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Assessment and Mitigation Strategies for Heavy Metals and Bacterial Contamination in Badshahpur Lake, Gurugram, India

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This study aims to assess the microbial load and heavy metals contamination in water samples from Badshahpur lake situated in Gurugram city, India across three zones. A total of 132 water samples were collected: 47 from zone 1, 40 from zone 2 and 45 from zone 3. The microbial load was quantified as total bacterial count (TBC) and concentrations of heavy metals *viz.* cadmium (Cd), copper (Cu), lead (Pb), chromium (Cr), arsenic (As), mercury (Hg), tin (Sn) and methyl mercury (MM) were measured using ICP-OES. In zone 1, TBC ranged from 5.2×10^3 to 3.7×10^9 CFU/mL, with the highest microbial load at IEWS-A11. Cadmium level was recorded higher at 0.044 mg/L at IEWS-A21 and copper concentrations reached 0.091 mg/L at IEWS-A18. Lead and chromium were also detected, with concerning levels of 0.039 mg/L and 0.031 mg/L, respectively. Zone 2 showed TBC from 4.0×10^4 to 6.7×10^8 CFU/mL, with significant heavy metal concentrations, particularly copper at 0.088 mg/L and cadmium at 0.038 mg/L. Zone 3 exhibited TBC ranging from 4.0×10^3 to 5.1×10^8 CFU/mL, with the highest cadmium concentration of 0.046 mg/L at IEWS-C25 and copper at 0.086 mg/L at IEWS-C12. Among all bacteria tested, the ubiquitous presence of *E. coli* across all zones indicates widespread faecal contamination. The results emphasize the areas with significant levels of heavy metal pollution, highlighting the importance of consistent monitoring of water quality, improved water treatment methods, and enhanced sanitation infrastructure to reduce health hazards and safeguard the stability of the environment.

Keywords: Water quality, Microbial contamination, Heavy metal pollution, Pathogenic bacteria, Total microbial count.

INTRODUCTION

Wastewater discharge into water bodies is a significant global environmental challenge. These effluents often introduce hazardous substances, such as heavy metals, pesticides and pathogenic bacteria, into aquatic ecosystems, posing severe risks to both human health and the environment [1]. The discharge of untreated or inadequately treated industrial wastewater is especially problematic due to the toxic, persistent and bioaccumulative nature of heavy metals [2].

Heavy metals in wastewater present a significant environmental challenge due to their persistence and toxicity, which can severely impact both ecological systems and human health [3]. Research has shown widespread contamination of water resources by heavy metals from various industrial activities. For example, Selvam *et al.* [4] documented elevated levels of arsenic, selenium, and lead in groundwater in Thoothukudi, India, surpassing WHO guidelines. In a similar vein, Hamed *et al.* [5] found increased concentrations of zinc, lead and copper in Manzala lake, linked to industrial discharges. Umar *et al.* [6] highlighted high chromium levels in tannery effluents in Nigeria, underscoring the urgent need for improved management strategies. Faisal *et al.* [7] reported that iron, manganese and chromium levels in groundwater and river water in Bangladesh exceeded permissible limits, indicating severe pollution. Industrial effluents often contain a range of heavy metals, including cadmium, lead, and chromium, as well as organic contaminants, which significantly degrade water quality and pose serious risks to aquatic life and local communities *et al.* [8]. These pollutants contribute to bioaccumulation in the food chain, adversely affecting human health through the consumption of contaminated water and agricultural products [9]. Additionally, safe water sources can become polluted due to runoff and leaching of pesticides used in agriculture, further disrupting ecological balance and posing further health risks [10,11].

Microbial contamination in wastewater is a significant concern due to its potential health and environmental impacts. Studies have reported diverse bacterial populations in industrial effluents across various regions. Selvam *et al*. [4] documented high levels of total coliforms, fecal coliforms, and *Escherichia coli* in groundwater contaminated by industrial discharges in Thoothukudi, India. Similarly, Faisal *et al*. [7] observed elevated bacterial contamination in groundwater and river water associated with industrial activities in Bangladesh. Umar *et al*. [6] identified *Bacillus* sp., *Pseudomonas* sp. and *E. coli* in tannery effluents in Nigeria, while Lejri *et al*. [12] reported the presence of *Pseudomonas* and *Enterococcus* in untreated tanning effluents. Tariq *et al*. [13] found high levels of total coliforms and fecal coliforms in wastewater from Kala Shah Kaku, Pakistan, indicating poor sanitation. Sponza *et al*. [14] highlighted the role of various microorganisms, including coliform bacteria and algae, in assessing the toxicity of textile and metal industry effluents. Overall, these studies illustrate the widespread presence of harmful bacteria in industrial effluents, posing risks to both human health and the environment [15]. Additionally, toxic heavy metals such as lead, cadmium and mercury found in these effluents can bioaccumulate in living organisms, leading to severe health issues such as neurological disorders, kidney damage, respiratory problems and increased cancer risk [16,17].

The assessment and mitigation of such pollutants are crucial for ensuring environmental safety and sustainability [18]. Various strategies, including the use of microbial consortia, have shown promise in reducing the toxicity of these pollutants. Microbial communities, particularly those adapted to heavy metal toxicity, can play a pivotal role in the bioremediation of contaminated sites by transforming and immobilizing heavy metals [19-21]. Badshahpur lake is a significant water source for various needs, including domestic use and irrigation, in Gurugram city and its environs, serving a large population. Therefore, ensuring its safety and cleanliness is crucial for promoting public health safety and sustainable development within the area. Additionally, the lake provides a habitat for many aquatic animals, including migratory birds, fish and other wildlife, while some species depend on it for drinking water contamination of the lake with heavy metals, pesticides and bacterial pathogens threatens these species' survival and disrupts the ecosystem's delicate balance.

Given the ecological and health risks associated with heavy metal and bacterial contamination in wastewater, this study aims to assess the current pollution levels in Badshahpur lake and evaluate potential mitigation strategies. The present study aims to comprehensively assess heavy metals and bacterial contamination in wastewater at Badshahpur lake to understand the extent of pollution and implement effective mitigation strategies to protect the environment. The findings will contribute to developing effective remediation techniques and management practices for contaminated water bodies in industrial regions, ensuring the health of ecosystems and communities reliant on these water sources.

EXPERIMENTAL

Study area and sampling location: For the study of Badshahpur lake, Gurugram (India) a total of 47 water samples were collected from various locations in zone 1, with the coordinates provided in Table-1. Similarly, 40 samples were collected from zone 2, with the coordinates detailed in Table-2 and 45 samples were collected from zone 3, with the coordinates listed in Table-3. All the water samples were collected in March 2023.

Sample collection and heavy metal analysis: Samples for the heavy metal analysis were collected in 120 mL plastic containers, which were initially washed with detergent and rinsed with distilled water. To ensure thorough cleaning, the containers were finally rinsed with 20% nitric acid before sampling. After collection, 1.5 mL of conc. HNO_3 was added to each 1 L of water sample to act as a preservative. The pH of the sample was then adjusted to 2.0 using a pH meter, maintaining an acidic environment to keep metal ions in solution and prevent precipitation. The samples were stored in a refrigerator at approximately 4 ºC to minimize any biological activity that could alter their composition before analysis. As water samples may contain particulate matter or organic materials, pre-treatment in the form of digestion was necessary before analysis. Nitric acid digestion was employed to breakdown organic matter and release metals into a measurable form. The digested samples were subsequently taken to the laboratory for analysis using an ICP-OES (Thermo iCAP 7000 series IC74DC173607). This method ensures accurate and reliable results by adequately preparing and preserving the samples before analysis [22].

Estimation of microbial load: For microbiological analysis, samples were collected in sterilized 500 mL capacity bottles. To quantify the bacteria in each water sample, serial dilutions were performed at a ratio of 1:10 by adding 25 mL of sample to 225 mL of 0.85% saline. The pour plate method was used with nutrient agar and the samples were incubated at 37 ºC. The total number of colonies on medium was calculated using the formula described by Chauhan & Jindal [23]. The colonies were observed under a colony counter and identical colonies were re-streaked on nutrient agar plates to obtain pure cultures.

Isolation and identification of *E. coli*: To detect *E. coli* in the water samples, the membrane filtration method was employed. Due to the turbidity of the collected samples, each sample was diluted in a 1:2 ratio before filtration. A 250 mL diluted water sample was then passed through a 0.45 µm filter paper, which was subsequently inoculated in MacConkey Broth. Identification of *E. coli* was confirmed through sub-culturing on eosin methylene blue agar and MacConkey agar plates. These plates were examined for the presence of pink colonies on MacConkey agar and green metallic sheen colonies on eosin methylene blue agar plates, which are characteristic of *E. coli*. Further confirmation was carried out through biochemical tests for *E. coli* according to the guidelines outlined in IS: 5887 (part 1) [24]. The presence or absence of *E. coli* in the water sample was determined by examining the characteristic colonies on the selective media and conducting morphological and biochemical evaluations. Based on these analyses, the results were recorded as either '*E. coli* Positive' or '*E. coli* Negative' in 250 mL water sample. Quality control measures were implemented during the experiment by utilizing pure cultures obtained from the Microbial Type Culture Collection, Chandigarh, India. For this experiment, *E. coli* was used as the positive control and *S. aureus* was used as the negative control [25].

Isolation and identification of *P. aeruginosa*: To detect *P. aeruginosa* in water sample, each turbid sample was diluted in a 1:2 ratio before filtration. A 250 mL diluted sample was then passed through a 0.45 µm filter. The filter paper was inoculated in cetrimide broth and incubated at 37 ºC for 48 h. Subsequently, the sample was subcultured on cetrimide agar plates, and characteristic green colonies were observed. Further confirmation was obtained by gram staining and biochemical tests as per IS: 13428 (Annexure-D) [26]. The presence or absence of *P. aeruginosa* in the water sample was determined based on the characteristic colonies and biochemical tests. Quality control was maintained by simultaneously running a positive control of *P. aeruginosa* and a negative control of *E. coli* during the experiment.

Isolation and Identification of *Bacillus* spp: To identify *Bacillus* spp. in water samples, each cloudy sample underwent a 1:2 dilution before filtration. A 250 mL diluted sample was then filtered through a 0.45 µm filter. The filter paper was placed into 225 mL of buffer peptone water (BPW) and subsequently incubated at 37 ºC for 48 h. Subculturing was performed on Mannitol Yolk Polymixin Agar (MYPA) plates, followed by confirmation through biochemical test [23].

Isolation and identification of *S. aureus*: To detect *S. aureus*, each 250 mL water sample underwent filtration through a 0.45 µm filter. Prior to filtration, turbid samples were diluted in a 1:2 ratio. The filter paper was then inoculated in a cooked medium and incubated at 37 ºC for 24 h. The enriched sample was subsequently subcultured on mannitol salt agar and Baird Parker agar plates. Yellow colonies on mannitol salt agar plates and black colonies on Baird-Parker agar plates were observed for characteristic growth. Further confirmation was conducted *via* Gram staining and biochemical tests as per IS: 5887 (Part-2) [27]. The results were recorded as '*S. aureus* Positive' or 'Negative' per 250 mL of water sample, based on characteristic colonies and biochemical tests. To ensure quality control, pure cultures of *S. aureus* were employed as the positive control, while *E. coli* served as negative control throughout the experiment.

Isolation and identification *Salmonella* sp.: To detect the presence of *Salmonella* sp. in water sample, the membrane filtration method was used. Due to the turbidity of the collected samples, each sample was diluted in a 1:2 ratio before filtration. A 250 mL diluted water sample was then passed through a 0.45 µm filter, and the filter paper was inoculated in buffered peptone water and incubated at 37 ºC for 24 h. After incubation, 0.1 mL of enriched sample was inoculated into 10 mL of Rappaport-Vassiliadis (RV) medium and incubated at 42 ºC for 24 h. Subsequently, the sample was subcultured on plates of brilliant green agar and bismuth sulphide agar, and the plates were incubated at 37 ºC for 24 h. The colonies were observed for characteristic features such as pink colonies on brilliant green agar and black metallic sheen colonies with H_2S on bismuth sulphide agar plates. Further confirmation was done by several biochemical and serological tests for *Salmonella*, as per the Indian Standard IS: 5887 (Part 3) [28]. To ensure quality control during the experiment, pure cultures obtained from the Microbial Type Culture Collection, Chandigarh, India, were used as positive and negative controls, with *Salmonella typhimurium* as positive control and *S. aureus* as negative control.

Isolation and identification of *Shigella* sp.: The diluted (1:2) water sample (250 mL) was first passed through a 0.45 µ filter, and the filter paper was then inoculated in nutrient broth. Confirmatory identification was carried out by streaking the inoculated nutrient broth on deoxycholate citrate agar. Further confirmation was conducted through Gram's staining and the use of HiMedia IMViC biochemical kit for *Shigella* sp. as per IS: 5887 (Part-7) 1976, Reaffirmed 2018 [29].

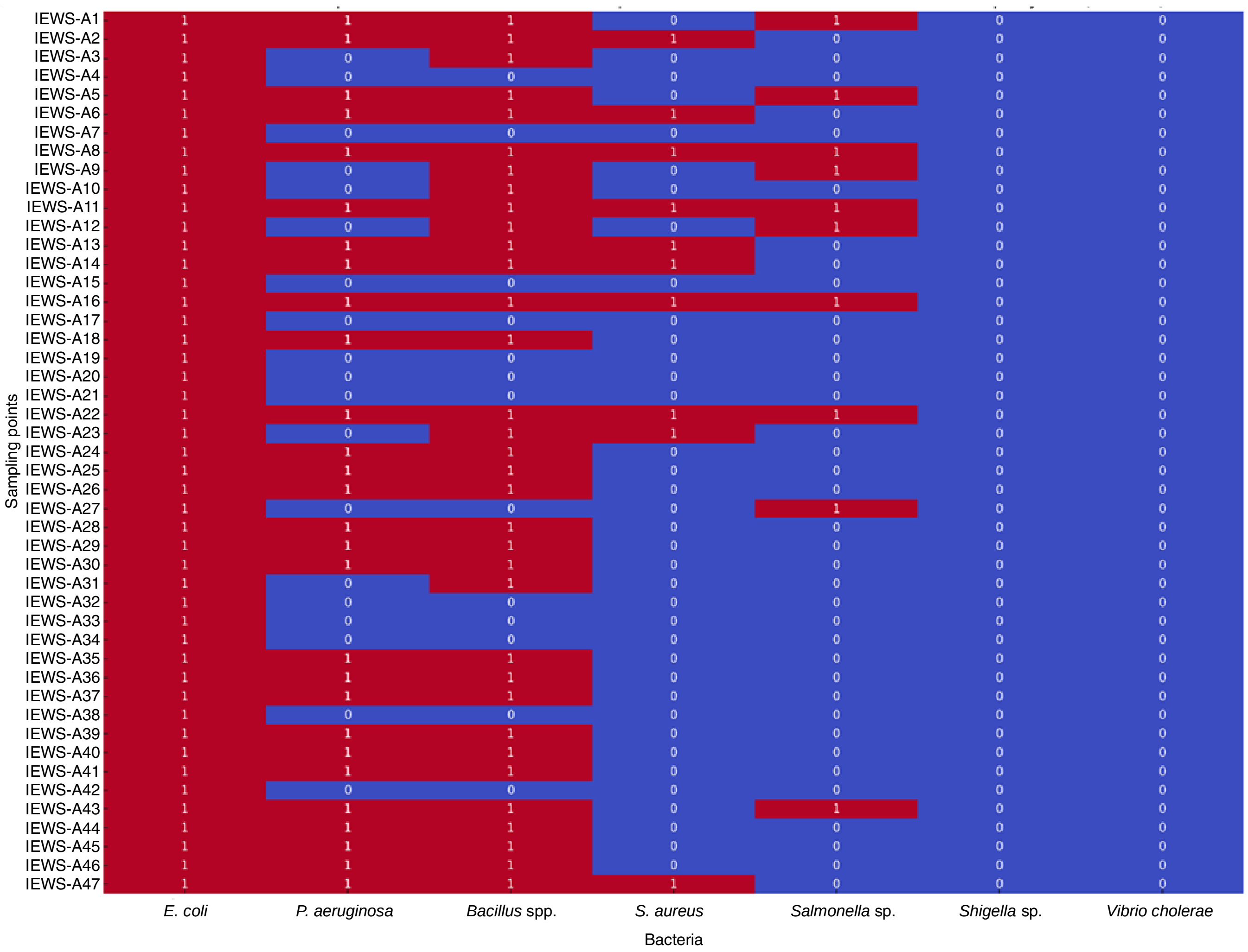
Isolation and Identification of *Vibrio* sp.: To isolate *Vibrio* strains, each turbid 250 mL water sample was diluted in a 1:2 ratio before filtration. The diluted sample was then passed through a 0.45 µ filter. Subsequently, the filter paper was inoculated in alkaline peptone water and incubated at 37 ºC for 24 h. After incubation, streaking was performed on thiosulfate-citrate-bile salts-sucrose agar plates. Further confirmation was achieved through Gram's staining and biochemical testing according to IS: 5887 (Part-5) 1976, Reaffirmed in 2018 [30].

RESULTS AND DISCUSSION

Assessment of microbial load and heavy metals in water samples from Badshahpur lake in different zones

Zone-1: The assessment of microbial load and heavy metals in water samples from various locations of Badshahpur lake (zone-1) provides a comprehensive understanding of the environmental health of this water body. The data collected from 47 sampling points reveal significant variations in both microbial and heavy metal contamination, which can have critical implications for public health and ecosystem stability. The total bacterial count (TBC), which is a measure of the microbial load in the water, exhibited a broad range across the sampling points. The highest microbial load was recorded at sampling point IEWS-A11, with a TBC of 3.7×10^9 CFU/mL, indicating extremely high levels of bacterial contamination. Other locations with notably high microbial loads include IEWS-A24 (3.1×10^9 CFU/mL), IEWS-A17 (2.3×10^9 CFU/mL) and IEWS-A36 (1.2×10^9 CFU/mL). In contrast, the lowest microbial load was observed at IEWS-A44, with a TBC of 5.2×10^3 CFU/mL, suggesting relatively clean water at this point. Several other points also showed high microbial counts, such as IEWS-A1 (3.0×10^8 CFU/mL), IEWS-A9 (6.6×10^8 CFU/mL) and IEWS-A29 (3.6×10^8 CFU/mL).

Fig. 1 shows the heatmap of distribution of specific bacteria in water samples from various locations of Badshahpur lake, illustrates the presence or absence of 7 pathogenic bacteria across 47 sampling points (IEWS-A1 to IEWS-A47). The results indicated that *E. coli* was detected at all sampling points, suggesting widespread fecal contamination, which poses a significant public health risk due to its potential to cause serious



Sampling points	*E. coli*	*P. aeruginosa*	*Bacillus* spp.	*S. aureus*	*Salmonella* sp.	*Shigella* sp.	*Vibrio cholerae*
IEWS-A1	1	1	1	0	1	0	0
IEWS-A2	1	1	1	1	0	0	0
IEWS-A3	1	0	1	0	0	0	0
IEWS-A4	1	0	0	0	0	0	0
IEWS-A5	1	1	1	0	1	0	0
IEWS-A6	1	1	1	1	0	0	0
IEWS-A7	1	0	0	0	0	0	0
IEWS-A8	1	1	1	1	1	0	0
IEWS-A9	1	0	1	0	1	0	0
IEWS-A10	1	0	1	0	0	0	0
IEWS-A11	1	1	1	1	1	0	0
IEWS-A12	1	0	1	0	1	0	0
IEWS-A13	1	1	1	1	0	0	0
IEWS-A14	1	1	1	1	0	0	0
IEWS-A15	1	0	0	0	0	0	0
IEWS-A16	1	1	1	1	1	0	0
IEWS-A17	1	0	0	0	0	0	0
IEWS-A18	1	1	1	0	0	0	0
IEWS-A19	1	0	0	0	0	0	0
IEWS-A20	1	0	0	0	0	0	0
IEWS-A21	1	0	0	0	0	0	0
IEWS-A22	1	1	1	1	1	0	0
IEWS-A23	1	0	1	1	0	0	0
IEWS-A24	1	1	1	0	0	0	0
IEWS-A25	1	1	1	0	0	0	0
IEWS-A26	1	1	1	0	0	0	0
IEWS-A27	1	0	0	0	1	0	0
IEWS-A28	1	1	1	0	0	0	0
IEWS-A29	1	1	1	0	0	0	0
IEWS-A30	1	1	1	0	0	0	0
IEWS-A31	1	0	1	0	0	0	0
IEWS-A32	1	0	0	0	0	0	0
IEWS-A33	1	0	0	0	0	0	0
IEWS-A34	1	0	0	0	0	0	0
IEWS-A35	1	1	1	0	0	0	0
IEWS-A36	1	1	1	0	0	0	0
IEWS-A37	1	1	1	0	0	0	0
IEWS-A38	1	0	0	0	0	0	0
IEWS-A39	1	1	1	0	0	0	0
IEWS-A40	1	1	1	0	0	0	0
IEWS-A41	1	1	1	0	0	0	0
IEWS-A42	1	0	0	0	0	0	0
IEWS-A43	1	1	1	0	1	0	0
IEWS-A44	1	1	1	0	0	0	0
IEWS-A45	1	1	1	0	0	0	0
IEWS-A46	1	1	1	0	0	0	0
IEWS-A47	1	1	1	1	0	0	0

Fig. 1. Heatmap illustrating the distribution of specific bacteria in water samples from various locations of Badshahpur Lake (Zone-1) Y-axis: Sampling points (IEWS-A1 to IEWS-A47), X-axis: Bacteria types (*E. coli*, *P. aeruginosa*, *Bacillus* spp., *S. aureus*, *Salmonella* Sp., *Shigella* sp., *Vibrio cholerae*) Color indication: Red color: Presence of bacteria; Blue color: Absence of bacteria

gastrointestinal infections. *Bacillus* spp. were found in 35 of the 47 samples, indicating their resilience and ability to form spores that survive in harsh conditions. Although not always harmful, certain strains can cause foodborne illnesses. *P. aeruginosa* was present in 27 samples and is known for its antibiotic resistance and potential to cause infections, especially in immunocompromised individuals. *S. aureus* was detected at 15 sampling points; its presence in water can lead to severe conditions, particularly when used for recreational activities or food preparation. *Salmonella* sp. was found in 11 samples, highlighting the risk of enteric diseases from this major cause of foodborne illness. *Shigella* sp. was detected in 9 samples, while *Vibrio cholerae* was absent, indicating a lower risk of cholera during the sampling period. Notably, sampling points IEWS-A11 and IEWS-A16 showed the presence of six different bacteria, marking them as highly contaminated and posing significant health risks. Other points like IEWS-A1, IEWS-A5, IEWS-A8, IEWS-A13, IEWS-A22, and IEWS-A43 also had high contamination levels with five types of bacteria present. Locations such as IEWS-A4, IEWS-A7, IEWS-A15, IEWS-A17, IEWS-A19, IEWS-A20, IEWS-A21, IEWS-A32, IEWS-A33, IEWS-A34, and IEWS-A38 showed the presence of only *E. coli*, indicating less diverse but still concerning fecal contamination. Sampling points IEWS-A27 and IEWS-A23 exhibited moderate contamination levels with the presence of *E. coli*, *Bacillus* spp. and *Salmonella* sp., with IEWS-A23 also having *S. aureus* and *Shigella* sp. The widespread presence of *E. coli* underscores the need for regular monitoring of water quality, improved water treatment, sanitation infrastructure, and public awareness to mitigate the health risks associated with using this water for drinking, recreational or agricultural purposes.

Cadmium levels were also detected in some samples, with the highest concentration found at IEWS-A21 (0.044 mg/L). Other notable cadmium levels include IEWS-A17 (0.034 mg/L), IEWS-A14 (0.032 mg/L) and IEWS-A41 (0.042 mg/L). These levels exceed typical environmental standards, indicating the potential health risks. Copper was consistently present across many sampling points, typically around 0.074 mg/L. The highest concentration was observed at IEWS-A18 (0.091 mg/L). Most other points, such as IEWS-A1, IEWS-A2 and IEWS-A3, had copper levels at 0.074 mg/L, indicating widespread contamination. Lead concentrations varied with the highest being 0.039 mg/L at IEWS-A29. Other points with detectable lead levels include IEWS-A10 (0.022 mg/L), IEWS-A47 (0.036 mg/L) and IEWS-A40 (0.033 mg/L). These concentrations are concerned due to the toxic nature of lead, even at low levels. Chromium was detected in fewer samples, with IEWS-A17 showing the highest concentration at 0.031 mg/L. Chromium presence, although limited, is significant due to its carcinogenic properties. Notably, arsenic, mercury, tin, and methylmercury were not detected in any of the samples (Table-1). This absence indicates that these particular heavy metals do not currently pose a contamination threat in Badshahpur lake (zone-1). The data indicate specific hotspots of contamination where intervention may be necessary. High microbial loads suggest possible sewage or organic pollution sources, which can lead to waterborne diseases. Elevated heavy metal concen-

TABLE-1
ASSESSMENT RESULTS OF MICROBIAL LOAD AND HEAVY METALS IN WATER SAMPLES OF DIFFERENT LOCATIONS OF BADSHAHPUR LAKE (ZONE-1)

Sampling point	Coordinates	Microbial load TBC	Heavy metals (mg/L)							
			Cd	Cu	Pb	Cr	As	Hg	Sn	MM*
IEWS-A1	28.442702, 76.975467	3.0×10^{8}	0.020	0.074	0.014	0.020	BQL	BQL	BQL	BQL
IEWS-A2	28.442594, 76.975798	6.5×10^{6}	BQL	0.072	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A3	28.442702, 76.975543	2.1×10^{7}	BQL	0.064	0.012	BQL	BQL	BQL	BQL	BQL
IEWS-A4	28.442637, 76.975745	6.2×10^{7}	0.017	0.083	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A5	28.442451, 76.976415	4.5×10^{6}	0.027	0.065	0.012	BQL	BQL	BQL	BQL	BQL
IEWS-A6	28.442402, 76.976935	5.8×10^{5}	0.018	0.051	0.019	BQL	BQL	BQL	BQL	BQL
IEWS-A7	28.442286, 76.977628	2.5×10^{4}	BQL	0.028	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A8	28.442278, 76.978022	1.1×10^{4}	0.016	0.043	0.021	BQL	BQL	BQL	BQL	BQL
IEWS-A9	28.442265, 76.977752	6.6×10^{8}	BQL	0.057	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A10	28.442262, 76.978214	7.1×10^{6}	0.020	0.066	0.022	BQL	BQL	BQL	BQL	BQL
IEWS-A11	28.442253, 76.977941	3.7×10^{9}	BQL	0.060	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A12	28.442344, 76.978218	1.4×10^{7}	0.026	0.063	0.017	BQL	BQL	BQL	BQL	BQL
IEWS-A13	28.442255, 76.978239	6.1×10^{6}	BQL	0.071	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A14	28.442346, 76.978553	3.5×10^{8}	0.032	0.072	0.016	BQL	BQL	BQL	BQL	BQL
IEWS-A15	28.442323, 76.978844	4.6×10^{7}	BQL	0.060	0.015	BQL	BQL	BQL	BQL	BQL
IEWS-A16	28.442349, 76.979213	7.7×10^{6}	0.016	0.065	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A17	28.442369, 76.979462	2.3×10^{9}	0.034	0.075	0.024	0.031	BQL	BQL	BQL	BQL
IEWS-A18	28.442470, 76.979663	4.4×10^{7}	BQL	0.091	0.022	BQL	BQL	BQL	BQL	BQL
IEWS-A19	28.442352, 76.979931	6.7×10^{8}	BQL	0.078	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A20	28.442256, 76.979989	3.6×10^{6}	0.026	0.083	0.015	BQL	BQL	BQL	BQL	BQL
IEWS-A21	28.442302, 76.980225	2.9×10^{5}	0.044	0.086	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A22	28.442281, 76.980372	5.8×10^{5}	BQL	0.072	0.013	BQL	BQL	BQL	BQL	BQL
IEWS-A23	28.442267, 76.980303	6.2×10^{7}	0.024	0.077	0.021	BQL	BQL	BQL	BQL	BQL
IEWS-A24	28.442171, 76.980404	3.1×10^{9}	BQL	0.069	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A25	28.442056, 76.980436	2.2×10^{4}	0.017	0.070	0.022	BQL	BQL	BQL	BQL	BQL
IEWS-A26	28.442224, 76.980716	5.3×10^{8}	0.022	0.074	0.016	BQL	BQL	BQL	BQL	BQL
IEWS-A27	28.442080, 76.980687	6.3×10^{6}	0.011	0.052	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A28	28.441939, 76.989654	5.5×10^{5}	BQL	0.074	0.024	BQL	BQL	BQL	BQL	BQL
IEWS-A29	28.441976, 76.980778	3.6×10^{8}	0.028	0.074	0.039	0.015	BQL	BQL	BQL	BQL
IEWS-A30	28.441986, 76.980950	4.3×10^{7}	0.018	0.065	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A31	28.441926, 76.981118	5.0×10^{4}	BQL	0.074	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A32	28.442089, 76.981296	2.5×10^{7}	0.028	0.065	0.022	BQL	BQL	BQL	BQL	BQL
IEWS-A33	28.442052, 76.981220	4.1×10^{8}	BQL	0.071	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A34	28.441979, 76.981221	3.0×10^{7}	0.020	0.074	0.026	BQL	BQL	BQL	BQL	BQL
IEWS-A35	28.442145, 76.981278	6.9×10^{5}	BQL	0.070	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A36	28.442054, 76.981322	1.2×10^{9}	0.033	0.072	0.023	BQL	BQL	BQL	BQL	BQL
IEWS-A37	28.441961, 76.981476	2.3×10^{6}	BQL	0.074	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A38	28.441941, 76.981443	4.5×10^{5}	0.018	0.073	0.014	BQL	BQL	BQL	BQL	BQL
IEWS-A39	28.441992, 76.981607	3.2×10^{7}	BQL	0.074	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A40	28.441895, 76.981531	8.4×10^{6}	0.023	0.074	0.033	BQL	BQL	BQL	BQL	BQL
IEWS-A41	28.441927, 76.981457	5.5×10^{4}	0.042	0.067	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A42	28.442020, 76.981612	7.4×10^{6}	BQL	0.074	0.014	BQL	BQL	BQL	BQL	BQL
IEWS-A43	28.441970, 76.981542	3.4×10^{8}	0.027	0.071	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A44	28.441969, 76.981626	5.2×10^{3}	BQL	0.074	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A45	28.441989, 76.981574	3.2×10^{6}	0.020	0.074	0.018	BQL	BQL	BQL	BQL	BQL
IEWS-A46	28.441991, 76.981621	5.1×10^{8}	BQL	0.065	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-A47	28.441908, 76.981593	4.0×10^{7}	0.018	0.074	0.036	BQL	BQL	BQL	BQL	BQL

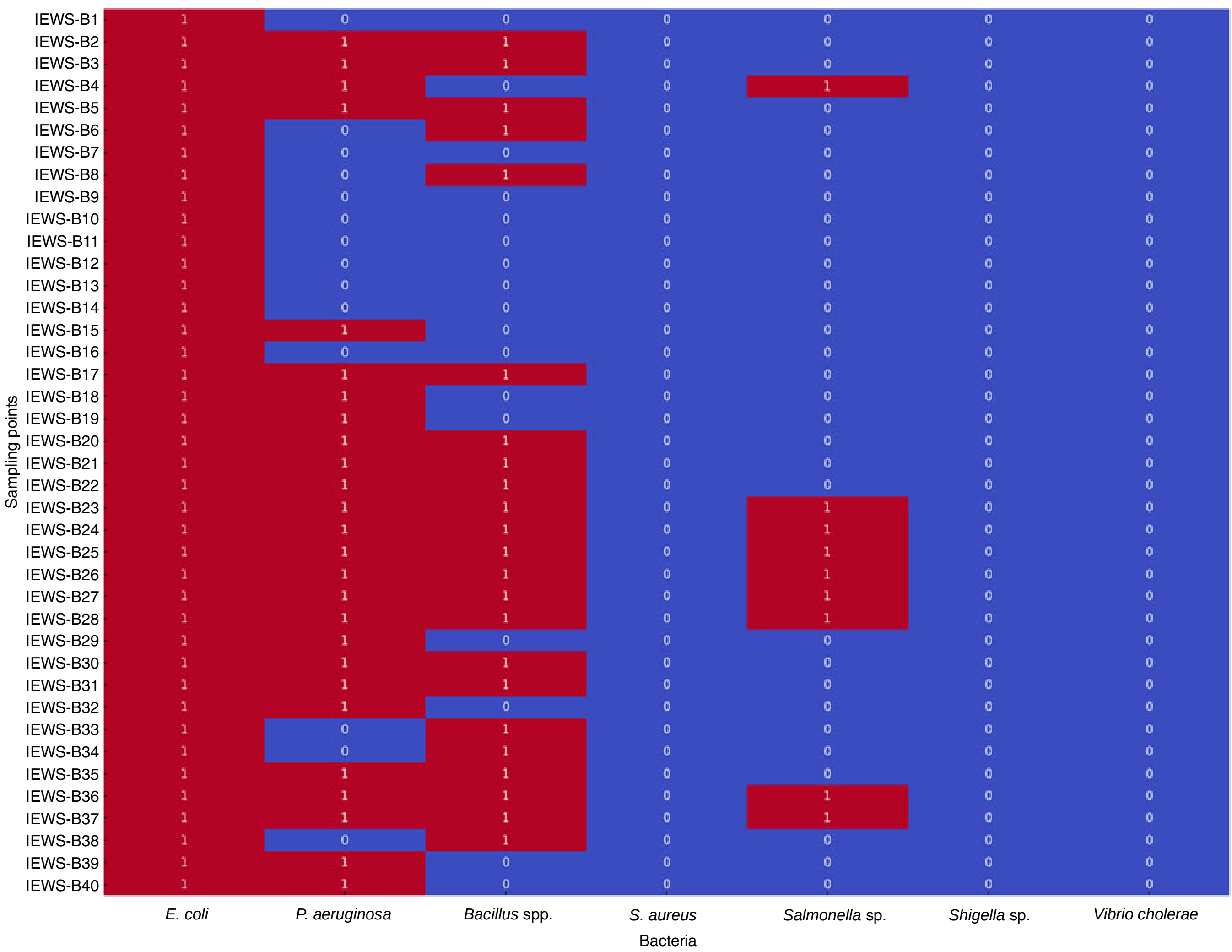
Quantification limit for Cd, Cu, Pb, Cr, Sn = 0.01 mg/L, for As and Hg = 0.005 mg/L and methyl mercury (MM)* = 0.005 mg/L; BQL-below quantification limit

trations, particularly cadmium, lead and copper, highlight the potential industrial or agricultural runoff that needs to be addressed to protect both human health and aquatic life.

Zone-2: The assessment of microbial load and heavy metals in water samples from various locations of Badshahpur lake of zone-2 reveals the significant variations in both microbial and heavy metal concentrations. The microbial load, expressed as TBC, ranged from 4.0×10^4 to 6.7×10^8 CFU/mL across different sampling points. The highest TBC was recorded at IEWS-B19 with 6.7×10^8 CFU/mL, indicating a substantial microbial presence. Conversely, the lowest TBC was found at IEWS-B25, with a count of 4.2×10^4 CFU/mL.

Fig. 2 shows the heatmap of distribution of specific bacteria in water samples from various locations of Badshahpur lake at zone-2 across the 40 sampling points. The results revealed that *E. coli* is present at all 40 sampling points, indicating pervasive fecal contamination throughout zone-2, which poses significant health risks due to potential gastrointestinal infections. *Bacillus* spp. were found in 23 of the 40 samples, showing their widespread presence and ability to survive in diverse environmental conditions. *P. aeruginosa* was detected in 25 samples, highlighting its prevalence and the associated risks due to its antibiotic resistance and potential to cause infections in immunocompromised individuals. *S. aureus* was found at four sampling points, less frequently than in zone-1, but still of concern given its potential to cause severe conditions when water is used for recreational purposes or food preparation. *Salmonella* sp. was detected at only one sampling point (IEWS-B4), indicating a lower risk of enteric diseases compared to zone-1.

Shigella sp. and *Vibrio cholerae* were not detected at any sampling points, suggesting a lower risk of dysentery and cholera in zone-2 during the sampling period. Notably, sampling points IEWS-B23, IEWS-B24, IEWS-B36, and IEWS-B37 showed the presence of four different bacteria, marking them as highly contaminated and posing significant health risks. Other points like IEWS-B2, IEWS-B3, IEWS-B5, IEWS-B17, IEWS-B20, IEWS-B21, IEWS-B22, IEWS-B25, IEWS-B26, IEWS-B27, IEWS-B28, and IEWS-B31 also exhibited high contamination levels with three types of bacteria present. Locations such as IEWS-B1, IEWS-B7, IEWS-B9, IEWS-B10, IEWS-B11, IEWS-B12, IEWS-B13, IEWS-B14, IEWS-B16, IEWS-B29,



	E. coli	*P. aeruginosa*	*Bacillus* spp.	*S. aureus*	*Salmonella* sp.	*Shigella* sp.	*Vibrio cholerae*
IEWS-B1	1	0	0	0	0	0	0
IEWS-B2	1	1	1	0	0	0	0
IEWS-B3	1	1	1	0	0	0	0
IEWS-B4	1	1	0	0	1	0	0
IEWS-B5	1	1	1	0	0	0	0
IEWS-B6	1	0	1	0	0	0	0
IEWS-B7	1	0	0	0	0	0	0
IEWS-B8	1	0	1	0	0	0	0
IEWS-B9	1	0	0	0	0	0	0
IEWS-B10	1	0	0	0	0	0	0
IEWS-B11	1	0	0	0	0	0	0
IEWS-B12	1	0	0	0	0	0	0
IEWS-B13	1	0	0	0	0	0	0
IEWS-B14	1	0	0	0	0	0	0
IEWS-B15	1	1	0	0	0	0	0
IEWS-B16	1	0	0	0	0	0	0
IEWS-B17	1	1	1	0	0	0	0
IEWS-B18	1	1	0	0	0	0	0
IEWS-B19	1	1	0	0	0	0	0
IEWS-B20	1	1	1	0	0	0	0
IEWS-B21	1	1	1	0	0	0	0
IEWS-B22	1	1	1	0	0	0	0
IEWS-B23	1	1	1	0	1	0	0
IEWS-B24	1	1	1	0	1	0	0
IEWS-B25	1	1	1	0	1	0	0
IEWS-B26	1	1	1	0	1	0	0
IEWS-B27	1	1	1	0	1	0	0
IEWS-B28	1	1	1	0	1	0	0
IEWS-B29	1	1	0	0	0	0	0
IEWS-B30	1	1	1	0	0	0	0
IEWS-B31	1	1	1	0	0	0	0
IEWS-B32	1	1	0	0	0	0	0
IEWS-B33	1	0	1	0	0	0	0
IEWS-B34	1	0	1	0	0	0	0
IEWS-B35	1	1	1	0	0	0	0
IEWS-B36	1	1	1	0	1	0	0
IEWS-B37	1	1	1	0	1	0	0
IEWS-B38	1	0	1	0	0	0	0
IEWS-B39	1	1	0	0	0	0	0
IEWS-B40	1	1	0	0	0	0	0

Fig. 2. Heatmap illustrating the distribution of specific bacteria in water samples from various locations of Badshahpur Lake (Zone-2) Y-axis: Sampling points (IEWS-A1 to IEWS-A47), X-axis: Bacteria types (*E. coli*, *P. aeruginosa*, *Bacillus* spp., *S. aureus*, *Salmonella* Sp., *Shigella* sp., *Vibrio Cholerae*) Color indication: Red color: Presence of bacteria; Blue color: Absence of bacteria

IEWS-B32, IEWS-B34 and IEWS-B39 showed the presence of only *E. coli*, indicating less diverse contamination but still significant fecal contamination. Sampling points IEWS-B30 exhibited moderate contamination levels with the presence of *E. coli*, *P. aeruginosa* and *Salmonella* sp. The widespread presence of *E. coli* underscores the need for regular monitoring of water quality, improved water treatment, sanitation infrastructure and public awareness to mitigate the health risks associated with using this water for drinking, recreational or agricultural purposes.

In terms of heavy metals, cadmium was detected in a few samples, with the highest concentration of 0.038 mg/L found at IEWS-B13. Copper was more consistently present, with concentrations ranging from 0.023 mg/L to 0.088 mg/L, the highest being at IEWS-B15 and IEWS-B25. Lead was detected at several points, with a maximum concentration of 0.036 mg/L at IEWS-B20, whereas chromium was found in fewer samples, with significant concentrations of 0.048 mg/L at IEWS-B9 and 0.038 mg/L at IEWS-B20. Arsenic, mercury, tin and methyl mercury were either undetected or present in negligible amounts across all sampling points (Table-2).

Zone 3: Zone-3 has a diverse range of microbiological and heavy metals concentrations as indicated from Table-3. The microbial load, quantified as TBC, varies significantly across different sampling points, with values ranging from 4.0×10^3 to 5.1×10^8 CFU/mL. The highest TBC was observed at IEWS-C33 with 5.1×10^8 CFU/mL, suggesting substantial microbial contamination, while the lowest TBC was recorded at IEWS-

TABLE-2
MICROBIAL RESULTS OF LOAD AND HEAVY METALS IN WATER SAMPLES OF DIFFERENT LOCATIONS OF BADSHAHPUR LAKE (ZONE-2)

Sampling point	Coordinates	Microbial load TBC	Heavy metals (mg/L)							
			Cd	Cu	Pb	Cr	As	Hg	Sn	MM*
IEWS-B1	28.441758, 76.981555	4.0×10^6	BQL	0.039	0.022	0.032	BQL	BQL	BQL	BQL
IEWS-B2	28.441755, 76.981563	5.5×10^5	0.017	0.071	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B3	28.441751, 76.981572	4.1×10^5	0.016	0.069	0.031	0.034	BQL	BQL	BQL	BQL
IEWS-B4	28.441744, 76.981584	5.2×10^5	BQL	0.066	0.020	BQL	BQL	BQL	BQL	BQL
IEWS-B5	28.441737, 76.981606	5.5×10^7	0.026	0.064	BQL	0.031	BQL	BQL	BQL	BQL
IEWS-B6	28.441734, 76.981630	4.8×10^5	BQL	0.068	0.022	BQL	BQL	BQL	BQL	BQL
IEWS-B7	28.441724, 76.981657	4.5×10^5	0.018	0.032	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B8	28.441718, 76.981678	5.1×10^4	BQL	0.039	0.014	BQL	BQL	BQL	BQL	BQL
IEWS-B9	28.441710, 76.981715	4.6×10^8	0.032	0.067	0.014	0.048	BQL	BQL	BQL	BQL
IEWS-B10	28.441706, 76.981737	4.1×10^6	0.015	0.081	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B11	28.441701, 76.981755	5.7×10^7	BQL	0.023	0.028	BQL	BQL	BQL	BQL	BQL
IEWS-B12	28.441693, 76.981788	5.4×10^8	0.016	0.058	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B13	28.441844, 76.981702	4.1×10^7	0.038	0.071	0.034	BQL	BQL	BQL	BQL	BQL
IEWS-B14	28.441828, 76.981718	6.5×10^6	BQL	0.074	BQL	0.020	BQL	BQL	BQL	BQL
IEWS-B15	28.441820, 76.981726	5.6×10^6	0.015	0.088	0.026	BQL	BQL	BQL	BQL	BQL
IEWS-B16	28.441809, 76.981738	4.7×10^6	0.016	0.074	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B17	28.441798, 76.981752	6.3×10^5	BQL	0.073	0.033	BQL	BQL	BQL	BQL	BQL
IEWS-B18	28.441782, 76.981767	6.4×10^7	0.028	0.081	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B19	28.441771, 76.981777	6.7×10^8	BQL	0.065	0.023	BQL	BQL	BQL	BQL	BQL
IEWS-B20	28.441796, 76.981665	4.6×10^6	0.022	0.076	0.036	BQL	BQL	BQL	BQL	BQL
IEWS-B21	28.441780, 76.981687	4.9×10^5	BQL	0.086	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B22	28.441754, 76.981749	4.8×10^5	0.022	0.069	0.026	BQL	BQL	BQL	BQL	BQL
IEWS-B23	28.441729, 76.981770	5.2×10^7	BQL	0.047	BQL	0.028	BQL	BQL	BQL	BQL
IEWS-B24	28.441720, 76.981804	4.1×10^6	0.019	0.064	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B25	28.441720, 76.981826	4.2×10^4	BQL	0.088	0.021	BQL	BQL	BQL	BQL	BQL
IEWS-B26	28.441708, 76.981851	5.3×10^8	0.025	0.076	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B27	28.441697, 76.981865	5.3×10^6	BQL	0.074	0.024	BQL	BQL	BQL	BQL	BQL
IEWS-B28	28.441686, 76.981885	5.5×10^5	0.024	0.072	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B29	28.441752, 76.981808	4.6×10^8	0.028	0.077	0.032	0.034	BQL	BQL	BQL	BQL
IEWS-B30	28.441713, 76.981810	3.3×10^7	BQL	0.079	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B31	28.441705, 76.981847	4.0×10^4	BQL	0.044	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B32	28.441693, 76.981818	5.5×10^7	0.022	0.065	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B33	28.441689, 76.981797	3.1×10^8	BQL	0.068	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B34	28.441691, 76.981835	3.2×10^7	0.019	0.042	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B35	28.441694, 76.981860	5.3×10^5	BQL	0.058	0.022	BQL	BQL	BQL	BQL	BQL
IEWS-B36	28.441677, 76.981859	4.2×10^7	0.016	0.053	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B37	28.441668, 76.981868	3.3×10^6	0.016	0.059	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B38	28.441687, 76.981870	3.5×10^5	BQL	0.064	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B39	28.441670, 76.981850	5.2×10^7	0.023	0.055	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-B40	28.441680, 76.981832	6.4×10^6	0.032	0.079	0.034	0.041	BQL	BQL	BQL	BQL

Quantification limit for Cd, Cu, Pb, Cr, Sn = 0.01 mg/L, for As and Hg = 0.005 mg/L and methyl mercury (MM)* = 0.005 mg/L; BQL-below quantification limit

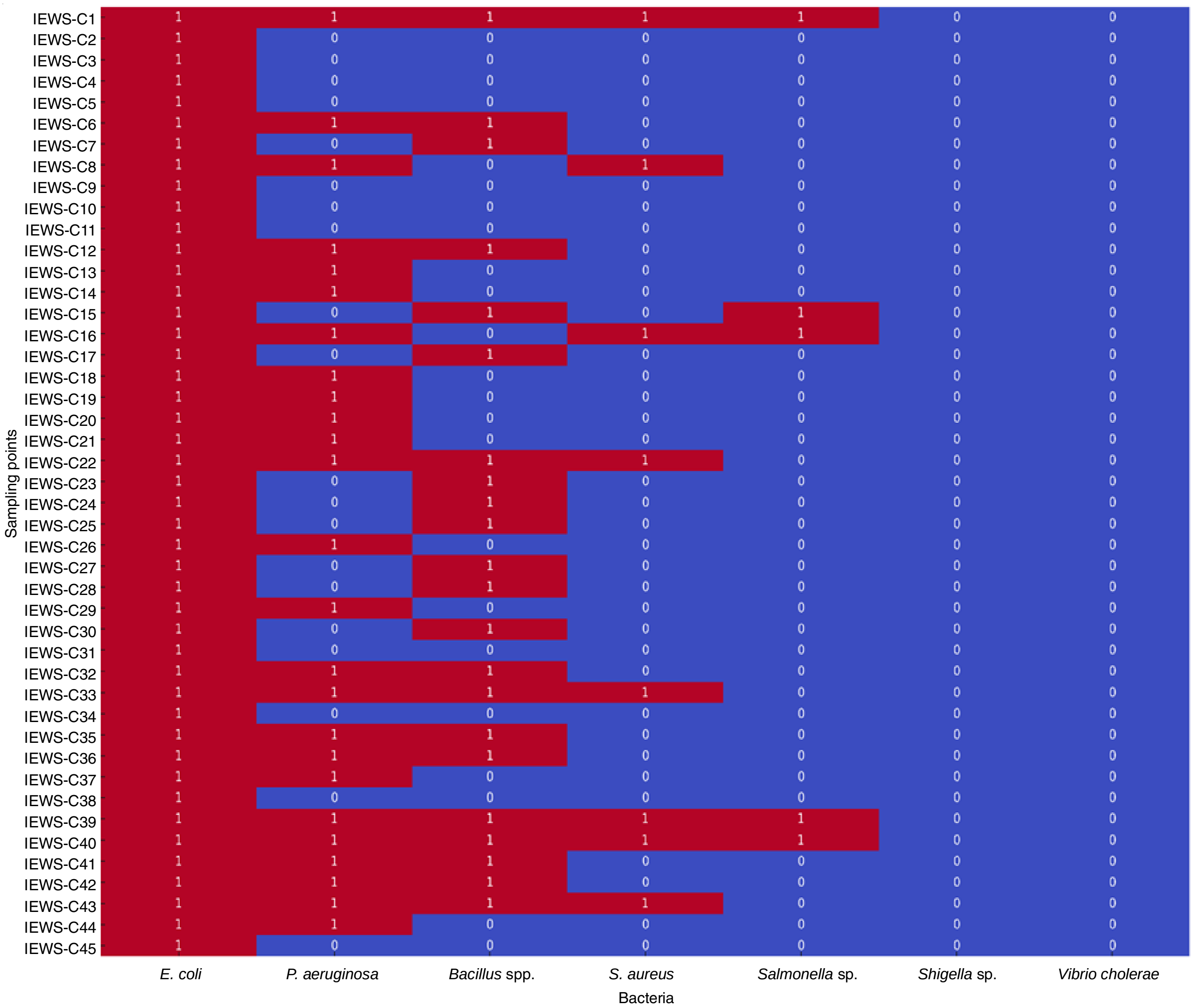
C31, with 4.0×10^3 CFU/mL. Regarding heavy metals, cadmium was detected at several points, with concentrations ranging from 0.015 mg/L to 0.046 mg/L. The highest cadmium concentration was found at IEWS-C25, whereas copper was consistently present in all the samples, with concentrations varying between 0.027 mg/L and 0.086 mg/L, highest at IEWS-C12. Lead was found in fewer samples, with concentrations up to 0.038 mg/L at IEWS-C34. Similarly, chromium was also detected at a concentration of 0.015 mg/L only at IEWS-C13. Arsenic, mercury, tin and methyl mercury were not detected in any of the samples, indicating their absence or presence in negligible amounts. Thus, the substantial microbial presence at certain points, alongside detectable levels of heavy metals such as cadmium, copper and lead, underlines the necessity for continued water quality monitoring and potential remediation measures to mitigate health risks and environmental impacts.

In zone-3 too, *E. coli* was present at all the sampling points, which highlights widespread fecal contamination, posing significant public health risks due to potential gastrointestinal infections, which can be anticipated from the heatmap of distribution of specific bacteria in water samples from various locations across the 40 sampling points (Fig. 3). *Bacillus* spp. were found

TABLE-3
ASSESSMENT RESULTS OF MICROBIAL LOAD AND HEAVY METALS IN WATER SAMPLES OF BADSHAHPUR LAKE (ZONE-3)

Sampling point	Coordinates	Microbial load TBC	Heavy metals (mg/L)							
			Cd	Cu	Pb	Cr	As	Hg	Sn	MM*
IEWS-C1	28.440497, 76.983683	2.0×10^6	0.015	0.071	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C2	28.440485, 76.983673	3.5×10^6	0.021	0.073	0.014	BQL	BQL	BQL	BQL	BQL
IEWS-C3	28.440457, 76.983673	3.1×10^7	BQL	0.068	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C4	28.440439, 76.983688	5.2×10^7	BQL	0.077	0.031	BQL	BQL	BQL	BQL	BQL
IEWS-C5	28.440431, 76.983700	6.5×10^4	0.018	0.065	0.021	BQL	BQL	BQL	BQL	BQL
IEWS-C6	28.440421, 76.983715	4.8×10^4	0.032	0.074	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C7	28.440449, 76.983749	5.5×10^6	0.021	0.027	0.023	BQL	BQL	BQL	BQL	BQL
IEWS-C8	28.440422, 76.983767	1.4×10^5	0.018	0.064	0.034	BQL	BQL	BQL	BQL	BQL
IEWS-C9	28.440398, 76.983766	4.6×10^5	0.025	0.063	0.021	BQL	BQL	BQL	BQL	BQL
IEWS-C10	28.440398, 76.983816	4.6×10^4	BQL	0.080	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C11	28.440383, 76.983840	5.7×10^6	BQL	0.079	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C12	28.440358, 76.983871	1.6×10^5	BQL	0.086	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C13	28.440329, 76.983858	4.1×10^7	0.019	0.079	0.031	BQL	BQL	BQL	BQL	BQL
IEWS-C14	28.440364, 76.983818	4.5×10^4	0.045	0.066	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C15	28.440362, 76.983865	5.6×10^6	0.036	0.069	0.032	BQL	BQL	BQL	BQL	BQL
IEWS-C16	28.440353, 76.983820	6.7×10^4	0.020	0.062	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C17	28.440363, 76.983870	6.3×10^5	BQL	0.074	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C18	28.440340, 76.983852	5.4×10^6	BQL	0.043	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C19	28.440355, 76.983882	5.7×10^6	0.016	0.072	0.034	BQL	BQL	BQL	BQL	BQL
IEWS-C20	28.440331, 76.983899	4.6×10^7	0.017	0.056	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C21	28.440305, 76.983910	3.9×10^6	0.015	0.055	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C22	28.440301, 76.983942	4.5×10^6	BQL	0.061	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C23	28.440296, 76.983977	5.2×10^8	0.018	0.075	0.023	0.028	BQL	BQL	BQL	BQL
IEWS-C24	28.440272, 76.983984	5.1×10^6	BQL	0.064	0.031	BQL	BQL	BQL	BQL	BQL
IEWS-C25	28.440257, 76.984031	3.2×10^4	0.046	0.055	0.011	BQL	BQL	BQL	BQL	BQL
IEWS-C26	28.440236, 76.984012	6.3×10^8	0.019	0.072	0.027	BQL	BQL	BQL	BQL	BQL
IEWS-C27	28.440237, 76.984056	4.3×10^7	0.021	0.075	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C28	28.440211, 76.984054	5.5×10^4	0.024	0.069	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C29	28.440201, 76.984082	6.6×10^4	0.016	0.058	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C30	28.440194, 76.984123	4.3×10^4	0.023	0.071	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C31	28.440167, 76.984145	4.0×10^3	BQL	0.078	0.011	0.022	BQL	BQL	BQL	BQL
IEWS-C32	28.440140, 76.984144	6.5×10^7	BQL	0.079	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C33	28.440141, 76.984199	5.1×10^8	BQL	0.071	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C34	28.440116, 76.984223	4.0×10^7	BQL	0.073	0.038	BQL	BQL	BQL	BQL	BQL
IEWS-C35	28.440097, 76.984219	4.9×10^6	0.023	0.056	0.027	BQL	BQL	BQL	BQL	BQL
IEWS-C36	28.440139, 76.984205	4.2×10^7	0.027	0.054	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C37	28.440126, 76.984177	4.3×10^6	0.016	0.065	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C38	28.440120, 76.984191	5.5×10^5	BQL	0.033	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C39	28.440131, 76.984205	2.2×10^7	0.023	0.056	0.035	0.021	BQL	BQL	BQL	BQL
IEWS-C40	28.440117, 76.984226	5.4×10^6	BQL	0.074	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C41	28.440094, 76.984206	6.5×10^4	0.015	0.079	0.034	BQL	BQL	BQL	BQL	BQL
IEWS-C42	28.440108, 76.984246	4.4×10^6	BQL	0.069	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C43	28.440088, 76.984233	5.4×10^6	BQL	0.064	0.011	BQL	BQL	BQL	BQL	BQL
IEWS-C44	28.440094, 76.984265	4.2×10^4	0.037	0.066	BQL	BQL	BQL	BQL	BQL	BQL
IEWS-C45	28.440066, 76.984237	5.2×10^5	0.023	0.068	BQL	BQL	BQL	BQL	BQL	BQL

Quantification limit for Cd, Cu, Pb, Cr, Sn = 0.01 mg/L, for As and Hg = 0.005 mg/L and methyl mercury (MM)* = 0.005 mg/L; BQL-below quantification limit



	E. coli	*P. aeruginosa*	*Bacillus* spp.	*S. aureus*	*Salmonella* sp.	*Shigella* sp.	*Vibrio cholerae*
IEWS-C1	1	1	1	1	1	0	0
IEWS-C2	1	0	0	0	0	0	0
IEWS-C3	1	0	0	0	0	0	0
IEWS-C4	1	0	0	0	0	0	0
IEWS-C5	1	0	0	0	0	0	0
IEWS-C6	1	1	1	0	0	0	0
IEWS-C7	1	0	1	0	0	0	0
IEWS-C8	1	1	0	1	0	0	0
IEWS-C9	1	0	0	0	0	0	0
IEWS-C10	1	0	0	0	0	0	0
IEWS-C11	1	0	0	0	0	0	0
IEWS-C12	1	1	1	0	0	0	0
IEWS-C13	1	1	0	0	0	0	0
IEWS-C14	1	1	0	0	0	0	0
IEWS-C15	1	0	1	0	1	0	0
IEWS-C16	1	1	0	1	1	0	0
IEWS-C17	1	0	1	0	0	0	0
IEWS-C18	1	1	0	0	0	0	0
IEWS-C19	1	1	0	0	0	0	0
IEWS-C20	1	1	0	0	0	0	0
IEWS-C21	1	1	0	0	0	0	0
IEWS-C22	1	1	1	1	0	0	0
IEWS-C23	1	0	1	0	0	0	0
IEWS-C24	1	0	1	0	0	0	0
IEWS-C25	1	0	1	0	0	0	0
IEWS-C26	1	1	0	0	0	0	0
IEWS-C27	1	0	1	0	0	0	0
IEWS-C28	1	0	1	0	0	0	0
IEWS-C29	1	1	0	0	0	0	0
IEWS-C30	1	0	1	0	0	0	0
IEWS-C31	1	0	0	0	0	0	0
IEWS-C32	1	1	1	0	0	0	0
IEWS-C33	1	1	1	1	0	0	0
IEWS-C34	1	0	0	0	0	0	0
IEWS-C35	1	1	1	0	0	0	0
IEWS-C36	1	1	1	0	0	0	0
IEWS-C37	1	1	0	0	0	0	0
IEWS-C38	1	0	0	0	0	0	0
IEWS-C39	1	1	1	1	1	0	0
IEWS-C40	1	1	1	1	1	0	0
IEWS-C41	1	1	1	0	0	0	0
IEWS-C42	1	1	1	0	0	0	0
IEWS-C43	1	1	1	1	0	0	0
IEWS-C44	1	1	0	0	0	0	0
IEWS-C45	1	0	0	0	0	0	0

Fig. 3. Heatmap illustrating the distribution of specific bacteria in water samples from various locations of Badshahpur Lake (Zone-3) Y-axis: Sampling points (IEWS-A1 to IEWS-A47), X-axis: Bacteria types (*E. coli*, *P. aeruginosa*, *Bacillus* spp., *S. aureus*, *Salmonella* Sp., *Shigella* sp., *Vibrio cholerae*) Color indication: Red color: Presence of bacteria; Blue color: Absence of bacteria

in 25 of the 45 samples, showing their resilience and ability to survive in various environmental conditions, though not all strains are harmful. *P. aeruginosa* was detected in 22 samples, indicating its substantial presence and associated health risks due to its antibiotic resistance and potential to cause infections, particularly in immunocompro-mised individuals. *S. aureus* was found at eight sampling points, suggesting lower contamination levels compared to zones 1 and 2, but still significant given its potential to cause severe conditions when water is used for the recreational activities or food preparation. *Salmonella* sp. was detected at only three sampling points (IEWS-C1, IEWS-C15, and IEWS-C40), indicating a lower risk of enteric diseases compared to the other zones.

Shigella sp. and *Vibrio cholerae* were not detected too at any sampling points, suggesting a lower risk of dysentery and cholera in zone-3 during the sampling period. Notably, sampling points IEWS-C1 and IEWS-C40 showed the presence of five different bacteria, marking them as highly contaminated and posing significant health risks. Other points like IEWS-C22, IEWS-C33 and IEWS-C39 also exhibited high contamination levels with 4 types of bacteria present. Locations such as IEWS-C2, IEWS-C3, IEWS-C4, IEWS-C5, IEWS-C9, IEWS-C10, IEWS-C11, IEWS-C23, IEWS-C24, IEWS-C25, IEWS-C27, IEWS-C28, IEWS-C30, IEWS-C31, IEWS-C34, IEWS-C38, IEWS-C45 showed the presence of only *E. coli*, indicating less diverse contamination but still significant fecal contamination. Sampling points IEWS-C6, IEWS-C8, IEWS-C12, IEWS-C13, IEWS-C14, IEWS-C18, IEWS-C19, IEWS-C20, IEWS-C21, IEWS-C26, IEWS-C29, IEWS-C32, IEWS-C35, IEWS-C36, IEWS-C37, IEWS-C41, IEWS-C42 and IEWS-C44 exhibited moderate contamination levels with the presence of *E. coli* and either *P. aeruginosa* or *Bacillus* spp.

The present study provides a comprehensive assessment of microbial and heavy metals contamination in water samples from Badshahpur lake across three zones, with significant findings that align with previous research. In zone 1, microbial loads ranged from 5.2×10^3 to 3.7×10^9 CFU/mL, with the highest recorded at IEWS-A11. The cadmium levels in this zone was at 0.044 mg/L and copper concentrations reached 0.091 mg/L. Lead and chromium were also detected with levels of 0.039 mg/L and 0.031 mg/L, respectively. These findings are consistent with the reported works [5,31] regarding the contamination of microbials in polluted water bodies.

In zone 2, TBC ranged from 4.0×10^4 to 6.7×10^8 CFU/mL, with notably high copper and cadmium concentrations of 0.088 mg/L and 0.038 mg/L, respectively. This pattern aligns with the observations of Selvam *et al*. [4], who reported the elevated heavy metals levels in industrially impacted water sources. Zone 3 exhibited TBC values from 4.0×10^3 to 5.1×10^8 CFU/mL, with the highest cadmium concentration of 0.046 mg/L and copper at 0.086 mg/L. The presence of *E. coli* across all zones underscores widespread fecal contamination, echoing concerns reported by Lejri *et al*. [12] and Oyetibo *et al*. [32], who found significant microbial contamination in similar environments.

The heavy metals concentrations observed in this study are consistent with previous research indicating industrial and agricultural impacts on water quality [33]. Tariq *et al*. [13] and Selvam *et al*. [4] highlighted the correlation between industrial activities and elevated levels of heavy metals such as cadmium and copper. The high cadmium and copper levels, particularly in zones 1 and 3, reflect broader patterns of contamination described in these studies. The high levels of fecal contamination and heavy metals in Badshahpur lake emphasize the urgent need for enhanced water quality management practices to protect public health and maintain ecosystem stability. To address the significant microbial and heavy metals contamination identified in Badshahpur lake, several mitigation strategies are essential. First, regular and comprehensive water quality monitoring should be established to promptly identify and address contamination hotspots. Enhanced water treatment technologies, such as advanced filtration and chemical treatments, should be implemented to remove heavy metals and pathogens. Additionally, improving sanitation infrastructure, including waste management systems and sewage treatment facilities, is crucial to prevent further fecal contamination. Public awareness and community engagement in maintaining clean water practices can also contribute to reducing pollution. By adopting these strategies, it is possible to mitigate health risks and protect the ecological balance of Badshahpur lake situated in Gurugram city of India.

Conclusion

The assessment of microbials and heavy metals contamination in water samples from Badshahpur lake in Gurugram city across three zones revealed significant variations, indicating diverse sources of pollution. High levels of total bacterial count (TBC) at specific sampling points highlight severe microbial contamination, posing considerable health risks. Detection of heavy metals such as cadmium, copper, lead and chromium highlights the need for addressing industrial and agricultural runoff to safeguard both human health and aquatic ecosystems. The pervasive presence of fecal indicator bacteria, particularly *E. coli*, suggests widespread fecal contamination, emphasizing the urgency for improved sanitation infrastructure and water treatment processes. The absence of certain pathogenic bacteria like *Shigella* sp. and *Vibrio cholerae* in zones 2 and 3 indicates a lower risk of specific waterborne diseases in these areas. This study highlights the critical importance of regular monitoring, targeted intervention strategies and community awareness programs to mitigate contamination risks and enhance water quality in Badshahpur Lake. Implementing these measures will not only protect public health but also contribute to the sustain-ability and resilience of the ecosystem surrounding the lake.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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