THE SEASONAL CYCLE OF THE PHYTOPLANKTON IN THE COASTAL WATERS OF CHATTOGRAM

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This is to certify that we have examined the above Master's thesis and have found that is complete and satisfactory in all respects, and that all revisions required by the thesis examination committee have been made

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APRIL 2021

Dedicated

To

My Beloved Parents

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The Author

Sanjoy Dey

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NO_2-N	Nitrite-Nitrogen
PO_4-P	Phosphate-Phosphorus
SiO_3-Si	Silicon-Silicate
NH_3-N	Ammonia-Nitrogen
mL	Milliliter
M	Miter
Mg	Milligram
Psu	Practical Salinity Unit
g/L	Gram Per Liter
mg/L	Milligram Per Liter
ºC	Degree Celsius
µg/L	Microgram Per Liter
mS/cm	Milisiemens Per Centimeter
<	Less than
>	Greater than
e.g	Example
et al.	And his associates
etc.	Et cetera
%	Percentage
Ppm	Parts Per Million
St	Station
Cm	Centimeter
TDS	Total dissolved solids
TSS	Total suspended solids
St	Station
Sig.	Significance
MS	Master of Science

ABSTRACT

The present investigation studied the seasonal variation of different physico-chemical parameters and phytoplankton composition from the northern BoB. Water samples were collected during monsoon and winter from the coastal waters of Chattogram (Bashbaria and Patenga). Surface water temperatures (ºC) varied from 25.4 to 32.2 whereas salinity values (psu) varied from 3.7 to 21.3 and the pH ranged between 6.7 and 7.6. Total dissolved solids (g/L) and total suspended solids (g/L) content varied from 2.82 to 22.3 and 0.55 to 0.94 respectively. The electro-conductivity (mS/cm) of all samples of surface water ranged between 5.6 and 44.7. The ranges of inorganic nutrients (µg/L) viz., nitrite, phosphate, silicate and ammonia were as 0.34-2.13; 0.55-0.93; 87.75-422.64 and 212-284.7 respectively. The ranges of alkalinity (ppm) and Chlorophyll-a concentration (µg/L) were 89.5-130 and 0.27-0.71 in turn. Significant seasonal variations found between two seasons ($p<0.05$) except for total suspended solids. During the study period total 7 genera of dominant phytoplakton under 3 classes were identified of which 4 genera under Bacillariophyta, 1 genera under Dinophyceae, and 2 genera under Coscinodiscophyceae. Identified dominant genera were *Thalassiothrix, Chaetocerus, Skeletonema, Cyclotella, Cerataulina, Coscinodiscus* and *Ditylum*. The maximum abundance of phytoplankton were 9.6×10^2 cells /L at station 1 (Bashbaria coast) and 13.4×10^2 cells/L at station 2 (Potenga coast) during monsoon. Among the phytoplankton samples, Bacillariophyceae was the most dominant class. The percentage of Bacillariophyta to the total phytoplankton community in two seasons varied between 45% and 47% in station 1 and 49.43% and 36.51% in station 2. Among the identified factors chlorophyll-a, water temperature, nitrite, and ammonia had a positive influence on phytoplankton abundance. Therefore, the findings of this study would be helpful for policymakers in improving management practices for maintaining water quality and conserving the phytoplankton population.

Keywords: Seasonal variation, phytoplankton, coastal water, Chattogram

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Plankton is the living fraction that floats in the sea which is moved inactively by wind or current (Boney, 1975). The suspended particulate matter in the aquatic environment consists of living organisms called plankton and dead particles commonly referred to as detritus. Life in the water column has been broadly classified into three groups, viz., the plankton, the nekton, and the benthos, which are floating, swimming, and creeping organism respectively. Plankton includes all organisms, plants, and animals that are passively 'drifting' along with water movements (Hensen, 1887). Victor Hensen coined the term "plankton" (Greek: wandering or drifting) in 1887. Based on the nutrition the plankton may be divided into plant plankton or phytoplankton and animal plankton or 'Zooplankton'.

Phytoplankton are made up of unicellular (exceptionally: multi-cellular) algae either solitary or colonial (Sournia, 1978). The term phytoplankton is derived from the Greek word "phyton" meaning "plant". Autotrophic plankton that generates glucose by photosynthesis, acting as the primary producers are generally called phytoplankton. It is defined as free-floating unicellular, filamentous, and colonial organisms that grow photo-autotrophically in aquatic environments. They are the base premises of food chains and food webs directly providing food to zooplankton, fishes, and some aquatic animals (Millman *et al*., 2005). They are autotrophs i.e. fix solar energy by photosynthesis, using carbon dioxide, nutrients, and trace metals. All these autotrophs contain photosynthetic pigments such as chlorophylls and carotenoids. Some phytoplankton organisms, fundamentally species of the dinoflagellates, can be temporarily heterotrophic i.e. feeds on build-up organic particulate matter from dissolved organic substances (osmotrophy) or even particulate organic matter (phagotrophy) (Sournia, 1978).

In contrast with numerous organisms, phytoplanktons are moderately homogeneously mixed all throughout the water column. Since these microscopic organisms rely upon light and nutrients, they populate the euphotic zone. It can range in size between 1µm and 500µm. The phytoplankton includes three principal branches viz. diatoms (for

example *Coscinodiscus*), dinoflagellates (e. g. *Noctiluca*), and the nanoplankton or µ-flagellates (for example *Monochrysis*) (Perkins, 1976).

The phytoplankton constitutes 95% of the total marine production (Nielsen *et al*., 1999). So they form the important source of energy at the first trophic level. Temperature is the main factor in regulating the development of phytoplankton (Goldinan, 1977). The main difference between essential production in the ocean and the land is that phytoplankton in the open ocean is eaten almost entirely by zooplankton while on land only around 10% of plant material is eaten by herbivores (Townsend *et al.*, 2000).

Phytoplankton population can vary from season to season. Seasonal variation of phytoplankton growth is complicated due to interaction between ecological factors and rates of regeneration of nutrients and their return to the water column by physico-chemical processes (Finenko and Lansakaya, 1971). Due to light penetration and water transparency, phytoplankton production is higher in winter and pre-monsoon season than in monsoon and post-monsoon season. The phytoplankton community in the estuary is high in March and December-January and lowest during July through October (Islam, 1982). In Bangladesh, the peak abundance of phytoplankton is normally observed during winter and pre-monsoon season (Elias, 1983), when the water transparency range between 66cm to 77.5 cm. Again, the relatively lower phytoplankton abundance observed during the monsoon period when the water transparency range between 17.5 cm and 38 cm (Zafar, 1986).

Phytoplankton is known as the primary producer that contributes about a quarter of global primary production (Longhurst *et al*., 1995; Fehling *et al*., 2012; Amadea *et al*., 2017). They form their vital source of energy at the first trophic level and also serve to contribute to species diversity, distribution, seasonal succession, and decomposition of phytoplankton that are available to various components of the food web. It is highly sensitive to gradient of chemical characteristics in the marine environment (Arvola *et al*., 1999; Rosen, 1981). The physical, chemical, and biological condition of the environment is sensible for the abundance of phytoplankton (Amenda *et al*., 2017). Dissolved oxygen, pH, salinity, temperature, and other factors affect the growth rate of microalgae (Veronica *et al*., 2014).

Nutrients are essential for the survival, reproduction, and growth of phytoplankton, and in an aquatic environment, it serves as bio-indicators. The quantity of nutrients in water

plays a significant role in the distributional patterns and species composition of plankton. Nutrient availability is frequently referred to as a key factor regulating phytoplankton growth, biomass, and species composition (Roelke *et al*., 1999). Therefore, the role of nutrients, especially nitrogen and phosphorus, as limiting factors of phytoplankton is an important aspect for eutrophication mitigation and management (Conley *et al*., 2009).

It is generally accepted that phosphorus is the most important nutrient regulating the primary production (Aldridge *et al*., 1993). Silicate often acts as nutrient that limits diatom growth, thus controlling diatom replacement with dinoflagellate in Si-deficient conditions. This means that silicate can play an important role in changing the phytoplankton community structure. (Tilstone *et al*., 2003). Usually, nitrogen (N) is considered limiting in marine systems (Ryther and Dunstan, 1971) and phosphorus (P) in freshwaters (Schindler, 1977). Besides sufficient light, nutrients are the second necessary condition for the biosynthesis of new phytoplankton cells.

The phytoplankton population represents the biological abundance of a water body establishing an essential connection in the food chain (Boyd, 1982; Hossain *et al*., 2006). They play a central role in the functioning of food webs and ecosystems (Sommer, 1996). It is the primary producer for the entire aquatic body and comprises the major portion in the ecological pyramids. The community of phytoplankton's especially the different species of diatoms is also used as an indicator of water pollution. Through the process of photosynthesis, they are capable of harvesting solar energy and transform into basic substances in the water to multiply and represent food and energy production for various animal species. What's more, a significant bi-product of their photosynthesis is oxygen, which is delivered into the water as another fundamental item for biota in these habitats.

During the calm season, river discharge, and a huge amount of groundwater flow carry nutrient in the ocean that promotes phytoplankton growth. About <1% of autotrophic phytoplankton species are responsible for ~50% of the global annual carbon-fixation in the carbon cycle (Falkowski, 2012). The change of species composition, biomass, community structure, and productivity of phytoplankton can indicate the change in an environment very clearly for their habit of bio-indicator (Babu *et al*., 2013). The quantitative assessment of potential fishing zone can be identified by the abundance of phytoplankton with the best mean (Gouda and parnigrahy, 1996).

Bangladesh is a low-lying, riverine country situated in South Asia with a marshy jungle coastline of 710 km (441 mi) on the northern littoral of the Bengal. The freshwater area involves around 171612 acres of land, the brackish and seawater areas are around 25000 square miles (Raihana, 1984). The Bay of Bengal, the largest triangular bay in the world, located in the northeast from the Indian Ocean (Dube *et al*., 2009; Vinayachandran *et al*., 2004). It is bounded by many territorial countries e.g. west part is bounded by India and Sri Lanka, the north part by Bangladesh, and the east part by Myanmar and the Andaman and Nicobar Islands (Boonyapiwat *et al*., 2008). The large basin is landlocked in the north which creates significant changes in water quality parameters for receiving a large volume of freshwater. Tropical monsoon has an important impact on the basin (Vinayachandran and Mathew, 2003).

The growth rate of phytoplankton is normally affected by the monsoonal cloud cover (Kumar *et al*., 2007). Neighboring rivers or excess precipitation over evaporation are responsible for this freshwater discharge. These freshwater discharges make a unique environment in the Bay of Bengal (Vinayachandran and Mathew, 2003). Human disturbance of coastal ecosystems is extreme and can veil ecological reactions to global climate change. Phytoplankton is a sensitive indicator of long-term climate variability in the open ocean, but apparently not in the nearshore coastal zone where human landscape transformations, fishing, aquaculture, river damming and diversions, introduced species, and contaminants are the dominant causes of biological changes (Cloern and Jassby, 2010). Hence, it is necessary to investigate phytoplankton abundance in the coastal water for detecting the integrated effects of different relevant physico-chemical factors.

1.2 Objectives of the research work:

The present studies have been carried out with following objectives:

a. To observe the seasonal variation of physico-chemical water quality parameters and Phytoplankton abundance in the coastal waters of Chattogram
b. To investigate the relationship between phytoplankton abundance and physico-chemical factors

CHAPTER TWO

REVIEW OF LITERATURE

Although a good number of research works have been conducted on plankton in different parts of the world but in composition with its benthos and nekton, it receives lower attention of the scientists working on coastal waters of Bangladesh. Reviews of some notable works conducted adjacent of Bangladesh have been included here.

In Panama, according to Allen (1939), the dispersion and function of surface diatoms are reliant on different seasons. Yamazi (1972) conducted research on various aspects of phytoplankton, emphasizing qualitative and quantitative estimation along with ecological factors. According to Perkins (1976), phytoplankton includes three principal groups viz. diatoms (e.g. *Coscinodiscus*, *Skeletonema*), dinoflagellates (e. g. *Noctiluca*, *perianium*), and the nanoplankton or µ-flagellates (e.g. *Isochrysis*, *Monochrysis*). Salam (1977) carried out an investigation on the benthic and planktonic algae of the Karnafuli river estuary and recorded 111 species under 57 genera of which Chlorophyta was the dominant group (48.46%) followed by Bacillariophyta (35.24%) and he also studied the occurrence and periodicity of the phytoplankton and benthic algae. Herodek (1977) worked to quantitatively examine phytoplankton in Balaton Lakes and identified phytoplankton.

An investigation was conducted by Nazneen (1980) on the influence of hydrological factors and the seasonal abundance of phytoplankton in Kinjhir Lake, Pakistan which shows the influence of different Physico-chemical parameters on pond fertility such as temperature, pH, O2, NO2, etc. on phytoplankton growth abundance as well as lack productivity. Pati (1980) mentioned that the environmental factor influences the seasonal and spatial variation of phytoplankton. Phytoplankton population of the Karnafuli River estuary was inspected by Islam (1982) with emphasis on the seasonal fluctuations of different physico-chemical parameters and phytoplankton populations and announced 107 types of phytoplankton and mentioned the highest production to be in March and December-January and lowest during July through October.

Rahman (1997) identified 25 species of phytoplankton under 22 genera from the Naf river of which Bacillariophyta was the dominant group (64%) pursued by the Chlorophyta (20%). Micronutrient and standing yield of phytoplankton in the coastal waters of Cox's Bazar was analyzed by Chowdhury (1999). 44 genera of phytoplankton

was identified from the Matamuhuri River during the investigation of Zafar (2000). Sharif (2002) made an investigation on quantitative dissemination of plankton and benthos at 5 unique stations of the Meghna river estuary during monsoon and 21 genera of phytoplankton were identified during post-monsoon. Saeedullah (2003) found 23 genera of Bacillariophyta, 90 genera of Chlorophyta, 30 genera of Cyanophyta showing the seasonal variation of phytoplankton at 5 unique stations of the Meghna river estuary with some biodiversity indices and correlation.

An ecological research was conducted on essential productivity, phytoplankton standing crops, and diversity of the river Padma at Mawaghat, Munshigong by Ahmed *et al*. (2004). Chowdhury (2005) investigated biodiversity in the Karnafuli River by examining the occurrences, abundance, and distribution of phytoplankton. Taimur (2006) studied on Abundance and Distribution of Phytoplankton in the vicinity of St. Martin's Island during Monsoon and Post-monsoon. Mamun *et al*. (2009) performed an investigation on the abundance and distribution of plankton in the Sundarbans mangrove forest and recorded a total of 15 genera of phytoplankton. The number of genera under the class Chlorophyceae, Myxophyceae, and Bacillriophyceae were identified at 5, 7, and 3 respectively. *Cosciodiscus sp*. and *Microcystis sp*. were the most dominant genera in the phytoplankton community. The study revealed the average phytoplankton abundance was 2510, 1786, and 2550 individuals /L in summer, monsoon, and winter respectively. Among the three classes of phytoplankton Myxophyceae (54 %) is the most dominant in summer in the Sundarbans mangrove forest. The abundance of Myxophyceae was 58% and 55% in monsoon and winter respectively.

A total of 134 phytoplankton species dominated by diatoms was identified by Rahman *et al*. (2013). 99 species from 41 genera of Bacillariophyta, 18 species from 6 genera of Pyrophyta, 12 species from 9 genera of Chlorophyta, 4 species from 4 genera of Cyanobacteria, and 1 Species of Ochrophyta were identified from three major river systems of the Sundarban. A total of 97 species were enumerated in Rupsha-Pashur while 122 and 110 in Khalpatua-Arpangachia and Bhola-Baleswar river framework individually. Abundance was the lowest in monsoon and the highest in summer in Bhola-Baleswar. Species composition was dominated by Bacillariophyta over the area except in summer in Bhola-Baleswar, where Cyanophyta become dominated. diversity, richness and evenness index varied between 2.03-4.64, 1.2-2.44, 0.77-1.5 in Rupsha-

Pashur; 2.47-3.85, 1.8-5.84, 0.78-0.94 in Khalpatua-Arpangachia and 0.66-4.27, 1.19-5.12, 0.59-1.29 in Bhola-Baleswar. Nutrient components for example NO_3^{-}, PO_4^{3-}, NH_4^{+}, and SiO_4^{4-} fluctuated seasonally from 0.0062 to 1.633 mgL-1, 0.005 to 0.772 mgL-1, 0.038 to 2.467 mgL-1, 3.124 to 27.234 mgL-1, separately. Chlorophyll-a concentrations fluctuated seasonally within 0.24 to 5.94 µgL-1 and the highest phytoplankton biomass was seen in Bhola-Baleswar in summer.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area:

Specific and sensible ecosystems, including the coastal and maritime environment will be considered in selecting the research stations. In this study, the water samples were collected from the coastal waters of Chattogram (northern part of the Bay of Bengal) covering two areas namely Basbharia coast, Sitakunda (Area A: St1, latitude 22°33'14" N, longitude 91°38'21" E); Patenga coast, Chattogram (Area B: St2, latitude 22°13'3" N, longitude 91°47'11" E) (Fig. 1). Those two locations were selected according to geo-morphological characteristics on the basis of phytoplankton abundance, easy to transport, boat availability and other environmental condition. This research selected two (02) stations (St) randomly along the coastal water to conduct this research which were approximately 2-5 km far towards the open sea from the nearby coastline.

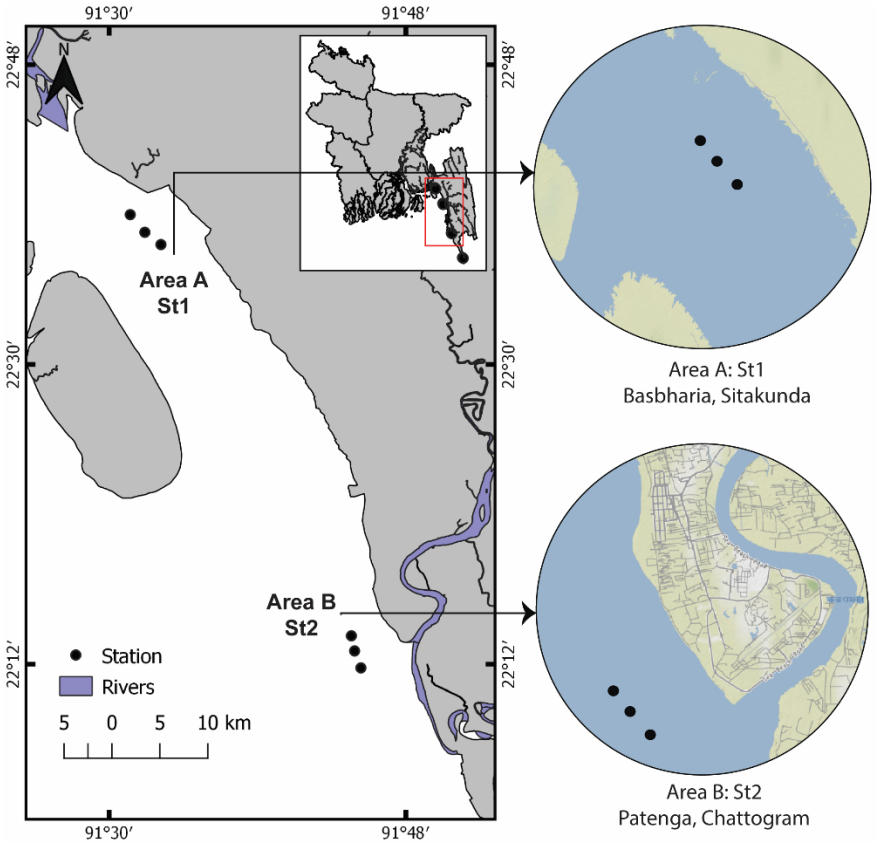

Figure 1: Location of the study area; Area A: Basbharia coast (station 1) and Area B: Patenga coast (station 2)

3.2 Sampling design:

Samples were collected for 2 representative seasons e.g. monsoon (June-August, 2019) and winter (December-January, 2020). Surface water samples collected during high tide condition for measuring water temperature, salinity, pH, alkalinity, electro-conductivity (EC), total dissolved solids (TDS), total suspended solid (TSS), chlorophyll-a, dissolved nutrients as nitrite, phosphate, silicate, and ammonia. Sub-surface water collected from two stations for measuring phytoplankton composition using a phytoplankton net (45 μm).

3.2.1 Analysis of physico-chemical water quality parameters:

The variation of temperature, salinity, pH, alkalinity, total dissolved solids (TDS), total suspended solid (TSS), chlorophyll-a, dissolved nutrients such as nitrite, phosphate, silicate, and ammonia were measured following standard methods (APHA, 2005).

In situ data collection: Water quality parameters as temperature (Celsius Thermometer), pH (Portable pH meter), salinity (Refractometer), electro-conductivity and TDS (Digital EC meter) were monitored in-situ during high tide condition on seasonal basis.

A) Temperature (ºC):

Water temperature was measured by using standard mercury-filled centigrade thermometer having a range from 0ºC to 100ºC (Prabu *et al*., 2008).

B) p^H:

Water pH value was determined by using a digital pen pH meter (HANNA Instruments, model HI 98107). Water pH meter was calibrated before every measurement.

C) Electro-conductivity (EC):

Electro-conductivity was determined by using calibrated digital Electro-conductivity meter (HANNA Instruments, model EC 98107).

D) Total dissolved solids (TDS):

The water TDS can be known by calibrated EC meter (HANNA Instruments).

E) Salinity (psu):

Salinity was determined by using calibrated Hand-Held Refractometer (ATAGO, S/Mill, Salinity 0-100psu, Japan).

Laboratory analysis:

Water samples were collected from each station and were taken to the laboratory as soon as possible for the alkalinity (Titrimetric method), TSS, chlorophyll-a, and nutrient (nitrite, phosphate, silicate, ammonia) analysis in the laboratory. Water samples were filtered through microfiber filter paper (Whatman GF/C) using a vacuum pressure air pump (Rocket filtration pump). The filtered water was used for alkalinity and nutrient analysis. The filter paper was taken for chlorophyll-a determination.

A) Total suspended solids (TSS):

Total suspended solids were measured by applying filtration procedure followed standard methods (APHA, 1985). For determination of total suspended solids (TSS) water samples were filtered through glass fiber filters which were dried at 105°C (>1 hr.) and weighted to obtain the quantity of suspended solids. At first filter paper was dried in the oven and placed into desiccator (at least 30 min at both stages). Then oven dried filter paper was weighted. 50 ml water sample was taken and filtered by using filter paper. After filtration filter paper was dried in oven at 104ºc and placed at desiccator. Then the weight of filter paper was measured with solid remaining and calculated the TSS in water sample

Calculation:

$$\text{TSS} = \frac{B-A}{50} \times 1000$$

Where,

A= Weight of the oven dried filter paper.

B = Weight of the filter paper with reaming solid.

B) Nitrite:

Nitrite was determined following the methods described by Bendschneider and Robinson (1952). 50 ml water sample was filtered by Whatman filter paper (0.1µm). Then 50 ml filtered sample were taken in a conical flask. 1 ml sulphanilamide added and mixed and allowed to react for 2-8 min. Then 1ml N-(-1-Napthal)-ethylene diaminedihydrochloride (NNED) was added and mixed and measured the extinction by Spectrophotometer (Model: Osk-15745) after 10 minutes but before 2hrs at 543 nm.

Calculation:

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

C) Phosphate:

Phosphate was determined following the methods described by Murphy and Riley (1961). 50 ml water sample was filtered by Whatman filter paper (0.1µm). Then 50 ml filtered sample were taken in a conical flask. 2 ml acid ammonium molybdate was added and mixed. Then 5 drops of stannous chloride was added. At last the absence of developed color measured by Spectrophotometer (Model: Osk-15745) at 690 nm.

Calculation:

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

D) Silicate:

Silicate was determined following the methods described by Mullin and Riley (1955). 50 ml water sample was filtered by Whatman filter paper (0.1µm). Then 50 ml filtered water sample were taken in a conical flask. 2 ml of 10% acid ammonium molybodate was added and mixed. Then 0.5 ml of 25% Sulphuric Acid was added. At last the absence of developed color was measured by Spectrophotometer (Model: Osk-15745) at 460 nm.

Calculation:

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

E) Ammonia: Ammonia was determined chemically analytical method. For the determination of Ammonia, the program 324 set in the photometer (pHoto Flex; WTWE, Germany) and zero adjustment was done using distilled water. The pH value of the sample was also checked whereas, the desired value; approx. pH 7. VARIO AMMONIA salicylate F10 powder pack and VARIO AMMONIA Cyanurate F10 powder pack needed to measure the ammonia in water sample. At first 10 ml of filtrate sample water was taken in empty cell using pipette. The contents of VARIO AMMONIA Salicylate F10 powder packs were added and the cell was closed with screw cap. Then the cell was shaken and allowed to react for 3 minutes. After that the content of VARIO AMMONIA Cyanurate F10 powder pack also added and the cell closed with screw cap. Then the cell was shaken and allowed to react for another 15

minutes. Then the cell inserted in the photometer and the photometric reading recorded afterwards.

F) Alkalinity:

For alkalinity measurement, 100 ml of filtrate sample water was taken into a conical flask. Then 2-4 drops of phenolphthalein indicator were added in the sample. As the color of the sample didn't change, it indicated that phenolphthalein alkalinity was absent. After that fresh 100 ml water sample was taken into another flask and 2-4 drops of Methyl Orange indicator were added in the sample. The color turned into yellow. Then the sample was titrated against standard H_2SO_4 (0.02N). Titration was continued until the yellow color turned into pink. The required amount of acid (H_2SO_4) was recorded and the result was calculated by the following formula (Boyd, 2015):

$$\text{Alkalinity} = \frac{\text{Acid used(ml)} * 0.02\text{N}\left(\begin{matrix}\text{Normality} \\ \text{of acid}\end{matrix}\right) * 50\left(\begin{matrix}\text{Gram Equvalent} \\ \text{weight of CaCO3}\end{matrix}\right) * 1000}{\text{Sample Volume (V)}}$$

G) Chlorophyll-a measurement:

A total 500 ml water samples were filtered through membrane filter (0.45µm) with the help of a vacuum pump. The filtered membranes were taken into 10 ml of 90% acetone and kept overnight. The filtered papers were mixed thoroughly with acetone using glass rod. Then centrifugation at 3500 RPM for 2.30 minutes was performed. The supernatant contents (exact) were taken into corvettes and the absorbance of extract was determined at 664, 647 and 630 nm comparing with blank acetone. The chlorophyll-a concentration was calculated by following equation (Talling and Driver, 1963):

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

Where,

A_{664} = Absorbance at 664 nm

A_{647} = Absorbance at 647 nm

A_{630} = Absorbance at 630 nm

V = Volume of acetone used (ml)

S = Volume of sample filter (ml)

3.2.2 Qualitative and quantitative estimations of plankton:

Plankton sample were collected by towing phytoplankton net of 45 μm mesh. The concentration sample preserved in small plastic bottles with 5% buffered formalin. Qualitative and quantitative estimations of plankton were done by using a Sedgewick-Rafter Cell containing 1000 $1mm^3$ cells. A 1 ml sample was taken in the S-R cell and left for 15 minutes undistributed to allow plankton settle. The plankton in 10 randomly selected cells were identified and counted under a binocular microscope with imaging facilities. The planktons were also observed under microscope to study the major plankton classes (APHA, 1985). For quantitative estimation number of phytoplankton species in 10 cells of S-R cell was calculated and made an average.

Plankton abundance was calculated by using Stirling (1985) formula:

N = (P*C*100)/L

Where,

N = Number of plankton cells or units per liter of original water (counted by using Sedgewick-Rafter cell)
P = The number of plankton counted in 10 fields
C = The volume of final concentration of the sample (ml)
L = The volume (L) of water sample

3.2.3 Identification procedure:

Identification was done by following the works of Davis (1955); Yamazi (1952, 1972, 1974); Newell and Newell (1979); Subramanyan (1946); Islam and Aziz (1977); Islam and Aziz (1980); Haque (1983); Rahman (1997); Rahaman et al. (2013); Noori (1999); Islam (2001); Zafar (2000); Sharif (2002) and Saeedullah (2003).

CHAPTER FOUR

RESULTS

4.1 Physico-chemical water quality parameters:

Water quality comprising temperature, salinity, conductivity, TDS, and TSS were measured during the investigation of each site. The ranges of the values of water quality parameters and nutrient substances are as following-

4.1.1 Temperature:

Surface water temperature was recorded from 25.4°C- 32.2°C from the studied area. The maximum temperature observed (30.5°C at St1 and 32.2°C at St2) during monsoon and minimum reported (25.4°C at St1 and 26.3°C at St2) during winter. Temperature was decreased from monsoon towards winter gradually (Fig. 2). Two-way ANOVA results showed that variations in water temperature among stations and seasons were significant ($p<0.05$) (Table 1).

4.1.2 pH:

The pH value of all samples of surface water was investigated in the range between 6.7-7.6. The value of pH was found lower (6.9 at St1 and 6.7 at St2) during monsoon and higher (7.6 at St1 and 7.2 at St2) value recorded in winter. pH was increased from monsoon towards winter gradually (Fig. 2). Two-way ANOVA results showed that pH variations among the stations and seasons were significant ($p<0.05$) (Table 1).

4.1.3 Salinity:

Surface water salinity was found to vary from 3.7-21.3 psu during this investigation period. The value of peak salinity was recorded as 21.3 psu at St2, following by 16.5 psu at St1 during winter. On the other hand, lower salinity concentration reported during monsoon period as 3.7 psu at St2, followed by 10.2 psu at St1. Salinity was increased gradually at St1 and sharply at St2 from monsoon towards winter (Fig. 2). Two-way ANOVA results showed that variations in salinity among the stations and seasons were significant ($p<0.05$) (Table 1).

4.1.4 Total dissolved solids (TDS):

In this investigation, the level of TDS in surface water was found to vary from 2.82-22.3 g/L. The value of TDS was minimum (11.14 g/L at St1 and 2.82 g/L at St2) in monsoon and maximum level investigated during (17.17 g/L at St1 and 22.3 g/L at St2) winter. The value of TDS was increased gradually at St1 coast and sharply at St2 coast from monsoon towards winter (Fig. 2). Two-way ANOVA results showed that variations in the value of TDS among the stations and seasons were significant ($p<0.05$) (Table 1).

4.1.5 Total suspended solids (TSS):

The level of TSS in surface water was found to vary from 0.55-0.94 g/L. The value of TSS was minimum (0.68 g/L at St1 and 0.55 g/L at St2) in monsoon and maximum level investigated during (0.93 g/L at St1 and 0.94 g/L at St2) winter. TSS was increased from monsoon towards winter gradually (Fig. 2). Two-way ANOVA results showed that variations in the value of TSS among the stations and seasons were not significant ($p>0.05$) (Table 1).

4.1.6 Electro-conductivity (EC):

The value of EC of all samples of surface water was investigated in the range between 5.6-44.7 mS/cm. The EC value was found lower (22.4 mS/cm at St1 and 5.6 mS/cm at St2) during monsoon and higher (34.2 mS/cm at St1 and 44.7 mS/cm at St2) value recorded in winter. The value of EC was increased gradually at St1 coast and sharply at St2 from monsoon towards winter (Fig. 2). Two-way ANOVA results showed that variations in EC among the stations and seasons were significant ($p<0.05$) (Table 1).

4.1.7 Alkalinity:

The observed value of alkalinity in surface water was fluctuated from 89.5-130 ppm. The value of alkalinity reached minimum (94 ppm at St1 and ppm at 89.5 ppm at St2) during monsoon and maximum (130 ppm at St1 and 122 ppm at St2) during winter. Alkalinity was increased from monsoon towards winter gradually (Fig. 2). Two-way ANOVA results showed that variations in alkalinity among the stations and seasons were significant ($p<0.05$) (Table 1).

4.1.8 Ammonia:

Ammonia concentration in surface water was found to vary from 212-284.7 μg/L. Higher concentration was recorded (258 μg/L at St1 and 284.7 at St2) during Monsoon whereas lower concentration was found (212 μg/L at St1 and 227.3μg/L at St2) in winter. The value of ammonia was decreased from monsoon towards winter gradually (Fig. 2). Two-way ANOVA results showed that variations in the value of ammonia among the stations and seasons were significant ($p<0.05$) (Table 1).

4.1.9 Nitrite:

The observed concentration of nitrite in surface water was found to vary from 0.34-2.13 μg/L during the investigation period. Higher concentration was recorded (2.13 μg/L at St1 and 2.02 μg/L at St2) during Monsoon and lower (0.34 μg/L at St1 and 0.56 μg/L at St2) during winter. The value of nitrite concentration was decreased from monsoon towards winter slowly (Fig. 2). Two-way ANOVA results showed that variations of nitrite concentration between 2 stations were not significant ($p>0.05$) but variations between 2 seasons were significant ($p<0.05$) (Table 1).

4.1.10 Phosphate:

The recorded concentration of phosphate in surface water was ranged between 0.55-0.93 μg/L during this investigation period. Phosphate concentration obtained lower (0.73 μg/L at St1 and 0.55 μg/L at St2) during Monsoon and higher (0.93 μg/L at St1 and 0.72 μg/L at St2) during winter. The value of phosphate was increased from monsoon towards winter slowly (Fig. 2). Two-way ANOVA results showed that variations in the value of phosphate among the stations and seasons were significant ($p<0.05$) (Table 1).

4.1.11 Silicate:

The silicate content was higher than that of the other nutrients. The observed silicate concentration in surface water was ranged 87.75-422.64 μg/L. Silicate concentration reached higher (422.64 μg/L at St1 and 148.64 μg/L at St2) during monsoon and lower (166.55 μg/L at St1 and 87.75 μg/L at St2) during winter. The value of silicate concentration was decreased from monsoon towards winter gradually (Fig. 2). Two-way ANOVA results showed that variations in the value of silicate among the stations and seasons were significant ($p<0.05$) (Table 1).

4.2 Determination of coastal productivity

4.2.1 Chlorophyll-a:

The concentration of chlorophyll-a (Chl-a) content in the surface water was found to vary from 0.27-0.71 µg/L. The value of Chl-a concentration was higher (0.29 µg/L at St1 and 0.71 µg/L at St2) during Monsoon and lower (0.27 µg/L at St1 and 0.59 µg/L at St2) during winter (Fig. 2). The value of chlorophyll-a was decreased from monsoon towards winter slowly. Two-way ANOVA results showed that variations in the value of chl-a among the stations and seasons were significant ($p<0.05$) (Table 1).

Table 1: Significance of physico-chemical factors with station and season

Factors	Station	Season
Water temperature	0.00**	0.00**
pH	0.00**	0.00**
Salinity	0.02*	0.00**
TDS	0.00**	0.00**
TSS	0.78	0.16
EC	0.00**	0.00**
Alkalinity	0.00**	0.00**
Ammonia	0.00**	0.00**
Nitrite	0.20	0.00**
Phosphate	0.04*	0.04*
Silicate	0.00**	0.00**
Chlorophyll-a	0.00**	0.004**

(*) is significant at the level of 5%, (**) is significant at the level of 1%

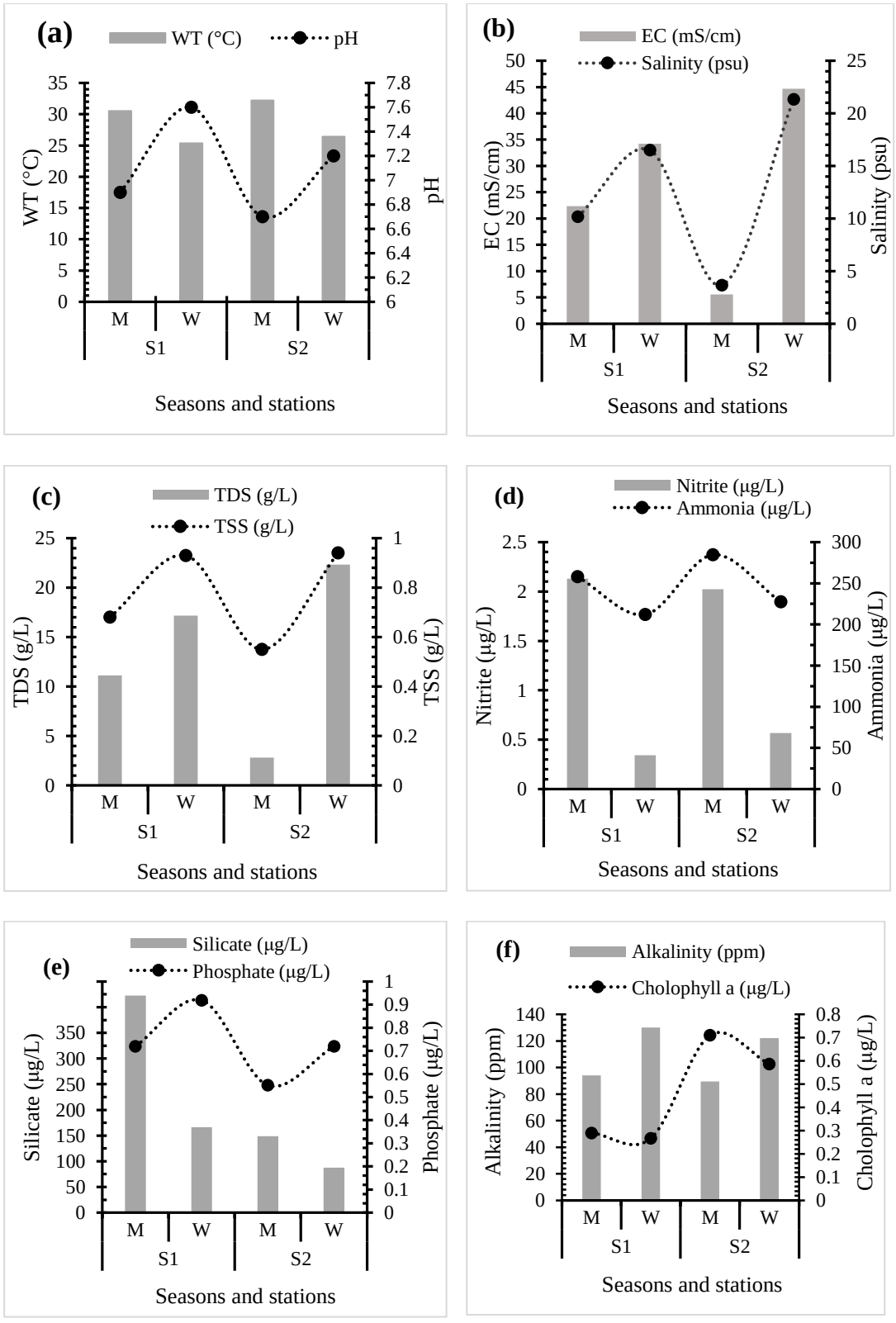

Figure 2: Seasonal variation of physico-chemical water quality parameters a) Water temperature (WT) and pH, b) Salinity and EC content, c) TDS and TSS content, d) Nitrite and ammonia concentration, e) Silicate and phosphate concentration, f) Alkalinity and chlorophyll-a concentration of the study area (S1= Bashbaria, S2=Patenga) during monsoon (M) and winter (W).

4.3 Cluster analysis:

Amalgamation steps of cluster analysis (CA) were performed using centroid clusturing with Euclidean distance. Firstly CA was applied among the physico-chemical water quality parameters, which brought out 3 significant clusters as cluster 1 includes TSS, phosphate, chlorophyll-a, nitrite, pH, salinity, TDS, water temperature, EC; cluster 2 includes salinity; cluster 3 includes silicate, Ammonia (Fig. 3). Parameters are clustered in minimum distance have a high affinity with same identical behavior during seasonal changes and also have a potential influence to each other.

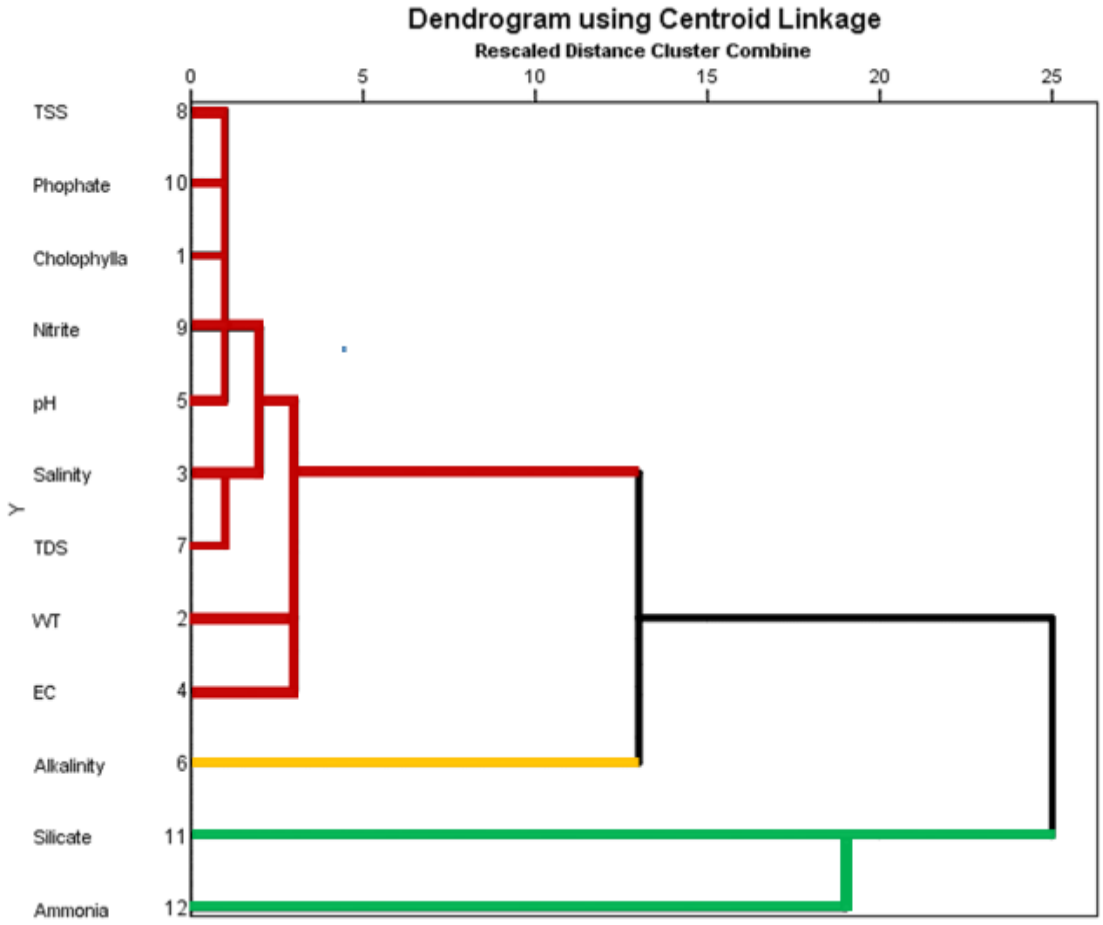

Figure 3: Dendrogram of physico-chemical water quality parameters (Three colors are representing three clusters; cluster 1: Red, cluster 2: Yellow and cluster 3: Green)

4.4 Correlation of physico-chemical water quality parameters:

The correlation (Pearson) among different physico-chemical water quality parameters were appeared in table 2. Nitrite and ammonia were strongly correlated with water temperature. EC, pH, alkalinity, and TDS were strongly correlated with salinity. Again

pH, alkalinity, and TDS were strongly correlated with EC. Alkalinity was also strongly co-related with TDS. In addition, alkalinity, TDS, and phosphate were strongly correlated with pH. Nitrite and Phosphate were also strongly correlated with one another. On the other hand, Chlorophyll-a was moderately correlated with water temperature and ammonia. TSS was also moderately correlated with salinity, EC, pH, alkalinity, and TDS. Phosphate was also moderately correlated with salinity, EC, alkalinity, TDS. Nitrite and silicate were moderately correlated with one another. Weakly correlated groups were nitrite-chlorophyll-a, phosphate-TDS, silicate-phosphate, and ammonia-silicate. Some parameters were also inversely correlated with others.

Table 2: Correlation of physico-chemical water quality parameters

Parameters	Chl-a	WT	Salinity	EC	pH	Alkalinity	TDS	TSS	NO_2-N	PO_4-P	SiO_3-Si	NH_3-N
Chl-a	1											
WT	.42	1										
Salinity	-.29	-.91**	1									
EC	-.33	-.90**	.99**	1								
pH	-.58*	-.94**	.75**	.75**	1							
Alkalinity	-.35	-.99**	.88**	.86**	.94**	1						
TDS	-.33	-.90**	.99**	1.0**	.75**	.86**	1					
TSS	-.14	-.48	.49	.48	.44	.47	.48	1				
NO_2-N	.21	.97**	-.85**	-.83*	-.89**	-.98**	-.83**	-.48	1			
PO_4-P	-.64*	-.65*	.51	.52	.74	.65*	.52	.38	-.54	1		
SiO_3-Si	-.59	.41	-.35	-.28	-.25	-.48	-.28	-.18	.62**	.11	1	
NH_4^+	.54	.98	-.89**	-.89**	-.94**	-.96**	-.89**	-.51	.914**	-.700*	.270	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4.5 Principal component analysis:

Principal component analysis (PCA) was performed to established possible factor that contributes towards the water quality parameters or their concentration and source apportionment. The number of significant principal component (PC) was selected on the basis of Varimax rotation with Kaiser Normalization with eigenvalue greater than 1. The rotated component matrix for water quality parameters is given in Table 3.

PCA of the water quality parameters developed 2 principle components (PC) as seen from the Eigen values.

Table 3: Rotated component matrix for water quality parameters

Parameters	**Component**	
	1	**2**
Cholophyll-a	-.305	-.918
WT	-.987	-.107
Salinity	.940	.029
EC	.925	.079
pH	.891	.304
Alkalinity	.981	.044
TDS	.927	.078
TSS	.551	.031
Nitrite	-.972	.122
Phophate	.607	.587
Silicate	-.479	.824
Ammonia	-.960	-.247
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. a. Rotation converged in 3 iterations.		

PC 1 were accounted for 69.486% of the total variance within positive factor loading of salinity, EC, pH, alkalinity, TDS, TSS, phosphate and negative factor loading of cholophyll-a, WT, nitrite, silicate, ammonia. Total variance are highly dominated by salinity, EC, pH, alkalinity, TDS, TSS, phosphate (Fig. 4).

PC 2 were accounted for 15.935% of the total variance within positive factor loading of all the parameters except cholophyll-a, WT, ammonia and total variance highly dominated by phosphate, silicate (Fig. 4).

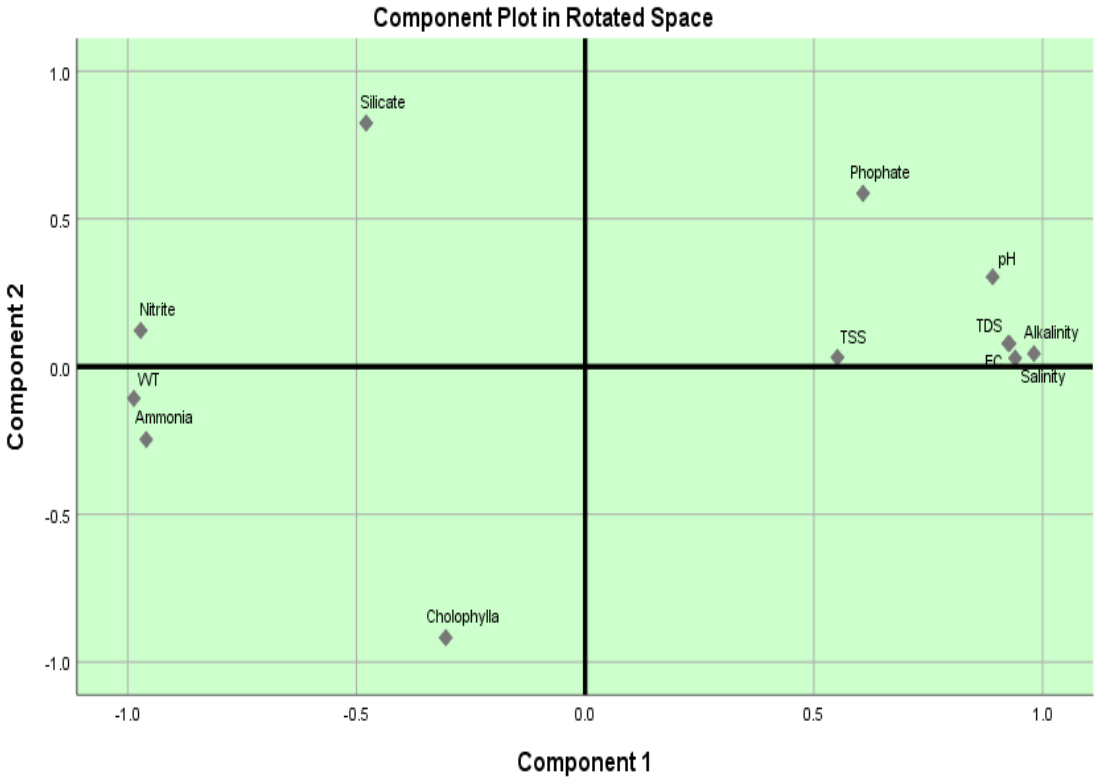

Figure 4: Component plot in rotated space for water quality parameters (Factor loadings, factor 1 vs. factor 2 Rotation: varimax normalized, extraction: principal components)

4.6 Phytoplankton composition:

Average concentration of phytoplankton at St1 during monsoon and winter were 9.6×10^2 cells/L and 8.2×10^2 cells/L respectively, at St2 the concentration of phytoplankton during monsoon and winter were 13.4×10^2 and 10.6×10^2 cells/L in turn. The observed three major classes of phytoplankton species were Bacillariophyceae, Dinophyceae, and Coscinodiscophyceae. Bacillariophyceae was the most dominant class at both stations. The contribution of Bacillariophyceae of the total phytoplankton community at St1 during monsoon and winter were 45% and 47% correspondingly followed by Dinophyceae 26.66%, and 20% in turn and Coscinodiscophyceae 16.67%, and 26% correspondingly (Fig. 5). At St2 the contributions of Bacillariophyceae, Dinophyceae, and Coscinodiscophyceae of the total phytoplankton community during monsoon and winter were 49.43%, and 36.51% respectively; 22.99%, and 26.99% in turn; 26.44%, and 36.51% correspondingly. One-

way ANOVA results showed that variations in the contribution of Bacillariophyceae and Dinophyceae between the seasons were not significant ($p>0.05$) and variations in the contribution of coscinodiscophyceae between 2 seasons were significant at the level of 5% ($p<0.05$) (Table 4).

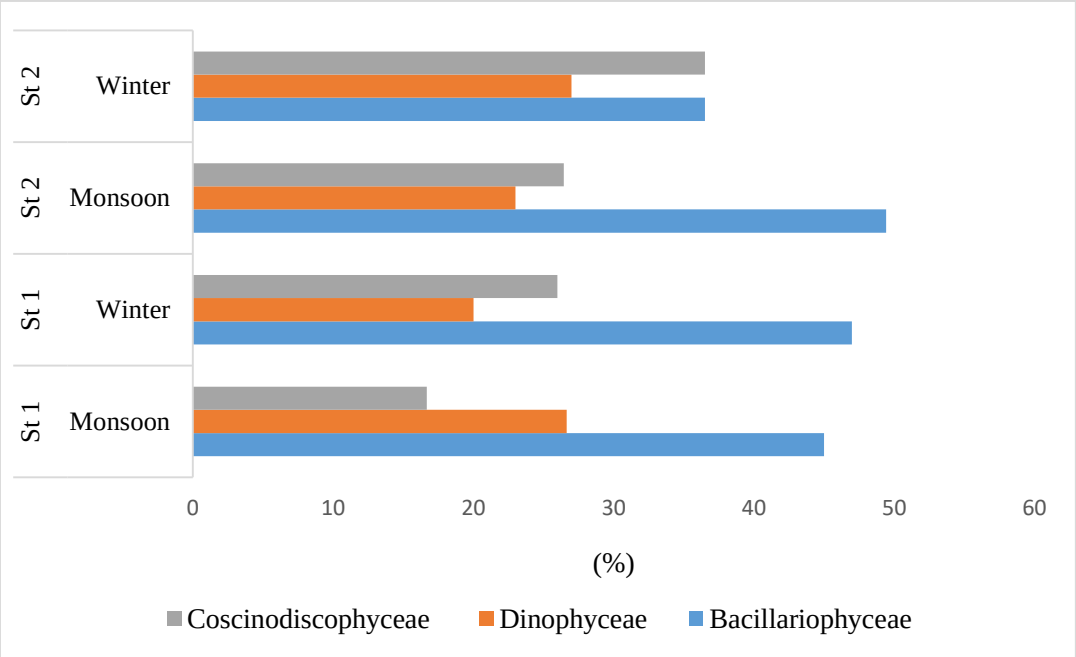

Figure 5: Seasonal variation of the contributions (%) of recorded phytoplankton classes at St1 (Bashbaria) and St2 (Patenga)

4.6.1 Bacillariophyceae:

During this research Bacillariophyceae dominated the plankton community with 4 genera. The most dominated genera of Bacillariophyceae including *Thalassiothrix, Chaetocerus, Skeletonema,* and *Cyclotella*. The contributions of *Thalassiothrix, Chaetocerus, Skeletonema,* and *Cyclotella* in St1 during monsoon were 25.93%, 25.93%, 11.11%, and 25.93% in turn and throughout the winter 42.55%, 12.77%, 29.79%, and 14.89% respectively of the total count of Bacillariophyceae. On the other hand, St2 contributed as 23.25%, 30.23%, 16.28%, and 30.23% respectively during monsoon and 30.43%, 13.04%, 13.04% and 30.43% respectively during winter of the total count of Bacillariophyceae (Fig. 6). One-way ANOVA results showed significant variations in the contribution of *Thalassiothrix and Chaetocerus* between seasons ($p<0.05$) (Table 4).

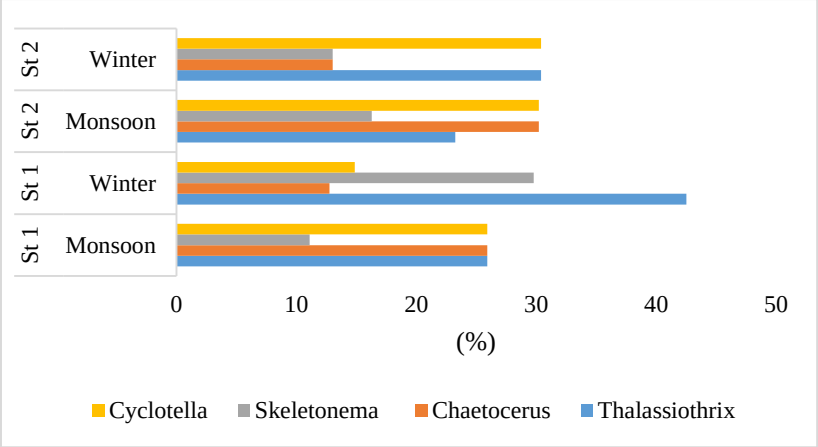

Figure 6: Seasonal variation of the contributions (%) of recorded phytoplankton genera of the total count of Bacillariophyceae at St1 (Bashbaria) and St2 (Patenga)

4.6.2 Dinophyceae:

The class Dinophyceae dominated the plankton community with single genus. The most dominated genus of Dinophyceae was *Cerataulina*. The contribution of *Cerataulina* in St1 during monsoon was 81.25% and during winter 72.59% and in St2 the contribution during monsoon was 78.33%, followed by 77.25% of the total count of Dinophyceae in winter period (Fig. 7). One-way ANOVA test showed that variations in the contribution of *Cerataulina* between the seasons were significant at the level of 5% (Table 6).

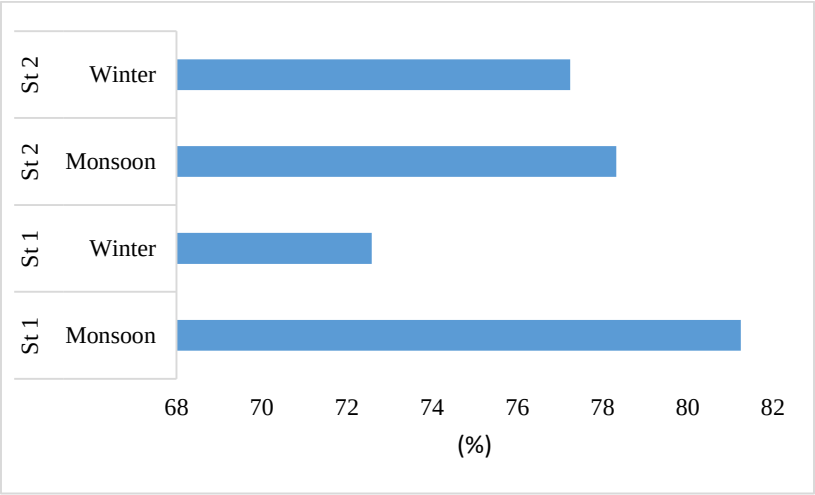

Figure 7: Seasonal variation of the composition (%) of recorded phytoplankton genus of the total count of Dinophyceae at St1 (Bashbaria) and St2 (Patenga)

4.6.3 Coscinodiscophyceae:

The class Coscinodiscophyceae dominated the plankton community with 2 genera. The most dominated genera of Coscinodiscophyceae were *Coscinodiscus* and *Ditylum*. The contributions of *Coscinodiscus* and *Ditylum* in St1 during monsoon were 70% and 30% in turn and 76.92% and 23.07% correspondingly during winter of the total count of Coscinodiscophyceae. In contrast, St2 contributed *Coscinodiscus* and *Ditylum* as 73.91% and 26.09% respectively during monsoon and 43.47% and 56.52% respectively of the total count of Coscinodiscophyceae during winter (Fig. 8).

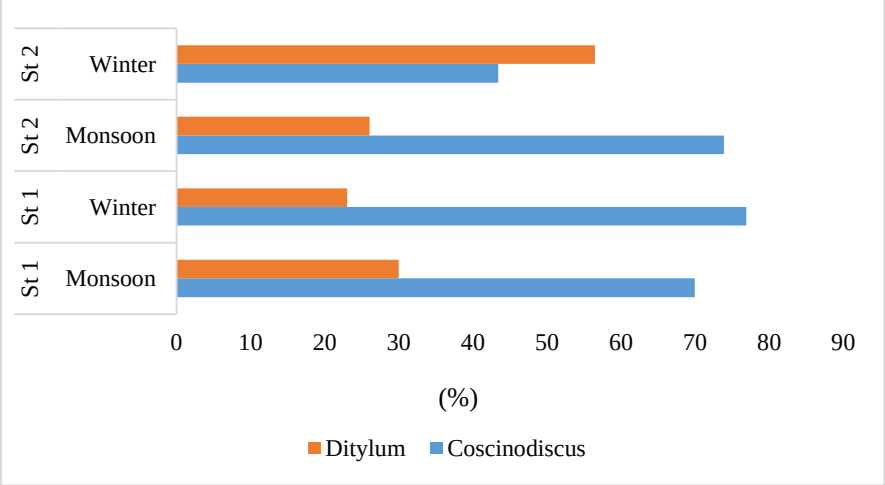

Figure 8: Seasonal variation of the contributions (%) of recorded phytoplankton genera of the total count of Coscinodiscophyceae at St1 (Bashbaria) and St2 (Patenga)

Table 4: Significance of phytoplankton abundance with season

Factors	**Sig.**
Bacillariophyceae (%)	.058
Dinophyceae(%)	.469
Coscinodiscophyceae (%)	.013*
Thalassiothrix(%)	.002**
Chaetocerus(%)	.000**
Skeletonema (%)	.077
Cyclotella(%)	.164
Cerataulina((%)	.003**
Coscinodiscus(%)	.149
Ditylum(%)	.150

(*) is significant at the level of 5%, (**) is significant at the level of 1%

4.7 Relationship with phytoplankton composition and water quality parameters:

Spearman rank correlations indicating significant correlation between environmental factor and phytoplankton assemblages. Phytoplankton abundance were positively correlated with chlorophyll-a, WT, nitrite, ammonia and inversely correlated with others. Among the identified factor chlorophyll-a, WT, ammonia were strongly correlated with the phytoplankton abundance (Table 5).

Table 5: Correlation of Phytoplankton composition with physico-chemical water quality parameters

	Chl-a	**WT**	**Salinity**	**EC**	**pH**	**Alkalinity**	**TDS**	**TSS**
Phytoplankton (cells/L)	.96**	.78**	-.39	-.39	-.78**	-.78**	-.39	-.19

	Nitrite	**Phosphate**	**Silicate**	**Ammonia**
Phytoplankton (cells/L)	.39	-.69**	-.35	.78**

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

CHAPTER FIVE

DISCUSSION

The northeastern part of the Bay of Bengal have many characteristics of the Indian ocean which is characterized by variation in phytoplankton distribution and abundance, shallow oceanic arm, sedimentation process, freshwater influx, surface waters with plenty of oxygen level, and plenty of fisheries resources (Hossain *et al*., 2014). These diverse characteristics were mostly influenced by the seasonal changes in water quality parameters. It is of paramount importance to study the hydro-chemical parameters to distinguish the difference in phytoplankton diversity on a seasonal scale in marine ecosystem (Chang, 2008).

5.1 Water quality parameters:

The water temperature is one of the important physical factors, which affects the chemical and biological reactions in water. It regulates the rate of photosynthesis in aquatic ecosystem. The temperature variation is one of the factors which may influence the physico-chemical characteristics (Soundarapandian *et al*., 2009). In the present study, water temperature significantly varied among seasons which was ranged from 30.5-25.4°C at St1 and 32.2-26.3°C at St2. Seasonal variations in temperature may attribute with wind force, influx of freshwater and atmospheric temperature. The findings of the present study also agreed with earlier reported works in Bangladesh coastal area conducted by Das (2002) who reported temperature variation between 25-30ºC with a marked seasonal fluctuations. Temperature values were significantly higher in the monsoon months while lower recorded in winter due to local climate condition which is mainly influenced by the south eastern and north western wind pattern prevailing in the Bay of Bengal coast (Holmgren, 1994). A similar trend was reported in the study conducted by Chowdhury *et al*. (2010). Seasonal variations in temperature may attribute with wind force, influx of freshwater and atmospheric temperature.

Salinity plays a major role as a limiting factor since it controls the faunal and floral diversity of coastal ecosystems (Govindasamy *et al*., 2000; Sridhar *et al*., 2006). The salinity of surface water varies depending on a number of factors such as rainfall, fresh water input, tidal flooding, evapotranspiration, soil type and vegetation (Vernberg, 1993). Higher salinity values during winter could be attributed to the low amount of rainfall, higher rate of evaporation and also due to sea water dominance in the study

area (Sampathkumar and Kannan, 1998; Govindasamy *et al*., 2000). The intrusion of neritic water and high intensity of solar radiation during summer could be the reason for high salinity, and the reduced salinity during monsoon might be due to the freshwater influence and fluctuation in tides (Jyothibabu *et al*., 2008). Similar trend in salinity fluctuations were noticed in the present study. Surface water salinity observed 10.2 psu at St1 and 3.7 psu at St2 in monsoon and 16.5 psu at St1 and 21.3 psu at St2 during the winter period.

The effect of pH on the chemical and biological properties of liquids makes its determination very important. It is one of the most important parameter in water chemistry and measured as intensity of acidity or alkalinity on a scale ranging from 0 to 14. The pH concentration gets changed with time due to the changes in temperature, salinity and biological activity. Most of the natural waters are generally alkaline due to the presence of sufficient quantities of carbonate (Trivedy and Goel, 1984). Changes in pH will depend on the factor like the removal of CO_2 by photosynthesis through bicarbonate degradation, fresh water influx, reduction in salinity and temperature and decomposition of organic matter (Rajasegar *et al*., 2002). The observed pH was lower (6.9 at St1 and 6.7 at St2) in monsoon and higher level of pH reported (7.6 at St1 and 7.2 at St2) in winter. Higher pH in winter be attributed due to increased salinity whereas the lowered pH value in monsoon was due to freshwater influx.

Total dissolved solids (TDS) correlates positively with conductivity, pH and salinity. The lower the pH and salinity, the lower the TDS and EC (Islam *et al*., 2017). Similar trend in salinity fluctuations were noticed in the present study. The value of TDS and EC were observed lower in monsoon likewise pH and salinity. TDS was lower (11.14 g/L at St1 and 2.82 g/L at St2) in monsoon and higher (17.17 g/L at St1 and 22.3 g/L at St2) concentration investigated during winter. In the same trend, EC was lower (22.4 mS/cm at St1 and 5.6 mS/cm at St2) throughout monsoon and higher (34.2 mS/cm at St1 and 44.7 mS/cm at St2) was found in winter. Thus the present investigation evidenced earlier reports on variation in salinity.

Total suspended solids (TSS) is the material in water that affects the transparency or light scattering of the water. TSS can influenced by changes in the level of pH. Changes in pH will cause some of the soluted to precipate of will affect the solubility of the suspended matter (Bilotta *et al*., 1983). The value of TSS recorded lower (0.68 g/L at

St1 and 0.55 g/L at St2) in monsoon and higher (0.93 g/L at St1 and 0.94 g/L at St2) in winter.

Alkalinity correlates positively with pH and salinity. pH values increase with salinity. The higher the pH of the water, the higher the alkalinity and therefore the more lime it contains. (Wong, 1979). Similar trend in alkalinity fluctuations were noticed in the present study. The value of alkalinity observed lower (94 ppm and 89.5 ppm at St1 and St2 respectively) in monsoon and higher concentration reported from (130 ppm at St1 and 122 ppm at St2) winter likewise pH and salinity.

Nutrients are considered as one of the most important parameters in the marine environment influencing growth, reproduction and metabolic activities of living beings. Nutrients such as nitrite, phosphate, and silicate in the coastal environment would exhibit substantial seasonal variations depending on the rainfall, freshwater input, tidal ingress and consumption of nutrients by autotrophs. Nitrate concentration was found higher (2.13 µg/L at St1 and 2.02 µg/L at St2) in monsoon and lower (0.34 µg/L at St1 and 0.56 µg/L at St2) in winter. The higher concentration of nitrite during monsoon could be due to fresh water inflow, terrestrial runoff, and high rate of biological production, oxidation of ammonia, reduction of nitrate and also by biodegradation of planktonic detritus present in the environment (Hutchinson, 1957; Govindasamy *et al*., 2000; Santhanam and Perumal, 2003).

The concentration of phosphate plays a vital role in primary productivity in an aquatic ecosystem as it promotes growth of organisms and limits the phytoplankton production (Cole and Sanford, 1989). The recorded phosphate values were lower (0.73 µg/L at St1 and 0.55 µg/L at St2) during monsoon and higher level found (0.93 µg/L at St1 and 0.72 µg/L at St 2) in winter. The lower concentration of phosphate in monsoon occurred due to adsorptions under aerobic conditions on clay mineral particles which are transported far in the sedimentation process and the utilization of phosphate by phytoplankton (Valiela, 1995; Senthilkumar *et al*., 2002).

The silicate content was investigated higher than that of the other nutrients. The recorded concentration of silicate was peak level (422.64 µg/L at St1 and 148.64 µg/L at St2) in monsoon and minimum level found (166.55 µg/L at St1 and 87.75 µg/L at St2) in winter. The recorded high monsoon values may be due to heavy inflow of monsoonal freshwater derived from land drainage carrying silicate leach out from rocks

(Govindasamy and Kannan, 1996; Rajasegar, 2003). The observed low values in winter could be attributed to uptake of silicates by phytoplankton for their biological activity (Mishra *et al*., 1993; Ramakrishnan *et al*., 1999).

The recorded concentration of ammonia was maximum (258 µg/L at St1 and 284.7 µg/L at St2) during monsoon and lower (212 µg/L at St1 and 227.3 µg/L at St2) throughout the winter. The higher concentration partially influenced by the incursion of terrestrial runoff, death and subsequent decomposition of phytoplankton and also due to the excretion of ammonia by planktonic organisms (Segar and Hariharan, 1989). Decreased ammonia concentration during winter may be attributed to quick utilization of specific phytoplankton community as they prefer ammonia more than nitrate at certain environment (Dugdale *et al*., 2007; Lipschultz, 1995).

Chlorophyll-a, the most principle pigment is responsible for primary production in marine water. The observed value of chlorophyll-a was higher (0.29 µg/L at St1 and 0.71 µg/L at St2) throughout monsoon and lower (0.27 µg/L at St1 and 0.59 µg/L at St2) in winter. The elevated concentration of chlorophyll-a in monsoon might be due to the availability of sufficient amount of UV radiation, pristine water condition, consumption of silicate, nitrite, and phosphate by primary producers, which were brought up by river runoff during monsoon (Sardessai *et al*., 2007; Prabhahar *et al*., 2011).

5.2 Phytoplankton abundance and composition:

The present investigation resulted in 7 genera of dominant phytoplankton were recorded. During the observation period 7 genera under 3 classes were identified of which 4 genera under Bacillariophyta, 1 genera under Dinophyceae, 2 genera under Coscinodiscophyceae. Bacillariophyceae was the most dominant group of phytoplankton throughout the study period. Islam and Aziz (1975, 1980) described 31 genera of Bacillariophyceae, 4 genera of Dinophyceae and 2 genera of Cyanophyceae from the inshore waters of the Bay of Bengal near Moheshkali and Sonadia islands. In different seasons from the offshore waters of the Bay of Bengal 10 genera of Chlorophyceae, 21 genera of Bacillariophyceae, 3 genera of Dinophyceae and 5 genera of Cyanophyceae were recorded (Mahmood *et al*., 2006).

The highest cell of phytoplankton were 9.6×10^2 cells /L at St1 and 13.4×10^2 cells/L at St2 during the monsoon season (Appendix I). Mahmood *et al*. (2006) recorded the

highest phytoplankton count during monsoon due to higher level of nutrients in the southeast coast of Bangladesh. Higher similar phytoplankton growth due to nutrient accumulation during rainy season from September to November in Maputo Bay was observed by Paula *et al*. (1998). It was reported elsewhere that the availability of nutrients in the coastal waters was related to rainfall and connected river discharge (Kitheka *et al*., 1995). It was reported that higher primary productivity in different estuarine and coastal was observed during monsoon season (Bryceson, 1977; Lugomela, 1995; Kitheka *et al*., 1995, Hossain *et al*., 2020). The rain cycle seems to be the main factor controlling the seasonality of plankton assemblages in the observed coastal waters.

CHAPTER SIX
CONCLUSION

The coastal environment of Bangladesh is enriched with plankton resources which play an important role in the fisheries sector. These plankton communities depend on different types of physico-chemical factors in the coastal environment. The present investigation summarizes the seasonal fluctuations in physico-chemical parameters and phytoplankton abundance. Efforts were made to retrieve data on phytoplankton abundance and water quality parameters as water temperature, salinity, pH, alkalinity, EC, TDS, TSS, chlorophyll-a, nitrite, phosphate, silicate, and ammonia in the study area. The addition of nutrients to the coastal waters are mainly due to rainfall, freshwater input, tidal ingress. It is clearly evidenced from this study that nutrients have significant variation between seasons and substantially influenced the phytoplankton diversity as well as their abundance. Phytoplankton abundance were positively correlated with chlorophyll-a, water temperature, nitrite, and ammonia concentration in waters.

Thus, the overall study gives a good outline of the seasonal cycle of phytoplankton as well as the seasonal dynamic relationship between phytoplankton and environmental parameters. This type of research work is time relevant and to know the seasonal cycle, spatial variation and distribution of phytoplankton is compulsory. The knowledge of morphology of phytoplankton is needed to identify the species. However, further analysis is needed to make a concrete comment on the seasonal distribution of phytoplankton in the coastal waters of Chattogram.

CHAPTER SEVEN

RECOMMENDATIONS AND FUTURE PERSPECTIVES

Phytoplankton forms the basis of the marine food web which used as an indicator of ecological status. The present investigation revealed data about seasonal cycle in physico-chemical parameters and their relations with seasonal phytoplankton response patterns at coastal waters of Chattogram. However, this study had some limitations. Investigation of the resources in coastal waterbody is time consuming and cost intensive. The major limitations of the research work were the unpredictability of the weather, sea related risks, tidal surge, rolling of boat, lack of proper vessel, and physical sickness during rolling made the study quite grievous. If there were time and facilities the study could be more efficient. Therefore considering the limitations and importance of coastal waters following criterion are recommended.

1. Proper research vessel with sampling facilities.
2. Proper safety measures.
3. Broad seasonal investigation.

The result of the present study could be used as a guideline for further studies as vertical distribution and sinking features of phytoplankton, seasonal variability in water chemistry, and assessment of pollution level in the coastal waters of Chattogram.

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REFERENCES

Aldridge, F.J., Schelske, C.L., Carrick, H.J. 1993. Nutrient limitation in a hypereutrophic Florida lake. Archiv fur Hydrobiologie, pp. 21-37.

Ahmed, A., Alfasane, M.A. 2004. Ecological studies of the river Padma at Mawa Ghat, Munshiganj II. Primary Productivity, phytoplankton standing crops and diversity. M. Sc. Thesis. Department of Marine Biology. University of Chittagong, pp. 121-134.

Allen, W.E. 1939. Surface distribution of marine plankton diatoms in the Panama region. Bulletin of the Scripps Institution of Oceanography, 4(7): 181-196.

Amadea, E., Takarina, N.D., Watdhana, W. 2017. Phytoplankton distribution and community structure in estuary and fishpond at Subang, Blanakan, West Java. In AIP Conference Proceedings, 1862: 030120.

APHA (American Public Health Association). 2005. Standard methods for examination of water and wastewater. In: Eaton A D, Clesceri, L. S., Rice, E. W. (eds.), 21st ed. American Water Works Association, Water Pollution Control Federation, Washington DC, New York.

APHA. 1985. In: Greenberg, Trussel A.E., Clesceri R.R., Franson L.S., MA. (eds.), Standard methods for the examination of water and wastewater. 16th ed. APHA, Washington DC.

Arvola, L., Eloranta, P., Jarvinen, M., Keskitalo, J., Holopainen, A.L. 1999. Phytoplankton. In: Keskitalo, J. Eloranta, P. (eds.), Limnology of humic waters, Backhuys Publishers, Leiden, pp. 137-171.

Babu, A., Varadharajan, D., Vengadesh, P.N., Thilagavathi, B., Manikandarajan, T., Sampathkumar, P., Balasubramanian, T. 2013. Diversity of phytoplankton in different stations from Muthupettai, south east coast of India. Journal of Marine Science: Research and Development, pp. 85-128.

Battish, S.K. 1992. Freshwater zooplanktons of India. A preliminary observation water quality and Oxford and IBH publishing co. Ltd., New Delhi.

Bendschneider, K., Robinson, R.J. 1952. A new spectrophotometric method for the determination of nitrite in sea water. Journal of Marine Research, 11: 87-96.

Bhaskar, J.T., Nagappa, R., Sardessai, S. 2008. Nutrient regimes and their effect on distribution of phytoplankton in the Bay of Bengal. Marine Environmental Research, 66: 337-344.

Bilotta, G. S., Brazier, R. E. 2008. Understanding the influence of suspended solids on water quality and aquatic biota. Water research, 42(12): 2849-2861.

Boney, A.D. 1975. Phytoplankton studies in Biology no. 52. Edward Arnold (Publishers) Limited, London, 16p.

Boonyapiwat, S., sada, M.N., Mandal, J.K., Sinha, M.K. 2008. Species composition, abundance and distribution of phytoplankton in the Bay of Bengal. The ecosystem-based fishery management in the Bay of Bengal. SEAFDEC, Thailand, pp. 53-64.

Boyd C.E. 2015. Water Quality: An Introduction (2nd Ed.), Springer International Publishing, Switzerland, pp. 161-162.

Boyd, C.E. 1982. Water Quality management of Pond Fish culture, Elsevier Science Publisher Company, Amsterdam, Oxford, New York, 318p.

Bryceson I. 1977. An ecological study of the phytoplankton of the coastal waters of Dar-es-Salaam. Ph. D. Thesis, University of Dar-es-Salaam, 153p.

Chang, H. 2008. Spatial analysis of water quality trends in the Han River basin, South Korea. Water Research, 42(13): 3285-3304

Chowdhury, M.R.K. 2005. Occurrence, abundance and distribution of phytoplankton in the Karnafuli River estuary with notes on biodiversity. M. Sc. Thesis. Institute of Marine Sciences, University of Chittagong, 81p.

Chowdhury, M.S.N., Hossain, M.S., Das, N.G., Barua, P. 2010. Environmental variables and fisheries diversity of the Naaf River Estuary, Bangladesh. Journal of Coastal Conservation, 15(1): 163-180.

Chowdhury, M.Z.R. 1999. Study on micronutrients and standing crop of phytoplankton in the coastal water of Cox's Bazar, Bangladesh. M. Sc. Thesis. (Unpublished), Institute of Marine Sciences, University of Chittagong, 98p.

Cloern, J.E., Jassby, A.D. 2010. Patterns and scales of phytoplankton variability in estuarine-coastal ecosystems. Estuaries and coasts, 33(2): 230-241.

Cole, C.V., Sanford, R.L. 1989. Biological aspects of the Phosphorus cycle. In: Proceedings of a Symposium "Phosphorous requirements for sustainable agriculture in Asia and Oceania March 6-10 1989". SCOPE/UNEP, 1989, International Rice Research Institute, 497p.

Conley, D.J., Paerl, H.W., Howarth, R.W., Boesch, D.F., Seitzinger, S.P., Havens, K.E., Lancelot, C., Likens, G.E. 2009. Controlling utrophication: nitrogen and phosphorus. Science, 323: 1014-1015.

Das, B., Khan, Y.S.A., Sarker, M.A.K. 2002. Trace metal concentration in water of the Karnaphuli river estuary of the Bay of Bengal. Pakistan Journal of Biological Sciences, 5: 607-608.

Davis, C.C. 1955. The marine freshwater plankton. Michigan State University Press. Chicago. USA, 562p.

Dube, S.K., Jain, I., Rao, A.D., Murty, T.S. 2009. Storm surge modelling for the Bay of Bengal and Arabian Sea. Natural Hazards, 51: 3-27.

Dugdale, R.C., Wilkerson, Hogue, V.E., Marchi, A. 2007. The role of ammonium and nitrate in spring bloom development in San Francisco Bay. Estuarine, Coastal and Shelf Science, 73 (1-2): 17-29.

Elias, S.M. 1983. Zooplankton of the Mathamuhuri estuary with special reference to shrimp and finfish larvae. M. Sc. Thesis (unpublished) Institute of Marine Sciences, University of Chittagong, 172p.

Falkowski, P. 2012. Ocean science: the power of plankton. Nature, 483(7387): 17-20.

Fehling, J., Davidson, K., Bolch, C.J., Brand, T.D., Narayanaswamy, B.E. 2012. The relationship between phytoplankton distribution and water column characteristics in North West European shelf sea waters. PLoS ONE, 7: e34098.

Finenko, Z.Z., Lansakaya, L.A. 1971. In ecological physiology of marine plankton algae in culture edited by Khilov. K.M., (Nankova, Damkakiev): 22.

Fraser, J. 1962. Nature adrift; the story of marine plankton. G.T. Publish and Co. Ltd. London, 172p.

Goldinan, J.C. 1977. Temperature effects of phytoplankton growth in continuous culture. Limnology and Oceanography, 22: 932-936.

Gopal, B., Trivedy, R. K., Goel, P. K. 1984. Influence of water hyacinth cover on the physico-chemical characteristics of water and phytoplankton composition in a reservoir near Jaipur (India). Internationale Revue der Gesamten Hydrobiologie und Hydrographie, 69: 859-865.

Gouda, R., Panigrahy, R.C. 1995. Seasonal distribution and behavior of nitrate and phosphate in Rushikulya estuary, East coast of India. Indian Journal of Marine Sciences, 24 (4): 233-235.

Gouda, R., Panigrahy, R.C. 1996. Ecology of phytoplankton in coastal waters off Gopalpur, east coast of India. Indian Journal of Marine Sciences, 25(2): 81-84.

Govindasamy, C., Kannan L. 1996. Ecology of rotifers of Pichavaram mangroves, Southeast coast of India. Indian Hydrobiology, 1: 69-76.

Govindasamy, C., Kannan, L., Azariah, J. 2000. Seasonal variation in physico-chemical properties and primary production in the coastal water biotopes of Coromandel coast, India. Journal of Environmental Biology, 21(1): 1-7.

Haque, M.R. 1999. Physico-chemical parameters and phytoplankton population in the Karnafuli river estuary during pre-monsoon (in March, 1998) M. Sc. Project (Unpublished), Institute of Marine Sciences, University of Chittagong, 32p.

Haque, S.M.A. 1983. Study on the phytoplankton of the Matamuhuri estuary and the fish ponds in the vicinity. M. Sc. Thesis. (Unpublished), Institute of Marine Sciences, University of Chittagong, 175p.

Haroon, A.K.Y., Islam, A.K.M.N. 1975. Limnological studies of the river Buriganga II. Biological aspect. Dacca University Student, 23(1): 24-44.

Herodek, S. 1977. Recent results of phytoplankton research in Lake Balaton. Anal Biologia, Tihany, Hungaria, 44: 181-198.

Hensen, V. 1887. About the determination of the plankton or the material floating in the sea. Berlin Commission for Scientific Investigation, Kiel, 5: 1-108.

Holmgren, S. 1994. An environmental assessment of the Bay of Bengal region. Swedish Centre for Coastal Development and Management of Aquatic Resources, 79p.

Hossain, M.Y., Begum, M., Ahmed, Z.F., Hoque, M.A., Karim, M.A., Wahab, M.A. 2006. A study on the effects of iso-phosphorus fertilizers on plankton production in fish ponds South Pacific Studies, 26: 101-110.

Hossain, M.S., Sarker, S., Sharifuzzaman, S.M., Chowdhury, S.R. 2020. Primary productivity connects hilsa fishery in the Bay of Bengal. Scientific reports, 10(1): 1-16.

Hossain, M.S., Chowdhury, S.R., Navera, U.K., Hossain, M.A.R., Imam, B. and Sharifuzzaman, S.M. 2014. Opportunities and strategies for ocean and river resources management. Dhaka: Background paper for preparation of the 7th Five Year Plan. Planning Commission, Ministry of Planning, Bangladesh

Hutchinson, G.E. 1957. Concluding remarks. CSH Symposium, 22: 415-457.

Islam A. K. M. N., Aziz A. 1975. Study on the marine phytoplankton from the north-eastern Bay of Bengal, Bangladesh. Bangladesh Journal of Botany, 4(1): 1-32.

Islam A. K. M. N., Aziz A. 1980. Marine diatoms from the Bay of Bengal, Bangladesh. Bangladesh Journal of Botany, 9(1): 29-35.

Islam, A.K.M.N., Aziz, A. 1977. Studies on the phytoplankton of the Karnafuli River estuary. Journal of Bangladesh Academy of Sciences, 1(2): 141-154.

Islam, A.K.M.N. 1982. Investigated the phygiographic, ecological conditions, vertical distribution of algal vegetation, coastal distribution and association of algae in the St. Martin's Island. Bangladesh Journal of Botany, 11(2): 167-171.

Islam, M.E. 2001. Phytoplankton of coastal waters of Bangladesh, A Review. B. Sc. (Hons.). Term paper, 79p.

Islam, M.M.I. 1982. Seasonal variation of the phytoplankton of Lotic (The Karnafuli River estuary) and Lentic waters (The Foy's Lake) environment. M. Sc. Thesis (Unpublished), Institute of Marine Sciences, University of Chittagong, 70p.

Islam, M.M.I. 1982. Seasonal variation of the phytoplankton of Lotic (The Karnafuli River estuary) and Lentic waters (The Foy's Lake) environment. M. Sc. Thesis (Unpublished), Institute of Marine Sciences, University of Chittagong, 70p.

Islam, R., Faysal, S. M., Amin, R., Juliana, F. M., Islam, M. J., Alam, M. J., Asaduzzaman, M. 2017. Assessment of pH and total dissolved substances

(TDS) in the commercially available bottled drinking water. Iosr Journal of Nursing and Health Science Ver. IX, 6(5): 35-40.

Jyothibabu, R., Madhu, N. V., Maheswaran, P. A., Jayalakshmy, K. V., Nair, K. K. C., Achuthankutty, C. T. 2008. Seasonal variation of microzooplankton (20-200 μm) and its possible implications on the vertical carbon flux in the western Bay of Bengal. Continental Shelf Research, 28(6): 737-755.

Kitheka, J.V., Ohowa, B.O., Mwashote, B.M., Shimbira, W.S., Mwaluma, J.M. Kazungu, J.M. 1995. Water circulation dynamics, water column nutrients and plankton productivity in Gaza Bay (Kenya). In Hemminga, M. (ed.), Interlinkages between Eastern African Coastal Ecosystems. Report EU TS3-CT 92-0114, N 100, Yerseke, pp. 95-121.

Kumar, S.P., Nuncio, M., Ramaiah, N., Sardesai, S., Narvekar, J., Fernandes, V. 2007. Eddy-mediated biological productivity in the Bay of Bengal during fall and spring intermonsoons. Deep Sea Research Part I: Oceanographic Research Paper, 54: 1619-1640.

Lipschultz, F. 1995. Nitrogen- specific uptake rates of marine phytoplankton isolated from natural populations of particles by flow cytometry. Marine Ecology Progress Series, 123: 245-258.

Longhurst, A., Sathyendranath, S., Platt, T., Caverhill, C. 1995. An estimate of global primary production in the ocean from satellite radiometer data. Journal of Plankton Research, 17: 1245-1271.

Lugomela, C.V. 1995. Spatial and Temporal dynamics of phytoplankton biomass and species composition in Chwaka Bay, ZanZibar. In Hemminga, M. (ed.) Interlinkages between Eastern African Coastal Ecosystems. Report EU T53-CT92-0114, N 100, Yerseke, pp. 166-172.

Mahmood, N., Saha, S.B., Noori, N.U. 2006. Seasonal changes of phytoplankton in the off shore waters of the Bay of Bengal along the eastern fringe of Bangladesh, Journal of the Asiatic Society of Bangladesh, Sci, 32(1): 11-22.

Mamun, M.M., Sarower, M.G., Ali, M.A., Rahman, S.M.B., Haq, K.A. 2009. Abundance and distribution of plankton in the Sundarbans mangrove forest. Journal of Innovation and Development Strategy, 3(3): 43-54.

Millman, M., Cherrier, C., Ramstack, J. 2005. The seasonal succession of the phytoplanktoncommunity in Ada Hayden lake, North Basin, Ames, Iowa. Limnology Laboratory, Iowa State University, Ames, Iowa.

Mishra, D., Panda, S., Panigrahy, R.C. 1993. Physico-chemical characteristics of the Bahuda estuary (Orissa), East coast of India. Indian Journal of Marine Sciences, 22: 75-77.

Mullin, J.B., Riley, J.P. 1955. The colorimetric determination of silicate with reference to sea and natural waters. Analytica Chimica Acta, 12: 162-176.

Murphy, J., Riley, J.R. 1962. A modified single solution method for the determination of phosphorous in natural waters. Analytica Chimica Acta, 27: 31-36.

Nazneen, S. 1980. Influence of hydrological factors on the seasonal abundance of phytoplankton in the Kinjhar Lake, Pakistan. Internationale Revue der gesamten Hydrobiologie, 65(2): 269-282.

Newell, G.E., Newell, R.C. 1979. Marine plankton a practical guide.(5thedi.). Hutchison and Co. (Publishers) Ltd. London, 244p.

Nielsen, T.G. and Hansen, B.W. 1999. Seasonal variation in nutrients, pelagic primary production and grazing in a high-Arctic coastal marine ecosystem, Young Sound, Northeast Greenland. Marine Ecology Progress Series, 179: 13-25.

Noori, M.N. 1999. An investigation on seasonal variation of micronutrients and standing crop of phytoplankton in neritic waters of the southeast coast of Bangladesh. M. Sc. Thesis, Institute of Marine Sciences, University of Chittagong, 91p.

Pati, S. 1980. Observation on the hydrography and inshore plankton of the Bay of Bengal of Balashore, India. Hydrobiology, 70: 123-132.

Paula, J., Pinto, I., Guambe, I., Montaro, S., Gove, D., Guerreiro, J. 1998. Seasonal cycle of planktonic communities at Inhaca Island, Southern Mozambique. Journal of Plankton Research, 20(11): 2165-2178.

Perkins, E.J. 1976. The biology of estuaries and coastal waters. Academic press, London, 678p.

Perumal, N.V., Rajkumar, M., Perumal, P., Rajasekar, K.T. 2009. Seasonal variations of plankton diversity in the Kaduviyar estuary, Nagapattinam, southeast coast of India. Journal of Environmental Biology, 30 (6): 1035-1046.

Prabhahar, C., Saleshrani, K., Dhanasekaran, D., Tharmaraj, K., Baskaran, K. 2011. Seasonal variations in physico-chemical parameters of Nagapattinam coastal area, Tamil nadu, India. International Journal of Current Life Sciences, 1(6): 29-32.

Prabu, V., Ashok, Mayalagu, Rajkumar, Perumal, Pachiappan. 2008. Seasonal variations in physico-chemical characteristics of Pichavaram mangroves, southeast coast of India. Journal of environmental biology / Academy of Environmental Biology, India, 29: 945-50.

Rahaman, S.M.B., Golder, J., Rahaman, M.S., Hasanuzzaman, A.F.M., Huq, K.A. 2013. Spatial and Temporal Variations in Phytoplankton Abundanceand Species Diversity in the Sundarbans Mangrove Forest of Bangladesh. Journal of Marine Science: Research and Development, 3: 126.

Rahman, M. 1997. Phytoplankton of the Naf River estuary during post monsoon near Teknaf Coast. M. Sc. Project. Institute of Marine Sciences, University of Chittagong, 24p.

Rahman, S.M.B., Golder, J., Rahaman, M.S., Hasanuzzaman, A.F.M., Huq, K.A., Begum, S., Bir, J. 2013. Spatial and temporal variations in phytoplankton abundance and species diversity in the Sundarbans mangrove forest of Bangladesh. Journal of Marine Science Res Development, 3: 1-9.

Rajasegar, M., Sirnivasan, M., Ajmal Khan, S. 2002. Distribution ofsediment nutrients of Vellar estuary in relation to shrimp farming. Indian ournal of Marine Science, 31(2): 153-156.

Rajasegar, M. 2003. Physico-chemical characteristics of the Vellar estuary in relation to shrimp farming. Journal of Environmental Biolog, 24: 95-101.

Ramakrishnan, R., Perumal, p., Santhanam, p. 1999. Spatio-temporal variations of hydrographical features in the Pichavaram mangroves and Mohi aqua farm, Southeast coast of India. In: Proc. Intl. Sem. Appl. Hydrogeochem., Annamalai

University, Annamalai Nagar, India, Published by Dept. of Geology, Annamalai University, Annamalai Nagar, India, pp. 197-203.

Rao, N. S. 2008. Factors controlling the salinity in groundwater in parts of Guntur district, Andhra Pradesh, India. Environmental monitoring and assessment, 138(1): 327-341.

Rao, N., Kumari, R.R., Rao, V.L., Sreeharsha, I.V., Grace, G., Jyothi, K. 2016. Variability of phytoplankton in the coastal waters of Visakhapatnam, Central East coast of India (Bay of Bengal) with special reference to environmental parameters. Journal of Biodiversity and Environmental Sciences, 9: 73-86.

Roelke, D.L., Eldridge, P.M., Cifuentes, L.A. 1999. A model of phytoplankton competition for limiting and non-limiting nutrients: implications for development of estuarine and nearshore management schemes. Estuaries, 22: 92-104.

Rosen, G. 1981. Phytoplankton indicators and their relations to certain chemical and physical factors, Limnologica-(Berlin), 13: 263-290.

Ryther, J.H., Dunstan, W.M. 1971. Nitrogen, phosphorus, and eutrophication in the coastal marine environment. Science, 171: 1008-1013.

Saeedullah, M. 2003. Seasonal distribution of phytoplankton in the Meghna river estuary of Bangladesh with notes on biodiversity. M. Sc. Thesis, Institute of Marine Sciences, University of Chittagong, 82p.

Salam, A.M.A. 1977. Algal flora of the Karnafuli estuary and ecological observation on changes in the growth of some inter tidal algae at Patenga coast. M. Sc. Thesis. Department of Marine Biology. University of Chittagong, 149p.

Sampathkumar, P., Kannan, L. 1998. Seasonal variations in physico-chemical characteristics in the Tranquebar-Nagapattinam region, South-east coast of India. Pollution Research, 17: 397-402.

Sardessai, S., Ramaiah, N., Prasanna Kumar, S., De Souza, S.N. 2007. Influence of environmental forcings on the seasonality of dissolved oxygen and nutrients in the Bay of Bengal. Journal of Marine Research, 65 (2): 301-316.

Schindler, D.W. 1977. Evolution of phosphorus limitation in lakes. Science, 195: 260-262.

Segar, K., Hariharan, V. 1989. Seasonal distribution of nitrate, nitrite, ammonia and plankton in effluent discharge area of Mangalore, west coast of India. Indian Journal of Marine Sciences, 18: 170- 173.

Sekh, S., Biswas, B., Mandal, M., Sarkar, N.S. 2016. Seasonal dynamics of the genus: Planktoniella Schutt in the estuarine waters of Indian Sundarbans. Springer Plus, 5: 611.

Senthilkumar, S., Santhanam, p., Perumal, p. 2002. Diversity of phytoplankton in Vellar estuary, southeast coast of India. In: Proc. 5th Indian Fisheries Forum (Eds.: Ayyappan, S., Jena, J.K. Joseph, M.). Published by AFSIB, Mangalore and AeA, Bhubanewar, India, pp. 245-248.

Sharif, A.S.M. 2002. A comparative study on plankton and benthos of the Meghna river estuary during monsoon and post monsoon. M. Sc. Thesis. Institute of Marine Sciences, University of Chittagong, pp. 102-103.

Sommer, U. 1996. Plankton ecology: The past two decades of progress. Naturwissenschaften, 83(7): 293-301.

Soundarapandian, P., Premkumar, T., Dinakaran, G. K. 2009. Studies on the physico-chemical characteristic and nutrients in the Uppanar estuary of Cuddalore, South east coast of India. Current Research Journal of Biological Sciences, 1(3): 102-105.

Sournia, A. (Ed.). 1978. Phytoplankton manual. In "Monograps on Oceanography Methodology 6" UNESCO, Paris. 337p.

Sridhar, R., Thangaradjou, T., Kumar, S. S., Kannan, L. 2006. Water quality and phytoplankton characteristics in the Palk Bay, southeast coast of Journal of Environmental Biology, 27(3): 561-566.

Stirling, H.P. 1985. Chemical and Biological methods of water analysis for aqua culturists. Institute of aquaculture, University of Stirling, Scotland, 119p.

Subramanyan, R. 1946. A systematic account of the marine plankton diatoms of the Madras coast Bangalore press. Bangalore, India, 198p.

Tailing J. F., Driver D. 1963. Some problems in estimation of Terrestrial algae: The British Physiological Society, Cambridge Taxonomic analysis of the genus Anabaenopsis. Archiv fur Hydrobiologie, 51: 3-24.

Taimur, F.M. 2006. Abundance and distribution of phytoplankton in the vicinity of St. Martin's Island during Monsoon and post-monsoon B. Sc. (Honours) term paper. Institute of Marine Sciences, University of Chittagong, 46p.

Tilstone G.H., Figueiras, F.G., Lorenzo, L.M., Arbones, B. 2003. Phytoplankton composition, photosynthesis and primary production during different hydrographic conditions at the Northwest Iberian upwelling system. Marine Ecology Progress Series, 252: 89-104.

Townsend, C.R., Harper; J.L., Begon, M. 2000. Essentials of ecology. Blackwell Science, Oxford, UK, 553p.

Valiela, I., Valiela, I. 1995. Marine ecological processes (Vol. 686). New York: Springer.

Vernberg, F. J. 1993. Salt-marsh processes: a review. Environmental Toxicology and Chemistry: An International Journal, 12(12): 2167-2195.

Veronica E., Leksono, A.S., Soemarno., Arfiati, D. 2014. Effect of water quality on Phytoplankton abundance in hampalam river and fish pond of Batanjung village. Journal of Environmental Science, Toxicology and Food Technology, 8: 15-21.

Vinayachandran, P., Chauhan, P., Mohan, M., Nayak, S. 2004. Biological response of the sea around Sri Lanka to summer monsoon. Geophysical Research Letter, 31: L01302

Vinayachandran, P., Mathew, S. 2003. Phytoplankton bloom in the Bay of Bengal during the northeast monsoon and its intensification by cyclones. Geophysical Research Letter, 30: 1572.

Wong, G. T. 1979. Alkalinity and pH in the southern Chesapeake Bay and the James River estuary 1. Limnology and Oceanography, 24(5): 970-977.

Yamazi, I. 1952. Plankton investigation in inlet waters along the coast of Japan, Publications of the Seto Marine Biological Laboratory.

Yamazi, I. 1972. Illustration of the marine plankton of Japan. Hoikusha publishing Co. Ltd. Osaka, Japan, 369p.

Zafar M. 1986. Study on zooplankton of Satkhira estuary system in the vicinity of aquaculture farms with special reference to penaeid post larvae. M. Sc. Thesis, Institute of Marine Science, University of Chittagong, Chittagong, Bangladesh, 238p.

Zafar, M. 2000. Study on Sergestid shrimp Acetes in the vicinity of the Matamuhuri river confluence, Bangladesh. Ph. D. Thesis. Institute of Marine Sciences, University of Chittagong, 223p.

APPENDICES

Appendix I: Phytoplankton composition recorded during study period.

I (A)

Phytoplanktons	**Mean count (×10^2 cells/L)**			
	Station 1		**Station 2**	
	Monsoon	**Winter**	**Monsoon**	**Winter**
Total Phytoplankton	9.6	8.2	13.4	10.6
Bacillariophyceae	4.32	3.85	6.62	3.87
Dinophyceae	2.56	1.64	3.08	2.86
Coscinodiscophyceae	1.6	2.13	3.54	3.87
Thalassiothrix	1.12	1.64	1.54	1.18
Chaetocerus	1.12	0.49	2	0.5
Skeletonema	0.48	1.15	1.08	0.5
Cyclotella	1.12	0.57	2	1.18
Cerataulina	2.08	1.19	2.41	2.21
Coscinodiscus	1.12	1.64	2.62	1.69
Ditylum	0.48	0.49	0.92	2.19

I (B)

Phytoplanktons	**Within the total count of**	**Percentage contribution (%)**			
		Station 1		**Station 2**	
		Monsoon	**Winter**	**Monsoon**	**Winter**
Bacillariophyceae	Total phytoplankton	45	47	49.43	36.51
Dinophyceae		26.66	20	22.99	26.99
Coscinodiscophyceae		16.67	26	26.44	36.51
Thalassiothrix	Bacillariophyceae	25.925	42.55	23.25	30.43
Chaetocerus		25.93	12.77	30.23	13.04
Skeletonema		11.11	29.79	16.28	13.04
Cyclotella		25.93	14.89	30.23	30.43
Cerataulina	Dinophyceae	81.25	72.59	78.33	77.25
Coscinodiscus	Coscinodiscophyceae	70	76.92	73.91	43.47
Ditylum		30	23.07	26.09	56.52

Appendix II: Physico-chemical factors recorded during investigation period.

Physico-chemical parameters	Station 1		Station 2	
	Monsoon	**Winter**	**Monsoon**	**Winter**
Cholophyll-a (µg/L)	0.29	0.266667	0.71	0.586667
WT (°C)	30.53333	25.36667	32.2	26.4
Salinity (psu)	10.16667	16.5	3.666667	21.33333
EC (mS/cm)	22.36667	34.2	5.566667	44.66667
pH	6.9	7.6	6.7	7.2
Alkalinity (ppm)	94	130	89.46667	122
TDS (g/L)	11.14	17.17	2.82	22.33
TSS (g/L)	0.68	0.93	0.55	0.94
Nitrite (µg/L)	2.129493	0.343893	2.02368	0.568747
Phophate (µg/L)	0.72957	0.918567	0.55116	0.71957
Silicate (µg/L)	422.643	166.55	148.6414	87.75213
Ammonia (µg/L)	258	212	284.6667	227.3333

Appedix III: Descriptions of Principle Component Analysis

III (A)

Component Transformation Matrix		
Component	1	2
1	.988	.152
2	-.152	.988
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.		

III (B)

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	8.338	69.486	69.486	8.338	69.486	69.486	8.189	68.241	68.241
2	1.912	15.935	85.421	1.912	15.935	85.421	2.062	17.180	85.421
3	.739	6.159	91.580						
4	.676	5.632	97.212						
5	.277	2.310	99.521						

6	.037	.311	99.832						
7	.011	.089	99.921						
8	.008	.066	99.987						
9	.001	.010	99.997						
10	.000	.003	100.000						
11	1.357E-5	.000	100.000						
12	5.182E-17	4.318E-16	100.000						
Extraction Method: Principal Component Analysis.									

III(C)

Component Score Coefficient Matrix		
Parameters	**Component**	
	1	**2**
Cholophyll-a	.016	-.453
WT	-.121	.005
Salinity	.120	-.042
EC	.115	-.016
pH	.097	.102
Alkalinity	.124	-.037
TDS	.115	-.016
TSS	.069	-.017
Nitrite	-.133	.122
Phophate	.043	.264
Silicate	-.112	.452
Ammonia	-.109	-.068
Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Component Scores.		

Appendix: IV Some pictures of research work

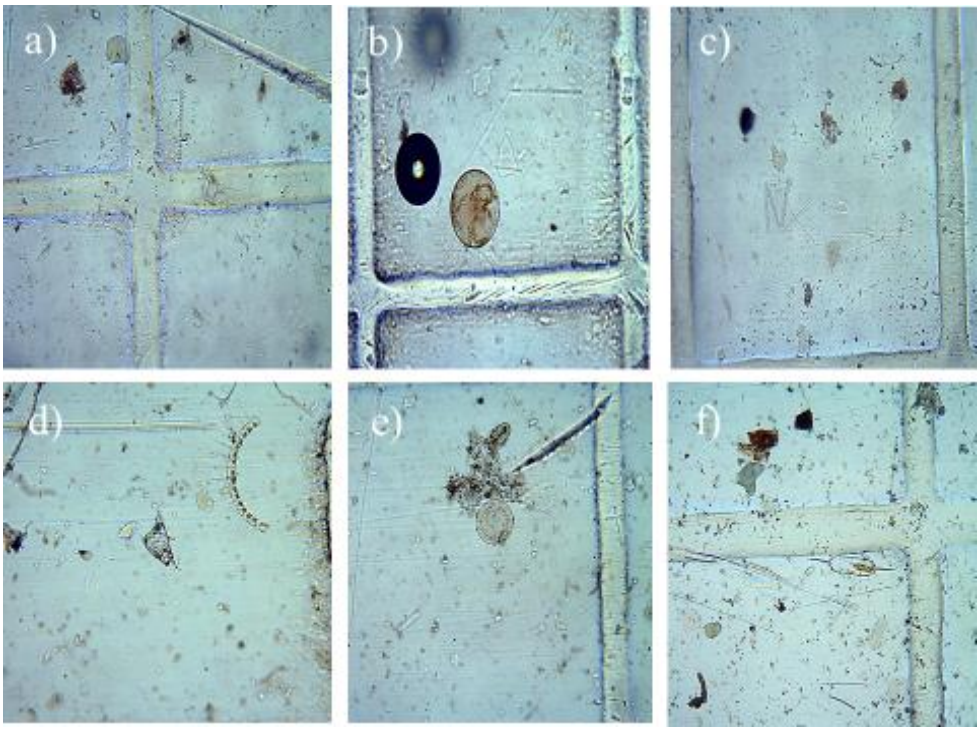

Figure 9: Microscopic images of some dominant species of phytoplankton; a) *Skeletonema*, b) *Coscinodiscus*, c) *Thalassiothrix*, d) *Chaetocerus*, e) *Cyclotella*, d) *Ditylum*

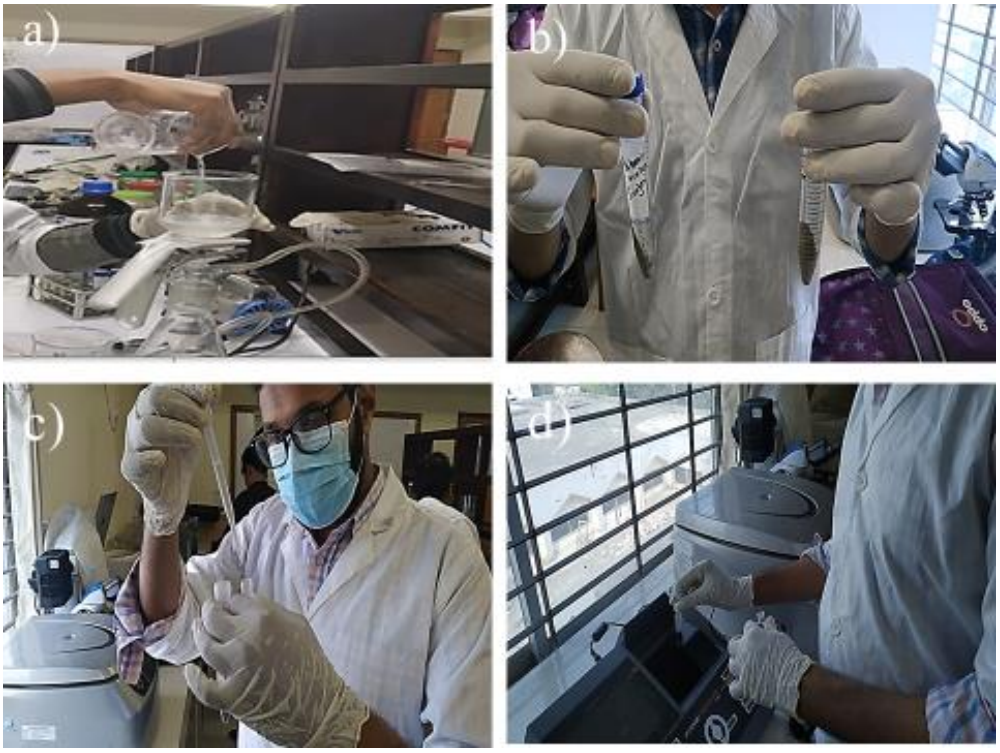

Figure 10: Chlorophyll-a measurement of sample; a) Filtering sample, b) After centrifugation, c) Acetone insertion, d) Measuring Photometric Absorbance

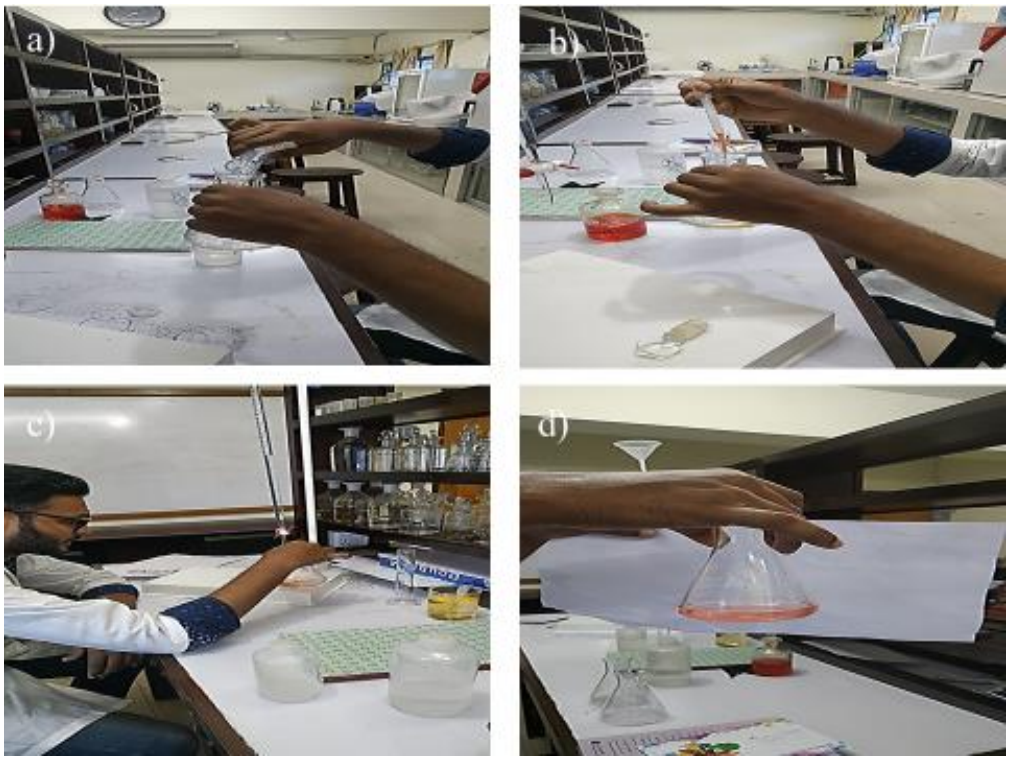

Figure 11: Determination of alkalinity; a) Filtrate sample in conical flask, b) Adding Methyl orange indicator, c) Titration against standard H2SO4(0.02 N), d) Ending point of titration

Figure 12: Ammonia determination of sample; a) and b) Required reagents c) Adding reagents, d) Ongoing reaction, e) Inseting vial, f) Ammonia analysis

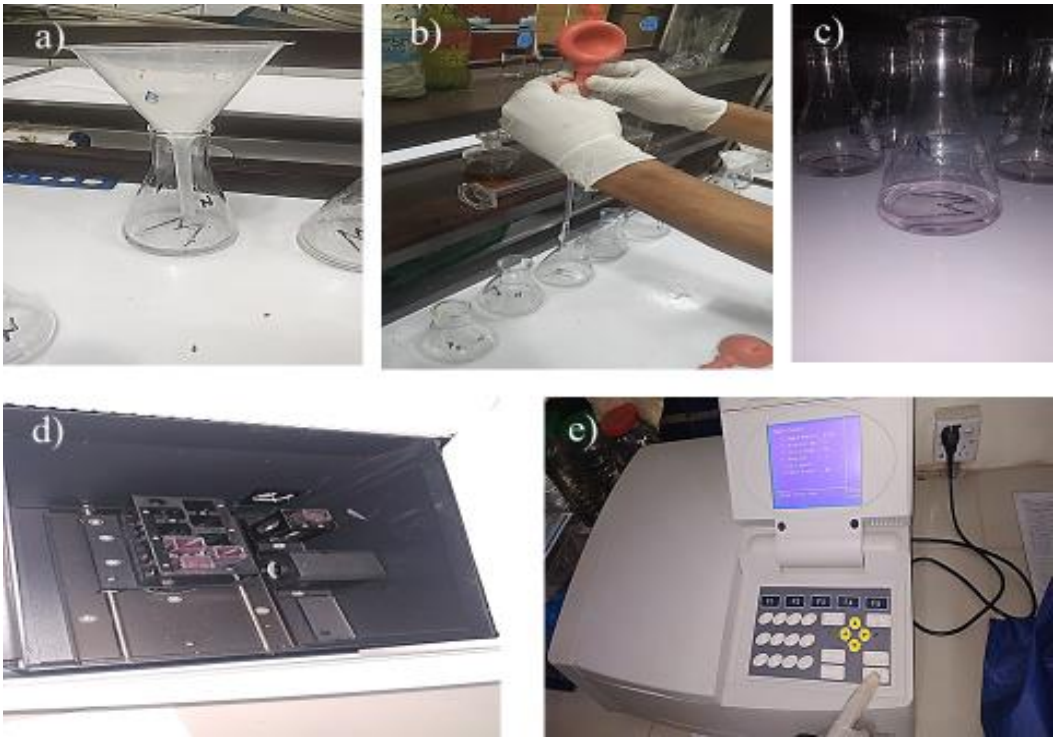

Figure 13: Determination of nitrite; a) Filtration of sample, b) Adding chemicals, d) Reaction, d) Insertion of vial, e) Photpmetric measurement

Figure 14: Determination of phosphate; a) filtration of sample, b) Required chemicals, c) Adding chemicals, d) Reaction, e) Insertion of vial, f) Photometric measurement

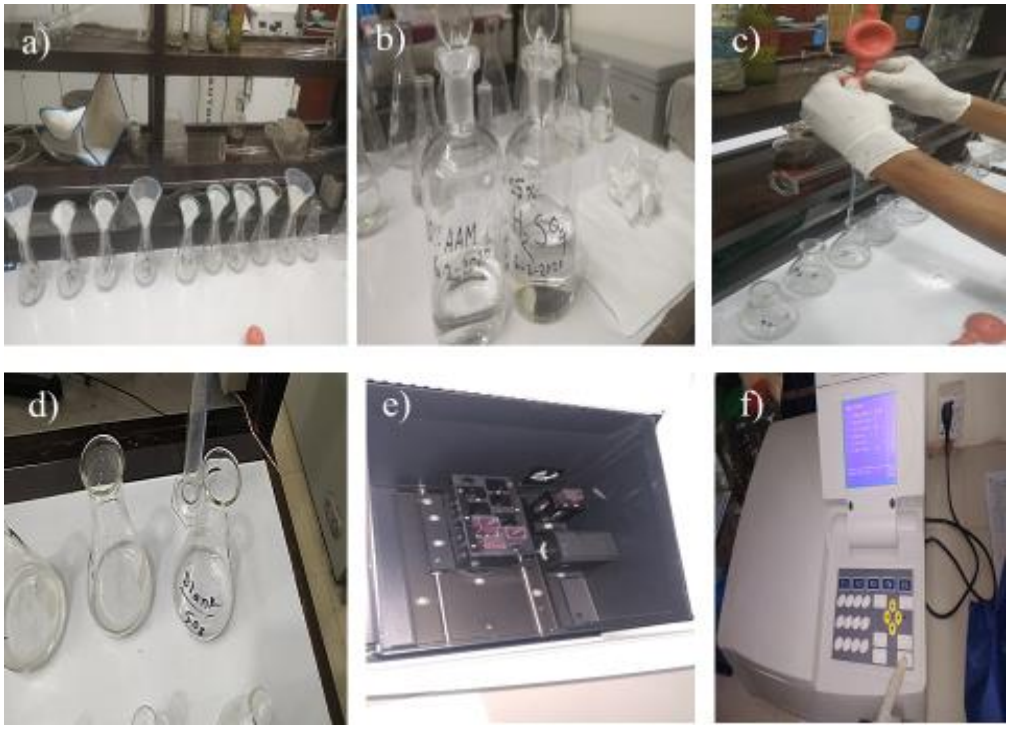

Figure 15: Determination of silicate; a) Filtration on sample, b) Required chemicals, d) Adding chemicals, d) Ongoing reaction, e) Insertion of vials, f) Photometric measurement

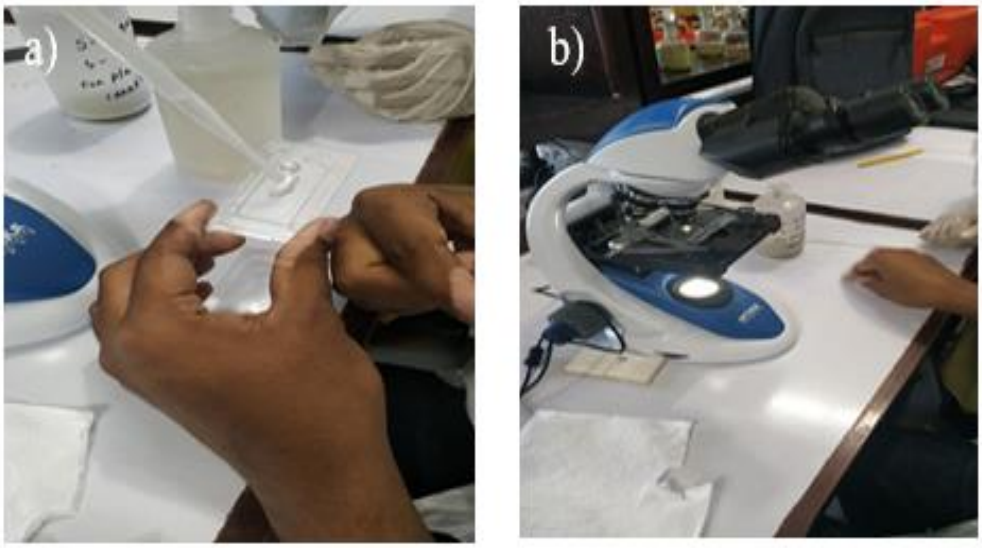

Figure 16: Phytoplankton observation; a) Sample in Sedgewick-rafter cell, b) Observation and counting

Figure 17: Field work: a) and b) Phytoplankton net towing, c) Insertion plankton sample in plastic bottle, d) pH measurement, e) Salinity measurement

BRIEF BIOGRAPHY OF THE AUTHOR

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