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Investigating the physico-chemical properties of drinking water: a case study of South Twenty-Four Parganas, West Bengal

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Abstract

The availability of safe and clean drinking water is very limited across the world. However, it is essential to have access to safe and quality drinking water to lead a healthy life and achieve Sustainable Development Goal 6.1 by 2030. This study examines the quality of drinking water in Palghat village of South Twenty-Four Parganas, West Bengal, considering households' level factors. A total of 78 households were selected for the study, which represents 15% of the total households. A cross-sectional research design was used and purposive sampling method was applied to conduct the household-level survey. Different improved sources of water were selected using random sampling techniques for the analysis of water quality. The water quality was determined using the water quality index (WQI). We found that 53.8% of the households in the village were dependent on tube wells for drinking water. Besides, 82.1% of the households were directly consuming drinking water without purification. The study depicts that the ordinary tube wells are slightly contaminated with arsenic heavy metals (0.05mg/L), and the overall water quality of the village is 'unfit for consumption' (WQI: 190.87). Therefore, the authors suggest paying special attention to the water quality of the ordinary hand pumps in the

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study area. Besides, monitoring of shallow tube wells and spreading public aware-
ness about clean and safe drinking water can improve the water quality and human
health in the region.

Graphical Abstract
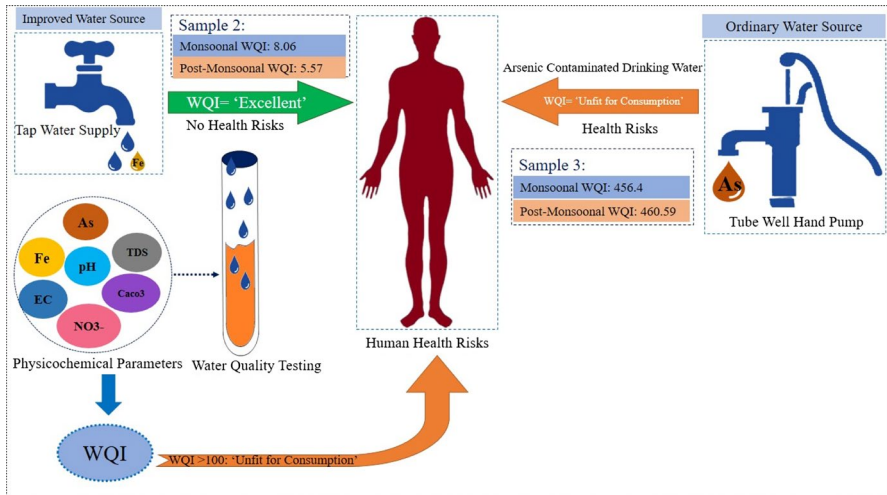
Keywords Arsenic · Cross-sectional research design · Drinking water quality ·
Human health · Palghat village · West Bengal

Introduction

Groundwater is one of the major sources of drinking water all over the World.
Approximately one-third of the world's population is dependent on groundwater for
drinking purposes (Prasanth et al. 2012). However, at least 2 billion people consume
contaminated drinking water, which is a serious concern for the health and well-
being of people. Microbial contamination in water can cause various waterborne
diseases such as diarrhoea, cholera, and polio. The presence of arsenic, fluoride, and
nitrate in drinking water, as well as emerging contaminants such as pesticides, phar-
maceuticals, and micro-plastics, poses a serious threat to public health (WHO 2022).
A study conducted by Khan et al. (2013) reflected that contaminated water with var-
ious pollutants and coliform bacteria is the primary source of waterborne disease.
The water quality is intimately linked with human health and wellbeing (Khan et al.
2017). To meet Sustainable Development Goal 6.1 (SDG 6.1-universal and equita-
ble access to safe and affordable drinking water for all) by 2030, access to safe and
quality drinking water is essential through extensive work. However, achieving SDG
6 by 2030 is a challenging task (Ho et al. 2020).

   A water quality index (WQI) is an effective method to assess the water quality on
different physico-chemical parameters. The Index was first developed by Horton in

1995, and since then it has been modified by several experts. In WQI, all physico-chemical parameters are combined in a single index value, which indicates the quality of water. Several parameters are weighted according to their respective standards in the index, and the measures have a significant impact. The WQI is calculated in three steps: (1) selection of parameters, (2) determination of the quality function for each parameter, and (3) aggregation through mathematical formulas (Akter et al. 2016; Atta et al. 2022; Tyagi et al. 2013).

Across Asia, drinking water quality has declined due to rapid urbanization, industrialization, overpopulation, and the use of agrochemicals in agricultural fields (Parvin et al. 2022). According to a recent study conducted in Pakistan (2017) unveiled that only 20% of its citizens have access to clean drinking water. In addition, the study stated that anthropogenic activities are responsible for 80% of all waterborne diseases and 33% of all deaths in the country. The leading causes of death include cholera, typhoid, dysentery, giardiasis, and cryptosporidiosis (Khan et al. 2017).

Many states in India are facing less access to safe drinking water. A study conducted in the Bhojpur district of Bihar revealed that the water quality in the villages close to the Ganga River is contaminated with arsenic (As) due to geological reasons. The study also reported that the area was highly contaminated by zinc, manganese, iron and other geological contains. In addition, Zinc was found mainly due to the excessive application of chemical fertilizers and pesticides in agricultural fields (Maity et al. 2020).

Arsenic contamination of groundwater in West Bengal was first recognized in 1982 and it came into the limelight during the International Conference on Arsenic in 1995 in Calcutta (Rahman et al. 2015). A detailed investigations by Chakraborti et al. (2009) revealed that 3417 villages in 107 blocks from nine districts in West Bengal contained high concentrations of As in groundwater (exceeding the permissible limit recommended by WHO). These districts include Malda, Murshidabad, Nadia, North Twenty Four-Parganas, South Twenty-Four Parganas, Bardhaman, Kolkata, Hugli, and Howrah.

In the South Twenty-Four Parganas district of West Bengal, arsenic is mostly found in silty clay and sandy layers. Excessive withdrawal of water for irrigation and domestic purposes is the most responsible factor, which influences water table fluctuation. It also includes the hydro geological processes. Due to it, carbonic acid forms in the empty parts of the ground, causing weathering of silicate materials and ion exchange (Singh et al. 2014).

A study conducted in Sonarpur block of South Twenty-Four Parganas revealed that the water was contaminated with arsenic, due to an abundance of arsenic-bearing minerals such as marcasite, opaque minerals, and limonite in the surface horizon of soil (De et al. 2022; Singh et al. 2014). Further, the amount of arsenic was very high in the surface horizon of the affected area and it was decreasing with an increase in depth from surface to sub-surface. It was also stated that the soil of Sonarpur block is of the 'illite' class. The soil is very deep, developed on alluvium, and it is cultivated with rice and guava (Ghosh et al. 2006). Frequent exposure to contaminated water in the state may cause diarrhoea, skin irritations, and respiratory diseases, depending on the level of pollutants present in the water (Ray et al. 2020).

A few studies have been conducted on the water quality of the study areas, including factors at the household level. The present study analyses the drinking water quality of Palghat village in the South Twenty-Four Parganas district of West Bengal. It also describes how the water quality is linked to human health. We hypothesized that prolonged consumption of contaminated drinking water will lead to the development of various chronic diseases. Long-term exposure to heavy metal (e.g., arsenic) will result in cancer-related deaths (Farzan et al. 2013; Xue et al. 2020). It will also have adverse effect on human health (Fig. 1) of people in the region (Yuan et al. 2016). Due to resource constraints, limited water samples were collected for this study. Nonetheless, we believe that this limitation will not undermine the novelty of this research. This study will assist in framing a micro-level policy and will open a new horizon of research. It will be useful to all stakeholders and public who are involved in supplying and consuming, respectively. It recommends that the future studies should be concentrated on determining the quality of water in the shallow tube wells and the presence of heavy metals in the groundwater with a large sample.

Study area

The Palghat village is situated in the Poleghat Panchayat of the Sonarpur block in South Twenty-Four Parganas, West Bengal (Fig. 2). The village is situated between 22°24′10″ N to 22°24′50″ N and 88°22′00″ E to 88°22′50″ E. Located 7.9 km away from the nearest statutory town of Rajpur, it has a total area of 103.03 ha, according to the Census of India, 2011. The total cultivated land in the village was 96 ha. Further, the total area of canals and tanks was 10.03 and 2 ha, respectively (Directorate of Census Operations, West Bengal 2014). Paddy and guava are the two major crops grown in this village. Rainwater harvesting, groundwater, and surface water (canals and ponds) are the major means of irrigation. There are 26 water bodies (including major or minor) in the village. It has a primary health sub-center and a dispensary.
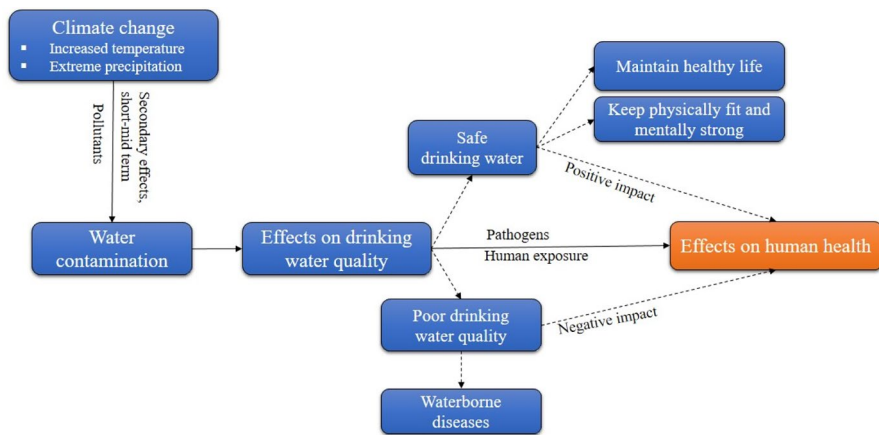

Fig. 1 Schematic framework of drinking water quality linkages with human health
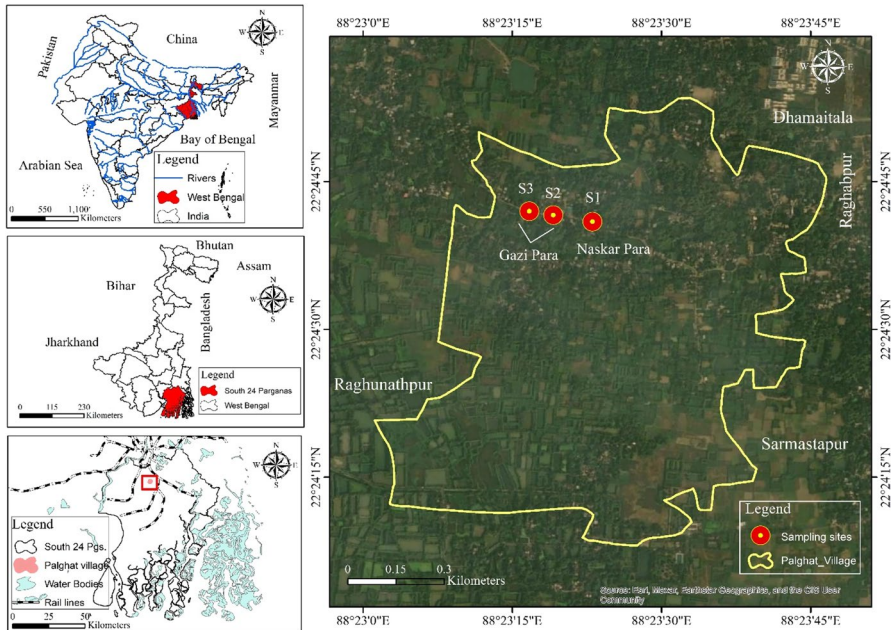
Fig. 2 Location map of the study area and water sampling sites

The population was 2360, out of which 1241 were males and 1119 were females and the sex ratio was 902 females per 1000 males. The village consisted of three major communities- Muslims, Hindus, and Christians. Its average literacy rate was 78.26%, of which, 82.59% were male and 73.46% were female (Directorate of Census Operations, West Bengal 2014).

Materials and methods

Data sources

A cross-sectional study was conducted to examine methods of consuming water among households in the village. A purposive sampling method was applied to conduct the household-level survey. Additional data were also collected, such as sources and location of drinking water, methods used to purify the water, and the time taken to fetch water (in a round trip including waiting time). Besides, a structured questionnaire was prepared to ask different socioeconomic questions from the household. The questions were on sex, age, marital status, religion, education level, employment status, and income earned by a household in a month in Indian rupees (INR). Additionally, educational levels of respondent is coded into five groups: illiterate (no formal education), primary (up to class VIII), secondary (up to class XII), higher secondary (above class XII), and don't know (unaware about their exact educational background). In the study area, around 11.5% people were "illiterate", while 46.2%

were primarily passed (Table 1). Lastly, the authors surveyed 78 households, which were 15% of the total households (i.e., 520).

Water samples for analysis were collected in polyethylene bottles with random sampling techniques from different water sampling sites. The American Public Health Association (APHA) standard procedures were followed for sample collection, preservation, and analysis. Water samples from bore wells or tube wells were collected after pumping of water for 3–5 min to clear all dirt, turbidity and slime. For metallic elements (e.g.-arsenic and iron), water samples were filtered and preserved with a few drops of 5% HNO_3 (nitric acid) to prevent soluble salts from converting into insoluble salts (Dahunsi et al. 2014; Parks et al. 2004). To maintain the accuracy and reliability of the test results, these procedures were followed to enable easy comparison with other studies. For the fecal coliform bacteria test, samples were collected from the sources in a H_2S glass bottle to avoid contamination. Furthermore, the collection of water samples from various improved water sources was done from July to September 2022 (Monsoon), and October to December 2022 (Post-Monsoon). Geographical data such as latitude and longitude of sampling sites were measured using a Global Positing System (GPS) device (Table 2).

Table 1 Socio-economic profile of respondents in Palghat village ($n = 78$)

Variable	Category	Frequency	Percent
Sex	Male	52	66.7
	Female	26	33.3
Age	17–30 years	28	35.9
	31–45 years	29	37.2
	> 45 years	21	26.9
Marital status	Married	68	87.2
	Unmarried	9	11.5
Religion	Hindu	9	11.5
	Muslim	61	78.2
	Christian	8	10.3
Level of education	Illiterate	9	11.5
	Primary	36	46.2
	Secondary	21	26.9
	Higher	10	12.8
	Don't Know	2	2.6
Current employment status	Yes	51	65.4
	No	27	34.6
Income of a household in a month (INR)	₹ 0–9999	15	19.2
	₹ 10,000–19,999	36	46.2
	₹ 20,000–29,999	18	23.1
	₹ 30,000–39,999	5	6.4
	₹ > 40,000	4	5.1

Source: Primary survey, Sept to Nov, 2022

Table 2 Location of sampling sites

Sample number	Habitation	Source type	Latitude	Longitude	Altitude (in meters)	HHs sample sizes (%)
S1	Naskar Para	India Mark II	22° 24′ 41″	88° 23′ 23″	8.53	11 (14.10)
S2	Gazi Para	Public Tap Water	22° 24′ 42″	88° 24′ 59″	9.14	19 (24.36)
S3	Gazi Para	Tube Well Ordinary	22° 24′ 42″	88° 23′ 17″	7.93	

Source: Primary survey; Sept to Nov, 2022

Data analysis

In this study, physico-chemical parameters of different improved water sources were analyzed in the field using a field testing kit (FTK) (Table 3). For analysis of various physico-chemical parameters of water samples, the 'HiMedia WT023' multi-parameters water testing kit was used. Further, analysis of arsenic traces in drinking water was carried out using, the 'HiMedia WT025' test kit. Besides, fecal coliform bacteria in drinking water was analyzed with the help of the 'HiMedia K055' test kit. This kit (HiMedia K055) primarily detects Salmonella, Citrobacter species and *Escherichia coli* based on H_2S production in a glass bottle (Fig. 3).

Various physico-chemical and bacterial parameters like Temperature, pH, TDS, Conductivity, Turbidity, Total Hardness ($CaCO_3$), Arsenic (As), Nitrate (NO_3), Residual Free Chlorine (Cl_2), Iron (Fe), and Fecal Coliform were also analyzed. Temperature, pH, TDS, and EC were measured using the digital meter tester, while the rest of the physico-chemical parameters were measured using Field Testing Kit (FTK). Besides, the colorimetric test was conducted to determine the concentration of Iron (Fe), Arsenic (As), and Nitrate (NO_3) in drinking water with the help of colour chart. The Turbidity was measured using a visual comparison method in the field. In addition, $CaCO_3$, Cl^-, and Cl_2 were measured by titration method, and the presence of fecal coliform in drinking water was measured using the H_2S method in a glass bottle. All fecal bacteria testing samples were kept in a closed room at around 30 °C and incubated for 24–48 hours (Islam et al. 2017). During the test, if colour turns black, the water source was considered not fit for drinking. A detailed methodology for analysing the physico-chemical properties including fecal coliform bacteria test in drinking water, is presented in Table 3.

Physicochemical parameters of water

Temperature

For measuring the kinetic energy of water, the temperature is a significant parameter that holds great importance. It denoted in Celsius (°C) and Fahrenheit (°F) units.

Fig. 3 **a** Public tap water connection at 'Bibir Chowk' **b** the women were fetching water from the hand pump at 'Gazi Para' **c** abandoned India Mark II hand pump at 'Gazi Para' **d** Fecal coliform bacteria test of drinking water samples

Table 3 Physicochemical analysis of water quality parameters

Parameter	Unit	Range	Method	BIS Standards
Temperature	°C	0–98.89	Electrode	–
pH	NA	0.00–14.00	Electrode	8.5
TDS	ppm	0–9999	Electrode	500
Conductivity (EC)	µS/cm	0–9999	Electrode	300
Total hardness (CaCO$_3$)	mg/L	25–600	Titration	200
Arsenic (As)	mg/L	0.05–3.0	Colorimetric	0.01
Nitrate (NO$_3^-$)	mg/L	0–100	Colorimetric	45
Fluoride (F$^-$)	mg/L	0–2.5	Colorimetric	1
Chloride (Cl$^-$)	mg/L	10–200 & 50–1000	Titration	250
Residual free chlorine (Cl$_2$)	mg/L	0–3.0	Titration	0.2
Turbidity	NTU	0–25	Visual Comparison	1
Iron (Fe)	mg/L	0–2.0	Colorimetric	0.3
Coliform bacteria	NA	NA	(H$_2$S Method)	0

The fluctuations in water depth, seasonal variations, and time of the day can affect the physicochemical characteristics of water. The freezing and boiling points of pure water are 32°F (0 °C) and 212°F (100 °C), respectively (Ma et al. 2020). In the present study, temperature was ranging from 22.5 to 33.3 °C, with a mean value of 28.55 °C.

pH of water

The acidity or alkalinity of water is determined by pH, which is a significant parameter. The pH ranges from 0 to 14, with 7 being normal, below 7 being acidic, and above 7 being alkaline. A pH level lower than 7 indicates the presence of acidic substances in the water, while a pH level higher than 7 indicates the presence of alkaline substances in the water (Ma et al. 2020; Rahmanian et al. 2015). In this study, pH is ranging from 7.1 to 8.08 in the drinking water, with a mean value of 7.54 that indicates that the water is slightly alkaline.

Total dissolved solids (TDS)

The measurement of total dissolved solids (TDS) is based on the quantity of inorganic and organic materials or salts present in water, such as sodium, potassium, calcium, bicarbonates, chlorides, magnesium, and sulphates. The range of TDS in the study area is ranging between 159 and 445 ppm, with a mean of 312.33 ppm. Besides, TDS contains essential minerals such as Calcium (Ca^{2+}), Magnesium (Mg^{2+}), and Potassium (K^+), which provides various health benefits to humans. For instance, Ca^{2+} helps in bone development, Potassium K^+ supports a robust nervous system, and Mg^{2+} can help protect against cardiovascular disease (Islam et al. 2016). Furthermore, TDS levels in groundwater are not hazardous to human health. Nevertheless, the excessive TDS levels in drinking water can have negative health effects with kidney and heart conditions. A high TDS level is indicative of water that is rich in minerals (Ma et al. 2020; Rahmanian et al. 2015).

$$\text{TDS (mg/L)} = k_e \times \text{EC } (\mu S/cm)$$

where k_e is a constant of proportionality (Taylor et al. 2018).

Electrical conductivity (EC)

Pure water is not a suitable conductor of electric current but it is a reliable insulator. The EC is related to water temperature and TDS presence in the water (Ma et al. 2020; Rahmanian et al. 2015). In the study area, the EC ranges from 290 to 897 μs/cm with a mean value of 617 μs/cm. It is noted that the concentration of ions in water increases its electrical conductivity. In general, the amount of dissolved solids in water determines its electrical conductivity (Meride and Ayenew 2016). Many factors that can affect mineral content in drinking water as well as soil includes agricultural activities, industrial activities, and land use. Additionally, the excessive EC

in soil may lead to the extinction of food plants and habitat-farming plants (Rahmanian et al. 2015).

Total hardness (CaCO₃)

Total hardness ($CaCO_3$) in drinking water is a crucial chemical parameter in drinking water. In the study area, $CaCO_3$ ranges from 75 to 400 mg/L, and a mean of 250 mg/L, which is 50 mg/L greater than BIS standard. A study conducted in the Netherlands revealed that there is no association between calcium, magnesium, and total hardness with heart disease or mortality in the general population (Leurs et al. 2010). Therefore, the total hardness has a fewer health impacts compared to other chemical parameters.

Arsenic (As)

Arsenic in drinking water has detrimental effects on human health. In the study area, arsenic value ranges from 0 to 0.05 mg/L, with a mean value of 0.02 mg/L. Besides, various human activities, including industrial wastewater dumping and the use of pesticides or herbicides on agricultural land, increase the likelihood of groundwater contamination with arsenic. Moreover, a study conducted by Roychowdhury (2010) stated that the concentration of arsenic depends on the depth of the tube wells as it gradually increases about 39.4 m from the surface, after which it declines. The chronic exposure to arsenic is linked to the development of cancerous and skin diseases (Rahmanian et al. 2015).

Nitrate (NO₃⁻)

Nitrate is one of the most critical parameters of drinking water. The presence of nitrate in drinking water is responsible for blue baby syndrome in infants (Johnson 2019; Yan et al. 2016). The sources of Nitrate in drinking water are the nitrogen cycle, industrial waste, nitrogenous fertilizer, etc. The nitrate value ranges from 0 to 10 mg/L, and a mean value of 3.33 mg/L, which is under permissible limits of BIS.

Fluoride (F⁻)

The fluoride in drinking water is one of crucial parameters to determine water quality in a place. In the region, fluoride value ranges from 0.2 to 0.5 mg/L, and a mean value of 0.35 mg/L, which is under the permissible limit of the BIS standard. A past studies revealed that excessive fluoride in drinking water is responsible for skeletal fluorosis (Srivastava and Flora 2020), and it adversely impact on human health and well-being (Chen et al. 2017; Zhang et al. 2017).

Chloride (Cl⁻)

The principal origin of chloride in water is from salts of hydrochloric acid, which can be found in table salt (NaCl), seawater, sewage, industrial waste, and other

sources (Meride and Ayenew 2016). Groundwater is more heavily contaminated with chlorides than surface water (Samadder et al. 2017). Additionally, excessive chloride levels in drinking water can cause harm to metallic pipes, structures, and the growth of plants (Meride and Ayenew 2016). The chloride in the study area ranges from 20 to 120 mg/L, with a mean value of 46.67 mg/L.

Turbidity

Turbidity indicates the amount of total dissolved solids present in drinking water (Ma et al. 2020; Rahmanian et al. 2015). And the turbidity value in the study area ranges from 0 to 10.1 NTU, with a mean value of 5.05 NTU. Furthermore, the high level of turbidity in drinking water can cause pathogens-related diseases, as shown in many past studies conducted across the world (Meride and Ayenew 2016; Stevenson and Bravo 2019).

Iron (Fe)

A significant amount of iron in drinking water causes skin diseases. An excess amount of iron in drinking water causes brown or yellow stains (Rahmanian et al. 2015). The iron ranges from 0.3 to 1 mg/L, and a mean of 0.48 mg/L, which is slightly higher than the Bureau of Indian Standards (BIS: 0.3 mg/L).

Bacterial contamination

The fecal coliform bacteria examination is a vital parameter in determining the quality of water (Fig. 4). It determines a specific set of coliform bacteria, including *E. coli*, Citrobacter, and Salmonella, among others, that indicates whether the water is safe for human consumption or not. The most prevalent bacterium found in drinking water is *E. coli*. Moreover, the presence of coliform bacteria in household drinking water is closely linked with the risk of diarrhea (Gruber et al. 2014).
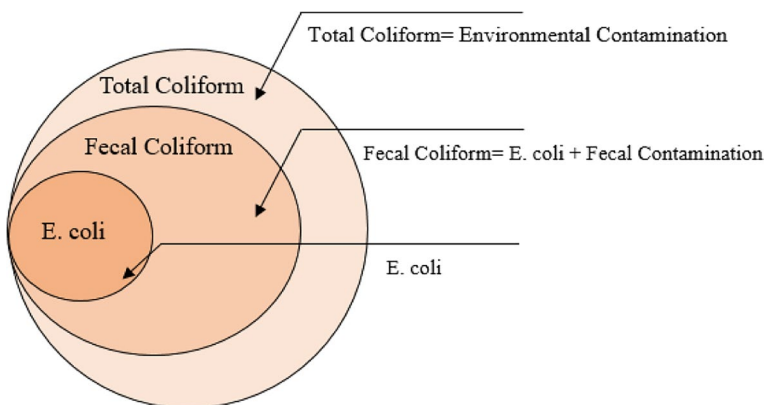

Fig. 4 Different groups of coliform bacteria

Weighted arithmetic water quality index (WAWQI) To analyze water quality, the weighted arithmetic water quality index (WAWQI) was applied. The WQI summarizes several physiochemical parameters into a single value that shows the quality of water. Its value ranges from 0 to > 100, where 0 indicates 'Excellent' and > 100 indicates 'unfit for consumption. The grading of WQI was proposed as 'Excellent' (0–25); 'Good' (26–50); 'Poor' (51–75); 'Very poor' (76–100); and 'unfit for consumption (> 100) (Addisie 2022; Osta et al. 2022; Uddin et al. 2022). The unit weight (Wn) factors for each parameter were calculated, using the formula:

$$Wn = \frac{K}{Sn} \tag{1}$$

$$K = \frac{1}{\frac{1}{S1} + \frac{1}{S2} + \frac{1}{S3} + \cdots + \frac{1}{Sn}} = \frac{1}{\sum 1/Sn}$$

where, in this case, "Sn" refers to the standard value that is considered desirable for the nth parameter. The sum of all the physicochemical parameters is used to determine a unit weight factor, which is denoted by "Wn = 1".

Calculation of sub-index (Qn) value using the formula.

$$Qn = \frac{[(Vn - Vo)]}{[(Sn - Vo)]} * 100 \tag{2}$$

In this context, "Vn" represents the value of the nth parameter being analyzed, while "Sn" represents the standard value of the same parameter. The WQI uses the BIS standard to determine Sn. For most water parameters, "V0" is typically equal to zero in pure water, except for pH, which is equal to 7.

Weighted arithmetic water quality index To calculate the weighted arithmetic water quality index (WAWQI), steps 1 and 2 must be combined. The mathematical representation of WAWQI is provided below.

$$WQI = \frac{\sum WnQn}{\sum Wn} \tag{3}$$

For statistical analysis of different physico-chemical parameters of drinking water samples, the Statistical Package for Social Sciences (SPSS 26) software was used. And spatial analysis of water samples were done using the inverse distance weighted (IDW) interpolation method. Lastly, Arc Map 10.4 software was used for the zonation of water quality in the study area (Fig. 5).
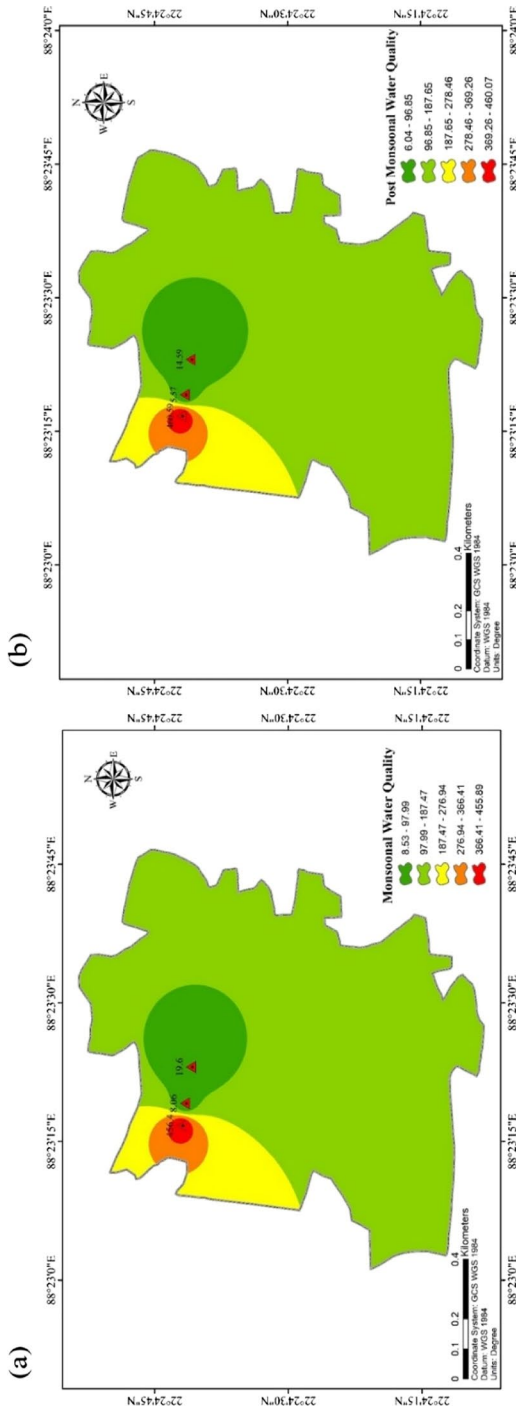
Fig. 5 **a** IDW interpolation of monsoonal water quality **b** IDW interpolation of post-monsoonal water quality

Results

Sources of drinking water, location, and methods of consuming water

Table 4 shows sources of drinking water, their location, and methods of consuming water. The study depicts that hand pumps or tube wells were the preferred sources of drinking water for the majority of the households (53.8%), followed by potable water (28.2%), and public taps or stand pipes (11.5%). About 46.8% of the households were taking drinking water from elsewhere (> 30 min) and 27.7% had water sources on their yard/plot. Meanwhile 26.0% had a source inside their dwellings. Data further show that most of the households (82.1%) were consuming unpurified water directly from the water source. The rest of the households (17.9%) used different techniques to purify the water. Approximately 88.5% households spent less than 30 minutes to fetch water. However, 2.6% of households took more than 30 minutes to fetch water.

Table 4 Improved water sources, their location, and methods of consuming water

	Frequency	Valid percent	Cumulative percent
Drinking water sources			
Tubewells/borehole	42	53.8	53.8
Public tap/stand pipe	9	11.5	65.4
Potable water	22	28.2	93.6
Submersible pump	2	2.6	96.2
Purifier	3	3.8	100
Location of drinking water sources			
In own dwelling	20	26.0	26
In own yard/ plot	21	27.3	53.2
Elsewhere	36	46.8	100
Missing	1		
Methods of consuming water			
Directly	64	82.1	82.1
Boil	10	12.8	94.9
Non-electric purifier	2	2.6	97.4
Electric purifier	2	2.6	100
Time to fetch water			
< 30 minutes	69	88.5	88.5
> 30 minutes	2	2.6	91.0
Don't know	7	9.0	100

Source: Primary survey, Sept to Nov, 2022

Table 5 Descriptive statistics for physicochemical parameters of water samples

Physico-chemical parameters

Parameters	Monsoon			Post-monsoon			Descriptive statistics				
	S1	S2	S3	S1	S2	S3	Min	Max	Mean	Median	SD
Temp	33.3	32.4	33.1	26	22.5	24	22.5	33.3	28.55	29.2	4.94
pH	7.3	7.8	7.1	7.55	8.08	7.42	7.1	8.08	7.54	7.48	0.35
TDS	337	159	407	360	166	445	159	445	312.33	348.5	121.96
EC	636	290	815	731	333	897	290	897	617	683.5	252.41
$CaCO_3$	250	75	375	275	125	400	75	400	250	262.5	130.38
AS	0	0	0.05	0	0	0.05	0	0.05	0.02	0	0.03
NO_3^-	0	10	0	0	10	0	0	10	3.33	0	5.16
F^-	0.3	0.4	0.3	0.2	0.5	0.4	0.2	0.5	0.35	0.25	0.11
Cl	30	20	50	40	20	120	20	120	46.67	35	37.77
Cl_2	0	0	0	0	0	0	0	0	0	0	0
Turbidity	10.1	5.2	0	10.1	0	5.3	0	10.1	5.11	5.05	4.51
Fe	1	0.3	0.3	0.5	0.5	0.3	0.3	1	0.48	0.4	0.27

Descriptive statistics of water parameters

The monsoon and post-monsoon data were collected from the different water sources (Table 5). Temperature ranged between 22.5 and 33.3 °C with a mean value of 28.55 °C ($\sigma: \pm 4.94$). The pH values of various drinking water sources were between 7.1 and 8.08, with a mean value of 7.54 ($\sigma: \pm 0.35$), indicating that the drinking water was slightly alkaline. On the other hand, total dissolved solids (TDS) varied between 159 and 445 ppm with a mean value of 312.33 ppm ($\sigma: \pm 121.96$). As was also detected in 'S3' (ordinary tube well) with a mean value of 0.02 mg/L ($\sigma: \pm 0.03$). India Mark II hand pump (S1) had a slightly high concentration of iron (Fe), with a mean concentration of 0.48 mg/L ($\sigma: \pm 0.27$). The other chemicals and anions such as $CaCO_3$, NO_3, F^-, Cl^-, and Cl_2 were found within the permissible limit of BIS standards.

Weighted arithmetic water quality index (WAWQI)

The water quality during monsoon and post-monsoon seasons is shown in Table 6. The water quality of the 'India Mark II' hand pump (S1) and the public tap (S2) was rated as 'excellent', while the 'ordinary tube well' hand pump (S3) was rated as 'unfit for consumption' (WQI: 456.4 & 460.59). The people of the 'Gazi Para' considers ordinary tube well as the primary source of drinking water (Fig. 3). However, the water quality of the ordinary tube well (S3) was rated as 'unfit for consumption'. Although, the water quality of Naskar Para (S1) was rated 'excellent', yet, it was rejected by the people for drinking purposes.

Table 6 Water quality index of different water sampling sites

Sample no	Source type	WQI	WQS	Remark
Monsoon water quality				
S1	India Mark II	19.60	Excellent	Users rejected
S2	Public Tap Water	8.06	Excellent	Currently, used as an alternative drinking water source
S3	Tube Well Ordinary	456.4	Unfit for consumption	Primary drinking water source
Post-monsoonal water quality				
S1	India Mark II	14.59	Excellent	Users Rejected
S2	Public Tap Water	5.57	Excellent	Currently, used as an alternative drinking water source
S3	Tube Well Ordinary	460.59	Unfit for consumption	Primary drinking water source
Overall	–	190.87	Unfit for consumption	–

Table 7 Pearson correlation among various physicochemical parameters of drinking water

Parameters	Temp	pH	TDS	EC	CaCO$_3$	As	NO$_3^-$	Cl$^-$	Turbidity	Fe
Temp	1									
pH	−0.56	1								
TDS	0.039	−0.844[*]	1							
EC	−0.018	−0.813[*]	0.997[**]	1						
CaCO$_3$	−0.03	−0.81	0.982[**]	0.986[**]	1					
As	0	−0.62	0.722	0.733	0.817[*]	1				
NO$_3^-$	−0.173	0.873[*]	−0.952[**]	−0.938[**]	−0.891[*]	−0.5	1			
Cl$^-$	−0.345	−0.41	0.751	0.764	0.782	0.786	−0.55	1		
Turbidity	0.311	−0.04	−0.049	−0.087	−0.234	−0.53	−0.13	.[a]	1	
Fe	0.24	−0.13	−0.015	−0.06	−0.113	−0.52	−0.24	−0.36	0.387	1

*. Correlation at 0.05(2-tailed)

**. Correlation at 0.01(2-tailed)

a. Constant variable...

There was a significant amount of iron in the drinking water of Naskar para (S1) and therefore, its residents did not use the 'India Mark II' hand pump. The overall quality of drinking water in the village was rated as 'unfit for drinking' (WQI: 190.87).

Pearson correlation among various physicochemical parameters of drinking water

The Pearson correlation matrix among various physicochemical parameters is presented in Table 7. Physicochemical parameters (TDS, EC, CaCO$_3$ and NO$_3$) exhibited significant relationships. A significant high negative correlation was found between pH and TDS ($r = −0.844$; $p < 0.05$). Additionally, pH and EC showed a significant high negative correlation ($r = −0.813$; $p < 0.05$). Besides, TDS had a strong positive correlation with EC ($r = 0.997$; $p < 0.01$) and CaCO$_3$ ($r = 0.982$; $p < 0.01$). The TDS had a significant negative strong correlation with NO$_3^-$ ($r = −0.938$; $p < 0.01$); whereas EC showed a significant very high positive correlation with CaCO$_3$ ($r = 0.986$; $p < 0.001$) and a significant very high negative correlation with NO$_3^-$ ($r = −0.938$; $p < 0.001$). Furthermore, CaCO$_3$ exhibited a significant high positive correlation with As ($r = 0.817$; $p < 0.05$) and a high negative correlation with NO$_3^-$ ($r = −0.891$; $p < 0.05$).

Discussion

The poor quality of drinking water affects human health and the quality of life (Li and Wu 2019). Mainly, accumulation of excessive levels of physical, chemical, and bacteriological parameters in drinking water can negatively affect human health (Meride and Ayenew 2016). It has been noticed that the study area has the

excessive levels of arsenic and iron traces, posing serious concerns to villagers who are regularly consuming the contaminated drinking water. A study indicated that drinking water contaminated with various heavy metals are very harmful for human health (Rehman et al. 2018). The study of Bain et al. (2014) revealed that water sources in rural low-middle-income countries (LMCs) are more likely to be contaminated with fecal coliform than those in urbanized developed countries. In India, the arsenic-contaminated drinking water primarily affects lungs, liver, kidneys, and skin (Basu et al. 2014; Saha et al. 1999). The non-carcinogenic health risks are linked to the ingestion of iron (Ghosh et al. 2020). Kumar et al. (2017) study in Uttar Pradesh unveiled that high exposure to iron may cause severe health problems such as liver cancer, diabetes, cirrhosis of the liver, diseases related to the heart and central nervous system and infertility. Similarly, a study conducted in China revealed that water pollution is more detrimental to the mental and physical health of those living in countries with low and middle incomes (Wang and Yang 2016; Slekiene and Mosler 2019; Toivettula et al. 2023).

Our study detected a slightly higher amount of arsenic (0.05 mg/L) in the 'ordinary tube well' (S3) (see supplementary material) at 'Gazi para', which exceeded the standard value of BIS standard (BIS*:* 0.01 mg/L). The traces of arsenic and heavy metals were also found in 'ordinary tube well' during the study, which can lead to chronic diseases like cancer (EPA 2017). However, we did not find any traces of fecal coliforms (i.e., E. coli, Citrobacter, and Salmonella). Therefore, there is less probability of human health impact in the village through bacterial contamination in drinking water. The present study depicts that the water quality of the 'India Mark II' (see supplementary material) hand pump was 'excellent'. However, due to presence of high levels of iron (1 mg/L) in the drinking water, people are not using this water source for drinking purposes whereas it is being used for other domestic purposes. The findings of our study shows that the overall quality of drinking water in the study village was 'unsafe for consumption' (WQI: 190.87). Therefore, it is imperative that access to safe and affordable drinking water is needed to prevent inevitable health consequences in the long run. Installing deep tube wells and using improved drinking water sources can improve water quality and maintain good health and well-being (Roy et al. 2023). The responsible use of chemical fertilizers and pesticides in the agricultural field can be helpful to minimize arsenic contamination in the soil as well as surface groundwater (Islam and Mostafa 2021). The present study is very significant for implementing policy and public health interventions at the micro-level as it is conducted at the village level. Besides, it is suggested that the future studies should be focused on water quality of entire region for targeted public health interventions.

The authors suggest frequent monitoring of contaminated sources of drinking water to prevent serious health impacts. By providing arsenic-free drinking water to the villagers and creating public awareness about water quality will reduce the adverse impacts of arsenic-contaminated drinking water on human health. The filtration of water is needed at that site through a sand filter or other cost-effective techniques to provide access to safe drinking water in the village (Noubactep 2010).

Drinking water quality, human health and well-being: observations from the field

The availability of clean water is essential for good health and well-being. Improving access to safe and affordable drinking water is crucial for a healthy life. However, excessive levels of physical, chemical, and biological parameters can have negative effects on human health. It is important to note that due to natural (such as climate change) and anthropogenic activities (including production of industrial wastewater, agricultural activities, and urbanization), drinking water quality has been adversely affected, posing serious risks to human health. Moreover, contaminated drinking water can expose the population to chronic diseases such as diarrhoea, cholera, jaundice, hepatitis C, skin disease, kidney damage, gastrointestinal stress, blue baby syndrome, circulatory system problems, nervous system disorders, and Typhoid (Ishaque et al. 2022; Meride and Ayenew 2016). Therefore, providing safe and affordable drinking water is essential to prevent long-term health consequences for the villagers.

It was observed that there were only a few deep tube wells (> 1000 feet deep) in the study area and they were sparsely distributed. While none of the households had access to tap water connections within their own dwellings or plots. In addition, due to high levels of bleaching, some households do not use public tap water or standpipes for drinking purposes. However, they use this water (public tap water) for cooking and other domestic purposes. Moreover, some households lack proper drainage facilities within their localities. Therefore, they demand proper drainage systems near their residence. On the other hand, a very small fraction of households are using pond water for cooking rice. Hence, to prevent long-term health consequences for the villagers, efforts should be made to ensure the quality and availability of water.

Conclusions

Access to safe and affordable drinking water is a fundamental indicator of the quality of life and it plays a significant role in maintaining human health and well-being. To achieve Sustainable Development Goal 6.1 (SDG 6.1- achieve universal and equitable access to safe and affordable drinking water for all), it is essential to ensure that everyone has access to safe and affordable drinking water by 2030. Therefore, our study tried to assesses the current state of water quality in the South Twenty-Four Parganas region of West Bengal, India.

The findings of the study are that the drinking water quality in the region is 'unfit for consumption'. About 82.1% of the sampled households are using contaminated water whereas only 5.2% are using purified drinking water. Public awareness about the quality of drinking water is essential. Thus, frequent monitoring of shallow tube wells, and installation of extra deep tube wells are needed for safe drinking water access. The arsenic removal filter can also be used for safe water. Minimum use of pesticides and fertilizers in the farmlands will minimize arsenic contamination. These measures will lead to better access to safe drinking water in the region. The role of local government is also important in spreading awareness

about contamination of water and in providing support to poor people. This study is significant as it provides insightful highlights and suggests a policy framework for micro-level planning.

Author contributions CR contributed to the conceptualization and study design. CR and SP performed the household-level survey. CR performed the physicochemical analysis of water samples and statistical analysis. CR interpreted the results and discussed the findings. CR, SK, VPS, and SP finalized the manuscript. All authors have read and approved the final manuscript.

Data availability The data was collected through a primary survey with proper consent from the households. Household-level data will be available with reasonable request to the corresponding author. Furthermore, physico-chemical parameters of different improved water sources data are available in the manuscript.

Declarations

Conflict of interest The authors do not have any conflicts of interest to disclose.

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