



WATER QUALITY INDEX FOR THE EVALUATION OF THE WATER QUALITY OF SAGAR LAKE IN MADHYA PRADESH, INDIA

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ABSTRACT

Using the Water Quality Index (WQI) method, Sagar Lake's water quality was assessed. Over a year, from April 2019 to March 2020, water samples were taken at eight specific Sagar Lake locations. Water quality indicators like temperature, depth, and colour were measured directly at the sampling site. Water depth was measured with a wooden stick dipped into the lake then measured with a measuring tape. Water temperature was measured using a centigrade mercury-in-glass thermometer. Total dissolved solids, salinity, dissolved oxygen, pH, electric conductivity, and total dissolved solids were all directly measured with portable HI 9812, Hanna equipment. Total alkalinity and chloride were analysed by titration method in the lab. The Pearson correlation matrix analysis revealed some of the measured values had a strong correlation. The two-way ANOVA also revealed significant variations in different parameters according to seasons. WQI values demonstrated the ease of understanding about the water quality in Sagar Lake. These findings indicate the urgent need for plans to stop water contamination in Sagar Lake.

Keywords: water quality index (WQI); water chemistry; water quality; Sagar Lake

INTRODUCTION

The main component of an ecosystem is water, a valuable natural resource and national asset (Tyagi et al., 2013). Rivers, lakes, glaciers, rainwater, groundwater, etc. are the most common water sources (Khilchevskiy et al., 2020). Lakes are freshwater reservoirs located inland and do not directly flow into the ocean. They can be shallow or deep, permanent or temporary, and can contain freshwater or saltwater (in arid climates). 50.01% of the water on the surface of the Earth is found in lakes, yet only 49.8% of it is freshwater. Freshwater is essential for the survival of many creatures, and humans frequently rely on lakes for a wide range of "goods and services" (Bhateria & Jain, 2016). In addition to water for drinking, water resources are essential to many economic sectors, including agriculture, animal production, forestry, industrial activities, hydropower generation, fishing, and other creative endeavours (Rasul, 2014). Some significant factors, such as population growth, industrialization, urbanisation, etc.,

have led to a decline in the quantity and quality of surface and groundwater (Mishra, 2011). Physical, chemical, and biological factors can be used to evaluate any specific area's or source's water quality. If the values of these parameters exceed the established limitations, it is detrimental to human health (Tyagi et al., 2013; Guide Manual, 2014).

As a result, the suitability of water sources for human consumption has been described in terms of the Water quality index (WQI), which is one of the most effective ways of describing water quality. WQI uses water quality data to aid in revising policies developed by various environmental monitoring agencies. It has been discovered that using individual water quality variables to describe water quality for the general public is difficult to understand (Akoteyon et al., 2011; Katyal, 2011). Therefore, WQI can condense a large amount of information into a single value to express data in a more simplified and logical manner. It gathers data from various sources and combines it to determine the overall state of a water system (Abbasi & Abbasi, 2012). Finally, they improve policymakers' and the general public's understanding of highlighted water quality issues (Nasirian, 2007).

Our main aim in the present work was to use physico-chemical techniques to monitor Sagar Lake's water quality, identify seasonal changes in water quality parameters, and investigate the relationships between various physico-chemical characteristics. The study's findings will probably be used to control lake water pollution and lower human health risks.

MATERIALS AND METHODS

Study area

The study was conducted at Sagar Lake, commonly called "Lakha Banjara," and the locations for the sampling and analysis is shown in Figure 1. The lake, which forms the center of the city is spread over an area of about 400 acres. Sagar Lake is located in the center of Sagar city (23° 50' N: 78° 45' E) with an area of 82 hectares. It is a shallow, rainy lake with a small catchment (588 ha), and its northwest drainage agrees well with the general northwest drainage pattern of the district (Mishra, 1969). The entire lake can be divided into two parts; the main lake is in 68 hectares, and a small wetland of 14 hectares. It has the deepest point (5.5 m) near the fort side and an average depth of about 2.56 m at the full tank level. The main lake is well protected by many ghats, temples, houses, roads and a stone fence wall that eventually ends up in a small wetland of satellites that connect the main lake with a narrow passageway, except for the southern ghats. The small wetland (Chota Talab) is surrounded by many trees, roads, hospitals, and the newly made Atal Park.

In the current study, a survey of water quality parameters of the freshwater lake was studied for one year, from April 2019 to March 2020. For the current investigation, mainly eight different sites were selected, four from the Main lake (Site 1 – 4) and four from the Small wetland - Chhota Talab (Site 5 – 8) and the details of these sampling sites are given in Table 1.

Sampling procedure and method of analysis

Water samples for the current study were collected monthly between 7 a.m. and 10 a.m. from Sagar Lake's main lake and small wetland. The water samples were collected in sterile sampling bottles. After collection, the samples were placed in an ice-cold box before being transported to the laboratory.

Water quality parameters such as temperature, depth, and color were measured on the sampling spot itself. Water temperature was determined using a centigrade mercury-in-glass thermometer, and the results were expressed in degree Celsius. Water depth was measured with

a wooden stick dipped into the lake and later measured with a measuring tape. The results were expressed in centimetres. Total Alkalinity and chloride were analyzed by titration method in the laboratory following the standard methods prescribed by APHA (2005). Dissolved oxygen mg/l, pH, Electric conductivity, total dissolved solids, and salinity were directly measured with portable equipment HI 9812, Hanna instrument.

WQI computation equations

The water quality index (WQI) is a measurement that reflects the combined impact of various water quality indicators (Ramakrishnaiah et al., 2009). WQI is a rating method that shows the composite impact of each water quality measure on the water's overall quality. Ten crucial factors were selected for the study's water quality index (WQI) calculation. The WHO-recommended requirements for drinking water quality were used to determine the WQI. The WQI computation and parameter choices are essential. Using too many factors will increase the water quality index. The intended use of water determines the significance of several factors. As a result, several steps of the weighted arithmetic index method (Brown et al., 1972) are given in the following steps.

- *Calculation of sub index of quality rating (q_n)*

Let (n) be the number of water quality parameters, and (q_n) be the quality rating or sub-index corresponding to the n^{th} parameter, which represents the parameter's relative value in the polluted water compared to its permitted standards value. The following equation is used to determine the value of q_n .

$$q_n = 100 [(V_n - V_{io}) / (S_n - V_{io})] \dots\dots\dots(1)$$

where: q_n = quality rating for the n^{th} water quality parameter; V_n = estimated value of the n^{th} parameter at a given sampling station; S_n = standard permissible value of the n^{th} parameter; V_{io} = ideal value of n^{th} parameter in pure water.

All the ideal (V_{io}) values are taken as zero (0) for drinking water for all other parameters except the parameter pH, where it is 7.0 (Tripaty & Sahu, 2005) and dissolved oxygen = 14.6 (Abdul et al., 2010).

- *Calculation of unit weight (W_n)*

Calculation of unit weight (W_n) for various water quality parameters is inversely proportional to the recommended standards S_n for the corresponding parameters.

$$W_n = K/S_n \dots\dots\dots(2)$$

where: W_n = unit weight for the n^{th} parameters; S_n = standard value for n^{th} parameter; K = constant for proportionality.

- *Calculation of WQI*

WQI is calculated from the following equation:

$$WQI = \Sigma q_n W_n / \Sigma W_n \dots\dots\dots(3)$$

The overall water quality index was calculated by linearly aggregating the quality rating with unit weight.

Assessment of water quality

WQI has been classified into five classes. Table 5 represents the five classes of water quality based on the WQI of the arithmetic WQI method.

In this study, different water quality parameters have been analyzed, and seven essential parameters were taken to determine the WQI of Sagar Lake. Standards limit parameters was introduced according to the World Health Organization (WHO, 1993).

In order to calculate WQI using the "weighted arithmetic index" approach, the "unit weight" assigned to each physicochemical parameter used in the computation must first be estimated. All relevant parameters across several units and dimensions are converted to a single scale by allocating unit weights. Table 3 shows the guideline limits of BIS and WHO.

Statistical analysis

All statistical analyses, including Pearson correlation and two-way ANOVA, were performed using SPSS statistics 22 (IBM Corp.). In contrast, graphical illustrations were made with the help of Graph Pad Prism 9 (Graphpad Software, LA, CA, USA) software. The QGIS software version 3.26 was used to map the location sites.

RESULTS

The physico-chemical parameters (mean \pm SEM) from eight sites of Sagar Lake obtained during the present work are presented in Table 2. The geological map of the study area showing the eight different sampling sites in the Sagar Lake, District Sagar, Madhya Pradesh, India, is shown in Figure 1.

Water Temperature

The average water temperature of the eight study sites from the Sagar Lake ranged from 22.14° C to 23.45° C during the study period (Table 2). The water temperature was highest during the summer season and lowest during the winter season. Water temperature showed highly significant and positive ($p < 0.01$ level) relationship with chloride ($r = 0.359$), whereas highly significant but negative ($p < 0.01$) were shown for depth ($r = -0.331$), pH ($r = -0.436$), and dissolved oxygen ($r = -0.402$) as shown in Table 4.

Depth

During the study period, the average depth of the eight study sites from Sagar Lake ranged from 73.96 cm to 117.22 cm (Table 2). The water depth was highest during the rainy season and lowest during the winter season. Water depth showed a highly significant and positive ($p < 0.01$ level) relationship with total Alkalinity ($r = 0.446$), whereas highly significant but negative ($p < 0.01$) were shown for chloride ($r = -0.460$) as shown in Table 4.

pH

In the present study, we observed that the average pH values of Sagar Lake's eight different study sites ranged from 7.00 to 7.60 (Table 2). The pH was highest for the winter season, whereas the pH was the lowest for the summer season. The pH showed a highly significant and positive ($p < 0.01$) relationship with dissolved oxygen ($r = 0.430$), whereas a highly negative and significant relationship ($p < 0.01$) was shown for total dissolved solids ($r = -0.305$). Similarly, significant and negative ($p < 0.05$) relationship of pH was also shown for electrical conductivity ($r = -0.205$) and salinity ($r = -0.208$) as shown in Table 4.

Total dissolved solids (TDS)

The average TDS of eight study sites from Sagar Lake ranged from 228.50 mg/l to 309.58 mg/l (Table 2). The maximum TDS in the present study was observed during the winter and the summer. In contrast, the rainy season had a comparatively lower TDS than the summer and rainy seasons. The TDS showed a highly significant and positive ($p < 0.01$) relationship with electrical conductivity ($r = 0.886$) and salinity ($r = 0.870$) in the present study, as shown in Table 4.

Dissolved oxygen (DO)

The average DO of the eight study sites from Sagar Lake ranged from 3.43 mg/l to 4.63 mg/l during the study period (Table 2). The DO for the winter season was the highest, whereas the rainy season had the lowest DO. The DO showed significant and positive ($p < 0.05$) relationship with chloride ($r = 0.210$) whereas highly significant and negative ($p < 0.01$) relationship was shown for temperature ($r = -0.402$) as shown in Table 4.

Electrical conductivity (EC)

In the current work, we observed that the average electrical conductivity values of the eight different study sites from Sagar Lake ranged from 414.75 to 569.50 $\mu\text{S}/\text{cm}$ (Table 2). The EC was highest during the rainy season and lowest during the winter season. The EC showed highly significant and positive ($p < 0.01$) relationship with the salinity ($r = 0.948$), TDS ($r = 0.886$) and with the total alkalinity ($r = 0.363$). On the other hand, it showed a significant ($p < 0.05$) negative relationship with pH ($r = -0.205$), as shown in Table 4.

Salinity

The average salinity of the eight study sites from Sagar Lake ranged from 201.67 mg/l to 280.83 mg/l during the study period (Table 2). The highest salinity value was observed during the rainy season, whereas the lowest value was observed during the winter. The salinity showed highly significant and positive ($p < 0.01$) relationship for TDS ($r = 0.870$), EC ($r = 0.948$) and total alkalinity ($r = 0.309$) whereas, there was significant and negative ($p < 0.05$) relationship with pH ($r = -0.208$) as shown in Table 4.

Chloride

In the current work, we observed that the average chloride values of the eight different study sites from Sagar Lake ranged from 88.62 to 94.10 mg/l (Table 2). The chloride was highest for the summer season, whereas it was lowest during the rainy season. The chloride showed highly significant and positive ($p < 0.01$) for temperature ($r = 0.359$), significant ($p < 0.05$) and positive for dissolved oxygen ($r = 0.210$). On the other hand, chloride showed a significant ($p < 0.05$) and negative relationship for depth ($r = -0.460$), as shown in Table 4.

Total alkalinity

The average total alkalinity of the eight study sites from the Sagar Lake ranged from 101.27 mg/l to 114.68 mg/l during the study period (Table 2). The highest value of total alkalinity was observed during the rainy season whereas the lowest value was observed for the winter season. The total alkalinity showed highly significant and positive ($p < 0.01$) relationship for depth ($r = 0.446$), EC ($r = 0.363$) and salinity ($r = 0.309$) as shown in Table 4.

The overall changes in the level of various physico-chemical parameters of the eight sampling sites from the Sagar Lake according to seasons are illustrated in Figure 2. The two-way ANOVA of these parameters on the basis of site, locations, and the interactions between site \times location is given in Table 7. The two-way ANOVA revealed significant variations in different parameters according to seasons.

WQI of Sagar Lake

The calculated WQI of eight different sampling sites of Sagar Lake according to the season is given in Table 6. From the table, we can observe that the WQI in Sagar Lake ranges from 68.05 to 95.90, reflecting very poor water quality to poor quality in Sagar Lake. Sampling site 7, during the rainy season, showed the lowest WQI, whereas sampling site 3 showed the highest WQI values. The first four sampling sites (Site 1-4) had very poor quality water with

high WQI values, whereas the last four sampling sites (Site 4-8) had poor quality water with WQI values comparatively lower than the first four sites. High WQI values in all these sampling sites in the Sagar Lake during the current study period may be due to the increasing concentrations of various physiochemical parameters in the lake, primarily due to anthropogenic activities. The overall changes in the WQI according to seasons in eight different sampling sites in Sagar Lake are shown in Figure 3.

CONCLUSION

In India, the management and preservation of surface water, one of the most valuable natural resources, is becoming a primary public concern (Kumar et al., 2005). The increase in human population has drastically changed the ecosystem of many natural water bodies. The type of use affects the water's quality. Additionally, the standard for "acceptable water quality" changes from time to time and region, depending on the circumstances. The conversion of lengthy, multi-parameter water analysis reports into single-digit scores requires the use of water quality indices.

According to the results of the physiochemical parameters used to calculate WQI, Sagar Lake has an organic load that flows through it. Based on the preceding discussions, it is reasonable to conclude that the WQI for all samples in 2019-20 ranged from 68.05 to 95.90. The WQI values of Sagar Lake clearly show that the water is unsuitable for human consumption.

The somewhat high level of WQI also suggests that the water must be treated before home usage. When thoroughly evaluating a water body, water quality is crucial. WQI is a valuable tool that can provide consumers with information about the water body by summarising the water quality status into a single number. Thus, monitoring water quality should be given the utmost attention, and indigenous technology should be used to purify water so it is fit for domestic and drinking purposes. Overall, these findings indicate the urgent need for plans to stop water contamination in Sagar Lake.

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CONFLICT OF INTEREST

The authors do not have any conflict of interest.

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Table 1: Details of the sampling stations and sites

Sl.No.	Sites	Latitude	Longitude	Description
1	Site 1	23°49'45.6"N	78°45'03.6"E	Chaitanya Hospital
2	Site 2	23°50'16.0"N	78°44'45.5"E	Takia Masjid Near teen Madiya
3	Site 3	23°50'08.7"N	78°44'24.4"E	Jawaharlal Nehru police Academy
4	Site 4	23°49'37.1"N	78°44'34.2"E	Hanuman Mandir (Army boat club)
5	Site 5	23°49'32.5"N	78°44'44.2"E	Bhalerababa Mandir
6	Site 6	23°49'36.5"N	78°44'50.9"E	Sanjay drive bridge
7	Site 7	23°49'27.7"N	78°45'03.6"E	Fisheries Department (Atal Park)
8	Site 8	23°49'17.6"N	78°44'54.6"E	Khabisabba BMC canal

Table 2: Physio-chemical parameters of data at different locations of Sagar-lake. Data is represented as mean \pm SEM (n=12).

Location	Temperature ($^{\circ}$ C)	Depth (cm)	pH	TDS (mg/l)	DO (mg/l)	EC (uS/cm)	Salinity (mg/l)	Chloride (mg/l)	Total alkalinity (mg/l)
Site 1	22.14 \pm 2.16	75.85 \pm 6.70	7.50 \pm 0.11	273.00 \pm 17.61	3.51 \pm 0.45	479.25 \pm 24.51	232.50 \pm 12.26	89.62 \pm 5.19	101.27 \pm 5.66
Site 2	22.32 \pm 2.21	117.22 \pm 10.30	7.61 \pm 0.14	238.67 \pm 13.85	3.80 \pm 0.62	434.25 \pm 21.92	210.00 \pm 10.22	93.04 \pm 5.76	106.65 \pm 5.48
Site 3	22.59 \pm 2.27	90.89 \pm 9.77	7.60 \pm 0.21	231.08 \pm 11.99	3.99 \pm 0.81	435.08 \pm 20.70	211.67 \pm 10.06	88.62 \pm 5.89	107.92 \pm 5.36
Site 4	22.84 \pm 2.27	75.11 \pm 8.50	7.71 \pm 0.20	228.50 \pm 13.90	4.63 \pm 0.77	414.75 \pm 21.70	201.67 \pm 10.63	92.24 \pm 5.23	109.78 \pm 5.97
Site 5	22.98 \pm 2.21	74.06 \pm 8.20	7.01 \pm 0.23	266.92 \pm 15.10	3.73 \pm 0.56	481.17 \pm 25.20	251.67 \pm 20.14	93.78 \pm 5.35	111.30 \pm 6.91
Site 6	23.17 \pm 2.24	73.96 \pm 7.48	7.09 \pm 0.17	248.83 \pm 13.77	3.49 \pm 0.55	456.33 \pm 26.77	218.33 \pm 15.12	93.91 \pm 6.01	112.13 \pm 5.77
Site 7	23.45 \pm 2.29	74.83 \pm 8.24	7.23 \pm 0.16	281.58 \pm 26.97	3.43 \pm 0.46	519.00 \pm 49.53	250.83 \pm 23.72	91.58 \pm 6.14	113.87 \pm 6.56
Site 8	23.42 \pm 2.29	83.88 \pm 7.06	7.00 \pm 0.14	309.58 \pm 35.85	3.61 \pm 0.33	569.50 \pm 74.51	280.83 \pm 37.87	94.10 \pm 5.45	114.68 \pm 6.49

Table 3: Values of physiochemical variables in Drinking water; Bureau of Indian Standards (BIS 2009) and WHO (2011) (units: mg/L, except, EC in $\mu\text{s/cm}$, salinity in ppt, and pH)

Parameter	Bureau of Indian Standards (BIS) 2009 acceptable limit	WHO standard 2011 desirable limit
pH	6.5 - 8.5	7.0 - 8.5
TDS	500	600
DO	5	NA
EC	750	750
Salinity	100 PPT	100 PPT
Chloride	250	250
Total alkalinity	200	200

NA = Not Available

Table 4: Pearson correlation matrix of variables measured (n=96)

	TEMP	DEPT	pH	TDS	DO	EC	SAL	CLD	TALK
TEMP	1								
DEPT	-0.331**	1							
pH	-0.436**	0.100	1						
TDS	0.122	-0.079	-0.305**	1					
DO	-0.402**	0.003	0.430**	0.019	1				
EC	0.069	0.092	-0.205*	0.886**	0.146	1			
SAL	0.078	0.035	-0.208*	0.870**	0.121	0.948**	1		
CLD	0.359**	-0.460**	-0.035	0.059	0.210*	-0.020	-0.007	1	
TALK	0.186	0.446**	-0.195	0.138	0.046	0.363**	0.309**	-0.070	1

**. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level

TEMP=Temperature; DEPT=Depth; TDS=Total dissolved solids; DO=Dissolved oxygen; EC=Electrical conductivity, SAL=Salinity, CLD=Chloride; TALK=Total alkalinity.

Table 5: Water quality scale

Water Quality Index (Yadav et al., 2010)	Water Quality
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Unfit for consumption

Table 6: Water quality scale indices and water quality of different locations in different seasons

LOCATI ON	WQI SUMMER	Water Quality (Yadav et al., 2010)	WQI RAINY	Water Quality (Yadav et al., 2010)	WQI WINTER	Water Quality (Yadav et al., 2010)
SITE 1	85.4	Very Poor	96.92	Very Poor	91.33	Very Poor
SITE 2	86.3	Very Poor	94.65	Very Poor	83.68	Very Poor
SITE 3	85.31	Very Poor	95.9	Very Poor	78.89	Very Poor
SITE 4	87.54	Very Poor	89.8	Very Poor	78.43	Very Poor
SITE 5	68.13	Poor	74.2	Poor	71.03	Poor
SITE 6	73.89	Poor	74.26	Poor	74.69	Poor
SITE 7	70.23	Poor	68.05	Poor	68.77	Poor
SITE 8	69.79	Poor	73.38	Poor	71.65	Poor

Table 7: Results of two-way ANOVA for various water quality related traits according to season. The two-way ANOVA was performed on the basis of different collection sites, season and their interactions.

Variables		Sum of squares	Df	Mean square	F	P value	% of total variation
Temperature (^o C)	<i>Site</i>	19.940	7	2.849	0.175	ns	0.374
	<i>Season</i>	4138.000	2	2069.000	127.400	***	77.600
	<i>S * T</i>	4.991	14	0.357	0.022	ns	0.094
	<i>Error</i>	1169.000	72	16.240			
Depth (cm)	<i>Site</i>	18904.000	7	2701.000	5.147	***	20.380
	<i>Season</i>	30748.000	2	15374.000	29.300	***	33.150
	<i>S * T</i>	5327.000	14	380.500	0.725	ns	5.744
	<i>Error</i>	37775.000	72	524.600			
pH	<i>Site</i>	7.258	7	1.037	3.202	**	18.580
	<i>Season</i>	3.716	2	1.858	5.738	**	9.510
	<i>S * T</i>	4.787	14	0.342	1.056	ns	12.250
	<i>Error</i>	23.310	72	0.324			
TDS (mg/l)	<i>Site</i>	66861.000	7	9552.000	1.934	ns	13.410
	<i>Season</i>	7944.000	2	3972.000	0.804	ns	1.594
	<i>S * T</i>	67934.000	14	4852.000	0.982	ns	13.630
	<i>Error</i>	355669.000	72	4940.000			
Dissolved oxygen (mg/l)	<i>Site</i>	12.800	7	1.828	0.481	ns	3.371
	<i>Season</i>	53.900	2	26.950	7.090	**	14.200
	<i>S * T</i>	39.230	14	2.802	0.737	ns	10.330
	<i>Error</i>	273.700	72	3.801			
Electric conductivity (uS/cm)	<i>Site</i>	217686.000	7	31098.000	1.774	ns	12.700
	<i>Season</i>	21038.000	2	10519.000	0.600	ns	1.227
	<i>S * T</i>	213090.000	14	15221.000	0.868	ns	12.430
	<i>Error</i>	1262471.000	72	17534.000			
Salinity (mg/l)	<i>Site</i>	61566.000	7	8795.000	1.784	ns	13.050
	<i>Season</i>	1144.000	2	571.900	0.116	ns	0.243
	<i>S * T</i>	53906.000	14	3850.000	0.781	ns	11.430
	<i>Error</i>	355025.000	72	4931.000			
Chloride (mg/l)	<i>Site</i>	353.800	7	50.540	0.177	ns	1.043

Total Alkalinity (mg/l)	<i>Season</i>	12521.000	2	6260.000	21.900	***	36.910
	<i>S * T</i>	473.600	14	33.830	0.118	ns	1.396
	<i>Error</i>	20578.000	72	285.800			
	<i>Site</i>	1611.000	7	230.200	0.634	ns	4.005
	<i>Season</i>	11607.000	2	5804.000	15.990	***	28.850
	<i>S * T</i>	885.600	14	63.260	0.174	ns	2.201
	<i>Error</i>	26134.000	72	363.000			

(* p < 0.05; ** p < 0.01; *** p < 0.001; ns = non-significant)

Figure 1: Geological map of the study area

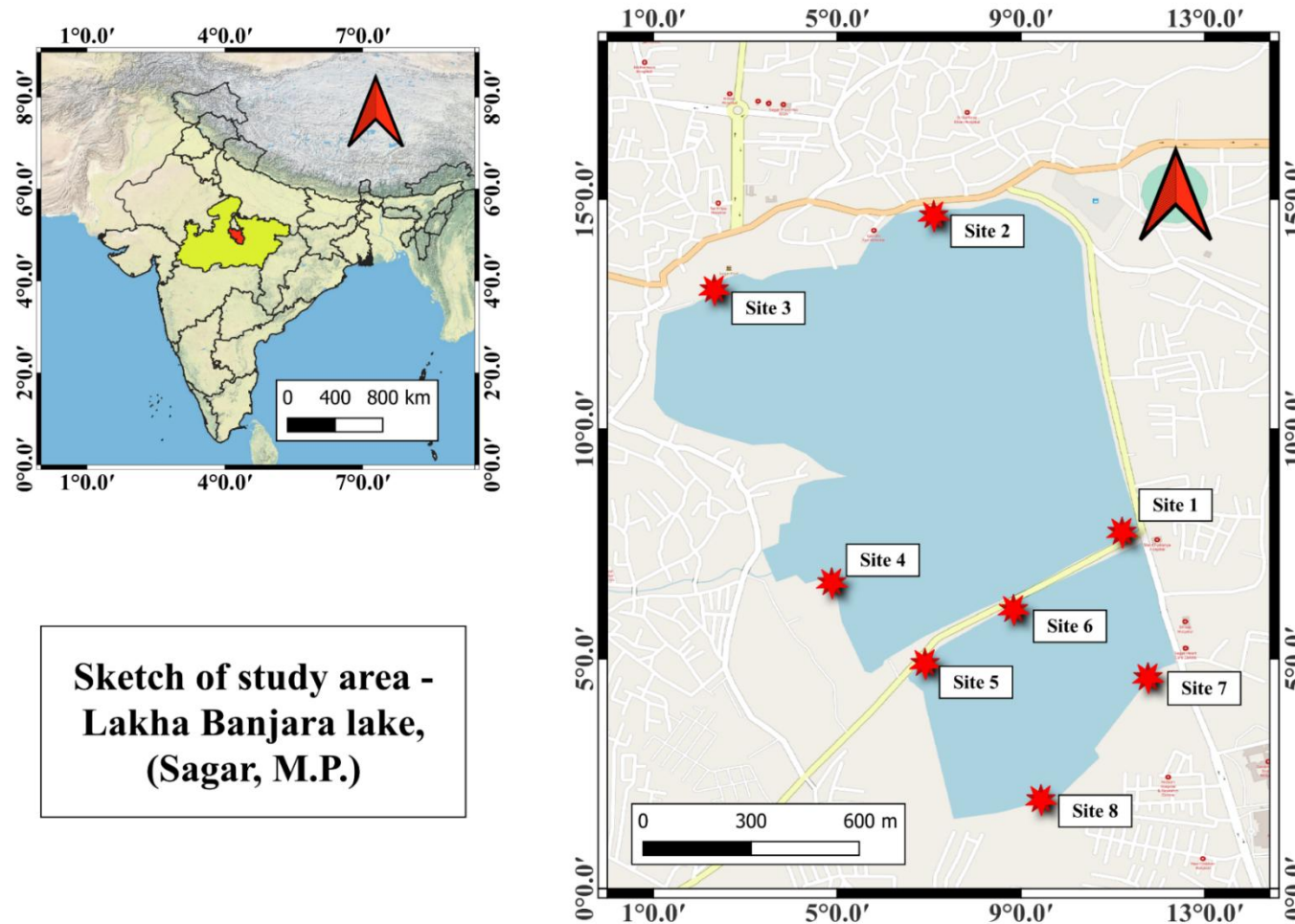


Figure 2: Changes in the level of various physiochemical parameters according to season a) Temperature, b) Depth, c) pH, d) Total dissolved solids, e) Dissolved Oxygen, f) Electric conductivity, g) Salinity, h) Chloride, and i) Total alkalinity

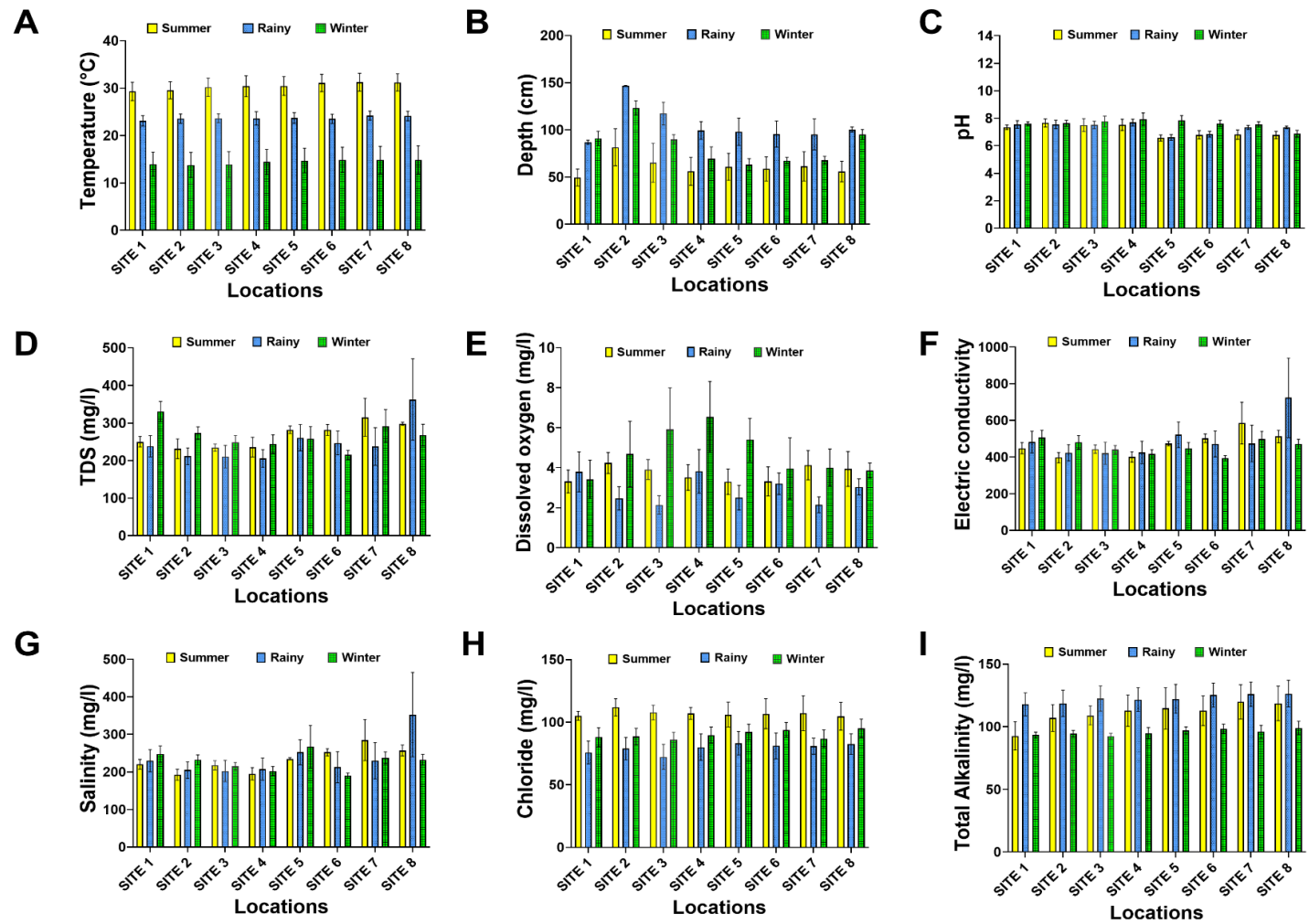


Figure 3: WQI of designated locations along the Sagar-lake.

