

Seasonal and Interannual Variations of Blue-Green Algal Taxa in the Chours of Supaul District, Bihar, India Driven by Distinct Nutrient Regimes

Sneha Kumari

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ABSTRACT

Supaul district of North Bihar is characterized by a diverse array of wetland ecosystems, including chours, swamps, dhars, mans, ditches, lakes, ponds and pools. These aquatic habitats have developed as a result of the region's extended rainy season and frequent flooding events. The abundance of water bodies in this area creates an ideal environment for the thriving of aquatic plant life, supporting over 120 species of algae and blue-green algae. Blue-green algae, also known as cyanobacteria, are photosynthetic

microorganisms that play a crucial role in aquatic ecosystems. However, excessive growth of these organisms can lead to harmful algal blooms, posing significant threats to water quality and ecosystem health. This study was conducted using weekly interval samplings from 2018 to 2023 and it investigates the seasonal and interannual variations of blue-green algal taxa in the chours (wetlands) of Supaul district, Bihar, India, with a focus on the influence of nutrient regimes. The research contributes to our understanding of the region's algal biodiversity, particularly the *Cyanophyceae* class. Present study investigated the response of blue-green algae (BGA) growth to environmental variations in various chours of Supaul district, focusing on the effects of nutrients, N:P ratios, and flow regime influenced by monsoon intensity.

Keywords Blue-green algae, Chours, North Bihar, Nutrient regimes, Supaul.

INTRODUCTION

The chours of Supaul district in North Bihar, India, are important freshwater ecosystems that support a diverse array of flora and fauna (Jha *et al.* 2014). These wetlands are subject to seasonal fluctuations in water levels and nutrient inputs, which can significantly impact the growth and composition of algal communities (Rani *et al.* 2019). Blue-green algae, in particular, are of interest due to their ability to form blooms under favorable conditions and their potential to produce toxins (Gupta *et al.* 2013, Bonilla *et al.* 2023). Understanding the dynamics of these algal

Sneha Kumari

University Department of Botany, Faculty of Science, North Campus, Bhupendra Narayan Mandal University, Madhepura 852113, Bihar, India

Email: sneha09mallik@gmail.com

populations is crucial for effective ecosystem management and water quality preservation.

Blue-green algae, despite their name, are actually photosynthetic bacteria that have inhabited Earth for billions of years. Their ability to adapt to various environmental conditions has allowed them to out-compete eukaryotic algae in many freshwater systems (Wang *et al.* 2021). However, when environmental conditions become favorable for rapid growth, these organisms can form harmful algal blooms (HABs) that pose significant threats to water quality, ecosystem health, and even human well-being (Igwaran *et al.* 2024). The increasing occurrence of blue-green algae (BGA) blooms, associated with excessive eutrophication and global warming, has become a critical concern in freshwater resource management worldwide (Paerl 2018, Treuer *et al.* 2021). These blooms produce compounds that adversely alter the taste and odor of drinking water, as well as toxins harmful to both human and animal health, such as microcystin and saxitoxins (Watson 2003, Falconer and Humpage 2005). BGA blooms significantly impact aquatic ecosystems by disturbing the ecological balance and rapidly depleting oxygen levels in the water, threatening the survival of aquatic life, including fish and invertebrates. Furthermore, these blooms in drinking water reservoirs complicate water treatment processes, resulting in higher costs for producing clean water (Walker 2014, Harris and Graham 2017, Treuer *et al.* 2021).

Given these widespread impacts, monitoring and predicting BGA dynamics is crucial for ensuring human health and safety, protecting aquatic environments and effectively managing water resources in the face of changing environmental conditions. The formation and persistence of blue-green algal blooms are influenced by a complex interplay of factors like nutrient availability (particularly nitrogen and phosphorus concentrations), water temperature, light availability, water flow and turbulence and seasonal variations (Oliver and Ganf 2000, Rose *et al.* 2021). In recent years, anthropogenic activities have led to increased nutrient loading in many freshwater ecosystems, often resulting in eutrophication. This process, combined with rising global temperatures due to climate change, has created conditions that

are increasingly favorable for cyanobacterial blooms (Paerl and Otten 2013, Rigosi *et al.* 2014).

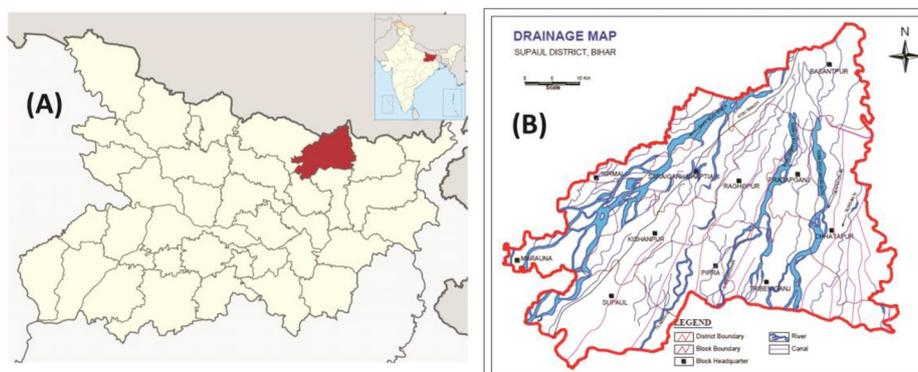
The chours of Supaul district provide an ideal setting to study these dynamics, as they experience distinct seasonal variations and are subject to the influences of monsoon patterns (Ahmad and Siddiqui 1990). By investigating the seasonal and interannual variations of blue-green algal taxa in these wetlands, we can gain valuable insights into the factors driving BGA growth and dominance. This knowledge is essential for developing effective strategies to mitigate the risks associated with harmful algal blooms and ensure the sustainable management of freshwater resources in the region. This study aims to investigate the complex relationships between nutrient availability, seasonal changes, and blue-green algal community dynamics in the chours of Supaul district. By examining these interactions over multiple years, we seek to identify patterns and drivers of cyanobacterial growth and dominance, providing valuable insights for water resource management and ecosystem conservation in the region.

MATERIALS AND METHODS

Study area

The study was conducted in selected chours of Supaul district, Bihar, India. Supaul district is located in the northern part of Bihar and is characterized by a subtropical climate with distinct seasonal variations (Jha 2023). Supaul district, one of Bihar's thirty-eight districts, is situated between 25°37' and 26°25' North latitude and 86°22' and 87°10' East longitude. As part of the Koshi Division, it encompasses an area of 2,425 square kilometers. The district is divided into eleven blocks i.e., Basantpur, Chhatapur, Kishanpur, Marauna, Nirmali, Pipra, Pratapganj, Raghapur, Saraigarh Bhaptiyahi, Supaul and Triveniganj. These blocks are further organized into four sub-divisions: Supaul Sadar, Birpur, Triveniganj and Nirmali.

Geographically, Supaul is bounded by Nepal to the north, Araria district to the east, Madhepura and Saharsa districts to the south, and Madhubani district to the west (Figs. 1 A–B). The Koshi River, often referred to as the “Sorrow of Bihar,” flows through



Figs. 1. (A) District map of Bihar showing Supaul district, (B) Map of Supaul district showing important drainages including the Kosi at the eastern parts of the district.

the district, making it prone to annual flooding. The district's landscape is characterized by alluvial soil, with some areas being acidic and others basic in nature. Supaul experiences a subtropical climate, with most of its rainfall occurring during the monsoon season. Between 2018-23, the district recorded an average rainfall of 2079.8 mm (Jha 2023). The climate of the district is basically temperate monsoon type. From early June to late September experiences above average rainfall. The climate during October to November and February to March is pleasant and December to January temperature lowers down to 8-12°C. During the period from April to July, the average temperature often reaches between 35°C – 40°C, making it a particularly hot time of year.

Field survey and sample collection

During the course of present taxonomic study altogether 450 samples (during January 2018 - December 2023) were collected from different wetlands of the Supaul district. The samples were analyzed for various physico-chemical parameters, including temperature, pH, dissolved oxygen, and nutrient concentrations (nitrogen and phosphorus). Sterile polythene bags were used to bring the algal samples from the fields. The materials were washed thoroughly and kept in previously prepared preservative.

Laboratory analysis and identification

Blue-green algal taxa were identified and quantified

using standard microscopic techniques. Briefly, the collected algal materials were first of all preserved with FAA solution containing 100 mL of 40% commercial formalin, 500 mL of 60% ethyl alcohol, 50 mL of glacial acetic acid and 350 mL of distilled water. To prevent desiccation, 50 mL of pure glycerine was added to each liter of this preservative solution. For microscopic examination, several temporary slides were prepared using 10% glycerine. Key taxonomic features were observed and documented. Specimens exhibiting mature stages and interesting algal taxa were carefully selected and retained for further analysis. Microscopic observations were conducted using an Olympus research microscope (model 7213). To capture detailed images of the specimens a prism-type camera lucida was employed for precise drawings and microphotographs were taken to document the algal material. For the identification of taxa, different monographs and standard literature were consulted (Singh *et al.* 2022). This methodology ensured accurate preservation and detailed examination of the blue-green algal taxa collected from the chours of Supaul district, allowing for comprehensive analysis of their seasonal and interannual variations.

Determination of water quality parameters

Water samples were collected weekly in triplicates from the wetlands at 30-70 cm below the surface from 2018 to 2023 and used in the assessment of water quality based on water temperature (WT), total suspended solids (TSS), Secchi depth (SD), as a measure

of water transparency and nutrient contents including total nitrogen (TN) and total phosphorus (TP), and phytoplankton CHL-a following (Jargal and Kwang 2023). Weekly and monthly values were averaged. This comprehensive water quality assessment provides valuable insights into the physical, chemical, and biological characteristics of the water body over a five-year period. The inclusion of both nitrogen and phosphorus measurements allows for the evaluation of nutrient dynamics, while chlorophyll-a serves as an indicator of phytoplankton biomass and potential algal blooms (Kim *et al.* 2021).

TSS was determined in samples filtered through a glass microfiber filter with a 1.2- μm pore size (Whatman) and dried for 1-2 h at 120°C. Total nitrogen content of the water samples was determined by UV spectrophotometry followed by potassium sulfate digestion (Crumpton *et al.* 1992) and total phosphorus was determined using unfiltered water digested according to the ascorbic acid method after persulfate oxidation (Prepas and Rigler 1982). The chlorophyll-a concentration was measured in GF/C-filtered, ethanol-extracted water samples using a spectrophotometer (Systronics). The monthly dynamics of phytoplankton biomass were derived from average Chl-a values by multiplying by 67 (APHA 2012). BGA samples were collected weekly from 2018 to 2023. These samples were placed in sterile 500-mL bottles, treated with FAA solution for preservation, and stored in a cool container until they could be processed in the laboratory.

RESULTS AND DISCUSSION

Seasonal variations

The study revealed distinct seasonal patterns in the abundance and composition of blue-green algal taxa in the chours of Supaul district. The highest diversity and abundance of blue-green algae were observed during the summer months, particularly from May to September. This period coincides with increased water temperatures and higher nutrient concentrations, which provide favorable conditions for algal growth (Table 1).

In the present study, six dominant cyanobacteria

isolates belonging to the genera *Oscillatoria*, *Anabaena*, *Nostoc*, *Scytonema*, *Lyngbya* and *Calothrix* were evaluated. During the winter months (December to February), the diversity and abundance of blue-green algae decreased significantly (Table 2, Fig. 2). This reduction can be attributed to lower water temperatures and reduced nutrient availability. However, certain genera like *Nostoc*, *Anabaena*, and *Oscillatoria* were found to persist throughout the year, demonstrating their adaptability to varying environmental conditions. *Lyngbya* was found to be more dominant during winter season.

Interannual variations

Interannual variations in blue-green algal communities were observed over the five-year study period (Table 1). These variations were primarily driven by differences in monsoon intensity and the resulting changes in nutrient regimes. Years with intense monsoons showed a distinct pattern of post-monsoon blooms, particularly in September.

The intense monsoon rainfall resulted in increased nutrient inputs, especially phosphorus, through soil washing and runoff. This phosphorus enrichment was crucial in promoting phytoplankton blooms, including blue-green algae, in the early post-monsoon period. In contrast, years with weaker monsoons exhibited lower algal abundance due to reduced nutrient inputs and stronger water column stability.

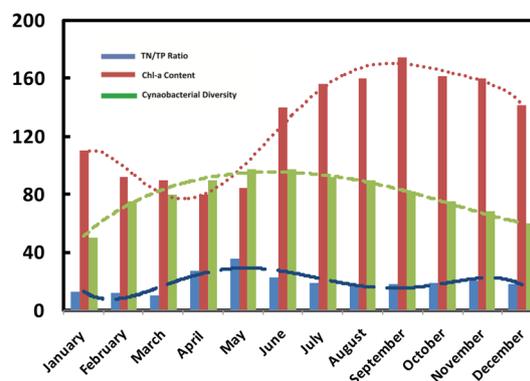


Fig. 2. Seasonal variations of blue-green algal taxa in Supaul driven by TN/TP ratio.

Table 1. Physico-chemical properties wetlands of Supaul District.

Year	Month	Temperature (°C)	pH	Total suspended solids (TSS) in mg/l	Secchi depth (SD)	Dissolved oxygen in mg/l	Total nitrogen (TN) in mg/l	Total phosphate (TP) in mg/l	TN/TP ratio
2018	January	12	7.8	104	1.2	8	7.2	0.6	12
	February	16	7.8	104	1.2	9	7	0.6	11.7
	March	25	8.1	106	1.1	9	7.2	0.7	10.3
	April	32	8.1	108	1.1	9	8.6	0.32	26.9
	May	38	7.7	94	1	10	8.9	0.25	35.6
	June	39	7.6	69	1.8	10	8.9	0.4	22.3
	July	39	7.2	63	1.94	11	11	0.6	18.3
	August	37	7.1	63	1.98	11	12	0.7	17.1
	September	36	7.1	64	1.92	12	14	0.8	17.5
	October	32	7.8	72	1.8	12	11	0.6	18.3
	November	24	7.8	98	1.6	11	10	0.5	20.0
	December	14	7.9	102	1.4	9	8.2	0.46	17.8
2019	January	13	7.9	106	1.2	8	7.4	0.6	12.3
	February	16	7.8	104	1.2	8	7.2	0.6	12.0
	March	26	8.1	106	1.1	9	7.2	0.7	10.3
	April	32	8.1	112	1.1	9	8.6	0.32	26.9
	May	38	7.7	94	1	11	8.9	0.25	35.6
	June	39	7.6	69	1.8	11	8.9	0.4	22.3
	July	39	7.2	64	1.94	11	11	0.6	18.3
	August	37	7.1	63	1.98	11	12	0.7	17.1
	September	36	7.1	64	1.92	12	14.8	0.8	18.5
	October	32	7.8	70	1.8	12	12	0.6	20.0
	November	24	7.8	98	1.6	11	10	0.5	20.0
	December	12	7.9	100	1.4	9	8.2	0.46	17.8
2020	January	14	7.9	102	1.2	9	7.2	0.6	12.0
	February	16	8	102	1.2	9	7	0.6	11.7
	March	25	8	102	1.1	9	7.2	0.7	10.3
	April	32	8.1	104	1.1	9	8.6	0.32	26.9
	May	38	7.7	94	1	10	8.9	0.25	35.6
	June	39	7.6	69	1.8	11	8.9	0.4	22.3
	July	39	7.2	64	1.94	11	12	0.6	20.0
	August	37	7.1	63	1.98	11	12	0.7	17.1
	September	36	7.1	64	1.92	12	14	0.8	17.5
	October	32	7.8	71	1.8	12	11	0.6	18.3
	November	24	7.9	97	1.58	11	10	0.5	20.0
	December	12	7.9	102	1.4	10	8.2	0.46	17.8
2021	January	12	7.8	102	1.2	8	7.2	0.6	12.0
	February	16	7.8	104	1.2	9	7.8	0.6	13.0
	March	25	8.1	104	1.1	9	7.2	0.7	10.3
	April	32	8.1	108	1.1	9	8.6	0.32	26.9
	May	38	7.7	94	1	10	8.9	0.25	35.6
	June	39	7.6	67	1.8	10	8.9	0.4	22.3
	July	39	7.2	64	1.94	11	11	0.6	18.3
	August	37	7.1	63	1.94	11	12	0.7	17.1
	September	36	7.1	64	1.9	12	14	0.8	17.5
	October	32	7.8	70	1.7	12	11	0.6	18.3
	November	26	7.8	97	1.6	11	10	0.5	20.0
	December	14	7.9	101	1.4	9	8.2	0.46	17.8
2022	January	13	7.9	102	1.2	8	7.2	0.6	12.0
	February	18	7.9	103	1.24	9	7.2	0.6	12.0
	March	25	8.1	104	1.1	9	7.2	0.7	10.3
	April	32	8.1	106	1.1	10	8.6	0.32	26.9
	May	38	7.7	92	1.1	10	8.9	0.25	35.6

Table 1. Continued.

Year	Month	Temperature (°C)	pH	Total suspended solids (TSS) in mg/l	Secchi depth (SD)	Dissolved oxygen in mg/l	Total nitrogen (TN) in mg/l	Total phosphate (TP) in mg/l	TN/TP ratio
2022	June	39	7.6	68	1.8	10	8.9	0.4	22.3
	July	39	7.2	62	1.94	11	11	0.6	18.3
	August	37	7.1	62	1.97	11	12	0.7	17.1
	September	36	7.1	63	1.9	12	14	0.8	17.5
	October	32	7.8	72	1.72	12	11.2	0.6	18.7
	November	27	7.9	98	1.6	11	10	0.5	20.0
	December	13	7.9	101	1.5	10	8.2	0.46	17.8

Dominant taxa

The study identified several dominant blue-green algal taxa in the hours of Supaul district. These included species belonging to the genera *Microcystis*, *Anabaena*, *Oscillatoria* and *Spirulina*. The relative

abundance of these taxa varied seasonally and interannually, reflecting their different ecological preferences and adaptations.

Microcystis species, known for their ability to form surface blooms, were particularly abundant

Table 2. Cynaobacterial diversity and abundance based on TN/TP and Chl-a. Symbol X represents the cyanobacterial diversity, where XX represent lowest and XXXXXX represent highest diversity.

Year	Month	Chl-a in mg/10 ltr	Cyanobacterial diversity	Dominant cyanobacteria taxa
2018	January	110	XX	<i>Lyngbya</i>
	February	92	XXX	<i>Lyngbya</i>
	March	90	XXXX	<i>Anabaena, Microcystis</i>
	April	80	XXXXXXX	<i>Scytonema, Oscillatoria</i>
	May	84	XXXXXXX	<i>Scytonema, Oscillatoria</i>
	June	140	XXXX	<i>Scytonema, Oscillatoria</i>
	July	156	XXX	<i>Calothrix, Anabaena</i>
	August	160	XXX	<i>Calothrix, Anabaena</i>
	September	175	XXX	<i>Calothrix, Anabaena</i>
	October	162	XXX	<i>Anabaena, Microcystis</i>
	November	160	XXX	<i>Anabaena</i>
	December	142	XX	<i>Lyngbya</i>
2019	January	114	XX	<i>Lyngbya</i>
	February	112	XXX	<i>Lyngbya</i>
	March	110	XXXX	<i>Anabaena, Microcystis</i>
	April	100	XXXXXXX	<i>Scytonema, Oscillatoria</i>
	May	92	XXXXXXX	<i>Scytonema, Oscillatoria</i>
	June	140	XXXX	<i>Scytonema, Oscillatoria</i>
	July	152	XXX	<i>Calothrix, Anabaena</i>
	August	164	XXX	<i>Calothrix, Anabaena</i>
	September	170	XXX	<i>Calothrix, Anabaena</i>
	October	160	XXX	<i>Anabaena, Microcystis</i>
	November	150	XXX	<i>Anabaena</i>
	December	142	XX	<i>Lyngbya</i>
2020	January	110	XX	<i>Lyngbya</i>
	February	92	XXX	<i>Lyngbya</i>
	March	90	XXXX	<i>Anabaena, Microcystis</i>
	April	80	XXXXXXX	<i>Scytonema, Oscillatoria</i>
	May	84	XXXXXXX	<i>Scytonema, Oscillatoria</i>

Table 2. Continued.

Year	Month	Chl-a in mg/10 ltr	Cyanobacterial diversity	Dominant cyanobacteria taxa	
2020	June	142	XXXX	<i>Scytonema, Oscillatoria</i>	
	July	156	XXX	<i>Calothrix, Anabaena</i>	
	August	160	XXX	<i>Calothrix, Anabaena</i>	
	September	172	XXX	<i>Calothrix, Anabaena</i>	
	October	162	XXX	<i>Anabaena, Microcystis</i>	
	November	158	XXX	<i>Anabaena</i>	
	December	140	XX	<i>Lyngbya</i>	
	2021	January	108	XX	<i>Lyngbya</i>
		February	90	XXX	<i>Lyngbya</i>
		March	90	XXXX	<i>Anabaena, Microcystis</i>
		April	78	XXXXXX	<i>Scytonema, Oscillatoria</i>
		May	88	XXXXXX	<i>Scytonema, Oscillatoria</i>
June		140	XXXX	<i>Scytonema, Oscillatoria</i>	
July		152	XXX	<i>Calothrix, Anabaena</i>	
August		157	XXX	<i>Calothrix, Anabaena</i>	
September		174	XXX	<i>Calothrix, Anabaena</i>	
October		162	XXX	<i>Anabaena, Microcystis</i>	
November		160	XXX	<i>Anabaena</i>	
December		142	XX	<i>Lyngbya</i>	
2022	January	110	XX	<i>Lyngbya</i>	
	February	90	XXX	<i>Lyngbya</i>	
	March	90	XXXX	<i>Anabaena</i>	
	April	80	XXXXXX	<i>Scytonema, Oscillatoria</i>	
	May	88	XXXXXX	<i>Scytonema, Oscillatoria</i>	
	June	136	XXXX	<i>Scytonema, Oscillatoria</i>	
	July	152	XXX	<i>Calothrix, Anabaena</i>	
	August	154	XXX	<i>Calothrix, Anabaena</i>	
	September	170	XXX	<i>Calothrix, Anabaena</i>	
	October	162	XXX	<i>Anabaena, Microcystis</i>	
	November	160	XXX	<i>Anabaena, Microcystis</i>	
	December	142	XX	<i>Lyngbya</i>	

during periods of high nutrient availability and stable water conditions. *Anabaena* species, capable of nitrogen fixation, were more prevalent in conditions of low N:P ratios.

Implications for ecosystem management

The findings of this study have important implications for the management of chours and other freshwater ecosystems in the region. The strong influence of monsoon intensity on nutrient inputs and subsequent algal blooms highlights the need for effective watershed management practices to control nutrient runoff. Monitoring of N:P ratios and dissolved phosphorus levels could serve as early warning indicators for potential blue-green algal blooms. Management strategies should focus on reducing phosphorus inputs, as this appears to be a key limiting factor for blue-green

algal growth in these ecosystems.

CONCLUSION

This study provides valuable insights into the seasonal and interannual dynamics of blue-green algal communities in the chours of Supaul district. The results demonstrate the complex interplay between climatic factors, nutrient regimes, and algal growth. Understanding these relationships is crucial for predicting and managing blue-green algal blooms in these important freshwater ecosystems. Future research should focus on long-term monitoring to better understand the impacts of climate change on these dynamics. Additionally, investigating the potential toxin production by dominant blue-green algal species would be valuable for assessing the risks to human and ecosystem health.

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