Indian Journal of Ecology (2024) 51(6) (SI): 1573-1579
DOI: https://doi.org/10.55362/IJE/2024/4443

Manuscript Number: 4443
NAAS Rating: 5.38

Spatiotemporal Fluctuation in Water Quality Parameters and Correlation with Phytoplankton Community at Sambhar Salt Lake, India

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Abstract: This research brings input on information regarding the effects of seasonal fluctuation in the physicochemical properties of water and phytoplankton communities. Water quality parameters and nutrients, including water temperature, pH, total alkalinity, DO, conductivity and heavy metals were quantitatively monitored from 2020 to 2021 and exhibited significant differences between locations and seasons. Based on the observed data of the temporal and spatial variations of physicochemical properties and phytoplankton abundance chlorophyceae, cyanophyceae and bacillariophyceae were the predominant groups, respectively. Heavy metals revealed the presence of cadmium, zinc, iron, lead, manganese and chromium and were found above the upper permissible limit (as per Indian standard IS 10500: 2012). The comparative analysis using the Pearson's correlation, the results showed that most phytoplankton group's density significantly correlates with water parameters. These results suggested that seasonal differences are major factors influencing water quality causing algal bloom and increased amount of heavy metals which should be taken as important criteria under consideration for effective water management. Therefore, strengthening the supervision for controlling damage to India's largest inland saline lake and the Ramsar site is urgently needed.

Keywords: Ramsar site, Seasonal fluctuations, Physicochemical parameters, Phytoplanktons, Correlation

Saline lakes are widespread globally in diverse sizes and found in arid and semiarid climates. These are mainly fed by small streams or rainfall with water lost by seepage or evaporation. The water chemistry of saline lakes fluctuates with seasons, time, temperature and other climate factors. Ensuring water security and accessibility is vital to the well-being of all living organisms and essential for the preservation of natural ecosystems worldwide (Devi and Tiwari 2024). Saline lakes, despite being widely distributed, have received less attention in terms of characterization compared to freshwater lakes (Baatar et al 2017). Due to the increasing discharge of industrial, municipal, and agricultural wastewater, the water quality of the lake has degraded (Elshemy 2016). Wetlands are widely recognized as dynamic ecosystems with diverse features, including unique biodiversity that provide abundant shelter and food for bird populations year-round (Harshavardhan and Girish, 2024). The health of aquatic ecosystems is entirely dependent on the correct proportions of nutrients in water and sediment. It is absolutely crucial to maintain this balance to preserve water quality and sustain life (Tibebe et al 2022). The study was conducted in India's largest inland saline lake which is most valuable for commercial salt production sources using several multi-pond solar salt pans. At the moment the lake is undergoing rapid industrialization and urbanization suffering from exposure to high inputs of domestic, industrial and agricultural pollutants. The brines are enriched with phytoplanktons and other microbes that facilitate a unique opportunity to study microbial successions along salinity gradients similar to the transition in water quality of the hypersaline lake. At present very limited Microbial exploration study with isolation and culture of halophilic bacteria from different bioprospecting outlooks of Sambhar lake is performed (Cherekar and Pathak 2016).

The degradation of water quality poses a threat to both aquatic life and human health by affecting underground water quality. It is important to consistently monitor spatiotemporal variations in water quality parameters and biological characteristics in order to gain a comprehensive understanding of a lake's environmental conditions (Maansi and Wats 2022). The quality of groundwater in a specific area varies depending on physical and chemical parameters, which are significantly affected by geological formations and human activities (Ganiyu et al 2018). Water pollution is a global environmental issue that causes a decline in water quality (Xu et al 2019). Effectively preventing and controlling eutrophication is of utmost importance to uphold the overall water quality and ensure the safety of the aquatic biota (Wei et al 2022).

Phytoplankton contributes 95% of primary production in aquatic ecosystems and is a natural bioindicator for water quality assessment. It responds rapidly to environmental changes, making it useful for assessing temperature, pH, salinity, nutrients, and turbidity concerning contamination (Clark et al 2017). Certain types of algae are crucial for purifying water bodies contaminated with organic waste.

Industrial waste can be recycled by producing microalgae using industrial wastewater, creating new sources of raw materials for various purposes. Pollution, ecological conditions, and human impact can affect the characteristics and growth of phytoplankton (Neelam et al 2019). Thus, phytoplankton based biomonitoring can be employed as an efficient, quick and affordable method for estimating water pollution (Konanc 2023, Subbaiah and Kaledhonkar 2024). To the best of our knowledge no seasonal and spatial fluctuation in microbial community and water quality parameters has been studied to date to understand the correlation of this very distinctive lake. Therefore, the present study, analyzes the temporal and spatial changes in water quality and vegetation coverage with the impact and apparent relevance of physicochemical properties on phytoplankton communities is discussed to develop and conserve this wetland.

MATERIAL AND METHODS

Site location: Sambhar lake, the largest inland hypersaline lake (Latitude 26.5760 N and Longitude 75.0500 E) in Rajasthan, India, with a catchment area of 230 km^2 is located in the eastern part of Rajasthan state in a closed depression of Aravalli schists (Bhatt et al 2016, Sinha 2004). The only Hypersaline Lake in India was declared a Ramsar site (wetland of international importance) in 1990 for hosting thousands of migratory birds including famous pink flamingos from northern Asia and Siberia every year. Sambhar salt lake falls in the rain shadow of the southwest monsoon, receiving an average annual rainfall ranging from 100 to 500 mm. The lake basin is primarily fed by atmospheric precipitation and seasonal streams, namely Mendha and Roopangarh rivers, during the monsoon season from July to September. Samples were collected from various locations at Devyani kyars and near pump house. Precipitations leaves kyars concentrated in salinity resulting pink color and other kyar rich with algal bloom in green color.

Sample collection and analysis: Brine samples were collected in all seasons of year 2020 and 2021 from different collection sites enriched with microflora. The microalgal diversity and color of brines change with seasons throughout the year with salinity ranging from 10.0-30.0 (% w/v, NaCl) and high pH (8-11). The lake water was sampled for physicochemical and biological analysis in prewashed plastic bottles from areas with different degrees of brine concentration. The temperature, pH and color of water samples were measured using a laboratory glass thermometer and pH meter respectively at the collection point. Ammonical nitrogen, COD (Chemical oxygen demand), BOD (biological oxygen demand), electrical conductivity, total hardness, total alkalinity, and dissolved oxygen were measured at laboratory according to APHA (Anonymous 1996). The presence of heavy metals was estimated by AAS (Atomic absorption spectrophotometry) (Bhateria and Jain, 2016). Permissible limit studies on physico-chemical characteristics were determined as per Indian standards (IS 10500: 2012) (Sankaranarayanan et al 2021).

The microscopic analysis was carried out to find out the presence of microalgae. Different algae cells were identified using a fluorescent microscope with inverted digital microphotography (Leica-1000) at 40X and 100X magnification as per the morphological description given by Iyenger and Desikachary (Raji and Abraham, 2018).

Statistical analysis: A two-way ANOVA test was used to analyze the collected data. A two-tailed Pearson product-moment correlation was performed using SPSS version 22 with Duncan's multiple range test.

RESULTS AND DISCUSSION

Physicochemical analysis of water: The water temperature varied between 5°C and 29°C at different sites. Minimum value was in December on site II while maximum in June at site I. The phytoplankton diversity and succession are affected by these variations of temperature. The positive correlation was studied between cyanophyceae and temperature (Table 2). The positive correlation between chlorophyceae and cyanophyceae group and temperature was reported by Deyab et al (2019). In most sites, salinity variations were due to the brine used for salt production. Salinity was highest at in summer and may be due to the high evaporation rate and lowest in September because of dilution with rain water. The maximum was at site II while minimum at site II. High salinity indicates increased pollutants in discharged water. The salinity was correlated negatively with phytoplankton groups as less number of algae were reported when salinity was highest in summer. There weak correlation with BOD, TN, Cr and was moderately correlated with Zn.

The mean Ammonical nitrogen (AN) ranged between 3 and 29.35 mg/L throughout the year. Minimum value of Ammonical nitrogen reported in summer at site I while maximum in winter at site III. Same results were observed by Gammal et al (2017). Bacillariophyceae and DO were correlated positively with ammonia while negatively correlated with pH COD and BOD. It is a decomposed product of organic nitrogen by bacteria showed maximum degradation in winter season. High pH was in winter season at 9.9 and lowest in rainy season 7.3. The variation in pH values shows high productive nature of the lake water (Gyanendra and Alam, 2023). All sites were reported alkaline may be due to domestic and agricultural runoff with lowest value at site I and highest at site IV. The pH value showed a positive correlation with Bacillariophyceae in winter while weak correlation with Mn. It was negatively correlated with Hardness, Mg and TN.

The COD varied between 154 to 706 mg/L. Maximum value was reported at site II while minimum at site I. The positive correlation was between COD and BOD and Cl. COD values indicated negative correlation with phytoplankton groups and total hardness, DO, TN. BOD (biological oxygen demand) is influenced by time and temperature. The level of pollution in a body of water is directly proportional to the BOD and was highest at site II with mean of 56.33 in rain and lowest with 23 mg/L at site I. It was positively correlated with cyanophyceae while negatively correlated with temperature and AN. BOD was significantly positive correlated with salinity and pH.

Chloride was lowest at site II with a mean of 5139 and highest at site IV with 127300 mg/L. The presence of chloride was decreased during the rainy season due to dilution and indicated a positive correlation with conductivity and salinity. Chloride showed moderate correlation with phosphate and negative correlation with phytoplankton groups in summer. The annual mean ranged between 1327 to 29788 mg/L. It was reported maximum in the winter season at site III and a minimum in the rainy season at site I.

Sulphate not only impairs the quality of drinking water, but also impacts the cycling of carbon, nitrogen, and phosphorus. This can lead to increased nutrient levels in water bodies, promoting the growth of plants and algae, and providing more food for aquatic organisms (Melese and Debella 2023). The average annual value of sulphate was 11453.31 mg/L with a mean minimum of 1327.5 and a mean maximum of 29788 mg/L. It was detected minimum in rain and maximum in winter at site III. Sulphate indicated negative correlation with Mg and TN and weak correlation with AN. Chlorophyceae and bacillariophyceae were positively correlated with Sulphate.

The annual mean conductivity was 14440 µs/cm low at site I in September month and high at site III. It was increased in summer with 333000 in May. Conductivity was attributed to the biogeochemical cycle, biodegradation and human activities and high dissolved solids resulted decrease in phytoplankton growth (Rus et al 2020). The positive correlation was reported between conductivity with salinity, chloride and sulphate and negative correlation with chlorophyceae, cyanophyceae, temperature and Mg. The total alkalinity mean ranged 448 to 17140 mg/L. The lowest value was during rainy season while the highest was in winter. It was positively correlated with all phytoplankton

Table 1. Seasonal fluctuation in physicochemical parameters

Para/ month	Temp	Sal	AN	pH	COD	BOD	Cl	SO_4	Hard	Mg	Con	ALK	DO	TN	Phos	Cd	Fe	Pb	Mn	Cr	Zn
January	7.66	143.88	7.26	9.11	609	46.66	79700	29788	1256	220.33	331000	9333.33	3.8	509.07	886.05	0.10	14.51	0.81	0.86	0.34	1.68
February	17.5	141.55	14.85	9.44	501.5	23	78400	13227.5	1350	245	274500	9055	5.0	694.87	843.14	0.02	10.63	2.54	0.81	0.28	2.01
March	8.5	229.8	21.6	8.75	627.5	53.5	127300	7336.5	365	65	374000	9590	3.4	501.74	494.37	-	4.63	1.03	0.52	0.45	1.46
April	12	204.4	24.65	8.97	487.5	40	113250	10250	318	47.5	323500	10820	4.2	523.54	432.94	0.08	2.61	0.94	0.58	0.35	0.34
May	14.5	204.8	29.35	8.68	568.5	42	116740	10885.5	91.5	37	333000	13570	4.1	403.52	387.06	0.56	3.15	0.98	0.60	0.32	0.43
June	28.5	122.58	7.15	9.75	594.5	43	67900	7204.5	45	7.5	204000	5635	3.9	432.75	356.28	0.16	7.69	0.24	0.34	0.23	0.48
July	23.5	96.04	3	9.27	595	51	108600	12852	90	15	292500	17140	2.9	785.98	313.65	0.28	4.39	0.39	0.36	0.33	0.60
August	21	87.74	7.06	9.04	593	56.33	46935.67	5094	58.66	34.66	131433.3	2125.33	2.6	867.49	224.65	0.21	1.25	0.72	0.23	0.05	0.81
September	21.5	9.3	9.8	8	193	27	5139	1327.5	54	30	14440	448	3.6	883.01	232.44	-	8.39	-	0.14	0.05	0.14
October	18.33	66.38	14.8	8.79	421.33	41	36766.67	6444	1134.66	769.33	116745	3500	3.8	763.02	432.67	0.19	13.64	0.14	0.83	0.58	0.90
November	12	66.69	20.93	8.57	392	37.33	36933.33	6211.66	1413.33	215	128333.3	5933.33	4.6	643.76	675.87	0.19	14.8	0.05	0.83	0.14	1.44
December	5.5	108.14	15.15	9.28	504	39	59900	26818.5	115	20	209000	9470	4.9	612.03	857.55	0.18	10.1	0.14	0.72	0.27	1.94

Table 2. Pearson's correlation between phytoplankton groups and physicochemical parameters

	CH	CY	BA	Temp	Sal	AN	pH	COD	BOD	Cl	SO_4	Hard	Mg	Con	Alk	DO	TN	Ph	Cd	Fe	Pb	Mn	Cr	Zn
CH	1																							
CY	0.483	1																						
BA	0.580	0.22	1																					
Temp	0.387	0.295	0.601	1																				
Sal	0.390	0.564	0.149	0.425	1																			
AN	0.300	0.580	0.098**	0.519	0.575	1																		
pH	0.103	0.344	0.194	0.186	0.279	0.348	1																	
COD	0.257	0.269	0.009	0.106	0.668	0.067	0.690	1																
BOD	0.208	0.172	0.220**	0.038	0.302**	0.178	0.190	0.701	1															
Cl	0.408	0.434	0.242	0.266	0.908	0.376	0.347	0.730	0.407	1														
SO_4	0.519	0.204	0.787	0.595	0.246	0.126	0.431	0.401	0.063	0.258	1													
Hard	0.070	0.368	0.590	0.317	0.085	0.099**	0.008	0.123	0.340	0.183	0.205	1												
Mg	0.251**	0.306	0.378	0.043	0.249	0.038	0.105	0.219	0.172	0.317	0.052	0.684	1											
Con	0.282	0.490	0.005	0.412	0.912	0.330	0.408	0.757	0.339	0.956	0.470	0.007	0.240	1										
Alk	0.162	0.354	0.006	0.244	0.602	0.212	0.358	0.562	0.227	0.838	0.455**	0.103	0.288	0.814	1									
DO	0.193	0.641	0.548	0.431	0.121	0.476	0.134	0.249	0.721	0.056	0.345	0.452	0.150**	0.072	0.089	1								
TN	0.356	0.771	0.070	0.357	0.771**	0.516**	0.317	0.510	0.132	0.630	0.343	0.003	0.204	0.692	0.452	0.370	1							
Phos	0.423*	0.445	0.877**	0.683	0.188	0.126	0.303	0.141	0.311*	0.072*	0.766	0.650	0.196	0.319	0.217	0.722	0.314**	1						
Cd	0.202	0.022	0.392*	0.099	0.201	0.353	0.426	0.219	0.354*	0.323	0.196	0.473	0.203	0.129	0.351	0.263	0.223	0.467	1					
Fe	0.240	0.283	0.772	0.254	0.420	0.134	0.040	0.343	0.435*	0.501	0.332	0.786	0.613	0.292	0.268	0.514	0.033	0.652	0.406	1				
Pb	0.041**	0.094	0.078	0.052	0.483	0.182	0.170	0.183	0.453	0.388	0.037	0.245	0.072	0.483	0.189	0.241	0.043	0.270	0.254	0.164	1			
Mn	0.006	0.676	0.748	0.623	0.238	0.381**	0.158**	0.107	0.235	0.124	0.534	0.810	0.591	0.312	0.236	0.669	0.354	0.819	0.272	0.674	0.143	1		
Cr	0.435	0.637	0.184	0.293	0.475**	0.282	0.181	0.336	0.185	0.504	0.241	0.276	0.574	0.527	0.424	0.097	0.370	0.217	0.017	0.158	0.010	0.544	1	
Zn	0.444	0.275	0.778	0.612**	0.135*	0.012	0.318	0.249	0.112	0.038	0.607	0.601**	0.216	0.247	0.108	0.503	0.104	0.891	0.484	0.542	0.302	0.686	0.183**	1

Ch. Chlorophyceae, Cy. Cyanophyceae, Ba. Bacillariophyceae.
*Significant correlation at $p<0.01$, **significant correlation at $p<0.05$, bold text indicates negative correlation

groups. Total alkalinity was moderately correlated with temperature, hardness, Mg, TN and Fe.

Nitrate is considered as predominant and most stable inorganic nitrogen form in salt water bodies and known as one of the main nitrogen sources for phytoplankton while the intermediate oxidation state between nitrate and ammonia makes nitrite concentrations useful in the aquatic system. High annual mean value of total nitrogen (TN) was detected at site III, while low values were detected at site II. It showed positive correlation with Chlorophyceae and Bacillariophyceae while negatively with BOD, Cl, conductivity, alkalinity and DO. TN at all sites increased from June to September as nitrifying bacteria increased with water temperature. The oxidation–reduction reactions of bacterial activity affected the concentration of total nitrogen in Lake area. The annual TN varied between 432.75 to 883.01 mg/L. Total nitrogen showed a correlation with cyanophyceae may be related to dependency on nitrogen. Deyab et al (2019) observed the highest values of TN in rainy season.

Phosphorus is considered an essential element for the primary production and growth of phytoplanktons. The annual mean value of phosphate ranged from 224.65 to 886.05 mg/L in the rainy season (minimum) and 0.8 to 6.05 mg/L in winter (maximum). It was reported positively correlated with chlorophyceae and BOD while weakly correlated with bacillariophyceae and TN. The cyanobacterial blooms occurrence is closely linked to the contents of phosphorus and nitrogen in water (Tang et al 2021). Excessive use of fertilizers in agriculture contributes greatly to water pollution due to nitrogen and phosphorus concentrations (Sarkar et al 2020). According to Margalef the phosphorus concentration ranged 0.2 to 2.8 mg/l is suitable for phytoplanktons especially bacillariophyceae and cyanophyceae (Rahman et al 2015). It was maximum at site III and minimum at site I.

Dissolved oxygen is essential for a well-balanced aquatic life. The concentration above 5 mg/L of dissolved oxygen is considered suitable for aquatic animals (Baleta and Bolaños 2016). During summer and autumn, there is almost no vertical water circulation due to thermal stratification and mineral stratification occurring at significant depths. This results in a reduction of the amount of dissolved oxygen (DO) towards the lake's bottom. This action has the potential to upset the delicate balance of aquatic ecosystems and harm the quality of water (Avram et al 2022, Xu et al 2022). Dissolved oxygen was reported less than 5 gm/l at most of the sites. The mean value of DO ranged between 2.6 to 5.0 mg/L at all sites. The maximum was observed in winter while minimum in August. DO has positively correlation with chlorophyceae and bacillariophyceae while negative correlation with temperature, BOD, COD, TN, Cd and weak correlation with Mg. A rise in urbanization and population growth results in stochastic anthropogenic nutrient supplies to the water, causing depletion of the aquatic oxygen supply (BR and Sivakumar 2024).

Apart from heavy metals, pollutants such as fluorides (F^-) and nitrates (NO_3^-) can harm human health and aquatic ecosystems (Githaiga et al 2021). Trace metal concentration was recorded by collecting water samples once a month seasonally. The results revealed the presence of cadmium, zinc, iron, lead, manganese and chromium. Cadmium was in upper permissible limit from 0.027 to 0.56 mg/L and was completely absent in March and September. Positive correlation was observed between cadmium and cyanophyceae but negative with chlorophyceae and bacillariophyceae. It was significantly correlated with BOD, Cl and Cr. Iron (Fe) ranged between 1.2 to 14.5 mg/L. It was reported positively correlated with chlorophyceae, bacillariophyceae, SO_4 and hardness. lead (Pb) and was between 0.24 to 2.5 mg/L maximum at site III in winter and lowest at site I in summer season. The positive correlation was observed between salinity, pH and COD but negative correlation with all phytoplankton groups with BOD and Cd. Manganese (Mn) was minimum at site II with mean value 0.14 mg/L and maximum 0.86 mg/L in winter season. Mn was positively correlated with bacillariophyceae, moderately correlated with AN, pH but negatively correlated with BOD and TN. Chromium (Cr) ranged between 0.51 to 0.58 mg/L. Waste from chromate-processing facilities can contaminate water bodies if improperly disposed of in landfills where chromium may be deposited for several years. Cr was positively correlated with bacillariophyceae and all presented heavy metals but negatively correlated with temperature and TN. Zinc (Zn) is an essential element for animals and plants but its presence in excess amounts may be harmful (Baricz et al 2021). The values of Zinc varied from 0.1 to 2.01 mg/L. The positive correlation was studied between chlorophyceae and bacillariophyceae while a negative correlation with BOD and TN. The significant correlation was with temperature, salinity and hardness. The presence of cadmium, chromium, manganese and lead was in upper permissible limit throughout the year. These results of fluctuation in physicochemical parameters with seasons attributed to the impact of various contamination sources.

Biological analysis: Chlorophyceae also known as blue green algae plays a crucial role in the global nitrogen, carbon and phosphorus cycle due to its high tolerance for weather conditions. Cyanophyceae, found in this study is a group of major photosynthetic organisms that is found in various aquatic environments. The cyanophyceae has photosynthetic pigments that result in a distinct turquoise color. Certain groups of cyanophyceae have the ability to fix nitrogen, which makes them significant for aquatic environments (Arsad et al 2021). Cyanophyceae are highly sensitive to copper, cadmium, and zinc metals (Agawany and Kaamoush 2023). To study the presence of halophilic microalgae the water samples were collected from brines of the Sambhar Lake area in all seasons of the year 2020 and 2021. The variety of colors indicated the dominance of algal diversity during the winter season (green and orange color) and bacterial diversity was dominant (pink color) in summer depending on pH and salt concentrations. Depending on pH and salt concentrations, a variety of colors showed that microalgal diversity was predominated in the winter (green and orange color).

Three phytoplankton groups were identified in all seasons. Chlorophyceae, cyanophyceae and bacillariophyceae were the predominant groups. Cyanophyceae was maximum in number followed by Chlorophyceae. The maximum number of total phytoplankton was in winter at site II and III while the minimum in rainy season at site I. The growth of chlorophyceae and cyanophyceae algae was heightened by the availability of Nitrogen and Phosphorus content in the winter and rainy seasons at all collection sites. These elements limited the primary productivity of algal biomass in the lake area (Carstensen et al 2018). Phosphorus is considered an essential element for the primary production and growth of phytoplankton in aquatic ecosystems (Turner et al 2023). The positive correlations were observed between the physicochemical parameters and biomass of most phytoplankton groups (Table 2). Members of chlorophyceae were positively correlated with cyanophyceae and bacillariophyceae. Chlorophyceae was moderately correlated with phosphate, Mg, DO, TN, alkalinity. Cyanophyceae phytoplanktons showed a significant correlation with temperature, BOD, alkalinity and TN. Bacillariophyceae indicated a positive correlation with pH, sulphate, conductivity and DO and a moderate correlation with AN, BOD, phosphate and Cd. According to this research all phytoplankton groups reported positive correlation with each other.

CONCLUSION

The physicochemical parameters investigated in the present study showed variability depending on season and location and correlation with phytoplankton groups. The high concentrations of physicochemical parameters during the dry seasons in the lake area were due to the low incidence of rainfall that may be caused by overexploitation of catchment areas for salt production and climate change**.** Three Phytoplankton groups were identified on most of the studied sites during all seasons and considered as natural bioindicators of pollution and water quality status due to their high proliferation rate, ease of handling and low cost.

The variability of different physicochemical parameters affected phytoplankton distribution and had a significant positive relationship with water pH, temperature, salinity, nitrogen, total alkalinity, ammonia and phosphorus. However, the information gathered from this study can serve as a baseline for additional research in the future, which can be utilized to monitor the situation, make management plans, and create mitigating measures for the conservation of water and biodiversity.

ACKNOWLEDGEMENTS

The authors thank to Rajasthan State Pollution Control Board (RSPCB) for providing laboratory facilities to analyse physicochemical parameters.

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Received 07 August, 2024; Accepted 22 November, 2024