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Limnological insights: Phytoplankton diversity and water quality in arid ecosystems

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Abstract
Limnology, which examines the biological, chemical and physical properties of inland water bodies, is crucial for understanding aquatic ecosystem health and management. Phytoplankton, as primary producers, form the base of the aquatic food web and play an essential role in nutrient cycling, oxygen production and carbon sequestration. Their diversity and abundance are influenced by environmental variables such as nutrient concentrations, temperature, pH and light availability. In arid regions like Rajasthan, where seasonal ponds are vital for sustaining biodiversity and water availability, understanding these dynamics becomes especially important. Numerous studies have shown that seasonal fluctuations in physicochemical parameters, such as nutrient levels and turbidity, significantly impact phytoplankton composition and water quality. Furthermore, anthropogenic influences, including agricultural runoff and pollution, exacerbate shifts in phytoplankton communities and water quality. This review synthesizes key findings from diverse studies on phytoplankton diversity, limnological investigations and the physicochemical factors affecting aquatic ecosystems. These insights are critical for improving water management practices, ensuring sustainable use of freshwater resource, and enhancing ecological resilience in both temperate and arid regions.

Keywords: Limnology, phytoplanktons, physiochemical properties of water etc

Introduction
Limnology, the study of inland water bodies such as lakes, rivers, and ponds, focuses on their biological, physical, chemical, and hydrobiological features, emphasizing the ecological balance maintained by biogenic material (Wetzel, 2001) [1]. Freshwater systems are vital for human civilization, serving as sources of life, agriculture, and industry, but are increasingly threatened by pollution and overexploitation (Moss, 2010) [2]. Rajasthan, a state with predominantly arid conditions, has a long tradition of water conservation through man-made lakes, ponds, and reservoirs designed for irrigation and drinking water purposes (Prakash, 1997) [3]. Seasonal ponds in this region play a crucial role in sustaining biodiversity and providing water during extended dry periods, despite the state's low rainfall and unpredictable monsoons. Understanding the limnological parameters of these water bodies is essential for improving water management and aquaculture practices in such arid zones. This study focuses on the limnological assessment of phytoplankton diversity and density in an open pond in Rajasthan, India, analyzing the physicochemical factors influencing these ecosystems to contribute to sustainable water resource management.

Phytoplankton diversity
Phytoplankton, microscopic organisms inhabiting the sunlit layers of aquatic ecosystems, are fundamental to freshwater and marine environments, driving primary production and forming the foundation of aquatic food webs (Reynolds, 2006) [4]. By harnessing solar energy through photosynthesis, they produce oxygen, sequester atmospheric CO_2 and transform nutrients into organic matter that sustains higher trophic levels, including fish and zooplankton (Falkowski & Raven, 2007) [5]. Their diversity spans taxa such as diatoms, cyanobacteria, dinoflagellates, and green algae, each exhibiting unique ecological roles—diatoms excel in nutrient cycling, while cyanobacteria can fix atmospheric nitrogen and dominate eutrophic systems (Paerl & Otten, 2013) [6]. Environmental factors like nutrient availability, light intensity, temperature, salinity, and hydrodynamic conditions govern phytoplankton distribution and productivity, making them indicators of ecosystem health (Boyce *et al*., 2010) [7]. However, disturbances like nutrient pollution, climate change, and harmful algal blooms (HABs) threaten their diversity, with cascading effects on water quality, fisheries, and human health (Anderson *et al*., 2012). Effective conservation strategies, including nutrient management, ecosystem restoration, and public education, are essential to preserve phytoplankton diversity and ensure the resilience of aquatic ecosystems for future generations (Richardson, 2008).

Limnological Investigation and Algal Diversity
Limnology, the study of inland water bodies such as lakes, ponds, rivers, and wetlands, is pivotal for understanding the intricate biological, chemical, and physical dynamics of aquatic ecosystems. Algae, a diverse group of photosynthetic organisms, play a crucial role in these environments as primary producers, driving nutrient cycling, carbon fixation, and oxygen generation while forming the foundation of aquatic food webs (Wetzel, 2001) [1]. This group includes cyanobacteria (blue-green algae), green algae, diatoms, dinoflagellates and red algae, each characterized by unique morphologies, pigmentations, and ecological roles. For instance, diatoms with silica cell walls contribute significantly to primary production, while cyanobacteria can fix atmospheric nitrogen and dominate nutrient-enriched ecosystems (Paerl & Otten, 2013) [6].
Limnological investigations employ multidisciplinary approaches, including field sampling, physicochemical

assessments, and advanced molecular techniques, to evaluate the health and dynamics of aquatic ecosystems. Parameters such as nutrient concentrations, temperature, pH, and turbidity, alongside tools like DNA barcoding and microscopy, enable precise identification and analysis of algal taxa (Reynolds, 2006) [4]. Environmental factors like nutrient availability, light intensity, hydrology, and human disturbances influence algal diversity and distribution. Excessive nutrient input from urban wastewater and agricultural runoff often leads to algal blooms, particularly of cyanobacteria, which can degrade water quality and disrupt ecosystem stability (Anderson *et al.,* 2012). Anthropogenic impacts, including pollution, habitat alteration and climate change, threaten algal diversity and aquatic ecosystem health, underscoring the need for sustainable management and conservation. Limnological research, through its integration of ecological principles and advanced analytical methods, provides critical insights for safeguarding aquatic biodiversity and ensuring the resilience of freshwater ecosystems (Falkowski & Raven, 2007) [5].

Physicochemical Parameters of Water

Water is a vital resource whose quality is determined by its physicochemical properties, which influence ecosystems, human health, and industrial utility. Key parameters include pH, temperature, dissolved oxygen (DO), turbidity, and nutrient levels, all of which are crucial for assessing water quality and ecosystem health (Wetzel, 2001) [1]. The pH of water affects biological processes, chemical solubility, and pollutant mobility, with deviations from optimal ranges potentially harming aquatic organisms and ecosystems (Mara & Horan, 2003) [8]. Temperature regulates species distribution, metabolic rates, and thermal stratification, with rising temperatures linked to climate change, urbanization, and deforestation exacerbating ecological stress (Reynolds, 2006) [4].

Dissolved oxygen, a critical indicator of water health, supports aerobic life and fluctuates with temperature, salinity, and organic decomposition. Low DO levels caused by eutrophication or organic pollution can lead to hypoxia, affecting fish habitats and promoting anaerobic conditions (Boyd, 2015) [9]. Turbidity, driven by suspended particles and runoff, influences light penetration and primary production, while excessive turbidity degrades water quality and hampers aquatic life (Davies-Colley & Smith, 2001) [10]. Nutrients like nitrogen, phosphorus, and carbon are essential for growth but can cause eutrophication and harmful algal blooms if present in excess, disrupting ecosystems and threatening water safety (Anderson *et al.*, 2002).

Understanding and monitoring these parameters enable policymakers and scientists to identify environmental stressors, manage water resources and implement strategies to protect aquatic ecosystems. Sustainable water resource management requires integrating ecological, hydrological, and socioeconomic considerations to preserve freshwater systems for future generations (Falkenmark & Rockström, 2004) [11].

Review of Literature

Phytoplankton diversity

Phytoplankton diversity studies have revealed significant insights into species composition, ecological relationships, and environmental influences across various aquatic ecosystems. Sayeswara (2014) [12] documented 45 species in Chikkamalappanakere Tank, Karnataka, with Cyanophyceae dominating. Wang *et al.*, (2013) [13] identified 133 species in Baiyangdian Lake, China, noting seasonal shifts in dominant species. Kumar and Oommen (2011) [14] found 45 species in Kanewal wetland, Gujarat, correlating nutrient parameters with phytoplankton composition. Mahadev *et al.*, (2011) [15] observed reduced diversity in Mysore's Cauvery River due to pollution, while Pareek *et al.,* (2011) [16] reported 24 diatom species in Galta Kund, Jaipur, with seasonal growth variations. Yasmin *et al.*, (2011) [17] highlighted oligotrophic indicators in Eastern Himalayas, and Sharma (2010) [18] reported Chlorophyta dominance in Manipur's Utra and Waithou Pats. Rajagopal *et al.*, (2010) [19] noted contrasting diversity in Tamil Nadu ponds based on pollution levels. Other studies include Santiago *et al.*, (2010) [20] on estuarine diatom dominance, Onuoha *et al.*, (2010)[21] on seasonal phytoplankton shifts in Ologe Lagoon, and Choudhury *et al.*, (2009) [22] on seasonal variations in Bihar chaurs. Gonulol *et al.*, (2009) [23] linked phytoplankton distribution to water properties in Turkish lagoons, while Sharma (2009) [24] observed species richness in Loktak Lake, Manipur. Laskar and Gupta (2009) [25] emphasized nutrient correlations in Assam’s Chatla Lake, and Jena and Adhikary (2007) [26] recorded 56 Chlorococcales species in Eastern India. Arhonditsis *et al.*, (2004) [27] studied seasonal phytoplankton patterns in Lake Washington, USA. These studies collectively highlight the role of environmental factors, seasonal dynamics, and anthropogenic impacts on phytoplankton diversity.

In various studies on limnology and algal diversity, researchers have explored the seasonal variations and species composition in different water bodies. Kagga (2020) [28] conducted limnological research in the River Chandraloi, Kota, Rajasthan, identifying 19 species of phytoplankton, with Chlorophyceae being the most dominant. Similarly, Bhatnagar and Bhardwaj (2013) [29] examined the seasonal variations in the Chambal River, finding 65 algal species, including 32 from Chlorophyceae and 18 from Cyanophyceae, which served as indicators of water contamination. Sharma *et al.*, (2011) [30] researched Lake Pichhola, Rajasthan, documenting 15 fish species alongside the limnological and planktonic diversity. Ali *et al.,* (2009) [31] investigated the River Gomti, observing a correlation between the phytoplankton population and factors like alkalinity, phosphate, nitrate, pH, and dissolved oxygen, with certain algae species acting as pollution markers. Wetzel and Likens (2006) [32] highlighted dissolved oxygen as a key indicator of water quality, while Le Quere *et al.*, (2005) [33] studied the effects of water flow on phytoplankton populations, noting seasonal variations tied to hydrological changes. These studies collectively emphasize the importance of plankton diversity in assessing the ecological health and water quality of aquatic ecosystems.

Studies on the physicochemical properties of water have been conducted in various regions to assess water quality and environmental impacts. Mishra and Kumar (2021) [34] observed high electrical conductivity (EC) values in water, indicating significant inorganic salts and elements. Nalawade and Bagul (2020) [35] linked the abundance of macrophytes and phytoplankton to free carbon dioxide concentrations, with photosynthesis playing a key role in regulating CO_2 levels. In Kerala, Harikumar *et al.*, (2020) [36] found that groundwater from the Kattampally and

Biyyam wetlands was generally suitable for human consumption, although some samples showed contamination by Escherichia coli, and only a small proportion were unsuitable. Similarly, Banjara *et al.,* (2019) [37] studied free carbon dioxide concentrations in ponds of Raipur, with the highest levels recorded in summer.

Further studies, such as those by Pant *et al.,* (2017) and Bhat *et al.,* (2018) [38, 39], revealed seasonal fluctuations in nitrate levels in water bodies like lakes and rivers, highlighting the influence of monsoons and agricultural runoff on nutrient concentrations. Jadhav and Singare (2015) [40] examined phosphate concentrations in the Ulhas River, showing a significant increase in phosphate levels from 2012 to 2013, mainly due to agricultural runoff and rainfall. Research by Bera *et al.,* (2014) [41] on West Bengal's Kangsabati reservoir showed that water quality parameters mostly fell within acceptable ranges for drinking and irrigation, though low conductivity was noted. Rajendran *et al.,* (2015) [42] found varying chloride concentrations in the Cauvery River, with natural and anthropogenic sources contributing to water contamination.

The seasonal variation in turbidity was studied by Sarwade and Kamble (2014) [43] in the Krishna River, noting higher turbidity levels in pre-monsoon periods, indicating increased contamination due to suspended particles. These findings emphasize the complex relationship between seasonal factors, pollution sources, and water quality across different water bodies.

Conclusion

The limnological investigation reveals that the physicochemical characteristics of water significantly influence phytoplankton diversity and density. Seasonal variations, along with factors like nutrient availability, temperature and light intensity, dictate the composition of phytoplankton communities. In Rajasthan's seasonal ponds, phytoplankton diversity is closely linked to the region's water management practices, which play a vital role in maintaining biodiversity despite the challenges of low rainfall and unpredictable monsoons. These findings underscore the need for targeted conservation efforts, including nutrient management and pollution control, to ensure the sustainability of freshwater ecosystems in arid zones. Further research into the long-term monitoring of these water bodies can enhance strategies for sustainable water resource management and aquaculture practices.

This investigation is part of research work during Ph.D.

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