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Spatio-Temporal Dynamics of Water Quality in Urban and Semi-Urban Lakes of Gujarat, India: An Integrated Assessment using Water Quality Index and Statistical Analysis

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Abstract

Urbanization is a major cause of environmental degradation, with significant impacts on freshwater ecosystems. The present study assessed and compared seasonal and spatial variations in water quality of urban Kankaria Lake and semi-urban Rani Lake situated in Gujarat, India, using physicochemical parameters such as pH, temperature, total dissolved solids (TDS), dissolved oxygen (DO), and turbidity. Seasonal WQI data were analysed and statistical significance was calculated to determine the effect of site, season and their interaction using a two-way ANOVA with replication, which shows that the water quality of the urban Kankaria Lake is significantly inferior to that of semi-urban Rani Lake across all seasons and variables. Based on the findings, water of both lakes is suitable for outdoor bathing but unsuitable for drinking, according to CPCB and BIS standards, respectively. This study highlights the impact of urbanization on freshwater ecosystems and underscores the need for targeted management techniques to prevent further deterioration and conserve these vital resources.

Key words : NSFWQI, Physicochemical parameters, Kankaria Lake, Rani Lake, two-way ANOVA.

Water is a key natural resource that supports life, ecosystems, and economic development. Despite covering 71% of the Earth's surface, only a small portion is available

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as potable freshwater, which is under increasing anthropogenic pressure from urbanization, pollution, and climate change[17,20]. Freshwater ecosystems are essential for maintaining ecological equilibrium. Lakes are a key source of freshwater on Earth. It provides key services such as irrigation, drinking water, recreation, fisheries, and climate management[19]. Urban lakes frequently have higher pollution loads due to industrial effluents, stormwater runoff, and sewage discharge, whereas rural lakes are typically influenced by agricultural runoff and seasonal changes[7]. Physicochemical properties of water such as pH, temperature, total solids, turbidity, and dissolved oxygen are some of the very important parameters that play a vital role in the sustainability of the lake environment and the growth of living organisms. Comparative studies of urban, semi-urban and rural lakes are required to understand the effects of land-use patterns on water quality and to create effective management techniques[12]. Studies in India have indicated that urban lakes are often more polluted than rural lakes[11,14]. However, the majority of research in Gujarat has focused on specific urban lakes or on regional two-lake comparisons; detailed multi-seasonal studies comparing urban, semi-urban, and rural lakes are still less common. The most prevalent technique for assessing water quality is the Water Quality Index (WQI), which was proposed by Horton[6]. The benefit of WQI is that it ultimately displays a single numerical number that was derived from numerous parameters. This technique aids in the more logical simplification of the information being presented.

The current study aims to assess and compare the water quality in terms of the Water Quality Index (WQI) of two lakes of India: the urban Kankaria Lake, situated in Ahmedabad City of Gujarat, and the semi-urban Rani Lake, situated in the vicinity of Idar town in the Sabarkantha district of Gujarat. The current study contributes to an understanding of the spatiotemporal shift in water quality caused by anthropogenic activities in semi-urban and urban lakes. The results are intended to support sustainable lake management and the creation of water quality improvement plans for fresh water ecosystem.

Study sites :

A. Urban site: Kankaria Lake :

Kankaria Lake is situated approximately at 23.006° N and 72.601° E in the Maninagar locality on the southeastern side of the city of Ahmedabad, Gujarat, India (Fig. 1). This water body is artificial in origin and was built in the year 1451 A.D. during the rule of Sultan Qutb-ud-Din Ahmad Shah II. It is also referred to as “Qutub Hojj” or “Hauj-e-Kutub.” It extends over nearly 76 acres and has a maximum depth of about 7 meters. The central island, known as Nagina Wadi, was historically a royal retreat and today functions as a recreational site. The surrounding landscape has been extensively developed into a cultural and leisure zone that includes a zoo, toy train, amusement park, and the annual Kankaria Carnival[8].

B. Semi-urban site: Rani Lake :

The Rani Lake, also known locally as Rani Talav, is located approximately at 23.862° N and 73.018° E in the vicinity of Idar town, which is situated at southernmost point of the Aravalli Mountain range in north Gujarat, India

(Fig. 1). Idar town was mentioned in Mahabharta as 'Ilvadurg'. It was the capital of the Idar State, which was governed by the Rathore Rajputs in the Mahi Kantha agency during the British Raj. Rani Lake covers roughly 94 acres and has a maximum depth of about 5 meters. It provides water for irrigation throughout the year. A Jain temple called the Pavapuri Jain temple is located in the centre of a lake, and it is connected to the land by a bridge (https://www.gujarattourism.com).

WQI :

Water samples were collected seasonally from both selected study locations for one year, from November 2023 to October 2024, to examine the variation in the water quality index across winter, summer, and monsoon seasons. Collected water samples were analysed for water quality index parameters such as pH, temperature (^{o}C), and dissolved oxygen (mg/L) were monitored at the sampling site, while TDS (mg/L) and turbidity (NTU) were evaluated in the laboratory as per the standard methods of APHA (1995). Measured parameters of water were evaluated by National Sanitation Foundation Water Quality Index (NSFWQI), which is one of the most widely used and practical WQI. The NSFWQI is calculated by selecting important parameters and assigning them relative weights (W_i) to indicate their importance in overall water quality[2]. Each parameter is then converted into a sub-index (Q_i) using rating curves to evaluate its contribution to water quality[5]. At last final WQI was calculated using following equation[2]:

$$WQI = \sum_{i=1}^{n} Wi\,Qi$$

Where Q_i = Sub index for i^{th} water quality parameter;
W_i = Weight associated with water quality parameter;
n = Number of water quality parameters

The resulting WQI score is interpreted on a scale of 0 to 100 (Table-2) with their corresponding water quality status[2]. Variation in each parameter of two study sites were analysed and compared by the two-factor ANOVA with replication test using Microsoft excel data analysis ToolPak, which helped us to determine a significance of difference between the seasons, sites and their interaction (season × site). The measured values of each parameter was also compared with Bureau of Indian Standards (BIS) for drinking water and Central Pollution Control Board (CPCB) water quality standards for surface waters[3,4].

The findings of each parameter vary between the selected sites, although TDS and DO reported major variations. In all seasons, DO was continuously higher in Rani Lake, and TDS was consistently much higher at urban Kankaria Lake (Table-1). Kankaria Lake's TDS value is over the acceptable limit (500 mg/L) and approaches the permissible limit (2000 mg/L) in accordance with CPCB[4] standards; however, Rani Lake's TDS value is under the acceptable limit, which is a desirable indicator of the good water quality state. The current study of comparison of water quality index for the urban site and semi-urban site shows that the urban site Kankaria Lake shows moderate water quality during the winter and summer seasons with index values of 66.2 and 61.2 respectively (Graph 1 and Table-3), which lies within the 51 to 70 range

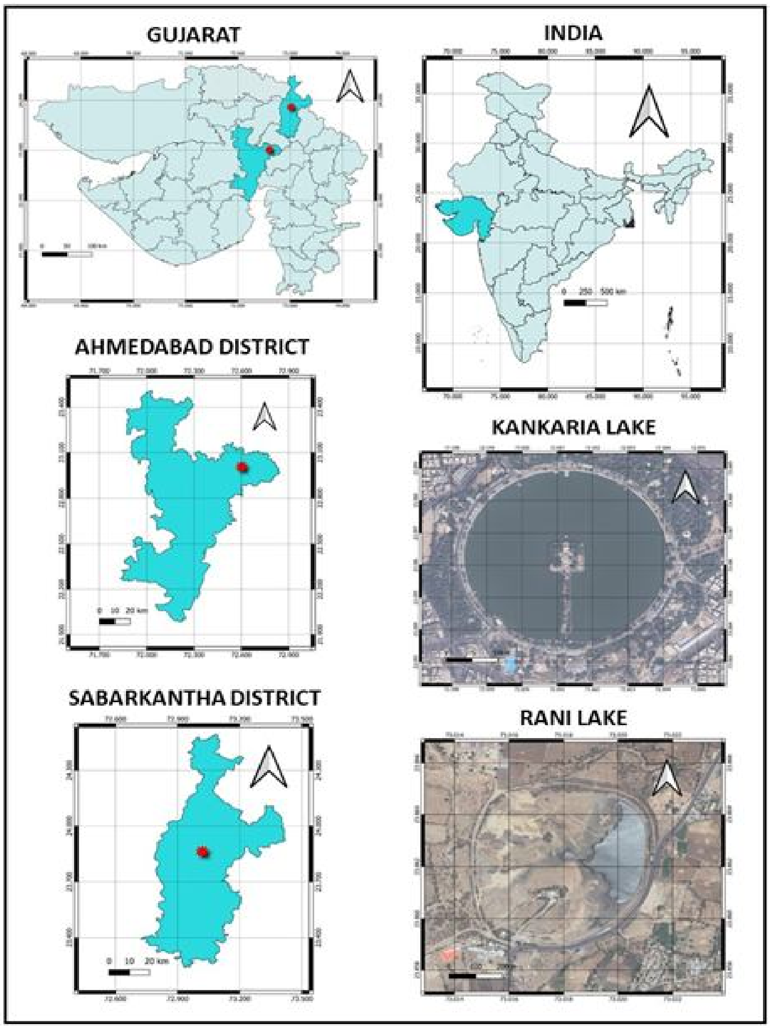


Fig. 1. Location map of study sites (QGIS software 3.34 version)

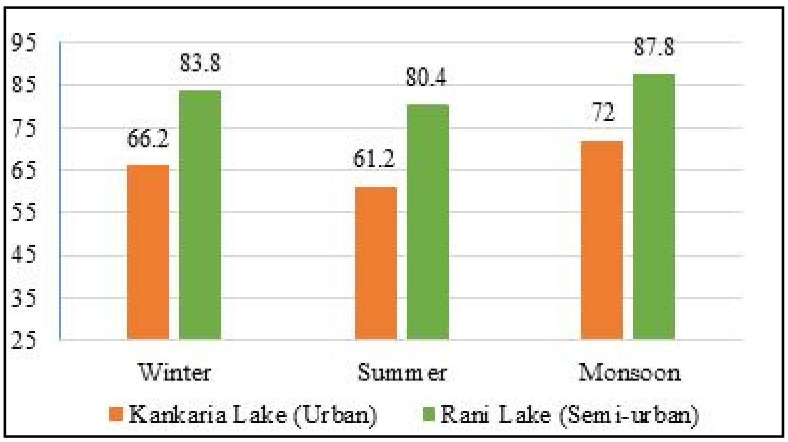
scale (Table-2); While it appears that it improved to good water quality status during the monsoon with an index value of 72 (Graph 1, Table-3), which lies between 71 to 90 scale. The decreased water quality during winter and summer might be due to reduced dilution capacity, a higher evaporation rate, and the accumulation of pollutants due to the non-rainy season and poor water exchange. The improved water quality during the monsoon season could be attributed to increased dilution of water by rain water. The semi-urban Rani Lake site consistently reported good water quality index values greater than 80 across all seasons, ranging from 71 to 90 on the scale (Graph 1, Table-3). This indicates less anthropogenic pressure and more stable environmental conditions. These results line up with earlier research conducted in India[11,14].

Table-1. Measured values of each parameter

Parameter	Kankaria Lake			Rani Lake		
	Winter	Summer	Monsoon	Winter	Summer	Monsoon
pH	8.5	8.9	8.2	8.2	8.5	7.9
TDS (mg/L)	988	1224	791	117	132	89
DO (mg/L)	6.1	5.4	6.5	7.6	6.8	8.2
Turbidity (NTU)	4	7	11	5	7	10
Temperature (^oC)	18	30	23	16.5	31	23

Table-2. WQI scale and water quality status
(Brown *et al.*, 1973)

Water Quality Index Scale	Water Quality Status
91-100	Excellent quality
71-90	Good quality
51-70	Moderate quality
26-50	Poor quality
0-25	Very poor quality



Graph 1 Season wise and site wise comparison of NSFWQI

Table-3. NSFWQI values and water quality status of both study sites

Parameters	Kankaria Lake (Urban site)			Rani Lake (Semi-urban site)		
	Winter	Summer	Monsoon	Winter	Summer	Monsoon
NSFWQI	66.2	61.2	72	83.8	80.4	87.8
Water quality status	Moderate	Moderate	Good	Good	Good	Good

The two-way ANOVA results (Table 4) revealed that both seasonal and spatial variations exerted significant influences on multiple physico-chemical parameters of the studied lakes, while their interaction effects (season × site) remained statistically non-significant across all parameters, indicating that seasonal trends were largely consistent between sites.

Table-4 Two-way ANOVA results showing the influence of seasonal and spatial variations on selected water quality parameters

Parameter	Source of Variation	df	F-value	p-value	Significance (p< 0.05)
pH	Between Seasons	2	14.34	< 0.001	*Highly significant*
	Between Sites	1	9.98	0.008	*Highly significant*
	Interaction (Site×Season)	2	0.12	0.885	Non-significant
Temperature (°C)	Between Seasons	2	43.39	< 0.001	*Highly significant*
	Between Sites	1	0.02	0.876	Non-significant
	Interaction	2	0.57	0.578	Non-significant
TDS (mg/L)	Between Seasons	2	5.79	0.017	Significant
	Between Sites	1	293.49	< 0.001	*Highly significant*
	Interaction	2	3.79	0.053	Non-significant
DO (mg/L)	Between Seasons	2	8.23	0.005	Significant
	Between Sites	1	37.52	< 0.001	*Highly significant*
	Interaction	2	0.07	0.924	Non-significant
Turbidity (NTU)	Between Seasons	2	22.22	< 0.001	*Highly significant*
	Between Sites	1	0.05	0.817	Non-significant
	Interaction	2	0.79	0.473	Non-significant

Water pH exhibited significant seasonal ($F = 14.34$, $p < 0.001$) and spatial ($F = 9.98$, $p = 0.008$) variations (Table-4), indicating dynamic buffering and biological processes influenced by climatic and anthropogenic inputs. The observed seasonal shift may be attributed to enhanced photosynthetic CO_2 assimilation during pre-monsoon and dilution effects during monsoon periods. Similar trends were reported in earlier studies, where higher pH during dry seasons corresponded to intensified eutrophication[9].

Water temperature showed highly significant seasonal variation ($F = 43.39$, $p < 0.001$) (Table-4), confirming its dependency on climatic conditions. However, no significant difference was observed between sites ($p > 0.05$), reflecting similar thermal regimes across both urban and semi-urban lakes. Seasonal peaks during summer align with studies in Udaipur lakes[15]. Globally, Wetzel[19] documented that seasonal stratification dominates over spatial differences in small lentic systems, consistent with our findings.

TDS exhibited both significant seasonal ($F = 5.79$, $p = 0.017$) and highly significant spatial variations ($F = 293.49$, $p < 0.001$) (Table 4). The notably higher spatial effect underscores the contrasting levels of anthropogenic input between the urban and semi-urban lakes, possibly from domestic effluents and surface runoff in urbanized catchments. Similar elevated TDS level found in urban Chinese lakes due to catchment imperviousness and stormwater discharge[10].

DO showed significant seasonal variation ($F = 8.23$, $p = 0.005$) and highly significant spatial variation ($F = 37.52$, $p < 0.001$) (Table-4). Higher DO concentrations during monsoon months suggest re-aeration from rainfall and dilution, while lower levels during summer indicate increased biochemical oxygen demand (BOD) and microbial decomposition. The urban lake's consistently lower DO aligns with earlier reports from India[13].

Turbidity demonstrated highly significant seasonal influence ($F = 22.22$, $p < 0.001$), whereas spatial and interaction effects were non-significant (Table-4). This seasonal dominance can be attributed to surface runoff and sediment re-suspension during monsoon, and sedimentation during post-monsoon phases.

Collectively, the data indicate that seasonal factors have a greater influence on temperature, turbidity, and pH, while spatial differences dominate TDS and DO, reflecting urbanization gradients. The absence of significant interaction terms suggests that while magnitude differs, the seasonal trends remain consistent across lake types. Such patterns are consistent with the multifactorial control of water quality described by Wetzel[19].

Considering the recreational importance of Kankaria Lake and the historical importance of Rani Lake, the water quality was assessed and compared using NSFWQI and two way ANOVA test. The results of the present study unambiguously show that the water quality of the semi-urban Rani Lake is superior to that of its urban counterpart Kankaria Lake. This variation was statistically supported by a two-way ANOVA test which revealed that seasonal variations significantly influence temperature, turbidity, and pH, while spatial differences are more pronounced for TDS and DO, underscoring the combined effects of seasonal dynamics and urbanization on lake water quality. The absence of significant interaction effects suggests consistent seasonal trends across sites, though the urban Kankaria Lake exhibits greater deterioration from anthropogenic pressures. Based on the results of each parameter, the water in both lakes is suitable for outdoor bathing according to CPCB water quality standards, but unsuitable for drinking according to BIS drinking water standards. It is recommended that future research emphasize on precise identification and quantification of pollution point sources to enable targeted mitigation and sustainable lake restoration. These findings highlight the urgent need for integrated lake management, stormwater regulation, and community-based monitoring programs to mitigate pollution loads and sustain aquatic health. It is further recommended to the concerned local authorities to prioritize urban catchment restoration, promote eco-sensitive urban planning. Such targeted and evidence-based actions will effectively reinforce India's National Lake Conservation Plan (NLCP) and advance progress toward achieving Sustainable Development Goal 6 (Clean Water and Sanitation).

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