

Hydro-Geo-Chemistry, Phytodiversity and Microbial Population in the Inland Water Bodies of the Subtropical City

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ABSTRACT

Inland waters are a key component in nutrient recycling and primary productivity; however, it is experiencing stress due to urbanization and inadvertent inflow of sewage, altering their bio-geo-chemical composition. This study assessed the health of 19 inland water bodies in a subtropical city using an interdisciplinary bio-chemical approach. Physico-chemical variables, viz. TDS, EC, pH, alkalinity, total hardness, major cations (Ca^{2+} , Na^+ , K^+), and anions (HCO_3^- , Cl^- , PO_4^{3-} , SO_4^{2-}) exceeded the BIS-prescribed limit for surface water. Macrophyte

diversity serves as bioassay for assessing the cumulative impact of both known and unknown chemicals, while microbial diversity acts as an indicator of sewage discharge and pathogens. Abundance (%) of macrophytes was found in order of *Pistias tratiotes* (84.21%) > *Lemna minor* (78.94%) > *Azolla pinnata* (73.68%) > *Eichhornia crassipes* (73.68%) > *Marsilea quadrifolia* (52.63%) > *Ipomoea aquatica* (47.37%) > *Hydrilla verticillata* (31.57%), and reflects the state of eutrophication and ageing. The presence of *E. coli* indicates faecal contamination across all the water bodies. Water Quality Index revealed that 79% of water bodies were ‘unsuitable’ for drinking, while 16% and 5% were ‘poor’ and ‘very poor’, respectively. Findings underline the threat of human activities to these freshwater ecosystems and warrant revival and conservation efforts.

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INTRODUCTION

Water, a paramount natural resource, is experiencing an escalating demand for potable supply to fulfil the expanding requirements of humans (Caballero-Gini *et al.* 2021). Freshwater with a salt concentration of less than 0.1% is crucial for sustaining terrestrial biota, ecosystems, and human sustenance. Besides this, it

also plays a significant role in maintaining the Earth's temperature and functioning of diverse ecosystems (Zhu *et al.* 2023, Caballero-Gini *et al.* 2021). It is noteworthy that a substantial two-thirds of this freshwater is sequestered in polar ice cover and glaciers, leaving a mere 0.77% distributed among various sources such as lakes, wetlands, rivers, groundwater, biota, soil, and the atmosphere (Downing *et al.* 2006).

Inland water bodies like lakes and ponds, classified as lentic systems, represent small but diverse freshwater habitats, offering essential resources to a broad spectrum of terrestrial and aquatic organisms (Rutter *et al.* 2022). Further, they also support water supply, flood prevention, aquaculture, tourism, biodiversity, nutrient recycling and other ecological requirements (Lynch *et al.* 2023). Despite their widespread distribution and significance for various species, including humans, these environments account for just over 3% of the Earth's total surface area. Recent evidence suggests that freshwater ecosystems confront greater threats compared to marine and terrestrial systems (Wu *et al.* 2022, Grasel *et al.* 2021). Water quality and biodiversity within these inland water environments are facing incremental threats from human activities, including habitat destruction, eutrophication, acidification, chemical pollution (Rutter *et al.* 2022). Another challenging aspect involves the introduction of non-indigenous species, including pathogens, plants, and animals, into freshwater ecosystems (Bried and Jog 2022, Wu *et al.* 2022).

Therefore, health assessment of inland water resources is of practical significance to ascertain their suitability for various purposes such as domestic consumption, recreation, agriculture, aquaculture, and ecosystem services (Iqbal *et al.* 2019). Further, it is also required to keep an eye on pollution status especially eutrophication and to protect the water quality and safety (Kaphle *et al.* 2025). Water quality indicators play a pivotal role in predicting changes in water resources over different times and locations, either degradation or restoration (Downing *et al.* 2006, Dubey *et al.* 2016). Physical, chemical, and biological factors are reliable in evaluating the surface water quality of a specific region or particular water source. Water quality index (WQI) has emerged as the most

effective method for characterizing the suitability of water sources for human consumption (Iqbal *et al.* 2019). While WQIs are based on a specific set of variables, they inherently involve some level of subjectivity. Further, indices using statistical methodologies help identify the most distinctive signs of the water body under investigation (Iqbal *et al.* 2019, Tripathi and Singal 2019).

Macrophytes grow naturally in water bodies and play a vital role in assessing the ecological conditions (Alahuhta *et al.* 2021, Haroon 2022). They are recognized for their impact on microclimate and biogeochemical processes in lentic water bodies' littoral areas, as well as sediment dynamics in freshwater systems (Galal and Farahat 2015, Hossain *et al.* 2017, Haroon 2022). Growth, distribution, and health of aquatic macrophytes are directly influenced by water quality and can be considered an outcome of both known and unknown chemicals. Overgrowth is attributed to nutrient enrichment and can lead to oxygen depletion in the water column, potentially causing mortality of fishes and other aquatic organisms (Galal and Farahat 2015, Hossain *et al.* 2017, Haroon 2022).

Microorganisms are ubiquitous on Earth, thriving in diverse environments that support life (Aryal *et al.* 2015). These habitats include familiar entities like soil, water, animals, and plants, extending to various human-made structures. The presence of a substantial microorganism population in a water body often indicates elevated nutrient levels (Aryal *et al.* 2015, Kim and Lee 2023). Water bodies receiving inputs from sewage systems or biodegradable industrial waste discharge typically exhibit higher bacterial counts (Aryal *et al.* 2015, Pandey *et al.* 2014). In aquatic settings with limited nutrient concentrations, microorganisms tend to proliferate on stationary surfaces and adhere to particulate matter (Aryal *et al.* 2015). This growth pattern enhances their access to nutrients compared to random suspension and drifting with water currents (Beck *et al.* 2017, Pandey *et al.* 2014). Aquatic environments display significant variability in resources and conditions affecting microbial growth (Aryal *et al.* 2015, Kim and Lee 2023). Within aquatic ecosystems, the coexistence of oxygen-producing and oxygen-consuming organisms is governed by the

equilibrium between photosynthesis and respiration (Kim and Lee 2023).

Lucknow has a warm subtropical climate with cool, dry winters from December to February and dry, hot summers from April to June. The rainy season is from mid-June to mid-September, when Lucknow gets an average rainfall of 1010 mm (40 in) mainly from the south-west monsoon winds. It spreads over 2528 square kilometers, housing a population of 2.8 million (2011 census). It is the eleventh most populous city and the twelfth-most populous urban agglomeration of India. The region is undergoing significant environmental transformations due to rapid urbanization and industrialization, posing challenges in land use, water management, housing, transportation, and healthcare.

The primary objective of this study was to assess the health of inland water bodies, such as ponds, lakes, and wetlands, in a sub-tropical city, Lucknow, by

adopting an integrated approach of bio-geo-chemical investigations.

MATERIALS AND METHODS

Site description

Lucknow is situated between 26.83° N and 80.92° E in the northern hemisphere. It is located in the Ganga-alluvial plane on the bank of the River Gomti. It consists of three distinct regional geomorphic surfaces, i.e. the active floodplain, river valley, and the upland terrace surface. Within each of these geomorphic surfaces, various micro-geomorphic features are present, including ponds, lakes, meander scars, paleo-channels, and ox-bow lakes.

Sampling locations

A total of nineteen (19) inland water bodies (S1 to S19, Table 1) were systematically selected from dis-

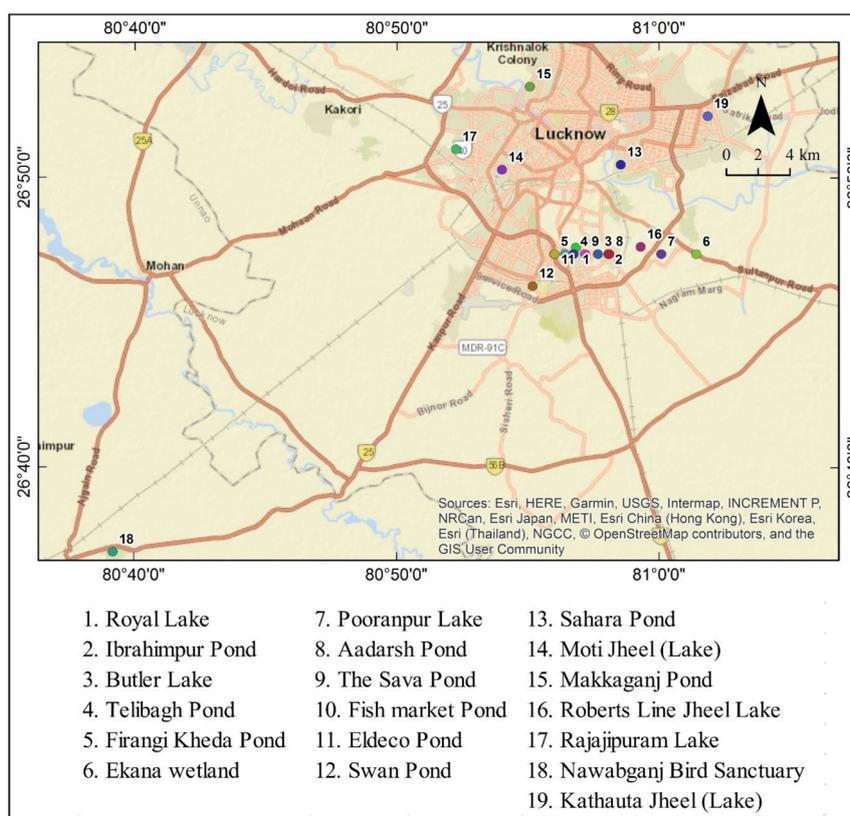


Fig. 1. Geographical map of Lucknow depicting sampling sites.

Table 1. Description of sampling locations, along with their corresponding geo-coordinates.

Sl. No.	Sample code	Sampling location	Site name	Latitude	Longitude
1	S1 (P)	Royal lake view apartment	Royal lake	26°47'36.1"	80°56'49.4"
2	S2 (P)	Ibrahimpur	Ibrahimpur pond	26°47'22.4"	80°58'04.1"
3	S3 (L)	Butler colony	Butler lake	26°47'22.4"	80°57'40"
4	S4 (P)	Telibagh road	Telibagh pond	26°47'22.4"	80°56'44.7"
5	S5 (P)	Firangi kheda road	Firangi Kheda pond	26°47'22.4"	80°56'00.1"
6	S6 (W)	Ekana stadium	Ekana wetland	26°47'22.4"	81°01'24.8"
7	S7 (L)	Pooranpur village	Pooranpur lake	26°47'22.4"	81°00'04.8"
8	S8 (P)	Ibrahimpur Marg	Aadarsh pond	26°47'22.4"	80°58'05.9"
9	S9 (L)	Rajeev Nagar, Nilmatha	The Sava pond	26°47'22.4"	80°57'10.5"
10	S10 (P)	The Old Lucknow (Restaurant)Telibagh	Fish market pond	26°47'22.4"	80°56'24.9"
11	S11 (P)	Durgapuri colony	Eldeco pond	26°47'22.4"	80°56'00.6"
12	S12 (P)	BBAU University	Swan pond	26°46'16.05"	80°55'10.76"
13	S13(L)	Sahara City, Gomti Nagar	Sahara pond	26°50'27.7"	80°58'31.93"
14	S14 (L)	Near Moti Colony, Aishbagh	Moti Jheel (lake)	26°50'17.07"	80°54'00.59"
15	S15 (P)	Makkaganj, near pakkapul banda Rd	Makkaganj pond	26°53'09.18"	80°55'03.94"
16	S16 (L)	Robert's line	Roberts Line Jheel (lake)	26°47'37.46"	80°59'17.87"
17	S17 (L)	Rajaji Puram	Rajajipuram lake	26°50'59.37"	80°52'15.22"
18	S18 (W)	Unnao District, Ravanhar village	Nawabganj bird sanctuary	26°37'04.68"	80°39'11.74"
19	S19 (L)	Vikapl khand, Gomti Nagar	Kathauta Jheel (lake)	26°52'10.51"	80°01'45.55"

Where, L= Lake, P= Pond, W= Watershed

tinct locations across Lucknow city, ensuring their designation as permanent water intake points (Fig. 1). Water specimens were collected by utilizing sterile 1000 ml pre-washed polyethylene containers.

Physiochemical parameters

For physicochemical analysis, water samples were collected using specialized sampling kits and then conveyed to the laboratory situated at the Department of Environmental Science, BBA University, Lucknow. These samples were stored at a temperature of 4°C for analysis. The physico-chemical characteristics such as pH, EC, turbidity, alkalinity, CO_3^- , HCO_3^- , TDS, Total hardness, NO_3^- , Cl^- , Na^+ , K^+ , Ca^+ , PO_4^{3-} , SO_4^{2-} were examined in water samples based on the established standard methods for the examination of water and waste water (APHA 2005).

Water quality index (WQI)

Water quality index was calculated using the methods of the Canadian Council of Ministers of the Environment (CCM 2001). The following formula was used to compute unit weight (W_i) for various parameters in the first stage (Lumb *et al.* 2011).

$$W = K \epsilon (1/S_n);$$

$$\text{Where, } K = 1/\sum (1/S_1 + 1/S_2 + S_3 + \dots + 1/S_n)$$

The quality rating scale (Q_i) for each parameter was calculated in the second stage using the equation:

$$Q_i = \{(Q_{\text{act}} - Q_{\text{ideal}}) / (\text{Std} - Q_{\text{ideal}})\} * 100$$

Except for DO and pH, the value of Q_{ideal} is zero, as it is the value of that parameter in pure water. The value of Q_{ideal} for pH is 7.0, whereas the value for Do is 14.0.

WQI was determined using the following formula after calculating the weight of the parameter and the quality rating scale:

$$WWQ = \sum_{i=0}^{i=n} WQ/\sum W_i$$

W_i is the unit weight of each water quality parameter, K denotes the proportionality constant, and Q_i denotes the quality rating scale for each parameter. The fact is the estimated concentration of the i^{th} parameter in the analyzed water. Q_{ideal} = Parameter value in pure water, Standard = Parameter standard value, n = Number of water quality parameters.

Aquatic macrophytes

Various aquatic macrophytes growing naturally in the water bodies were gathered from various sampling locations and subsequently transported to the laboratory for identification and further investigations.

Microbial diversity in water samples

The estimation of microbial diversity in water samples was conducted using the Nutrient agar (NA) and Eosin Methylene Blue (EMB) methods (Bai *et al.* 2022, Garrido *et al.* 2017).

The Colony Forming Unit (CFU) is a measure of viable colonize cell numbers in CFU/ml with the help of serial dilution. These are an indication of the number of cells that remain viable enough to proliferate and form small colonies (Bai *et al.* 2022, Houchmandzadeh and Ballet 2023).

$$\text{CFU/ml} = (\text{No. of colonies} \times \text{Total dilution factor}) / \text{Volume of culture plated in ml}$$

Statistical analysis

All the samples were replicated across randomly selected sample sites, each with three determinations ($n=3$). Results were analyzed using one-way ANOVA (SPSS statistical package and MS excel) at $p < 0.05$.

RESULTS AND DISCUSSION

Physico-chemical characteristics

The physico-chemical health of selected water bodies is listed in Table 2. The pH of the analyzed surface water samples ranged from 7.41 to 9.20, with an average of 8.27, indicating the alkaline nature of water bodies. It has been found that 11 (54%) of the sampling sites exceeded the permissible limit. Notably, a pH range of 6.0-9.0 is considered suitable for fish culture, but it is not ideal for ensuring water quality for drinking and irrigation purposes (Hameed-Ur-Rehman *et al.* 2015).

Electrical Conductivity (EC) is the ability to carry current and is governed by the concentration of ions, their mobility, valence state and temperature. EC

ranged from 1030 $\mu\text{S/cm}$ (S3) to 9290 $\mu\text{S/cm}$ (S2), with an average of 4111 $\mu\text{S/cm}$ (Table 2). Factors such as temperature increase can contribute to higher EC values due to enhanced evaporation and concentration of dissolved solids (Walton 1989).

Total Dissolved Solids (TDS), representing the cumulative total of all mineral components dissolved in water, ranged from 580 to 7760, with an average of 3572.63 mg L^{-1} (Table 2). All 19 samples exceeded the desirable drinking water limit of 500 mg/l of IS: 2296, with carbonate, salt and agricultural runoff identified as contributing sources. Higher TDS increases the color and temperature of water and adversely affects the rate of photosynthesis, resulting in impaired DO levels (Diwan 2025).

Total Hardness (TH) is influenced by the presence of bicarbonates, sulfates, chlorides, and nitrates (Haritash *et al.* 2008). TH varied between 96 and 448, with an average of 275.58 mg L^{-1} , exhibiting a soft to very hard water range (Table 2). 73.68% of water samples exceeded the maximum desirable limit (200 mg L^{-1}) of IS:10500.

In the studied water bodies, five samples exceeded the permissible limits, while 14 samples were found to be within the permissible limits (Table 2). The minimum, maximum, and average alkalinity in all the collected surface water samples were found to be 16.67, 736.00, and 208.31, respectively. Natural degradation of living organisms and organic wastes contributes to the release of carbonates and bicarbonates, besides industrial discharge, causing alkaline conditions (Sudarshan *et al.* 2019).

Bicarbonate and carbonates in the studied samples ranged from 4 to 608 mg L^{-1} and from 9.60 to 38.40 mg L^{-1} , with average of 179.53 mg L^{-1} and 30.82 mg L^{-1} , respectively. Bicarbonates are generated through the release of carbon dioxide from the soil zone and the subsequent dissolution of carbon minerals, as well as the reaction of silicates with carbonic acid (Neha *et al.* 2017, Kumar *et al.* 2022).

Water is categorized as turbid when the suspended particles become visibly noticeable (Yang *et al.* 2014). Turbidity ranged from 9.54 to 37.53, with an

Table 2. Physico-chemical characteristics of inland water samples of Lucknow at selected sites.

Sl. No.	Sample code	pH	EC	Turbidity	Alkalinity	CO ₃ ²⁻	HCO ₃ ⁻	TDS	Total hardness	NO ₃ ⁻
	BIS Standard 2012 (Desirable)	6.50-8.50	2000	1	200	30	200	500	200	45
	BIS Standard 2012 (Permissible)	8.50	NX	5	600	400	600	2000	600	NX
	WHO guidelines, 2006	<8.0	NS	NS	NS	<400	200	1000	<500	45
1	S1 (P)	7.79 ±0.5	8780±352	19.3±0.8	200±11	211.2±18	152± 9	4480±148	384±23	2720±217
2.	S2 (P)	7.59±0.3	9290±387	20.12±0.7	36±2.1	19.2±0.8	4±0.14	4790±121	324±27	980±71
3	S3 (L)	7.81±0.1	1030±36	9.54±0.4	64±3.4	28.8±1.7	16± 0.31	5060±178	224±13	920±67
4	S4 (P)	7.73±0.5	1150±45	16.75±0.6	116±4.7	24±1.5	76± 3.8	5700±203	420±29	2780±224
5	S5 (P)	7.65±0.2	1470±61	22.5±1	144±4.8	34±1.7	144±6.5	7760±325	448±27	2158±193
6	S6 (W)	7.41±0.3	1160±47	19.17±0.8	96±2.3	30±1.7	96±5.2	6020±301	336±21	2400±174
7	S7 (L)	8.74±0.4	3060±103	17.8±0.6	40±1.1	19.2±1.1	8±0.23	1810±101	124±5	6580±384
8	S8 (P)	7.99±0.1	5860±280	15.45±0.7	68±2.3	14.4 ± 0.8	44±2.8	2920±211	264±17	4600±347
9	S9 (L)	8.15±0.08	2520±96	15.45±0.8	32±1.2	19.6 ±1.4	16±0.45	1280±92	96±7	1400±54
10	S10 (P)	8.22±0.5	7460±298	25.43±2.1	64±2.1	25±1.8	64±.7	4450±238	296±15	3560±217
11	S11 (P)	8.29±0.7	1030±43	37.53±1.8	92±4.7	14.4±0.7	68±2.6	5230±219	232±18	3640±231
12	S12 (P)	8.36±0.2	7980±277	15.45±0.6	20±0.9	21±1.1	20±0.71	3950±217	100±7	1940±
13	S13(L)	8.50±0.4	8170±391	13.25±0.2	432±24	48±2.3	352±26.5	4160±195	300±18	380±22
14	S14 (L)	8.57±0.5	5470±179	19.80±0.8	372±22	33.6 ± 1.7	316±20.8	2740±183	260±13	2500±158
15	S15 (P)	8.64±0.3	1230±64	35.00±2.3	736±51	38.4 ±2.3	672±42	630±41	400±27	4320±275
16	S16 (L)	8.71±0.7	6270±182	18.54±0.5	420±27	43.2 ±2.1	348±27	3220±167	280±21	2060±119
17	S17 (L)	8.78±0.6	1150±49	15.5±0.6	640±41	19.20±0.8	608±47	580±24	400±23	800±47
18	S18 (W)	8.92±0.4	2550±103	16.75±0.7	180±13	33.6 ± 1.8	124±7.8	1900±118	180±11	1760±87
19	S19 (L)	9.20±0.6	2480±114	14.00±0.3	176±12	28.8 ± 1.8	13±0.74	1200±75	168±10	2080±106
	Min	7.41±0.3	1030±43	9.54±0.4	20±0.9	14.4 ± 0.7	4.0±0.14	580 ±24	96 ± 7	380±22
	Max	9.20±0.6	9290±387	37.53±1.8	736±51	211.2±18	672±42	7760±325	448±27	6580±384
	Average	8.27±0.5	4111±175	19.33±0.7	206.7±14	30.82±1.9	165.3±9	3572.6±169	275.6±16.4	3526.32±182

Where, concentration in mg L⁻¹ except for pH, EC (µS/cm) and PO₄³⁻ in µg mL⁻¹, Turbidity (NTU), Results are expressed as mean of triplicates (i.e. n=3) ± SD, NS- Not specified, NX- No relaxation.

average of 19.33 NTU. Higher turbidity adversely affects the dissolved oxygen budget and photosynthesis due to interference with the light transmission (Kjelland *et al.* 2015).

Nitrate levels in the collected samples ranged from 380 to 6580, with an average of 3526.32 mg L⁻¹ (Table 2). A major factor responsible for nitrate contamination was probably agricultural runoff. Soil characteristics and precipitation levels may also be held responsible for nitrate levels in water sources (Picetti *et al.* 2022, Hosseini *et al.* 2023).

Major ion chemistry

Cations, viz. sodium (Na⁺), potassium (K⁺) and calcium (Ca²⁺) are naturally occurring elements in water due to environmental processes and are

typically harmless, but elevated levels can pose potential health risks (Ubuoh *et al.* 2024, Kumar *et al.* 2024). Results (Fig. 2) revealed that 14 out of the 19 samples had sodium levels below the permissible limit of 12-102 mg L⁻¹ defined by WHO (2011). The minimum, maximum, and average concentrations of Na⁺ in the samples were noted as 19.00, 91.00, and 46.92 mg L⁻¹, respectively. Agricultural runoff containing fertilizer residues may be held responsible for higher sodium levels. Potassium constitutes 2.4% by mass in the Earth's crust and is the 7th most abundant element. Potassium (K⁺) levels exceeded the permissible limits in all 19 samples, with concentrations ranging from 46.00 to 65.00 mg L⁻¹ (average 56.00 mg L⁻¹), surpassing the recommended level of 8 mg L⁻¹. Calcium is naturally found in waters at lower concentrations, but wastewater and municipal discharge increase its concentration in surface water

(Grochowska *et al.* 2024). Calcium concentrations exceeded the permissible limit of 80.10 mg L^{-1} in 9 out of the 19 samples, with values ranging from 20.18 to 122.79 mg L^{-1} , with an average of 67.38 mg L^{-1} . Higher calcium levels adversely affect the uptake of metal ions across the gills in fish, thereby increasing the dissolved concentration of metals and causing toxicity (Beto 2015, Sudarshan *et al.* 2019).

Concentrations of major anions, viz., chloride, bicarbonate, phosphate, and sulphate, were also analyzed in selected water bodies. Chloride is naturally present in water sources; however, its occurrence can also be linked to other factors such as dissolution of deposits and discharge of effluents from chemical industries (Yadav *et al.* 2023). Chloride concentration exceeded the WHO (2011) acceptable limit of 250 mg

L^{-1} in 11 out of 19 samples, ranging from 39.00 to 870.00 mg L^{-1} (average 280.14 mg L^{-1}). In the presence of amines chlorides can be transformed to chloramines, posing toxic effects to fish, amphibians, and reptiles (Pasternak *et al.* 2003, Edwards *et al.* 2024).

Bicarbonates can be formed through the dissolution of carbonates and silicate minerals, facilitated by the carbonic acid produced during specific chemical reactions. Bicarbonate levels were within the permissible limit (600 mg L^{-1}) prescribed by BIS (2012) in all the samples, with concentrations ranging from 0.00 to 819.84 mg L^{-1} (average 169.49 mg L^{-1}). Bicarbonates are responsible for raising the pH of the water bodies, resulting in alteration of natural ion chemistry.

The concentration of phosphate ranged between

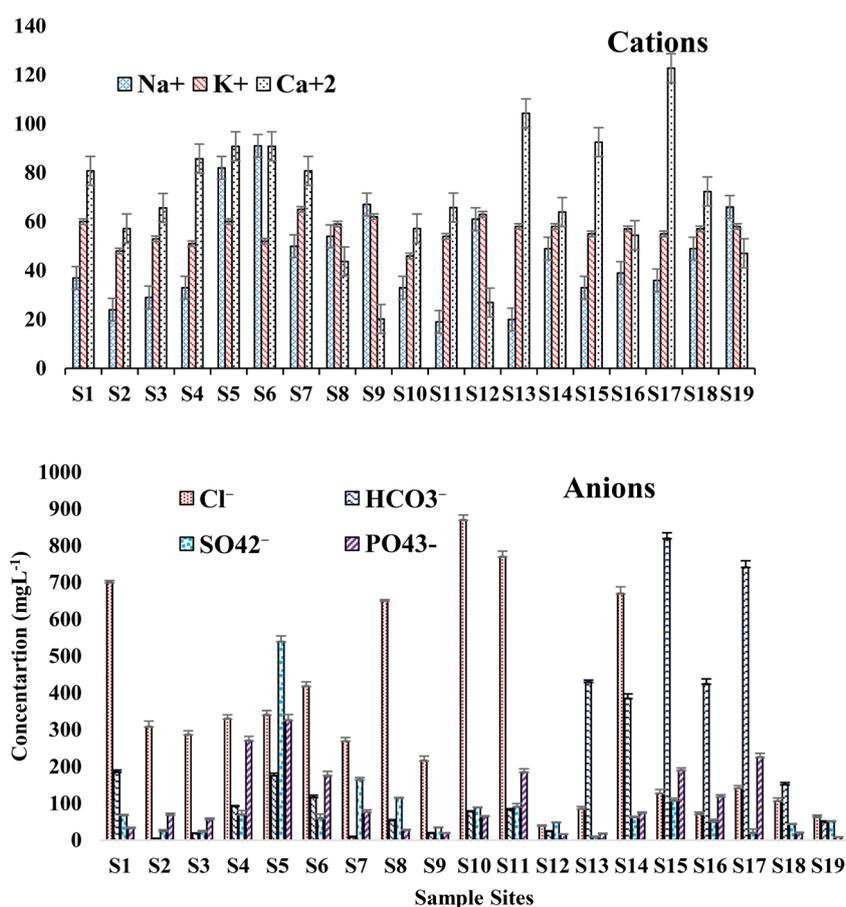


Fig. 2. Levels of major cations (Na^+ , K^+ , Ca^{2+}) and anions (Cl^- , HCO_3^- , PO_4^{3-} and SO_4^{2-}) in selected inland water bodies.

Table 3. Summary of water quality index (WQI) of inland water bodies of Lucknow.

Sl. No.	Sampling site	WQI value	Rating	Grading
1	S1	153.131	Unsuitable for drinking	E
2	S2	249.446	Unsuitable for drinking	E
3	S3	137.274	Unsuitable for drinking	E
4	S4	147.649	Unsuitable for drinking	E
5	S5	133.303	Unsuitable for drinking	E
6	S6	146.758	Unsuitable for drinking	E
7	S7	112.673	Unsuitable for drinking	E
8	S8	141.231	Unsuitable for drinking	E
9	S9	63.43	Poor water quality	C
10	S10	75.62	Very poor water quality	D
11	S11	132.131	Unsuitable for drinking	E
12	S12	125.992	Unsuitable for drinking	E
13	S13	147.807	Unsuitable for drinking	E
14	S14	72.255	Poor water quality	C
15	S15	103.86	Unsuitable for drinking	E
16	S16	116.433	Unsuitable for drinking	E
17	S17	92.642	Poor water quality	C
18	S18	100.47	Unsuitable for drinking	E
19	S19	102.711	Unsuitable for drinking	E

8.58 and 326.20 mg L⁻¹ with an average of 92.86 mg L⁻¹. Phosphorus enrichment of water can boost the growth of algae and macrophytes, which can diminish the dissolved oxygen concentration, resulting in

eutrophication (Yadav *et al.* 2023). Sulphate is found in natural waters through dissolution of sulphate and oxidation of sulphide minerals, besides precipitation (Nag and Suchetana 2016, Khan *et al.* 2020). Whereas, manmade sources include discharges from smelters, paper and pulp mills and textile industries (Khan *et al.* 2020, Yadav *et al.* 2023). The concentration of sulphate ranged from 20.00 to 539.50 mg L⁻¹ with an average of 39.39 mg L⁻¹. At higher levels sulphate interferes with the salinity and hardness of water (Nag and Suchetana 2016).

Water quality index (WQI)

The initial step to determine the WQI involves employing a weighted arithmetic index that assigns unit weight to each parameter. WQI plays a crucial role in synthesizing diverse and reliable analytical values to evaluate and categorize water quality (Finotti *et al.* 2015, Kumar *et al.* 2023). WQI score can be interpreted as follows: 0-25: Excellent, 26-50, Good; 51-75: Poor; 76-100: Very Poor, >100: Unsuitable (Chowdhury *et al.* 2012). WQI inferred that water quality at 15 out of 19 sites was unsuitable for drinking purposes (WQI>100), poor at three sites (WQI - 51-75), and

Table 4. Summary of the microbial diversity elucidated on EMB and NA media.

Sampling code	D/F type of diversity	CFU/ml			No. of coliform	CFU/ml 10 ⁵	Type of diversity
		10 ⁵	10 ⁶	10 ⁷			
		Eosin Methylene blue			Nutrient agar		
S1	21.00	21	2.1	0.21	18	1.45	5
S2	25.00	25	2.5	0.25	25	5.78	10
S3	15.00	15	1.5	0.15	10	2	3
S4	18.00	18	1.8	0.18	14	7.35	8
S5	26.00	26	2.6	0.26	22	2	5
S6	8.00	8	0.8	0.08	13	4.76	4
S7	12.00	12	1.2	0.12	33	6.98	3
S8	17.00	17	1.7	0.17	4	3.76	7
S9	10.00	10	1	0.10	5	0.01	1
S10	20.00	20	2	0.02	17	0.45	2
S11	13.00	13	1.3	0.13	37	8.20	11
S12	2.00	2	0.20	0.02	2	0.03	2
S13	5.00	5	0.50	0.05	3	15.72	12
S14	6.00	6	0.60	0.06	19	10.62	9
S15	11.00	11	1.1	0.11	26	8.11	8
S16	8.00	8	0.80	0.08	40	6.27	4
S17	6.00	6	0.60	0.06	5	7.65	4
S18	8.00	8	0.80	0.08	12	1.24	13
S19	4.00	4	0.40	0.04	4	2	5

Table 5. Distribution of aquatic macrophytes across various inland water bodies of Lucknow.

Sl. No.	Site name	Aquatic macrophytes						
		<i>A. pinnata</i>	<i>E. crassipes</i>	<i>P. stratiotes</i>	<i>H. verticilata</i>	<i>I. aquatica</i>	<i>L. minor</i>	<i>M. quadrifolia</i>
1	Royal lake	+	+	+	+	-	+	-
2	Ibrahimpur pond	+	+	+	-	-	+	+
3	Butler lake	-	+	+	+	+	+	-
4	Telibagh pond	+	+	+	-	+	-	+
5	Firangi Kheda pond	+	+	+	-	-	+	+
6	Ekana wetland	+	+	+	+	-	+	-
7	Pooranpur lake	+	-	+	-	+	+	+
8	Aadarsh pond	+	+	+	-	-	+	+
9	The Sava the pond	-	-	+	-	-	-	+
10	Fish market pond	-	-	-	-	-	+	-
11	Eldeco pond	-	+	+	+	+	-	+
12	Swan pond	+	+	+	-	-	+	+
13	Sahara pond	+	+	+	-	+	+	-
14	Moti jheel (Lake)	+	+	-	-	+	-	-
15	Makkaganj pond	+	-	-	+	+	+	+
16	Roberts linejheel (lake)	+	+	+	-	-	+	+
17	Rajajipuram lake	-	-	+	+	-	+	-
18	Nawabganj Bird Sanctuary	+	+	+	-	+	+	-
19	Kathauta jheel (lake)	+	+	+	-	+	+	-

Note: Present (+), Absent (-).

very poor at site S1 (WQI - 76-100) (Table 3).

Microbial diversity in the lentic water bodies of Lucknow

Various bacterial strains were identified in the inland water bodies, their Colony Forming Unit (CFU) values, are presented in Table 4. *E. coli* bacteria were detected at all the sampling sites, with the highest and lowest at S16 and S12, respectively. Notably, the surface quality standard (IS: 2296) prescribes the permissible limit of 50 MPN/100ml for total coliforms in surface water, and the CFU count should not exceed 5×10^{-2} . The presence of *E. coli* indicates water contamination by faecal matter, likely due to open defecation practices.

Aquatic macrophytes

Aquatic macrophyte's ability to store harmful elements within their tissues either passively by the flow of water through their roots, or actively, through the transport of substances by epidermal cells in their roots, makes them highly efficient bio-indicators for detecting comprehensive impacts of pollution (Neha *et al.* 2017, Nabi 2021, Kumar *et al.* 2022). Further, these macrophytes also act as steadfast natural bi-

ological filters, actively purifying water bodies by sequestering dissolved ions and toxins within their tissues (Vardanyan and Ingole 2006, Polechońska and Klink 2023, Nabi 2021). Aquatic macrophytes found at selected water bodies were comprised of *Pistias stratiotes* (84.21%), *Lemna minor* (78.94%), *Azolla pinnata* (73.68%), *Eichhornia crassipes* (73.68%), *Marsilea quadrifolia* (52.63%), *Ipomoea aquatica* (47.37%) and *Hydrilla verticilata* (31.57%). 71.42% of aquatic macrophytes were found at sites where water was found unsuitable for drinking, whereas 42.86% and 14.28% aquatic macrophytes were found in poor and inferior quality water, respectively (Table 5).

CONCLUSION

The objective of the current investigation was to assess the water quality in small inland water bodies to determine their suitability for various designated uses. A comprehensive approach, including physico-chemical and biological tools, including macrophytes and microbial analysis, was adopted. Parameters such as TDS, EC, pH, alkalinity, total hardness, major cations (Ca^{2+} , Na^+ , K^+), and major anions (HCO_3^- , Cl^- , PO_4^{2-} , SO_4^{2-}) surpassed permissible limits outlined by BIS IS:2296 for surface water quality standards. Natural

weathering, surface runoff, dissolution, alkaline conditions and sewage discharge are responsible for high concentrations of ions. The overall water quality index indicated that sites S9 (Seva Kheda Pond), S14 (Moti Jheel), and S17 (Rajajipuram Lake) fell into the 'poor' category, while S10 (Fish market pond) is classified as 'very poor', whereas the remaining locations are deemed 'unsuitable'. Bacterial presence in all the samples, including *E. coli*, revealed potential contamination from sewage discharge, particularly human faecal matter. Presence of aquatic macrophytes across all the water bodies confirmed the cumulative nutrient enrichment.

Over a long period, these water bodies have been treated as sacred places for performing various rituals. Furthermore, in addition to the local communities, these small water bodies have significant economic importance to the state as well. The study underscores the need for immediate measures to prevent the influx of polluted water to enhance the water quality in the study area. Findings may be referred to assess the probable ecological implications of future development around the inland water bodies.

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