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Diatoms Species Analysis in Lakes of Uttarakhand and its Comparative Analysis of Water Bodies of Delhi-NCR

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Abstract

Diatoms are a group of unicellular algae with silica-based cell walls and recognized as valuable indicators of water quality in water ecosystems. Examining the species composition and distribution of diatoms in Uttarakhand's lakes and comparing them with those in Delhi-NCR can provide valuable insights into these distinct aquatic ecosystems' ecological dynamics and environmental health. The review attempts to explore the universe of diatoms in water bodies of Uttarakhand and Delhi-NCR focusing on the species, diversity patterns, and geographical diversity. Elucidating the relationships between diatoms and their environment in these contrasting regions will help in preserving the ecological integrity and biodiversity of India's freshwater ecosystems. It was observed that the water bodies of Uttarakhand exhibited less pollution, witnessed less population in the surrounding, less agriculture runoff, high altitude, and less urbanization while the water bodies of Delhi-NCR were found to be high in pollution, urbanization was high, the population in surrounding areas is high, more industrial effluents, less altitude, and heat is more compared to water bodies of Uttarakhand. Water pollution causes a threat to the species of diatom. The increase in pollution levels causes a decrease in the quality of water.

Keywords: Diatoms; Water Bodies; Uttarakhand; Delhi-NCR

Abbreviations

NCR: National Capital Region;

Introduction

Ecosystems comprise lakes, rivers, and wetlands, and all of them have a pivotal role in the natural milieu, fostering a plethora of aquatic life and delivering indispensable ecosystem services [1]. Along with the multitudinous species of organisms populating these environments, diatoms transpire as dominant entities. Diatoms are unicellular algae having intricate silica cell walls known as frustules which exhibit a variety of shapes and structures [2]. They are known to have approximately 15,000 known species [3].

Diatoms are valuable entities for assessing the water quality, and ecological health along with environmental

conditions in the water habitats because of their wide distribution and diverse characteristics [4]. Uttarakhand and the National Capital Region (NCR) of Delhi are different landscapes in India. While Uttarakhand boasts pristine mountainous areas with numerous freshwater bodies, the NCR is known for its high population density along with varying climatic factors. The water bodies in these regions serve as crucial water sources, recreational areas, and habitats for various plants and animals.

Uttarakhand is a northern state situated in the foothills of the Himalayas. It witnesses a great scenic beauty with diverse topography which varies from glaciers at high altitudes to plains in sub-tropical areas. It is home to various types of habitats, helpful for the proliferation of different species of diatoms [5]. Uttarakhand's landscapes remain untouched compared to the locations of Delhi-NCR which results in offering a unique opportunity to study and analyze the diatom communities present here. However, in some places activities in the name of urbanization like deforestation, and increasing anthropogenic pressures such as agriculture and tourism pose major threats to the ecological wholeness of Uttarakhand's water bodies reducing the importance of diatom assessment for future conservation plans.

In contrast to the water bodies of Uttarakhand, Delhi-NCR represents a significantly dense populated urban mass distinguished by anthropogenic pursuits and related degradation of the environment. The Yamuna River along with other lakes and water reservoirs found in Delhi- NCR is subjected to various pollutants such as the effluent released from different types of industries, domestic waste as well as agriculture runoff, all of these lead to the deterioration of the water quality and imbalance in its ecology [6]. Despite the factors that hamper the quality of water, the study of factors on how these organisms face the changing environmental conditions and their importance in indicating environmental health [7]. The comparison between the species analysis found in Uttarakhand and Delhi NCR provides an overall outlook on the factors influencing the environment and water bodies. Factors that influence the diatom assemblage are water PH, temperature, nutrient levels, and sediment composition [8]. By deducing the possible relationship between the biotic and abiotic factors of the environment, strategies and models can be developed to mitigate the negative impact on the aquatic bodies [9]. To add on, the attempt to make a review on this contributes to informed decision-making and sustainable practices, thereby leading to safeguarding water resources and biodiversity. The comparative analysis of diatom communities in these regions, and the complex interaction taking place between environmental factors and the biotic assemblages ultimately resulted in sustainable management practices.

Diatoms can be easily found in areas where there is light and moisture. The different types of habitats where diatoms can be found include freshwater, soil, ice, and even rocks. According to Round and Sims (1981), of approximately 175 living and fossil diatom genera, 70% are exclusively marine, 17% are freshwater and the remaining 13% are either marine or freshwater [10]. In current times, diatoms have been proven to be one of the most important primary producers and are highly prevalent in the ocean's fertile areas. There is also a high correlation between waters having high nitrate concentration and phosphorous concentration [11].

Diatom has a frustule which is the outer silicious covering that consists of overlapping valves. The larger valve is called epivalve and the smaller valve is known as hypovalve [12]. Diatoms are classified into centrales and pennales. Centrales have a radial symmetry and pennales have a bilateral symmetry [13].

The majority of the classification of diatoms is based on the pattern of ornamentation which is found on the face of the valve. Some of the key features used to distinguish diatoms are pores (areolae), processes, marginal and submarginal spines, hyaline (clear) areas, along other specialized structures.

In the case of centric diatoms, the presence, number of processes, type, spines, or any specialized structures, the pattern of areolae, the number of areolae per 10 micrometers, and any variation along the diameter of valve or even any interruption in the areolar pattern. Whereas in the case of pennate diatoms, the characteristic features that are kept distinguishing are valve shape, longitudinal slits, areolar pattern and pattern of any hyaline fields, and the presence of other special structures on apices. Diatoms are capable of both sexual and asexual modes of reproduction. Simple binary fission can occur by diatoms dividing themselves between one and eight times a day, division is regulated by the light intensity, duration, and nutrient concentration.

Methods and Methodology

Database collection

Different scientific papers databases are used such as Google Scholar, PubMed, Web of Science, etc. Different journals and scientific research papers are studied for the chosen topic. Papers with relevant topics were targeted and an in-depth study was done in each of the relevant papers. Specific keywords were used to search the papers relevant to the study such as diatoms and diatoms found in Delhi-NCR and Uttarakhand. The data availability of diatoms found in Uttarakhand and Delhi-NCR was only of prominently found water bodies, therefore no exclusion or inclusion criteria

were required. Data Extraction was done from the journals, and the locations were noted down.

Discussion and Observation

The Table 1 given below mentions the species of diatoms found in water bodies across the state of Uttarakhand. The water bodies that have been covered in the table include 1. Kosi (Almora), 2. Saryu River (Bageshwar), 3. Gomati River (a tributary of Saryu River), 4. Doon Valley (Dehradun), 5. Ganga River (Haridwar), 6. Naukuchital (Nainital), 7. Bheemtal Lake (Nainital), 8. Mandakini (Rudraprayag) [11].

S. No	Site	Diatoms Species	Genus Family Order
1	Kosi (Almora)	1. *Epithemia sorex Kuetzing*	*Epithemia* Epithemiaceae Pennales
		2. Melosira varians Agardh	*Melosira* Melosiraceae Melosirales
		3. Fragilaria crotonensis	*Fragolaria* Fragilariaceae Fragilariales
		4.Cymbella turgida Gregory	*Cymbella* Cymbellaceae Cymbellales
		5. Cymbella obtusa Gregory	*Cymbella* Cymbellaceae Cymbellales
		6.Navicula subrhynchocephala Hustedt	*Navicula* Naviculaceae Naviculales
		7.Cocconeis placentula Ehrenberg	*Cocconeis* Cocconeidaceae Achnanthales
2	Saryu River (Bageshwar)	*1.Synedra dorsiventralis Muller*	*Synedra* Fragilariaceae Fragilariales
		2.Diatoma vulgare Bory	*Diatoma* Fragilariaceae Fragilariales
		3.Fragilaria varians Ralfs	*Fragilaria* Fragilariaceae Fragilariales
		4.Achnanthes lanceolata	*Achnanthes* Achnanthidiaceae Achnanthales
		5.Navicula radiosa Kuetzing	*Navicula* Naviculaceae Naviculales

		6.Nitzschia microcephala	*Nitzschia* Nitzschiaceae Bacillariales
3	Gomati River	*1.Cymbella ventricosa*	*Cymbella* Cymbellaceae Cymbellales
		2.Cymbella tumida	*Cymbella* Cymbellaceae Cymbellales
		3. Reimeria sinuata	*Reimeria* Gomphonemataceae Cymbellaes
		4. Stoermer	*Cyclostephanos* Stephanodiscaceae Thallasiosirales
4	Doon Valley (Dehradun)	*1. C. subleptoceros*	*Cavinula* Cavinulaceae Cymbellales
		2. C. excisa	*Cymbella* Cymbellaceae Cymbellales
		3.G. parvulum	*Gephyria* Entopylaceae Entopylaceae
		4.N. viridula	*Navicula* Naviculaceae Naviculales
		5.Co. placentula	*Cocconeis* Cocconeidaceae Cocconeidales
		6. Ni. palea	*Nitzschia* Bacillariaceae Bacillariales
		7. Achnanthes linearis	*Achnanthes* Achnanthaceae Achnanthales
		8.Achnanthes biasolettiana	*Achnanthes* Achnanthaceae Achnanthales
5	Ganga (Haridwar)	*1. Diatoma tenuis*	*Diatoma* Diatomaceae Diatomales
		2.Fragilaria crotonensis	*Fragilaria* Fragilariaceae Fragilariales
		3.Gomphonema parvulum	*Gomphonema* Gomphonemataceae Gomphonematales

		4.Amphora coffeaeformis	*Amphora* Cymbellaceae Cymbellales
		5. Cymbella cistula	*Cymbella* Cymbellaceae Cymbellales
		6.Achnanthes exigua	*Achnanthes* Achnanthaceae Achnanthales
6	Naukuchital (Nainital)	*1. Cymbella parva Cleve*	*Cymbella* Cymbellaceae Pennales
		2.C. cymbiformis Brebisson	*Cymbella* Cymbellaceae Pennales
		3.C. obtusa Gregory	*Cymbella* Cymbellaceae Pennales
		4.C. turgida Gregory	*Cymbella* Cymbellaceae Pennales
		5.Cymbella cymbiformis (Kuetz.) Brebisson	*Cymbella* Cymbellaceae Pennales
		6.Epithemia sorex	*Epithemia* Epithemiaceae Pennales
		7.Amphora exigua Gregory	*Amphora* Amphoraceae Pennales
7	Bheemtal Lake (Nainital)	*1.Gomphonema montanum Schumann*	*Gomphonema* Gomphonemataceae Cymbellales
		2. Brachysira vitrea (Grunow) Ross	*Brachysira* Cymbellaceae Cymbellales
		3. Cymbella parva	*Cymbella* Cymbellaceae Pennales
		4. Cyclotella ocellata Pantocsek	*Cylotella* Stephanodiscaceae Thalassiosirales
		5. Gyrosigma sp.	*Gyrosigma* Gyrosigmataceae Bacillariales
		6. Aulacoseira ambigua Simenson	*Aulacoseira* Aulacoseiraceae Centrales

		7. Cymbella helvetica Kuetzing	*Cymbella* Cymbellaceae Pennales
		8. Cocconeis placentula	*Cocooneis* Cocconeidaceae Cocconeidales
8	Mandakini (Rudraprayag)	*1. Achnanthidium biasolettianum (Grunow)*	*Achnanthidium* Achnanthidiaceae Achnanthales
		2.Achnanthidium minutissimum (K¨utzing)	*Achnanthidiaceae* Achnanthidiaceae Achnanthales
		3.A. biasolettianum	*Achnanthidium* Achnanthidiaceae Achnanthales

Table 1: Overview of Water Bodies in Uttarakhand.

The Table 2 given below includes the mention of diatoms observed in the water bodies of Delhi-NCR. The water bodies that have been covered in the table are 1. Yamuna River (Palla Village + Okhla Barracks), 2. Hauz Khas Reservoir, 3. Sanjay Lake, 4. Bhalswa Lake, 5. Old Fort Lake, 6. Lotus Pond, 7. Damdma Lake [13].

S. No	Site	Diatoms species	Genus Family Order
1	Yamuna River (Palla Village + Okhla Barracks)	*1. Cyclotella atomus*	*Cyclotella* Stephanodiscaceae Thalassiosirales
		2.Cyclotella meneghiniana	*Cyclotella* Stephanodiscaceae Thalassiosirales
		3.Cyclotella pseudostelligaria	*Cyclotella* Stephanodiscaceae Thalassiosirales
		4.Cyclotella striata,	*Cyclotella* Stephanodiscaceae Thalassiosirales
		5.Cyclotella stelligera	*Cyclotella* Stephanodiscaceae Thalassiosirales
		6.Stephanodiscus parveus	*Stephanodiscus* Stephanodiscaceae Thalassiosirales
		7.Stephanodiscus minutulus	*Stephanodiscus* Stephanodiscaceae Thalassiosirales

		8.Stephanodiscus binderanus	*Stephanodiscus* Stephanodiscaceae Thalassiosirales
		9.Fragillaria capucina	*Fragilaria* Fragilariaceae Fragilariales
		10.Fragillaria rumpens	*Fragilaria* Fragilariaceae Fragilariales
		11.Synedra acus	*Synedra* Synedraceae Fragilariales
		12.Achnanthidium hoffmannii	*Achnanthidium* Achnanthidiaceae Achnanthales
		13.Achnanthidium minutissimum	*Achnanthidium* Achnanthidiaceae Achnanthales
		14.Achnanthidium eutrophilum	*Achnanthidium* Achnanthidiaceae Achnanthales
		15.Neidium iridies	*Neidium* Neidiaceae Naviculales
		16.Navicula cryptotenella	*Naviculaceae* Navicula, Naviculales
		17.Plagiotropis Lepidoptera var.proboseidea	*Stauroneidaceae* Plagiotropis, Naviculales
		18. Tryblionella brunoi	*Tryblionella* Bacillariaceae Bacillariceae
		19.Nitzschia acicularis	*Nitzschia* Bacillariaceae Bacillariceae
		20. Nitzschia fonticola grunow	*Nitzschia* Bacillariaceae Bacillariceae
		21.Nitzschia palea Nitzschia recta	*Nitzschia* Bacillariaceae Bacillariceae
		22.Nitzschia recta	*Nitzschia* Bacillariaceae Bacillariceae

2	Hauz Khas Reservoir	*1.Fragilaria crotonensis*	*Fragilaria* Fragilariaceae Fragilariales,
		2.Synedra	*Synedra* Fragilariaceae Fragilariales
		3. Cocconeis sp.	*Cocconeis* Cocconeidaceae Achnanthales
		4. Achnanthes longipes	*Achnanthes* Achnanthaceae Bacillariophyceae
		5.Navicula ingenua	*Navicula* Naviculaceae Naviculales
		6.Diatoma vulgaris	*Diatoma* Fragilariaceae Fragilariales
		7.Cymbella cistula	*Cymbella* Cymbellaceae Cymbellales
3	Sanjay Lake	*1.Amphora ovalis*	*Amphora* Amphoraceae Amphorales
		2. Surirella robusta	*Surirella* Surirellaceae Surirellales
		3. Fragilaria crotonensis	*Frafilaria* Fragilariaceae Fragilariales
		4. Nitzschia palea	*Nitzschia* Bacillariaceae Bacillariales
		5. Pinnularia viridis	*Pinnularia* Bacillariaceae Bacillariales
		6.Melosira varians	*Melosira* Melosiraceae Centrales
		1. Craticula molestiformis	*Craticula* Craticulaceae Craticulates
		2. Cymbella	*Cymbella* Cymbellaceae Cymbellales

4	Bhalswa Lake	*3. Nitzschia*	*Nitzschia* Bacillariaceae Bacillariales
		4. Encyonema minutum	*Encyonema* Encyonemataceae Encynomatales
		5. Ulnaria ulna	*Ulnaria* Naviculaceae Naviculales
		6. Gomphonema parvulum	*Gomphonema* Gomphonemacataceae Gomphonematales
5	Old fort lake	*1. Amphora ovalis*	*Amphora* Amphoraceae Amphorales
		2. Fragilaria crotonensis	*Fragilaria* Fragilariaceae Fragilariales
		3. Navicula pelliculosa	*Navicula* Naviculaceae Naviculales
		4. Nitzschia sigma	*Nitschia* Bacillariaceae Bacillariales
		5. Cocconeis placentula	*Cocconeis* Cocconeidaceae Cocconeidales
		6. Synedra ulna	*Synedra* Synedraceae Fragilariales
		7. Afrocymbella barkeri	*Afrocymbella* Cymbellaceae Cymbellales
		1.Pinnularia viridis	*Pinnularia* Bacillariaceae Bacillariales
	Lotus pond	*2. Syndera ulna*	*Synedra* Synedraceae Fragilariales
		3. Achnanthes exigua	*Achnanthes* Achnanthaceae Achnanthales
		4. Diatoma vulgaris	*Diatoma* Bacillariaceae Bacillariales

		5. Cymbella cistula	*Cymbella* Cymbellaceae Cymbellales
		6. Gomphoneis olivaceum	*Gomphoneis* Gomphonemataceae Gomphonematales
		7. Thalassiosira pseudonana	*Thalassiosira* Thalassiosiraceae Thalassiosirales
7	Damdma Lake	*1.Gomphonema pseudoaugur*	*Gomphonema* Gomphonemataceae Gomphonematales

Table 2: Overview of Water Bodies in Delhi NCR.

Conclusion

The comparative analysis of species of diatoms found in the water bodies of Uttarakhand and Delhi-NCR led to a conclusion, due to the different ecological conditions like climate, altitude, degree of urbanization, etc there was a difference in the species found in the water bodies. There are varying numbers of factors that affect the assemblages of diatoms when conducting a comparative analysis between Delhi-NCR and Uttarakhand. Water pollution is more prevalent in the water bodies of Delhi NCR, it can have a significant impact on diatom species. When the quality of water deteriorates significantly, entire species of diatoms face the risk of extinction. Since they are not evolved enough to sustain a life in a polluted environment, it may lead to a loss of ecological stability. Urban areas where high pollution levels cause low dissolved oxygen in the water will witness species like Gomphonema parvulum, Gomphonema pseudoaugur, and Nitzschia palea since they are known to have a higher tolerance to pollution.

Urbanization can have a significant impact on the species of diatoms, affecting the distribution and abundance of diatoms communities. It has also created a profound impact on the species of diatoms altering their distribution and their roles in the ecosystem. The building of artificial reservoirs also affects the diatoms, they can lead to diatom diversity. The composition of the species of diatoms is more responsive to urbanization as compared to the physical and chemical parameters of the water quality. Different taxa of diatom respond differently to urbanization. Some species dominate in low-nutrient water habitats while others dominate in polluted ones of urban areas. Urbanization has caused changes in riverbeds leading to an increase in diatom diversity and richness in species. Species like Pseudostaurosira brevistriata and S. construens var. venter are prevalent in urban upstream sites whereas Nitzchia palea is a species tolerant to heavy pollution and found in urban downstream sites.

Studies have proven that diatom species are notably linked with soil acidity, organic matter content along moisture which all combine to indicate the sensitivity of diatoms. Researchers have also contributed and highlighted the correlation between agriculture runoff and diatom communities. Samples taken during different seasons showed varying compositions of species with some of them dominating a particular season while others dominating in the different seasons. This variation of dominance was seen due to their response to specific environmental conditions like turbidity caused by soil particles along with the sediments from agriculture runoff. Diatom taxa like Achnanthidium minustissimum, Eolimna minima, and Navicula symmetrica were abundantly found in sites that had been packed with agricultural runoff during the rainy season.

Industrial activities also leave a major impact on species of diatoms in water bodies. Due to industrial activities, changes in depth, conductivity, ionic concentration, and overall species concentration of diatoms occur. The presence of extra fine sediment deposition can also affect species composition. When such conditions form they often support species like Gyrosigma, Nitzschia, and Surirella. Diatoms play a crucial role as they can thrive in different environments and therefore indicate varying parameters like conductivity, salinity, phosphorous levels, and water quality as well.

Another factor influencing diatoms species includes land use patterns, it has been proven that it has a profound impact on the species of diatoms. In a study conducted, it was found that the influence of land use and liming on stream quality caused the composition of diatom species to change. Therefore it was concluded that the composition of diatom species changed after liming and it is dependent on dominant land cover and the method adopted for liming.

Different species of diatoms responded differently to these changes which indicated the sensitivity of diatoms and how they responded to alterations in the practices of land use. The land use variations can also impact the species richness along with diversity and the evenness of diatom communities. Sites in urban settings where oxygen is less may support species like Gomphonema gracile, Gomphonema parvulum, and Nitzchia palea. In contradiction, sites impacted agriculturally may favor species like Achnanthidium minutissimum, Achnanthidium shbhudsonis, Gomphonema pumilum, and Navicula schroeteri. The climate change has caused various impacts on diatom communities. They cause an impact on growth, and distribution along with the ecological roles in the aquatic environment. Since diatoms are an important part of aquatic life, they show changes to any change in the environment also and especially those resulted due to climate change. Studies have provided conclusions that a rise in temperature causes significant adaptations in species of diatoms.

Along with this, it can lead to a decrease in trace metals also which are crucial for diatom growth. Climate change results in the warming of the ocean and acidification as well which is bound to have complex effects on diatoms too. Diatoms are also affected by the altitudes of where the water bodies are situated in. Since they are predominantly found in high-altitude lakes and streams, they are sensitive to changes also caused by environmental variations. High altitude environment conditions are unique in nature and they are bound to affect the diversity along with distribution of the species of diatoms found in the water bodies situated there. General environmental conditions found in high altitudes include light intensity, temperature, and nutrient availability. Researchers have also found that variables that are related to ph-alkalinity gradient, trophic condition, and physical factors including radiation at the bottom have a major impact on diatom composition. Due to the presence of rock glaciers in high-altitude environments, another threat exists to diatoms, they are capable of altering the physical as well as chemical properties of the water. A study that was conducted in the Western Mediterranean Basin resulted in a finding that diatom assemblages were found to be primarily impacted by high elevation and while contradictory to this, in low-elevation lakes, salinity had more deeper effect in water bodies present there. The comparative analysis of diatoms assemblages between the water bodies of Uttarakhand and Delhi-NCR highlights the differences between the two areas. The different climatic conditions along with the human population present at respective places and the activities conducted by those populations, all have over time caused a profound effect on the environment and thereby the aquatic life of diatoms as well.

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