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ORIGINAL ARTICLE

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Seasonal variations in Phytoplankton, Chlorophyll and NPK content in the Ganga River in Bihar

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ABSTRACT

This study investigates the seasonal dynamics of the ganga river in bihar, focusing on changes in phytoplankton density, chlorophyll-a concentration, and nutrient levels (potassium, phosphorus, and nitrogen) during the pre- and post-monsoon periods. Water samples were collected from three locations, and standard analytical methods were used. The results show a significant decrease in phytoplankton density and chlorophyll-a levels after the monsoon, which was linked to nutrient washout from monsoonal floods. Post-monsoon, nitrogen levels increased, likely from agricultural runoff, while potassium levels decreased due to dilution. Phosphorus levels showed minimal change, suggesting adsorption onto sediments. Correlation analysis revealed strong nutrient-phytoplankton interactions prior to the onset of the monsoon, particularly highlighting the role of nitrogen in primary productivity. After the monsoon, these correlations weakened, indicating disruptions in the dynamics of nutrient cycling. These findings emphasize the role of seasonal hydrological processes in shaping river ecosystems and highlight the need for sustainable management practices to mitigate eutrophication and preserve ecological balance.

1 | INTRODUCTION

In the global biogeochemical cycle, rivers are vital ecosystems that sustain a diverse array of aquatic life and regulate nutrient fluxes across various environments. The ganga river is one of the most important rivers in India. It plays a vital role in the country's ecology, culture, and economy. It provides a lifeline for millions of people, but it is also under increasing pressure from human activities, including pollution, industrial discharge, and agricultural runoff (Srinivas *et al.,* 2020). Primary productivity and nutrient availability are two key effects of seasonal hydrological fluctuations resulting from monsoon rainfall patterns on the river's physicochemical characteristics (Kumar *et al.,* 2021). The small organisms known as phytoplankton, which form the foundation of aquatic food webs, are crucial indicators of river health. According to Paerl *et al.,* 2011, abiotic factors such as light penetration, hydrodynamics, and nutrient availability have a significant impact on the growth and density of these organisms. Phytoplankton biomass and production are frequently measured using chlorophyll-a, a pigment essential for photosynthesis (Hughes *et al.,* 2018). Seasonal variations in chlorophyll-a content and phytoplankton density provide important insights into the cycling of nutrients and the functioning of ecosystems. In aquatic environments, nutrient elements including potassium (K), phosphorus (P), and nitrogen (N) (NPK) are essential for promoting primary production. Nevertheless, seasonal fluctuations in their concentrations in river systems are caused by precipitation, sediment loading during monsoon seasons, and agricultural runoff (Naik *et al.,* 2020). Water quality and aquatic biodiversity can be impacted by eutrophication, which is caused by excessive nutrient loading, particularly of nitrogen and phosphorus (Smith *et al.,* 2006). On the other hand, nutrient shortages may reduce primary productivity, changing the dynamics of the food web and the ecological balance. Despite the ganga river's ecological significance, there are still few studies on seasonal fluctuations in phytoplankton density, chlorophyll-a content, and NPK concentrations, especially in Bihar. Through an evaluation of the interactions between these variables during the pre-monsoon and post-monsoon seasons, this study aims to bridge the existing knowledge gap. The results will help guide sustainable management plans for the ganga river and provide further insight into nutrient dynamics in a seasonally changing riverine ecosystem.

2 | MATERIALS AND METHODS

2.1 | Study Area

Water samples were collected from three different sites along the Ganga River in Eastern India to analyze phytoplankton, nutrients, and chlorophyll content. Samples were collected at three sites in the region: Doriganj (S1), Patna City (S2), and Barh (S3) in April and May, as well as in November and December 2023. The first site is a semi-urban environment located near the Doriganj block (84.836295°, 25.727691°), the second site is an urban environment situated in a residential area near the city of Patna (85.207449°, 25.61206°), and the third site is in Barh block (85.714197°, 25.494913°). Patna is the most populous and fastest-growing metropolis in the state of Bihar, with approximately 3,741,652 residents and a land area of 3,202 km². The Ganga River spans 445 km in Bihar, with the majority of its length situated in the Patna district. The study area map is shown in Fig.1.

2.2 | Sample collection and laboratory analysis

Water samples were collected from specific locations along the Ganga River to measure the levels of chlorophyll-a, phosphorus, potassium, and nitrogen, as well as to assess the presence of phytoplankton. Sterilized plastic 1-liter bottles were used for collecting phytoplankton samples from the surface water. Subsurface water (approximately 30 cm below the surface) was collected to avoid surface debris. Samples were preserved immediately by adding 1% Lugol's iodine solution to fix the phytoplankton. The bottles were stored in a cool, dark environment and were then transported to the laboratory for further analysis (APHA, 2017). Using a Sedgwick-Rafter counting chamber, phytoplankton were observed under a microscope equipped with a CMOS 5MP digital camera. Images were taken using 4X and 10X objectives at different magnifications. The Kjeldahl method, which involves digesting samples with sulfuric acid and a catalyst, followed by ammonia distillation and titration with standard HCl, was used to measure nitrogen

HIGHLIGHTS

- Phytoplankton density and chlorophyll-a levels significantly decline in Ganga river post-monsoon due to nutrient washout, while nitrogen levels increase from agricultural runoff.
- Strong correlations exist between nutrients (especially nitrogen) and primary productivity during pre-mosoon season, which weaken post-monsoon due to hydrological disruptions.
- Seasonal hydrological processes play a critical role in shaping river ecosystems, stressing the need for sustainable strategies to mitigate eutrophication and maintain ecological balance.

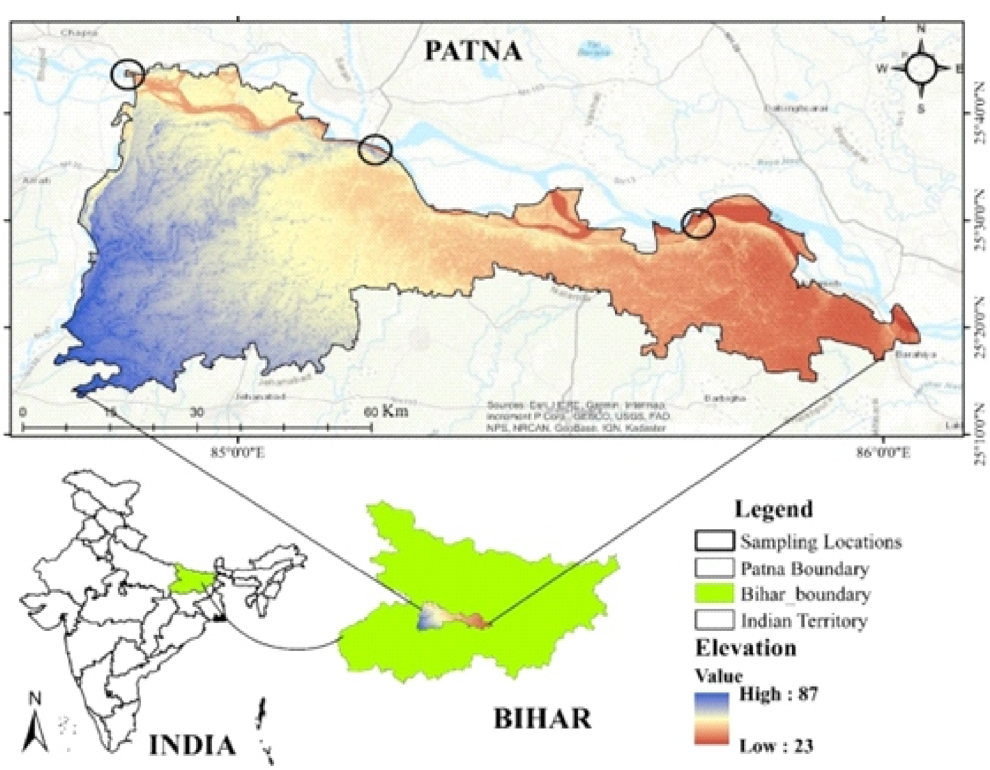

FIGURE 1 Location map of the three studied sites

(AOAC International, 2019). The molybdenum blue method was employed to detect phosphorus, and a spectrophotometer was used to measure absorbance at 880 nm (CSIR-NEERI, 2013). A flame photometer measured the intensity of light emitted by potassium ions at 766.5 nm, thus determining the quantity of potassium (APHA, 2017; Murphy & Riley, 1962; Jackson, 1958). Chlorophyll-a was assessed by filtering water samples through GF/C filters. Pigments were removed using 90% acetone and analyzed spectrophotometrically at a wavelength of 664 nm. Chlorophyll-a concentration was determined using established equations (APHA, 2017; Strickland & Parsons, 1972). These methods provided a comprehensive evaluation of phytoplankton diversity, nitrogen levels, and primary productivity in the Ganga River.

3 | RESULTS

3.1 | Chlorophyll-a Concentrations

All sites exhibited a significant decrease in chlorophyll-a levels after the monsoon. At Site S1, the values reduced from 2.521 mg/L pre-monsoon to 0.913 mg/L post-monsoon. Likewise, S2 decreased from 1.024 mg/L to 0.954 mg/L, and S3 declined from 2.662 mg/L to 1.119 mg/L (Table 1). These findings suggest a notable reduction in phytoplankton productivity following the onset of the monsoon season. All sites exhibited a significant decrease in chlorophyll-a levels after the monsoon.

3.2 | Phytoplankton Density

Phytoplankton density also decreased significantly after the monsoon. At Site (S1), the density dropped from 121 cells/L before the monsoon to 31.6 cells/L after the monsoon. At Site S2, it decreased from 50.6 to 41.6 cells/L, while at Site S3, it declined from 126.6 to 65.8 cells/L (Table 1). These fluctuations indicate a seasonal impact on phytoplankton biomass. *Fig.2* shows microscopic images of some of the most common phytoplankton cells.

3.3 | Nutrient levels (N, P, K)

Nitrogen concentrations rose at all sites following the monsoon. For instance, at S1, levels increased from 9.2 mg L^{-1} before the monsoon to 12.6 mg L^{-1} afterward. At S2, they

TABLE 1 Concentration of Chlorophyll-a, Phytoplankton and nutrients (N, P, K) in all sites in pre-monsoon and post-monsoon

Sites	Variables	Pre-Monsoon	Post-Monsoon
S1	Chlorophyll-a (mg L^{-1})	2.521	0.913
	Phytoplankton Density (cells L^{-1})	121	31.6
	Nitrogen (mg L^{-1})	9.2	12.6
	Phosphorus (mg L^{-1})	5.68	5.92
	Potassium (mg L^{-1})	5.36	4.13
S2	Chlorophyll-a (mg L^{-1})	1.024	0.954
	Phytoplankton Density (cells L^{-1})	50.6	41.6
	Nitrogen (mg L^{-1})	6.2	16.8
	Phosphorus (mg L^{-1})	4.86	5.71
	Potassium (mg L^{-1})	4.23	3.89
S3	Chlorophyll-a (mg L^{-1})	2.662	1.119
	Phytoplankton Density (cells L^{-1})	126.6	65.8
	Nitrogen (mg L^{-1})	9.8	14.8
	Phosphorus (mg L^{-1})	4.86	5.71
	Potassium (mg L^{-1})	7.26	5.06

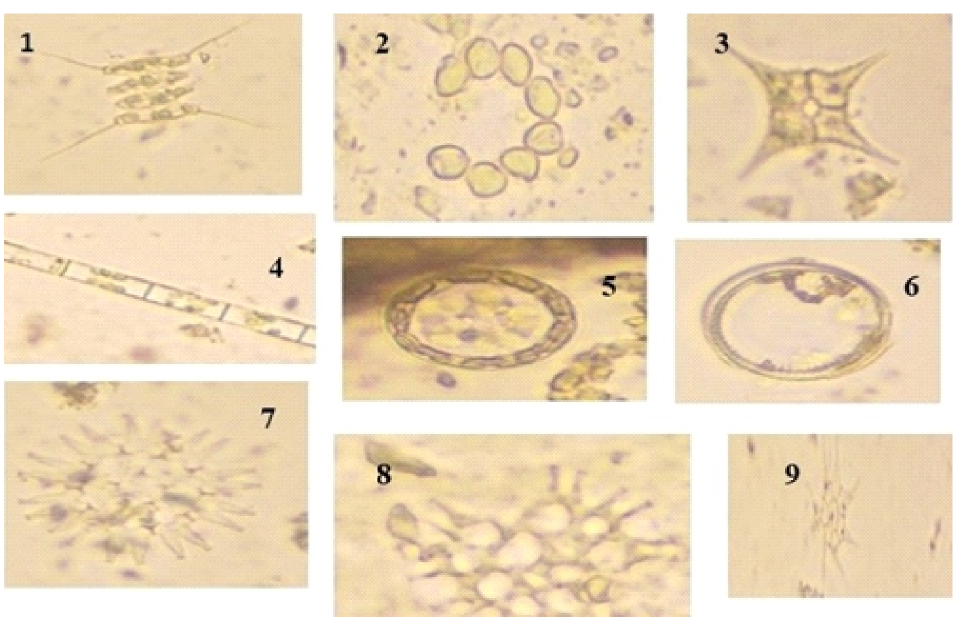

FIGURE 2 Microscopic images of Phytoplankton's cells (1. Scenedesmus quadricauda, 2. centric diatoms, 3. Staurastrum, 4. Spirogyra, 5. Volvox, 6. Cyclotella, 7. Myrionecta rubra, 8. Asteromphalus, 9. Diatoms)

jumped from 6.2 mg L^{-1} to 16.8 mg L^{-1}, and at S3, from 9.8 mg L^{-1} to 14.8 mg L^{-1}. Phosphorus levels also experienced slight increases after the monsoon. At S1, these levels rose from 5.68 mg L^{-1} before to 5.92 mg L^{-1} after the monsoon. Similarly, S2 and S3 showed minor gains, indicating that phosphorus availability remains relatively consistent throughout the seasons. Conversely, potassium levels fell at all sites post-monsoon. At S1, potassium decreased from 5.36 mg L^{-1} pre-monsoon to 4.13 mg L^{-1} post-monsoon. Likewise, at S2, levels dropped from 4.23 mg L^{-1} to 3.89 mg L^{-1}, and at S3, they fell from 7.26 mg L^{-1} to 5.06 mg L^{-1} (Table 1).

3.4 | Pre-Monsoon Correlation Analysis

The pre-monsoon correlation matrix reveals substantial positive associations between chlorophyll-a and nitrogen (r = 0.997) and between chlorophyll-a and phytoplankton density (r = 1.000). These relationships suggest that nitrogen plays a crucial role in enhancing primary productivity, as indicated by chlorophyll-a levels. A moderate positive connection was found between potassium and chlorophyll-a (r=0.830), indicating that potassium plays an important role in phytoplankton growth. However, phosphorus had a weaker connection with chlorophyll-a (r = 0.431), which could imply restricted bioavailability due to sediment adsorption during the low-flow pre-monsoon season (*Fig. 3*).

3.5 | Post-Monsoon Correlation Analysis

Nutrient dynamics underwent significant changes following the monsoon season. The association between chlorophyll-a and nitrogen has greatly diminished (r = 0.215), most likely due to the dilution from monsoonal floods. A negative association was found between chlorophyll-a and phosphorus (r = -0.654), possibly due to nutritional washout and changes in the nitrogen-to-phosphorus ratio. Despite these changes, a high correlation between chlorophyll-a and phytoplankton density persisted (r = 0.995), indicating that phytoplankton density remains a reliable proxy for chlorophyll-a concentrations even after the monsoon (*Fig. 4*).

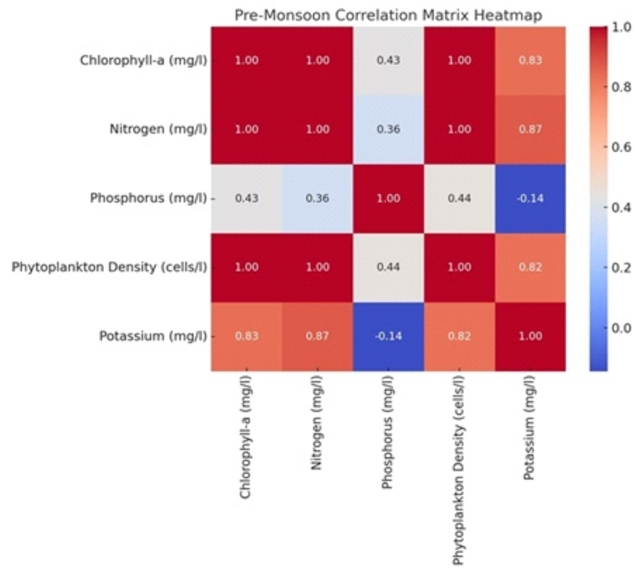

FIGURE 3 Correlation of Phytoplankton with different factors in Pre-monsoon

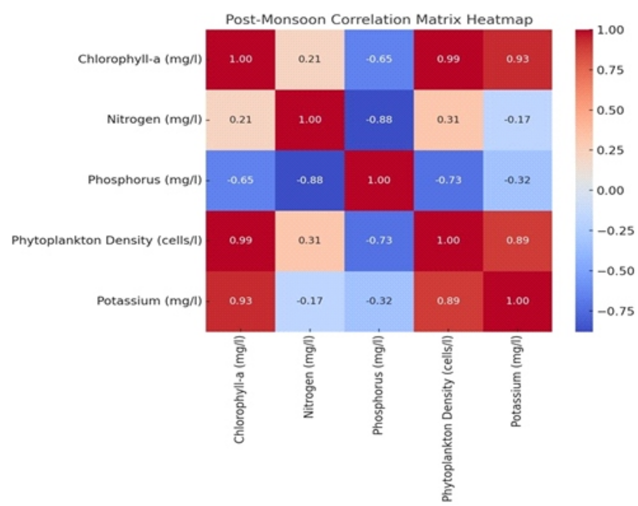

FIGURE 4 Correlation of Phytoplankton with different factors in Post monsoon

4 | DISCUSSION

4.1 | Seasonal Impact on Chlorophyll-a and Phytoplankton Density

The notable decline in chlorophyll-a and phytoplankton density after the monsoon emphasizes the effect of monsoon floods on primary productivity in riverine systems at specific times of the year. This reduction can be attributed to several factors, including nutrient dilution, increased turbidity, and the physical scouring of phytoplankton biomass resulting from higher water flow rates. Increased sediment loads during the monsoon reduce light penetration, thereby limiting photosynthesis and inhibiting the growth of phytoplankton (Bharathi & Sharma, 2019). Additionally, turbulent flows during floods can dislodge and wash away phytoplankton communities, disrupting their natural growth cycles (Stockwell *et al.,* 2020). Beyond the physical effects, nutrient availability plays a crucial role in determining the productivity of phytoplankton. While nitrogen and phosphorus concentrations showed a slight increase post-monsoon, the rapid flushing and redistribution of nutrients during the floods might lead to imbalances, resulting in reduced primary productivity (Siddiqui *et al.,* 2020). Notably, the seasonal impact observed in this study corresponds with findings from other monsoon- affected river systems. For instance, studies in the Brahmaputra River by Sharma *et al.* (2017) and the Mekong River by Tran *et al.* (2022) reported similar post-monsoon declines in chlorophyll-a and phytoplankton density, driven by comparable hydrological and nutrient dynamics. These findings emphasize that monsoonal seasonality has a consistent and widespread impact on riverine ecosystems across diverse geographical regions. The implications of these results extend beyond primary productivity. A reduced phytoplankton density affects the entire aquatic food web, as phytoplankton serve as primary producers and a crucial food source for higher trophic levels. Moreover, changes in chlorophyll-a levels may influence carbon sequestration rates and biogeochemical cycling in riverine systems, as phytoplankton play a key role in these processes (Litchman *et al.,* 2007). To enhance our understanding of the seasonal dynamics of phytoplankton productivity, future studies could focus on long-term monitoring of nutrient fluxes, sediment transport, and hydrological patterns alongside biological responses. Incorporating remote sensing techniques for large-scale chlorophyll-a monitoring (Ahmad *et al.,* 2025) and modeling approaches to predict the effects of climate change on monsoonal variability could further deepen our understanding of these processes (Verma *et al.,* 2021).

4.2 | Seasonal variation in nutrient dynamics

The post-monsoon increase in nitrogen levels indicates inputs from agricultural runoff and watershed deposition during floods (Sinha *et al.,* 2022). The rising trend suggests that, unlike phosphorus, nitrogen remains relatively soluble and mobile in water bodies, which aligns with the findings of (Siddiqui *et al.,* 2020), who identified nitrogen influx as a dominant factor in post-monsoon nutrient dynamics. Despite monsoon flooding, phosphorus levels increased only slightly, indicating that it may be adsorbed onto sediments or held in particulate forms during high-flow conditions. This low variability in phosphorus availability is consistent with the known behavior of sediment binding in aquatic environments, as reported by (Li *et al.,* 2019). The observed decrease in potassium levels following the monsoon could be attributed to monsoon-induced dilution. Because potassium promotes the development of phytoplankton, its reduced content after the monsoon may have had a significantly greater impact on primary productivity. (Gangaiah *et al.,* 2019) obtained similar results, highlighting the importance of potassium in maintaining aquatic ecosystems under stable flow conditions. The substantial positive correlations seen during the pre-monsoon season suggest nutrient-driven eutrophication, likely caused by nitrogen and potassium inputs from anthropogenic sources such as agricultural runoff and untreated sewage. The lesser correlation of phosphorus may be attributed to its decreased mobility in sediments at low river flow. These findings align with prior research that highlights the crucial role of nutrients in boosting primary productivity under stable flow conditions (Dolph *et al.,* 2019). In contrast, the post-monsoon season is characterized by a breakdown in nutritional equilibrium caused by monsoonal floods. The weakening nitrogen-chlorophyll-a association, as well as the negative correlation between phosphorus and chlorophyll-a, illustrates the effects of nutrient dilution and washout during this period. These findings support previous research identifying monsoons as a natural flushing process for rivers, temporarily resetting nutrient levels while modifying biological production (Pandey *et al.,* 2020).

4.3 | Ecological Implications

The strong pre-monsoon nutrient correlations indicate a high risk of eutrophication, which could lead to harmful algal blooms and degraded water quality. While post-monsoon flooding helps to reduce nutrient loads, it may temporarily impair productivity and disturb aquatic ecosystems. The durability of the chlorophyll-a and phytoplankton density association implies that phytoplankton development is extremely sensitive to nutrient fluctuations, particularly nitrogen. Understanding these seasonal changes is crucial for implementing effective river management techniques, particularly in monsoon-dominated regions like the Ganges.

5 | CONCLUSIONS

This study offers insight into the seasonal variations in phytoplankton productivity and nutrient availability in the ganga river. Monsoonal flooding significantly impacts primary productivity by diluting nutrient concentrations and increasing turbidity, leading to reduced phytoplankton density and chlorophyll-a levels. The pre-monsoon period is marked by nutrient-driven eutrophication threats, with nitrogen playing a crucial role in enhancing production. In contrast, post-monsoon dynamics demonstrate the natural reset mechanism of monsoon flooding, which temporarily alleviates nutrient loads but compromises ecological stability. These seasonal fluctuations underscore the intricate interplay between hydrological processes and nutrient cycling, emphasizing the need for focused management techniques to address anthropogenic nutrient inputs while preserving riverine health. Future studies should focus on long-term monitoring and the development of integrated systems to balance ecological and socio-economic pressures on the ganga river.

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CONFLICT OF INTEREST

The authors state that they have no financial or personal connections that could have influenced the work in this paper.

DATA AVAILABILITY STATEMENT

Data will be provided upon request.

AUTHOR'S CONTRIBUTION

V: Investigation, resources, formal analysis, visualization, writing - original draft; SKS: Supervision, conceptualization, writing - review and editing.

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