Huq et al., 2020; Rahman et al., 2016). Furthermore, there are seasonal and geographical variations in the country's water service distribution, and the service quality is typically worse in hydro-geologically sensitive and difficult-to-reach places (Mondal, 2015). Thus, achieving the SDG for Bangladesh requires giving extra consideration to hydro-geologically critical, difficult-to-reach water-insecure places (Hossain et al., 2021).

Gopalganj district holds significant importance in terms of water-quality risk in Bangladesh's central south. Gopalganj is not particularly close to any coasts, yet there have recently been reports of high salinity in the surface water and groundwater systems (Shammi et al., 2017). Several important variables, including stream flow, poor watershed management, climate variability, and human-induced activities, are contributing to the diminishing quality of groundwater in Gopalganj (Shaibur et al., 2024a). Contamination has been increasing in surface water and groundwater (Shaibur et al., 2024b). As and manganese (Mn) also negatively impact the south-central regions of Bangladesh, which are important in terms of water quality (Atikul Islam et al., 2017). Prior investigations focused on Gopalganj and the adjacent areas indicated the distribution of heavy metals in the south-central region (Atikul Islam et al., 2017; Shaibur et al., 2024b). Gopalganj found both carcinogenic and noncarcinogenic human health risks associated with arsenic, iron, nitrate, copper, manganese not only for adults but also for children. Most of the samples from Gopalganj and 85% of Kashiani upazila revealed chronic human health risks (Rahman et al., 2018; Shaibur et al., 2024a).

In recent years, the practice of drinking bottled water has expanded in upper-middle-class and high-income countries due to a variety of factors, including contaminated ground and surface water (Hu et al., 2011; Ward et al., 2009). However, 1.8 billion people worldwide use fecally contaminated jars and bottled water (Bain et al., 2014; Onda et al., 2012). Packaged water from low and lower-middle-income countries was 4.6 and 13.6 times more likely to have total coliforms and fecal indicator bacteria, respectively, than packaged water from upper-middle and high-income countries (Williams et al., 2015). Restaurants, medical facilities, diagnostic centers, schools, residential areas, and nearly all offices and industries in Bangladesh receive commercially supplied jars and bottled water (Zuthi et al., 2009). In Chittagong, a study found that the majority of people used supplied jar water, with 60.53% of samples contaminated by microbial entities such as total coliform, fecal coliform, and 11 bacterial species (Mina et al., 2018). Moreover, fecal coliform was found in the supplied jar water in Nakla, Sherpur, where the heterotrophic plate count was 2.4×10^5 cfu/100 mL (Sarker et al., 2019).

Contaminated drinking water causes about 17% of global communal diarrhea, according to a previous study (Levy, 2015). In developing nations, water-related illnesses account for around 80% of all illnesses and more than one-third of all fatalities (Mazurkiewicz et al., 2020). Globally, almost 7 million people die from different diseases related to water every year (WHO, 2017). An estimated 2,000 children under the age of five pass away from water related disease every day throughout the world (UNICEF, 2013). The estimated annual death toll from waterborne infections was 1.8 million individuals worldwide, the majority of whom were children from developing nations (WHO, 2022a). Poor sanitation and contaminated water supplies were responsible for the majority of the fatalities (Rochelle-Newall et al., 2015).

Microbial and trace element contamination in potable drinking water in Bangladesh, along with Gopalganj, is increasing day by day. As a result, people use improved and treated commercially supplied jar water for their daily lives. To prevent further pollution, it is now critical to monitor the quality of water sources, particularly microbial characteristics. Typically, we employ chemical and microbiological indicators to evaluate quality, but from a public health perspective, microbial quality is more crucial as some pathogenic organism-caused epidemic outbreaks can spread rapidly. On the other hand, trace element-contaminated water can cause cancer in the human body. The study evaluates the microbiological quality of commercially supplied jar water in the Gopalganj municipal area focusing on the presence of total coliform bacteria and fecal bacteria such as *Escherichia coli* (*E. coli*), as well as the concentration of trace elements like iron and arsenic and the health risks associated with them.

2 Materials and methods

2.1 Study area

Thirteen areas in the Gopalganj municipal area were selected for the study (Table 1). In the region. different companies sell drinking water in jars and they collect water from sallow or deep-water tubewell. Gopalganj is located on the Madhumati riverbank at 23°00′47.67″ N and 89°49′21.41″ E. The Gopalganj municipal area is composed of 15 wards and 46.88 km^2 (Bangladesh Bureau of Statistics, 2011). Gopalganj appears to be less than 2 m above sea level. The following floodplains make up Gopalganj: 23% Old Meghna, 41% Gopalganj-Khulna Beels, 5% Ganges, 30% active low Ganges River, and 1% others (Molla, 2019; Shaibur and Howlader, 2020). The main

TABLE 1 Location of the companies.

Sample no	Name of the area	Latitude	Longitude
1	Sobujbag	89°49′40.93″ E	23°0′3.17″ N
2	Model School Road	89°49′41.65″ E	23°0′17.84″ N
3	Bedgram	89°50′22.45″ E	23°0′48.98″ N
4	Gatepara	89°50′10.50″ E	23°0′54.88″ N
5, 6	Ghoserchor	89°49′26.13″ E	23°0′58.92″ N
7, 15	Pacuria	89°49′ 20.41″ E	23°0′5.71″ N
8, 9, 10	Nabinbag	89°49′6.72″ E	22°59′44.18″ N
11	Sobahan Sorok	89°48′47.92″ E	22°58′3.12″ N
12	Hirabari	89°49′43.23″ E	23°0′9.10″ N
13	Kazipara	89°49′19.11″ E	23°0′45.45″ N
14	Bottola	89°49′51.84″ E	23°0′21.89″ N

productive aquifer, which is between 35 and 145 feet below the surface, is roughly 40 feet thick (Ferdous et al., 2016).

2.2 Sampling

A total of 15 water samples were collected in the post monsoon season from different companies in the Gopalganj Municipal Area that were used for drinking and supplied through commercial jars among the consumers. Several distinct companies in the municipality supplied the drinking water, and this study aimed to include all of them. Four sets of sterile and cap-secured glass bottles were used for sampling, one set for physicochemical analysis, one set for microbial analysis, and the rest of the sets for trace element analysis. For microbial analysis, bottles were autoclaved at 121°C for 30 min, and the collected samples were immediately transferred to the laboratory. Furthermore, during sampling, 65% concentrated HNO_3 acid was added to the trace metals analysis sample immediately to bring the pH level to 2 to minimize precipitation and adsorption onto the bottle walls (Haque et al., 2020). A calibrated multi-parameter water quality meter was used to measure the physicochemical parameters such as temperature, pH, TDS, electrical conductivity (EC), and salinity (HQ40d multi, HACH International, United States). For determining the arsenic (As) concentration, this study used atomic absorption spectroscopy (AAS) (AA-7000, Shimadzu Corporation). Samples were digested to remove organic matter interference and change particulate-associated metals into an AAS-detectable state (Sankararamakrishnan and Mishra, 2018). A UV–VIS spectrophotometer (UV-1900i, A125358, Shimadzu Corporation) was used to measure the amount of iron (colorimetric method). The samples were filtered through glass fiber filter (GF/F; 0.45 µm) paper. The number of coliform bacteria present in a water sample was determined by the coliform test using the membrane filtration method (Pant et al., 2016). The water was pumped through the filter paper using a vacuum or suction pump (AS20). The filters were cultured for 24 h at 35°C or 44.5°C in Petri dishes that were filled with MFC broth. After incubation, the petri dishes were taken out of the incubator, and coliform colonies were counted on each plate. All the samples were analyzed in triplicate to ensure reproducibility and statistical validity.

2.3 Human health risk assessment of metal contamination

Risk assessment is the process of determining how likely it is that any particular magnitude of harmful health effects will occur over a certain time period, depending on the hazard and exposure (Bortey-Sam et al., 2015). Each trace element or metalloid's health risk assessment is often based on quantification of the risk level and expressed as a cancer-causing or non-carcinogenic health risk (US EPA, 2009a). Two primary toxicity risk variables are the slope factor (SF) to determine cancer risk and the reference dose (RfD) to determine cancer prevention risk (Supplementary Table S1; Lim et al., 2008). According to Liu et al. (2011), the exposure mechanisms for metals include the dermal absorption of pollutants in water, which adhere to exposed skin, and direct swallowing of water. This study calculated the chronic daily intake from oral and skin absorption pathways using (Equation 1), which was adapted from the US Environmental Protection Agency (Ecetoc, 2001; Giri and Singh, 2015; USEPA, 2004; Wongsasuluk et al., 2014):

$$\mathrm{CDI}_{\mathrm{Oral}} = \frac{(\mathrm{CW} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ED})}{(\mathrm{BW} \times \mathrm{AT})} \qquad (1)$$

Here, CDI = chronic daily intake (µg/kg/day), CW = concentration of trace metal in water (µg/L), IR = ingestion rate (L/day; 2.2 for adults, 1 for children), EF = exposure frequency (days/year, 365), ED = exposure duration (year; oral = 70 for adults, 10 for children), BW = body weight (kg; 70 kg for adults, 25 kg for children), AT = average time (days; 25,550 for adults, 3,650 for children) [Ecetoc, 2001; EPA, 2001; Kavcar et al., 2009; US Environmental Protection Agency (USEPA), 1999; USEPA, 2009a; USEPA, 2004; Weyer et al., 2001].

This research evaluated the health risks of drinking groundwater by looking at its long-term (noncancerous) and short-term (cancerous) effects. It was done by calculating the CDI and toxicity values for each heavy metal or metalloid. The hazard quotient (HQ) was used in this study to look at any possible non-cancerous risks that might come with being exposed to pollutants that are cause for concern (Equation 2). The HQ is calculated by dividing the estimated contaminant intakes from each oral exposure route by the reference dose (RfD). If the value of HQ exceeds 1, the risk of negative non-carcinogenic health impacts is undesirable, but acceptable if it is less than 1 (Giri and Singh, 2015; Wongsasuluk et al., 2014).

$$HQ = \frac{CDI}{RfD} \tag{2}$$

This study creates the Hazard Index (HI) by combining the separate HQs for elemental risk evaluation (Equation 3). There may be possible non-cancerous consequences for health if the values of HQ and HI exceed 1, whereas HI less than 1 implies there is no danger of health problems (Supplementary Table S2; Haque et al., 2021; Sikder et al., 2013).

$$HI = HQ_1 + HQ_2 + \ldots + HQ_n \ldots \tag{3}$$

The incremental chance that a person will eventually acquire cancer as a result of exposure to a suspected carcinogen is known as carcinogenic risk (CR) (Habib et al., 2020; Islam et al., 2020). The accepted specific slope factor (CSF) of the carcinogens in Equation 4 was used to evaluate the risk of exposure.

$$CR = CDI \times CSF \tag{4}$$

Where CR is the cancer risk for each metal for the specific routes, CSF is called the slope factor of cancer-causing contaminants $(\mu g/kg/day)^{-1}$. CSF can vary for various routes and one of them is oral, the CSF value of As for adults and children is 0.0015 and 0.00038 $\mu g Kg^{-1} day^{-1}$, respectively (De Miguel et al., 2007; EPA, 2001; Gao et al., 2019). A risk value $<10^{-6}$ represents no carcinogenic risk to health, while a risk value $>1 \times 10^{-4}$ suggests a high risk of developing cancer. A risk value ranging from 1×10^{-6} to 1×10^{-4} signifies an acceptable risk to human health (Boateng et al., 2019; Habib et al., 2020; USEPA, 2009b).

2.4 Microbial health risk assessment

According to WHO (2006), total coliform, fecal coliform specially *E. coli* must not be detected in the water. This study divides drinking water samples into five risk categories based on the *E. coli* concentration. These categories are (i) no risk (*E. coli* concentration < 1 CFU/100 mL), (ii) low risk (*E. coli* concentration 1–10 CFU/100 mL), (iii) intermediate risk (*E. coli* concentration 11–100 CFU/100 mL), (iv) high risk (*E. coli* concentration 101–1,000 CFU/100 mL), and (v) very high risk (*E. coli* concentration > 10,000 CFU/100 mL) (Odonkor and Mahami, 2020).

2.5 Statistical analysis

Bivariate statistical analysis namely Pearson's correlation matrix (PCM) was performed by SPSS (V.22). Microsoft Excel 2016 was also used for statistical analysis and other calculations.

3 Results and discussion

3.1 Physico-chemical properties of water

Table 2 displays the physicochemical parameters of the collected samples, including temperature, pH, TDS, EC, salinity, Fe, and As. The average value of pH was 6.73 ± 0.49. According to WHO (2022b), almost all the samples, ~73.33%, were within the drinking limit, while ~26.67% were below the range (Figure 1A). A previous study portrayed that the surface water and groundwater pH of Gopalganj District were 8.24 (7.50–9.60) and 7.15 (6.89–7.78), respectively (Shammi et al., 2016). On the other hand, the pH value of Dhaka city groundwater varied from 6.66 to 8.19 with an average of 7.32 (Bodrud-Doza et al., 2020), whereas the pH in Rajshahi city varied from slightly acidic to neutral (Mostafa et al., 2017). These differences were most likely based on geographical locations, as Dhaka and Rajshahi are farther from the coastal zone than this study. From the temperature data, the average value was 25.9 ± 1.14°C (Figure 1B). In this study, the water collected from the jar at room temperature. The TDS of drinking water samples has an average value of 4.42 ± 7.90 mg/L (Figure 1C) which were within the acceptable limit prescribed by WHO (2022b). In Dhaka city, groundwater TDS values varied from 32.9 to 211.0 mg/L, with an average of 72.22 (Bodrud-Doza et al., 2020). In Khulna City, the average value of tubewell water was 1188.7 mg/L (Mahmud et al., 2020), and another study reported the range from 237.0 to 3,112 mg/L with an average of 1,556.05 mg/L (Islam et al., 2017). For commercially supplied jar water in Chittagong City, TDS varied from 0 to 0.00015 g/L (Mina et al., 2018). These variations were most likely caused by the location of the sampled regions and the depth of the water sources. The EC value of this study was 9.60 ± 16.81 µS/cm (Figure 1D). The groundwater of Gopalganj city's EC was 3206.95 (pre-monsoon) and 3218.47 µs/cm (post-monsoon); the EC values ranged from 600 to 9,380 µs/cm during pre-monsoon and 274–9,190 µs/cm during post-monsoon (Rahman et al., 2018). The study showed that EC ranged from 55 to 353 µs/cm, with a mean of 120.64 µs/cm in the groundwater of Dhaka (Bodrud-Doza et al., 2020) and a mean of 1,650 µs/cm in Khulna (Mahmud et al., 2020). Changes in the depths of the water sources most likely caused the fluctuation in EC, although their locations may also have played a role. In addition, low salinity was found throughout the study area, with an average of 0.003 ± 0.01 ppt (Figure 1E). A previous study reported that the range of groundwater was 0.2–5.2 ppt, with an average of 1.70 ppt (Rahman et al., 2018).

This study further investigated the trace metals of the studied samples (Figure 2). The mean value of arsenic was 0.016 ± 0.05 mg/L (Figure 2A) where almost 87% were safe for drinking. Rahman et al. (2018) investigated that, in the groundwater of Gopalganj during the pre-monsoon, the As concentration ranged from 5 to 198 µg/L (mean 50.3 µg/L), whereas in the post-monsoon, it ranged from 5 to 102.5 µg/L (mean 37.17 µg/L). The observed seasonal changes in arsenic levels in groundwater were attributed to a mixture of mineral dissolution, microbiological activity, and river-water flow (Rahman et al., 2018). In

TABLE 2 Descriptive statistics of the parameters in the studied samples.

Parameter	Descriptive statistics				Water quality standards		
	Minimum	Maximum	Mean	Standard deviation	DoE Bangladesh standard (DoE, 2019)	WHO standard (WHO, 2011)	USEPA standard (US EPA, 2009b)
Temperature (°C)	24.3	29.9	25.95	1.14	20–30	-	-
pH	5.64	7.37	6.73	0.49	6.5–8.5	6.5–8.5	6.5–9
TDS (mg/L)	0.272	28.1	4.42	7.90	1,000	1,000	500
EC (µS/cm)	0.82	59.9	9.60	16.81	1,500	500	-
Salinity (ppt)	0.0	0.03	0.003	0.01	300–600	< 500	
Fe (mg/L)	0.0219	0.658	0.16	0.15	0.3–1.0	0.3	0.3
As (mg/L)	0.001	0.206	0.016	0.05	0.05	0.01	0.01

this study, Figure 2B describes mean value of Fe which was 0.16 mg/L. According to Rahman et al. (2018), average concentrations of Fe in the groundwater of Gopalganj at pre-monsoon and post-monsoon were 5.12 and 3.31 mg/L, respectively. Iron is essential for human nutrition, but excessive amounts of drinking water can cause lethargy and chronic anemia (Søgaard et al., 2017). Most of the samples were within the standard limit, but some samples were not because of the age or malfunctioning of the treatment machines. The variation of arsenic and iron might be caused by the treatment process. This study treated all commercially supplied jar water, while other studies directly collected samples from various sources. This study treated all commercially supplied jar water, while other studies directly collected samples from various sources. In treated jar water in Chittagong, a lower amount of Fe was found, but there was no trace of As, Pb, or Cr (Mina et al., 2018).

3.2 Overview of microbial parameter

This study collected drinking water samples from 15 different sources. Table 3 presents the concentration of indicator bacteria in water samples from each source. The studied water sample describes the range of total coliform, which was 99–5,265 CFU/100 mL. The mean was 1309.33±1472.25 CFU/100 mL, while the 25% quartile was 248 and the 75% was 1,525 (Figure 3A). The maximum count of the fecal coliform was 2,210 CFU/100 mL, and the minimum count was 74 CFU/100 mL (Figure 3B). The mean of the parameter was 398.73 ± 519.22 CFU/100 mL (Figure 3C). The range of *E. coli* was 0–5,265 CFU/100 mL. The mean was 29.73 ± 34.80 CFU/100 mL, while the 25% quartile was 1 and 75% was 50 CFU/100 mL. According to the WHO, there must be no *E. coli* in the drinking water (WHO, 2006). Around 20% of the water sample was within the standard range, whereas 80% of the sample exceeded the limit range. According to PCR analysis and a cultural test, the prevalence of bacteria in commercially provided drinking jar water in Chittagong City, Bangladesh, was 60.53 and 50% of the sample, respectively (Mina et al., 2018). Deep-tube well water and commercially supplied water are devoid of bacteria that cause illness such as water-borne disease, diarrhea, and vomiting (Shaibur et al., 2012). Poor environmental conditions and worker personal hygiene significantly contribute to the pollution of commercially supplied drinking water in developing countries (Mina et al., 2018). The presence of indicator organisms in the water poses a serious threat to the community, as all these earlier studies emphasized, and they urged processors and handlers to employ proper manufacturing methods (Mina et al., 2018).

3.3 Human health risk assessment

3.3.1 Risk due oral ingestion

Table 4 presents a summary of non-carcinogenic and carcinogenic risks for adults and children. The average HI of these trace elements was greater than 4, which indicates a higher chronic risk for these non-carcinogenic elements. Compared to adults, HI values were almost three times higher in the child section. This suggests that children were more vulnerable than adults in the sampling areas. The carcinogenic risk for both adults and children exceeded the standard limit (10^{-6} to 10^{-4}) (USEPA, 2004).

However, the mean (range) HQ oral (adult) for As and Fe were 1.676±5.513 (0.104–21.58) and 0.169 ± 0.016 (0.0023–0.689), respectively. In addition, the mean (range) HQ oral (children) for As and Fe was 3.556 ± 11.693 (0.222–45.77) and 0.0359 ± 0.034 (0.0049–0.1461), respectively. The average strength of HQ oral values in the study area ranked As higher than Fe for both adults and children. The HI calculation was also done for adults and children. It indicates that there is a non-carcinogenic risk for both adults and children. In this case, children were more vulnerable than adults. Furthermore, approximately 73% of the samples were within the acceptable range with respect to arsenic carcinogenic risk. The other four samples contain 27%, which poses a significant carcinogenic risk to adults and children (Figure 4).

Researchers have proven that oral ingestion of drinking water increases the risk of cancer in both adults and children (Das et al., 2009). Additionally, increased threats at low concentrations of As exposure result in deaths from cancer cardiovascular disease, and other infectious diseases in Bangladesh (Sohel et al., 2009). Moreover, iron has a potential link to several chronic illnesses, including diabetes and heart disease (Ghosh et al., 2020).

According to Rahman et al. (2018), the groundwater in Gopalganj poses a significant health risk to adults and children, with mean Hazard Quotient and Hazard Index values based on Fe, As, Mn, NO^{3-}, B, and F-fluctuating depending on seasonal change. In the pre-monsoon and post-monsoon seasons, the

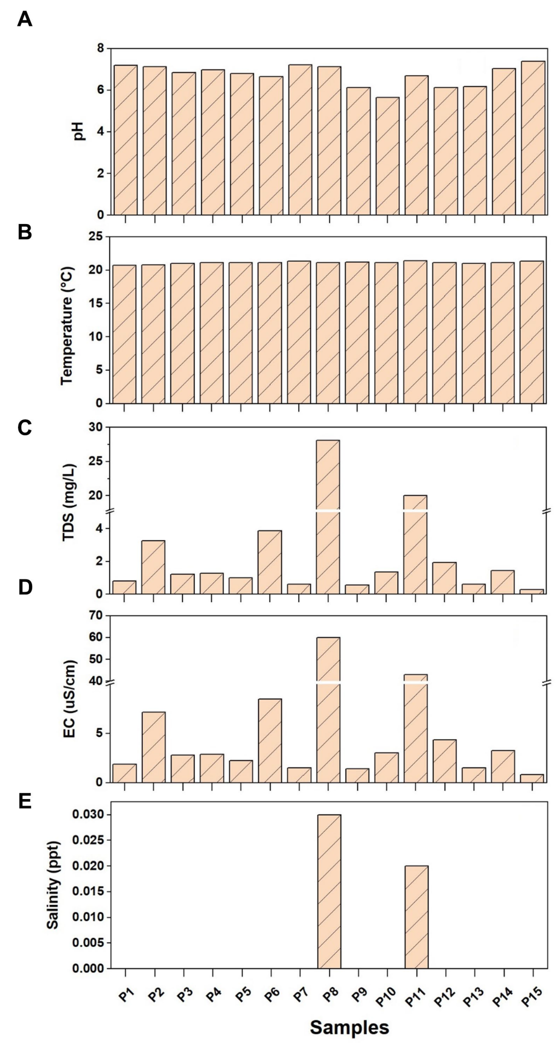

FIGURE 1
The physicochemical parameters of the studied samples, whereas **(A)** pH, **(B)** Temperature, **(C)** Total Dissolved Solids (TDS), **(D)** Electrical Conductivity (EC), and **(E)** Salinity.

mean HQ of Fe, As, Mn, NO_3^-, B, and F^- were 1.14, 11.18, 0.67, 0.41, 1.42, 0.43 and 0.54, 5.27, 0.31, 0.20, 0.67, and 0.20, respectively. In both seasons, there was a high risk of As-related cancer in adults (65.20%) and children (69.57%). Another study found that the carcinogenic risk (CR) in Kashiani Upazila under the Gopalganj district was extremely high. The CR ranged from 1.11×10^{-3} to 9.0×10^{-2} for adults and 2.7×10^{-6} to 4.2×10^{-2} for children (Shaibur et al., 2024a). According to a recent examination, in Manikganj district, a higher level of As was found in groundwater, which was related to a higher CR for children (1.94×10^{-3}) in comparison to adults (9.20×10^{-4}) (Rahman et al., 2020). In the Bengal basin, the study area's geology (Das et al., 2009; Rahman et al., 2016) and human activity (Kundu et al., 2008) were the two possible sources of As. Furthermore, children in Bangladesh's capital are at risk for carcinogenic health problems if they consume contaminated groundwater over an extended period of time (Bodrud-Doza et al., 2020).

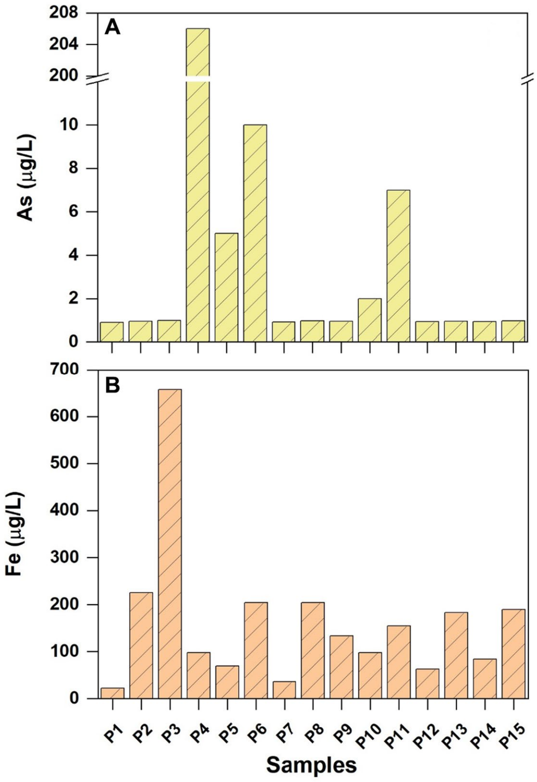

FIGURE 2
The concentration of **(A)** As and **(B)** Fe of the studied samples.

3.3.2 Microbial contamination

According to the WHO guideline, all the samples of total coliform and fecal coliform exceeded the standard limit, causing serious human health effects. Moreover, 80% of samples containing *E. coli* exceed the standard limit (Figure 5A). It can cause severe stomach cramps, bloody diarrhea, and vomiting (Alizadeh Behbahani et al., 2019). In Gopalganj, substantial rates of acute watery diarrhea-related morbidity and even mortality—which is uncommon in Bangladesh—were reported to be very high (Khan et al., 2023) which might be due to microbial contamination. According to WHO (2006) and based on *E. coli*, there were 7% of samples with high risk, around 47% with medium risk, 26% with low risk, and 20% with no risk (Figure 5B). The investigation found no samples that exceeded the extremely high limit. The graph indicates a concerning level of contamination in the treated jar water. Mina et al. (2018) conducted research and found that, in Chittagong, there were 26.32 and 18.42% of total and fecal coliform, respectively, in commercially supplied jar water. Furthermore, the authors discovered *E. coli* and other microbial organisms in the jar water. Mahbub et al. (2012) reported that the Dhaka WASA-supplied drinking water tested positive for *E. coli* bacteria in 51.11% of samples and positive for coliform in 57.78% of tests. Another study revealed that *E. coli* contaminated 46% of Dhaka's drinking water (Saima et al., 2023). In Chittagong, treated water supplied by WASA for drinking was highly contaminated with *E. coli*, with a load of more than 8×10^3 CFU/mL (Debnath et al., 2022). In the

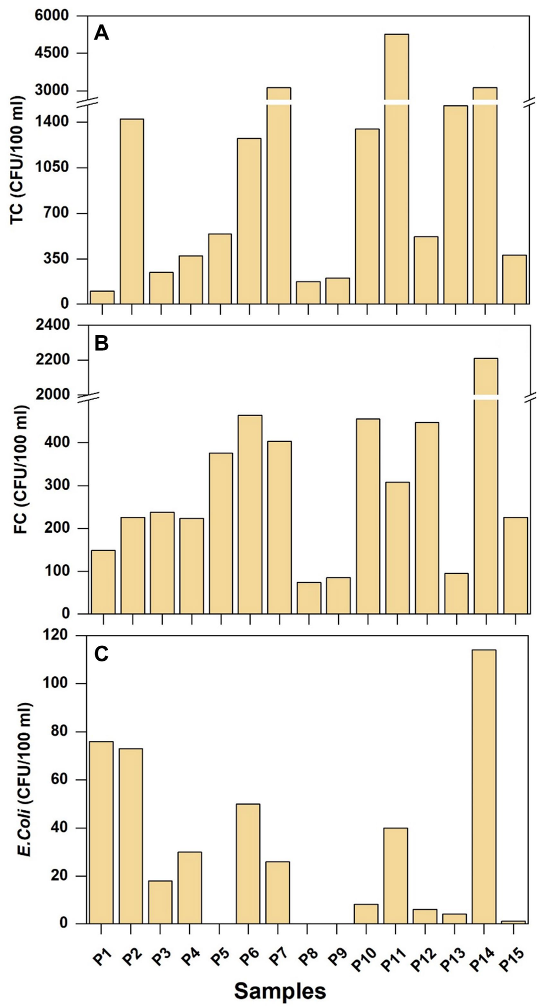

FIGURE 3
The microbial parameters of studied samples, where as **(A)** Total Coliform (TC), **(B)** Fecal Coliform (FC), and **(C)** *Escherichia coli*.

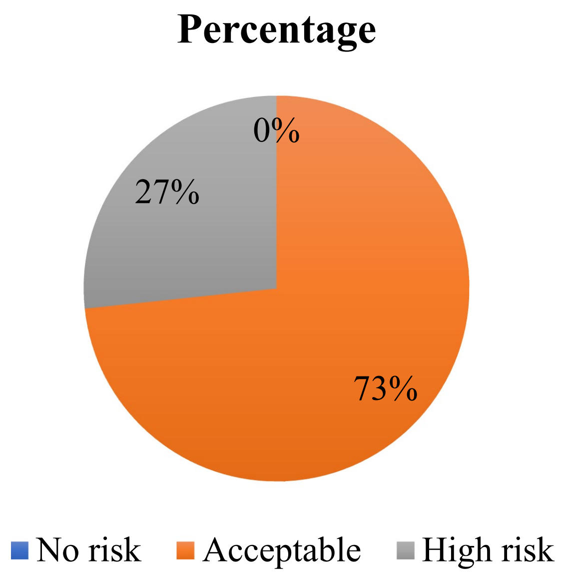

FIGURE 4
Carcinogenic risk due to arsenic contaminated water.

drinking water that Khulna City Corporation supplies, total coliform counts at Nirala, Sonadanga, Rupsa, and Hadispark were 23, 93, 23, and 460 CFU/100 mL, respectively (Nasrin et al., 2022). Mou et al. (2023) investigated whether TC, FC, and *E. coli* were present in the drinking water provided at various restaurants. While *E. coli* infected 70% of the samples, TC and FC contaminated 100% of them. According to earlier research, the majority of Bangladesh's drinking water filtration processes were insufficient in their ability to eliminate microbiological contamination. The primary reason for this was improper management of the instruments and processes (Nishat et al., 2023). Another contributing factor was the prolonged use of unwashed bottles (jars). Research has shown that poor personal hygiene and sanitation of transporters and handlers, along with environmental sanitation, significantly contribute to the contamination of commercially supplied drinking water in developing nations (Ashbolt, 2004; Dada, 2009; Mina et al., 2018). The Bangladesh Standards and Testing Institute (BSTI) provided guidelines and clearance for the manufacturing of commercially supplied drinking water, including handling, processing, and delivery from factory to customer. However, many companies were unable to meet these requirements. As a result, disease-causing bacteria and pathogens have infiltrated the drinking water in the provided jars. Furthermore, a large number of the defaulting manufacturers lacked the necessary licenses to operate, which could be the cause of additional contamination in the supplied drinking water (Mina et al., 2018). The suppliers claimed to follow the treatment process, as depicted in Figure 6. However, a field survey revealed that they did not adhere to the entire process, and the majority of the RO machines had expired. Effective adherence to the BSTI's implemented processes is crucial.

3.4 Correlation matrix

This study used bivariate statistics to carry out Pearson's correlation matrix (PCM) and determine the influence of parameter pairs on drinking water quality. Table 5 presents the results of the correlation analyses. Several pairs have a strong relationship with a very high level of significance. This study found a perfect correlation between EC-TDS ($r = 1.000$) and strong correlations between EC-Salinity ($r = 0.992$). Besides, in terms of microbial analysis, there was a strong correlation between *E. coli* and fecal coliform ($r = 0.656$). The pH showed a positive correlation with TDS, EC, salinity, and other microbial and heavy metal parameters, while temperature showed a negative correlation. TDS showed a very high positive correlation ($r = 0.992$) with salinity, as well as a positive correlation with other parameters. It had strong negative correlations with As ($r = -0.095$), FC ($r = -0.160$), and *E. coli* ($r = -0.104$). However, it had weak positive correlations with temperature ($r = 0.255$), Fe

TABLE 3 Descriptive statistics of indicator bacterial of water samples.

Indicator bacteria	Min	Percentiles			Max	Mean	Std. deviation
		25%	Median	75%			
TC	99	248	544	1,525	5,265	1309.33	1472.25
FC	74	149	238	447	2,210	398.73	519.22
E. coli	0	1	18	50	114	29.73	34.80

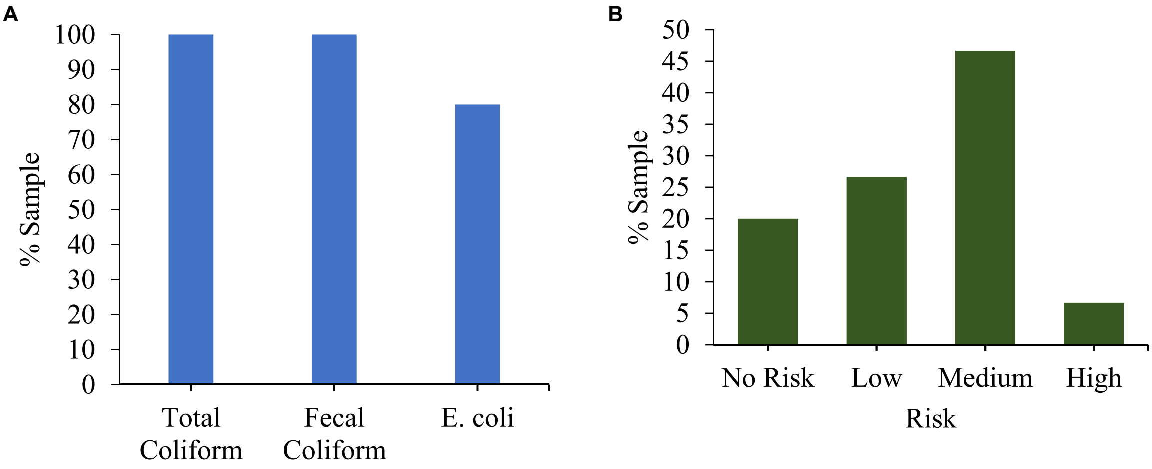

FIGURE 5
(A) Percentage of samples exceeding the standard limit; and **(B)** Percentage of samples which has human health risk due to microbial contamination.

TABLE 4 Summary of HQ and HI of As, Fe, and CR of As.

Health risk	Inhabitants	HQ oral for As	HQ oral for Fe	HI	Non-carcinogenic risk
Non-carcinogenic	Adult	1.673	0.0169	1.6931	Medium
	Child	3.548	0.0359	3.5914	Medium
		Carcinogenic risk (CR) of As			Carcinogenic risk
Carcinogenic	Adult	7.5×10^{-4}			High
	Child	1.6×10^{-3}			High

($r = 0.075$), and TC ($r = 0.268$). In addition, there was also a negative correlation between EC, As, Fc, and *E. coli*. Salinity also had a positive correlation with temperature, Fe, and TC, while it had a negative correlation with As, Fc, and *E. coli* (Table 5). The temperature was very low, negligible, and exhibited a low positive correlation with As ($r = 0.25$), FC ($r = 0.081$), and TC ($r = 0.485$), while it had a negative correlation with Fe ($r = -0.103$) and *E.coli* ($r = -0.391$). In terms of As, it was negatively corelated with Fe, FC, and TC, whereas there was a minor positive correlation with *E.coli* ($r = 0.006$). Fe was negatively associated with three other microbial parameters (FC, TC, and *E. coli*). Fe had a low positive correlation with TC ($r = 0.405$) and a moderate positive correlation with *E. coli* ($r = 0.656$). Furthermore, there was a positive correlation between TC and *E. coli* ($r = 0.384$).

4 Conclusion

The surface and groundwater in the Gopalganj municipal area are not suitable for drinking because salinity and pollution are increasing. In their daily lives, people used to drink commercially supplied jar water. The study monitored microbial and trace element contamination in commercially supplied drinking water, as well as the human health risks associated with these factors in the post-monsoon season. The study also determines the physicochemical condition of the water, and it appears that the majority of the drinking water samples meet the standard limits set by the WHO and DoE. However, the results of the evaluation of the human health risk associated with metal contamination through oral ingestion are extremely concerning. The

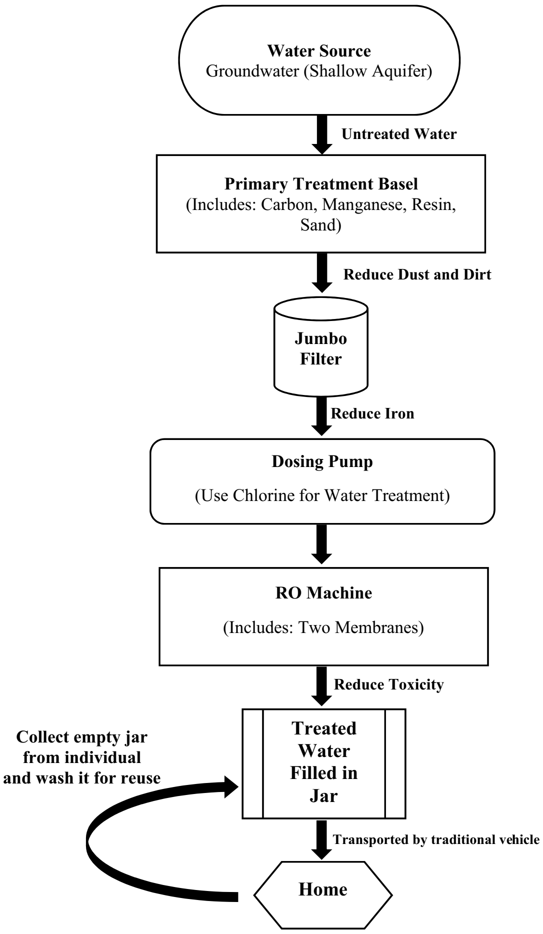

FIGURE 6
The treatment process of water according to the water suppliers in Gopalganj.

TABLE 5 Pearson's correlation matrix (PCM) of analyzed parameters.

Correlations										
	pH	TDS	EC	Salinity	Temp	As	Fe	FC	TC	*E.coli*
pH	1									
TDS	0.160	1								
EC	0.160	1.000**	1							
Salinity	0.170	0.992**	0.992**	1						
Temp	−0.078	0.254	0.255	0.281	1					
As	0.120	−0.095	−0.095	−0.095	0.025	1				
Fe	0.074	0.075	0.075	0.060	−0.103	−0.117	1			
FC	0.097	−0.160	−0.160	−0.177	0.081	−0.094	−0.186	1		
TC	0.032	0.266	0.268	0.244	0.485	−0.158	−0.186	0.405	1	
E. coli	0.395	−0.104	−0.104	−0.157	−0.391	0.006	−0.137	0.656**	0.384	1

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

noncarcinogenic risk associated with the water is medium, but the carcinogenic risk is very high for children and high for adults. Moreover, the microbial condition of the water sample is very alarming, where 100% of the samples exceed the standard guidelines of the WHO for total coliform and fecal coliform and 80% of *E. coli* samples are outside the standard limit. The study also reveals a strong correlation between salinity, TDS, and EC in terms of physicochemical parameters and a strong relationship between fecal coliform and *E. coli*. Finally, this study suggests that Gopalganj lacks sufficient water quality monitoring, necessitating periodic chemical analysis to assess the water's suitability for human consumption.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

PB: Data curation, Formal analysis, Investigation, Methodology, Software, Visualization, Writing – original draft. SA: Conceptualization, Data curation, Investigation, Methodology, Supervision, Validation, Writing – original draft. MH: Formal analysis, Investigation, Software, Supervision, Visualization, Writing – original draft, Writing – review & editing. MK: Resources, Software, Visualization, Writing – review & editing.

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Conflict of interest

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frwa.2024.1441313/full#supplementary-material

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