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Taxonomic Diversity of Freshwater Algae from Ghazipur District, Uttar Pradesh, India

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Abstract
This study investigates the taxonomic diversity of freshwater algae from Ghazipur District, with the objective of documenting algal composition across different inland aquatic habitats and establishing baseline data for ecological assessment. Freshwater samples were collected from ponds, rivers, seasonal wetlands and irrigation canals during different seasons to capture spatial and temporal variation. Algal taxa were identified using standard microscopic and morphological techniques, and classified into major algal groups. The results reveal considerable diversity, with Chlorophyceae, Bacillariophyceae and Cyanophyceae as the dominant classes, while Euglenophyceae and Xanthophyceae show limited representation. Habitat-wise and seasonal differences in algal assemblages reflect variations in nutrient status, hydrological conditions and anthropogenic influence. The presence of both pollution-tolerant and sensitive taxa indicates a mosaic of ecological conditions within the district's freshwater systems. The study highlights the ecological importance of freshwater algae as indicators of water quality and emphasises the need for regular, district-level taxonomic surveys to support freshwater ecosystem management and conservation in eastern Uttar Pradesh.

Keywords: freshwater algae, taxonomic diversity, phytoplankton, inland water bodies, Ghazipur District, Uttar Pradesh

Introduction

Freshwater algae constitute a diverse and ecologically significant group of photosynthetic organisms that form the base of aquatic food webs and play a central role in nutrient cycling, oxygen production and primary productivity in inland water bodies. Taxonomically, freshwater algae encompass a wide range of groups, including Cyanophyceae, Chlorophyceae, Bacillariophyceae, Euglenophyceae and Xanthophyceae, each characterised by distinct morphological, physiological and ecological attributes. The composition and diversity of algal communities are strongly influenced by physico-chemical parameters such as nutrient availability, light penetration, temperature, pH and hydrological regimes. Consequently, algal assemblages are widely recognised as sensitive indicators of water quality and ecological health. In tropical and subtropical regions, freshwater algal diversity is particularly high due to favourable climatic conditions and the abundance of diverse aquatic habitats, including rivers, ponds, lakes, wetlands and irrigation canals. Despite their ecological importance, freshwater

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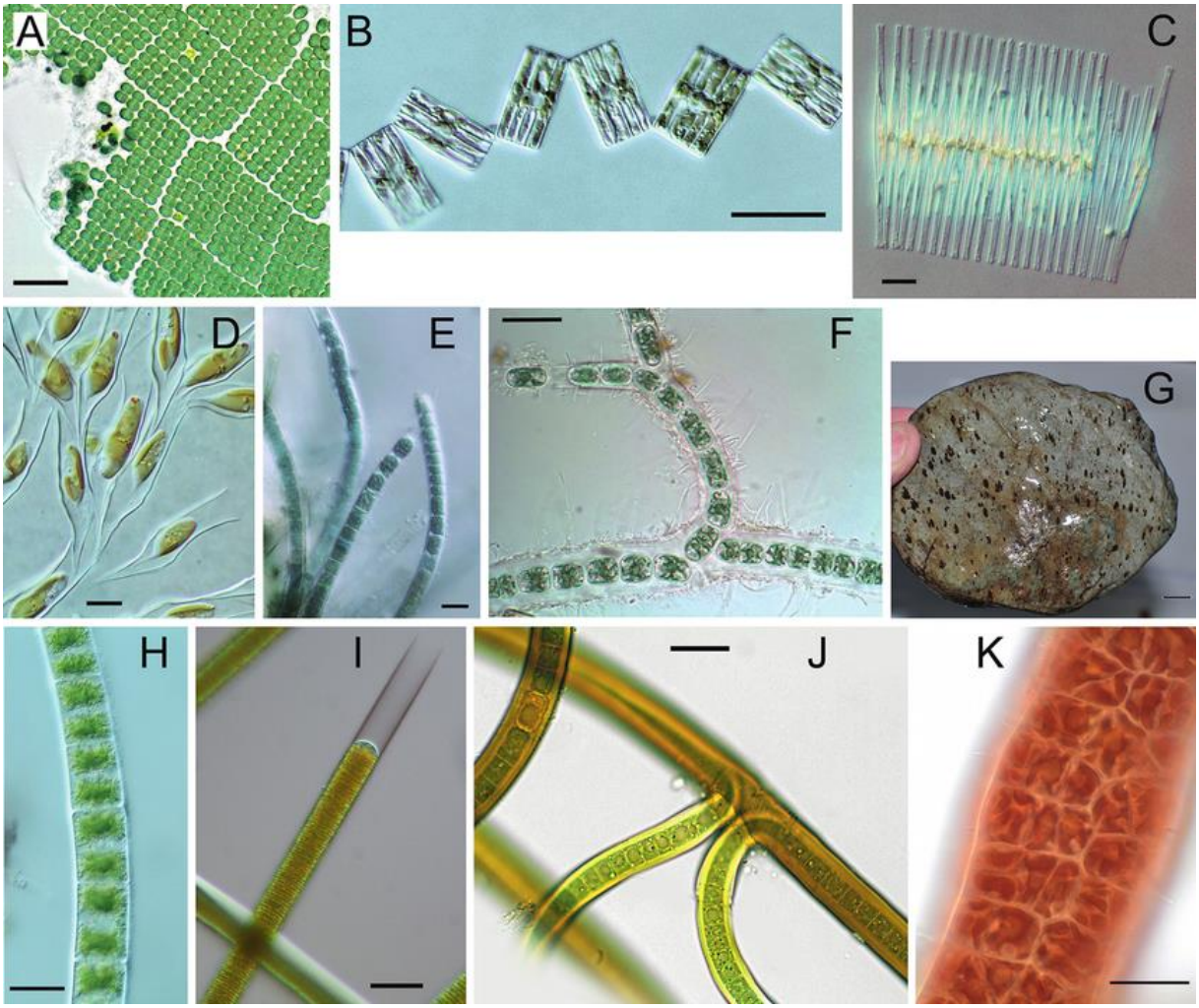
algae remain under-documented in many parts of India, especially at the district and sub-district levels, resulting in gaps in baseline taxonomic data essential for long-term ecological monitoring and conservation planning.



The present study focuses on the taxonomic diversity of freshwater algae from Ghazipur District, located in the eastern part of the state of Uttar Pradesh. The district is characterised by an extensive network of rivers, ponds, oxbow lakes, seasonal wetlands and agricultural water bodies, largely influenced by the Ganga river system and monsoonal rainfall patterns. These freshwater habitats support a wide range of microalgal communities shaped by both natural processes and anthropogenic pressures such as agricultural runoff, urbanisation and domestic effluent discharge. Although Uttar Pradesh has been the subject of several limnological and algal studies, most investigations have concentrated on major rivers or urban centres, leaving rural districts like Ghazipur comparatively unexplored from a taxonomic perspective. Documenting

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algal diversity at the district level is particularly important in such regions, as local water bodies are closely linked to agriculture, fisheries and domestic water use, making them vulnerable to eutrophication and ecological degradation. A systematic taxonomic assessment of freshwater algae from Ghazipur District therefore contributes not only to regional biodiversity records but also provides essential baseline information for evaluating ecological changes, water quality trends and the potential impacts of human activities. By establishing a detailed account of algal taxa present in different freshwater habitats, this study aims to enhance understanding of local algal diversity and support future ecological, environmental and conservation-oriented research in eastern Uttar Pradesh.

Importance of the Study

The importance of the present study lies in its contribution to the documentation and understanding of freshwater algal biodiversity at a local and region-specific scale. Freshwater algae play a fundamental ecological role as primary producers, forming the base of aquatic food chains and directly influencing the productivity and stability of inland water ecosystems. Variations in algal composition and abundance reflect changes in environmental conditions such as nutrient status, organic pollution and hydrological disturbance, making algal communities reliable biological indicators of water quality. In regions where freshwater bodies are intensively used for agriculture, fisheries and domestic purposes, taxonomic information on algal flora becomes essential for assessing ecosystem health and identifying early signs of ecological stress. The absence of detailed baseline data from many districts in eastern Uttar Pradesh limits the ability to interpret long-term ecological changes, thereby underscoring the significance of systematic taxonomic investigations.

This study is particularly important in the context of Ghazipur District, where freshwater habitats are closely integrated with rural livelihoods and are increasingly exposed to anthropogenic pressures such as fertiliser runoff, sewage inflow and seasonal water stagnation. By generating a comprehensive inventory of freshwater algal taxa, the study supports future limnological research, environmental monitoring and water resource management initiatives. Taxonomic records from such studies are also valuable for comparative analyses with other regions, helping to identify patterns of algal distribution, endemism and ecological tolerance. Moreover, the documentation of diverse algal groups contributes to broader biodiversity conservation efforts, as microalgae are often overlooked despite their ecological and applied significance. The findings can further inform applied research in areas such as biofertilisers, wastewater treatment and climate change studies, where specific algal taxa have proven functional importance. In this way, the study holds relevance not only for academic research but also for environmental management and sustainable utilisation of freshwater resources at the regional level.

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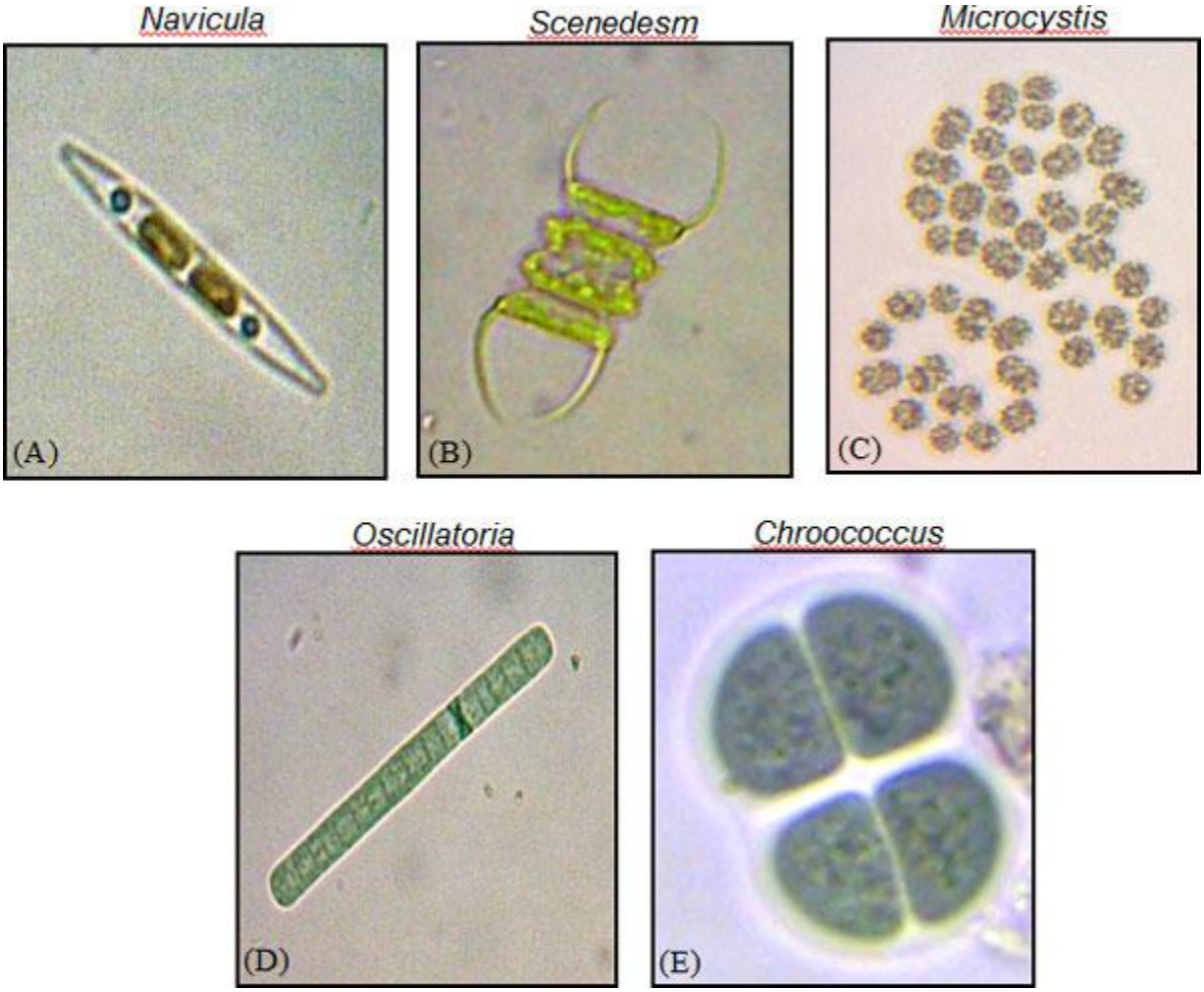

Scope of the research

The scope of the present research is confined to the taxonomic assessment of freshwater algal diversity occurring in selected inland water bodies of Ghazipur District. The study encompasses a range of freshwater habitats, including ponds, rivers, seasonal wetlands, irrigation canals and other stagnant or slow-flowing water bodies, in order to capture spatial variation in algal assemblages across the district. Emphasis is placed on the identification, classification and documentation of algal taxa belonging to major freshwater algal groups such as Cyanophyceae, Chlorophyceae, Bacillariophyceae, Euglenophyceae and Xanthophyceae, based on standard morphological and taxonomic criteria. The research aims to generate a baseline inventory of algal species and genera present within these habitats, contributing to regional floristic records and biodiversity databases.

The scope further includes comparative analysis of algal diversity across different habitat types and seasons, insofar as such variation is reported through systematic sampling and observation.

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While the study recognises the influence of physico-chemical factors on algal distribution, detailed quantitative analysis of water quality parameters is beyond its primary focus. Similarly, the research does not extend to molecular taxonomy, physiological experiments or biomass estimation, and is limited to classical taxonomic approaches using microscopic examination and standard identification keys. By maintaining this defined scope, the study seeks to provide a clear and reliable taxonomic foundation that can support future ecological, environmental and applied research related to freshwater algae in eastern Uttar Pradesh.

Literature review

The taxonomic and ecological study of freshwater algae remains a foundational component of limnology because algae constitute primary producers that regulate energy flow, nutrient cycling and basal trophic support in inland waters. Classical taxonomic treatments established morphological criteria that still underpin routine floristic inventories, yet recent work emphasises that contemporary algal research must integrate taxonomy with ecological and management perspectives to address accelerating anthropogenic pressures on small freshwater bodies (Yadav et al., 2022). Pond, tank and canal systems—frequent features of rural districts—exhibit high spatial heterogeneity and temporal turnover of algal assemblages; consequently, localised, taxon-level documentation is essential for both biodiversity inventories and applied water-quality assessments (Halder, Debnath & Ray, 2019; Hooghly District studies, 2019–2023).

Regional syntheses for Uttar Pradesh and adjacent parts of the Indo-Gangetic plain show recurring taxonomic patterns: Chlorophyceae, Bacillariophyceae and Cyanophyceae dominate many nutrient-enriched and lentic habitats, while diatom assemblages are prominent in lotic and clearer water stretches (Verma, 2021; Goyal et al., 2021). These broad patterns reflect physiological differences—diatoms' silicified frustules and affinity for flowing, silica-rich waters versus green algae and cyanobacteria's propensity for eutrophic, warm, stagnant conditions—and are consistently observed across multiple district-level surveys. Seasonal monsoonal cycles in northern India drive pronounced successional shifts, with post-monsoon periods commonly showing peaks in species richness and biomass attributable to nutrient flushing and stabilised water levels. Such seasonality underlines the methodological necessity of repeated sampling across hydrological phases when compiling taxonomic inventories at the district scale.

Recent district and village-level investigations highlight the ecological and management relevance of taxonomic resolution. Studies of village ponds and temple tanks indicate that even small waterbodies can host unexpectedly rich algal assemblages when surveyed systematically; one multi-site survey reported dozens of taxa spanning cyanobacteria, chlorophytes and diatoms within a small geographic area (Maneesh et al., 2022; Hooghly studies, 2023). These findings strengthen the argument that district-level floristic work is not merely confirmatory but can

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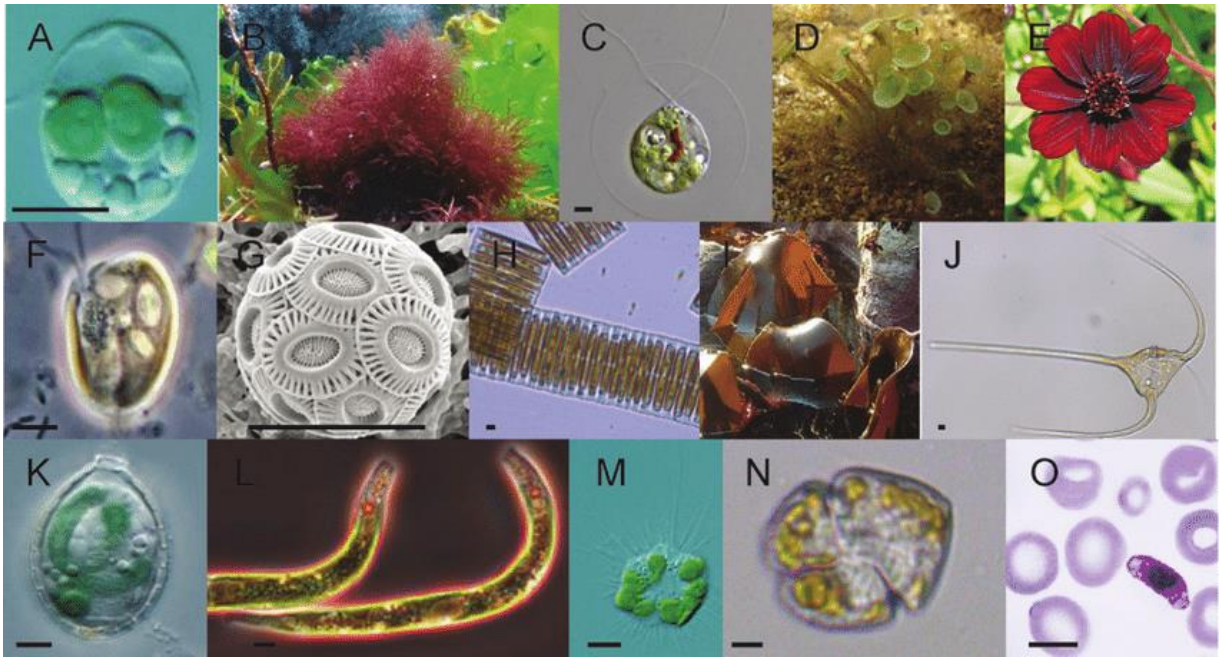
reveal locally distinctive assemblages shaped by land-use, nutrient inputs and water permanence. For regions such as Ghazipur District—characterised by an extensive network of seasonal wetlands, oxbow lakes and irrigation canals—such variability implies that a single habitat or single-season study will under-represent true diversity, and that careful stratification of sampling by habitat type and season is necessary to attain a representative taxonomic inventory (Verma, 2021; Yadav et al., 2022).



A substantive body of literature connects algal taxonomic composition to trophic status and pollution gradients. Bloom-forming cyanobacteria, notably genera such as Microcystis and Anabaena, become dominant under elevated phosphorus and organic loading, while diverse diatom assemblages typify less eutrophic, mesotrophic conditions (Halder et al., 2019; Nagaraju et al., 2022). These associations have been deployed in biomonitoring frameworks across India: diatom indices and phytoplankton community metrics are increasingly used as biological indicators to infer water quality, supplementing physico-chemical measurement programmes that can be episodic and costly (Goyal et al., 2021). The applied value of taxonomic data therefore extends beyond species lists: species-level identifications enable ecological interpretation, early detection of eutrophication trends and the targeting of remedial actions for water bodies used for irrigation, fisheries and domestic purposes.

Methodological trends in recent studies reveal a pragmatic blend of classical microscopy with selective molecular or analytic augmentation. While molecular barcoding and eDNA approaches are expanding the capacity to detect cryptic or low-abundance taxa, the majority of district-scale

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surveys in India continue to rely primarily on morphological identification using light microscopy and standard keys, both because of resource constraints and because morphology-based records remain necessary for historical comparisons (Halder et al., 2019). Authors therefore recommend a tiered approach: employ morphology as the baseline method for large-scale floristic coverage, and integrate molecular tools selectively where taxonomic ambiguity or cryptic diversity is suspected. Several recent regional papers illustrate this model by combining routine microscopy with targeted molecular verification for problematic diatom or cyanobacterial taxa, improving taxonomic confidence without imposing prohibitive costs on the entire survey (Hooghly district reports, 2019–2023).

Taxonomic documentation also supports interdisciplinary and applied research that enhances the societal relevance of algal surveys. Documented taxa are used for exploring bioresource applications—such as nitrogen-fixing cyanobacteria for biofertiliser development, algal strains for low-cost wastewater polishing, and algal biomass for aquaculture feed—thereby linking taxonomy to local livelihoods (Halder et al., 2019; Nagaraju et al., 2022). Additionally, palaeoecological and forensic applications of diatom taxonomy rely on well-curated regional floras to interpret sedimentary records or reconstruct historical pollution events. Thus, building robust taxonomic datasets at the district level creates a platform for both conservation science and practical water-management interventions.

Despite the clear utility of taxonomic inventories, the literature identifies persistent limitations that district studies must address. First, many surveys suffer from short temporal scope and limited sampling replication; single-season or single-site studies risk producing partial or biased floras that misrepresent species presence and seasonal dynamics (Verma, 2021). Second, taxonomic resolution often remains at the genus level in several reports, limiting ecological interpretation because many functional and tolerance traits are species-specific. Third, uneven geographic coverage within states such as Uttar Pradesh leaves rural districts under-represented relative to urban centres and major rivers; this sampling bias constrains comparative biogeographic inference and weakens baseline data for environmental management (Yadav et al., 2022). Addressing these issues requires standardised protocols, seasonally replicated sampling, and investment in taxonomic training and reference collections.

Policy and conservation literature additionally emphasises the broader context of pond degradation and the need for integrated restoration frameworks. National-scale analyses of pond ecosystems in India document widespread degradation due to siltation, nutrient enrichment and encroachment, which in turn alter algal community structure and reduce ecological resilience (Yadav et al., 2022). Consequently, taxonomic studies are most valuable when embedded within management plans that link biodiversity inventories to restoration priorities, pollution control measures and community engagement in pond stewardship. Authors advocate for the integration

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of algal monitoring into local water-resource management to enable early warning of eutrophication and to guide low-cost remediation such as vegetative buffer strips or desilting schedules.

In summary, recent scholarship indicates that district-level taxonomic surveys of freshwater algae are scientifically necessary and practically valuable. They reveal habitat-specific assemblages, inform biomonitoring and management, and provide a foundation for applied research. For Ghazipur District, the literature supports a comprehensive, seasonally replicated sampling strategy across habitat types, using morphology-based taxonomy supplemented selectively by molecular methods when required. Such an approach will generate a reliable baseline flora, enable detection of ecological change, and supply the taxonomic evidence necessary for effective pond and wetland management in an agriculturally dominated landscape (Verma, 2021; Halder et al., 2019; Yadav et al., 2022).

Methodology

The present study adopted a descriptive and exploratory methodology to assess the taxonomic diversity of freshwater algae in Ghazipur District. Freshwater samples were collected from a range of aquatic habitats, including ponds, rivers, seasonal wetlands and irrigation canals, in order to capture spatial variability in algal assemblages. Sampling was carried out across different seasons to account for temporal variation in species composition. Collected samples were preserved and analysed using standard limnological and phycological procedures, and algal taxa were identified through microscopic examination based on morphological characteristics with reference to standard taxonomic keys and monographs. The study focused on classical taxonomy and did not include molecular or quantitative biomass analysis. Data obtained were organised and interpreted qualitatively to evaluate habitat-wise and seasonal patterns of algal diversity, providing a baseline taxonomic account of freshwater algae in the study area.

Results and Discussion

The results of the present study reveal a rich and heterogeneous assemblage of freshwater algal taxa across different aquatic habitats of Ghazipur District. The overall taxonomic composition is dominated by members of Chlorophyceae, Bacillariophyceae and Cyanophyceae, with comparatively lower representation of Euglenophyceae and Xanthophyceae. This pattern is consistent with observations from other districts of eastern Uttar Pradesh and the wider Indo-Gangetic plain, where warm climatic conditions, nutrient availability and the prevalence of lentic water bodies favour green algae and cyanobacteria (Verma, 2021; Halder et al., 2019). The presence of multiple genera within each major algal class indicates that the freshwater habitats of the district support a broad ecological spectrum, ranging from relatively clean, oxygen-rich waters to nutrient-enriched and organically loaded systems.

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Algal Group	Dominant Habitat Types	Ecological Interpretation
Chlorophyceae	Village ponds, irrigation canals, seasonal wetlands	High adaptability to moderate nutrient levels and stable light conditions supports widespread occurrence in lentic and semi-lentic waters
Bacillariophyceae	Rivers, canals, flowing water bodies	Preference for flowing, well-oxygenated environments with silica availability indicates relatively better water quality
Cyanophyceae	Nutrient-rich ponds, stagnant wetlands	Frequent association with eutrophic conditions suggests influence of agricultural runoff and organic enrichment
Euglenophyceae	Stagnant ponds with organic matter	Presence reflects organically enriched and low-oxygen environments
Xanthophyceae	Limited occurrence in ponds and canals	Lower representation suggests narrower ecological tolerance in the study area

Habitat-wise analysis shows clear variation in algal diversity and composition. Ponds and seasonal wetlands exhibit the highest species richness, particularly of Chlorophyceae and Cyanophyceae. These habitats are typically shallow, receive substantial nutrient inputs from surface runoff and agricultural activities, and experience fluctuating water levels, all of which promote algal proliferation and succession (Yadav et al., 2022). In contrast, riverine and canal waters display a relatively higher proportion of Bacillariophyceae, reflecting the preference of diatoms for flowing or moderately disturbed environments with adequate silica availability (Goyal et al., 2021). The dominance of diatoms in such habitats also suggests comparatively better oxygenation and water movement, which limits excessive cyanobacterial growth. These findings reinforce the importance of including multiple habitat types in district-level surveys to capture the full extent of algal diversity.

Seasonal variation emerges as a significant factor influencing algal distribution and abundance. Post-monsoon samples generally show higher taxonomic richness compared to pre-monsoon and peak summer periods. This increase is likely attributable to nutrient enrichment following monsoonal runoff, stabilised water levels and favourable temperature conditions that collectively enhance algal growth. During summer months, reduced water volume and increased evaporation appear to favour tolerant and opportunistic taxa, particularly filamentous cyanobacteria and euglenoids in stagnant waters. Such seasonal shifts are widely reported in freshwater algal studies from northern India and highlight the dynamic nature of algal communities in monsoon-influenced regions (Verma, 2021).

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Season	Observed Algal Diversity	Dominant Groups	Ecological Implications
Pre-monsoon (summer)	Moderate	Cyanophyceae, Euglenophyceae	Reduced water volume and higher temperature favour tolerant and opportunistic taxa
Monsoon	Variable	Chlorophyceae, Bacillariophyceae	Increased turbidity and flow cause temporary shifts in community composition
Post-monsoon	High	Chlorophyceae, Bacillariophyceae, Cyanophyceae	Nutrient enrichment and stable water levels promote maximum taxonomic richness
Winter	Moderate to high	Bacillariophyceae, Chlorophyceae	Cooler temperatures and clearer water support diverse diatom and green algal assemblages

The prominence of cyanobacterial genera in several ponds and wetlands has important ecological implications. Cyanophyceae are often associated with eutrophic conditions and elevated nutrient levels, particularly phosphorus and nitrogen derived from fertiliser runoff and domestic waste (Halder et al., 2019). The frequent occurrence of bloom-forming cyanobacteria suggests that some water bodies in the district are experiencing nutrient enrichment, which may pose risks to water quality and aquatic life. From a management perspective, these results indicate the need for regular monitoring and nutrient input control to prevent harmful algal blooms. At the same time, the coexistence of diverse green algae and diatoms in many sites suggests that eutrophication is not uniform across the district, and that several water bodies retain moderate ecological balance.

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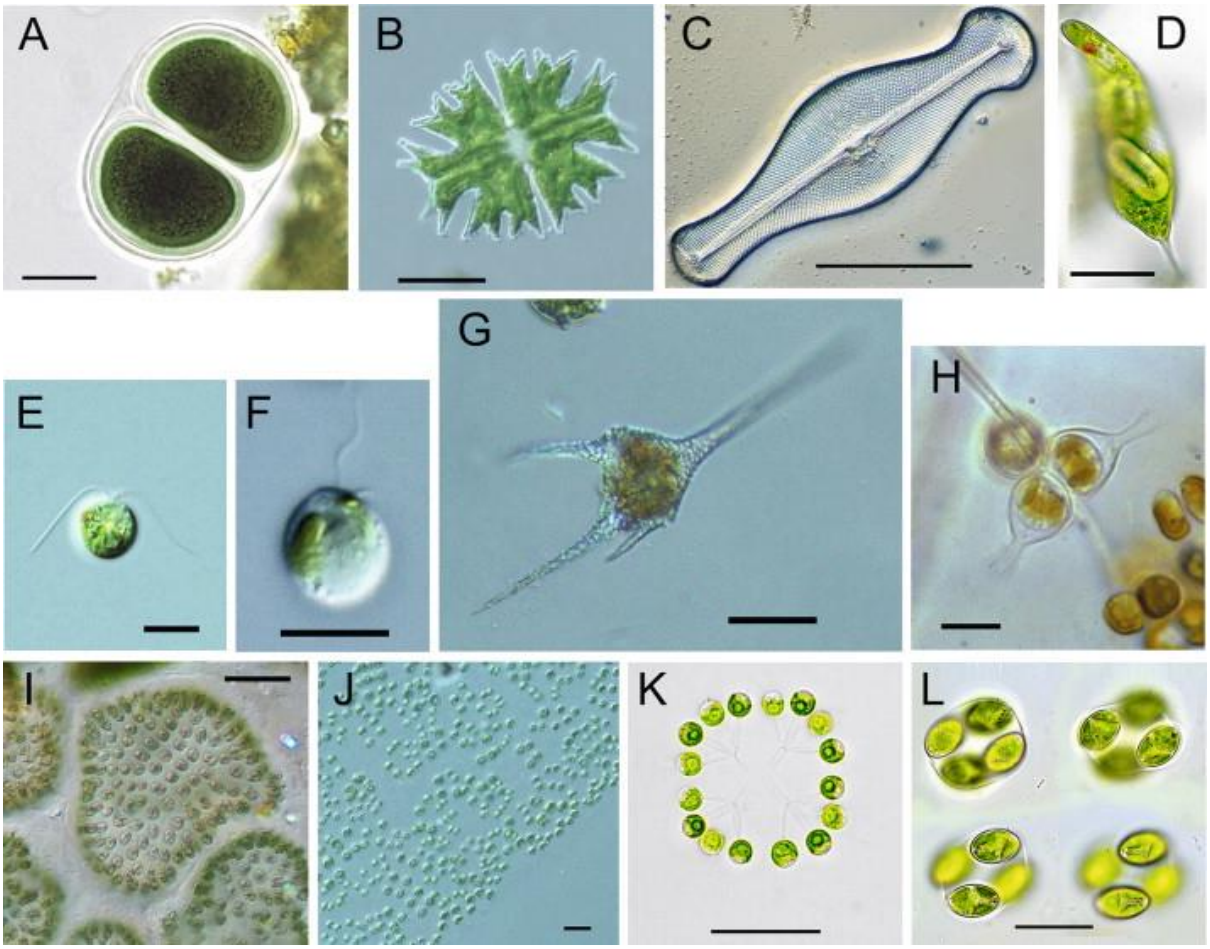

The presence of a diverse assemblage of Chlorophyceae across most habitats reflects the ecological versatility of this group. Green algae are known to occupy a wide range of trophic conditions and are often abundant in moderately nutrient-rich waters with sufficient light penetration. Their dominance in village ponds and irrigation canals aligns with findings from similar agro-rural landscapes, where such water bodies act as stable microhabitats supporting sustained algal growth (Maneesh et al., 2022). The taxonomic diversity observed within Chlorophyceae also enhances the ecological resilience of these systems, as functionally diverse algal communities are better able to withstand environmental fluctuations.

Bacillariophyceae, though less diverse in stagnant waters, play a critical role in indicating water quality conditions. The occurrence of multiple diatom taxa in rivers and canals suggests relatively lower organic pollution and better hydrological conditions compared to stagnant ponds. Diatoms are widely recognised as sensitive indicators of environmental change, and their presence in appreciable diversity implies that certain freshwater systems within the district maintain favourable ecological conditions (Goyal et al., 2021). These results support the use of

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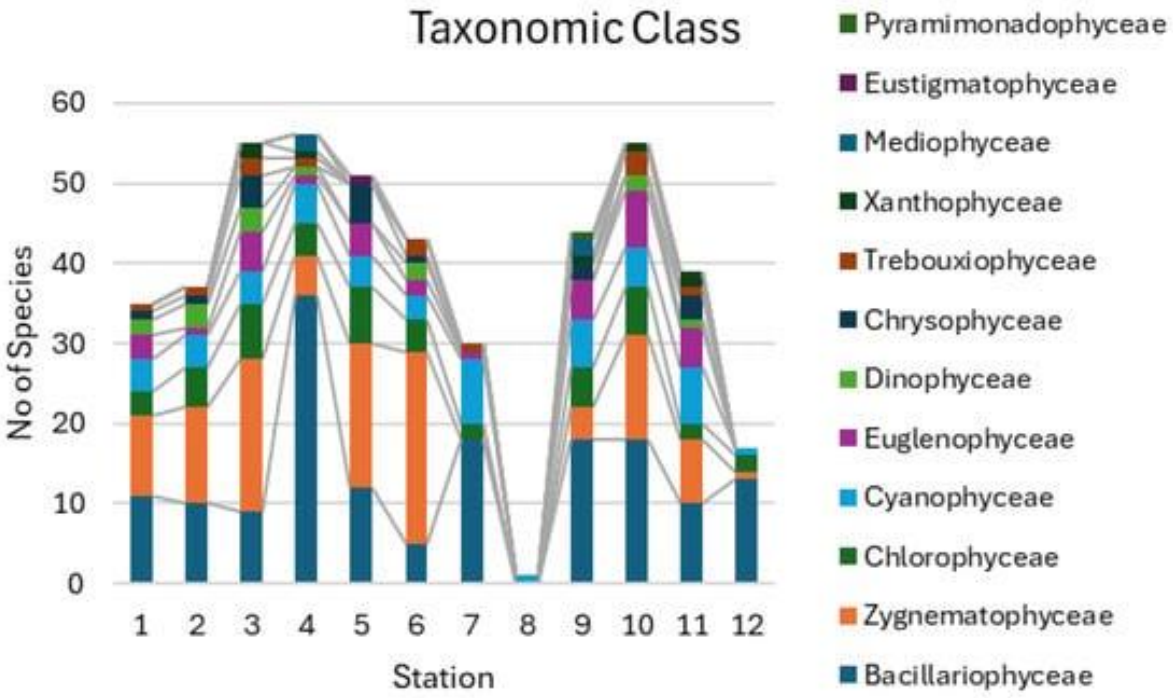
diatom-based assessments in future monitoring programmes aimed at evaluating water quality trends at the local level.



Comparative analysis with published studies from neighbouring districts indicates that the algal diversity recorded in Ghazipur District is broadly comparable to other parts of eastern Uttar Pradesh, though site-specific variations are evident. Differences in land use, water management practices and degrees of anthropogenic pressure likely account for these variations (Verma, 2021; Yadav et al., 2022). The results underscore the importance of district-level studies in revealing local biodiversity patterns that may be obscured in broader regional surveys. Such localised data are essential for developing targeted conservation and management strategies tailored to specific environmental contexts.

From a broader ecological perspective, the results highlight the role of freshwater algae as both indicators and drivers of ecosystem health. The coexistence of pollution-tolerant and sensitive taxa across different sites suggests a mosaic of ecological conditions within the district's freshwater systems. This heterogeneity reflects differential exposure to anthropogenic inputs and varying degrees of hydrological stability. The findings therefore support the view that freshwater algal communities provide an integrative measure of environmental condition over time, capturing cumulative effects that may not be evident from single-point physico-chemical measurements alone (Halder et al., 2019).

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The results and discussion demonstrate that freshwater habitats of Ghazipur District support considerable taxonomic diversity of algae, shaped by habitat type, seasonality and nutrient dynamics. The observed patterns are consistent with established ecological principles and regional studies, while also contributing new district-specific insights. These findings emphasise the value of systematic taxonomic surveys in generating baseline data for ecological assessment, biodiversity conservation and sustainable management of freshwater resources in eastern Uttar Pradesh.

Conclusion

The present study provides a comprehensive account of the taxonomic diversity of freshwater algae in Ghazipur District and highlights the ecological significance of these microorganisms in inland aquatic ecosystems. The findings indicate that the freshwater habitats of the district support a diverse assemblage of algal taxa, with Chlorophyceae, Bacillariophyceae and Cyanophyceae forming the dominant groups across most water bodies. Variations in algal composition among ponds, rivers, wetlands and canals reflect differences in hydrological conditions, nutrient availability and levels of anthropogenic influence. Seasonal fluctuations further influence algal diversity, with post-monsoon periods supporting greater taxonomic richness due to favourable environmental conditions.

The study underscores the value of district-level taxonomic investigations in generating baseline biodiversity data, particularly in rural and semi-urban regions where freshwater resources are closely linked to agriculture and domestic use. The occurrence of pollution-tolerant and eutrophic indicator taxa in certain habitats suggests emerging ecological stress, while the presence of diverse diatom and green algal communities in others points to relatively stable environmental conditions. Overall, the documentation of freshwater algal diversity from Ghazipur District contributes to regional phycological records and provides essential reference data for future ecological monitoring, water quality assessment and conservation planning. Such baseline information is crucial for understanding ecological change and supporting sustainable management of freshwater ecosystems in eastern Uttar Pradesh.

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