Vol. 10 Special Issue 1 November 2025
E-ISSN: 2456-5571

Investigation of Seasonal Shifts in Water Quality and Index Assessment of Chakkamkandam Lake, Kerala, India

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Open Access

Manuscript ID:
BIJ-SPL1-NOV25-MD -105

Subject: Zoology

Received : 23.07.2025
Accepted : 05.08.2025
Published : 13.11.2025

DOI: 10.64938/bijsi.v10si1.25.Nov105

Abstract
Lakes play a crucial role in supporting ecological balance by regulating river discharge and serving as essential freshwater reserves, especially during dry periods. Ensuring the health of these aquatic systems is vital for sustainable water resource management. In Kerala, India, many lakes are increasingly threatened by human-induced stress, particularly from the continuous inflow of domestic wastewater and agricultural runoff, which significantly alter water chemistry. This study focuses on assessing the seasonal variation in water quality and calculating the Water Quality Index (WQI) of Chakkamkandam Lake in Kerala. Water samples were collected from four different sites over three distinct seasons—pre-monsoon, monsoon, and post-monsoon—between October 2019 and September 2020. Standard analytical methods were employed to measure various physicochemical parameters, along with concentrations of heavy metals such as lead, cadmium, iron, and chromium. The WQI was determined using the weighted arithmetic mean method. Results indicated that most water quality parameters exceeded acceptable standards, except for pH, nitrate, and fluoride. Notably, the highest levels of organic pollutants and heavy metals were recorded during the pre- and post-monsoon seasons. The WQI scores—1693.7 (pre-monsoon), 235.8 (monsoon), and 389.3 (post-monsoon)—classified the lake's water quality as "very poor" across all seasons. These findings highlight the significant impact of industrial, agricultural, residential, and tourism-related activities on the lake's ecosystem. The study emphasizes the urgent need for continuous water quality monitoring and the implementation of stringent environmental regulations. It provides valuable insights for local authorities, researchers, and public health stakeholders globally.
Keywords: chakkamkandam lake, estuarine lake, heavy metals, kerala, water quality index

Introduction

Surface water contamination is a pressing global issue, particularly in developing nations, due to increasing water scarcity and the prevalence of waterborne diseases. Recognizing this urgency, the United Nations included access to safe and clean water as part of the Sustainable Development Goals (SDGs). Despite ongoing efforts, nearly one-third of the global population still lacks access to safe drinking water. Surface water bodies-such as lakes, rivers, and ponds-are vital for daily human needs, yet their quality is increasingly compromised by anthropogenic pressures, including agricultural runoff and untreated municipal and industrial discharges.

Globally, an estimated 80% of wastewater is released back into the environment without adequate treatment. This results in severe water quality degradation and health risks, as nearly 1.8 billion people rely on water sources contaminated with fecal matter. In India alone, over 61,000 million liters of sewage are generated daily, with only about 38% undergoing treatment. The remaining untreated wastewater significantly alters the physicochemical and microbiological characteristics of receiving water bodies, raising levels of turbidity, nutrients, heavy metals, and pathogenic organisms—leading to outbreaks of diseases like cholera, dysentery, and typhoid.

To address these concerns, tools like the Water Quality Index (WQI) are used to simplify complex water quality data into a single value representing overall water health. WQI effectively communicates the usability of a water body and supports informed water resource management decisions.

Kerala, a state in southern India, receives high annual rainfall and is rich in water bodies, yet faces growing freshwater scarcity due to urbanization, population growth, and mismanagement. While several studies have examined major lakes in the region, Chakkamkandam Lake remains under-researched. This study aims to fill that gap by assessing the lake's seasonal water quality and evaluating it using WQI to support sustainable water resource planning.

Methodology

Study Area

Chakkamkandam is a village area near Chavakkad and Guruvayur of the Thrissur district of Kerala on the southwest coast of India. The area was famous for its beauty, and a few years ago, it was a perfect choice for recreational activities as the place sits on the shores of a water body. A few decades ago, this lake was the local people's income from conventional fishing and aquaculture. The state of the lake has now turned from an income-generating resource to a garbage dump. At Chakkamkandam, the sewers of Guruvayoor municipality, a famous pilgrimage center, merge as a surface river with the water of lake Chakkamkandam. Then it flows forward to lake Chettuva and then meets the Lakshadweep Sea. In the course of the current, it enriches many hectares of rice fields and recharges the water table. As of now, part of the lake is fenced off for aquaculture. The geographical position of the lake is 10º 31′ 4″ N latitude and 76º 2′ 28″ E longitude. The geographical location and sampling locations of the Chakkamkandam lake are presented in Fig. 1.

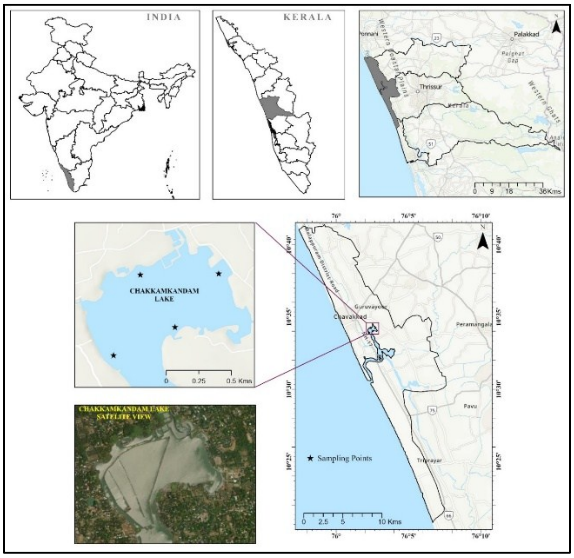

Figure 1 Study Area and Sampling Location

Samples were collected from four lake stations during three different seasons (pre-monsoon, monsoon, and post-monsoon) from October 2019 to September 2020. Surface water samples were collected using an acid-cleaned, pre-rinsed polythene bottle and were taken to the laboratory under refrigeration. Sampling, preservation, and water quality assessment were carried out as per American Public Health Association (APHA) standard methods (APHA).

Water Quality Index (WQI)

In this study, twenty-one key parameters were taken for the calculation of the water quality index. They were pH, TSS, TDS, DO, BOD, TH, TA, NH_3, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-} NO_3^-, HCO_3^-, F^-, Cr, Cd, Fe, and Pb. The seasonal mean values were taken into account. The weighted arithmetic mean WQI was computed using the drinking water quality standards recommended by the Bureau of Indian Standards. The weighted arithmetic mean approach calculates the WQI in four steps (Horton 1935) as follows:

a. Each parameter was assigned a value based on its significant role for the overall water quality in accordance with the guidelines of the standardization organizations. The parameters with low permissible limit values can cause the maximum degree of contamination even with slight fluctuations, while the high permissible value indicates relatively low contamination probabilities. For this study, the two key factors were taken into account to assign a unit weight, i.e., permissible limit as per drinking water quality standards by BIS and the health risk index (HRI) reported by Singh *et al.* (2018). Accordingly, unit weightage of 1–3 (1 for least important and 3 for most important) was assigned in this study according to their relative importance

b. Computing the relative weight (W_i) of each parameter using Eq. 1.

$$w_i = \frac{w_i}{\sum_{n=1}^{n} w_i} \qquad \text{----------------(1)}$$

Where W_i is the relative weight, w_i is the weight of each parameter, and n is the number of parameters

c. A quality rating scale (q_i) for each parameter is computed by dividing its concentration in each water sample by its respective standard according to the guidelines laid down by BIS[21], and then, the result was multiplied by 100 as given in Eq. 2.

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100 \qquad \text{----------------- (2)}$$

q_i = quality rating, C_i = concentration of each chemical parameter in each water sample in mg. L^{-1}, S_i = Indian drinking water standard[21] for each chemical parameter in mg. L^{-1} except for pH.

d. Finally, for computing the WQI, the water quality sub-index (SI_i) for each chemical parameter is first determined, which is then used to calculate the WQI as per the Eqs. 3 and 4.

$$SI = W_i q_i \qquad \text{----------------- (3)}$$

$$WQI = \sum_{i=1}^{n} SI_i \qquad \text{-----------------(4)}$$

Where SI_i is the sub-index of the i^{th} parameter, q_i is the rating based on the concentration of the i^{th} parameter, and n is the number of parameters. The final water quality index obtained was utilized to categorize the overall quality of water as summarized in table 1.

Table 1 Water Quality Index (WQI) and Status of Water Quality (Ravikumar *et al.,* 2013)

WQI value	Water quality	Description for the use
< 50	Excellent	No water treatment is required, use for normal purposes and conservation of the ecosystem
50–100	Good	Requires pre-water treatment for human consumption and conservation of the ecosystem
100–200	Poor	Not safe for human consumption requires normal treatment for farming and ecosystem conservation
200–300	Very poor	Special water treatment before use
> 300	Water unsuitable for drinking	Can be used for navigation, unsafe for any type of consumption

Statistical Analysis

The collected data were analyzed using the IBM Statistical Package for the Social Sciences (SPSS) Version 21 and expressed as a box plot (minimum, maximum, and mean ± standard deviation values). The water quality index was calculated using the software Microsoft excel 2013.

Results and Discussion

Correlation analysis

The correlation study can be utilized to measure the strength and statistical significance of the relation between two or more water quality parameters. The degree of a linear association between any two of the water quality parameters, as measured by the simple correlation coefficient (r^2), is represented in fig 3. It is seen that pH is significantly correlated with all the ionic species (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-} and

Vol. 10 Special Issue 1 November 2025
E-ISSN: 2456-5571

NO_3) and Fe; this interrelationship could depend on environmental conditions, especially these elements' oxidation and reduction nature. Similarly, a positive correlation was observed among TDS, total hardness, and ionic species (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-} and NO_3^-). The higher concentration of basic ions in the water sample is the primary reason for the water's alkaline pH and higher TDS and hardness content (Figs 2a and 2b). This interrelationship could also indicate that the hardness of the water is permanent in nature (Thakre *et al.,* 2011). The use of inorganic fertilizers in the nearby agricultural areas could be a significant source for the nutrient load in lake water (WHO).

BOD is positively correlated with Cr, Fe, Cl^-, K^+, Na^+, SO_4^{2-}, $Mg^{2+,}$ and Ca^{2+}, which might be attributed to increased salinity, temperature, and biological activity.[41,42] BOD is negatively correlated with DO because microorganisms will degrade the biological organic matter with the help of oxygen, which eventually leads to a reduction in DO content when BOD increases. A positive correlation of NH_3 with Fe, Cl^-, and NO_3^- indicates that these pollutants are mainly from similar sources like human or animal waste and agriculture runoff (Egereonu *et al.,* 2005) Calcium shows a good correlation with chlorides and sulfates, indicating that calcium may present in the form of $CaCl_2$ and $CaSO_4$ in the water of the studied area. A more significant relationship was observed between and within the cations (Ca^{2+}, Mg^{2+}, $Na^{+,}$ and K^+) and anions (Cl^-, SO_4^{2-} and NO_3^-). This reflects the fact of marine water intrusion into the estuarine lake, which increases the salts content of the water body.

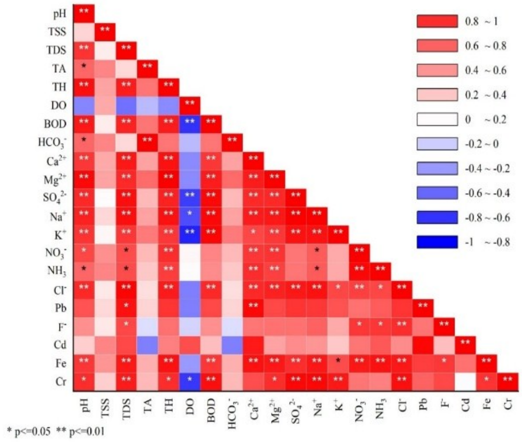

Figure 3 Pearson's correlation matrix for the analyzed water quality parameters along the lake Chakkamkandam

Water Quality Index (WQI)

The Water Quality Index (WQI) values for Chakkamkandam Lake indicate poor quality across seasons. Excessive TDS, hardness, and chloride—12,708 mg/L, far above safe limits—impact usability. Lead levels were 59 times higher than permissible, posing serious health risks and corrosion issues if used for domestic purposes.

Table 2 Calculation of Water Quality Index during Pre-Monsoon in Chakkamkandam Lake

Parameters	Observed Values	S_n	Unit Weight	Q_n	W_n*Q_n
pH	7.843	6.5-8.5	0.0714	100	7.143
Total Suspended Solids (TSS)	520.25	500	0.0714	104.05	7.432
Total Dissolved Solids (TDS)	29730	500	0.0476	5946	283.143
Total Alkalinity (TA)	165.75	120	0.0238	138.125	3.289
Water Hardness (TH)	12412.5	300	0.0476	4137.5	197.024
Dissolved Oxygen (DO)	3.575	5	0.0714	71.5	5.107
Biological Oxygen Demand (BOD)	8.145	5	0.0714	67.239	4.803
Calcium (Ca^{2+})	890	75	0.0237	1186.666	28.226
Magnesium (Mg^{2+})	2476.25	30	0.0237	8254.166	196.331
Sulphate (SO_4^{2-})	3216	150	0.0237	2144	50.997
Nitrate (NO_3^-)	3.248	45	0.0714	7.217	0.516
Chloride (Cl^-)	12708.25	250	0.0476	5083.3	242.062
Sodium (Na^+)	6326	50	0.0238	12652	301.238

Iron (Fe)	4.43	0.3	0.0476	1476.666	70.318
Bicarbonate (HCO_3^-)	165.75	300	0.0237	55.25	1.314
Lead (Pb)	0.59	0.01	0.0238	5900	140.476
Cadmium (Cd)	0.02	0.003	0.0714	666.666	47.619
Potassium (K^+)	336.5	10	0.0237	3365	80.039
Fluoride (F^-)	0.428	1	0.0714	42.75	3.054
Chromium (Cr)	0.127	0.05	0.0476	253.34	12.064
Ammonia (NH_3)	0.81	0.5	0.0714	162	11.571
				WQI	1693.764

Table 3 Calculation of Water Quality Index during Monsoon in Chakkamkandam Lake

Parameters	Observed Values	S_n	Unit Weight	Q_n	W_n*Q_n
pH	7.198	6.5-8.5	0.0714	100	7.143
Total Suspended Solids (TSS)	509.25	500	0.0714	101.85	7.275
Total Dissolved Solids (TDS)	942	500	0.0476	188.4	8.972
Total Alkalinity (TA)	112.975	120	0.0238	94.1458	2.242
Water Hardness (TH)	174	300	0.0476	58	2.762
Dissolved Oxygen (DO)	5.35	5	0.0714	107	7.643
Biological Oxygen Demand (BOD)	2.595	5	0.0714	125.052	8.932
Calcium (Ca^{2+})	33.725	75	0.0237	44.966	1.070
Magnesium (Mg^{2+})	21.798	30	0.0237	72.658	1.729
Sulphate (SO_4^{2-})	20.575	150	0.0237	13.716	0.326
Nitrate (NO_3^-)	1.95	45	0.0714	4.3333	0.310
Chloride (Cl^-)	371.825	250	0.0476	148.73	7.082
Sodium (Na^+)	100	50	0.0238	200	4.762
Iron (Fe)	1.295	0.3	0.0476	431.666	20.556
Bicarbonate (HCO_3^-)	112.975	300	0.0237	37.658	0.896
Lead (Pb)	0.07	0.01	0.0238	700	16.667
Cadmium (Cd)	NIL	0.003	0.0714	0	0.000
Potassium (K^+)	19.5	10	0.0237	195	4.639
Fluoride (F^-)	0.24	1	0.0714	24	1.714
Chromium (Cr)	1.295	0.05	0.0476	2590	123.333
Ammonia (NH_3)	0.548	0.5	0.0714	109.5	7.821
				WQI	235.871

During the monsoon, pollution decreased, with only lead and chromium exceeding limits—6 and 2 times higher, respectively-due to dilution from rainfall. Water quality improved compared to other seasons. However, post-monsoon levels of TDS, sulfate, chloride, lead, and cadmium rose again, indicating increased pollution after the rains.

Table 4 Calculation of Water Quality Index in Post-Monsoon in Chakkamkandam Lake

Parameters	Observed Values	S_n	Unit Weight	Q_n	W_n*Q_n
pH	7.3	6.5-8.5	0.0714	100	7.143
Total Suspended Solids (TSS)	296.5	500	0.0714	59.3	4.236
Total Dissolved Solids (TDS)	7370	500	0.0476	1474	70.191
Total Alkalinity (TA)	121.75	120	0.0238	101.458	2.416
Water Hardness (TH)	299.5	300	0.0476	99.833	4.754

Dissolved Oxygen (DO)	3.6	5	0.0714	72	5.143
Biological Oxygen Demand (BOD)	5.19	5	0.0714	98.0208	7.002
Calcium (Ca^{2+})	19.26	75	0.0237	25.68	0.611
Magnesium (Mg^{2+})	61.088	30	0.0237	203.625	4.843
Sulphate (SO_4^{2-})	1312.25	150	0.0237	874.833	20.809
Nitrate (NO_3^-)	0.425	45	0.0714	0.944	0.068
Chloride (Cl^-)	1894	250	0.0476	757.6	36.076
Sodium (Na^+)	1909.5	50	0.0238	3819	90.929
Iron (Fe)	0.377	0.3	0.0476	125.556	5.979
Bicarbonate (HCO_3^-)	121.75	300	0.0237	40.583	0.965
Lead (Pb)	0.195	0.01	0.0238	1950	46.429
Cadmium (Cd)	0.01	0.003	0.0714	333.333	23.810
Potassium (K^+)	204.25	10	0.0237	2042.5	48.582
Fluoride (F^-)	0.04	1	0.0714	4	0.286
Chromium (Cr)	0.06	0.05	0.0476	120	5.714
Ammonia (NH_3)	0.235	0.5	0.0714	47	3.357
				WQI	389.340

The water quality index indicates that the pollution was medium during the post-monsoon period (Table 5). Sreeraj *et al.* (2018) recently concluded that one of the major lakes in Kerala, named Sasthamcotta, faces a series of challenges in several years due to the increasing level of pollutants. Similarly, Prasad & Kani (2017) have reported that the water quality of Ashtamudi Lake is not agreeable with the BIS standards recommended for drinking purposes. The current water quality assessment study showed that chakkamkandam lake is highly polluted, eutrophic, and unsuitable for human consumption due to sewage discharges and other anthropogenic activities.

Conclusion

Water quality in Chakkamkandam Lake varied seasonally, with WQI indicating unsafe conditions, especially pre- and post-monsoon. High levels of TDS, hardness, and heavy metals impair usability. Though currently unfit for public use, the lake holds potential as a vital water source, highlighting the need for urgent monitoring and pollution control.

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