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Article

Arsenic and microbial contamination in drinking water wells: A field study in West Bengal, India

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Highlights

- Arsenic contamination in groundwater is widespread, with notable local variations.
- Arsenic and microbial contamination co-occur across the study site.
- Land use activities are a primary contributor to groundwater contamination.
- Safe drinking water sources and monitoring programs are needed.

Abstract

The co-occurrence of arsenic (As) and microbial pathogens in groundwater represents a serious threat to public health. The complex interactions between chemical and microbial parameters can increase mobility and bioavailability of As, exacerbating water quality challenges in affected regions. The present study deals with the screening of As and microbial contamination in drinking water wells in rural villages of West Bengal, India. The percentage of As contaminated tube wells (i.e., >10 μg/L) is highest in Dewli (81.66%), followed by Ghentugachi (72.37%), Dubra (60.37%) and Sorati (54.72%). The presence of microbial parameters (i.e., total and fecal coliform bacteria) is highest in Silinda-II (68.21%), whereas lowest percentage in Madanpur-I (7.94%). Additionally, the co-occurrence of As contamination and total and fecal coliform bacterial populations in tube wells is also determined. Silinda-II has the highest As and microbial presence in 34.65% of the tube wells, whereas, the lowest percentage was observed in Tatla-II, constituting 1.47% of the tube wells. The co-occurrence of As and microbial pathogens in tube wells varies geographically across several villages in the study area. Such observation is primarily linked to rural land use, tube well depths, and the location of tube wells close to the pit latrine, pond, and agricultural land. This study highlights the necessity for immediate intervention to improve water quality in rural villages, such as the improvement of sanitation infrastructure, and monitoring of tube wells to ensure safe drinking water supply.

Keywords: Arsenic; Groundwater; Total Coliform; Fecal Coliform, West Bengal.

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1. Introduction

Groundwater is a critical natural resource that is essential for both daily human activities and economic development. However, groundwater quality is increasingly threatened due to uncontrolled extraction for agricultural and industrial activities, increase in demand associated with population growth, climate and land use changes (Foster and Chilton, 2003; Nath et al., 2021). The occurrence of arsenic (As) and the presence of microbial pathogens in groundwater posing significant risks to public health (van Geen et al., 2011; Dong et al., 2024). Arsenic, a naturally occurring metalloid, releases into groundwater primarily through geogenic processes, such as the reductive dissolution of As-bearing minerals in alluvial aquifers (Bhattacharya et al., 1997; Nickson et al., 1998; Harvey et al., 2005; Pathak et al., 2022). Exposure to As-contaminated water is associated with severe health consequences, including skin lesions, cancer, cardiovascular diseases, and developmental disorders (Chakraborti et al., 2018). Long term intake of As-enriched groundwater causes health crisis in many countries worldwide, especially in Gangetic plain of India and Bangladesh (Chakraborti et al., 2018).

Arsenic enrichment in Gangetic plain is a long debated natural phenomenon creating health hazards to the large community since groundwater is a commonly used sources of drinking water in rural and urban areas because of its easy accessibility and free from pathogens (Mall et al., 2006; Nath et al., 2008). Rigorous studies were undertaken to understand the sources and mobilization processes of As and to develop proper mitigation strategy (Harvey et al., 2005; Nath et al., 2022). The presence of As in drinking water has emerged as a great concern on the health of millions of inhabitants through their sufferings (Saha and Chakraborti, 2001; Mukherjee et al., 2006; Chakraborti et al., 2018). Additionally, the use of As-contaminated groundwater for irrigation posing adverse effects on the crop yield (Sandil et al., 2021). Due to this, As is entering the food chain through groundwater-soil-crop-food transfer. Epidemiological study of population exposed to high level of As ingestion via drinking water was reported in many countries, including Argentina, Bangladesh, Chile, China, India, Mongolia, and Taiwan (Chatterjee et al., 2010; Leber et al., 2010; Huang, 2014; Lu et al., 2016). Studies revealed that arsenate, the analog to phosphate, can be able to transport phosphate anion and replace that through biogeochemical reaction.

Fecal coliform presence in groundwater systems is an important public health issue in rural areas. Shallow aquifers are mostly affected by fecal coliform bacteria, which indirectly involved in releasing As from sediment to groundwater (Islam et al., 2001; Neumann et al., 2009; Valenzuela et al., 2009; van Geen et al., 2011; Shen et al., 2013). The most compelling evidence is that a large number of microbial pathogens and a high concentration of As were found in areas where surface water is recharging the groundwater (Islam and Mostafa, 2021; Barman et al., 2024). These lotic and lentic movements influence As biogeochemical processes by affecting its mobilization, transformation, and distribution in aquatic systems (Leber et al., 2010; Majumder et al., 2016). The most common bacteria found in water systems include *Pseudomonas* sp. (typically forming white, cream, or greenish-blue colonies), *Achromobacter* sp. (typically forming white to pale yellow colonies), and *Rhizobium* sp. (typically forming white, cream, or pale-yellow colonies) (Madigan et al., 2015). Most of them are catalase-positive, citrate-utilizing, and predominantly Gram-negative bacteria (Shen et al., 2013; Sarkar et al., 2014; Wang et al., 2016). Arsenate respiration occurs when organic carbon and hydrogen sulfide are oxidized, and arsenate is converted to arsenite through a natural microbial process (Malasarn et al., 2004; Wang et al., 2016). The distribution patterns of microbial communities in the sediment are diverse and heterogeneously distributed, which induces mobilization of As from sediment to groundwater (Gnanaprakasam et al., 2017). These aquifers mostly contain high amounts of Fe, NH_4^+, and total organic carbon (TOC), which drive microbial processes (Leber et al., 2010; Lu et al., 2016).

In West Bengal, the alluvial aquifer is vulnerable to As and microbial contamination (Barman et al., 2024). Considering the hazard to human health posed by As and microbial pathogens, the screening of drinking water wells is needed to determine the extent of contamination in different geographic regions to highlight various interventions for the local governments to adopt. Therefore, our present study is aimed to identify the occurrence and distribution of As contamination as well as the presence of microbial pathogens in rural drinking water wells in West Bengal, India. We have quantitatively determined As and microbial parameters in groundwater samples from these affected regions.

2. Materials and methods

2.1 Study area

The study area is located in Chakdaha Block (23.02–23.14°N and 88.49–8.62°E), Nadia district, West Bengal (**Fig. 1**). The location of the study area is approximately 65 km north of Kolkata and nearly 175 km inland from the present-day coastline of Bay of Bengal. The area is an integral part of the Ganges River delta. The area is largely

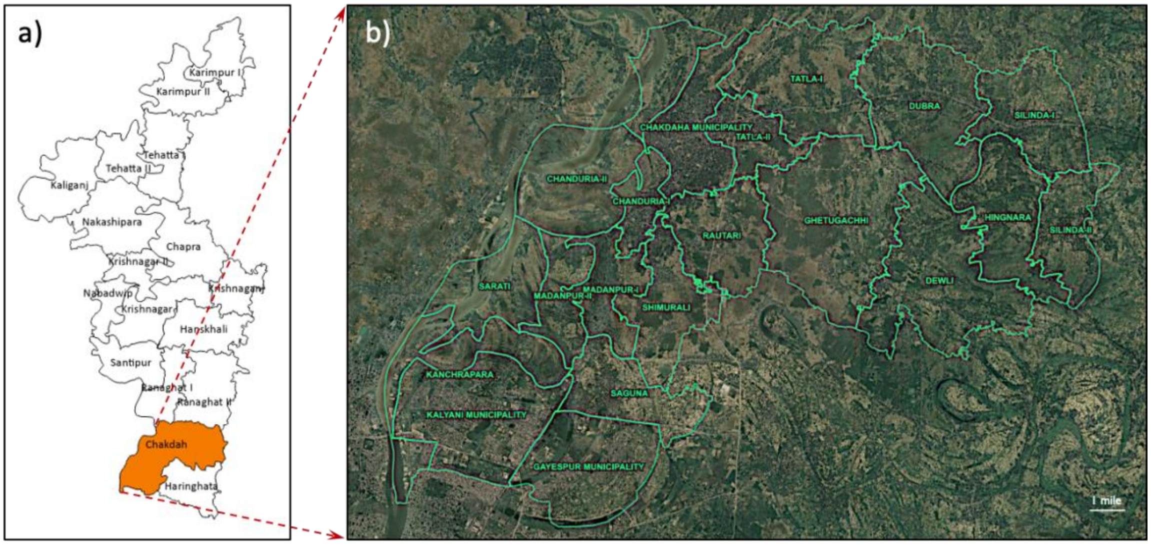

Figure 1. Map of the study area showing the location of the studied gram panchayats in Chakdaha block of West Bengal, India. (a) The location of Nadia district, including the administrative boundaries of 17 blocks. (b) The administrative boundaries of 17 gram panchayats within the Chakdaha block. The administrative boundaries also include three municipalities (not included in this study).

made of alluvium deposited by the Ganges River. The ambient temperatures are largely varying, which is ranging between 12°C and 42°C indicating winter and summer.

The groundwater is collected from shallow tube wells (<50 m below ground level), which is primarily acting as a source of drinking water for the entire rural population. The water quality survey was conducted in seventeen Gram Panchayat (GP), a local governance unit overseeing rural village clusters. These village clusters are: Dewli, Routari, Shimurali, Ghentugachi, Madanpur-I, Madanpur-II, Chanduria-I, Chanduria-II, Saguna, Dubra, Sorati, Kanchrapara, Hingnara, Tatla-I, Tatla-II, Silinda-I and Silinda-II. The total number of surveyed tube wells is 3,252, with the sample breakdown for each village cluster provided in **Table 1**. In the surveyed villages, nearly every household is using tube wells for their domestic requirements, such as drinking, cooking and bathing. These tube wells are hand operated and are shallow in depth (<50 m) for easy accessibility of groundwater.

2.2 Sample collection and analysis

During sampling, each tube well was purged for ten minutes to remove standing water and obtain fresh groundwater samples from the aquifers. After sampling, all the samples were stored at ~4°C in an air-tight ice box and immediately transferred to the laboratory. The concentration of As have been analyzed using hydride generation atomic absorption spectrophotometer (HG–AAS, Varian-240), which has a detection limit <1 μg/L. Microbial analyses (total and fecal coliform count) of the water samples were also determined. For microbial analysis (total and fecal coliform count), water samples were collected in pre-washed (sterile) high density polyethylene vials (Tarsons) to prevent any ambient contamination during sampling following standard protocol (APHA, 1998; WHO 2010). ISO 9308-1:2014 outlines a method for enumerating *Escherichia coli* (*E. coli*) and other coliform bacteria. This method involves membrane filtration, followed by culturing on chromogenic coliform agar, and calculating the number of target organisms in the sample. Chromocult coliform agar is ideal for detecting coliforms and *E. coli* due to its chromogenic substrates that differentiate these organisms based on colony color and the selective agents that inhibit non-coliform growth (Finney et al., 2003). The genera *Escherichia*, *Enterobacter*, *Klebsiella*, and *Citrobacter* are the key groups supported by this medium. A detailed procedure for chemical and microbial analysis, including total and fecal coliform counts, can be found in Ghosh et al. (2020).

2.3 Data processing

The data processing involved analyzing the co-occurrence of As and microbial contamination in the surveyed tube wells. Percentages were used to highlight the proportion of tube wells with As concentrations >10 μg/L, the presence of total and fecal coliforms, and the co-occurrence of both As and microbial contamination. These percentages served as a screening tool to assess the prevalence of As contamination, microbial contamination, and their co-occurrence across the study area, helping to identify areas with higher risks.

Table 1. Arsenic and microbial contamination in tube wells in different Gram Panchayat of Chakdaha block of West Bengal, India.

Gram Panchayat	Tube wells tested	As >10 µg/L (%)	Presence of total and fecal coliform (%)	Percentage of both As and microbial contamination
Chanduria-I	152	26.97	34.21	15.13
Chanduria-II	102	32.35	45.09	21.56
Dewli	289	81.66	38.75	32.87
Dubra	265	60.37	36.22	27.16
Ghentugachi	333	72.37	19.21	18.01
Hingnara	235	23.82	54.04	24.68
Kanchrapara	150	14.66	26.00	10
Madanpur-I	151	8.60	7.94	3.97
Madanpur-II	129	22.48	31.00	13.95
Routari	124	29.03	8.9	5.64
Saguna	303	26.73	35.31	25.41
Shimurali	152	7.89	25.65	5.92
Silinda-I	280	31.42	32.14	18.21
Silinda-II	101	44.55	68.31	34.65
Sorati	148	54.72	16.21	16.21
Tatla-I	135	28.14	17.03	17.03
Tatla-II	203	1.97	27.58	1.47

Note: Microbial contamination is based on the presence or absence test of total and fecal coliform bacteria in groundwater samples.

3. Results and discussion

3.1 Arsenic concentration

Arsenic (As) and microbial contamination was measured and screened in the tube wells of seventeen gram panchayats (i.e., cluster of villages) of Chakdaha block, Nadia district (**Table 1**). Arsenic concentration is often exceeding the WHO guideline value and Bureau of Indian Standards (BIS) recommended maximum permissible limit of 10 µg/L. Arsenic concentration is ranged between below detection limit (BDL) and 272 µg/L, with the median values of 124 µg/L. Dewli gram panchayat has been identified as the most contaminated locality with As concentrations >10 µg/L in 81.66% of the surveyed tube wells, whereas Tatla-II is ranked the lowest where As contamination was only present in 1.97% of the surveyed tube wells.

The data indicate that the As contamination in tube wells is widespread throughout the village clusters surveyed (**Table 1**). It is interesting note that the percentage of As contaminated wells are the highest in Dewli (81.66%), followed by Ghentugachi (72.37%), Dubra (60.37%), and Sorati (54.72%). In Dewli and Ghentugachi shallow tube wells (<50 m) are mostly present and used by the villagers for domestic water use, such as cooking and bathing. These tube wells are privately owned by the villagers because of the increased dependency on groundwater over the years. On the other hand, the use of shallow tube wells (<50 m) in Shimurali is limited and villagers usually collect water from deep tube wells (>100 m). This has been reflected in the observed lower percentage of As contaminated tube wells, constituting 7.89% of the surveyed tube wells. Deep tube wells are the common source used by the local government to provide treated drinking water to the community through piped water network. The result suggests that the percentage of As contaminated tube wells is depending on the factors such as the tube well depths and the location, i.e., controlled by the surface features including land use pattern and geomorphology (Bhowmick et al., 2013; Das et al., 2021).

Table 2. Arsenic contamination in tube wells in different blocks of Nadia district, West Bengal, India.

Block	Tube wells tested	As >10 μg/L (%)	Highest As concentration (μg/L)
Chakdaha	3,144	34.6	318
Chapra	2,196	10	384
Hanskhali	1,530	12	448
Haringhata	1,804	43.18	360
Kaliganj	2,600	38	761
Karimpur-I	893	50	740
Karimpur-II	1,388	54.82	596
Krishnaganj	1,632	13	311
Krishnanagar-I	1,598	15.7	207
Krishnanagar-II	900	28	581
Nabadwip	1,253	9.17	209
Nakashipara	2,400	34	650
Ranaghat-I	1,924	20.94	402
Ranaghat-II	2,674	22.4	623
Santipur	1,320	24	217
Tehatta-I	1,451	14.74	321
Tehatta-II	530	20.94	667

We have also collected groundwater samples (n=29,237) from the entire Nadia district. The summary data shows that the percentage of As contaminated tube wells and the observation of highest As concentrations vary by location (**Table 2**). These variations are linked to specific geographic and land use characteristics (Bhowmick et al., 2013; Nath et al., 2022). The data shows that Kaligang and Karimpur-I blocks have the highest As concentration, whereas Krishnagar-I, Nabadwip, and Santipur blocks have the lowest As concentration for the entire Nadia district. In addition to that, the percentage of As concentration greater than 10 μg/L in tube wells varies in different locations (**Table 2**). This is quite similar to our localized study of different village clusters within the Chakdaha block. The variations in groundwater As from local- to regional-scale have been earlier attributed to geomorphological settings, aquifer characteristics, and geochemical processes (Bhowmick et al., 2013; Ghosh and Donselaar, 2023). Ghosh and Donselaar (2023) demonstrated that the anoxic environment of oxbow lakes and clay plugs in the Ganges Delta region, enriched with organic matter, promotes microbial processes that mobilize As. They further highlighted that the presence of natural and anthropogenic organic matter in the sediment enhances microbial As release through reductive dissolution. Our study further supports these observations, highlighting the role of local conditions in influencing As concentrations and emphasizing the need for regular monitoring and mitigation strategies in affected regions.

3.2 Microbial contamination

Microbial contamination has been observed in the study area (**Table 1**). It has been found that Silinda-II has the highest percentage of tube wells that are screened for microbial contamination (68.21%), whereas the lowest percentage has been observed in Madanpur-I (7.94%). Similarly, Sarkar et al. (2022) observed widespread bacterial contamination in shallow tube wells in Kathmandu, Nepal. The variation in the presence of microbial contamination in groundwater is largely source dependent and exists in all the monitoring village clusters. However, their nature, type and amiability largely vary. During the field visit, it was noticed that the contaminated tube wells are usually shallow and located near pit latrines, ponds, cattle waste dump sites, and man-made ditches. Putri et al. (2024) concluded that the factors contributing to bacterial contamination in groundwater are linked to the proximity of wells to septic tanks and population density.

This study advocates that microbial contamination levels are varying and related to certain land use features and local characteristics which are likely affecting the tube well water quality (Neumann et al., 2009; Chatterjee et

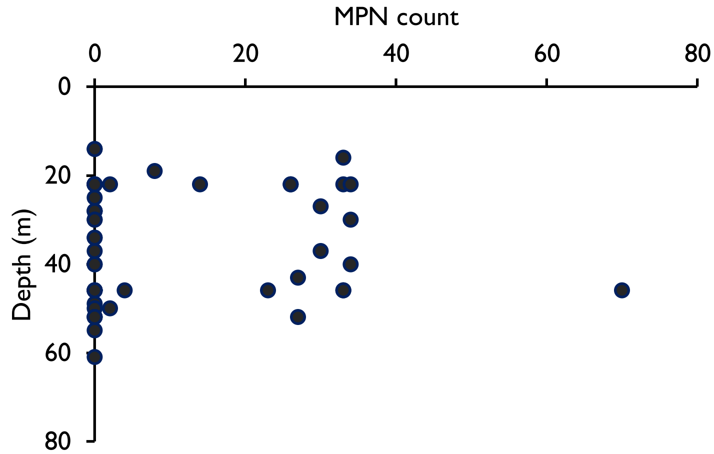

Figure 2. Distribution of microbial contamination (Most Probable Number) at different depths of tube wells in the study area for a subset of tube wells.

al., 2010). Paul et al. (2024) observed a link between bacterial contamination in well water and open waste dumping, suggesting that leachate from the waste dumping site is likely polluting groundwater sources. Another study also highlighted that microbial contamination is a repeatable phenomenon and contamination is due to local water sources such as ponds (Valenzuela et al., 2009). Islam et al. (2001) also suggested that the rural areas of Bangladesh groundwater supply are microbially contaminated and are also contain As greater than 10 μg/L. Dey et al. (2022) observed that the abundance of total and fecal coliform in groundwater is linked to seasonal hydrology. They observed the highest abundance of bacterial pollution during monsoonal periods in comparison to pre- and post-monsoon periods. Our study suggests that most of the contaminated tube wells are shallow (<50 m) and contain both total and fecal coliform bacteria (**Fig. 2**). Microbial contamination is primarily found in shallow aquifer zones, typically <50 m below ground level (Nayebare et al., 2022). Bacterial contamination is not only widespread in rural areas, Invik et al. (2017) reported the presence of total coliform bacteria in public well water samples in Alberta, Canada. These observations highlight the urgent need for stronger policy interventions to safeguard public health and ensuring sustainable water quality across all communities (Hynda et al., 2014; Dong et al., 2024).

4. Co-occurrence of arsenic and microbial contamination

Groundwater As is commonly referred to as threats to drinking water quality and agricultural productivity. The co-occurrence of As and microbial contamination in tube wells could significantly influence groundwater potability. Silinda-II has been identified as having the highest percentage (34.65%) of tube wells with As concentration greater than 10 μg/L, along with the presence of microbial contamination. Whereas the lowest percentage has been identified in Tatla-II where both As and microbial contamination percentage is 1.47%. This result is similar to the observed 26.5% of tube wells containing both As and microbial contamination, i.e., 7,760 out of 29,237 tube wells in the entire Nadia district.

Figure 3 shows the relationships between As concentrations and microbial occurrence (MPN count) in randomly selected tube wells in the study area. Based on the screening data for As and microbial contamination in groundwater, microbially mediated mobilization of As could be occurring in the study area (Kappler et al., 2004; Chatterjee et al., 2010; van Geen et al., 2011). In the microbially-mediated mobilization of As, the role of organic matter is important (Islam et al., 2004; Gault et al., 2005). In the present study, it has been found that the contaminated wells are mostly located near ponds, pit latrines and cattle waste dumping sites. These are the common source of fresh organic matter and potentially seep into groundwater (Chatterjee et al., 2010; Ghosh and Donselaar, 2023). Earlier studies have also suggested these sources are responsible for the supply of organic matter and their role in mobilization of As in groundwater. Microorganisms are ubiquitous in our environment, found in both surface and subsurface environment, and their presence is associated with various influencing factors including complex interactions between human and the environment (Bagordo et al., 2024). These microbial populations interact with As and other elements through various biogeochemical processes, such as transformation, reduction, and methylation. Islam et al. (2004) explained how microbial As mobilization can occur

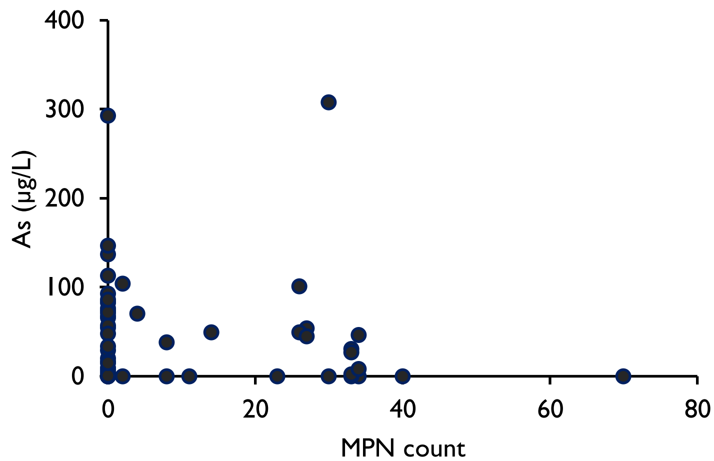

Figure 3. Relationships between As concentrations and microbial presence (Most Probable Number) in a subset of tube wells in the study area.

in aquifers, effectively releases As into groundwater. This process is typically catalyzed by the breakdown of organic matter and the concomitant reduction of Fe(III) to Fe(II), which releases sorbed As into the groundwater (Kappler and Bryce, 2017). In these circumstances, the reducing conditions of the aquifer help maintain the biogeochemical process.

In the study site, the groundwater chemistry is mostly alike, but its variation is influenced by geospatial signatures, sediment texture, and mineralogy (Bhowmick et al., 2013). Similarly, the presence of As-reducing bacteria, such as *Acinetobacter sp*., has been reported at a depth of 45 m in the aquifer (Islam et al., 2004; Gault et al., 2005). Hydrogeochemical studies show that the gray sand aquifer is particularly vulnerable to As contamination and favors microbial mediated As release (Biswas et al., 2012). These aquifers contain enriched concentrations of NH_4^+, PO_4^{3-}, Fe and As, and are in reducing conditions characterized by negative redox potential. The anoxic nature of these aquifers, along with their water type ($CaHCO_3$) and elevated concentrations of Na^+, Cl^-, DOC, PO_4^{3-}, and Fe (Nath et al., 2008; Biswas et al., 2011), creates conditions favorable for microbial activity that can mobilize As into the groundwater. Bhowmick et al. (2013) suggested that anthropogenic activities and oxbow lakes contribute to As release. Understanding depth-dependent As chemistry and redox processes is crucial for studying the biogeochemical mechanisms that lead to As release in the aquifer (Biswas et al., 2011).

5. Conclusion

Our study suggests a co-occurrence of As-contaminated tube wells and positive microbial counts. The distribution of contaminated wells is spatially variable. Most of the contaminated wells are located near rural land uses, such as pit latrines, ponds, agricultural lands, and waste dump sites. Additionally, factors like tube well depth and local reducing conditions may contribute to the enrichment of both As and fecal contamination. Our screening results indicate not only As contamination in tube wells but also the widespread presence of microbial loads in shallow groundwater. These findings highlight the urgent need for immediate intervention by local government authorities, provide safe drinking water, and implement tube well screenings to monitor contamination.

6. Data availability statement

The data is presented in the manuscript as figures and tables. The data can be made available on request from the corresponding author.

7. Author contributions

A. Mukhopadhyay: formal analysis, and writing – original draft. P. Ghosh: conceptualization, data curation, formal analysis, writing – original draft, and writing – review & editing. J. Jana: supervision, and writing – review & editing. D. Chatterjee: conceptualization, funding acquisition, supervision, and writing – review & editing. All authors approved the final version of the manuscript.

8. Conflict of interest

The authors declare no conflict of interest related to this study.

9. Ethical statement

This study does not involve human or animal subjects. Ethical approval is not required for this research.

10. Copyright statement

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