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Phytoplankton diversity in selected area of the Indian Sundarbans

Mousumi Bandyopadhyay[1], Deepmala Pathak[2]
[1] Department of Botany, Suri Vidyasagar College, Suri, Birbhum, West Bengal, India
[2] Department of Botany, Mansarovar Global University, Madhya Pradesh, India

Abstract
The present study investigates the biodiversity and composition of phytoplankton in selected areas of the Indian Sundarbans, one of the largest and most dynamic mangrove ecosystems in the world. Water samples were collected from nine sampling stations—Arampur, Birajnagar, Dayapur, Godkhali, Gosaba, Mazid Bari, Pakhiralay, Sonagar and Sudhanyakhali — during the last week of December, 2025 using a conical nylon plankton net and preserved with 1% Lugol's solution. Qualitative and quantitative analyses were carried out using standard microscopic techniques. The phytoplankton community was represented mainly by Bacillariophyceae (diatoms), Chlorophyceae (green algae), Cyanophyceae (blue green algae) and Euglenophyceae with diatoms forming the dominant group across most stations. Spatial variation in species composition and abundance was observed among the sampling sites, likely influenced by differences in salinity, nutrient availability, and freshwater influx. The present investigation suggests that the Sundarbans estuarian waters support a diverse and productive phytoplankton community, highlighting the ecological significance of this environment. This study provides baseline information on phytoplankton diversity in the Indian Sundarbans and also serve as a reference for future environmental monitoring and conservation planning of this vulnerable region.

Keywords: Biodiversity, phytoplankton, Indian Sundarbans, dynamic ecosystems

Introduction

The study of composition, diversity and distribution of phytoplankton in certain area of Indian Sundarbans is important because phytoplankton are primary producer, support for fisheries and monitoring environmental change. They act as an early bio-indicators of environmental changes such as increased salinity, nutrient loading and heavy metal pollution, because of their rapid response to environmental changes [32]. Phytoplankton exhibit remarkable adaptions that help them remain suspended in sea water. Most marine phytoplankton stay in the photic zone, to utilized solar radiation for photosynthesis [27, 33]. An increase in the global phytoplankton population results in greater absorption of carbon dioxide from the atmosphere. These microscopic creatures donate at least 50% of all oxygen to our atmosphere, and play a vital role in regulating the global carbon cycle by absorbing approximately 37 billion metric tons of CO_2 which represents about 40% of the global CO_2 produced [5]. The reduction of this greenhouse gas helps reduce the average atmospheric temperature. Mangroves are the vital ecosystems that support rich biodiversity and productivity. The Sundarbans is the World's largest mangrove forest covering approximately 10,000 km², of which about 6,017 km² lies in Bangladesh, around 4,260 km² occurs in West Bengal [39], spanning the district of North and South 24 parganas. This deltaic region extends from the Hooghly River in West Bengal to the Baleshwar River in Bangladesh [8]. The Indian part of the Sundarbans is located between 21˚13′N and 22˚40′N latitude and 88˚03′E and 89˚07′E longitude [2]. The Sundarbans contains more than10% of the world's mangrove forests, in which 38% lies within the Indian Territory and the remaining 62% within Bangladesh [26].

The Sundarbans, known for its unparalleled diversity of flora and fauna, has received World Heritage Site by UNESCO in 1987 (Bangladesh) and 1997 (India) and by IUCN in 1989 [9]. Furthermore, the Indian Sundarbans was declared as a Ramsar Site in 2019 due to its outstanding wetland and ecological significance [1, 35]. The deltaic ecosystem of Sundarbans is characterized by wide range of biodiversity [21], consisting of phytoplankton, zooplankton, amphibian, microorganisms, mammals and numerous benthic species [35]. The Sundarbans' mangrove forests are home to the wide range of life forms of halotolerant and manglicolous organisms [6]. This biodiversity-rich ecosystem is under increasing pressure from industrialization, climate change, oil spilling, pollution and sea-level rise [24]. Higher pollution levels in the Sundarbans directly affect plankton community as these organisms absorb excess nutrients for growth and reproduction, which may result in algal bloom and eutrophication [25].

The term plankton is derived from the Greek word *"planktos"*, meaning that which drifts or wanders in aquatic environments. Plankton are generally divided into phytoplankton (plant-like form) and zooplankton (animal-like form) [33]. Phytoplankton are predominantly microscopic, photosynthetic organisms that drift in aquatic environment. They form the base of aquatic food chain and as well as food web by photosynthesis act as a producer and mitigates climate change by transporting carbon from surface waters to the deep ocean. When phytoplankton die or are consumed, the carbon they contain sinks as particulate organic matter, where it can remain sequestered for centuries or longer [10].

Phytoplankton plays an important role in aquatic ecosystems by converting solar energy into chemical energy through photosynthesis, making it essential for maintaining atmospheric oxygen and carbon dioxide levels. As primary producers, phytoplankton form the foundation of the aquatic food web, serving as the primary food source for zooplankton, small fish, and shellfish [10]. Although phytoplankton contribute only about 1% of the Earth total biomass they are responsible for nearly 90% of aquatic primary production and approximately 50% of global photosynthetic activity [17].

Phytoplankton are widely used as a bioindicator of water quality. Their presence and growth can influence several physiochemical properties of water, including pH, colour, taste and odor**.** In a practical sense, they are a part of water quality [23]. The diversity of phytoplankton is also influenced by salinity, temperature, nutrient availability, light intensity and hydrodynamic condition of water of that ecosystem. Thus, the objective of the present study was to assess the current status of the abundance and diversity of phytoplankton in relation to different physiochemical conditions in the Sundarbans Mangrove Ecosystem**.**

The estimated annual rainfall in the Indian Sundarbans showed an increasing trend, recorded as 1551 mm in 2022, 1572 mm in 2023, and 2137 mm in 2024 [14-16]. Estimated annual rainfall for the Indian Sundarbans in 2025 is ~1,800–2,600 mm. Quantitatively, the southwest monsoon seasonal rainfall over the country as a whole is likely to be 106% of the Long Period Average (LPA) over the country as a whole during the monsoon season (June to September), 2025 [18,37]. The above - average monsoon rainfall during 2025 (Figure 1) resulted in enhance fresh water influx causing reduced salinity and increased nutrient availability (delivery of silicate, nitrate and phosphate through terrestrial runoff). These conditions favored enhance primary productivity, particularly diatoms.

Materials and Methods

The Sundarbans delta represents one of the World's most dynamic estuarian regions [28]. The selected sites cover diverse hydrological conditions and salinity gradients within the estuarian network. The study area is marked by brackish water, strong tidal influence and extensive mangrove vegetation. Samples were collected from nine sampling stations *viz*. Arampur, Birajnagar, Dayapur, Godkhali, Gosaba, Mazid Bari, Pakhiralay, Sonagar and Sudhanyakhali (Figure 2) during last week of December, 2025 using a conical nylon net (35 inches depth 12 inches diameter) made of bolting netting cloth. The collected samples were preserved in polyethylene bottles using Lugol's 1% Solution. During phytoplankton sampling basic physio-chemical parameter such as salinity, pH, and water temperature were simultaneously measured at all sampling stations. Salinity was measured in parts per thousand (ppt) using a refractometer (ERMA INC. TOKYO JAPAN), pH was determined using digital pH meter (Konvio Neer Imported Tds Meter) and water temperature measured by standard laboratory thermometer (Dimple). Latitude and longitude obtained by using a GPS device (Garmin, etrex 10) and mobile GPS app. Samples were observed using Dewinter microscope with or without phase contrast, coupled with an image analyzing system.

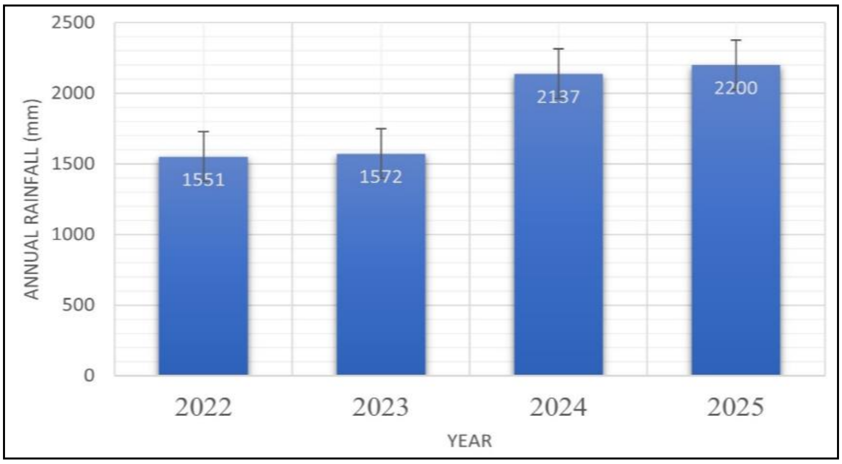

Fig 1: Estimated annual rainfall in the Indian Sundarbans from 2022 to 2025. Derived from IMD

Result and Discussion

Table 1: Geographic coordinates and water temperature with time of the sampling sites

Sl. No.	Sampling Site	Latitude (°N)	Longitude (°E)	Water temperature(˚C) with Time
1	Arampur	22.165955	88.791181	22 (1.32 PM)
2	Birajnagar	22.152188	88.7944	23.5 (2.06 PM)
3	Dayapur	22.124535	88.829546	21 (9.23 AM)
4	Godkhali	22.10112	88.47310	22 (11.30 AM)
5	Gosaba	22.061714	88.801504	22 (11.45 AM)
6	Mazid Bari	22.09873	88.47375	22 (12.16 PM)
7	Pakhiralay	22.129666	88.823002	21 (8.41 AM)
8	Sonagar	22.124634	88.784407	23 (3.33 PM)
9	Sudhanyakhali	22.10224	88.801672	21 (10.26 AM)

Table 1 shows surface water temperature at nine sampling stations showed an increasing trend from morning to midday, mainly influenced by intensity of solar radiation. In present study, the lowest temperature recorded was 21.00 C between 9.23 AM and 10.23 AM while maximum temperature was 23.5 C at 2.06 PM.

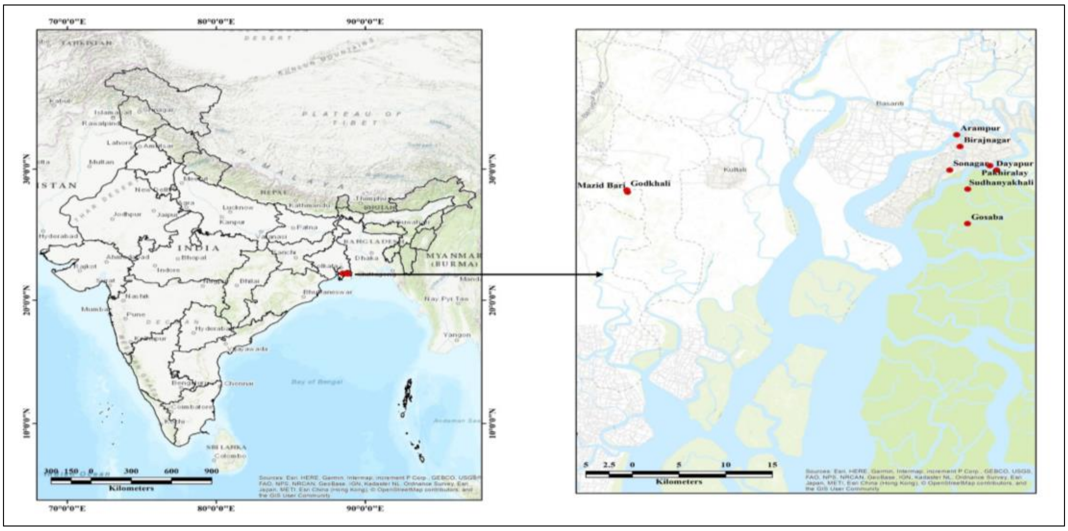

Fig 2: Location of the sampling stations in Indian Sundarbans

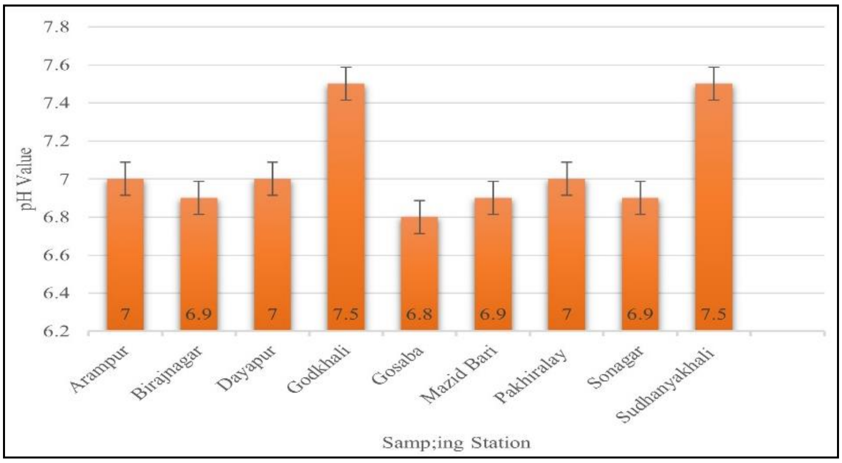

Fig 3: pH of nine sampling stations

Figure 3 illustrates the pH of water at nine sampling stations in Indian Sundarbans ranged from 6.8 to 7.5, i.e. near-natural to slightly alkaline conditions. Based on hydrological conditions of the Sundarbans, a pH range 6.8-7.5 along with above normal rainfall [37] suggests a generally healthy estuarine environment likely driven by high freshwater influx [26]. The Sundarbans estuarine water is typically slightly alkaline (with pH generally ranging between 7.9 and 8.3), but with heavy rainfall, this can fluctuate [26]. However, mangroves are highly dynamic environments, subject to frequent fluctuations in salinity, nutrient levels, and water availability, which they must constantly adapt to in order to survive [22]. The small spatial variation in pH indicates to stable chemical buffering in the estuarine environment at the time of sampling [26]. The alkaline nature of water with low variations between the sampling stations, suggested that the water mass remained well buffered, and it indicated the presence of biodegradable organic matter in the water column [4]. A possible exaptation is the utilization of bicarbonate during photosynthesis, leading to removal of carbon dioxide from the system, along with decomposition of organic wastes [4, 7].

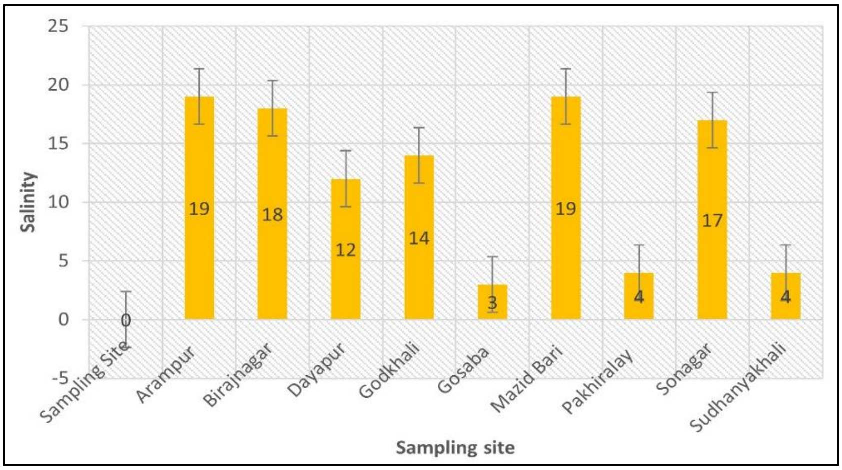

Fig 4: Salinity of nine sampling sites

Figure 4 represents salinity of nine sampling sites, showing wide variation from 3 ppt. to 19 ppt. The low salinity at Gosaba (3 ppt), Pakhiralay and Sudhanyakhali (4 ppt) indicates stronger fresh water input, whereas higher values at the remaining stations reflect greater marine influence. Salinity of water in the Indian Sundarbans acts as a clear indicator of climate change. Salinity levels are strongly influenced on the volume of freshwater coming from the upstream. The variation is dependent on the nature of tide in the area. Changes in freshwater inflow directly affect the annual salinity pattern within the estuarine system [3]. Several studies have reported an increasing salinity trend across the Sundarbans [41]. Salinity in the Indian Sundarbans is primarily regulated by a combination of anthropogenic factors (human-driven) and natural factors [38]. Global climate change, alterations in regional hydrology and shifts in local socio-economic conditions are the primary factors contributing to the increase in salinity levels [40].

Table 2: Station-wise distribution of major phytoplankton groups in the study area (Indian Sundarbans)

Sl. no	Sampling Station	Bacillariophyceae	Chlorophyceae	Cyanophyceae	Euglenophyceae
1.	Arampur	*Navicula*	-	*Anabaena, Oscillatoria*	-
2.	Birajnagar	*Cyclotella, Melosira, Melosira varians, Surirella, Tabellaria*	*Microspora*	*Lyngbya, Oscillatoria*	-
3.	Dayapur (pond)	*Coscinodiscus, Melosira, Navicula, Nitzschia, Pinnularia, Thalassiosira*	-	*Oscillatoria*	*Euglena, Phacus*
4.	Godkhali	*Achnanthes, Biddulphia, Bacillaria Cyclotella, Fragilaria, Melosira, Navicula, Nitzschia, Odontella, Tabellaria, Ulnaria/Synedra*	*Cosmarium, Ulva, Nannochloris, Oocystis, Spirogyra*	*Microcystis, Nostoc*	*Lepocinclis*
5.	Gosaba	*Melosira*	*Rhizoclonium*	*Anabaena*	-
6.	Mazid Bari	*Nitzschia, Pinnularia*	-	*Anabaena, Lyngbya*	-
7.	Pakhiralay	*Coscinodiscus, Gyrosigma, Melosira, Nitzschia,*	*Spirogyra*	-	-
8.	Sonagar	*Coscinodiscus, Navicula, Pinnularia*	*Rhizoclonium*	*Lyngbya, Oscillatoria, Phormidium*	-
9.	Sudhanyakhali (pond)	*Fragilaria, Gyrosigma, Navicula, Pinnularia Pleurosigma. Synedra/Unlnaria*	*Actinastrum, Chlorella, Cladophora, Spirogyra*	*Anabaena*	*Euglena*

Table 2 illustrates total 36 phytoplankton genera were recorded from different sampling stations, of which 17 genere belonged to Bacillariophyceae (diatoms), (Figure 5) 10 genera to Chlorophyceae, (Figure 6) 6 genera to Cyanophyceae (Figure 6) and 3 genera to Euglenophyceae and showed spatial variation in phytoplankton diversity. Diatoms constituted most dominant and widely distributed group almost all sites with higher generic richness at Godkhali (11genera), Dayapur (pond) (6 genera) and Sudhanyakhali (pond) (6 genera). The centric diatoms (radial symmetry) include *Biddulphia, Coscinodiscus, Cyclotella, Melosira, Odontella* and *Thalassiosira,* (total 6 genera) whereas pennate diatoms (bilateral symmetry) include *Achnanthes, Bacillaria, Fragilaria, Gyrosigma, Navicula, Nitzschia, Pinnularia, Pleurosigma, Surirella, Tabellaria* and *Ulnaria/Synedra* (total 11 genera) are predominantly distributed. According to the report of Kulikovskiy *et al.* (2016) *Ulnaria /Synedra* is a non-raphid pennate species [20]. The diatom *Melosira* and *Navicula* were recorded at five sampling sites whereas *Pinnularia* was observed at four sampling sites out of the nine study sites. A unicellular leaf-shaped euglenoid *Phacus* (Euglenophyceae) was recorded in low abondance in the brackish water pond at Dayapur. A few individuals of *Euglena* were also observed in the same pond and another pond of Sudhanyakhali.

Diversity among sampling areas

The richness of diatoms (47%) (Figure 8) indicates availability of high nutrients, specifically silicate, for siliceous phytoplankton as diatoms require dissolved silica i.e. silicic acid ($Si\ (OH)_4$) to construct their frustules [11]. Cyanobacteria (6 genera) are showed a patchy distribution, suggesting localized responses to nutrient availability and hydrodynamic conditions [19]. Chlorophyceae (10 genera) displayed moderate diversity whereas Euglenophytes (e.g., *Euglena*, *Phacus*, *Lepocinclis*) occurred only at selected stations, indicating organic-rich and slow-moving water [13] often associated with organic pollution [29]. Freshwaters, saline waters and moist soils rich in organic matter provide the most common habitats for euglenophytes. *Euglena* and *Phacus* are the most ubiquitous and abundant genera of Euglenophyta, which are responsible for blooms formed at the water surface during different seasons [36]. Sundarbans, showing maximum diversity of euglenophytes including *Phacus a*nd *Euglena* together with other planktonic species [34]. The planktonic organism *Lepocinclis* is cosmopolitan but predominantly present in lakes, ponds and streams, some species have been found in brackish water [31]. A low abondance of *Lepocinclis* was recorded in the brackish water at Godkhali. Many species of Euglenophyceae were rare, having a negligible frequency of occurrence, but they were very important because they controlled the levels of species diversity [30].

The pH values of different study areas showed only minor variation within a narrow range indicating stable buffering conditions whereas salinity exhibited considerable spatial variation and appear to play a key role influencing phytoplankton community structure. Normally fresh water dominated stations were characterized by greater contribution of Chlorophytes and Euglenophytes while with higher marine influence supported a greater dominance and diversity of diatoms.

Godkhali recorded the highest phytoplankton diversity among all sampling stations, with 19 genera representing several taxonomic groups including Bacillariophyceae, Chlorophyceae, Cyanophyceae and Euglenophyceae. Sudhanyakhali (12 genera), Dayapur (9 genera) showed relatively high diversity followed by Birajnagar and Sonagar with 8 and 7 genera respectively. Arampur and Gosaba recorded the lowest diversity with only 3 genera (Figure 7). This distribution pattern reflects considerable spatial heterogeneity in phytoplankton community across the study area.

The physiochemical conditions significantly control phytoplankton diversity and community succession as they can either promote or inhibit growth of different phytoplankton. The spatial and temporal variation of phytoplankton are controlled by physicochemical factors that determine their composition, abundance, and distribution [30]. Seasonal fluctuations further modify these conditions, thereby influencing community structure and diversity. For example, intense monsoon rainfall and runoff increase turbidity and decrease light penetration, limiting photosynthesis and altering phytoplankton productivity and community composition [12].

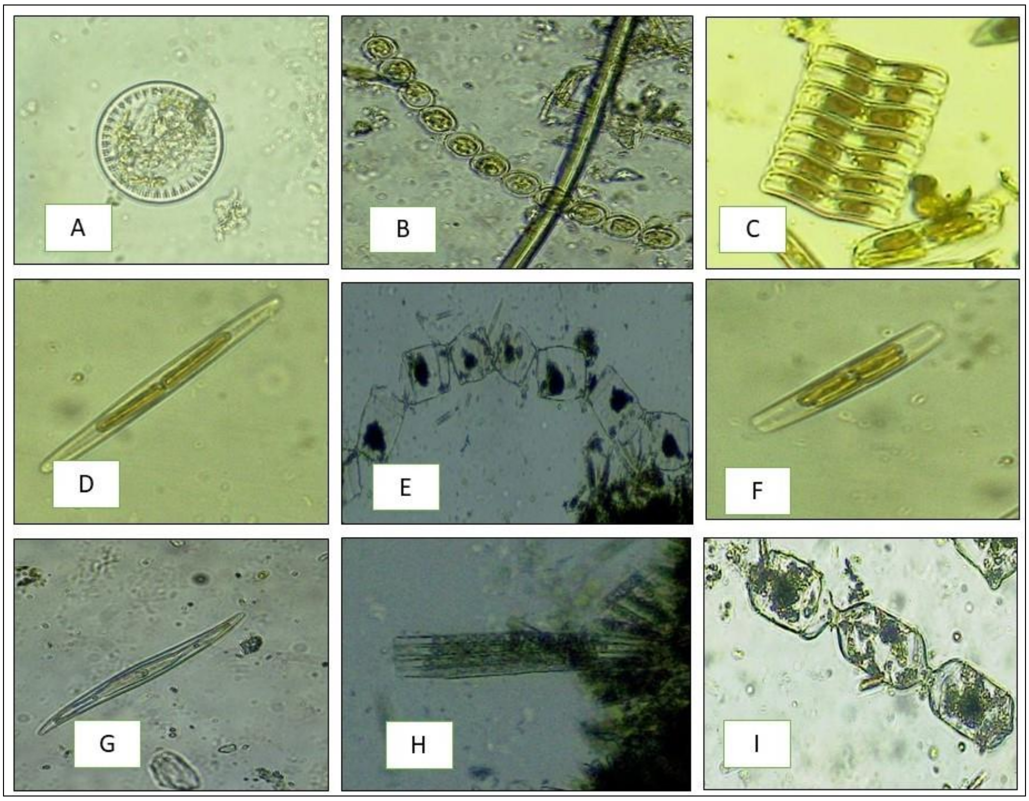

Fig 5: Compound microscope images of few Phytoplankton species (A-I): (A) *Cyclotella* sp.; (B) *Melosira* sp.; (C) *Achnanthes* sp.; (D) *Ulnaria/Syne* sp.; (E) *Odontella* sp.(F) *Pinnularia* sp.; (G) *Pleurosigma* sp.; (H) *Fragilaria* sp.; (I) *Biddulphia* sp.

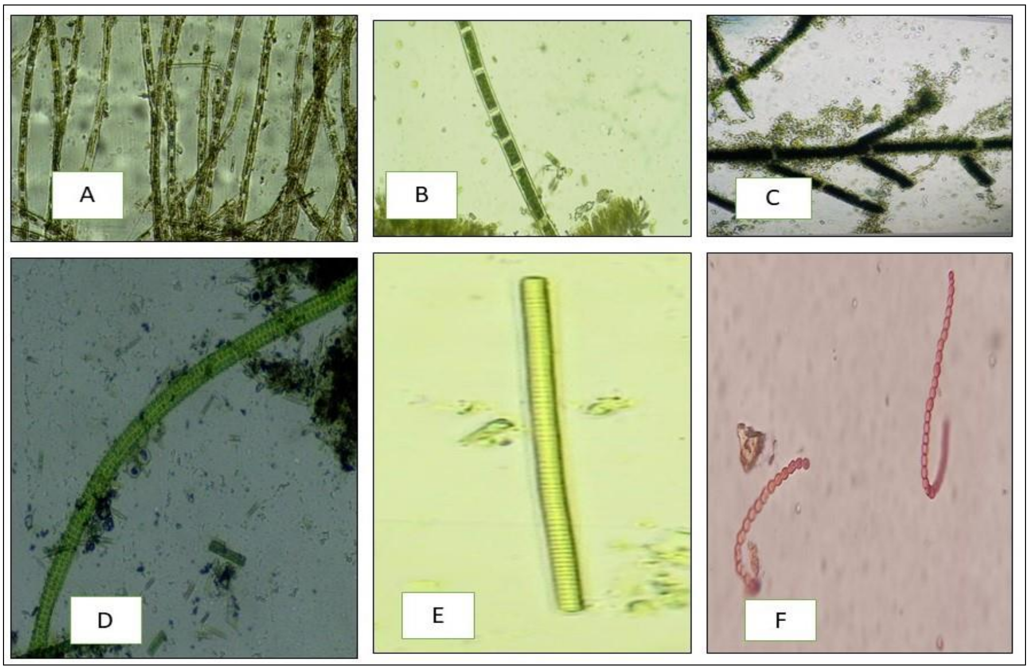

Fig 6: Compound microscope images of few Phytoplankton species (A-F): (A) *Rhizoclonium* sp. (many); (B) *Rhizoclonium* sp.(single); (C) *Cladophora* sp.; (D) *Ulva* sp.; (E) *Oscillatoria* sp.; (F) *Nostoc* sp.

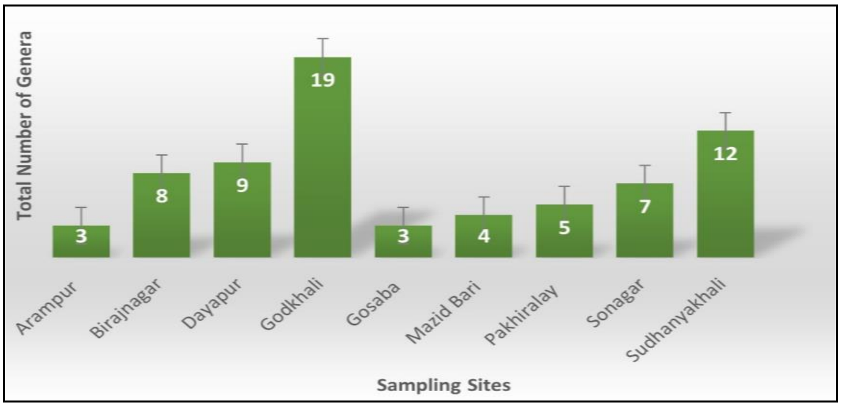

Fig 7: Station-wise phytoplankton generic richness. Phytoplankton members belonging to different classes

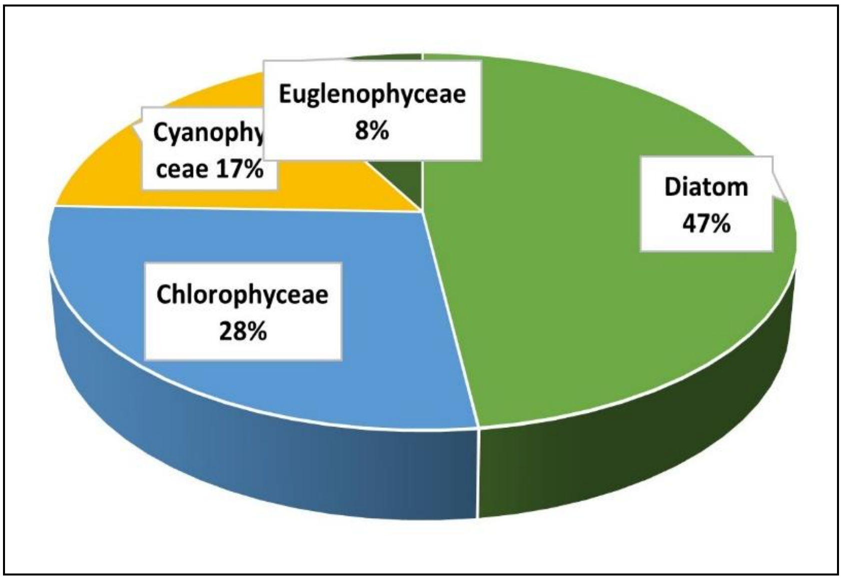

Fig 8: Propositional representation of phytoplankton groups

Conclusion

The present investigation suggests that, the Sundarbans estuarian waters support a divers and productive phytoplankton community, highlighting the ecological significance of this environment. In December 2025, the phytoplankton composition reflected a specific ecological shift characterized by Chlorophyceae at 28% and Cyanobacteria at 17%. While Bacillariophyceae traditionally dominate (47%) this Sundarbans ecosystem (Figure 8), these figures indicate a transition typically seen during the post-monsoon or early winter period, influenced by changing water quality and nutrient loads**.** The presence of Euglenophyceae at some sampling stations indicates organic pollution in the water bodies. During winter the decomposition of excess organic wastes produced by uncontrolled tourist activities, improper garbage disposal and the degradation of surrounding vegetation contribute to the deterioration of water quality and increase ecological stress in this mangrove ecosystem. Major cyclones, including Fani, Amphan, Bulbul, and Yaas, affected the region during 2019–2021, increased saltwater intrusion, which is ultimately linked to climate change. This study provides baseline information on phytoplankton diversity in the Indian Sundarbans and also serve as a reference for future environmental monitoring and conservation planning of this vulnerable region.

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