CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Phytoplankton has a profound impact on the Earth's ecosystems as it emit oxygen in atmosphere and the planet's overall redox condition over the course of their long evolutionary history (Lyons et al., 2014). They play a difficult part in supplying food webs with animal matter, contributing an estimated 45 percent of the planet's photosynthetic net primary production (Field et al., 1998). Basilisk population proportions, which have resulted in enormous feculence that can be seen in the geological plaint, are responsible for the edification of mineral appearance (e.g., silica frustules, calcite plates, and aragonite spicules) in the symposia (Knoll, 2003). As the autotrophic (self-feeding) members of the plankton community, phytoplankton plays an important role in both marine and freshwater environments. This term was coined from two Greek words: phyton, meaning "plant," and plankton, meaning "wanderer" or "drifter" (Wang et al., 2011).

Phytoplankton consists of single-celled or colonial unicellular (remarkably: multicellular) algae (Jacques and Sournia, 1978). Photo-autotrophs are defined as free-floating unicellular, filamentous, or colonial organisms that grow and thrive in aquatic environments through the sole use of light for their metabolism. Phytoplankton are typically more numerous and varied, and they also produce more biomass. The coastal production is more dynamic than the open ocean (Ryther, 1963). In arctic, high productivity in coastal waters can be attributed to a combination of factors encouraging high development of phytoplankton and physical parameters that are conducive to the accumulation of biomass (convergence, low mixing rates, etc.). Highest phytoplankton biomass in estuaries is often seen along the availability mixing gradient between freshwater and marine water masses (Malone and Esposito, 1980; Pennock and Sharp, 1986). The marine water mass is characterized by its high salinity and low turbidity, while the brine water mass is characterized by its high salinity and high nutrient and turbidity levels. The characteristics of the marine water mass will change with the tides, wind force, and other factors (Day et al., 1989), and with offshore circulation patterns, whereas the properties of the low salinity water mass will change with the rate of flow of waterways into the estuary and associated inputs. The transition from freshwater to salty water is a very dynamic process. The transition zone is ideal for phytoplankton growth as it provides an abundance of nutrients and light. This creates a region of the mixing gradient known as the "optimal growth zone," where phytoplankton concentrations are higher than elsewhere. (Demaster and Pope, 1996; Smith and Demaster, 1996).

Phytoplankton provides the basis of marine food webs and feeding cycles that provide sustenance to zooplankton, fish, and some aquatic animals (Millman et al., 2005). Autotrophs replenish their own solar energy through photosynthesis using carbon dioxide, nutrients, and trace metals. All of these primary producers contain photosynthetic pigments, like chlorophylls and carotenoids. Temporarily heterotrophic phytoplankton are predominantly dinoflagellate species; they consume organic materials that has settled to the bottom of an ecosystem via osmotrophy and phagotrophy (Jacques and Sournia, 1978). Phytoplankton populations are vital to aquatic ecosystems because they act as both primary producers and primary energy suppliers for marine food chains. Near coastal areas, especially in marine conditions, tend to have the greatest phytoplankton species richness (Cole and Cloern, 1987; Day et al., 1989). Phytoplankton biomass also exhibits substantial spatial and temporal variation due to the highly dynamic nature of phytoplankton abundances in estuarine environments. The distribution and abundance of phytoplankton are profoundly affected by changes in physical parameters including light, salinity, and temperature. The composition of the water plays a role in the density of phytoplankton. Phytoplankton require a sufficient nutrition source in order to grow and reproduce (e.g. NO_3, PO_4, SiO_3). Light and food are the two most important factors in determining how quickly phytoplankton may multiply (Harding, 1986; Cole and Cloern, 1987; Malone et al., 1988; Smith and Harrison, 1991). These limiting conditions are very variable in estuarine settings, contributing to the dynamic nature of phytoplankton populations in these environments. Phytoplankton biomass in an estuary responds to both environmental factors, such as light and nutrients, and the phytoplankton themselves. Higher phytoplankton abundance, by self-shading, can decrease both accessible light and available nutrition as a function of population uptake (Bannister, 1974; Cloern, 1996).

As light penetration and water clarity is available, phytoplankton production is greatest in the Monsoon prior to the winter season and lowest after the Monsoon. The phytoplankton species in the estuary are at their highest in March and their lowest in October (Islam, 1982). Phytoplankton populations shift with the seasons. When the water purity is between 66 -77.5 centimeters, which it often is in Bangladesh throughout the Monsoon and Post-Monsoon seasons, the macrophyte richness is at its highest (Elias, 1983). Phytoplankton densities are again lower in the winter season, when water clarity ranged 17.5- 38 centimeters (Zafar, 1986).

Approximately 50% of the annual carbon fixation in the carbon cycle is carried out by the 1% of autotrophic phytoplankton species prevalent in the oceans (Falkowaski, 2012; Field et al., 1998). Carbon, nitrogen, and phosphorus stoichiometric ratios in marine phytoplankton assemblages may vary along gradients of marine biome resources (Martiny et al., 2013; Geider and Roche, 2002). When it comes to global issues like the carbon cycle, climate change, nutrient enrichment, and pollution (plankton bloom), phytoplankton play a key role (Rippeth, 2005; Gowen and Stewart, 2005). Changes in phytoplankton bioindicators such as species composition, biomasses, community structure, and productivity can be used as unambiguous evidence of environmental change (Babu et al., 2013). The best mean phytoplankton concentration can be utilized to pinpoint productive fishing areas (Gouda and Panigrahy, 1996).

1.2 Statement of the problem

Phytoplankton are the fundamental components of the world's aquatic food chain. They have tiny plant components with sizes ranging from one micron to many centimetres (Marshall et al., 2009). More than 90% of total marine primary output is attributed to phytoplankton. Many published publications detail their specialized roles, such as calcification, silicification, and nitrogen fixation. They are portrayed as direct food sources for primary consumers such as zooplankton and larvae for both fin and shellfish. Several studies have suggested that energy from phytoplankton is transmitted to higher trophic level species (Rajkumar et al., 2009). During the photosynthetic process, phytoplankton produce oxygen, which is essential for aquatic biota. Their presence and abundance in the aquatic environment accurately reflect the state of water quality (Medupin, 2011). Several anthropogenic influences, like as eutrophication, the introduction of exotic species, and changes in the predation community, have been found to affect the quality of coastal waterways (Cloern, 1996). These create non-periodic and atypical blooms of both toxic and non-toxic phytoplankton species that last for a few weeks to months, interfering with the seasonality of the most prevalent phytoplankton population.

The phytoplankton community must be investigated during the development of an aquatic ecosystem management plan because these communities form the foundation of the food chain (Cloern 1999; Monbet 1992; Sin et al., 1999). Phytoplankton populations from Bangladesh's coastal waters have received little scientific attention to date. The phytoplankton community of Bangladesh's north-eastern coast and the Karnafuli estuary of Bangladesh's south-eastern coast has been recorded in the literature (Islam and Aziz 1975, 1977). Furthermore, there have been a few reports on phytoplankton diversity along Bangladesh's south-western coast (Aziz et al., 2012).

Marine phytoplankton has an important role as a primary producer. They regulate the entire food web and contribute to ocean carbon sequestration (Falkowski et al., 1998). Therefore, studying the geographic diversity of phytoplankton in the Bay of Bengal is crucial. The taxonomy and biology of the phytoplankton *Biddulphia* sp. from Bangladesh's Naf estuary was studied (Mehedi et al., 2017). Furthermore, there has been little research into the seasonal distribution of phytoplankton abundance in Bangladeshi coastal waters (Rahaman et al., 2013). As a result, the current study was an attempt to broaden our understanding of the seasonal distribution of phytoplankton populations in connection to nutrients in the coastal area of Cox's Bazar under Chattogram division in Bangladesh. The study's findings will advance understanding of the ecology of phytoplankton populations on the coasts, particularly in Bangladesh.

1.3 Research questions

The study was conducted to find out the following research questions-

Are the selected sites water nutrients have any relation to phytoplankton production?

Does the qualitative and quantitive abundance of Phytoplankton affect the coastal productivity?

1.4 The Objectives of this study include

- ✓ To explore the pattern of seasonal phytoplankton diversity, density and abundance cycle
- ✓ To identify relationship of phytoplankton with nutrients availability of the coastal region

1.5 Significance of this study

The plant-like organisms are also devoured by smaller fish and invertebrates, which in turn are consumed by larger ones. Phytoplankton is the harbinger of aquatic area information. Temperature and nutrition levels through the examination of phytoplankton, a person can learn about their own cycles and patterns of behavior. Through photosynthesis, phytoplankton absorb as much carbon dioxide as forests and other land plants. Some of the carbon produced by phytoplankton sinks to the ocean floor when these creatures decompose their waste, reproduce, and die, while other phytoplankton are consumed by other species that decompose their food.

This little research on phytoplankton may directly or indirectly helps to implement goals to understand those resources under the water body as to mericulture ultimate entity of Chlorophyll-a value.

CHAPTER TWO

REVIEW OF LITERATURE

Although there have been numerous studies on plankton in various parts of the world, in comparison to benthos and nekton, it receives less attention from scientists working in Bangladesh's coastal waters. Here are reviews of some important works done in the vicinity of Bangladesh.

Phytoplankton are autotrophic (self-feeding) components of the plankton community that play an important role in ocean and freshwater ecosystems. The name is derived from the Greek words (phyton), which means 'plant,' and (planktos), which means 'wanderer' or 'drifter' (Okere et al M. C., 2020; Lessios, 2016; Karlusich et al., 2020). Phytoplankton, like trees and other land plants, get their energy from photosynthesis. This means that phytoplankton require sunlight to survive, which is why they live in the well-lit surface layers (euphotic zone) of seas and lakes. Phytoplankton are dispersed over a larger surface area than terrestrial plants, are subject to less seasonal change, and have far faster turnover rates than trees (days versus decades). As a result, phytoplankton adapt fast to climate changes on a worldwide scale. Phytoplankton are crucial participants in the global carbon cycle and form the foundation of marine and freshwater food webs. Despite accounting for only approximately 1% of world plant biomass, they contribute for almost half of global photosynthetic activity and at least half of global oxygen production. Phytoplankton is a complex group of organisms that includes photosynthesizing bacteria, plant-like algae, and armour-plated coccolithophores. Phytoplankton groups that are important include diatoms, cyanobacteria, and dinoflagellates, among many others (Lessios, 2016). Most phytoplankton are too small to be individually seen with the unaided eye. However, when present in high enough numbers, some varieties may be noticeable as colored patches on the water surface due to the presence of chlorophyll within their cells and accessory pigments (such as phycobiliproteins or xanthophylls) in some species. Marine photosynthesis is dominated by microalgae, which together with cyanobacteria, are collectively called phytoplankton (Apt et al., 1996). Phytoplankton are extremely diverse, varying from photosynthesizing bacteria (cyanobacteria), to plant-like diatoms, to armour-plated coccolithophores (Lindsey et al., 2010; Lessios, 2016).

A total of 63 different genera of phytoplankton and 40 different species were discovered in the coastal bays of Maryland (MCBs). *Paulinella ovalis* (Cercoza), *Dactyliosolen fragilissimus* (Bacilliariophyta), and *Cryptomonas* sp. (Crytophyta) were the top three species (Oseji et al., 2019). 42 species of phytoplankton were identified from the karnafully river estuary (Islam and Aziz 1975). These organisms came from a variety of different classes, such as the Cholorophyceae (6 genera, 12 species), Euglenophyceae (1 genera, 1 species), Chrysophyceae (1 genera, 1 species), Bacillariophyceae (9 genera, 17 species), Dinophyceae (2 genera, 5 species), and Cyanophyceae (4 genera, 6 species). Benthic and planktonic algae were studied by (Salam, 1977) in the Karnafuli river estuary. They found 111 species across 57 genera, with Chlorophyta being the most abundant (48.46%) and Bacillariophyta coming in second (35.24%). Salam also analyzed the regularity and cycle of the benthic and planktonic algae.

Specific biodiversity indices and co-relation were used to indicate seasonal fluctuation of phytoplankton at 5 different stations of the Meghna river estuary. 23 genera of Bacillariophyta, 90 genera of Chlorophyta, and 30 genera of Cyanophyta wrer identified (Saeedullah, 2003).185 different species of phytoplankton identification were aslo done. This included 166 different types of diatoms, 16 different types of dinoflagellates, 2 different types of cyanobacteria, and 1 different type of silicoflagellate. The majority of the organisms were diatoms (90%), then dinoflagellates (8%), cyanobacteria (1%), and silicoflagellates (1%) (Sahu et al., 2012).

Phytoplankton, the backbone of the aquatic environment, is highly connected with specific abiotic factors such as temperature and salinity (Iqbal et al., 2017). There were 42 different types of phytoplankton detected in the coastal waters of the northern Bay of Bengal, Bangladesh. 13 of these were particularly numerous, and 13 were particularly dominant (Al et al., 2019). Ochrophyta (20.41%), Bacillariophyta (17.01%), Ciliophora (16.36%), Cyanobacteria (14.39%), Myoza (12.45%), Miozoa (10.24%), Chlorophyta (7.21%), and Haptophyta (1.94%) were the eight groups found in the study. In the Sundarbans mangrove forest, researchers (Mamun et al., 2009) looked at the number and distribution of plankton and found 15 different taxa of phytoplankton. Specifically, 5 genera were found to belong to the Chlorophyceae, 7 to the Myxophyceae, and 3 to the Bacilliriophyceae. The most common genera of phytoplankton were Cosciodiscus sp. and Microcystis sp. According to the data, the average number of phytoplankton in the water over the study's summer, Monsoon, and winter periods was 2510, 1786, and 2550 Cells/L respectively. Summertime in the Sundarbans mangrove forest is home to the highest concentration of Myxophyceae (54%) among the three classes of phytoplankton. In the Monsoon, Myxophyceae was at 58% abundance, while in the winter it was at 55%. 17 different species of phytoplankton in the coastal waters of Dhamra in the Bay of Bengal on the East coast of India were identified. A wide range of environmental factors, including sea surface temperature, dissolved oxygen, salinity, sulfate, sulfate, and nutrients like silicate, phosphate, and nitrate are strongly co-related with plankton diversity. Changes in these variables over space and time were strongly correlated with shifts in phytoplankton abundance (Das et al., 1997).

Cox's Bazar coastal waters were analyzed for micro-nutrient content and phytoplankton biomass (Noori, 1999). A total of 107 species of phytoplankton were identified in the St. martins Island (Islam, 1982). Phytoplankton population in the St. Martin Island fluctuated seasonally with various physic-chemical parameters. The highest production of phytoplankton populations was found in March and December while the lowest was recorded from July to October (Islam, 1982). 20 species of marine diatoms from Bay of Bengal, Bangladesh recorded by (Islam and Aziz, 1980). The recorded species were *Bactenastrum* (2 sp.), *Belleerochea* (1 sp.), *Cerataulina* (1 sp.), *Cyclotella* (1 sp.), *Nitzchia* (1 sp.), *Rhizosolenia* (1 sp.), *Schroederella* (1 sp.), and *Thallassiosira* (2 sp.). A total of 76 species and 26 genera of phytoplankton in the north-central Bay of Bengal, classified as Plasmodium, Bacillariophyceae, Dinophyceae, and Cyanophyceae (four different kinds, two different families) Growth of phytoplankton and growth of bacteria in the northeastern part of the Bay of Bengal in July has a quality ratio of 8:1. This ratio is 3:1 during the Monsoon and 6:1 during the fall. Diatom production declined despite being the dominant phytoplankton species, even though it increased when salinity was lowered throughout the summer (Islam and Aziz, 1975).

Nutrient enrichment has the potential to dramatically alter water quality. Changes in Maryland's Coastal Bays (MCBs) over the past two decades are a result of an increase in the nitrogen load necessary for phytoplankton growth (oseji et al., 2019). Strong negative connections between dissolved inorganic nutrients and salinity in the ocean throughout the rainy season, providing further evidence for the reliability of nutrient delivery from runoff. 17 different species of phytoplankton in the coastal waters of Dhamra in the Bay of Bengal on the East coast of India were identified. A wide range of environmental factors, including sea surface temperature, dissolved oxygen, salinity, sulfate, sulfate, and nutrients like silicate, phosphate, and nitrate are strongly co-related with plankton diversity. Changes in these variables over space and time were strongly correlated with shifts in phytoplankton abundance (Das et al., 1997).

The phytoplankton community was varied spatially for water quality parameters like Salinity, pH, TSS, Water temperature and silt (Sharif and Bhuyan 2017). The effect of physico-chemical parameters on the phytoplankton community predicted to change. Micro phytoplankton, bio volume and biomass considered to indicate the changes controlled by the water quality parameters. *Coscinodiscus* was the indicator of global scale for the significant event which was influenced by salinity in the estuarine waters of the North-eastern Bay of Bengal (Mukherjee et al., 2013). Among 95 investigated species of phytoplankton in the Bay of Bengal diatoms were the dominant in the groups of Bacillariophyceae, Dinophyceae, Cyanophyceae, Haptophyceae. There was a positive relation of phytoplankton with chlorophyll-a concentration and various physico-chemical parameters i.e temperature, pH, salinity, dissolved oxygen, biological oxygen demand, nitrites, nitrates, ammonia, phosphate and silicate (Panda et al., 2012). Salinity, transparency, dissolved oxygen (DO), and water nutrients were found to be the most important environmental variables of phytoplankton diversity (Al et al., 2019).

Since our sea and the entire country are affected by its economy, climate, and metrology, marine science is of great importance in Bangladesh. Because oceanographic research in Bangladesh is so poorly co-ordinated and spread out, surprisingly little is known about the phytoplankton that live in the country's coastal waters. Research on phytoplankton communities was preceded by a review of their previous research on species diversity, species composition, and seasonal succession. Little is known about the phytoplankton of our estuaries and the Bay of Bengal, despite the fact that the topic was briefly examined here.

CHAPTER THREE

MATERIALS & METHODS

3.1 Study Area

Bangladesh is situated on the north east coast of Bay of Bengal which is extended part of the Indian Ocean. In this study, water samples were taken from Chattogram's coastal waters in two areas: Sonar para shore in Cox`s Bazar (Area A: Latitude-21°26´43´´N, Longitude- 91°56´25´´E, $St_1$; Latitude- 21°25` 37`` N, Longitude- 91° 56` 42`` E, St_2) and Ali akbar deil shore in Kutubdia (Area B: Latitude- 21° 75` 89`` N, Longitude- 91° 85` 88`` E, St_3; 21°44´16´´N, Longitude-91°49´24´´E, St_4).

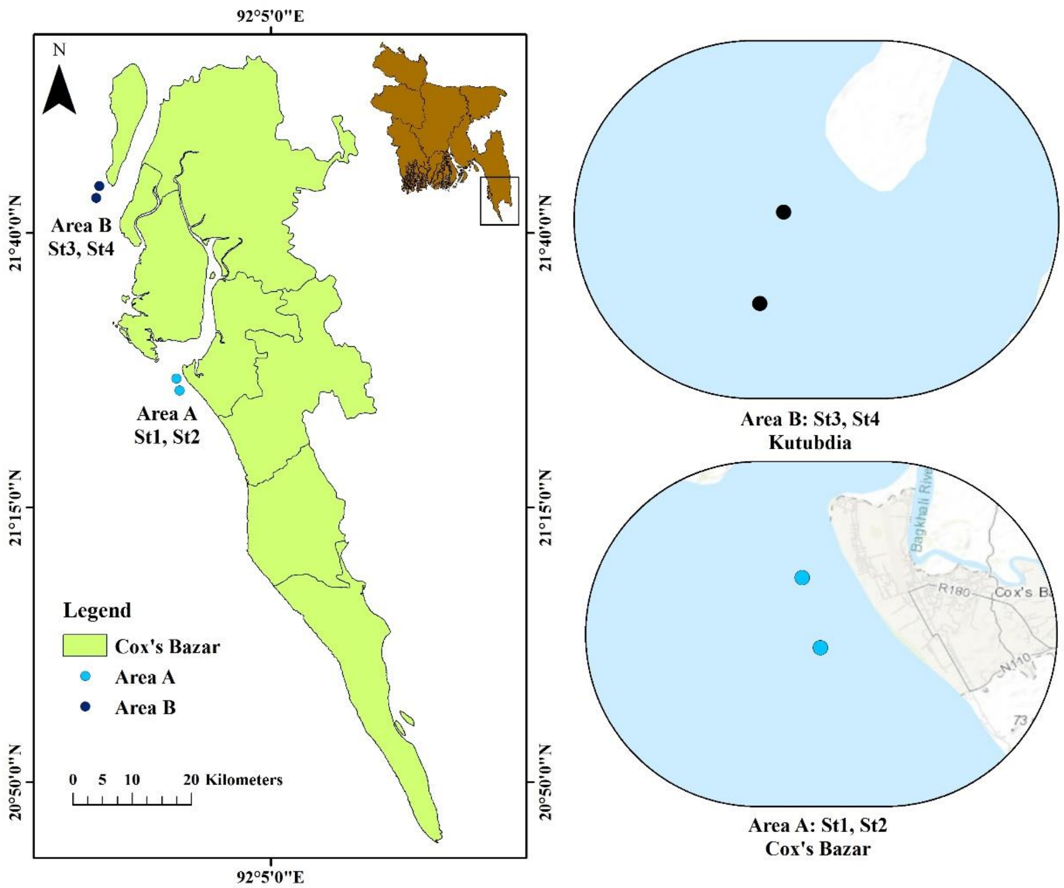

Fig. 1: Locations of the study area; Area A: Cox`s Bazar coast (station 1 and station 2) and Area B: Kutubdia coast (station 3 and station 4).

These two areas were chosen based on geo-morphological criteria such as the availability of boats, ease of transportation, phytoplankton richness and diversity. In order to perform this study, four (04) stations (St) of two areas both having two unique stations along the coastal water that was 2.5-6 km out to sea from the adjacent shoreline were randomly chosen.

3.2 Sampling Design:

The climate of Bangladesh is individualized by a dry cooler season from mid-november to february, pre-monsoon hot season from march towards may, rainy summer monsoon season from june through mid-october, and a short autumn or post monsoon from mild-october to mid-november (Ahmed and Kim, 2003).

Pre-Monsoon (May), monsoon (June), post-monsoon (September), and winter (January) samples were taken to adequately represent the yearly cycle. At high tide, Using a phytoplankton net (45 µm), the composition of the surface water in two area were determined.

Surface water samples were collected to analyze dissolved nutrients like Chlorophyll-a, nitrite, phosphate, and silicate as well as temperature, salinity, pH, electro-conductivity (EC), total dissolved solids (TDS), NaCl, total suspended solids (TSS), and DO.

3.2.1 Qualitative and quantitative estimations of plankton:

The sample of phytoplankton was collected using a net of 45 µm wide phytoplankton mesh that was towed horizontally. Concentration of samples were stored in small plastic vials containing 5% buffered formalin. The quality and quantity of plankton were evaluated using a sedgewick-rafter cell containing one thousand 1mm^3 cells. A 1 ml sample was let to sit in the S-R cell for 15 minutes to let the phytoplankton settle. Phytolankton in 10 randomly selected cells were identified and counted using a binocular microscope with imaging capabilities. Planktons were also studied under a microscope to identify the different types of plankton (APHA, 2007). The average number of phytoplankton species in 10 S-R cells was calculated for a quantitative estimation.

The Stirling (1985) formula was used to determine the abundance of plankton.

N = (P*C*100)/L

The number of plankton cells, or units, per liter of source water is denoted by the symbol "N." (Counted by using Sedgewick-Rafter cell)

P = Total amount of plankton found throughout 10 fields

C = Sample's ultimate concentration volume (ml)

L = Water sample's volume (L); 5 L volume bucket was used to collect the surface water.

3.2.2 Identification process:

The following references were used to make the identifications:

(Sharif et al., 2017), (Rahaman et al., 2013), (Chowdhury, 1998), (Islam and Aziz, 1980), (Mizuno, 1978).

3.2.3 Analysis of physic-chemical water quality parameters:

Standard techniques were used to measure the fluctuations in Chlorophyll-a, dissolved nutrients such as nitrite, phosphate, silicate and temperature, salinity, pH, total dissolved solids (TDS), NaCl, total suspended solids (TSS), and DO.

In-situ Data collection:

The following water quality parameters were measured in-situ at high tide conditions on a seasonal basis follows the full moon phase.

- ✓ **Temperature (^{0}C):** A conventional mercury-filled centigrade thermometer with a range of 0-1000 ^{0}C was used to measure the temperature of the water (Prabu et al., 2008).
- ✓ **Salinity (psu):** The salinity was measured using a handheld refractometer (ATAGO, S/Mill, Salinity 0-100 psu, Japan) that had been calibrated beforehand.
- ✓ **pH:** The water's acidity was assessed with a digital pH pen meter (HANNA Instruments, model HI 98107). The water pH meter was adjusted for accuracy before each experiment.
- ✓ **Electro-conductivity (EC):** A calibrated digital electro-conductivity meter was used to measure electro-conductivity (HANNA Instruments, model EC 98107).
- ✓ **Total Dissolved Solids (TDS):** An EC meter that has been calibrated may measure the TDS in water (The Hanna Instruments HI98301).
- ✓ **NaCl:** A calibrated digital electro-conductivity meter was used to measure electro-conductivity (HANNA Instruments, model EC 98107).
- ✓ **Dissolved Oxygen (DO):** The Winkler Method was used to quantify the amount of dissolved oxygen present (H. O. PUB. No. 607. 1955).

Laboratory Analysis:

Water samples were taken from each location and shipped off to the lab for analysis of Chlorophyll-a, and nutrients (nitrite, phosphate, and silicate) also for total suspended solids (TSS). All of the water samples were filtered through Whatman GF/C microfiber filter paper under vacuum using an air pump (Rocket filtration pump). The filter paper was extracted for the purpose of chlorophyll-a analysis. Filtered water was used for nutritional analysis.

I. Chlorophyll-a measurement:

A membrane filter was used to purify 500 ml of water samples using a vacuum pump (0.45 µm). Once the membranes had been filtered, they were immersed in 10 ml of 90% acetone, and left there overnight. Filtered sheets were thoroughly mixed with acetone using a glass rod and 2.30-minute centrifugation at 3500 RPM followed. To compare the extract to a control sample of acetone, the same amount of supernatant was transferred to corvettes, and the absorbance was measured at 664, 647, and 630 nm. The concentration of chlorophyll-a was calculated using the following equation (Talling and Driver, 1963):

Chlorophyll-a = $(11.85\ A_{664} - 1.54\ A_{647} - .08\ A_{630})*(V/S)*1000$

Where,

The value at 664 nm is referred to as A_{664}.

The value at 647 nm is referred to as A_{647}.

The value at 630 nm is referred to as A_{630}.

V is the amount of acetone utilized (ml)

S = Sample Filter Volume (ml)

II. Nitrite:

Nitrite concentrations were calculated using the methods described by (Bendschneider and Robinson, 1952). 50 ml of water was filtered via Whatman filter paper (0.1 m). Finally, 50 ml of the filtered material was added to a conical flask. Initially, 1 ml of sulphanilamide was introduced, mixed in, and let 2-8 minutes to react. After 10 minutes and before 2 hours, a spectrophotometer was used to measure the extinction at 543 nm after adding 1 cc of N-(1-Napthal)-ethylene diamine dihydrochloride (NNED) and stirring the mixture (Model: Osk-15745).

Calculation:

(μg at NO_2-N/Kg): Factor (19.84) X (Absorbance of samples – abs. of blank).

III. Phosphate:

Following the procedures outlined by (Cai et al., 1994) phosphate was determined. Whatman filter paper (0.1 m) was used to filter a 50 ml sample of water. Then a conical flask was filled with a 50 ml filtered sample. The acid ammonium molybdate was combined with 2 cc of water. Then stannous chloride was added in 5 drops. Finally, the lack of developed color was determined at 690 nm using a spectrophotometer (Model: Osk-15745).

Calculation:

(μg at PO_4-P/Kg): Factor (45.93) x (Absorbance of sample − abs. of blank).

IV. Silicate:

Silicate concentrations were calculated using methods similar to those described by (Mullin and Riley, 1955). We filtered 50 ml of water via Whatman filter paper (0.1 μm). A 50 ml sample of filtered water was then placed in a conical flask. The 2 ml of 10% ammonium molybdate was added and thoroughly mixed. The next step was to add 0.5 cc of 25% sulfuric acid. Finally, the lack of color output was measured using a spectrophotometer (Model: Osk-15745) set to 460 nm.

Calculation:

(μg at SiO_3-Si /Kg): Factor (5372.58) x (Absorbance of sample − abs. of blank).

V. Total Suspended Solids:

By using a filters operation that adhered to established procedures, total suspended solids were measured (APHA, 2007). Water samples were filtered using glass fiber filters for the purpose of determining total suspended solids (TSS), which were then dried at 105°C for more than one hour and weighed to determine the amount of suspended solids. Filter paper was initially dried in an oven and placed in a desiccator (at least 30 min at both stages). Filter paper was then weighted after drying in the oven. It was decided to take a

50 ml water sample and filter it via some paper. After filtering, the filter paper was baked at 104°c, and placed in a desiccator. Finally, the TSS was calculated by weighing the filter paper after the solid had been filtered out.

Calculation:

$$TSS = (B-A)/A \times 1000$$

Where,

A = Filter paper's weight after being dried in the oven.

B = Filter paper weight after firm reaming.

3.2.4 Statistical data analysis

Phytoplankton and water quality data of all the four stations and four seasons were demonstrated using Microsoft Excel 2013, SPSS 26, and R-studio software.

CHAPTER FOUR

RESULTS

4.1 Phytoplankton composition

4.1.1 Station-wise variation

Bacillariophyceae was the most dominant class at all four stations. The contribution of Bacillariophyceae in St_1 to St_4 was in 75.6%, 77.5%, 71%, 65% respectively (Fig. 2: A-D). Maximum abundance in total count of *Cyclotella* under Bacillariophyceae was prominent in all stations except St_3 where the *Coscinodiscus* was prominent.

The second dominant class was Dinophyceae which contributed as 17.1% in St_1, 15.5% in St_2, in St_3 22%, and in St_4 27% (Fig. 2: A-D). Presence of *Ceretium* was highest in all stations but *Dinophysis* abundance was highest in St_3.

The less counted class Cyanophyceae was in St_1 7.3%, St_2 7.1%, St_3 7%, St_4 8% (Fig. 2: A-D). In total counting *Trichodesmium* under Cyanophyceae was maximum in St_4.

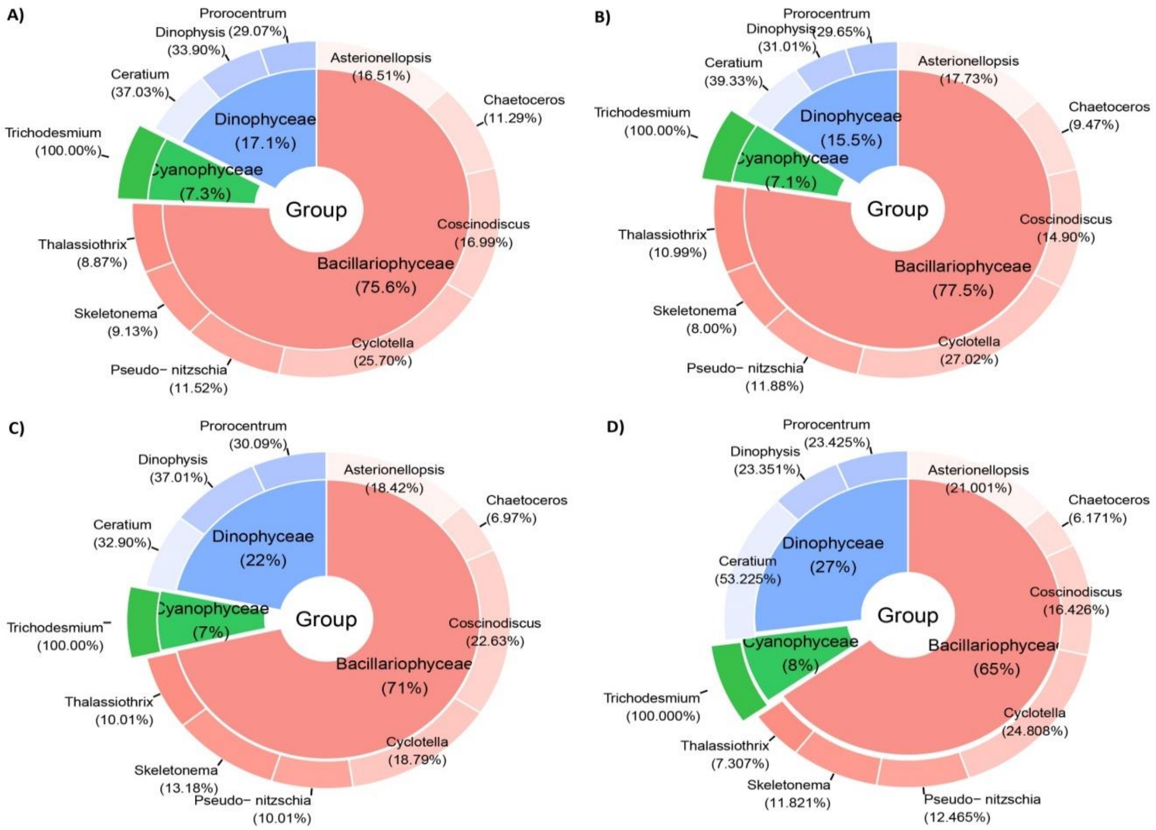

Fig. 2: Station-wise variation of Phytoplankton Classes and Genus (A=St_1, B=St_2, C=St_3, and D=St_4).

4.1.2 Seasonal variation

Bacillariophyceae was the most dominant class at all four seasons. The contribution of Bacillariophyceae of the total phytoplankton community was 74% in Pre-Monsoon, 73% in Monsoon, 73.1% in Post-Monsoon and 74% in winter. Seven genera were identified under Bacillariophyceae including *Asterionellopsis, Chaetoceros, Coscinodiscus, Cyclotella, pseudo-nitzchia, Skeletonema, Thalassiothrix.* Average contribution of *Cyclotella* in all seasons was about 24-25%. Second dominant species *Coscinodiscuscus* showed higher percentage in both seasons post-monsoon and winter (Fig. 3: A-D).

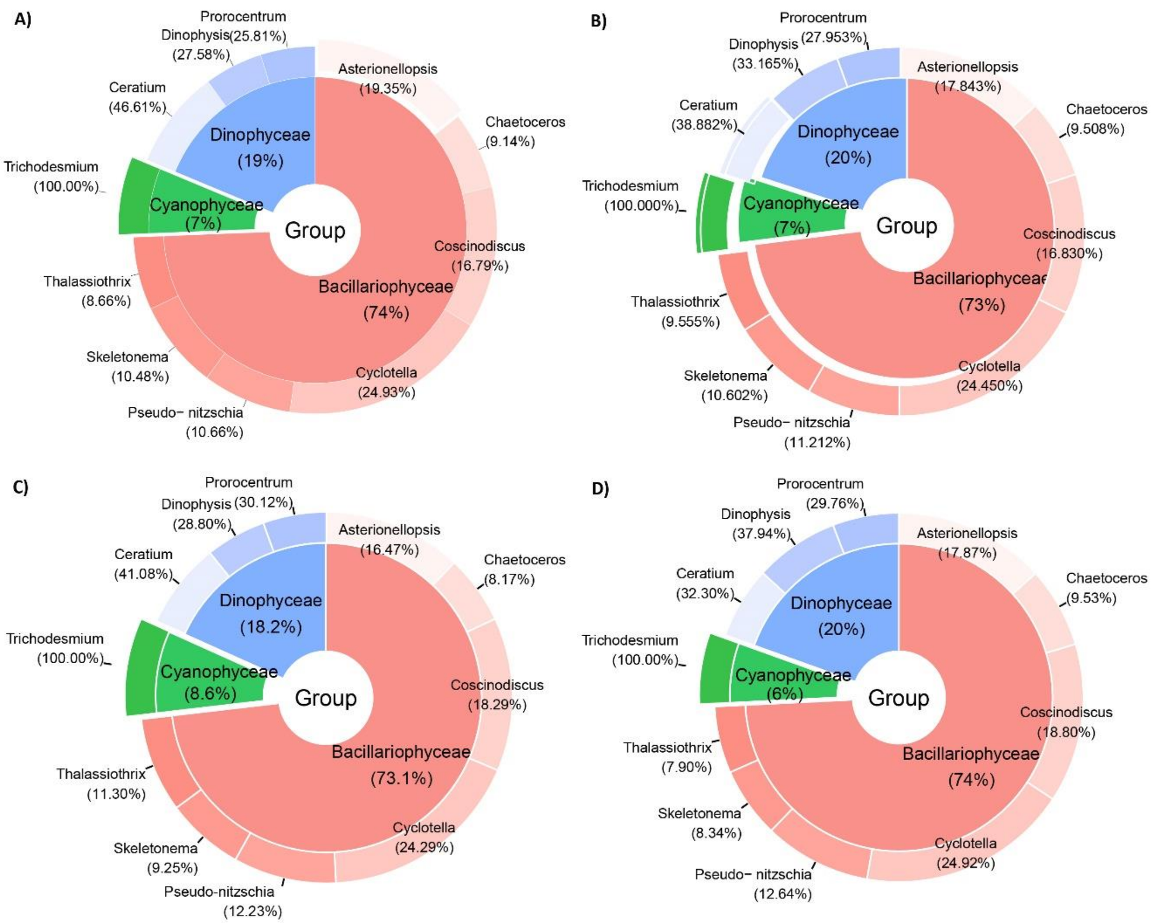

Fig. 3: Season-wise variation of Phytoplankton Classes and Genus; A= pre-monsoon, B= monsoon, C= post-monsoon, D=winter.

The contribution of Dinophyceae of the total phytoplankton community in Pre-Monsoon was 19%, 20% in Monsoon, 18.2% in Post-Monsoon and 20% in winter. Three genera were identified under Dinophyceae including *Ceratium, Dinophysis, Prorocentrum* and *Ceratium* contributed higher in post-monsoon season. Another two species showed higher contribution in monsoon (Fig. 3: A-D).

The contribution of Cyanohyceae of the total phytoplankton community in Pre-Monsoon was 7%, 7% in Monsoon, 8.6% in Post-Monsoon and 6% in winter. One genera was identified under Cyanophyceae naming *Trichodesmium* (Fig. 3: A-D).

One-way ANOVA results showed that variations in the contribution of Bacillariophyceae, Dinophyceae, and cyanophyceae among 4 seasons were significant at the level of 5% ($p<0.05$) (Table 1).

Table 1: Significance of phytoplankton (Classes) ($p<0.05$).

Phytoplankton Classes	Significance
Bacillariophyceae	0.017
Dinophyceae	0.000
Cyanophyceae	0.005

One-way ANOVA results showed that variations in the contribution of Trichodesmium among 4 seasons were significant at the level of 5% ($p<0.05$) (Table 2).

Table 2: Significance of phytoplankton (Genus) ($p<0.05$).

Genus	Significance
Chaetoceros	0.954
Thalassiothrix	0.315
Coscinodiscus	0.891
Cyclotella	0.981
Pseudo- nitzschia	0.352
Skeletonema	0.662
Asterionellopsis	0.762
Ceratium	0.367
Prorocentum	0.747

Dinophysis	0.448
Trichodesmium	0.349

4.2 Determination of coastal primary productivity

4.2.1 Chlorophyll-a

Chlorophyll-a concentrations in surface water were measured between 0.74 and 0.1986 μg/L. The value of chlorophyll-a was reported in all four stations as St_1 0.30-0.74 μg/L, St_2 0.26-0.632 μg/L, St_3 0.18-0.47 μg/L, St_4 0.1986-0.361 μg/L. Chloroiphyll-a was highest in monsoon 0.36-0.74 μg/L, followed by pre-monsoon 0.26-0.67 μg/L, post-monsoon 0.21-0.36 μg/L, and minimum recorded in winter 0.1986-0.28 μg/L (Fig. 4: A and B). A two-way ANOVA was produced to show the significance (Table 3).

4.2.2 Nutrients availability

4.2.2.1 Nitrite

The value of nitrite of all samples of surface water was investigated in the range between 0.013-0.8634 μg/L. The value of Nitrite was ranked in all four stations as St_1 0.34-0.8634 μg/L, St_2 0.15-0.62 μg/L, St_3 0.013-0.74 μg/L, St_4 0.15-0.38 μg/L. Nitrite was outreached in monsoon 0.35-0.8634 μg/L, followed by post-monsoon 0.16-0.64μg/L , pre-monsoon 0.31-0.70 μg/L, and lower in winter 0.013-0.30 μg/L (Fig. 4: C and D). Two-way ANOVA, was performed to evaluate significance of nitrite ($p<0.05$) (Table 3).

4.2.2.2 Phosphate

The value of phosphate of all samples of surface water was investigated in the range between 0.117-0.5687 μg/L. The value of phosphate was ranked in all four stations as St_1 0.18-0.42 μg/L, St_2 0.14-0.35 μg/L, St_3 0.14-0.5687 μg/L, St_4 0.1171-0.46 μg/L. Phosphate was observed highest in monsoon 0.34-0.5687 μg/L, followed by post-monsoon 0.15-0.25 μg/L, pre-monsoon 0.24-0.35 μg/L, and lowest in winter 0.013-0.19 μg/L (Fig. 4: E and F). Phosphate changes were statistically significant ($p<0.05$) using a two-way analysis of variance (Table 3).

4.2.2.3 Silicate

The value of silicate of all samples of surface water was investigated in the range between 2.964-32.24 μg/L. The value of Silicate was varied in all four stations as St_1 8.2-32.24

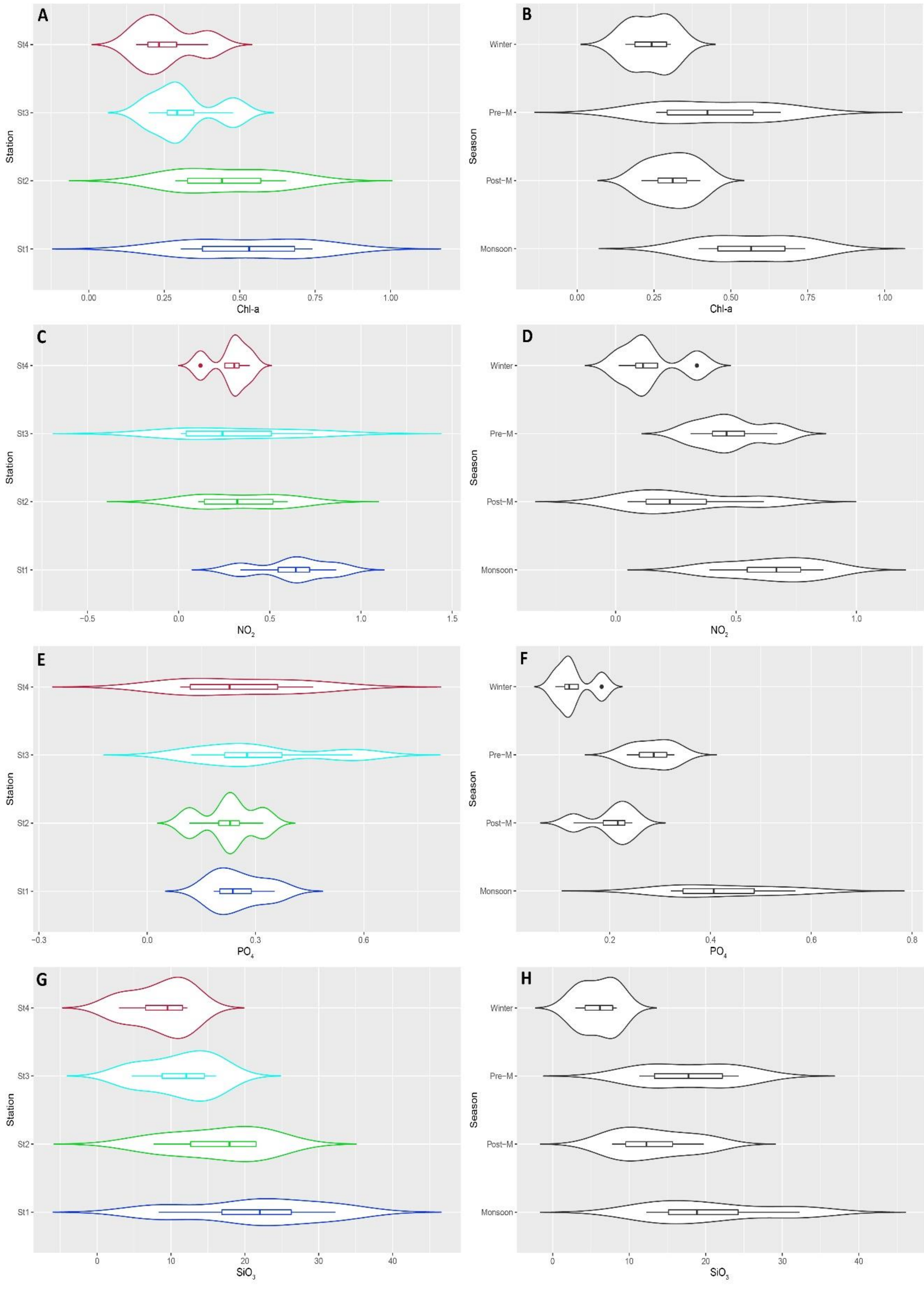

Fig. 4: Station-wise and seasonal variation of chlorophyll-a (A and B), Nitrite (C and D), Phosphate (E and F) and silicate (G and H).

The value of Silicate was varied in all four stations as St_1 8.2-32.24 µg/L, St_2 6.9-22.8 µg/L, St_3 4.8-17.3 µg/L, St_4 2.964-13.5 µg/L. Silicate was observed highest in monsoon 13.7-32.24µg/L, followed by pre-monsoon 12.1-24.6 µg/L, post-monsoon 6.6-19.9 µg/L, and lowest in winter 2.964-7.41 µg/L (Fig. 4: G and H). The silicate changes were performed to show significance ($p<0.05$) according to a two-way ANOVA (Table 3).

4.3 Other physico-chemical parameters

During this course of the inquiry, water quality parameters like temperature, salinity, pH, electro-conductivity, total dissolved solids (TDS), NaCl, total suspended solids (TSS), and DO were recorded.

4.3.1 Temperature

Surface water temperature was varied 20.1-35.5°C in the studied area. Temperature showed variation in all four stations as St_1 21-33.5°C, St_2 20-31.4°C, St_3 23.1-35.5°C, St_4 22.2-35°C. Temperature was recorded in monsoon 29-32.5°C, post-monsoon 23.2-27.5°C, pre-monsoon 31.9-35.5°C, and in winter 20-23.1°C. The temperature decreased from Pre-Monsoon towards winter gradually (Fig. 5: A and B). Water temperature differences between stations and Seasons was performed ($p<0.05$) in a two-way analysis of variance (Table 3).

4.3.2 Salinity

The surface water salinity was found to vary from 6-34.2 psu during this investigation period. Salinity variation in all four stations as St_1 22.4-32.4 psu, St_2 20-34.2 psu, St_3 9.9-31.1 psu, St_4 6-30 psu. Salinity was observed lowest in monsoon 6.1-22 psu, followed by post-monsoon 27.2-31.5 psu, pre-monsoon 16.3-25 psu, and increased in winter 30-34.2 psu. Salinity increased gradually at Cox`s Bazar and sharply at Kutubdia from Monsoon towards Winter (Fig. 5: C and D). In a two-way analysis of variance, salinity differences were found to be statistically significant ($p<0.05$) (Table 3).

4.3.3 pH

The pH value of all samples of surface water was investigated fluctuated between 6.9-9.8. pH fluctuated in all four stations as St_1 7.8-8.2, St_2 6.9-8.7, St_3 7-9.5, St_4 7.8-8.3. pH was measured highest in monsoon 8.2-9.8, followed by post-monsoon 8.1-8.4, winter 7.7-8.1, and lowest in pre-monsoon 6.8-7.4 (Fig. 5: E and F). pH shifts were shown to be statistically significant ($p<0.05$) based on a two-way analysis of variance (Table 3).

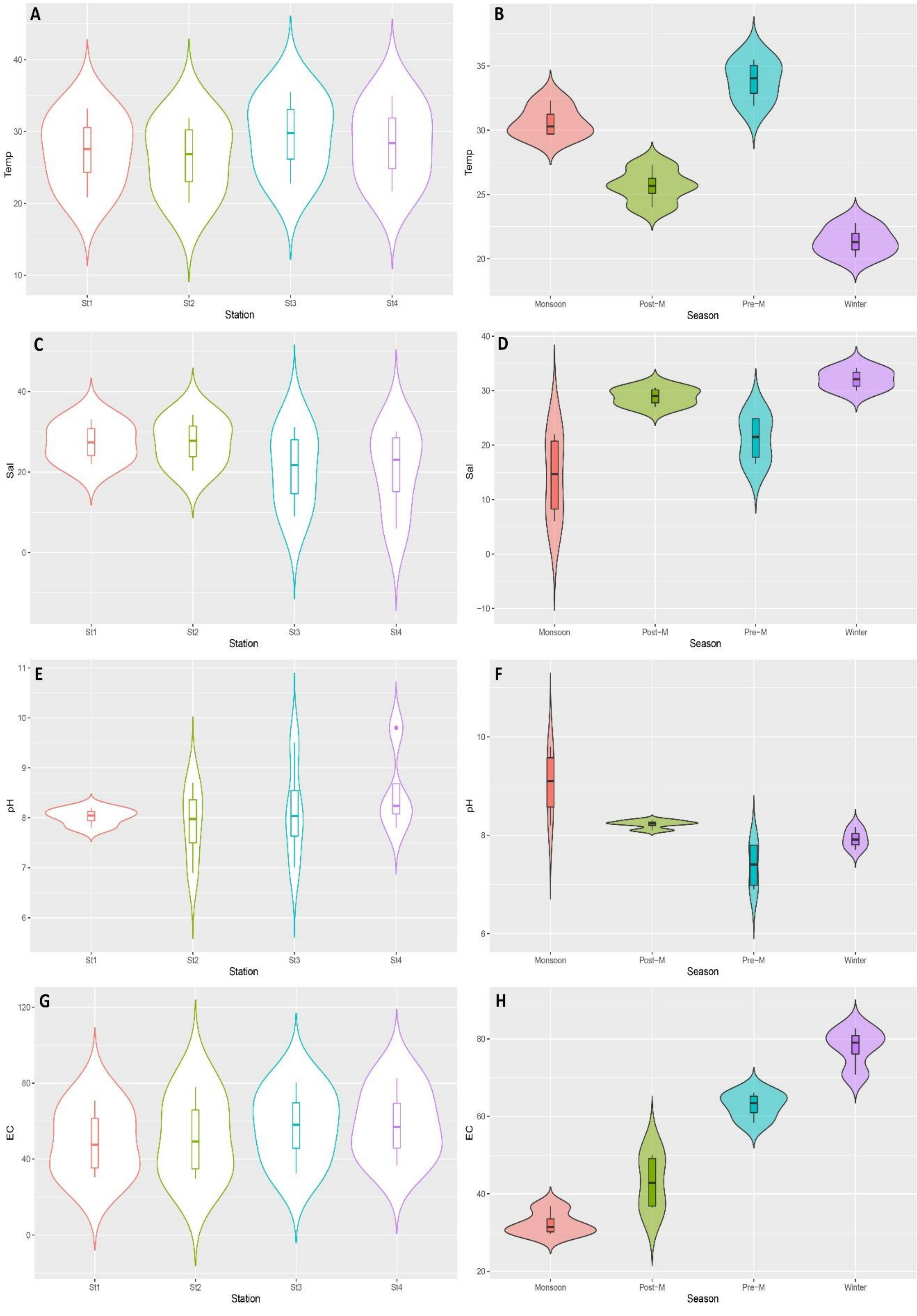

Fig. 5: Station-wise and seasonal variation of temperature (A and B), salinity (C and D), pH (E and F) and EC (G and H).

4.3.4 Electro-conductivity (EC)

The value of EC of all samples of surface water was investigated in the range between 29.64-82.75 mS/cm. EC fluctuated in all four stations as St_1 29.64-71.4 mS/cm, St_2 28-78.3 mS/cm, St_3 34-80.1 mS/cm, St_4 36.4-82.75 mS/cm. EC ranged lowest in monsoon 30-37.9 mS/cm, after that increased in post-monsoon 38.3-50.4 mS/cm, pre-monsoon 58-66.7 mS/cm, and highest in winter 71.2-82.75 mS/cm (Fig. 5: G and H). Changes in EC were statistically significant ($p<0.05$) based on a two-way analysis of variance (Table 3).

4.3.5 Total dissolved solids (TDS)

In this investigation, the level of TDS in surface water was found to vary 22.83-42.77 mg/L. TDS was arrayed in all four stations as St_1 22.83-34.2 mg/L, St_2 24-32.8 mg/L, St_3 27.3-38.1 mg/L, St_4 26.9-42.77 mg/L. TDS showed lowest value in monsoon 22.83-27.7 mg/L, after that gradual increased post-monsoon 28-33.4 mg/L, pre-monsoon 29.7-37 mg/L, and highest in winter 26.5-42.77 mg/L (Fig. 6: A and B). A two-way analysis of variance revealed statistically significant ($p<0.05$) differences in TDS value among samples (Table 3).

4.3.6 NaCl

The value of NaCl of all samples of surface water was investigated in the range between 97.89-155.4 %. NaCl was noticed in all four stations as St_1 111.1-155.4 %, St_2 97.89-140 %, St_3 101-134.5 %, St_4 107.2-40.9%. TDS was lowest in monsoon 97.89-111%, icreased by post-monsoon 113-121.7%, pre-monsoon 122.7-148.1 %, and highest in winter 134-155.4%. The value of NaCl slowly increases from Monsoon towards winter (Fig. 6: C and D). Two-way ANOVA performed to show variations in NaCl ($p<0.05$) (Table 3).

4.3.7 Total Suspended Solids (TSS)

The level of TSS in surface water was found 0.0007-17.98. The value of TSS was appeared in all four stations as St_1 1.9-3.8, St_2 0.0007-3.4, St_3 7.8-17.98, St_4 4.1-16.2. TSS was lowest in monsoon 0.0007-7.8, increased by post-monsoon 0.1-12.4, pre-monsoon 3.2-13.42, and highest in winter 3.9-17.98 (Fig. 6: E and F). According to a two-way analysis of variance (ANOVA), the differences between TSS values were statistically significant ($p<0.05$) (Table 3).

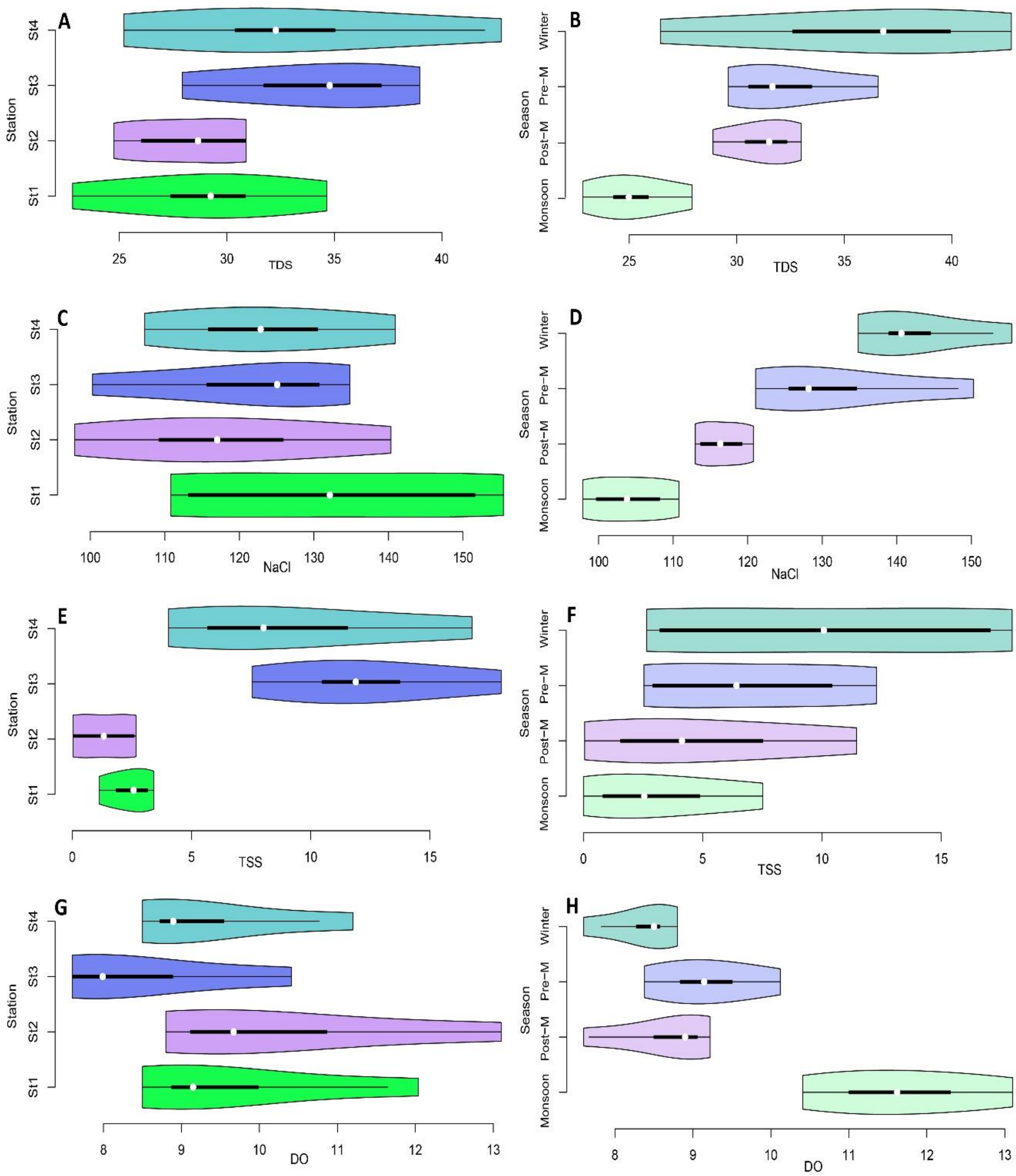

Fig. 6: Station-wise and seasonal variation of TDS (A and B), NaCl (C and D), TSS (E and F) and DO (G and H).

4.3.8 DO

The value of DO of all samples of surface water was investigated in the range between 7.6-13.1 mg/L. The value of DO was ranked in all four stations as St_1 8.5-11.7 mg/L, St_2 8.7-13.1 mg/L, St_3 7.6-10.4 mg/L, St_4 8.5-10.6 mg/L. DO was highest in monsoon 10.5-13.1 mg/L, followed by pre-monsoon 8.4-10.1 mg/L, post-monsoon 7.6-9.2 mg/L, and lowest in winter 7.6-8.8 mg/L (Fig. 6: G and H). Two-way ANOVA was performed (Table 3).

Table 3: Two way ANOVA results for different physico-chemical parameters ($p<0.05$).

Parameters	Stations	Seasons	Stations* Seasons
Chlorophyll-a	0.000	0.008	0.012
Nitrite	0.146	0.355	0.360
Phosphate	0.000	0.001	0.001
Silicate	0.002	0.004	0.008
Temperature	0.482	0.497	0.497
Salinity	0.000	0.000	0.000
pH	0.000	0.000	0.000
EC	0.000	0.001	0.001
TDS	0.000	0.001	0.001
Nacl	0.007	0.144	0.161
TSS	0.000	0.000	0.000
DO	0.301	0.373	0.376

4.4 Relationship of phytoplankton composition with nutrients

In this study, nitrite was highest in St_1 than all other stations. All the stations showed higher nitrite availability during monsoon, followed by pre-monsoon, post-monsoon, and lowest in winter. Higher presence of nitrite affected higher abundance of total phytoplankton.

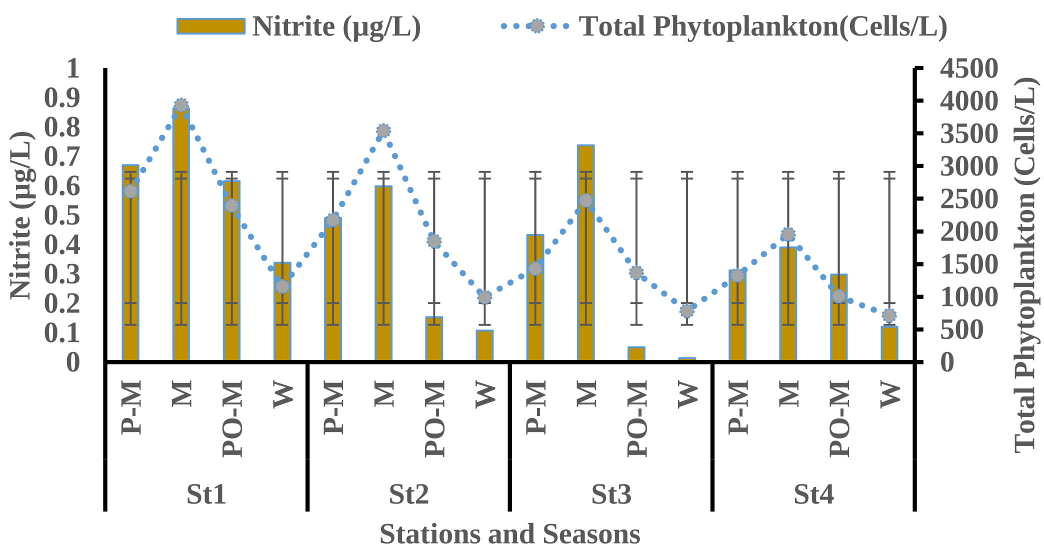

Fig. 7: Station-wise and seasonal variation of nitrite with phytoplankton abundance.

The number of phytoplankton in water is affected by nutrient content, such as phosphate. Phosphate is essential for the growth and metabolism of phytoplankton, which serve as indicators of water quality and fertility. Phosphate presence was higher in St_3 among four stations and prominent during monsoon, reduced by pre-monsoon, post-monsoon, and lowest in winter.

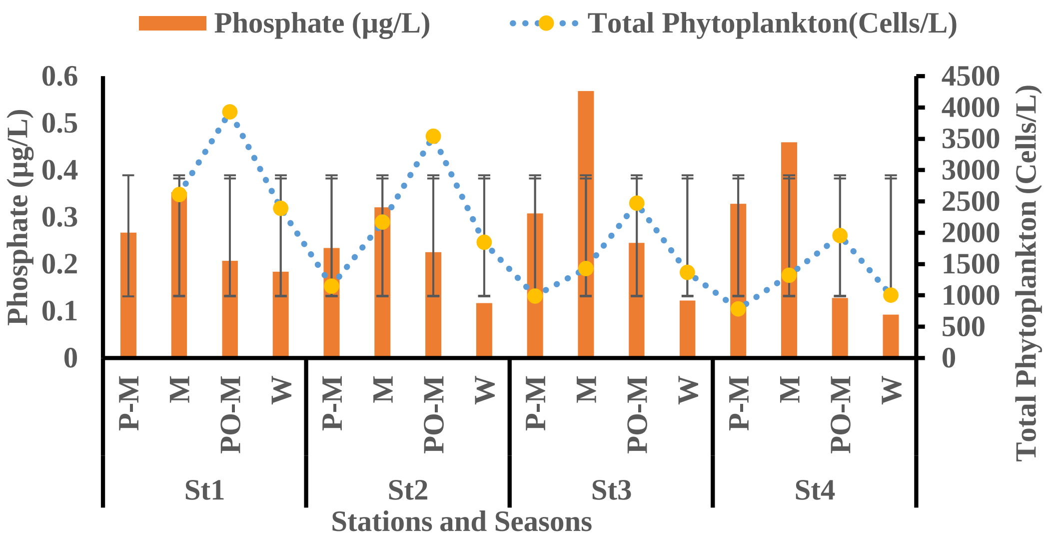

Fig. 8: Station-wise and seasonal variation of phosphate with phytoplankton abundance.

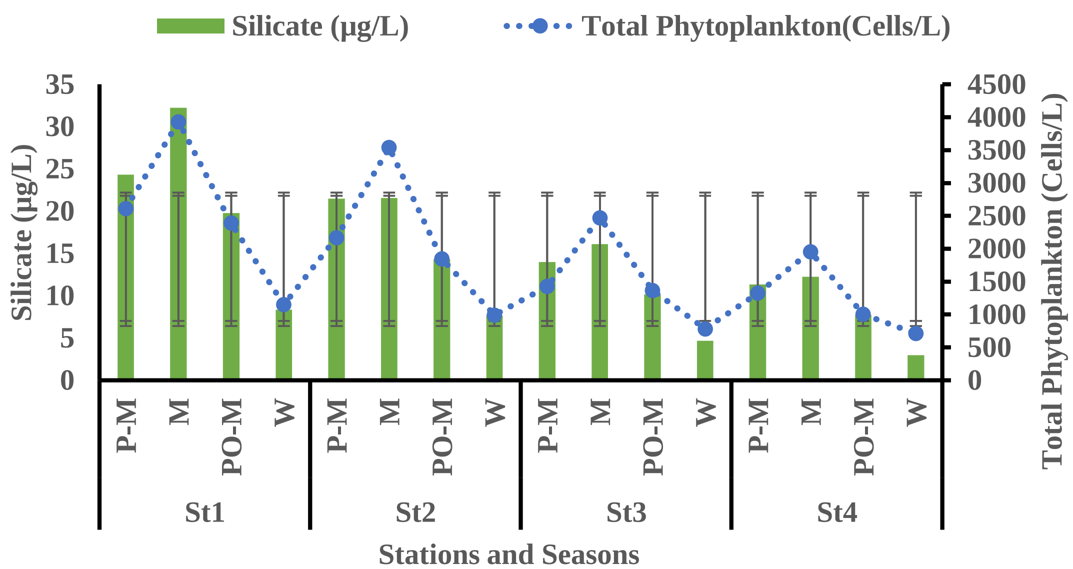

Fig. 9: Station-wise and seasonal variation of nitrite with phytoplankton abundance.

Silicate is another crucial nutrients for phytoplankton growth showed it's presence in all stations but foremost was in St_1. Among all seasons highest was in monsoon, reduced by pre-monsoon, post-monsoon and lowest presence in winter.

There was a strong relationship between environmental factors and phytoplankton assemblages, as shown by the Spearman rank correlations. The number of phytoplankton was positively connected with chlorophyll-a, salinity, silicate, electrical conductivity, and sodium, and negatively correlated with pH, nitrite, phosphorus, and dissolved oxygen (Table 4).

Table 4: Co-relation of phytoplankton composition with physico-chemical water quality parameters (* Correlation is significant at the 0.05 level and ** Correlation is significant at the 0.01 level).

Parameters	Chlorophyll-a	pH	WT	Salinity	Nitrite	Silicate
Phytoplankton (Cells/L)	0.956**	-0.715**	0.492	0.774*	-0.285	0.247
Parameters	Phosphate	TDS	EC	NaCl	TSS	DO
Phytoplankton (Cells/L)	0.694**	0.388	0.679**	0.821**	0.009	-0.491

4.5 Co-relation plot of physico-chemical water quality parameters with phytoplankton

The co-relation plot among different physico-chemical water quality parameters and phytoplankton is demonstrated in Fig. 10. Phytoplankton had the strong positive relation with silicate, nitrite, chlorophyll-a, DO, and positive relation with phosphate, pH and temperature. It had the strong negative relation with TSS, TDS, electro-conductivity, and negative relation with NaCl, and salinity. Chlorophyll-a indicated highly strong relation with silicate, and phytoplankton abundance.

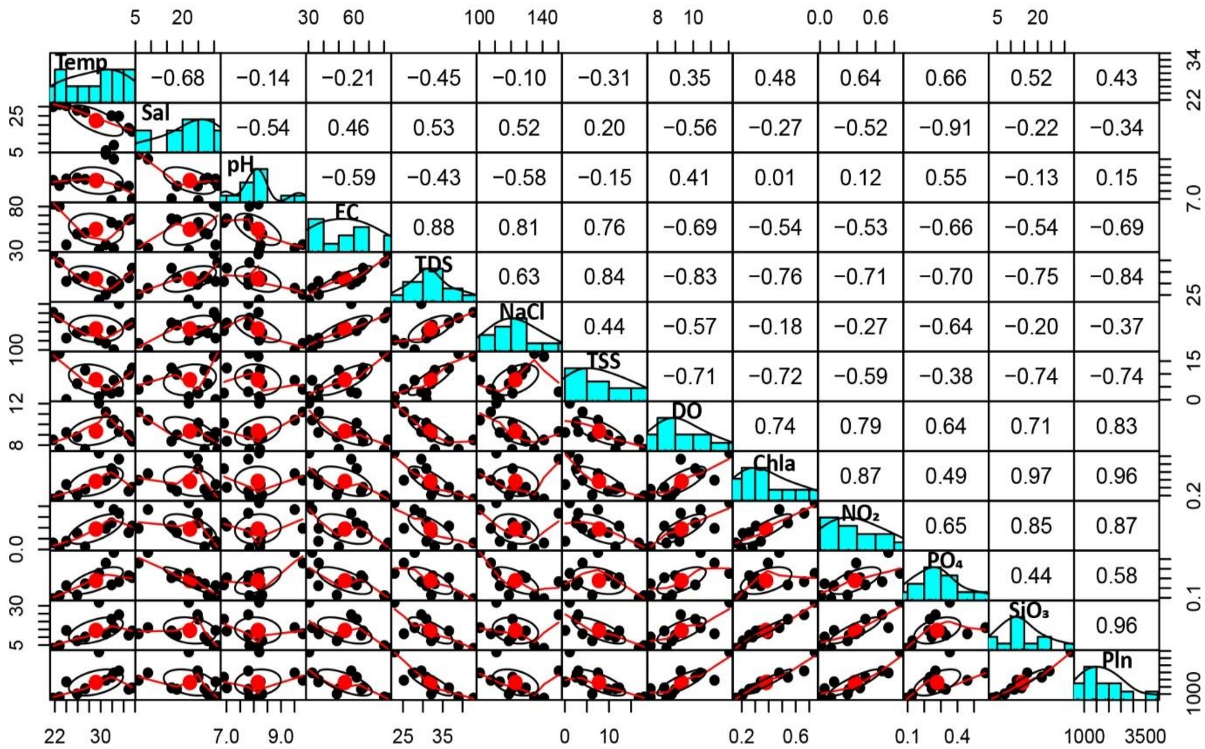

Fig. 10: Co-relation plot among different parameters: temperature, salinity, pH, EC, TDS, NaCl, TSS, DO, chlorophyll-a, nitrite, phosphate, silicate and phytoplankton abundance.

4.6 Principal component analysis

The spatio-temporal variability of different water sources were analyzed using principal component analysis (PCA) to determine the most likely contributing factors. Principal components (PCs) with an eigenvalue greater than one were chosen using Varimax rotation and Kaiser Normalization. It (Table 5) provides the rotatable component matrix for water quality variables. According to the Eigen values, principal component analysis (PCA) of the water quality metrics resulted in the development of 3 PC.

Table 5: Rotated component matrix for water quality parameters (Extraction method: Principal component analysis. Rotation method: Varimax with Kaiser Normalization.).

Parameters	Component		
	PCA 1	PCA 2	PCA 3
Chlorophyll- a	.122	.826	-.375
pH	.138	-.874	-.044
Temperature	.153	-.064	.951

Salinity	-.076	.559	-.769
Nitrite	.722	-.029	.560
Silicate	.834	.095	.448
Phosphate	.308	-.530	.694
TDS	-.858	.328	-.104
EC	-.663	.637	-.199
Nacl	-.371	.783	-.241
TSS	-.929	.032	.139
DO	.738	-.397	.267

In PC 1, the positive factor loadings of Chlorophyll-a, pH, temperature, nitrite, silicate, phosphate, and DO whereas, negative factor loadings of Salinity, TDS, EC, NaCl, and TSS accounted for 34.146% of the total variation (Fig. 11). On the other hand, positive factor were Chlorophyll-a., salinity, silicate, TDS, EC, NaCl, and TSS in PCA2 while, negative factors as pH, temperature, nitrite, phosphate, and DO accounted for 27.820% of the total variance (Fig. 11). In addition, positive factor loading of temperature, nitrite, silicate, phosphorous, TSS, and DO whereas, negative factor loading of Chlorophyll-a, pH, salinity, TDS, EC, NaCl, and DO accounted for 23.623% of the total variance (Fig. 11).

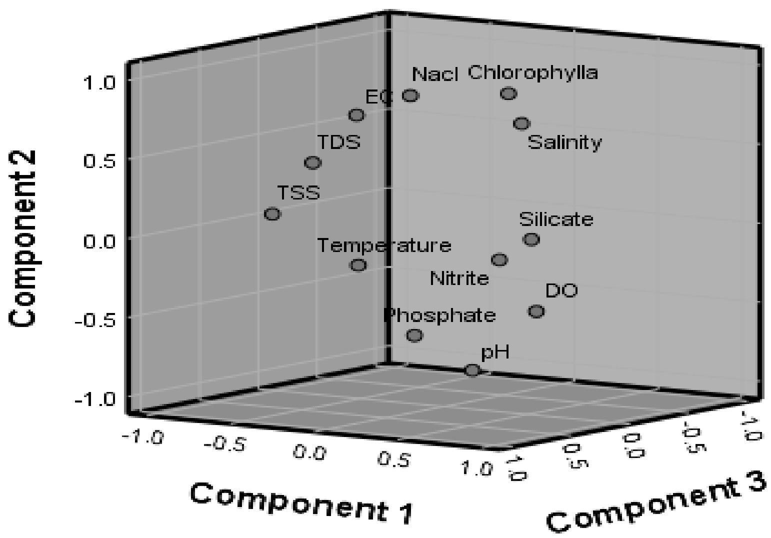

Fig. 11: Rotated component space plot for coastal waters characteristics.

CHAPTER FIVE
DISCUSSION

5.1 Phytoplankton abundance and composition

The proximal waters of the Bay of Bengal around Moheshkali and Sonadia islands (Islam and Aziz, 1975, 1980) reported 31 Bacillariophyceae genera, 4 Dinophyceae genera, and 2 Cyanophyceae species. The offshore waters of the Bay of Bengal have yielded new discoveries from 10 Chlorophyceae, 21 Bacillariophyceae, 3 Dinophyceae, and 5 Cyanophyceae families throughout the course of many seasons (Mahmood et al., 2006). In the summer 1.015 × 10^5 cells/L in Rupsha-Pashur, in the winter 4.197 × 10^5 cells/L were found in Khalpatua-Arpangachia, and in the summer, 5.03 × 10^5 cells/L were detected in the coastal waters of Bangladesh (Rahaman et al., 2013).
The density of phytoplankton cells in the Reju khal estuary was between 9.408×10^3-21.964×10^3 cells/L (Mehedi et al., 2017). During the Monsoon season, enhanced primary productivity was recorded in various estuarine and coastal environments (Bryceson, 1977; Lugomela, 1995).

During this study, average concentration of phytoplankton was highest in Cox`s Bazar St_1 3.931×10^3 cells/L, St_2 3.54×10^3 cells/L and in Kutubdia St_3 2.471×10^3 cells/L , St_4 1.956×10^3 cells/L during Monsoon. The observed three major classes of phytoplankton were Bacillariophyceae, Dinophyceae, and Cyanophyceae. Seven genera of Bacillariophyceae, three genera of Dinophyceae, and one genus of Cyanophyceae were discovered in this study. Bacillariophyceae was the prominent in all stations and seasons. It appears that the seasonality of plankton assemblages in these coastal waters is mostly determined by the rain cycle, temperature, availability of light and most importantly presence of nutrients.

In this research, The contribution of Bacillariophyceae of the total phytoplankton community was in St_1 75.6%, St_2 77.5%, St_3 71%, and St_4 65%. The contribution of Dinophyceae of the total phytoplankton community was in St_1 17.1%, St_2 15.5%, St_3 22%, and St_4 27%.The contribution of Cyanophyceae of the total phytoplankton community was in St_1 7.3%, St_2 7.1%, St_3 7%, St_4 8%.

Bacillariophyceae of the total phytoplankton community in Pre-Monsoon was 74%, 73% in monsoon, 73.1% in post-monsoon, and 74% in winter. The contribution of

Dinophyceae of the total phytoplankton community in pre-monsoon was 19%, 20% in monsoon, 18.2% in post-monsoon and 20% in winter. The contribution of Cyanohyceae of the total phytoplankton community in pre-monsoon was 7%, 7%in monsoon, 8.6% in post-monsoon and 6% in winter.

5.2 Coastal productivity

5.2.1 Chlorophyll-a

Chlorophyll-a levels are higher in the monsoon possibly because of an abundance of UV light, clean water, and the use of silicate, nitrite, and phosphate by primary producers (Sardessai et al., 2007; Prabhahar et al., 2011).

Chloroiphyll-a was highest in monsoon 0.36-0.74 μg/L, followed by post-monsoon 0.21-0.36 μg/L, pre-monsoon 0.26-0.67 μg/L, and lowest in winter 0.1986-0.28 μg/L. Chlorophyll-a abundance is often prominent in or after rainfall due to flushes of nutrients in water body.

5.2.2 Nutrients availability

The process of living things involves nutrients in a useful way. The phrase has historically been used nearly exclusively in relation to nitrite, phosphate and silicate in chemical oceanography. Nutrients in the water serve to support the marine food webs. In the ocean, phytoplanktons are the main providers of food and they do this to create food for zooplanktons, which higher-level species in the food chain ultimately ingest. When it comes to the health of marine life, nutrients play a pivotal role in growth, reproduction, and energy metabolism. Rainfall, freshwater inflow, tidal ingress, and autotrophic nutrient intakes all have a role in the seasonal changes of coastal nutrients like nitrite, phosphate, and silicate.

In the Shibsa River, which is located on the southwest coast of Bangladesh, the Nitrate content ranges from a high of 1.9 µg/L in May to a low of 0.7 µg/L in September, as documented by (Shah et al., 2008). The average value fluctuated from 0.126 to 1.198 µg/L during the Monsoon season on Bangladesh's southeast coast (Bay of Bengal) (Noori, 1999).

Nitrite was outreached highest in monsoon 0.35-0.8634 μg/L, reduced to post-monsoon 0.16-0.64μg/L, pre-monsoon 0.31-0.70 μg/L, and lowest in winter 0.013-0.30 μg/L

The quantity of phosphorus in an aquatic ecosystem is critical for primary productivity because it stimulates organisms growth while limiting phytoplankton production (Cole and Sanford, 1989). Phosphate was observed highest in monsoon 0.34-0.5687 μg/L, followed by post-monsoon 0.15-0.25 μg/L, pre-Monsoon 0.24-0.35 μg/L, and lowest in winter 0.013-0.19 μg/L. The high levels observed during the Monsoon season may be explained by the fact that these waters, which originate from land drainage and carry silicate leach out of rocks, arrive in enormous quantities (Govindasamy and Kannan., 1996; Rajasegar, 2003).

Phytoplankton uptake of silicates for biological activity may account for the reported low amounts observed during the winter (Mishra et al., 1993; Ramakrishnan et al., 1999). The range 32.24-2.964 µg/L was explored for silicate concentrations in all surface water samples. This study found the value of silicate sharply changed from winter towards monsoon.

5.3 Other physico-chemical parameters

Seasonal temperature fluctuations may be attributed to wind force, freshwater input, and atmospheric temperature. The current study's findings also aligned with prior reported research in the Bangladesh coastline area undertaken by (Das et al., 2002), who reported temperature variations ranging 25-30 °C with significant seasonal variations. As a result of the prevailing southeastern and northwesterly wind patterns along the Bay of Bengal coast, the local climate was primarily characterized by markedly higher temperatures during the monsoon months and dramatically lower temperatures during the winter. A similar trend was seen in the research conducted by (Chowdhury et al., 2011). Wind speed, the amount of precipitation, and the ambient temperature are all potential causes of seasonal temperature changes. The research along the Kalpakkam coast lends credence to these hypotheses (Achary et al., 2014). The temperatures near the estuary of the Karnafully river in Bangladesh ranges from a low of 25 °C during the winter to a high of 31°C during the monsoon (Barman, 2013). At Sangu river estuary in the Bay of Bengal at Cox's Bazar (Haque et al., 2015) observed temperatures as high as 32.5 °C in August and as low as 20.8 °C in December.

The surface water temperature ranged 35.5-20.1 °C during the course of this study. Throughout the summer and the monsoon, the ocean reached its highest temperature. It's possible that the colder water temperatures experienced this winter are due to the strong winds that have been blowing in from the northeast. Salinity levels in the Sangu river estuary of the Bay of Bengal range from a high of 34 practical salinity unit in April to a low of 17 practical salinity unit in October, according to research by (Haque et al., 2015). Salinity of the Karnafully river estuary ranged from a low of 12 practical salinity unit during the pre-Monsoon period to a high of 21 practical salinity unit during the monsoon (Barman, 2013). In this study, salinity was observed lowest in monsoon 6.1-22 psu, increased by post-monsoon 27.2-31.5 psu, pre-monsoon 16.3-25 psu, and highest in winter 30-34.2 psu. The cause for reduced salinity during the Monsoon season is the presence of land runoff and rainfall, which diffused the water and diminishes salinity.

The highest pH was in October (8.45) and in November (8.40) in Sangu river estuary (Haque et al., 2015). The level pH of the Karnafully river estuary is highest (6.5) before and during the monsoon, and lowest (4.5) after the monsoon (Barman, 2013). This research measured pH in monsoon 8.2-9.8, post-monsoon 8.1-8.4, pre-monsoon 6.8-7.4, winter 7.7-8.1. The seasonal pattern of pH was increased from winter towards monsoon gradually. Seawater intrusion and intense biological activity as well as the presence of robust photosynthetic activity, may be responsible for the elevated summertime pH (Das et al., 1997; Subramanian and Mahadevan, 1999).

TDS and EC increase when salinity decreases (Islam et al., 2017). In the current investigation, a similar tendency in salinity changes was observed. TDS and EC levels were found to be lower during the monsoon season. Particles in water that reduce its visibility or increase its light scattering are known as total suspended solids (TSS). Changes in pH have an effect on TSS because they cause some solutes to precipitate and modify the solubility of the suspended components (Bilotta et al., 2008). TSS levels in surface water were found 17.98-0.007 in this investigation. Monsoon saw the lowest TSS values whereas winter saw the highest value.

Oxygen dissolution is known to be influenced by both temperature and salinity (Vijayakumar et al., 2000). Intense rain and the ensuing freshwater mixing may contribute to the reported high Monsoonal values (Das et al., 1997). Seasonal change in dissolved oxygen has been linked to freshwater flow and terrigenous influence of sediments, according to (Mitra et al., 1990). Dissolved oxygen levels were found to be highest in this study at all locations during the monsoon season. Dissolved oxygen levels exhibited a seasonal inverse relationship to both temperature and salinity.

CHAPTER SIX
CONCLUSION

Chlorophyll-a concentration in phytoplankton were shown to fluctuate with the seasons and among different regions. In addition to studying phytoplankton and nutrients concentration, this study also examined the effects of and co-relations among environmental variables. The Chlorophyll-a concentration follows seasonal trends due to changes in water nutrients. The interplay between nutrients and chlorophyll-a concentration exemplifies the complexity of this coastal ecosystem. As a result, this study draws a detail picture of the seasonal variation and seasonal dynamics of phytoplankton in relation to environmental conditions. The principal sources of nutrients addition to coastal waters depends on light availability, precipitation, freshwater runoff, and tidal intrusion.

This research provides conclusive evidence that nutrients availability significantly affect phytoplankton diversity, abundance, and seasonal change. Knowing the seasonal variation of phytoplankton and its spatial variation and distribution is crucial for this kind of study. Acute knowledge of phytoplankton morphology is essential for accurate identification. No definitive conclusions can yet be formed about the seasonal distribution of phytoplankton in the coastal waters of Chattogram without further investigation. The fisheries sector of Bangladesh relies heavily on the copious plankton resources found along the country's coastline. Several physico-chemical factors influence the composition of coastal phytoplankton communities. This study provides a concise summary of seasonal variability in physico-chemical parameters and phytoplankton abundance. Major implications of this study includes- future mericulture in coastal areas depending on coastal productivity (Chlorophyll-a), indirect implementation of Sustainable development goals of United Nations 2015-30.

CHAPTER SEVEN

RECOMMENDATIONS AND FUTURE PERSPECTIVES

Phytoplankton is the foundation of the marine food chains, and their abundance can be used to gauge the state of the environment. This study analyzed physico-chemical characteristics and phytoplankton reaction patterns in the coastal waters of Chattogram to get better assumption of seasonal changes. Although this research had some limitations, it was nevertheless worthwhile to pursue. It might take a lot of time and money to study coastal waterways but month-wise sample collection may enrich deeper knowledge. Unpredictable weather, marine risks, tidal surge, rocking of the boat, lack of a suitable vessels, and physical illness from rolling significantly hampered this study. If more study were available, it could be more effective. Future contemplation on phytoplankton horizontal and vertical distribution, sinking characteristics, water chemistry, seasonal fluctuations, and pollution levels in Chattogram's coastal waters may benefit from the information provided by this study.

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APPENDICES

Appedix I: One way ANOVA for Phytoplankton (Classes and Genus)

I (A):

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Bacillariophyceae	Between Groups	4615294.000	3	1538431.333	5.079	.017
	Within Groups	3634941.000	12	302911.750		
	Total	8250235.000	15			
Dinophyceae	Between Groups	367820.188	3	122606.729	22.757	.000
	Within Groups	64651.250	12	5387.604		
	Total	432471.438	15			
Cyanophyceae	Between Groups	45992.188	3	15330.729	7.108	.005
	Within Groups	25882.750	12	2156.896		
	Total	71874.938	15			

I (B):

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Chaetoceros %	Between Groups	3.117	3	1.039	.108	.954
	Within Groups	115.422	12	9.618		
	Total	118.538	15			
Thalassiothrix %	Between Groups	23.909	3	7.970	1.314	.315
	Within Groups	72.799	12	6.067		
	Total	96.708	15			

Coscinodiscus %	Between Groups	16.628	3	5.543	.204	.891
	Within Groups	325.421	12	27.118		
	Total	342.049	15			
Cyclotella %	Between Groups	3.107	3	1.036	.058	.981
	Within Groups	215.713	12	17.976		
	Total	218.820	15			
Pseudo- nitzschia %	Between Groups	14.977	3	4.992	1.199	.352
	Within Groups	49.953	12	4.163		
	Total	64.929	15			
Skeletonema %	Between Groups	16.343	3	5.448	.544	.662
	Within Groups	120.255	12	10.021		
	Total	136.598	15			
Asterionellopsis %	Between Groups	12.510	3	4.170	.391	.762
	Within Groups	128.037	12	10.670		
	Total	140.547	15			
Ceratium %	Between Groups	569.206	3	189.735	1.154	.367
	Within Groups	1972.410	12	164.368		
	Total	2541.616	15			
Prorocentrum %	Between Groups	84.689	3	28.230	.413	.747
	Within Groups	821.224	12	68.435		
	Total	905.913	15			
Dinophysis %	Between Groups	274.488	3	91.496	.948	.448
	Within Groups	1158.659	12	96.555		
	Total	1433.147	15			

Trichodesmium%	Between Groups	18.137	3	6.046	1.207	.349
	Within Groups	60.120	12	5.010		
	Total	78.257	15			

Appedix II: Two way ANOVA for Parameters

II (A):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
Chlorophyll- a	Based on Mean	7.958	3	44	.000
	Based on Median	4.461	3	44	.008
	Based on Median and with adjusted df	4.461	3	25.413	.012
	Based on trimmed mean	7.706	3	44	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: Chlorophyll- a

b. Design: Intercept + Station + Season + Station * Season

II (B):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
pH	Based on Mean	14.353	3	44	.000
	Based on Median	9.536	3	44	.000

	Based on Median and with adjusted df	9.536	3	20.049	.000
	Based on trimmed mean	14.343	3	44	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: pH

b. Design: Intercept + Station + Season + Station * Season

II (C):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
Temperature	Based on Mean	.835	3	44	.482
	Based on Median	.807	3	44	.497
	Based on Median and with adjusted df	.807	3	40.742	.497
	Based on trimmed mean	.840	3	44	.479

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: Temperature

b. Design: Intercept + Station + Season + Station * Season

II (D):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
Salinity	Based on Mean	30.327	3	44	.000
	Based on Median	28.521	3	44	.000

	Based on Median and with adjusted df	28.521	3	35.256	.000
	Based on trimmed mean	30.286	3	44	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: Salinity

b. Design: Intercept + Station + Season + Station * Season

II (E):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
Nitrite	Based on Mean	1.888	3	44	.146
	Based on Median	1.111	3	44	.355
	Based on Median and with adjusted df	1.111	3	29.063	.360
	Based on trimmed mean	1.767	3	44	.167

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: Nitrite

b. Design: Intercept + Station + Season + Station * Season

II (F):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
Silicate	Based on Mean	5.787	3	44	.002
	Based on Median	5.193	3	44	.004
	Based on Median and with adjusted df	5.193	3	21.276	.008

	Based on trimmed mean	5.680	3	44	.002

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: Silicate

b. Design: Intercept + Station + Season + Station * Season

II (G):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
Phosphate	Based on Mean	7.604	3	44	.000
	Based on Median	6.841	3	44	.001
	Based on Median and with adjusted df	6.841	3	26.192	.001
	Based on trimmed mean	7.624	3	44	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: Phosphate

b. Design: Intercept + Station + Season + Station * Season

II (H):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
TDS	Based on Mean	7.441	3	44	.000
	Based on Median	6.856	3	44	.001
	Based on Median and with adjusted df	6.856	3	23.262	.002
	Based on trimmed mean	7.395	3	44	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: TDS

b. Design: Intercept + Station + Season + Station * Season

II (I):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
Conductivity	Based on Mean	7.505	3	44	.000
	Based on Median	6.910	3	44	.001
	Based on Median and with adjusted df	6.910	3	35.675	.001
	Based on trimmed mean	7.464	3	44	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: Conductivity

b. Design: Intercept + Station + Season + Station * Season

II (J):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
Nacl	Based on Mean	4.606	3	44	.007
	Based on Median	1.898	3	44	.144
	Based on Median and with adjusted df	1.898	3	21.217	.161
	Based on trimmed mean	4.009	3	44	.013

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: Nacl

b. Design: Intercept + Station + Season + Station * Season

II (K):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
TSS	Based on Mean	20.780	3	44	.000
	Based on Median	17.136	3	44	.000
	Based on Median and with adjusted df	17.136	3	30.144	.000
	Based on trimmed mean	20.654	3	44	.000

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: TSS

b. Design: Intercept + Station + Season + Station * Season

II (L):

Levene's Test of Equality of Error Variances[a,b]

		Levene Statistic	df1	df2	Sig.
DO	Based on Mean	1.256	3	44	.301
	Based on Median	1.068	3	44	.373
	Based on Median and with adjusted df	1.068	3	32.776	.376
	Based on trimmed mean	1.216	3	44	.315

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Dependent variable: DO

b. Design: Intercept + Station + Season + Station * Season

Appendix III: Descriptions of Principle Component Analysis

III (A):

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	6.528	54.396	54.396	6.528	54.396	54.396	4.097	34.146	34.146
2	2.263	18.857	73.254	2.263	18.857	73.254	3.338	27.820	61.966
3	1.480	12.334	85.588	1.480	12.334	85.588	2.835	23.623	85.588
4	.675	5.624	91.212						
5	.357	2.973	94.186						
6	.306	2.550	96.736						
7	.131	1.088	97.825						
8	.113	.938	98.762						
9	.086	.717	99.480						
10	.035	.295	99.774						
11	.019	.162	99.936						
12	.008	.064	100.000						

Extraction Method: Principal Component Analysis.

III (B):

Component Matrix[a]

	Component		
	1	2	3
Chlorophyll- a	.569	.704	.135
pH	-.555	-.426	-.544
Temperature	-.618	-.194	.716
Salinity	.750	.505	-.304
Nitrite	-.776	.356	.328

Silicate	-.724	.547	.287
Phosphate	-.849	-.295	.222
TDS	.801	-.399	.232
EC	.892	-.039	.296
Nacl	.802	.278	.297
TSS	.560	-.703	.277
DO	-.842	.223	-.119

Extraction Method: Principal Component Analysis.

a. 3 components extracted.

III (C):

Rotated Component Matrix[a]

	Component		
	1	2	3
Chlorophyll- a	.122	.826	-.375
pH	.138	-.874	-.044
Temperature	.153	-.064	.951
Salinity	-.076	.559	-.769
Nitrite	.722	-.029	.560
Silicate	.834	.095	.448
Phosphate	.308	-.530	.694
TDS	-.858	.328	-.104
EC	-.663	.637	-.199
Nacl	-.371	.783	-.241
TSS	-.929	.032	.139
DO	.738	-.397	.267

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 6 iterations.

Appendix V: Research works

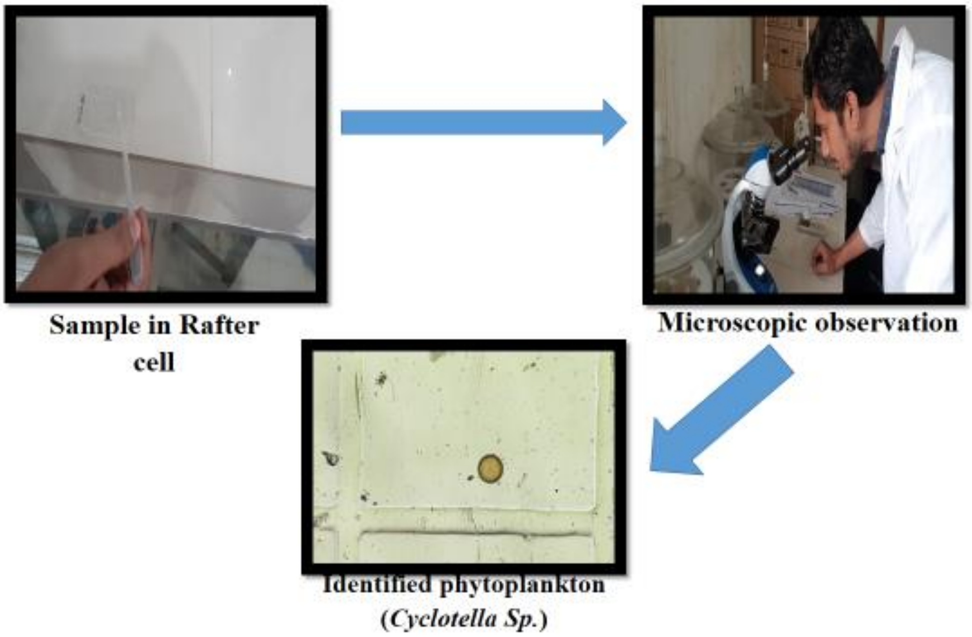

Fig. 12: Identification process

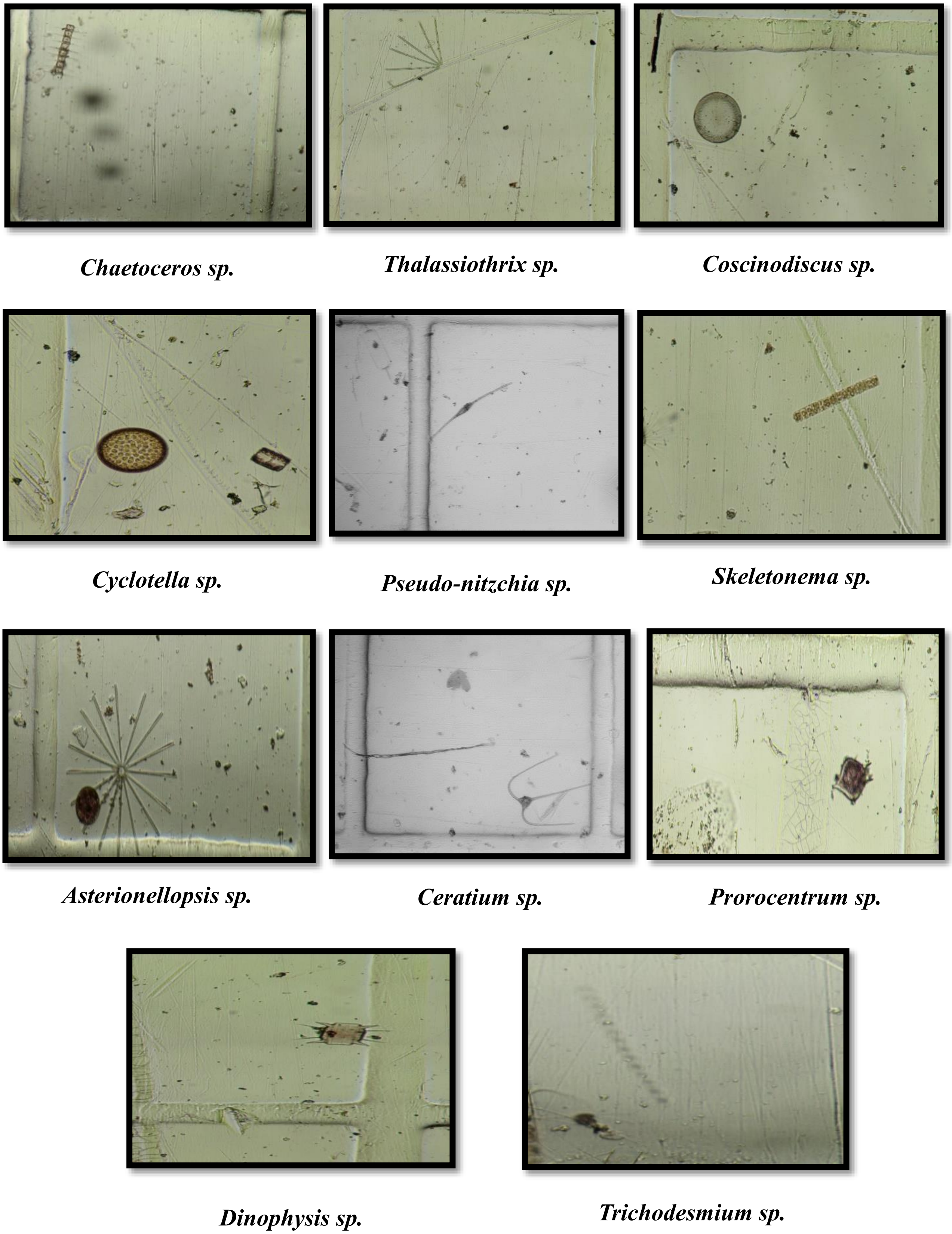

Fig. 13: Microscopic images of different species of phytoplankton

BRIEF BIOGRAPHY OF THE AUTHOR

This is MD. SHAFIUL ALAM ANIK, son of Md. Jahangir Alam and Mrs. Rahana Chowdhury from Matlab (S) Upazila under Chandpur district of Bangladesh. He passed the Secondary School Certificate Examination in 2012 from Matlabgonj J. B. Pilot High School, followed by Higher Secondary Certificate Examination in 2014 from Cambrian College, Dhaka. He obtained his B. Sc. in Fisheries (Hons.) Degree in 2019 from Faculty of Fisheries, Chattogram Veterinary and Animal Sciences University (CVASU), Chattogram, Bangladesh. Now, he is a candidate for the degree of MS in Marine Bioresource Science under the Department of Marine Bioresource Science, Faculty of Fisheries, CVASU. He has great interest on scientific research on Marine Science.