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Phytoplankton Distribution in Estuarine and Coastal Waters of Mumbai, Maharashtra

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***Abstract*-- Neretic and near shore subtropical biodiversity includes phytoplankton, zooplankton, Benthos, sea weeds and mangroves in the coastal region of the country. Among many coastal ecosystems studied, one is Ulhas river estuary-Vasai creek - Thane creek (Thane) adjoining Rewas creek-Karanja creek (which receives water from Amba river, Patalganga river and Bhogwati river towards Uran-Mandve village side) in coastal waters of Mumbai. Small rivers Ulhas river, Mithi river are present at west coast forming estuarine systems in coastal region of Mumbai. Coastal water receives approximately 1800 MLD of sewage water which affects assimilative capacity of coastal waters. The phytoplankton distribution study was conducted during three seasons viz. premonsoon, after monsoon and post monsoon seasons 2007-08. Phytoplankton 19 species, 18 species and 27 species and diatoms as dominant group were observed at 16 sampling stations of 4 transects in coastal waters (near shore, 1km, 3km, and 5km distance from shore) in premonsoon, after monsoon and post monsoon. Freshwater, salinity tolerant and marine water phytoplankton species *Klebsormidium elagans*, *Navicula petersenii*, *Nitzschia seriata*, *Thalassiothrix longissima*, *Coscinodiscus radiatus*, *Gyrosigma balticum* were recorded in estuarine and coastal waters. Moderate values of Shannon wiener diversity index were observed in surface waters of estuary and coastal waters. Simpson index of species dominance was decreased in estuarine water during high tide though the dominated phytoplankton species belong to marine phytoplankton. Maximum phytoplankton numbers 27900/l (TC8W-premonsoon), 18180/l (TC9W-monsoon) and 104000/l (TC6W-postmonsoon) were observed in estuarine waters. Dominance of *Klebsormidium elagans* (Chlorophyceae) was observed in estuarine waters from sampling stations 1 to 13 (East, Center, and West of the sampling stations). Scattered diagram of phytoplankton species distribution in coastal water and two ways ANOVA had shown seasonal variations of phytoplankton in coastal waters.**

Key words - Phytoplankton, Shannon wiener index (SWI), Simpson index (SI), estuarine waters, Coastal waters

I. Introduction

The ecology was studied to understand seasonal changes of phytoplankton in estuarine waters (Thane creek) and coastal waters of Mumbai. A different nature from freshwater ecosystem and recent review (O'Boyle and Joe-silken, 2010) described phytoplankton changes in estuarine and coastal waters are governed by physical processes viz. presence of tidal and thermo cline fronts wind and topographically associated coastal upwelling, advection landward of offshore water-masses and flow of coastal and oceanic currents. In estuary, scenario is somewhat changes in response to seasonality and local factors operating over much smaller time-scales, in order of days and weeks, while episodic changes in river flow create a broad range of changes in chemical parameters that result in greater variation in phytoplankton biomass. Beside physical processed-sunlight and nutrients in temperate regions reported to be driven by seasonal changes in the vertical stability of water column limiting phytoplankton growth (Margalef, 1978, Legendre, 1981, Tett and Edwards, 1984).

Seasonal variations of nutrients are mainly related to water exchange in river, estuary and coastal waters. Another Study in Aegean Sea reveals that precipitation leads to large changes in temperature, salinity, dissolved oxygen and nutrients at five sampling stations. Highest nutrients were observed during rainy season except o.PO_4-P and TPO_4-P.

Anthropogenic loading for dissolved inorganic nitrogen (DIN), soluble reactive phosphate (SRP) and dissolved reactive silicon a point sources inputs, but for dissolved organic nitrogen(DON), a nonpoint sources input were observed in Sishili Bay located in the northern Yellow Sea from December 2008 to March 2010 (Wang et al., 2012). Unlike point source pollution, which involve a relatively constant waste water discharge from a known place, non-point source (NPS) or diffuse pollution were transported into coastal waters via ground water, streams and rivers, the atmosphere, combined sewage-overflows, storm drains and as the release of toxic chemicals from contaminated sediments among other pathway, seaweb.org/sources/briefings/ nonpoint source.

Diatoms account for approximately 40% of the ocean carbon fixation and are sources of vast majority of biogenic silicates (frustules). The autotrophs diatoms growth and nutrients utilization in high nitrate, low chlorophyll regions are mostly regulated by iron availability in the world oceans. Diatom are acclimatized to iron limitation by decreasing cell size. Variations in degree of silicification and nutritional requirements of iron-limited diatoms have been hypothesized to account for higher cellular is and/or lower cellular N and C e.g. *Fragilariopsis kergnelensis,* (Marchetti and Cassar, 2009).

Plankton abundance is varied in response to river forms shallow channel (demarcated at one end as freshwater flow and on the other side wide spread mouth region) as it joins the sea and constantly under the tidal influence. Consequently the hydrography and stratification of tidal front in estuary is dominated by strong horizontal flows. The boundary between mixed and stratified water column is created and separates deeper offshore summer water from shallow inshore tidally mixed water. The study have shown in a large thermohaline front known as the Irish Shelf Front (ISF) somewhere under the 150m isobaths, west of Ireland (Huang et al., 1991; McMahon et al., 1995).

Phytoplankton depends on availability of sun light and generally it reaches up to 100m with degree of light attenuation in the water column. Holmes (1956) found little phytoplankton in the Labrador Sea from November to April with marked instability of water column.

Variables like sea surface temperature and dissolved oxygen influence the phytoplankton population in the south-east coast of India (Sampath kumar et al., 2015). Favourable Salinity, pH, temperature and light penetration leads to higher phytoplankton density in summer season among four seasons, in Mangroves of Kachchh – Gujarat (Saravana kumar et al., 2008b) Another study revealed phytoplankton species richness was found minimum during post monsoon and maximum during summer season correlated with lower and higher salinity and pH in Pichavaram mangroves (Mani, 1992).

The increase temperature and salinity with more phytoplankton abundance under a low value of DO concentration in surface waters was observed in Nethravati – Gurupura estuary, South West Coast of India during postmonsoon, (Shruthi and Rajashekhar, 2013). Stability of the salinity and hydrological parameters led more phytoplankton production in Nethravathi eatuary, (Rajesh et al., 2002). Major decrease in salinity and temperature i.e increase in volume, dilution with river discharge and impact of abrupt changes in the environmental conditions, as scattered distribution of phytoplankton were observed in Kuduviyar estuary, Nagapattinam, South East Coast of India, (Perumal et al., 2009). Salinity is the main influencing factor in functional physiology and reproductive activity of the marine organisms (Kinne,1971), Similarly positive correlation was observed between temperature and phytoplankton diversity and richness in post monsoon and summer season (January and February, 2012&2013) in Muthukuda mangrove environment, South - East Coast of India(Dinesh Kumar et al., 2017).

Most of the oceans, less than 1% of the inorganic carbon exists CO_2 and bicarbonates is negligible. Phytoplankton growth is influenced in presence of abundant cations $Ca^{2+,}$ Na^+, Mg^{2+} and K^+ in Seawater. Most of the total CO_2 present in the sea water however existed bicarbonate and carbonate ions entering thus are derived from continental weathering processes involving CO_2 and their charges balanced mainly by abundant cations. In oxygenated seawater, there are no abundant anions comparably which tend to associate with hydroxyl ions. The combined effect of the carbonate equilibrium give surface sea water a pH characteristically in the range pH 7.8 to 8.4. The entry of CO_2 to the ocean from the atmosphere thus reduces the pH (pH = -log a H^+). Increase in pH favours the formation of carbonate ions and decrease in pH favours the formation of free $CO_{2.}$, Which assimilated in phytoplankton (Raymont J.E.G., 1980 Chapter-2 Chemical composition and characteristics of seawater, pp. 31-64 Plankton and productivity in the Ocean).

Nutrients were negatively correlated with phytoplankton density indicated the utilization of nutrients. another aspect studied was lower concentration of chlorophyll '*a*' during premonsoon season might be due to anthropogenic activity, discharges from the river causing turbidity and less availability of light in Coleroon estuary, South-East Coast of India, (Vengadesh perumal et al., 2009; Thillai Rajasekar et al., 2005) Phytoplankton organisms mixed-type (few river water phytoplankton species to many marine water forms as lean water flow of Ulhas-river in the creek) were observed in Ulhas river-estuary -Thane creek waters. These observations were provided insight to the quantitative record of phytoplankton in Ulhas river-estuary -Thane creek waters and coastal waters of Mumbai.

II. MATERIAL AND METHODS

Physico-chemical parameters and phytoplankton sampling were carried out in Ulhas river-estuary -Thane creek waters (Lat. 18º.55'to 19º30' N and Long. 72º.49'to 73º 00E) and coastal waters from Greater Bombay to Vasai creek, Mumbai coast (Lat. 19º04'43.67" to 19º10'51.07" and Long. 72º45'02" to 72º57'52.15") (Figure-1).

Figure 1: Sampling stations 1 to 16 (4-Transects) in coastal waters and 1 to 13 (3-transects) in estuary for physico-chemical and phytoplankton monitoring

Surface water samples of physicochemical parameters i.e. water temperature, pH, Dissolved oxygen (DO), Biological oxygen demand (BOD), Inorganic orthophosphate (PO_4-P) and Ammonical Nitrogen (NH_4-N) were collected twice after 7 days gap (sampling days - during high tide and low tide) and again twice after 7 days gap (sampling days - during spring tide and neap tide) by fishing boat from sampling stations 1 to 13 forming estuarine zone 35 kms of Ulhas river-estuary-Thane creek in May and June-2000. Sampling stations 1 to 13 in estuarine zone divided in to three transects - west side, centre and east side at width of the river. Samples of physico-chemical analysis were conducted using a manual of sea water analysis (Strickland and Parsons, 1968) (Grasshoff, Ehrhardt, and Kremlings 1983). Phytoplankton samples were also collected from surface waters of sampling stations 1 to 13, Ulhas river-estuary-Thane creek during three seasons plus spring tide and neap tide period in 2007-08.

In coastal water sampling, phytoplankton samples were collected from four sampling transects and total 64 sampling stations i.e. transects - near shore, 1km, 3km, and 5km distance from the shore and sampling station 1 at Colaba and Greater Bombay side to sampling station 16 at Vasai creek side) during three seasons plus spring tide and neap tide period in 2007-08. Water samples were collected to assess phytoplankton population in coastal waters. Analysis of samples was conducted following Standard Methods of examinations of water and waste water. Microscopic identification and enumeration of phytoplankton were done by Lackey drop count method (APHA, 1999) and statistical analysis was carried out using Introduction to Statistics for Biology (McCleery, watt and Hart, 2007). Phytoplankton diversity were studied using following indices (Hellawell, 1978).

Shannon- Wiener index:

$H' = \Sigma$ pi $\log_2$ pi

Where pi is the proportions of abundance of species i in a community where species proportions are p_1, p_1, p_3--------pn

Simpson index

$D = \Sigma$ ni (ni-1)/N (N-1)

Where ni is the number of individuals of species i and N is the total number of individuals

III. Results and Discussion

Physico-chemical parameters water temperature, pH, dissolved oxygen, biochemical oxygen demand, nutrients viz. ammonical Nitrogen (NH_4-N^-) orthophosphate **(**PO_4^{3-}-P) along with phytoplankton were studied in present observations covering 39 and 64 sampling stations in Estuarine waters and coastal waters of Mumbai. Sampling and analysis of various parameters were conducted to understand ecology of estuarine water -Thane creek water.

Salinity: Estuary is classified on the basis of salinity. The distribution of organisms is depending upon salinity gradient in estuary. Sampling stations wise increasing trend, the lowest average (9ppt) at station 1 on reverine end and gradually increased (21.98ppt) at stn. 6 were observed in Ulhas river estuary, (Mishra, Quadros and Athalye, 2007).

Water Temperature: As it is known that water temperature reduces as the depth of the water increases in estuarine waters and coastal waters. Maximum water temperature 32.25±0.82 was observed in summer. Water temperature were ranged from 30.6° C ±0.52° C (HT) to 30.3° C ± 0.67° C (LT) and 30.55° C±0.55° C (HT) to 30.05° C± 0.60° C (LT) in estuarine waters on day 1 and day 2. The water temperature were observed higher than the normal values (25° C to 30° C) due to samples collected in summer months. On occurrence of monthly spring and neap tidal period, water temperature were more or less ranged from 32° C ±0.66° C (HT) to 32.25° C ± 0.82° C (LT) during spring tide and 32.55° C±0.68° C (HT) to 32° C± 0.67° C (LT) during leap tide in estuarine waters on day 1 and day 2. The water temperature was observed still higher in day time during spring and neap tide.

pH: pH was ranged from neutral range and above throughout the water stretch from sampling stations 1 to 13 Thane creek water. Water pH was ranged 7.15±0.14 to 7.21±0.13 (HT) and 7.07±0.05 to 7.11±0.1 (LT) in estuarine waters on day 1. Second observation indicates pH were ranged 7.63±0.19 to 7.76±0.27 (HT) and 7.46 ± 0.31 to 7.58±0.22 (LT) in estuarine waters on day 2. The water pH was influenced by fresh water influx in creek water during low tide. On occurrence of monthly spring and neap tidal period, water pH was ranged higher than the normal estuarine water pH. pH were ranged from 7.80±0.22 to 8.08±0.18 (HT) and 7.82±0.22 to 8.06±0.23 (LT) in estuarine waters on day 1. These pH values were slightly reduced from 7.16±0.13 to 7.22±0.11 (HT) and 7.08 ± 0.04 to 7.1±0.11 (LT) in estuarine waters on day 2. The observation of spring tide, pH was increased than normal day pH of estuarine waters due to samples collected in estuarine waters during spring high tide and premonsoon period. pH of estuarine waters was influenced more during spring tide.

Dissolved Oxygen, (DO): >3mg/l was observed in transect 1 to 4 receiving waste water discharges from Thane Municipal Corporation waste water treatment plant (CTP) during high tide period and travel up to transect 4 during low tide period. DO value resides <3 mg/l during low tide in estuarine water along centre and east side. DO <4mg/l were reported at transect 5 to 7 mid-stretch of estuarine waters. DO more than 4 mg was observed 2/5 parts of the water samples. DO samples were collected at transect 6 and 7 which located near to Ghatkopar discharge point significantly a cause of DO depletion between spring high tide and low tide period. DO >4 mg/l were observed from sampling stations 7 to 10 transects among 2/3 parts of the sample during low tide 8/9 parts of samples during high tide period.

Dissolved oxygen moderately low values were observed in estuarine waters. Average and standard deviation of DO were ranged from 3.11±1.09mg/l to 3.28±1.16 mg/l (HT) and 2.55± 0.66mg/l to 3.12±1.27 mg/l (LT) along the complete stretch of estuary on normal tidal days of day 1. The second observation had shown in DO were ranged from 2.92±1.33mg/l to 3.69±1.38mg/l (HT) and 2.74±0.66mg/l to 3.18±0.87mg/l (LT) in estuarine waters. DO values become more influenced by spatial changes then by temporal change in estuarine waters.

DO values were increased during spring tide (HT and LT period) as compared to neap tide (HT and LT). DO values were ranged from 3.14±1.71 mg/l to 3.63±1.19mg/l (HT) and 2.92±1.66mg/l to 3.37±1.50 mg/l in estuarine water on day 1 during spring tide. Another sampling during leap tide, DO were ranged from 2.92±1.39mg/l to 3.27± 1.32 mg/l (HT) and 1.96±0.69mg/l to 2.71± 1.73 mg/l during neap tide along the stretch of estuary.

Biochemical Oxygen Demand, (BOD): Dissolved oxygen concentration affects growth and physiology of planktonic organisms along with physical parameters e.g. sun light and temperature. Any external organic matter was entering in to river and estuarine water increases oxygen demand. Bacterial consumption increase oxygen demand in estuarine water during summer season. Better water quality along the centre and east was observed during high tide period in estuarine waters. During spring tide period while residing water showed high oxygen demand.

BOD of river water was observed more as compared to mouth region of the estuary. Variation in BOD was observed from 5±3.16mg/l to 9.9±9.12 mg/l (HT-C to W) and 8.25±4.80mg/l to 9.87±10.68 (LT-E to W) along the complete stretch of estuary on normal tidal days of day 1. Ulhas River to estuarine waters were ranged from 6.45±4.32mg/l to 6.9±4.15mg/l (HT) and 11.43 ± 10.62 to 14.8±12.64mg/l (LT) during normal tidal period of day 2. BOD of estuarine waters were ranged from 3.91 ± 3.9mg/l (HT) to 5.02±4.31 mg/l (LT) during high and low tide of spring tide period and 6.25±4.78mg/l (HT) to 9.14± 8.37mg/l (LT) during high and low tide of neap tide period., BOD values were increased at sampling stations 1 to 5 in estuarine water as compared to mouth region of estuary.

Nutrients**:** In aquatic ecosystem, phytoplankton yield is essentially determined by minimum quantity of nutrient present in water, (Liebig, 1843). Nitrogen, Phosphorus and Silicon are essential elements required for Diatom growth.

Ammonical Nitrogen, NH_4-N^- : Nitrogen is present in all the three forms NO_3-N, NO_2-N and NH_4-N in water body. While In this study, NH_4-N was observed in higher concentration in centre and western bank along Ulhas river estuary. Mac Isaac and Dugdale, (1972) explained out of 68% combined uptake -50% as NH_4-N and remaining assimilated as NO_3-N nitrogen in the Peruvian upwelling area. Highest concentration 1.810mg/l was during Neap tide - low tide (NTLT) in Thane creek. Mathew (1987) has reported in 1984-85, its range between 0.191 mg/l and 1.05 mg/l (avg. 0.62mg/l). The present range and average values are significantly higher than the above indicating build up of NO_3-N in estuary. Jeffrey et al. (1991) nitrogen mineralization in late spring is of the correct order of magnitude to supply a substantial quantity (up to 74% in some areas) of the calculated daily nitrogen requirements of the algae.

NH_4-N was ranged from 0.496± 0.29mg/l to 0.9 ±0.42 mg/l (HT) and 0.761±0.55mg/l to 1.278± 0.66mg/l (LT) in Ulhas river estuary. NH_4-N variation was fluctuated from sampling station 1-9 except sampling station 10 which was located at mouth region of creek on sampling day 1. The increase in NH_4-N values was observed during next sampling after 10 days. NH_4-N values were ranged from 0.866±0.83mg/l (centre-LT) to 2.03±1.81 mg/l (west-LT) in estuarine part of Thane creek.

Higher NH_4-N values were observed along the centre line and west bank of estuary. NH_4-N were support rich phytoplankton especially Chlorophyceae in upper riche and Bacillariophyceae in middle and confluence to sea region of estuary. NH_4-N was ranged from 0.642 ±0.33mg/l (east-HT) to 1.137±0.63mg/l (west-HT) and 0.957±0.63mg/l (east-LT) to 1.366±0.61mg/l (west-LT) along the stretch of estuary. As NH_4-N values were increased over daily tidal cycle during spring tide in Thane creek waters. NH_4-N was varied from 0.509±0.25 mg/l (east-HT) to 1.26±0.55mg/l (west-HT) and 0.581±0.27mg/l (east-LT) to 1.603±0.44mg/l (west-LT) during neap tide in estuarine part of Thane creek on 2^nd^ sampling day.

Orthophosphate**, (**PO_4^{3-}-P): Inorganic orthophosphate is essential for building molecular requirements of Phytoplankton and stored poly phosphate inclusions in phytoplankton cell. Strickland and Solórzano (1966) were detected 0.03 mg/l PO_4-P in of shore waters, whereas inshore PO_4-P may reach up to 0.5 mg/l, (observed in samples influenced by red tide dinoflagellate bloom decay). The PO_4-P values ranged from 0.006 to 0.805 mg/L with overall average

0.120 mg/l which have shown temporal decrease in Ulhas river estuary - thane creek from observations were made in year 2000). In general the PO_4-P average values were higher than 0.086 mg/l, the limit for unpolluted water (Yentsch and Ryther, 1957).

PO_4-P values were ranged from 0.273±0.21 mg/l to 0.304±0.24mg/l (HT) and 0.247±0.12 mg/l to 0.381±0.21mg/l (LT) in estuarine waters of Ulhas river on day 1. River end PO4-P values were moderate high as compare to estuarine mouth region. Second sampling, the samples PO_4-P were ranged from 0.28±0.15mg/l to 0.312±0.19 mg/l (HT) and 0.281±0.23mg/l to 0.404±0.31mg/l (LT) in full stretch of the estuarine waters. PO_4-P values were moderately high in centre line of the estuary than east and west bank sides.

The PO_4-P was decreased than over daily tidal cycle due to external sources act upon spring and neap tidal days. During spring tides, PO_4-P values were ranged from 0.131±0.06mg/l to 0.158±0.05mg/l (HT) and 0.185±0.06mg/l to 0.241±0.09mg/l (LT) in estuarine waters. Second sampling of PO4-P during neap tide, PO_4-P were ranged from 0.237±0.18mg/l to 0.256±0.15mg/l (HT) and 0.197±0.21mg/l to 0.371±0.26mg/l (LT) in estuarine waters. PO_4-P values were recorded moderately high along the line of east bank of estuary.

Silicate – Silicon, (SiO_3-Si): The availability of silicate-silicon is one of the important factors that can regulate the species composition of phytoplankton assembly (Egge and Aksenes, 1992). The SiO_3-Si in Ulhas river estuary ranged between 1.65 mg/l and 89.43 mg/l with overall average 18.14 mg/l indicating high SiO_3-Si as compared to most Indian estuaries (Mishra, Quadros and Athalye, 2007). Dissolved silicon is present in sea water in chemically reactive forms. This could be the reason for the exceptionally high SiO_3-Si in Ulhas river estuary, and Thane creek, (18° 45'N to 19°16'N and 72°45' to 73°20'E) (NEERI Report, 2000).

Phytoplankton in estuarine waters: The subtropical region is topographically variables in terms of semidiurnal pattern of tides, water currents movements in sea. Phytoplankton biomass is stated to be more variable and far less predictable and in other words "variable" particular hydro-morphological and chemical characteristics of estuarine waters in terms affect especially phytoplankton biomass and year around availability of nutrients (Clabby et al., 2008).

Phytoplankton is autotrophic, rapid growing 2-3 division d^{-1} and indicator of water quality in freshwater, estuarine and coastal waters. The photo-autotrophic type being recognized as in trophic levels as primary producers. In presence of sun light, bicarbonates source of carbon dioxide and nutrients have known to help in synthesis of cell carbohydrate for growth and multification in photosynthesis process. Ammonium (NH_4^+N),Nitrate (NO_3-N), Orthophosphate as PO_4-P, and Silicate as SiO_3-Si and Dissolved organic matter (DOM) are proportionately present in surface water, midwaters and deepwaters and consequent transformation of element cycle to bring about changes in plankton population.

Earlier phytoplankton communities comprised of total 77 phytoplankton genera belong to five groups Bacillariophyceae, Dinophyceae, Chrysophyceae, Haptophyceae, and Dicthyochophyceae were identified and environmental factors were affected phytoplankton genera distribution and the changes in Izmit Bay (Aktan et al., 2007). *Prorocentrum* spp. was dominated bloom in all sampling periods, while the diatoms (shifts were observed in dominant diatoms) contributed most to the settling biomass.

Klebsormidium elagans was dominant at 1-13 sampling stations of estuarine waters -Thane creek in premonsoon and post monsoon season (Table-1). Phytoplankton variation at number of sampling stations and SWI were ranged from 200/l (TC1) to 27900/l (TC8W) (<1000/l at 10 SS, >1000/l to10, 000/l at 14 SS and <100,000/l at 9 SS) and 0.92 (TC1) to 3.14 (TC11W) in Ulhas river estuary during premonsoon season. In monsoon (samples were collected just after monsoon months) phytoplankton at number of sampling stations and SWI were varied from 140/l (TC9C) to 18180/l (TC9C) (<1000/l at 10 SS, >1000/l to10, 000/l at 19 SS, <100,000/l at 2 SS) and 0.46 (TC5E) to 2.99(TC8E) irrespective of density of phytoplankton in Ulhas river estuary. Phytoplankton at number of sampling stations were ranged from 1290/l (TC5C) to 104000/l (TC6E) (<1000/l at 2 SS, >1000/l to 10000/l at 20 SS, <100,000/l at 3SS) and reached to maximum numbers in estuarine waters in post monsoon season. Diversity of phytoplankton (SWI) were varied from 1.4 (TC10E) to 2.7 (TC6E) (Figure 2 to 4).

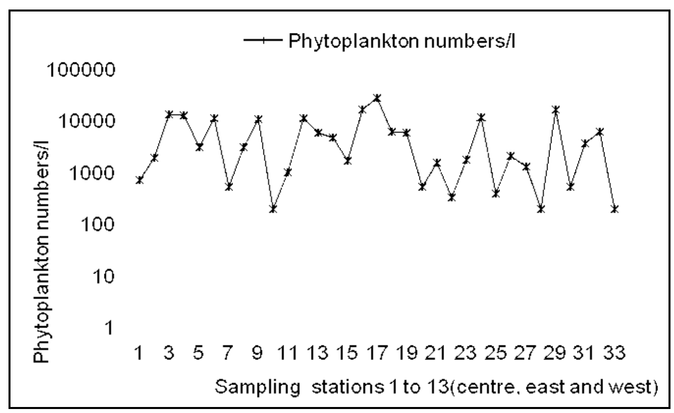

Figure 2: Phytoplankton numbers variations in Ulhas river estuary – Thane creek from sampling stations 1 to 13 (premonsoon 2008)

In present investigation, total 44 species were flourished at 13 sampling stations in estuarine waters of Ulhas river estuary-Thane creek during three seasons. Percentage composition of phytoplankton species were belong to Bacillariophyceae 51.02%, Chlorophyceae 48.14%, Euglenophyceae 0.472%, Cyanophyceae 0.368% and Dinophyceae 0% in estuarine waters (premonsoon season) (Figure-5).

Phytoplankton species *Nitzschia palea* (22-SS), *Thalassiothrix longissima* (11-SS), *Klebsormidium elagans* (28-SS), *Navicula petersenii* (16-SS), *Coscinodiscus radiatus* (23-SS), *Gyrosigma balticum* (9-SS) and *Biddulphia pulchella.* (9-SS) were occurred in percentage composition in premonsoon. Dinophyceae species were observed in monsoon being not detected in samples in premonsoon and post monsoon. Increase in percentage composition of phytoplankton species belong to Bacillariophyceae 58.874%, Chlorophyceae 36.657%, Euglenophyceae 1.846%, Cyanophyceae 2.588% and Pyrrophyceae 0.395% were observed in estuarine waters (monsoon season) (Figure- 6).

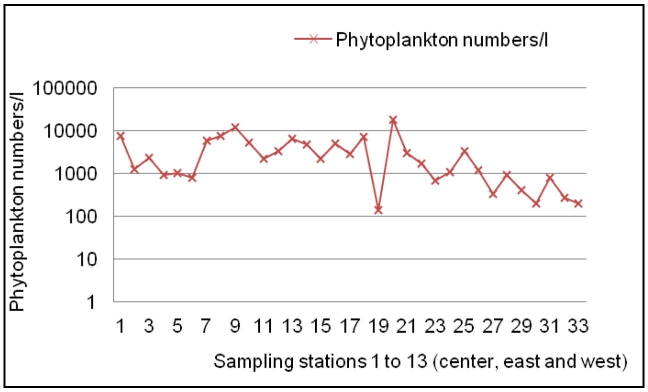

Figure 3: Phytoplankton numbers variations in Ulhas river estuary – Thane creek from sampling stations 1 to 13 (monsoon 2007)

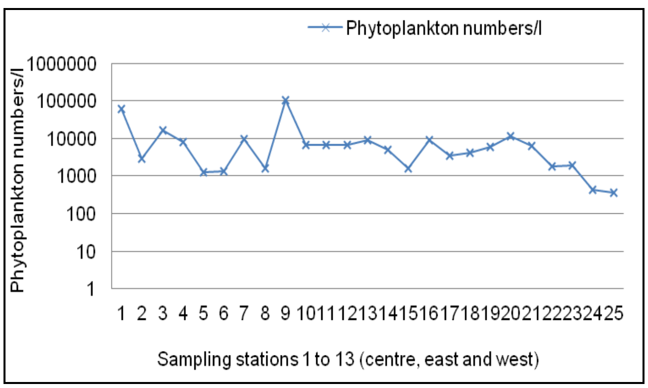

Figure 4: Phytoplankton numbers variations in Ulhas river estuary – Thane creek from sampling stations 1 to 13 (post monsoon 2007)

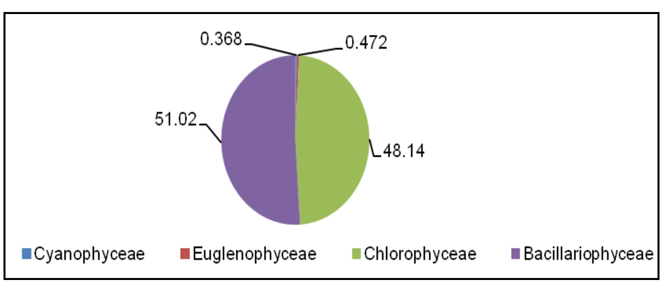

Figure 5: Phytoplankton composition in surface waters of Ulhas river estuary – Thane creek in premonsoon

Studies of phytoplankton ecology findings in estuarine and coastal waters around Ireland show salient features (I) at the time of Cryptophytes and other flagellate can be numerically dominant but diatoms provide the larger contribution to chlorophyll concentration and total volume of phytoplankton in winter (Pybus, 2007). (ii) spring bloom consists mainly of diatom species such as *Thalassiosira* sp., *Skeletonema* sp., *Asterionopsis gracialis* and *Chaetoceros* sp. with species such as *Rhizosolenia* sp., *Ceratulina pelagica* becoming more common later in spring and in early summer (Dooley, 1973, Pybus, 1996) (iii) at the boundary between mixed and stratified water tidal mixing can fuel additional phytoplankton growth.

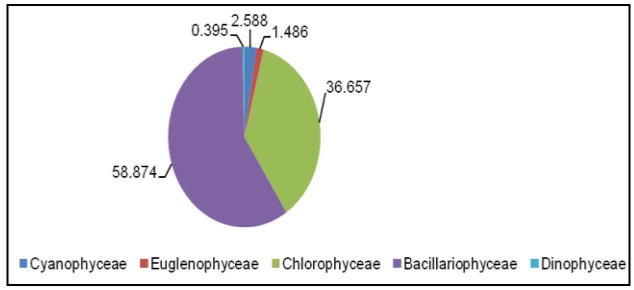

Figure 5: Phytoplankton composition in surface waters of Ulhas river estuary – Thane creek in monsoon

Higher biomass levels are usually found on the stratified side of the front while on the mixed side, chlorophyll levels are lower as phytoplankton populations are mixed out of the euphotic zone (Simpson et al., 1979). (iv) Presence of offshore stratification influence diffusion of nutrients from below the pycnocline resulting declined in surface mixed layer biomass during summer season. At the base of thermocline is a diffusion of nutreints which promote the development of large monospecific dinoflagellate populations e.g. *Karenia mikimotoi* also common surface bloom of heterotrophic dinoflagellate *N. scintilans* (Raine, 1993 C).

In addition to above mentioned phytoplankton species, Klebsormidium *elagans* (48-SS), *Thalassiothrix longissima* (12-SS), *Nitzschia palea* (9-SS), *Navicula petersenii* (6-SS), *Biddulphia pulchella.* (6-SS) were observed after monsoon season.

Density of phytoplankton was more or less varied all three seasons as compared to coastal water where reduction of phytoplankton was coincided with monsoon. Percentage composition of phytoplankton species belong to Bacillariophyceae 66.08%, Chlorophyceae 31.24%, Euglenophyceae 2.32%, Cyanophyceae 0.36% and Dinophyceae 0% were observed in estuarine waters (post-monsoon season) (Figure-7).

Phytoplankton species *Klebsormidium elagans* (27-SS), *Coscinodiscus radiatus* (26-SS), *Gyrosigma balticum* (20-SS), *Thalassiothrix longissima* (20-SS), *Nitzschia palea* (19-SS), *Navicula petersenii* (19-SS), *Amphipleura pellucida* Kutz. (10-SS) and *Leptocylindrus danicus* (6SS) were observed in post-monsoon season. Phytoplankton species distribution at number of sampling stations was shown in scattered diagrams.

As compared with phytoplankton numbers 200/l (15A) to 2000/l (1D) in coastal waters, higher number of (>4000/l) were observed as many as 10 sampling stations of estuarine water during monsoon season. This is clear indication that nutrients play important role in spatial distribution of phytoplankton. Bacillariophyceae were dominant group in post monsoon. Phytoplankton group Chlorophyceae numbers and percentage in composition were increased as compared to Bacillariophyceae at many sampling stations in estuarine waters during monsoon and post monsoon seasons.

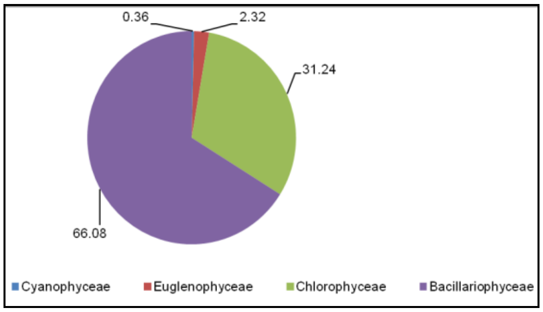

Figure 5: Phytoplankton composition in surface waters of Ulhas river estuary – Thane creek in post monsoon

Phytoplankton belong to *Oscillatoria mujuscola*, *Anabaena* sp. *Spirulina laxissima*, (Cyanobacteria), *Phacus curvicauda* swir, (Euglenophyceae), *Chlamydomonas reinhardtii*, *Rhizoclonium hieroglyphicum*, *Ankistrodesmus acicularis*, *Klebsormidium elagans*, *Zygnema pectinatum*, desmids (Chlorophyceae) and *Cylindrotheca* sp., *Surrirella oblonga*, *Cymbella* sp., and *Skeletonema costatum* were observed at sampling stations 1 to 13 (East, Centre, West).

Recent review were given an excellent record of estuarine and coastal waters around Ireland (O'Boyle and Silke, 2010). The estuarine waters are influenced by advection of offshore waters, stratification from water depth and tidal movements in creek water. The high winter POC and phytoplankton was originated from summer or autumn primary production (autotrophic). Author assumed based on carbon loss rate of just 3% of total organic carbon per day. Phytoplankton groups 39% Chlorophyceae, 33% Cyanobacteria and 25% Bacillariophyceae were observed very consistently in both seasons. (Schumann et al., 2005).

Many phytoplankton of marine water were observed due to advection landward (diurnal tidal variation) of offshore waters in estuary. Phytoplankton species *Coscinodiscus radiatus*, *Rhizosolania eriensis*, *Navicula petersenii*, *Nitzschia palea*, *Thalassiothrix longissima*, *Leptocylindrus danicus*, *Biddulphia pulchella*, Synedra *ulna*, *Gyrosigma balticum*, *Thalassiosira weissflogii*, (tropical marine phytoplankton) were observed in estuarine waters of Ulhas river estuary-Thane creek (Table-1).

Phytoplankton dominance (Simpson Index) as (i) phytoplankton number 12920/l, percentage composition - Chlorophyceae 84%, Bacillariophyceae 16%, SI-0.862 at TC4C were observed in premonsoon; (ii) phytoplankton numbers 18180/l, percentage composition - Chlorophyceae 11%, Bacillariophyceae 89%, SI-0.853 at TC9E were observed in monsoon; (iii) phytoplankton numbers 9570/l, percentage composition - 86% Bacillariophyceae, 14% Chlorophyceae, SI-0.826 at TC5W were observed in post monsoon. Simpson Index of phytoplankton species was found to be much higher than coastal waters.

Phytoplankton in coastal waters: A total of 46 phytoplankton species were identified in coastal waters of Mumbai. Phytoplankton study was conducted in coastal waters during premonsoon, after monsoon and post-monsoon seasons. Pielou (1966) reviewed the different methods of measurement of diversity such as Brillouin's measure of information (diversity of small collections), SWI for diversity of larger collections, random sampling with known number of species as Basharin's formula and random sampling with unknown number of species as good's method in different type of biological collection.

SWI for diversity of larger collections was used in diversity assessment. *Leptocylindrus denicus* was dominant in west-coast waters of Mumbai as reported Leptocylindricus *denicus* bloom in the coastal waters of Kerala south-east Arabian Sea (Nushad et. al., 2018). Variation in diversity of phytoplankton seems to be dependent on spatial variations of phytoplankton generally higher diversity of phytoplankton were observed in increasing phytoplankton numbers. Maximum phytoplankton numbers 22130/l (12D-pre-monsoon), 2000/l (1D- monsoon) and 2, 75,930/l (6A-post monsoon), corresponding to SWI 3.74(4B), 3.04(1D), and 3.17(8B) were observed. Phytoplankton variation (<1000/l at 6 SS, >1000/l to10,000/l at 37 SS and <100,000/l at 4 SS) in pre-monsoon, (<1000/l at 31 SS, and >1000/l to10,000/l at 16 SS) after monsoon and (<1000/l at 15 SS, >1000/l to10,000/l at 17 SS and <100,000/l at 12 SS and >100,000/l 3SS) in post-monsoon were observed at number of sampling stations in coastal waters (Figure 8 to 12).

Density of phytoplankton and Simpson Index of dominance belongs individual species dominance, as 8130/l, SI - 0.19 at 12A (13% Euglinophyceae, 10.7% Chlorophyceae, 93.3% Bacillariophyceae), 200/l, SI- 0.666 at 4D (100% Bacillariophyceae), 1000/l, SI 0.625 at 14A (6.7% Chlorophyceae, 93.3% Bacillariophyceae) were observed in coastal waters during premonsoon season. The dominance was increased resulting in lower numbers and higher dominance (i) 1070/l, SI-0.2 (100% Bacillariophyceae) (ii) 600/l, SI- 0.709 (33.3% Chlorophyceae, 66.7% Bacillariophyceae at 1B), and (iii) 1600/l, SI-0.722 (41.7% Cyanophyceae, 16.6% Chlorophyceae, 41.7% Bacillariophyceae) were noticed in monsoon season.

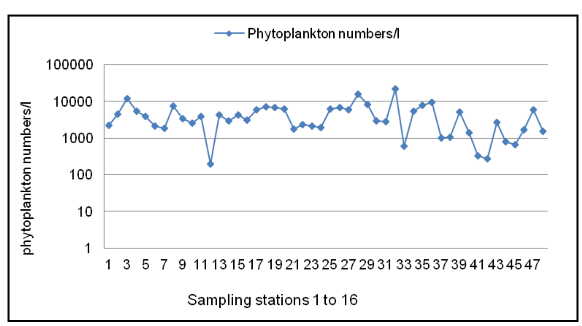

Figure 8: Phytoplankton numbers variation in the coastal water of Mumbai (Premonsoon 2008)

TABLE 1
phytoplankton species presence in estuarine environment of Ulhas river-estuary

S. No.	Phytoplankton Group	Pre-monsoon	Monsoon	Post-monsoon
1	Cyanophyceae			
	Anabaena sp.	-	+	+
2	*Oscillatoria mujuscola*	+	-	+
	Spirulina laxissima	-	-	+
3	Euglinophyceae			
4	*Phacus curvicauda* swir	+	+	+
	Chlorophyceae			
5	*Chlamydomonas reinhardtii*	+	-	+
6	*Cosmarium pananense* Presc.	+	-	+
7	*Desmidium swartzii* C. Agardh ex Ralfs	+	+	+
8	*Staroustrum singulum* (West&G.S.West) G.M. Smith.	+	+	-
9	*Rhizoclonium hieroglyphicum*	-	-	+
10	*Klebsormidium elagans*	+	+	+
11	*Cylindrocystis sp.*	+	+	+
12	*Zygnema pectinatum (Vauch.) C.A.Agardh*	-	-	+
13	*Mougeotia genuflexa* (Roth) C.Agardh	+	+	+
14	*Ankistrodesmus acicularis*	+	+	+
15	*Closteridium lunula* Reinsch	-	+	-
	Bacillariophyceae			
	Pennales			
16	*Navicula petersenii*	+	+	+
17	*Nitzschia palea* (Kutz.) W.Smith,1986	+	+	+
18	*Amphipleura sp*	+	+	+
19	*Pleurosigma directum*	+	+	+
20	*Gyrosigma balticum*	+	+	+
21	*Cylindrotheca sp.*	+	-	+
22	*Cyamatopleura* sp.	-	+	-
23	*Surrirella oblonga* Ehr.	-	+	+
24	*Diploneis elliptica (kutz.)Cl.*	-	+	-
25	*Cymbella sp.*	+	-	+
26	*Cocconeis littoralis*	+	+	+
27	*Synedra ulna*	+	+	+
28	*Skeletonema costatum (Greville) Cleve*	-	-	+
29	*Eucampia cornuta*	+	+	-
30	*Ditylum brightwelli*	+	+	+
	Centrales			
31	*Leptocylindrus danicus*	+	+	+
32	*Planktoniella sol*	+	-	+
	Chaetoceros pseudonitzschia	+	-	-
34	*Coscinodiscus radiatus*	+	+	+
35	*Cyclotella meneghiniana*	-	-	+
36	*Biddulphia pulchella* S.F.Gray	+	+	+
37	*Biddulphia chinensis*	+	-	+
38	*Rhizosolania eriensis*	+	+	+
39	*Thalassionema nitzschiodes*	-	+	-
40	*Thalassiothrix longissima* (cleve and Grunow,1887)	-	+	+
41	*Thalassiosira weissflogii*	+	+	+
42	*Triceratium formosum*	+	+	+
43	*Stephanodiscus hantzschii* Grun.	+	-	+
44	Dinophyceae			
45	*Ceratium horridum*	-	-	+

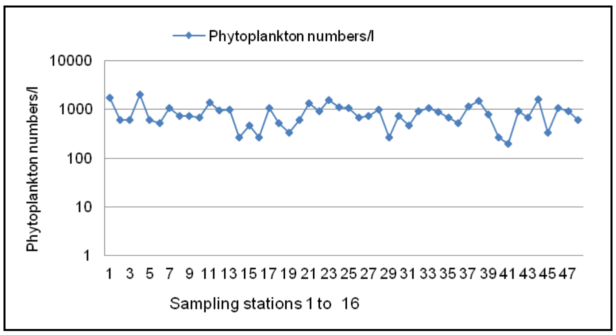

Figure 9: Phytoplankton numbers variation in the coastal water of Mumbai (Monsoon 2008)

Simpson Index of dominance of single species was decreased in coastal waters during post monsoon season. Similarly, Maximum number, percentage composition and SI and sampling station (i) phytoplankton biomass 2260/l, SI-0.238, (100% Bacillariophyceae, at 3C), (ii) 9600/l, 91.6% Chlorophyceae, 8.4% Bacillariophyceae SI-0.545 at 15D, (iii) 13190/l, 88.90% Chlorophyceae, 11.10% Bacillariophyceae, SI-0.6 at 16A) (iv) 8790/l, 33.3% Bacillariophyceae 66.7%, Chlorophyceae, SI- 0.625 at 14A, (v) 4600/l, 33.3% Chlorophyceae, 66.7% Bacillariophyceae, SI- 0.666 at 4D and (vi) 7060/l, (3.80% Chlorophyceae, 96.20% Bacillariophyceae SI- 0.709 at 6D, were observed in coastal waters post-monsoon season.

Higher density and diversity and percentage composition of phytoplankton species were belong to Bacillariophyceae

77.202%, Chlorophyceae 13.816%, Euglenophyceae 7.771%, Cyanophyceae 0.553%, and Pyrrophyceae 0.658% were observed in coastal waters (pre monsoon season) (Figure-13).

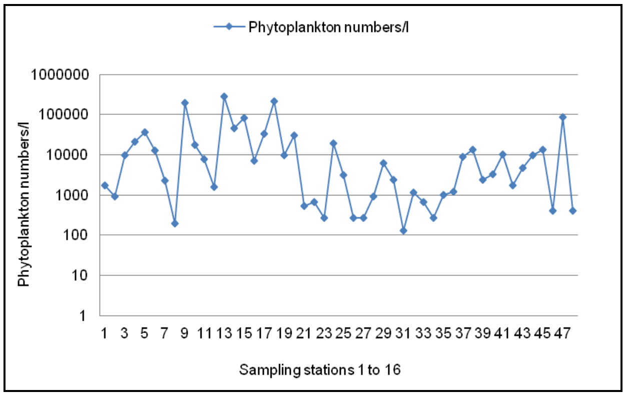

Figure 10: Phytoplankton numbers variation in the coastal water of Mumbai (Post monsoon 2007)

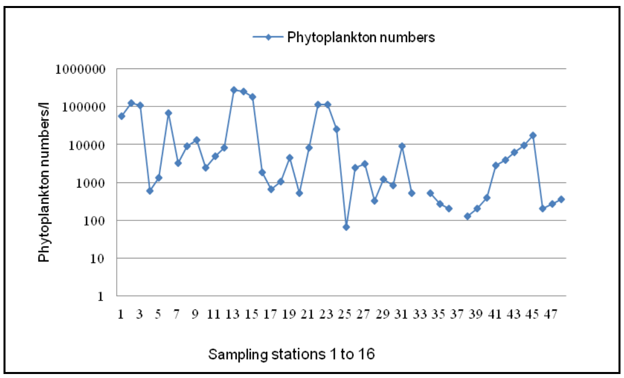

Figure 11: Phytoplankton numbers variation in the coastal water of Mumbai (Spring high tide)

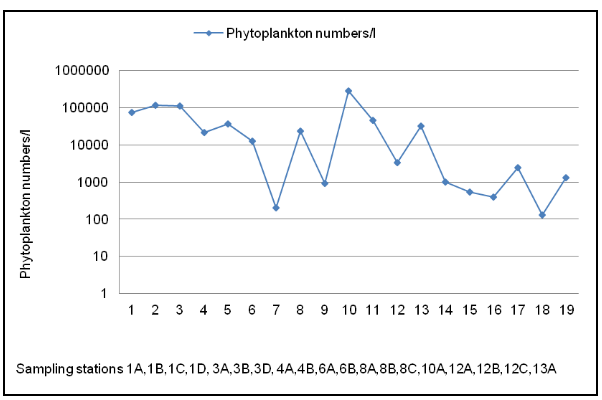

Figure 12: Phytoplankton numbers variation in the coastal water of Mumbai (Spring low tide)

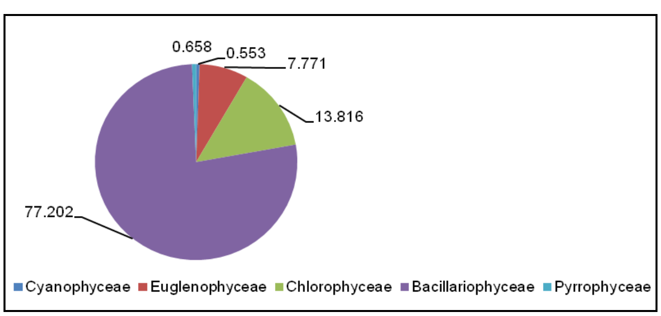

Figure 13: Phytoplankton composition in surface coastal waters of Mumbai in premonsoon

Phytoplankton species *Coscinodiscus radiatus* (23 SS), *Navicula petersenii* (22 SS), *Nitzschia seriata* (20 SS), *Thalassiothrix longissima* (18 SS), *Thalassionema nitzschiodes* (17 SS), *Gyrosigma balticum* (16 SS), *Eucampia* sp. (16 SS), *Chlorella marina* (14 SS), *Biddulphia pulchella* (12 SS), *Chaetoceros pseudonitzschia* (9 SS), *Ditylum brightwellii*, (14 SS) and *Trichodesmium erythraeum* (7 SS), were observed at number of sampling stations in pre monsoon season.

The increase in percentage composition of Cyanophyceae species and total percentage composition were indicated presence of Bacillariophyceae 70.06%, Chlorophyceae 12.58%, Euglenophyceae 9.585%, Cyanophyceae 7.183% and Pyrrophyceae 0.592% in coastal waters (after monsoon season) (Figure-14).

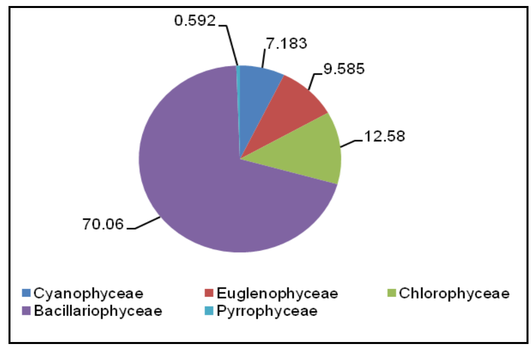

Figure 14: Phytoplankton composition in surface coastal waters of Mumbai in monsoon

Higher percentage of phytoplankton species and less density of phytoplankton were recorded in quantitative analysis at many sampling stations. Phytoplankton species *Coscinodiscus radiatus* (42 SS), *Navicula petersenii* (36 SS), *Gyrosigma balticum* (35 SS), *Thalassiothrix longissima* (32 SS), *Pleurosigma angulatum* (18 SS), and *Leptocylindrus denicus* (7 SS) were shown distinct presence after monsoon. Phytoplankton numbers were reduced more or less ¼ the in coastal waters during monsoon season (dormant stages of certain phytoplankton and dilution of seawater) as compared to premonsoon and post-monsoon.

Percentage composition of phytoplankton species were belong to Bacillariophyceae 61.272%, Chlorophyceae 38.249%, Euglenophyceae 0.479%, Cyanophyceae 0%, and Pyrrophyceae 0% in coastal waters (post-monsoon season) (Figure-15).

Phytoplankton species *Coscinodiscus radiatus* (42 SS), *Navicula petersenii* (36 SS), *Gyrosigma balticum* (35 SS), *Thalassiothrix longissima* (32 SS), *Pleurosigma angulatum* (18 SS), *Chlamydomonas* sp. (15 SS), *Amphipleura pellucida* (12 SS), *Thalassiosira weissflogii* (10 SS), *Biddulphia pulchella* (8 SS) and *Ceratium hirundinella* (8 SS), were present at number of sampling stations in post monsoon season.

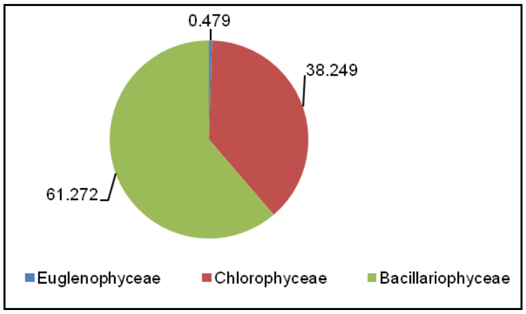

Figure 15: Phytoplankton composition in surface coastal waters of Mumbai in post-monsoon

Other study reveals plankton species were dominated due to limiting a nutrient concentration or factor in temperate waters. A discrepancy termed as the paradox of the plankton i.e. numbers of known coexisting plankton species for exceeds their expected biodiversity (Menden-Deuer and Rowlett, 2016). Similarly, phytoplankton species were following the trend for few phytoplankton species along coastal waters of Mumbai.

The study in eastern Adriatic estuary revealed that waters were mostly P limited, PO_4 and TIN 3-5 times lower, resulting in a fivefold decrease in biomass (<100ng chlorophyll 'a' l^{-1}) in middle estuary and coastal sea. Due to reduced nutrient input in summer, the phytoplankton distributed in the upper estuary (1000ng chlorophyll 'a' l^{-1}). To assess group presence, detection of biomarker pigments were used as fucoxanthin, alloxanthin and 19'-hexanoyloxyfucoxanthin, while lower but indicative contribution of peridinin and chlorophylls (Uilicic et. al., 2008). The nanoplanktonic species was comprised of unicellular diatoms, Dinoflagellates, Cryptophytes and Chlorophytes.

Bloom of *Biddulphia pulchella*, *B. biddulphiana* and *B. laevis* in association with *Cladophora* sp. in were reported in demarcated Lake-Coastal zone "LC zone" (Araniar river-lagoon confluence, south-close to seashore) of Pulicat lagoon (Santhanam et al., 2018).

The studies of phytoplankton 132 taxa belongs 3 taxonomic groups (composition - diatoms, Dinoflagellates and Silicoflagellates) were recorded in coastal water of the Datca and Bozburun peninsulas between 2002-2004. Spatial changes revealed that phytoplankton *Prorocentrum micans*, and *Thalassionema nitzschiodes* were very sensitive to ecosystem changes (Tas, 2014).

In addition, transect wise *Klebsormidium elagans*, *Phacus curvicauda*, *Cosmarium pananense*, *Dictylococcopsis* sp. were recorded in post-monsoon season. Number of phytoplankton species *Trichodesmium erythraeum*, *Thalassiosira weissflogii*, *Eucampia cornuta*, *Biddulphia pulchella*, *Chaetoceros pseudonitzschia Navicula petersenii*, *Nitzschia palea*, *Thalassiothrix longissima*, *Thalassionema nitzschiodes*, *Rhizosolania setigera*, *Coscinodiscus radiatus*, *Cymatopleura* sp., were present in transect A,B,C, and D during post-monsoon. *Ditylum brightwellii*, *Chlorella marina* were present at sampling stations of transect B. *Klebsormidium elagans*, *Phacus curvicauda*, *Cylindrocystis brebissonii*, *Gyrosigma balticum*, *Ceratium hirundinella*, *Nitzschia palea*, *Biddulphi pulchella*, *Eucampia cornuta*, *Cymatopleura solea*, and *Synedra ulna* were present at sampling stations of transect C. Few phytoplankton *Navicula petersenii*, *Ditylum brightwellii*, *Biddulphia pulchella*, *Eucampia cornuta*, *Trichodesmium erythraeum* and *Klebsormidium elagans* were observed at sampling stations of transect D(Table-2).

TABLE 2

List of Phytoplankton species recorded in (Transect 1 to 4) in Coastal waters during the study period (+++ indicates highly abundant > 10,000 cells/L; ++ moderately abundant 100-10,000 cells/L; + present 1-100cells/L; - absent)

S. No.	Species	Pre monsoon	Monsoon	Post monsoon	High tide	Neap tide
	Cyanobacteria					
1	*Oscillatoria rubescence* De landi's/*O. Mujuscola* (Dillwyn) Dillwyn 1817	-	-	+	-	-
2	*Anabaena Spiroides var. crass Lemm*	-	+	-	-	-
3	*Phormidium ambiguum* Gom.	-	-	-	-	+
4	*Trichodesmium erythraeum*	+	+	+	++	-
5	*Calothrix braunii* dr-ralf-wagner.de	-	-	-	-	+
	Euglenophyceae					
6	*Phacus curvicauda* swir	-	-	++	+	++
	Chlorophyceae (Planktonic Green algae					

7	*Chlamydomonas polypyrenoidenum*	++	-	-	-	-
8	*Chlorella marina*	+	-	+	+	++
9	*Planktosphaeria* sp.	-	-	-	+	-
10	*Closteridium lunula* Reinsch	-	-	-	-	+
11	*Dictylococcpsis* sp.	-	-	+	-	-
12	*Staroustrum singulum* (West & G.S. West) G.M. Smith.	-	-	-	-	+
13	*Spirotaenia Condensata* Brébisson in Ralfs	-	-	-	-	+
14	*Cylindrocystis brebissonii* Menegh.	++	++	++	+++	++
15	*Cosmerium* sp.	-	-	+	-	++
16	*Desmidium swartzii* C. Agardh ex Ralfs	-	-	-	+	++
17	*Klebsormidium flaccicum* (*Ulothrix* sp.-Hor midium sp.)	-	-	+	+++	+++
18	*Mougeotia genuflexa* (Roth) C.Agardh	-	-	-	+++	+++
	Bacillariophyceae					
19	*Navicula petersenii* Hustedt.	++	++	++	+++	++
20	*Nitschzia* pelea (Brébisson) Ralf	++	++	++	++	++
21	*Nitzschia seriata*	-	+	++	+	+
22	*Amphipleura pellucida* (Kützing)	++	-	-	+	+
23	*Thalassiothrix longissima* (cleve and Grunow,1887)	++	++	++	++	++
24	*Thalassiosira weissflogii*	+	-	+	++	+
25	*Thalassionema nitzschiodes*	++	-	+	++	++
26	*Rhizosolania setigera* (Brightwell)	++	+	++	+	++
27	*Leptocylindrus danicus* Cleve	-	++	++	++	++
28	*Pleurosigma angulatum* (Queckett.) W. Smith,1852	+	+	++	-	+
29	*Gyrosigma acuminatum* (Kutz.) Cleve	++	+	+	++	++
30	*Biddulphia pulchella S.F.Gray*	-	+	++	+	+
31	*Biddulphia chinensis*	++	++	+	++	++
32	*Coscinodiscus radiatus* Ehrenberg	++	+	++	+	+
33	*Stephanodiscus* hantzschii Grun	-	-	-	+	++
34	*Ditylum brightwellii*	++	+	++	+	++
35	*Diploneis* sp.	+	-	-	-	++
36	*Synedra ulna (Nitzsch.) Ehrenberg*	+	-	+	-	+
37	*Chaetoceros pseudonitzschia*	++	+	++	-	++
38	*Cymatopleura solea* (Brébisson) W.Smith	-	+	+	-	-
39	*Amphiprora paludosa* W. Smith	-	+	++	-	-
40	*Asterionella Formosa* Huss.	-	-	-	+	++
41	*Eucampia cornuta* (Cleve) Grunow	-	-	++	-	+
42	*Cyclotella meneghiniana* Kutz.	-	-	-	+	-
43	*Bacillaria paradoxa* J.F.Gmelin	-	-	-	-	+
44	*Skeletonema costatum* (Greville) Cleve	-	-	-	+	+

	Pyrrophyceae					
45	*Ceratium hirundinella* (O.F.Muller) Duj.	++	-	+	-	-
46	*Peridinium cinctum* (O.F.Muller)Ehrenberg	-	-	-	+	-
	Total phytoplankton species	19	18	27	27	35

Statistical analysis of data, two ways ANOVA following sequences (i) Source of Variation, (ii) Sum of Squares (iii) Degree of Freedom (iv) Mean Squares and (v) Variance Ratio were studied with relation to seasonal variation of phytoplankton at 64 sampling stations, transect A,B,C,and D in coastal waters (Table: 3-5).

TABLE 3
Phytoplankton distribution in coastal waters
(Premonsoon-Summary)

Source of Variation	Sum of Squares	Degree of Freedom	Mean Squares	Variance Ratio
Treatments (Zones)	241,430.19	3 (t-1)	80,476.73	2.9880
Transects	673,789.69	25 (t-1)	26951.68	1.0008
Residuals	2,019,935.78	75	26932.47	-
Total	2,935,155.66	103	-	-

TABLE 4
Phytoplankton distribution in coastal waters
(Monsoon-Summary)

Source of Variation	Sum of Squares	Degree of Freedom	Mean Squares	Variance Ratio
Treatments (Zones)	8,240.7	3 (t-1)	2,746.9	0.2684
Transects	143,826.2	19 (t-1)	7,569.8	0.7397
Residuals	583,314.2	57	10,233.58	-
Total	735,381.1	79	-	-

TABLE 5
Phytoplankton distribution in coastal waters
(Post-monsoon-Summary)

Source of Variation	Sum of Squares	Degree of Freedom	Mean Squares	Variance Ratio
Treatments (Zones)	20,930,308	3 (t-1)	6,976,769.3	15.29
Transects	36,933,454.1	18 (t-1)	2,051,858.56	4.498
Residuals	24,631,253	54	456,134.31	-
Total	82,495,015.1	75	-	-

Comparing the Sums of squares

In this case, premonsoon period, sum of square is 241,430.19/2,935,155.66 = 0.0822 or 8.22% of the variation in phytoplankton numbers. After rainy season, the sum of squares for treatments seems much smaller than that for correct, suggesting treatments explain a substantial part of the variation in phytoplankton numbers in fact, to be precise it is 8,240.7/735,381.2 = 0.0112 or 1.12% of the variation in phytoplankton numbers. In post-monsoon period, phytoplankton sum of square is 20903308/82495015.1 = 0.2533 or 25.33% of the variation in phytoplankton numbers. This quantity is useful measure of how good the model is and it is called "R-squared" or r^2.

F-ratio

Four observations were selected from one population and allocated to treatments at random, we expect an F-ratio of 1 as treatment and error mean square would be equal. In premonsoon period, Phytoplankton F-ratio is 80476.73/26932.47 = 2.988. If the treatments explained nothing, the F-ratio is 0.1 as in case of monsoon, here we got a value of 0.2684 (2,746.9/10,233.58). If treatments explained every thing, the F-ratio will be infinity (very large!). The larger our variance ratio, the more evidence we have that the treatments differ from each other more than just by chance as in case of post monsoon. In post-monsoon period, Phytoplankton F-ratio is 6976769.3/456134.31 = 15.295.

IV. Conclusion

Number of places Ulhas river receives discharge of industrial and domestic waste from point sources on west bank in the city . Estuary is having variable depths i.e. water table 2-3meters in upper reaches of Ulhas river is largely affected due to pollution. In coatal waters at certain locations marine out fall ate locater 3km to 5km in nearshore waters. This phytoplankton monitoring research was conducted considering phytoplankton density in response to seasonility and local factors influencing phytoplankton in Ulhas river estuary and coastal zone in three seasons premonsoon, after monsoon and post monsoon at Mumbai, Maharashtra.

Indigenous phytoplankton biomass only flourish or show bloom when in estuary the population growth rate is greater than the flushing rate i.e. the time required for a parcel of water, irrespective of source to leave the water body and get mixed with coastal waters. The reason behind is the salinity variation in coastal waters as resultant interaction of variable local factors, river discharges, tidal state and wind conditions. The distribution of phytoplankton wer observed performing autotrophic living, rapid growing 2-3 division d^{-1}.These are good indicators of water quality in estuarine zone .

Phytoplankton Chlorophyceae members and group percentage composition were increased as compared to Bacillariophyceae in estuarine waters at many sampling stations during monsoon and post monsoon.

Phytoplankton were observed in euphotic zone of coastal waters during all three seasons. *Cylindrocystis brebissonii*, *Chlorella marina*, and *Chlamydomonas* sp. (Chlorophyceae) salinity tolerant forms were present in all four transects A,B, C and D in premonsoon and postmonsoon seasons (Raymont, 1980). Toxin producing phytoplankton species *Trichodesmium* sp. (Cyanophyceae), *Chaetoceros pseudonitzschia* (Diatom), *Ceratium hirundinella* (Pyrrophyceae), which are also known to be bloom forming sp. were observed in coastal waters of Mumbai. Species of planktonic Chlorophyceae, Euglinophyceae and Pyrrophyceae were observed at Worli, Bandra and Errangal marine out fall outfalls in 2 and 3 transects lines of coastal zone. Coastal phytoplankton belong to *Ditylum brightwellii*, *Leptocylindrus danicus*, *Chaetoceros pseudonitzschia*, *Biddulphia pulchella*, *Coscinodiscus radiatus* and *Gyrosigma balticum* were observed at sampling stations of transect D.

Micronutrients promote growth of phytoplanktonic algae physiological processes e.g. inorganic ions CO,CD,Zn in carbon dioxide acquisition; Fe and Mn in carbon fixation; Zn and Cd and Se in silica uptake; Fe and Mo in N2 fixation and Fe,Cu and Ni in organic N utilization (Baeyens et al., 2018). Phytoplankton assimilate energy in presence of micronutreints for growth (Morel et al., 2003) and simultaneously phosphorus is limiting factor of cell multiflication . Themain inorgnic forms nitrate, nitrite and ammonium, can all be utilized as nitrogensources by majority of algal speies. IN sea water this effect is not so significant because the medium is buffered and ammonium is at least as useful a source as the other inorganic forms for most phytoplankton in culture and appers, moreover, to be universally utilizable. Nitrate supports good growth with most phytoplankton but there are some exceptions e.g. flagellates (Raymont J.E.G., 1980. Plankton and productivity in the Ocean Chapter-7 Factor Limiting primary production: Nutrients pp. 297-345).

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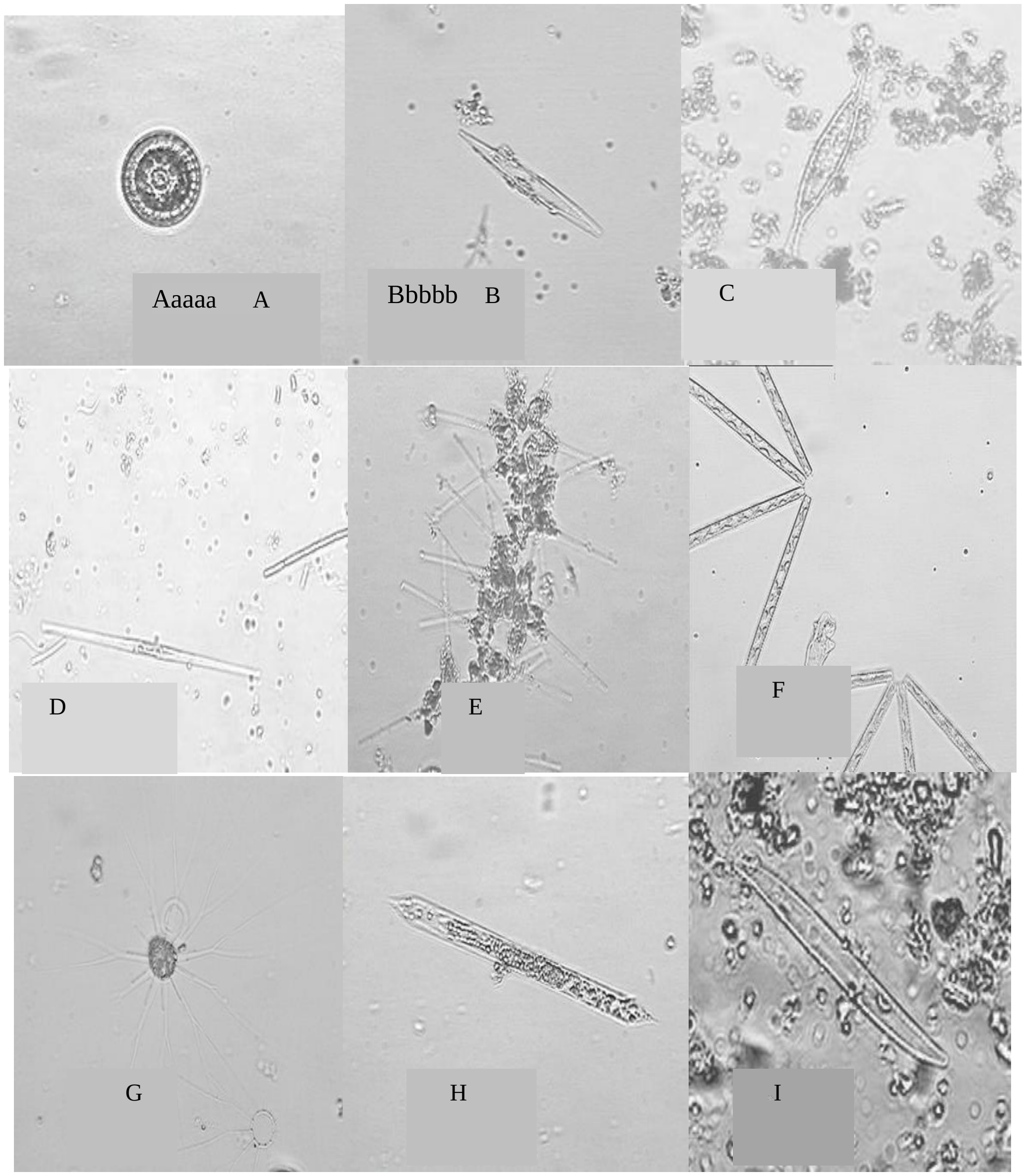

Plate 1: Phytoplankton in Estuarine waters and coastal waters

A. *Cyclotella meneghiniana* **B**. *Amphipleura pellucida* **C**. *Gyrosigma fasciola* (Ehrenb.) Griffith & Henfrey **D**. *Ankistrodesmus* sp. **E**. *Thalassiothrix nitzschiodes* Cleve & Round **F**. *Asterionella japonica* **G**. *Bacteriastrum hyalinum* **H**. *Rhizosolania alata* **I** . *Gyrosigma strigilis*

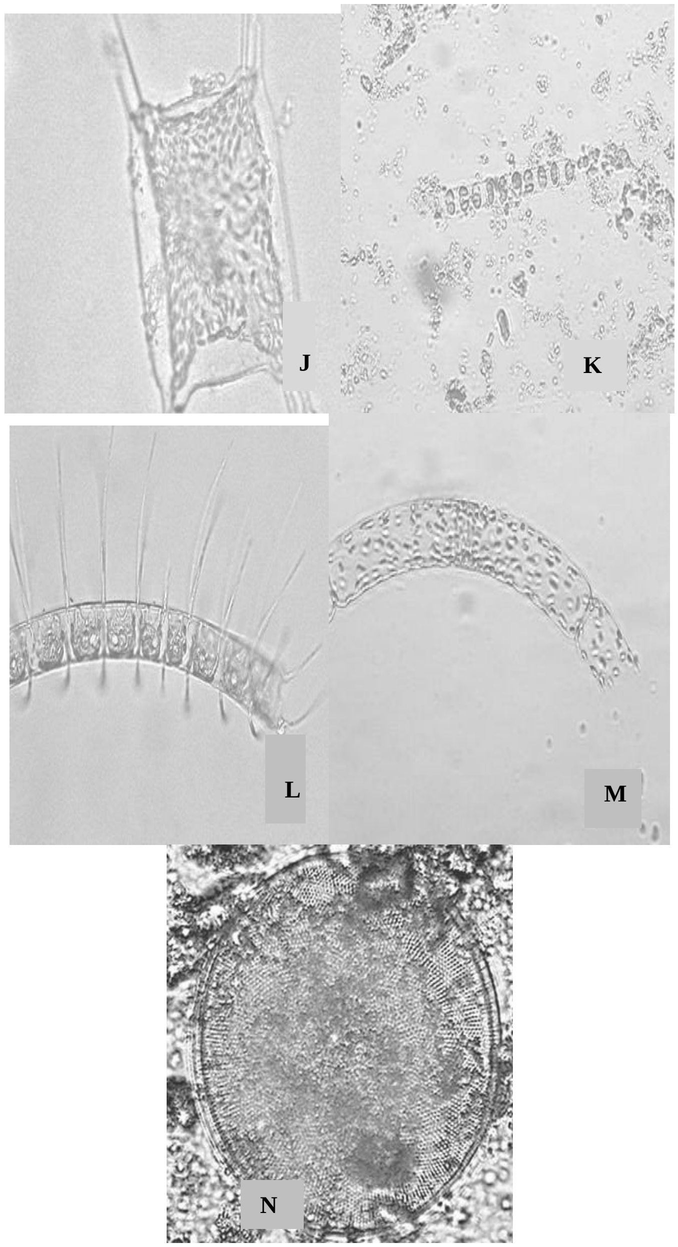

Plate 2: Phytoplankton in coastal waters

J. *Biddulphia laevis* **K.** *Skeletonema costatum* **L.** *Coscinodiscus radiatus* **M**.*Chaetocros pseudonitzschia* **N**. *Leptocylindrus denicus*