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Assessment of Physico-Chemical Parameters of Lonar Lake Water with Reference to Seasonal Variations

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ABSTRACT

Study of physico-chemical analysis helps in assessing water quality, detecting pollution sources, and understanding seasonal or anthropogenic changes in the ecosystem. It also provides insight into trophic status (oligotrophic, mesotrophic, or eutrophic) and helps predict ecological responses to environmental stress. Lonar Lake, which having unique saline and alkaline characteristics, therefore, the present study was carried out to assess the quality of Lonar Lake water, which is an important criterion for evaluating its aquatic health and ongoing environmental changes. Total 23 physico-chemical parameters were studied for the pre-monsoon and post-monsoon periods, i.e., June 2024 and December 2024 respectively. Water samples were collected and analyzed for various parameters such as, Color, Odor, Temperature, Electrical Conductivity, Turbidity, Total Solids, Total Dissolved Solids, pH, Total Alkalinity, Total Hardness, Calcium, Magnesium, Salinity, Chloride, Sodium, Sulfate, Nitrate, Silica, Phosphorous, Potassium, Chemical Oxygen Demand, Biological Oxygen Demand, Dissolved Oxygen. The water samples were taken from four different sampling stations and analyzed using the standard methodology. The results showed variations in the parameters due to anthropogenic activities, climatic conditions and continuous inflow of freshwater stream inside the crater lake.

Keywords Physico-chemical properties, Lonar Lake, Pre-post monsoon, Environmental stress, Anthropogenic, Trophic status.

INTRODUCTION

The Lonar Crater Lake is located at 19°58’ North and 76°31’ East in Buldhana, Maharashtra, India. It was formed by a hypervelocity meteorite impact crater in basaltic rock with distinct features, including being highly saline and alkaline (Fredriksson *et al.* 1973). Lonar is globally recognized as an ecological wonder and a unique research site, due to several factors. The Lake is scientifically important for its studies of adaptation as it is a place of specialized life under extreme conditions (saline and alkaline). The lake has a unique saline and alkaline nature that supports diverse and specialized microbial communities adapted to its extreme environmental conditions (Nimonkar *et al.* 2022).

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Lonar Lake is one of the youngest, and best preserved, impact craters on Earth. The lake has unique water properties and is a hydrologically active body of water. Hence, it was designated as a Wildlife Sanctuary in 2000 and India's 41st Ramsar Site in 2020. Considering the importance of the Lonar Lake which is unique ecological and geological system owing to its exceptional flora and fauna, distinctive geoclimatic conditions, and unusual water chemistry. Its saline-alkaline nature, impact-crater origin, and specialized biodiversity make it one of the most remarkable inland aquatic ecosystems in India (Shinde and More 2013; Antony *et al.* 2013). Hence, the present research work has been carried out by collecting water samples from four selected sites in the Lonar Lake. As the lake has a meteoritic origin, it is essential to continuously monitor water quality and preserve this ecological wonder for future generations.

Continuous monitoring of physico-chemical parameters such as pH, dissolved oxygen, turbidity, hardness, alkalinity, chlorides, nitrates, and microbial load is essential for assessing water quality and ecosystem health (Trivedy R. K. and Goel, P. K. (1984). Chemical and biological methods for water pollution studies). Regular monitoring, together with effective water management, sanitation practices, and pollution control measures, is necessary to ensure the sustainable use and conservation of aquatic resources (APHA 2017). Phosphorus was often the limiting nutrient in freshwater systems and played a key role in eutrophication. Human activities have a profound impact on the physico-chemical properties of lake water, often leading to environmental degradation. Thus, the hydrological assessment revealed deteriorating changes in water quality due to various factors like pollution, climate change and anthropogenic activity (Smith and Schindler 2009).

MATERIALS AND METHODS

Study Area: This study assessed water quality in Lonar Lake in June 2024 and December 2024, i.e., the pre-monsoon and post-monsoon seasons, respectively. Total eight samples were collected from four different sampling stations during the study period in the early morning from the periphery of the Lonar Crater Lake. The samples were collected from the above-mentioned sampling sites: Kamalajadevi Temple, Mor Mahadev Temple, Wagh Mahadev Temple, and Vishnu Temple, denoted by blue signs labeled S1, S2, S3 and S4, as mentioned in Fig. 1.

Water samples were collected from different selected sampling sites of Lonar Lake to assess the physico-chemical characteristics. Samples were collected in washed, wide-mouth plastic cans during the pre-monsoon and post-monsoon seasons at early morning hours. Some parameters, such as Temperature, pH, TDS, Electrical Conductivity, and Dissolved oxygen, were analyzed *in-situ* at sampling site using handy meters, and the remaining parameters were analyzed in the laboratory empirically. Collected samples were stored in a cool and dark place and were analyzed using standard procedures described by APHA (2017), Trivedy and Goel (1984). Parameters such as Color is determined by visual comparison and Odour is generally determined by sensory observation. Temperature, Electrical conductivity, TDS, and pH were measured using calibrated digital instruments and recorded in the field. Total solids were determined using gravimetric method. Total alkalinity and total hardness were determined by titrimetric methods, while calcium and magnesium were estimated using appropriate complexometric method. Chloride was determined by argentometric titration. Sodium and potassium were analyzed by flame emission photometry, whereas sulphate, nitrate, silica, and phosphorus were determined by spectrophotometric method. Chemical oxygen demand (COD) was determined by the dichromate oxidation method, while biochemical oxygen demand (BOD) was determined from the decrease in dissolved oxygen during the prescribed incubation period.

Dissolved oxygen was estimated by the Winkler iodometric method to determine dissolved oxygen (DO) in water. The dissolved oxygen (DO) concentration is calculated using the formula DO (mg/L) = ($V_t \times N_t \times 8000$) /$V_S$, where V_t represents the volume of sodium thiosulfate used during titration in millilitres (mL), N_t is the normality of the sodium thiosulfate solution (0.025N), and V_s is the volume of the water sample titrated in milliliters (300 mL). The factor 8000 represents the equivalent weight conversion factor for oxygen and is used to express the final



Fig. 1. Google Earth image showing sampling sites of the Lonar Lake.

dissolved oxygen concentration in milligrams per liter (mg/L).

RESULTS AND DISCUSSION

In the present study, a total of 23 physico-chemical parameters were analyzed from the four selected sites, namely S1, S2, S3, and S4 (shown in Table 1 & Fig.1), during June 2024 and December 2024 (pre-monsoon and post-monsoon seasons) in the periphery of Lonar Crater Lake. The results from the water-sample analysis are presented in Table 2.

Physico-chemical Characteristics

1) Color: The water was light to dark green in color in all the sampling stations in both the seasons. The greenish color may indicate an algal bloom and

Table 1. Samplings sites of the study area with their geographical coordinates.

Sl. No.	Sampling Site	Location	Latitude	Longitude
1	S1	Kamalajadevi Temple	19.971737° N	76.512217° E
2	S2	Mor Mahadev Temple	19.971143° N	76.510454° E
3	S3	Wagh Mahadev Temple	19.972126° N	76.512334° E
4	S4	Vishnu Temple	19.976752° N	76.513932° E

Table 2. Imperial values of Water samples from study area for Pre- Monsoon and Post Monsoon period.

Sr. No.	Parameter	Unit	Pre-Monsoon 2024				Post-Monsoon 2024				Permissible limit
			S1	S2	S3	S4	S1	S2	S3	S4	
1	Color	-	Light Green	Dark Green	Dark Green	Dark Green	Light Green	Dark Green	Dark Green	Light Green	
2	Odor	-	Offensive	Offensive	Offensive	Offensive	Offensive	Offensive	Offensive	Offensive	
3	Temperature	(°C)	29	28.5	29	28.9	26	26	26	27	-
4	Electrical Conductivity	(µS/cm)	496.2	744.1	800.3	796.8	682	710	739	747	-
5	Turbidity	NTU	1.3	0.6	3.7	1.2	0.9	0.1	1.3	0.2	< 1
6	Total Solids	mg/l	4536	4132	5352	4313	4130	4084	4454	4324	< 100

Table 2. Continued.

Sr. No.	Parameter	Unit	Pre-Monsoon 2024				Post-Monsoon 2024				Permissible limit
			S1	S2	S3	S4	S1	S2	S3	S4	
7	TDS	mg/l	3839	3882	3903	3930	3255	3463	3541	3168	< 500
8	pH	pH	10.65	10.7	10.73	10.46	9.18	9.5	9.1	8.99	6.5 – 8.5
9	Total Alkalinity	mg/l	680	620	660	570	610	585	590	530	<200
10	Total Hardness	mg/l	158	142	154	146	146	134	142	138	<200
11	Calcium	mg/l	26.45	30.46	16.83	18.43	20.84	24.04	12.82	14.42	< 75
12	Magnesium	mg/l	60.65	43.51	73.84	65.93	61.97	48.78	72.52	67.25	< 30
13	Salinity	mg/l	9600	8450	9530	10250	7125	6842	6235	7743	-
14	Chloride	mg/l	1755.45	1775.44	1689.47	1795.44	1545.45	1559.80	1531.44	1503.08	< 250
15	Sodium	mg/l	1173	1016	1163	1204	980	865	941	1004	< 200
16	Sulfate	mg/l	10.68	10.09	9.80	11.38	8.40	8.16	7.92	8.21	< 200
17	Nitrate	mg/l	10.30	9.26	10.17	19.69	9.13	8.32	10.0	11.12	< 45
18	Silica	mg/l	7.61	7.76	7.80	13.01	5.33	6.47	6.81	9.32	--
19	Phosphorous	mg/l	0.4	0.47	0.42	0.83	0.50	0.54	0.61	0.87	< 0.1
20	Potassium	mg/l	1.9	2.1	2.8	1	0.6	1.1	1.3	0.8	< 10-12
21	COD	mg/l	112.84	128.4	132.29	116.73	92	112	124	108	< 40
22	BOD	mg/l	22.0	24.0	24.0	20.0	19.8	20.4	20.7	17.7	< 10
23	DO	mg/l	0.93	0.86	0.80	1.1	1.3	1.2	1.1		--

high levels of phytoplankton in the water, reflecting high nutrient loading and eutrophication. The study highlighted that the green to pink/red color change of Lonar Crater Lake was primarily attributed to an increase in the salinity and alkalinity of the lake. These conditions augmented the proliferation of microorganisms, particularly of haloarchaea bacteria, which are microorganisms that produce red pigments. This microbial bloom was further intensified by lowered water levels and higher temperatures. The lake was a result of that and the water in the lake had a different shade of pink to reddish color (Jadhav and Mali, 2020).

2) Odor: Smell was observed offensively in all stations which confirmed decomposing organic matter and poor water quality. The characteristic odor of Lonar Lake is primarily associated with its highly alkaline and saline nature, together with intense microbial activity and anaerobic decomposition processes occurring in the lake sediments. The stratified water column and oxygen-deficient bottom layers promote the production of sulfur containing compounds and other metabolic by-products that contribute to the distinctive smell of the lake (Basavaiah *et al.* (2014); Antony *et al.* (2013).

3) Temperature: The water temperature in the pre-monsoon and post-monsoon periods was 28.5°C-29°C and 26°C-27°C, respectively (as shown in Fig. 2). Rainfall and increased water volume with the reduction of atmospheric heating causes

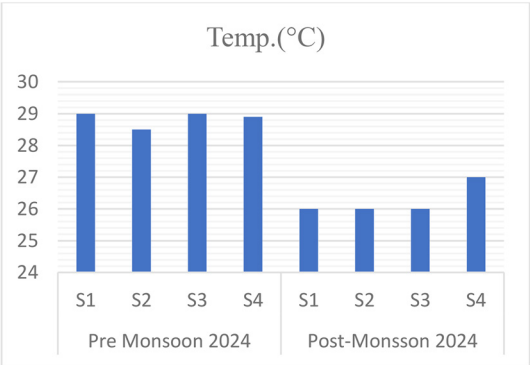


Fig.2. Graphical representation of Temperature for pre-monsoon and post-monsoon 2024.

the decrease in temperature after the monsoon. The temperatures were also within the prescribed range (20-35°C), but high temperatures in the pre-monsoon period could increase the biological activity and oxygen consumption. Jadhav and Mali (2020) mentioned the temperatures were very high, above 42°C- 45°C.

4) Electrical Conductivity: The electrical conductivity values shown in pre-monsoon ranged from about 496 µS/cm-800 µS/cm, whereas during post-monsoon was 682 µS/cm -747 µS/cm (as shown in Fig. 3). High conductivity can be interpreted as a high concentration of dissolved ions and high TDS value. The water in the lake is thus highly mineralized. The conductivity was seen to be higher under the condition of soda lake with high salinity (Surakasi *et al.* 2007).

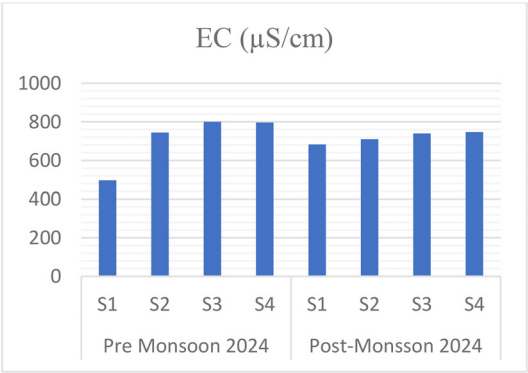


Fig. 3. Graphical representation of EC for pre-monsoon and post-monsoon 2024.

5) Turbidity: Turbidity values varied between 0.6 and 3.7 NTU during pre-monsoon and 0.1 to 1.3 NTU during post-monsoon (as shown in Fig. 4). All values were below the permissible limit, indicating relatively low suspended particulate matter. The reduction in turbidity after the monsoon suggests dilution and settling of suspended particles. Pedge and Ahirrao (2013) reported that turbidity in the water of Lonar Lake increased during the monsoon period due to the influx of suspended solids and surface runoff.

6) Total Solids: The pre-monsoon and post-monsoon total solids were found to be 4132 mg/l-5352 mg/l and 4084 mg/l-4454 mg/l, respectively (as shown in Fig. 5). The values are much higher than the prescribed value (<100 mg/l), which reflects the high level of

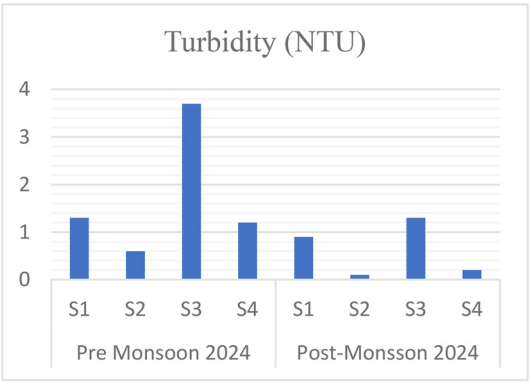


Fig.4. Graphical representation of Turbidity for pre-monsoon and post-monsoon 2024.

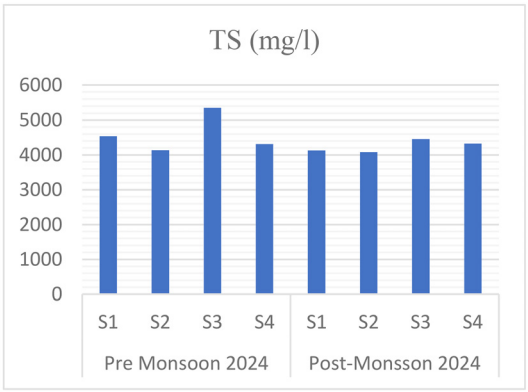


Fig. 5. Graphical representation of TS for pre-monsoon and post-monsoon 2024.

deposition of dissolved and suspended matter in the lake. High salinity, chloride and alkalinity were reported by Khobragade and Pawar (2016) which suggested that lake water was saline with high content of dissolved solids.

7) Total Dissolved Solids: The TDS levels were found to be higher than the permissible limit, with the pre-monsoon range of 3839 mg/l -3930 mg/l and in post-monsoon 3168 mg/l -3541 mg/l (shown in the Fig. 6). which suggested that a high concentration of dissolved salts and minerals was present in the water, making it unsuitable for drinking and various domestic applications. The decrease of post monsoon values points to the dilution from the rain water. The lake water was a high TDS (5596 mg/l) recorded by Gaikwad and Sasane (2013) and suggested that the

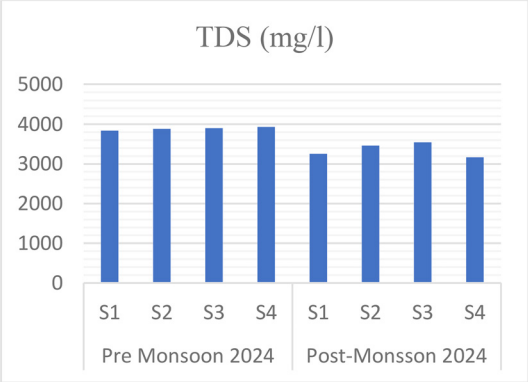


Fig. 6. Graphical representation of TDS for pre-monsoon and post-monsoon.

water was not potable for human use and the possibility of pollution from different human activities.

8) pH: The pre-monsoon pH range was 10.46-10.73, and post monsoon pH range was 8.99-9.50 (as shown in Fig. 7). The values were significantly higher, suggesting strong alkaline water. Khobragade and Pawar (2016) noted the continuous inflow of freshwater into the Lonar crater has led to the decrease in its pH levels in the past few years along with its salinity. Borul and More (2024) recorded 10.2 pH.

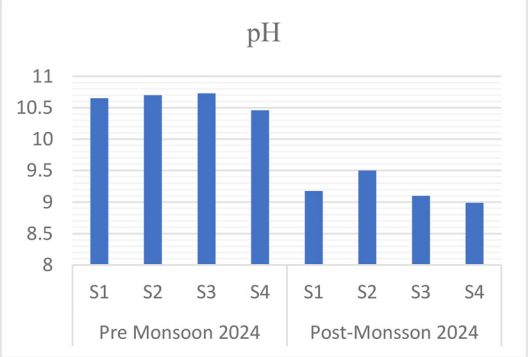


Fig. 7. Graphical representation of pH for pre-monsoon and post-monsoon 2024.

9) Total Alkalinity: Total alkalinity in the pre-monsoon period ranged from 570 mg/l to 680 mg/l, while in the post-monsoon period it ranged from 530 mg/l to 610 mg/l (as shown in Fig. 8). The values were much higher than permissible limit and reflected a high buffering capacity of the lake waters and the alkaline characters of the lake water. Surve *et al.* (2021) reviewed long-term limnological changes in Lonar Lake and reported that total alkalinity has decreased.

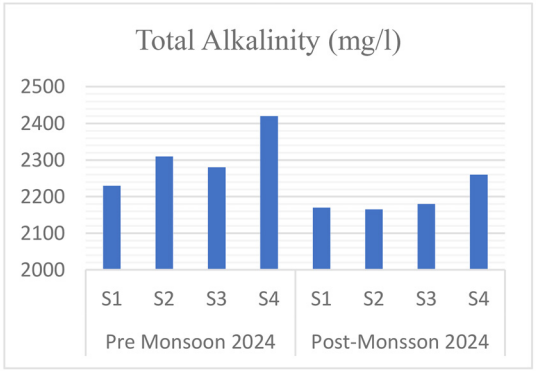


Fig. 8. Graphical representation of TA for pre-monsoon and post-monsoon 2024.

10) Total Hardness: Total hardness ranged from 142 mg/l to 158 mg/l in pre-monsoon and from 134 mg/l to 146 mg/l in post-monsoon. These values were within the desired range 100 mg/l-300 mg/l (as shown in the Fig. 9), and can be considered moderately hard water. Borul and More (2024) recorded a total hardness was 128 mg/l. Jadhav and Mali (2018) reported that calcium and magnesium concentrations derived from basalt weathering contribute to the total hardness of Lonar Lake.

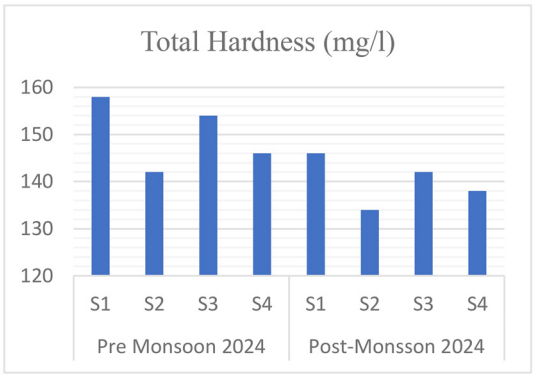


Fig. 9. Graphical representation of TH for pre-monsoon and post-monsoon 2024

11) Calcium: Calcium levels were below the prescribed limit. In the pre-monsoon and post-monsoon, it ranges between 16.83 mg/l -30.46 mg/l and 12.82 mg/l -24.04 mg/l respectively (shown in the Fig. 10).

Khan and Jadhav (2022) recorded calcium concentration was found to have different seasonal variations. Calcium along with magnesium is responsible for the total hardness and the influence of calcium was affected by rainfall, evaporation and fresh water inflow. It was noted that the varying amounts of calcium in the lake during the seasons influence the lake's ionic composition and ecological properties.

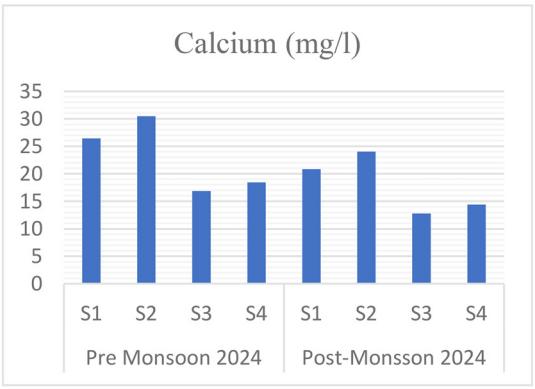


Fig. 10. Graphical representation of Calcium for pre-monsoon and post-monsoon 2024.

12) Magnesium: Magnesium values ranged from 43.51 mg/l to 73.84 mg/l in pre-monsoon and from 48.78 mg/l to 72.52 mg/l in post-monsoon, (as shown in Fig. 11) suggesting geological weathering or anthropogenic input. Khan and Jadhav (2022) reported magnesium concentrations ranging from 25.76 mg/l to 51.03 mg/l.

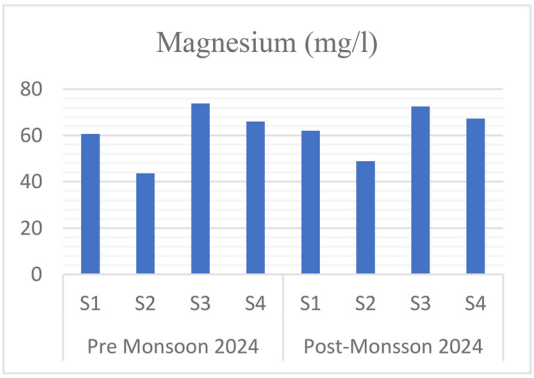


Fig. 11. Graphical representation of Magnesium for pre-monsoon and post-monsoon 2024.

13) Salinity: Salinity levels were very high during both the pre- and post-monsoon, with mean values ranging from 8450 mg/l to 10250 mg/l and 6235 mg/l to 7743 mg/l, respectively (as shown in Fig. 12). Beyond the recommended permissible limit of 500 mg/l, suggesting a significant accumulation of dissolved salts, likely due to factors such as evaporation, agricultural run-off, effluent discharge, or geology. Gaikwad and Sasane (2013) stated highly alkaline and saline water of the lake because of continuous evaporation, mineral dissolution and limited water outflow from the lake. Khobragade and Pawar (2016) observed seasonal fluctuations in salinity and reported that salinity generally increases during the pre-monsoon season because of intense evaporation and decreases during the monsoon and post-monsoon seasons owing to dilution by rainfall and freshwater inflow.

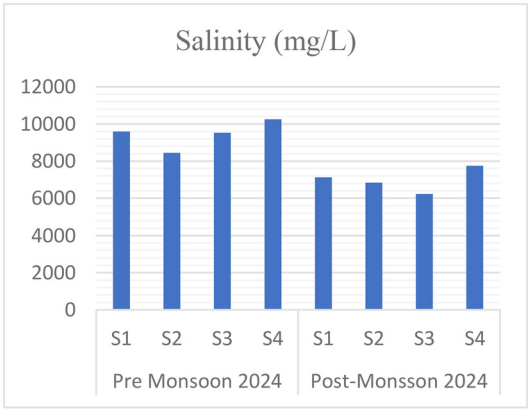


Fig. 12. Graphical representation of Salinity for pre-monsoon and post-monsoon 2024.

14) Chloride: The chloride concentration for pre-monsoon ranged from 1689.47 mg/l -1795.44 mg/l, and for post-monsoon ranged from 1503.08 mg/l-1559.80 mg/l (as shown in Fig. 13). The values were far higher than the limit of 250 mg/l. Ganbas and Garode in 2024 reported Chloride levels up to 1876 mg/l. Borul and More (2024) recorded the concentration of chlorides in the lake water was 1391.6 mg/l.

15) Sodium: Sodium concentrations were high, ranging from 1016 mg/l to 1204 mg/l during pre-monsoon and 865 mg/l to 1004 mg/l during post-monsoon (as shown in Fig. 14), exceeding the limit. Borul and More (2024) recorded a high concentration sodium.

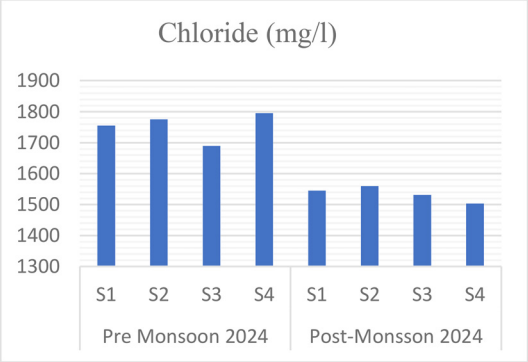


Fig. 13. Graphical representation of Chloride for pre-monsoon and post-monsoon 2024.

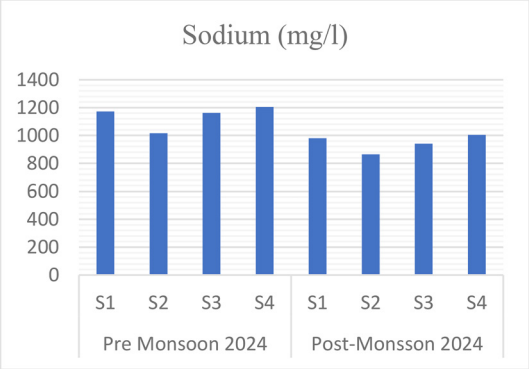


Fig. 14. Graphical representation of Sodium for pre-monsoon and post-monsoon 2024.

16) Sulfate: The concentration range for sulphate 7.92 mg/l to 11.38 mg/l was recorded during pre-monsoon and post-monsoon (as shown in Fig. 15), and

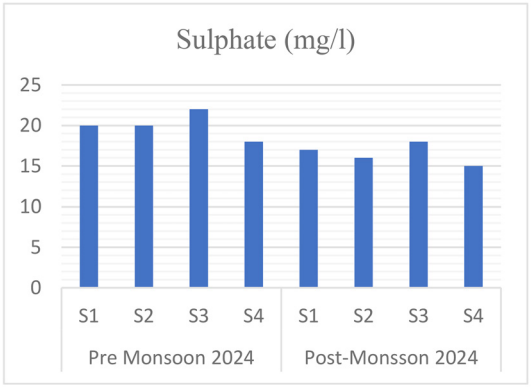


Fig. 15. Graphical representation of Sulfate for pre-monsoon and post-monsoon 2024.

sulphate was found to be an important component of the lake's saline-alkaline environment. Khan and Jadhav (2022) reported that sulfate concentrations varied among sampling locations due to differences in local inflow, evaporation, and sediment-water interactions.

17) Nitrate: Nitrate concentration ranged from 9.26 to 19.69 mg/l during pre-monsoon and from 8.32 to 11.12 mg/l during post-monsoon (as mentioned in Fig. 16) and was below the permissible limit of 45 mg/l. This suggests that there were agricultural inputs or decomposition of organic matter. Surve *et al.* (2021) stated that a rise in anthropogenic activities, tourism, agricultural runoff, and domestic waste entering the catchment could result in a gradual increase in nitrogen loading.

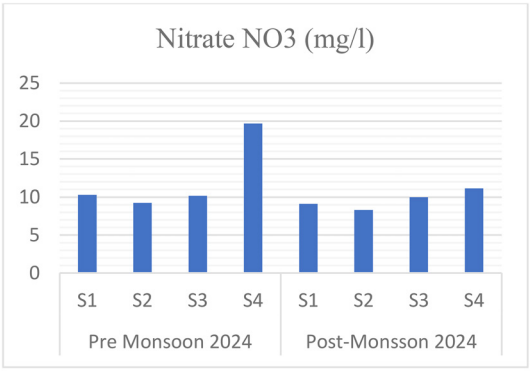


Fig. 16. Graphical representation of Nitrate for pre-monsoon and post-monsoon 2024.

18) Silica: Silica levels ranged from 7.61 to 13.01 mg/l in pre-monsoon and 5.33mg/l to 6.81 mg/l in post-monsoon (as shown in Fig. 17). These concentrations were representative of natural water and can promote diatom growth. Dabhade and Tandale (2016) recorded silicate concentration in Lonar Lake water ranged from 0.31 ± 0.30 mg/L at sampling site S3 to 0.89 ± 2.00 mg/L at sampling site S4.

19) Phosphorus: Phosphorus ranged from 0.40 mg/l to 0.87 mg/l, well above the prescribed limit of 0.1 mg/l (as shown in Fig. 18), suggesting nutrient enrichment and eutrophication that can lead to excessive growth of algae, contributing to the green hue of the water. Surve *et al.* (2021) noted that anthropogenic activity has the capacity to add more phosphorus that

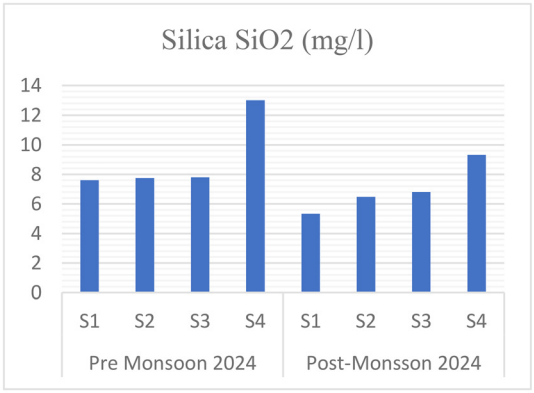


Fig. 17. Graphical representation of Silica for pre-monsoon and post-monsoon 2024.

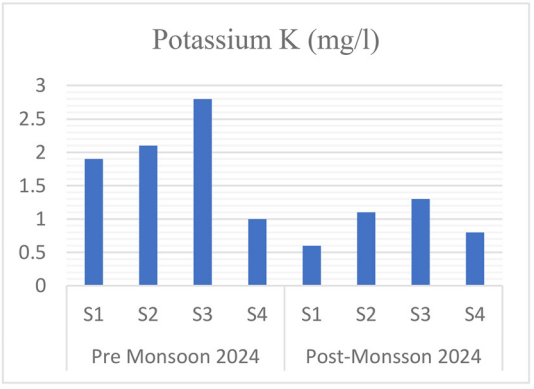


Fig. 19. Graphical representation of Potassium for pre-monsoon and post-monsoon 2024.

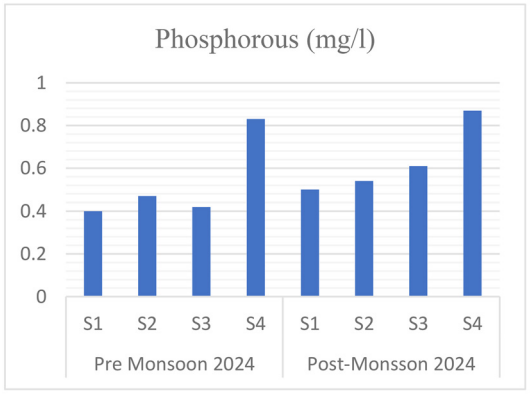


Fig. 18. Graphical representation of Phosphorous for pre-monsoon and post-monsoon 2024.

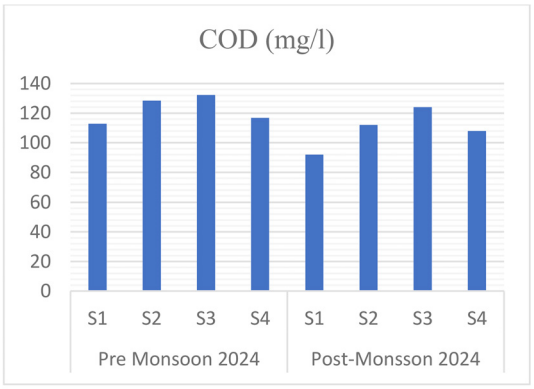


Fig. 20. Graphical representation of COD for pre-monsoon and post-monsoon 2024

can speed up the eutrophication.

20) Potassium: Potassium concentrations ranged from 0.6 mg/l to 2.8 mg/l (Fig. 19), and they remained within the prescribed limit, indicating no significant potassium contamination. Borul and More (2024) reported 6.51 potassium in the lake water.

21) Chemical Oxygen Demand (COD): Pre-monsoon COD was in the range of 112.84 mg/l to 132.29 mg/l, and during post-monsoon, it ranged from 92 mg/l to 124 mg/l (as shown in Fig. 20). These values were greater than the prescribed limit of 10 mg/l, which showed a high load of oxidizable organic matter as well as chemical pollutants. High COD indicated high organic pollution of the lake. The COD recorded by Khobragade and Pawar (2016) was in the range of approximately 120 mg/l-280 mg/l which indicates there was ample organic and inorganic oxidizable matter.

22) Biochemical Oxygen Demand (BOD): Pre-monsoon BOD recorded ranged from 20 mg/l to 24 mg/l, while post-monsoon BOD ranged from 17.7 mg/l to 20.7 mg/l (as shown in Fig. 21). High BOD value was a sign of intensive microbial decomposition of organic matter and significant organic pollution. After the monsoon, there was a slight drop, indicating dilution effects. Surve *et al.* (2021) reported that variations in BOD are closely related to dissolved oxygen, nutrient enrichment, and microbial decomposition.

23) Dissolved Oxygen (DO): The concentration of

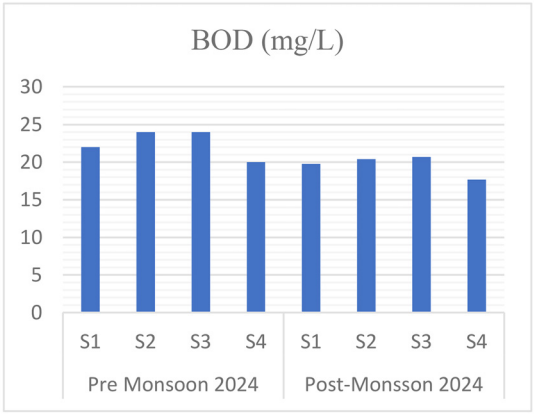


Fig. 21. Graphical representation of BOD for pre-monsoon and post-monsoon 2024.

dissolved oxygen in pre-monsoons and post-monsoon was found to be 0.80 mg/l to 1.10 mg/l and 1.10 mg/l to 1.60 mg/l, respectively, (as shown in Fig. 22). Gaikwad and Sasane (2013) investigated that low DO reflects increased microbial respiration and organic decomposition, which may adversely affect aquatic life and indicate deteriorating water quality. Singh and Singh (2018) recorded DO value range 4.02 mg/l -4.34 mg/l.

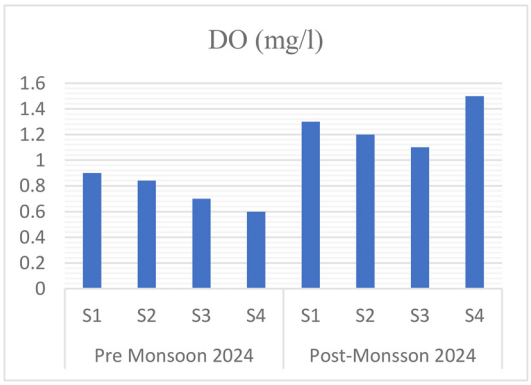


Fig. 22. Graphical representation of DO for pre-monsoon and post-monsoon 2024.

The dilution effects of monsoonal rainfall and steady supply of fresh water from springs resulted in lower values of most of the parameters such as water temperature, pH, TDS, salinity, chloride, sodium, COD and BOD during the post-monsoon season. Temporary improvement of water quality was observed as dissolved oxygen (DO) increased post monsoon. A few parameters were still higher than the permissible limits, indicating continued environmental stress. The lake was found to be highly alkaline, saline, with high TDS contents, high chloride and sodium, high magnesium, high phosphorus, high COD and BOD with very low DO which shows severe organic pollution and eutrophic. The chronic smell of the attack and greenish attack color also indicated excessive algal growth and nutrient enrichment. The overall water quality was poor as a result of high concentrations of dissolved salts and organic pollution, although turbidity, total hardness, calcium, sulfate, nitrate, silica and potassium were all acceptable. Thus, although there is a slight improvement in the post monsoon period, Lonar lake is a polluted lake, ecologically stressed and eutrophic and so needs continuous monitoring and effective conservation and management.

The lake water was characterized by high pH, elevated salinity, and significant concentrations of sodium, carbonate, bicarbonate, and other dissolved minerals (Surve *et al.* 2021). Cultural eutrophication was considered as the universal phenomenon in inland water bodies and no water body was left without serious ecological stress (Yannawar and Bhosle (2013). Turbidity is a good index of sediment input, plankton density, organic matter and human activities in lakes and is used to assess the ecological condition of lakes (Trivedy and Goel 1984). Increased temperatures lead to rise in both evaporation and biological metabolism; whereas decreased temperatures increase oxygen solubility and decrease metabolic rates. Thus, temperature is an important parameter that reflects the ecological quality and seasonal changes of water bodies (Goldman and Horne 1983; Wetzel 2001). Higher EC values indicate greater concentrations of dissolved salts and electrolytes such as sodium, potassium, chloride, carbonate, bicarbonate, calcium, and magnesium ions.

Excess amount of nutrients like nitrates and phosphates has led to eutrophication (Ghutke *et al.* 2018). Potassium is an essential macronutrient required for photosynthesis, enzyme activity, and cellular metabolism in aquatic organisms (Wetzel 2001). Along with other water quality parameters dissolved oxygen is

one of the most important because adequate oxygen levels are essential for the well-being of aquatic life, for metabolic processes, and for the biological balance in the system (Chapman 1996). The physico-chemical characteristics of lake water are significantly influenced by seasonal fluctuations, and parameters such as temperature, dissolved oxygen, and nutrient concentrations often exhibit considerable temporal variations due to changes in climatic conditions, hydrological processes, and biological activity (Dodds and Whiles 2020). Nutrient concentrations, especially nitrogen and phosphorus, can have a significant impact on water quality; excess nutrient levels can cause eutrophication leading algal blooms, decreases in transparency and depletion of oxygen (Smith & Schindler 2009). Sindhu (2025) said that sustainable management of aquatic ecosystem requires the continuous monitoring and timely pollution control measures that would help in minimizing eutrophication and water degradation and protect aquatic ecosystem from anthropogenic induced stress.

CONCLUSION

The overall study showed that the hydro-chemical features of Lonar Lake were controlled by a combination of climatic factors, geological formations, freshwater inflows and biological activities. The physico-chemical conditions observed in the lake suggested that the lake was gradually eutrophication and degrading ecologically, probably due to higher nutrient load, organic load, freshwater inflow and human impacts in the lake catchment. The ecological balance and the unique biodiversity of this internationally significant crater lake ecosystem was endangered by these changes. Hence, continuous water quality monitoring, controlling the sewage and nutrient load, catchment conservation measures and the implementation of sustainable lake management practices are crucial to restore and preserve the ecological integrity and long-term sustainability of Lonar Lake.

Poor water quality, eutrophication and ecological stress in the lake requires urgent conservation and restoration action. The reduction of the inputs of nutrients such as phosphorus and organic matter should be given priority to limit eutrophication and overgrowth of algae. It is very important to monitor physico-chemical parameters to evaluate the health of water quality and to gain early warning of environmental changes. The inputs of freshwater springs, domestic untreated effluents, agricultural runoff and other anthropogenic wastes must be carefully monitored with proper waste management and treatment systems. A vegetative buffer zone may be established around the lake to reduce the inflow of sediment, nutrients and pollutants from the surrounding catchment area. Protection of its special biodiversity in terms of the conservation of its habitat and sustainable use of its resources should also be included in the conservation of the lake ecosystem. Public awareness programs and community involvement are encouraged to promote responsible environmental practices and increase the conservation effort. Moreover, the implementation of an integrated lake basin management (ILBM) approach with scientific monitoring, involvement of stakeholders, policy support, and the application of ecological restoration measures was recommended to secure long-term sustainability and ecological integrity of the lake ecosystem.

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