

Evaluating River Water Quality in India: A Focus on Samudrakoop, A Protected Monument

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ABSTRACT

This study reviews the water quality of rivers at different religious and historical places in India and investigates the seasonal dynamics of algal communities and the associated water quality parameters in Samudrakoop, an ancient well located at an archaeological site in Prayagraj, India. The research evaluates the relationship between physicochemical parameters (temperature, pH, turbidity, dissolved oxygen and nutrient levels) and algal diversity, providing insights into the well's ecological health across different seasons. The findings reveal variations in algal communities and water quality, which are influenced by seasonal changes, anthropogenic activities and the well's historical significance. The critical analysis of different research papers reveals anthropogenic activities as the main cause of degradation of water quality. This study offers valuable data for conservation efforts and the management of ancient water bodies.

Keywords: Algal communities, Conservation, Physicochemical Parameters, River water quality, Samudrakoop, Seasonal dynamics.

Highlights

A review of the assessment of water quality at different religious and historical places found anthropogenic activities as the main cause of the deterioration of river water.

Seasonal monitoring of algal communities at the Samudrakoop monument in Prayagraj showed seasonal variations in physicochemical parameters.

Algal community composition varied in different seasons.

Key water quality parameters analyzed showed the influence of temperature, dissolved oxygen and turbidity on algal composition.

Pearson's correlation coefficient showed a significant positive correlation between nutrient concentrations (phosphorus and nitrogen) and algal abundance during summer and monsoon.

The Shannon-Wiener diversity index showed higher diversity of the algal community during the winter and autumn months.

Findings emphasize the importance of regular monitoring for the conservation of heritage site.

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INTRODUCTION

Assessment of water quality refers to the analysis of various physical, chemical and biological parameters within the water sample of a particular site to evaluate whether the water meets specific standards based on its intended use, ensuring the safety of humans and aquatic life. Temperature, turbidity, conductivity, color, odor, taste and solids are the measures under physical parameters, while pH, organic matter, dissolved oxygen, nutrients, biological oxygen demand, hardness, organic and inorganic substances and heavy metals are chemical and bacteria, algae, protozoa and viruses are biological parameters (Hassan Omer, 2020). A monument is a structure or site that has been built or designated to commemorate a significant person or event. Samudrakoop is an Archeological Survey of India (ASI) protected monument, situated in Prayagraj, Uttar Pradesh, near the confluence of the Ganges and the Yamuna rivers. It holds immense historical, cultural and religious significance. Constructed during the Gupta dynasty by Maharajadhiraja Shri Samudragupta, it is mentioned in ancient scriptures such as the Matsya Purana. The well, encircled by shrines and frequented by pilgrims, serves as a vital heritage site and a symbol of ancient architectural ingenuity. Similar wells constructed by Samudragupta are located in Mathura, Varanasi, Ujjain and Patalpur (now Patna), making them important markers of historical legacy.

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Monuments like Samudrakoop are not just relics of the past; they represent cultural identity and are crucial for historical research, tourism and the local economy. However, these heritage sites face numerous threats, including environmental degradation, pollution and anthropogenic activities. In particular, religious rituals and agricultural runoff can contribute to the contamination of water in these wells, jeopardizing their ecological balance and historical integrity.

Conserving such monuments is essential to preserving their cultural significance and ecological value. Effective conservation efforts require a thorough understanding of the ecological state

of these water bodies, including the seasonal dynamics of algal communities and water quality. By identifying the key factors affecting the well's ecosystem, this study aims to provide insights into sustainable management and protection of Samudrakoop, ensuring it remains a living part of the region's heritage.

According to Ramaraj *et al.*, (2014), algae are crucial to maintaining the ecological balance of water bodies because they are primary producers in freshwater ecosystems. They are highly sensitive to environmental changes, especially those driven by seasonal fluctuations in nutrients, light and temperature. Variations in water temperature, dissolved oxygen and nutrient concentrations are known to impact algal growth and species composition (Jeppesen *et al.*, 2000).

Several studies have highlighted the importance of seasonal sampling. For example, Skirbekk *et al.*, (2016) identified four hydrological seasons in the Arctic based on samples collected during spring, summer and fall. Similarly, Kumari and Sharma (2018) conducted a year-round assessment of water quality, emphasizing seasonal changes. Honeyfield and Maloney (2014) observed that factors like conductivity, temperature and overstorey cover influenced periphyton profiles differently across seasons. Additionally, Pérez-Gutiérrez *et al.*, (2017) documented seasonal variations in nitrogen removal efficiency in on-farm water storage systems.

In freshwater ecosystems, algae are integral for sustaining aquatic life by providing food for herbivores and contributing to oxygen production (Zhu *et al.*, 2023). Environmental factors such as light, temperature, nutrient availability and pH play a key role in determining algal composition and biomass (Huisman *et al.*, 2004). Among the common algal groups, diatoms, green algae and cyanobacteria exhibit varying responses to environmental changes (Samson *et al.*, 2019).

Seasonal changes significantly influence algal growth. Warmer temperatures and increased nutrient availability during summer can lead to rapid algal proliferation, sometimes resulting in harmful algal blooms (HABs) (Paerl & Otten, 2013). Conversely, colder temperatures and reduced sunlight during winter generally limit algal growth (Smith *et al.*, 2005).

Human activities such as urbanization, agricultural runoff and religious rituals can alter the physicochemical properties of water, thereby affecting algal diversity and water quality (Zongo & Boussim, 2015). Given the cultural significance of Samudrakoop, it experiences considerable human activity, which may lead to water contamination and eutrophication. This study aims to examine the seasonal variation in algal communities and correlate it with the physicochemical properties of water in Samudrakoop. By understanding these dynamics, we can assess the health of the well and contribute to future conservation strategies. The manuscript also tries to attract attention to the deteriorating river water quality of various religious and historical places in India that need urgent attention, awareness and people's participation.

Assessment of Water Quality of Rivers in India

India is a land with significant holy river sites and associated ponds along their banks, where people often bathe for religious reasons and consider the water sacred. As populations grow and cities expand, the disposal of industrial and household waste, along with agricultural runoff carrying pesticides and chemicals,

combined with religious practices like idol immersion and dumping of garbage in water bodies, significantly contribute to the pollution of holy water sources, degrading their quality and impacting aquatic life (Sial *et al.*, 2022). Different studies on river water quality of various religious and historical places in India find continuous and serious deterioration demanding urgent attention, awareness and people's participation.

The water quality index of Lakhota Lake (Ranmal Lake) situated in the center of Jamnagar district, Gujarat, assessed on eight parameters, revealed that the water was not safe for drinking for both humans and animals due to increased industrial and agricultural activities and population load. The researchers suggested appropriate wastewater treatment and plantations along the lake to preserve its water quality and scenic beauty (Ruhela *et al.*, 2024).

Water reservoirs in Aurangabad, Maharashtra (India), selected for water quality assessment based on 19 different water quality parameters, showed pollution at all five sites of Gajgaon Lake, Harsul Lake, Salim Ali Lake, Nehru Lake and Kham River (Sonar *et al.*, 2024).

A review of the assessment of the water quality of the Yamuna River, an important water source in India, points out the industrial discharge, agricultural runoff and urban waste as the main culprits of polluting the holy river. This review article emphasizes the need to adopt an effective and advanced waste treatment process along with adopting environment-friendly agricultural practices to ensure the sustainable health of the river (Sharma *et al.*, 2024).

The study on the water quality of Deepor Beel Lake, the only Ramsar site of Assam, found deterioration of water quality with time during a three-year study period and suggested the adoption of a better management plan for the survival of fresh freshwater lake, which is ecologically and economically important for maintaining the livelihood of inhabitants and survival of various species. The study reveals anthropogenic activities and the discharge of fertilizers, pesticides, municipal solid waste and industrial effluents as the main cause of its deterioration (Roy and Majumdar, 2022).

The evaluation of pH, temperature, alkalinity, TDS and other secondary data parameters found anthropogenic activities as the main reason for rapid eutrophication and deterioration of the water quality of Dal Lake in Jammu and Kashmir. Remedial measures, like, centralized treatment plant, removal of excess weeds, construction of sanitation latrines for villagers, afforestation, avoiding use of excess fertilizers by the farmers and restoration of natural drainage are suggested for the restoration of the Lake (Samie and Khan, 2022).

Water quality index (WQI) at Prashar Lake in Mandi district of Himachal Pradesh was categorized as "Excellent" (0–24) during the two-year study period of 2008–09 and 2009–10. The researchers found water standards within permissible limits of the WHO, ICMR and ISI standards, suggesting its use for drinking and irrigation purposes (Jindal *et al.*, 2014).

The water quality assessment of 14 major ponds of Varanasi city of Uttar Pradesh was carried out to understand the suitability of pond water. The studies revealed that the majority of ponds were unfit for human consumption and cattle drinking. Poor management, garbage dumping, idol immersion,

eutrophication, infilling and pollution were assigned as the major threats to ponds. Measures like source identification and control, pond treatment, people's participation and environmental awareness were suggested to safeguard the pond ecosystem (Azam *et al.*, 2015).

The river water of Ramkund in Nashik city of Maharashtra was found unfit for drinking and other domestic purposes as its BOD and COD exceeded the permissible limit recommended by WHO (Bhadane, 2023).

Rahi *et al.*, (2025) investigated the Narmada River water quality at six sampling stations by developing a model using the fuzzy water quality index method (FWQI). They observed eleven parameters and categorized water quality at the first to fourth stations into the poor category, whereas those of the fifth and sixth stations into the good category. They recommended FWQI as an effective modelling tool for river basin management action plans.

MATERIALS AND METHODS

Study Area and Sampling

Samudrakoop is a culturally significant monument situated on the eastern bank of the Ganges River near Jhusi, Prayagraj, Uttar Pradesh, India, at coordinates 81.9001° E and 25.4256° N. The site was constructed by Samudragupta of the Gupta era and has religious and cultural significance. This heritage site, frequently visited by pilgrims—especially during major festivals—features a stone-constructed well built by Maharajadhiraja Shri Samudragupta of the Gupta dynasty. The well, which is 22 feet in diameter, is mentioned in ancient texts such as the *Matsya Purana* and similar structures by Samudragupta are found in Mathura, Varanasi, Ujjain and Pataliputra (modern Patna).

The area has a humid subtropical climate with mild winters (around 9°C), scorching summers (up to 42°C) and a monsoon season (June–September). Rainfall averages about 1,037 mm

per year. Jhusi and its surroundings have seen urbanisation in recent years, with built-up areas taking the place of fallow lands and natural vegetation. The physicochemical properties of water bodies like Samudrakoop can be impacted by these land use changes as well as seasonal climate variance.

Water and algal samples were collected during four key seasonal periods in 2022: winter (December), summer (May), monsoon (August) and autumn (October). At each sampling event, a total of six composite samples were collected—three from the central zone and three from the periphery of the well—to ensure representative coverage of the waterbody. Each sample was collected in sterilized 250-ml glass bottles, using a clean, non-contaminating water sampler and was transported to the laboratory in an icebox for immediate processing. This sampling design was chosen to reflect both spatial and temporal variation in water quality and algal communities at the monument (Fig. 1).

Physicochemical Parameter Analysis

The physicochemical characteristics of each sample—including temperature, pH, turbidity, dissolved oxygen (DO) and nutrient concentrations—were measured using standardized procedures. Temperature was measured using a digital thermometer (DTM-100) and pH levels were determined with a pH meter (GSI-011). DO concentrations were assessed using a DO meter (STI-470, Sky Tech India). Turbidity was measured with a turbidity meter (HANNA-HI93703). Nutrient analysis focused on nitrogen (in the forms of nitrate and ammonium) and phosphorus (as phosphate), both of which were analyzed using colorimetric methods in accordance with APHA (1995) guidelines (Fig. 2).

To verify the accuracy of the measurements, physicochemical characteristics were cross-checked using water analyzers (HANNA HI98196-web).



Fig. 1: ASI-protected sampling site Samudrakoop



Fig. 2: Instrument used, A-Thermometer, B-pH meter, C- DO meter, D-Turbidity meter



Fig. 3: Collected samples and experimental setup with water analyzer (HANNA HI98196).

Algal Identification and Statistical Analysis

Algal samples were preserved in Lugol's iodine and examined microscopically using a compound microscope (Blisco India, ISO 900:2015) at the Department of Botany, CMP Degree College, Prayagraj (Fig. 3). Algal genera were identified using standard taxonomic keys and monographs by Desikachary (1959) and Bellinger & Sigeo (2010). To quantify algal diversity, the Shannon-Wiener diversity index (Shannon, 1948) was calculated.

All data were statistically analyzed using SPSS software (v.25). Seasonal variations in physicochemical parameters and algal abundance were assessed using Analysis of Variance (ANOVA). Relationships between physicochemical variables and algal diversity were explored using Pearson's correlation coefficient to determine the strength and direction of associations.

RESULTS

Seasonal Variation in Physicochemical Parameters in Samudrakoop

The seasonal analysis of water quality parameters in Samudrakoop revealed distinct fluctuations throughout the year (Table 1, Fig. 4). Water temperature exhibited significant seasonal fluctuations, with the highest values recorded during the summer (34°C) and the lowest in winter (12°C). The pH values remained relatively stable throughout the year, ranging from 7.5 to 8. Dissolved oxygen (DO) levels showed considerable seasonal variation. The highest DO concentration was observed in winter (8.2 mg/L), while the lowest was recorded in summer (5.1 mg/L). This trend suggests a potential impact of temperature on DO solubility. Concentrations of both nitrogen and phosphorus increased during the summer months, likely due to increased biological activity and nutrient runoff. Turbidity levels were highest during the monsoon season (6 NTU), likely due to increased sediment suspension from rainfall (Table 1).

The temperature was highest during the summer, while dissolved oxygen levels were lower in the summer, likely due to higher microbial activity and reduced water mixing. Nutrient levels were highest in summer, which can stimulate algal growth.

Algal Community Composition

The algal community in Samudrakoop displayed notable seasonal variation (Table 2, Fig. 5). Diatoms are most abundant during the winter (55%) and autumn (50%). Their percentage decreases in the monsoon (30%) and summer (40%), which

Table 1: Seasonal changes in the physicochemical parameters of water with standard error (SE)

Parameter	Winter (Dec)		Summer (May)		Monsoon (Aug)		Autumn (Oct)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Temperature (°C)	12	0.5	34	0.7	25	0.6	20	0.5
pH	7.5	0.1	8.0	0.1	7.8	0.1	7.6	0.1
DO (mg/L)	8.2	0.3	5.1	0.4	7.4	0.3	7.9	0.2
Nitrogen (mg/L)	0.8	0.05	1.5	0.07	1.2	0.06	1.0	0.05
Phosphorus (mg/L)	0.3	0.02	0.8	0.03	0.6	0.025	0.5	0.02
Turbidity (NTU)	3.2	0.2	4.8	0.3	6.0	0.25	4.0	0.2

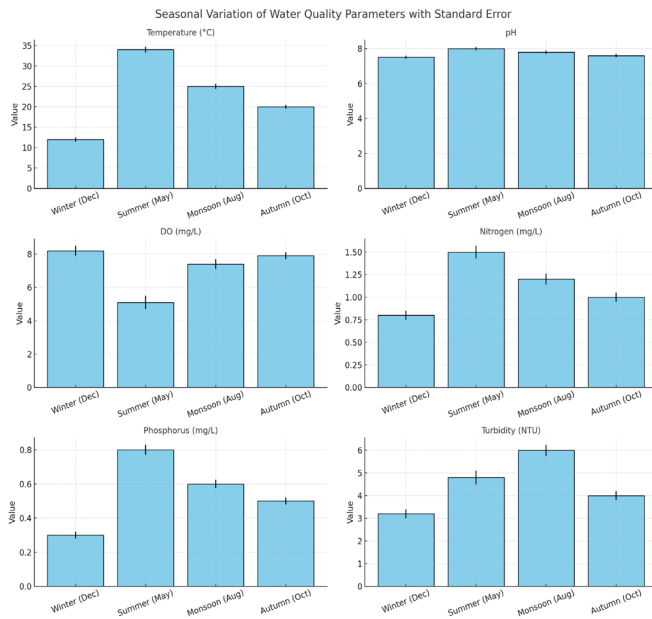


Fig. 4: Variations in physicochemical parameters in four different seasons

suggests that this algal group thrives in cooler and more stable conditions, which may be more prevalent in winter and autumn. Green algae show the highest percentage during the summer (40%) and a somewhat consistent presence in the monsoon (35%) and autumn (30%). Their lowest abundance occurs in winter (25%), which might be due to colder temperatures or other limiting factors during this season.

Cyanobacteria show a notable increase during the monsoon (30%), which could be due to favourable conditions such as higher water availability or specific nutrient conditions. Their percentage is relatively low in winter (10%), summer (15%) and autumn (10%). Euglenophytes show a fairly low presence across all seasons, with their highest percentage in winter and autumn (10%) and lowest in summer and monsoon (5%). This suggests that they might be less influenced by seasonal changes compared to other groups, or other environmental factors may limit their growth.

Diatoms were the most abundant group across all seasons, followed by green algae. Cyanobacteria were more abundant in the monsoon, indicating a potential for algal blooms due to increased nutrient influx from rainfall.

Algal Diversity

The Shannon-Wiener diversity index (Fig. 6) for each season was as follows:

- Winter: 2.3
- Summer: 1.8
- Monsoon: 1.6
- Autumn: 2.1

Higher diversity was observed during the winter and autumn months, which suggests that cooler temperatures and lower nutrient levels promote a more diverse algal community.

Correlation between Physicochemical Parameters and Algal Abundance

A significant positive correlation (Fig. 7) was found between nutrient concentrations (particularly phosphorus) and algal abundance during the summer and monsoon months ($r = 0.82$ for phosphorus and $r = 0.75$ for nitrogen).

Fig. 7 illustrates the significant positive correlation between nutrient concentrations (phosphorus and nitrogen) and algal abundance during summer and monsoon. Phosphorus shows a stronger correlation ($r = 0.82$) compared to nitrogen ($r = 0.75$), emphasizing its critical role in promoting algal growth.

DISCUSSION

The critical analysis of research papers on water quality in different culturally, historically and religiously important sites showed that the disposal of industrial and household waste, agricultural runoff carrying pesticides and chemicals, religious practices like idol immersion, dumping of garbage & urban waste in water bodies, anthropogenic activities, poor management, lack of awareness and negligence as the major reasons for deterioration of water quality. The case study of Samudrakoop revealed that seasonal changes significantly affect both water quality and algal community structure in Samudrakoop. Elevated nutrient levels during summer and monsoon coincided with increased algal biomass, particularly cyanobacteria, which can lead to eutrophication (Chaffin *et al.*, 2014). Reduced diversity during summer and monsoon suggests that nutrient enrichment and warmer temperatures favor the proliferation of a few dominant species, increasing the risk of harmful algal blooms (Planas & Paquet, 2016). Decreased dissolved oxygen levels in summer and higher turbidity during monsoon further indicate ecological stress, likely exacerbated by natural factors

Table 2: The dominant algal groups observed during each season

Algal Group	Winter (%)	Summer (%)	Monsoon (%)	Autumn (%)	Total (%)	Dominant Genera
Diatoms (Bacillariophyceae)	55	40	30	50	175	Navicula, Nitzschia, Fragilaria
Green Algae (Chlorophyceae)	25	40	35	30	130	Chlorella, Scenedesmus, Spirogyra, Stigeoclonium, Chlamydomonas
Cyanobacteria	10	15	30	10	65	Microcystis, Anabaena, Oscillatoria, Nostoc
Euglenophytes	10	5	5	10	30	Euglena, Trachelomonas
Total (%)	100	100	100	100	400	

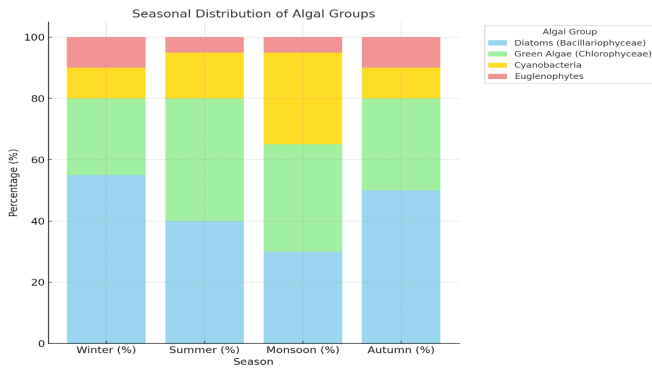


Fig. 5: Seasonal distribution of algal groups during the study period

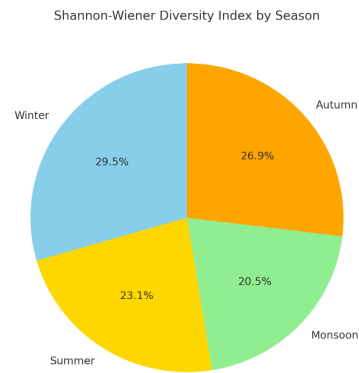


Fig. 6: Seasonal Shannon-Wiener diversity index values.

and human activities such as religious rituals and agricultural runoff (Bakker & Hilt, 2015).

This study highlights the intricate relationship between seasonal changes and the dynamics of algal communities in Samudrakoop. The results indicate that seasonal temperature variations, dissolved oxygen, nutrient availability and turbidity significantly influence the diversity and abundance of algal populations. Similar findings have been reported in other aquatic ecosystems, emphasizing the global relevance of understanding such dynamics.

During the summer, higher temperatures and increased nutrient concentrations were observed to promote algal growth, particularly cyanobacteria, which is consistent with previous studies by Paerl & Otten (2013). This phenomenon is often associated with eutrophication and can lead to harmful algal blooms (HABs) that deteriorate water quality. The correlation analysis further supported these observations, showing a strong positive relationship between nutrient levels (particularly phosphorus) and algal abundance. Elevated phosphorus levels have been recognized as a key driver of algal blooms in numerous studies (Lurling *et al.*, 2017).

In contrast, during winter and autumn, lower temperatures and reduced nutrient inputs appeared to create conditions favourable for greater algal diversity. Diatoms, which were

the dominant group across all seasons, thrived in these cooler conditions, as reported by Huisman *et al.* (2004). The relatively stable pH levels throughout the year suggest that pH was not a limiting factor for algal growth in this study.

The significant seasonal variations in dissolved oxygen levels observed in Samudrakoop are critical for understanding the overall health of the water body. High dissolved oxygen levels during winter are indicative of better aeration and lower microbial activity, while the reduced levels during summer can be attributed to increased microbial respiration and decomposition, consistent with findings by Smith *et al.* (2005).

The monsoon season presented a unique scenario where increased turbidity due to rainfall and sediment suspension influenced the algal community structure. High turbidity can limit light penetration, affecting photosynthesis and favouring species that can tolerate low-light conditions, such as certain cyanobacteria. Similar seasonal effects of turbidity on algal growth have been documented in studies by Samson *et al.* (2019) and Kumari & Sharma (2018).

Anthropogenic activities, particularly during religious festivals, likely contributed to the increased nutrient load in Samudrakoop. This highlights the importance of managing human-induced impacts on heritage water bodies. Vortmann *et al.* (2015) stressed that mass gatherings and associated activities

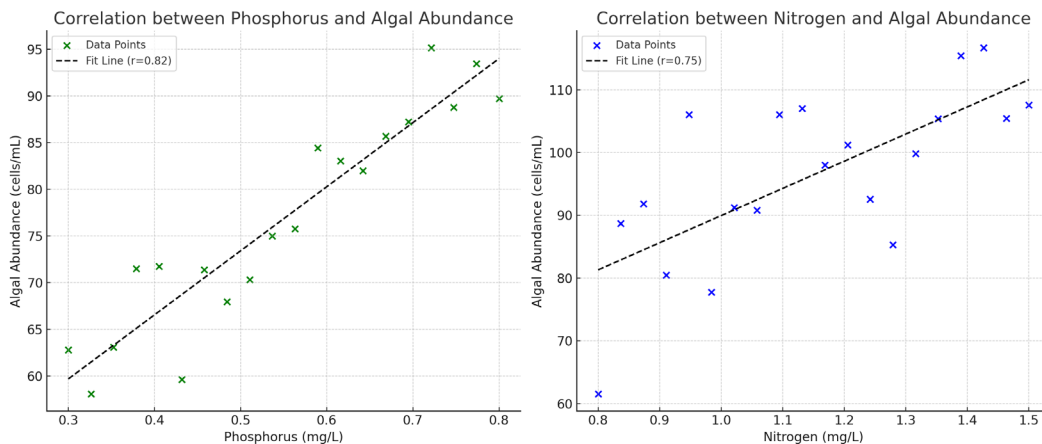


Fig. 7: Correlation of nutrient concentrations with algal abundance

can drastically alter the water quality of culturally significant aquatic systems. Therefore, sustainable management strategies, including regular monitoring and community engagement, are essential to mitigate these impacts.

While this study provides valuable insights into the seasonal variations in water quality and algal communities within the historically significant Samudrakoop monument, it is not without limitations. The investigation was limited to a single year of seasonal sampling, which may not capture long-term trends or interannual variability influenced by climatic or anthropogenic changes. Additionally, while basic physicochemical parameters and dominant algal groups were assessed, advanced molecular or microscopic techniques were not employed, which could have provided deeper taxonomic resolution and insight into cryptic or less abundant species. Moreover, the study did not account for potential external influences such as nearby human activity, land use changes, or groundwater interactions, which may affect water quality. Future research should incorporate multi-year monitoring, employ molecular tools like environmental DNA (eDNA) for more precise biodiversity assessment and evaluate the impacts of human activity and surrounding environmental variables. Such integrated approaches would enhance understanding of water quality dynamics and support more effective conservation of monument-associated water bodies.

Overall, the findings of this study underscore the critical need for continuous monitoring and conservation of heritage water bodies like Samudrakoop. The interplay of natural and human-induced factors requires a holistic approach to water management, ensuring the ecological integrity of such culturally significant sites.

CONCLUSION

The critical analysis of research papers on the quality of water bodies and case studies emphasizes the need for proper management and research. Measures, like, control of anthropogenic activities, proper training of the cultivators to optimize the use of fertilizers and pesticides, strict implementation of a better management plan and relocation of waste dumping site for minimizing the pollution of the lake with better sewage treatment facilities should be adopted.

This research emphasizes the significant impact of seasonal variations on algal communities and water quality in Samudrakoop, a culturally important well. As an ancient well, it has likely witnessed centuries of environmental changes and human activities. Key findings highlight that temperature, nutrient levels and dissolved oxygen are crucial in shaping algal populations. Elevated nutrients during summer and monsoon led to increased algal biomass, particularly cyanobacteria, raising concerns about eutrophication. Cooler temperatures in winter and autumn supported greater algal diversity, mainly diatoms. The study also stresses the negative influence of human activities, such as religious events and agricultural runoff, on water quality, worsening nutrient loading and turbidity. To address these issues, the study calls for community-based initiatives, stricter regulations during peak periods and sustainable water management. A comprehensive approach to preserving Samudrakoop and other heritage sites to maintain

and protect their heritage and aesthetic properties involves continuous monitoring, raising awareness and implementing conservation measures that balance cultural and ecological needs. Future research should explore long-term trends in algal dynamics, pollution impacts and eco-friendly interventions. Ultimately, preserving Samudrakoop's ecological integrity requires collaboration among researchers, policymakers and the local community.

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AUTHOR CONTRIBUTIONS

The authors contributed equally to the conceptualization, methodology, data analysis and manuscript writing.¹RS- conceptualization, data analysis, methodology;²SC- manuscript drafting and editing;^{1*}AP- review and supervision. All authors approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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