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PHYTOPLANKTON DIVERSITY IN DIGBOI OIL REFINERY EFFLUENT RECEIVING STREAM OF ASSAM, INDIA

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Key words: Phytoplankton, Water quality, Oil refinery effluent, Digboi, Assam

Abstract

A comprehensive study was carried out to investigate phytoplankton community and water quality in the Digboi oil refinery effluent stream. Taxonomic composition, abundance, spatial distribution, temporal dynamics of phytoplankton were studied along with physicochemical properties of water based on monthly data collected from seven selected sampling stations during April, 2011 - March, 2012. Altogether 139 species (7 orders, 19 families, 67 genera) of phytoplankton were identified of which Bacillariophyceae was the dominant class with 45 species followed by Chlorophyceae 40, Cyanophyceae 34 and Euglenophyceae 20. Though distinct changes in community structure were reported, higher phytoplankton abundance revealed during the post monsoon months. Correlation analysis showed influence of phenol and total oil content (TOC) along with pH, inorganic phosphorus and nitrate content in distribution and abundance of the phytoplankton.

Introduction

Phytoplankton are microscopic plants that grow in water bodies. They are very sensitive to slightest changes in environmental conditions of their habitat (Palmer 1959). Being located at the base level of energy transfer or trophic structure phytoplankton provide more accurate information on changing habitat characteristics compared to other aquatic lives (McCormick and Cairns 1994). Therefore, phytoplankton observation has been used as a reliable tool for biomonitoring of pollution in any aquatic bodies (Mathivanan *et al.* 2007). Digboi is the place in India where for the first time crude oil was explored in Asia during late 19th century and Digboi refinery is the oldest petroleum refinery in the subcontinent established in the year 1901. The refinery has been regularly discharging hazardous chemicals such as oil, hydrocarbon, phenol etc. to a natural stream that created a stress condition for growth of aquatic flora and fauna including phytoplankton. A little work has so far been done to understand the effect of petroleum refinery effluent on fresh water algal community in the region (Singh and Gaur 1988, Baruah *et al.* 2009). The present investigation was planned to undertake a study on diversity, distribution and abundance of phytoplankton community of effluent receiving stream of Digboi oil refinery (Assam), India in relation to water quality. Correlation between different water parameters and phytoplankton data were also studied to evaluate their interactions.

Materials and Methods

The study was conducted during April 2011 to March 2012. The effluents of the refinery are pushed out through an open drain named Telnala flowing through Digboi municipal area and discharged into a natural stream that originates from Digboi reserve forest and flows through paddy fields. Seven sampling stations (Fig. 1) were selected and designated as S1, S2, S3, S4, S5, S6 and S7. S1 station was the effluent receiving point of the drain. S2, S3 and S4 were about 500 m, 1 km and 2 km away from S1, respectively. S5 was the confluence of the effluent carrying

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drain (Telnala) and the natural stream. S6 was at 500 metre upstream and S7 was 500 meter downstream on the natural stream from the confluence point (S5). From each station phytoplankton and water samples were collected in three replicates in monthly intervals using Nansen sampler. Identification of phytoplankton samples were done by morphological observations consulting literature and monographs of Fritsch (1935, 1961), Smith (1950), Desikachary (1959), Ramanathan (1964), Prescott (1975), Gandhi (1998), Perumal and Anand (2009) and Yamagishi (2010). The physicochemical parameters, such as water temperature, pH, conductivity, turbidity were measured on the spot using Systronics Digital Water Analyzer 371. DO, free CO_2, BOD, COD, inorganic phosphorus, nitrate, phenol and total oil content (TOC) were measured following APHA (2012). The abundance values were calculated under Sedgwick rafter plankton counting cell. The species with more than 75% frequency were designated as common, followed by frequent (40 - 75%) and rare (< 40%), respectively. Pearson's correlation coefficients among the variables of water quality along with phytoplankton abundance were computed and analyzed using XLstat version 2013.5.

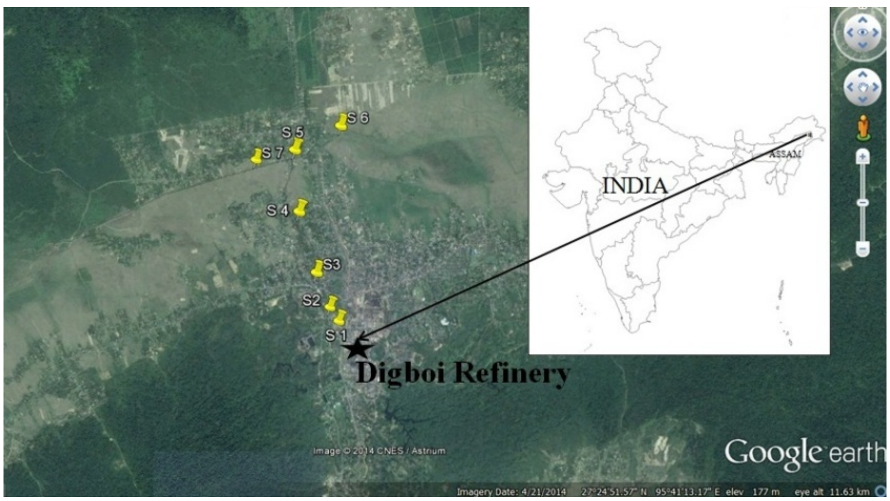

Fig 1. Location map of sampling stations along the Digboi refinery effluent stream.

Results and Discussion

The phytoplankton species recorded during the present endeavour are depicted in Table 1 along with their frequency of occurrence and abundance in different sampling stations. A total of 4 classes, 7 orders, 19 families, 67 genera and 139 species of phytoplankton were recorded from the Digboi oil refinery effluent receiving stream, which belonged to Cyanophyceae (17 genera, 34 species), Chlorophyceae (22 genera, 40 species), Euglenophyceae (8 genera, 20 species) and Bacillariophyceae (20 genera, 45 species).

The Bacillariophyceaean members were dominant in the Digboi refinery effluent receiving stream (Table 1). Kelly (1998) reported that Bacillariophycean dominance in an aquatic ecosystem is a major indicator of water quality and environmental condition as they are adapted to a wide range of physico-chemical parameters. Out of 20 Bacillariophyceaen genera recorded in the present study, 12 were Palmer's pollution tolerant genera (Palmer 1969). They were *Melosira*, *Cyclotella, Fragilaria, Synedra, Achnanthes*, *Navicula*, *Pinnularia, Gomphonema*, *Cymbella*, *Nitzschia, Hantzschia* and *Suriella* (Table 1) and they indicated higher pollution load (Atici and

Table 1. List of recorded phytoplankton along with their distribution, frequency and abundance in the Digboi refinery effluent stream.

Name of species	Study sites and Frequency and Abundance													
	S1		S2		S3		S4		S5		S6		S7	
	F	A	F	A	F	A	F	A	F	A	F	A	F	A
Class: Cyanophyceae; Order: Chroococcales; Family: Chroococcaceae														
Microcystis flos-aquae (Wittrock) Kirchner	-	-	C	+++	-	-	C	+++	-	-	-	-	-	-
Chroococcus varius A. Braun	C	++	C	+++	-	-	-	-	F	+++	-	-	-	-
C. turgidus (Kützing) Nageli	C	+	C	++	-	-	C	++	C	+	-	-	-	-
Gloeocapsa stegophila Rao	C	++	C	+	-	-	-	-	R	++	-	-	-	-
Aphanocapsa delicatissima West & West	C	++	R	+	C	+	-	-	C	++	-	-	-	-
A. virescens Nageli	-	-	R	+	-	-	-	-	-	-	-	-	-	-
Aphanothece bullosa (Menegini) Rabenhorst	R	+++	R	+++	R	++	R	++	-	-	-	-	-	-
Aphanothece saxicola Naegeli	-	-	C	++	C	++	C	+	F	+	-	-	-	-
Coelosphaerium kuetzingianum Naegeli	C	+++	C	+++	F	+++	-	-	-	-	-	-	F	+++
Cyanosarcina burmensis Skuja	-	-	F	+++	F	+++	-	-	-	-	-	-	-	-
Merismopedia punctata Meyen	-	-	-	-	-	-	C	+++	C	+++	F	+++	C	+++
Dactylococcopsis fascicularis Lemmerman	C	+	C	++	C	++	-	-	R	++	R	++	-	-
Order: Nostocales; Family: Oscillatoriaceae														
Oscillatoria acuminata Gomont	F	++	-	-	-	-	-	-	C	+++	C	++	C	+++
O. curviceps Ag. Ex Gomont	R	+	F	+	F	+	-	-	-	-	-	-	F	+
O. limnetica Lemmerman	-	-	F	+	F	+	-	-	C	++	R	+	F	+
O. princeps Vaucher Ex Gomont	-	-	-	-	C	++	C	+	F	+	-	-	R	+
O. proteus Skuja	-	-	R	+	-	-	R	+	-	-	-	-	-	-

(Contd.)

O. pseudogeminata Schmidt	-	-	R	+	R	+	-	-	-	-	-	-	-	-
O. raoi J. De Toni	R	+	F	+	F	+	-	-	R	+	-	-	-	-
O. rubescene De Candolle	-	-	F	+	C	++	F	-	-	-	-	-	R	-
O. subbrevis Schmidt	-	-	F	+	F	+	F	+	-	-	-	-	F	+
O. subuliformis Kützing	-	-	-	-	C	++	C	+	F	+	-	-	F	+
O. tenuis Agardh Ex Gomont	C	+	C	+++	C	++	F	+	-	-	F	-	F	+
Phormidium ambiguum Gomont	-	-	-	-	-	-	F	+	C	++	-	-	C	++
P. inundatum Kützing	F	+	F	++	C	++	F	+	C	+	-	-	-	-
Lyngbya aeugineo-coerulea (Kützing) Gomont	-	-	-	-	-	-	-	-	C	+++	-	-	C	+++
L. contorta Lemmerman	R	+	F	+	F	++	-	-	-	-	-	-	F	+
L. majuscule Harvey Ex Gomont	-	-	C	++	C	++	F	++	C	++	-	-	F	+
Cylindrospermum stagnale (Kützing) Bornet *et* Flahault	-	-	-	-	-	-	-	-	-	-	F	+	R	+
Nostoc linckia (Roth) Bornet Ex Bornet *et* Flahault	C	+	-	-	-	-	-	-	C	+	C	+	C	+
Anabaena circinalis Rabenhorst Ex Bornet *et* Flahault	-	-	-	-	-	-	-	-	C	+	-	-	C	++
A. sphaerica Bornet *et* Flahault	-	-	R	+	R	+	-	-	-	-	-	-	-	-
Aulosira fertissima Ghose	-	-	-	-	C	+	C	+	-	-	-	-	F	+
Scytonema coactile Montagne Ex Bornet *et* Flahault	-	-	C	+	C	+	-	-	C	+	-	-	-	-
Class: Chlorophyceae; Order: Volvocales; Family: Volvocaceae														
Eudorina elegans Ehrenberg	C	+	C	++	C	++	C	++	-	-	-	-	-	-
Pandorina morum (Mueller) Bory St. Vincent	-	-	-	-	R	+	C	++	-	-	-	-	-	-
Gloeodendron ramosum Korshikov	-	-	R	+	-	-	-	-	-	-	-	-	-	-
Chlorococcum humicola Nageli	C	++	C	++	-	-	-	-	-	-	-	-	-	-
Tetraedron trigonum (Nageli) Hansgirg.	-	-	R	+	-	-	-	-	-	-	-	-	-	-

(Contd.)

Family: Oocystaceae														
Ankistrodesmus falcatus (Corda) Ralfs	-	-	C	+	C	+	C	+	-	-	-	-	-	-
A. fusiformis Corda	C	+	C	++	-	-	-	-	-	-	-	-	-	-
Monoraphidium indicum Hindak	-	-	C	+	F	+	-	-	-	-	-	-	-	-
M. mirabile (West & West) Pankow	-	-	-	-	F	+	-	-	-	-	-	-	-	-
Podohedra longipes Duer	-	-	F	+	-	-	R	+	-	-	-	-	-	-
Treubaria setigera (Archer) Smith	-	-	-	-	-	-	-	-	R	+	-	-	-	-
Botryococcus braunii Kützing	F	+	-	-	-	-	R	+	C	++	-	-	-	-
B. protuberans West & West	-	-	R	+	-	-	-	-	-	-	-	-	-	-
Dimorphococcus lunatus Braun	-	-	C	+	C	+	R	+	-	-	-	-	-	-
Family- Radiococcaceae														
Diplochloris lunata Fott	R	+	-	-	-	-	-	-	-	-	-	-	-	-
Coelastrum proboscideum Bohlin	C	+	F	+	C	+	C	-	F	+	-	-	-	-
C. pulchrum Schmidle	R	+	-	-	R	+	-	-	-	-	-	-	-	-
Dicloster acuatus Jao. Wei & Hu	R	+	-	-	-	-	-	-	-	-	-	-	-	-
Desmodesmus armatus Chodat	C	+++	C	+++	-	-	-	-	C	+	-	-	-	-
D. communis (Hegewald) Hegewald	C	+	-	-	-	-	-	-	-	-	-	-	-	-
Scenedesmus acutiformis Schroeder	F	++	-	-	-	-	-	-	-	-	-	-	-	-
S. acuminatus Lagerheim	C	+	C	++	C	++	C	++	C	++	R	+	C	++
S. acunae Comas	F	+	C	++	-	-	C	++	C	+	-	-	F	+
S.hunanensis Jao	R	+	-	-	-	-	R	+	-	-	-	-	-	-
S. perforates Lemmarman	F	+	R	+	R	+	-	-	R	++	-	-	-	-
S. praetervisus Chodat	-	-	R	+	-	-	-	-	-	-	-	-	-	-
S. pseudopoliensis Horto	R	+	R	+	-	-	-	-	C	+	-	-	-	-

(Contd.)

S. quadricauda (Turpin) Brebission	C	+	C	+	R	+	-	-	C	++	R	+	-	-
S. bijugatus (Turpin) Kuetzing	C	+	C	+	-	-	-	-	C	++	C	+	C	+
Tetrastrum elegans Playfair	-	-	-	-	-	-	-	-	-	-	-	-	R	+
Order: Ulotrichales; Family: Ulotrichaceae														
Ulothrix aequalis Kützing	-	-	-	-	-	-	-	-	-	-	C	+	C	+
Spirogyra gratiana Transeau	-	-	-	-	-	-	C	+	C	+	C	++	C	+
Family: Desmidaceae														
Closterium acerosum (Schrank) Ehrenberg	C	+	C	+	-	-	C	+	C	+	-	-	-	-
Cl. closteriodies (J. Roy *et* Bisset)	C	+	-	-	-	-	-	-	F	+	-	-	-	-
Cl.cynthia De Notaris	C	+	C	+	R	+	F	+	-	-	-	-	-	-
Cl. navicula (Brebisson) Lutkemuller	R	+	-	-	-	-	-	-	-	-	-	-	F	+
Cosmarium abbreviatum Raciborski	-	-	C	+	C	+	C	+	C	+	-	-	-	-
C. portianum Archer	F	+	C	+	C	+	C	+	-	-	-	-	-	-
C. pseudoretusum Ducellier	R	+	R	+	-	-	-	-	-	-	-	-	-	-
Staurastrum gracile Ralfe	C	+	C	+	-	-	-	-	C	+	C	+	C	+
Class: Euglenophyceae; Order: Euglenales; Family: Euglenaceae														
Euglena acus Ehrenberg	-	-	-	-	C	+	C	+	C	+	-	-	-	-
E. viridis Ehrenberg	-	-	-	-	-	-	F	+	C	+	-	-	-	-
E.. gracilis Klebs	-	-	-	-	-	-	C	+	C	+	-	-	-	-
E. elastica Prescott	-	-	-	-	-	-	R	+	F	+	-	-	-	-
E. polymorpha Dangeard	-	-	-	-	F	+	R	+	R	+	-	-	-	-
E. spirogyra Ehrenberg	-	-	-	-	-	-	R	+	C	+	-	-	-	-
Helikotropis okteres Pochmann	-	-	R	+	-	-	-	-	-	-	-	-	-	-
Lepocinclis acicularis Fran	-	-	C	+	C	+	C	+	C	+	-	-	C	+
*L..ovum (*Ehrenberg) Lemmerman	-	-	-	-	C	+	C	+	-	-	-	-	-	-

(Contd.)

Phacus acuminatus Stokes	-	-	C	+	C	+	C	+	C	+	-	-	C	+
P. carinatus Pochmann	-	-	-	-	-	-	-	-	F	+	-	-	-	-
P. curvicauda Swire	R	+	C	+	C	+	-	-	C	+	-	-	C	+
P. ovalis (Woronichin) Popova	-	-	C	+	C	+	C	+	-	-	-	-	-	-
Strombomonas longicauda (Swire) Defl	-	-	-	-	R	+	F	+	F	++	-	-	-	-
Trachelomonas abrupta Swire	R	+	-	-	-	-	R	+	R	+	-	-	-	-
T. armata (Ehernberg) Stein	C	+	-	-	-	-	-	-	-	-	-	-	-	-
T. curta Da Cunha	-	-	F	+	F	+	-	-	-	-	-	-	-	-
T. superba Swire	-	-	R	+	F	+	R	+	-	-	-	-	-	-
Family: Peranemaceae														
Peranema limax Christopher	-	-	-	-	-	-	-	-	R	+	-	-	-	-
Family: Petalomonadaceae														
Petalomonas platyrhyncha Skuja	-	-	F	+	-	-	C	+	C	+	-	-	-	-
Class: Bacillariophyceae; Order Centrales; Famil: Aulacosiraceae														
Aulacoseira granulata (Ehrenberg) Simon.	C	+	F	+	-	-	-	-	-	-	-	-	-	-
Family: Melosiraceae														
Melosira granulata (Ehrenberg) Ralfs	C	+	C	+	C	+	R	+	R	+	-	-	R	+
Himantidium arcus Ehrenberg	-	-	R	+	F	+	F	+	-	-	-	-	-	-
Cyclotella glomerata Bachmann	C	+	C	+	C	+	-	-	C	+	-	-	C	+
Order Pennales; Family: Fragilariaceae														
Fragilaria biceps (Kützing) Lange-Bertalot	F	+	-	-	F	+	-	-	-	-	-	-	-	-
F. crotonensis Kitton	-	-	R	+	-	-	-	-	-	-	-	-	-	-
F. pinnata Ehrenberg	C	+	C	+	C	+	C	++	C	+++	-	-	C	+
F. ungeriana Grunow	-	-	-	-	-	-	R	+	R	+	-	-	-	-
Synedra tabulata Kützing	C	+++	C	+++	-	-	C	+	C	++	-	-	C	+
S. crystallina Kützing	-	-	-	-	-	-	-	-	F	+	R	+	R	+
*S. ulna (*Nitzch) Ehrenberg	C	+++	C	++	C	+++	C	+	C	++	-	-	C	+

(Contd.)

Family: Eunotiaceae														
Eunotia camelus Ehrenberg	R	+	-	-	F	+	-	-	-	-	-	-	-	-
Family: Achnanthaceae														
Achnanthes lanceolata (Brebisson) Grunow	C	+	C	+	C	+	C	+	C	++	-	-	C	+
A. exigua Grunow	F	+	-	-	F	+	-	-	-	-	-	-	-	-
Family: Naviculaceae														
Diadesmis confervacea Kützing	F	+	C	+	C	++	-	-	-	-	-	-	-	-
Navicula amphirhynchus Ehrenberg	C	+	C	+	C	+	C	+	C	+	-	-	C	+
N. capitata Ehrenberg	F	+	F	+	C	+	C	+	C	++	C	+	C	+
N. cincta Kützing	C	+	C	+	C	+	C	++	C	+++	R	+	C	+
N. cryptocephala Kützing	F	+	C	+	C	+	C	++	C	++	-	-	-	-
N. cuspidata Kützing	-	-	C	+	C	+	C	+	C	+	-	-	C	+
N. gracilis Ehrenberg	-	-	F	+	-	-	C	+	-	-	-	-	-	-
N. sphaerophora Kützing	R	+	R	+	F	+	-	-	-	-	-	-	-	-
N. viridis Kützing	F	+	F	+	C	+	C	+	C	++	-	-	-	-
N. viridula Kützing	-	-	R	+	-	-	-	-	F	++	-	-	-	-
Pinnularia appendiculta (Ag.) Cleve	F	+	F	+	F	++	-	-	R	+	-	-	R	+
P. braunii (Grunow) Cleve	F	+	F	+	-	-	-	-	C	+++	R	+	C	+
P. interrupta W.Smith	C	+	-	-	F	+	-	-	-	-	-	-	-	-
Mastogloia braunii Grunow	F	+	C	+	C	+	-	-	-	-	-	-	-	-
Tropidoneis lapidoptera (Gregory) Cleve	-	-	-	-	R	+	-	-	-	-	-	-	-	-
Gomphonema augur Ehrenberg	F	+	C	++	C	+	-	-	-	-	-	-	-	-
G. lanceolatum Ehrenberg	C	+	C	+++	C	+	C	++	C	++	-	-	C	+
G. parvulum Kützing	C	+	C	+	C	++	C	+	C	+	C	+	C	+
Amphora elliptica Kützing	-	-	-	-	-	-	-	-	-	-	F	++	-	-

(Contd.)

Cymbella cymbiformis (Agardh) Kützing	C	+	C	++	C	+	C	++	C	+++	-	-	F	+
C. gracilis (Ehrnberg) Kützing	C	+	C	+	F	+	-	-	-	-	-	-	-	-
C. kappii Cholnoky	F	+	-	-	-	-	-	-	-	-	-	-	-	-
C. turgida Grunow	F	+	R	+	-	-	-	-	-	-	-	-	-	-
Family: Epithemiaceae														
Epithemia gibberula Kützing	R	+	-	-	R	+	-	-	-	-	-	-	-	-
Family: Bacillariaceae														
Nitzschia frustulum (Kützing) Grunow	C	+	C	++	C	++	C	++	C	+++	F	+	C	++
N. palea Kützing	-	-	C	++	C	+	C	+	C	++	-	-	-	-
N. spiculiodes Hustedt	-	-	-	-	F	+	-	-	-	-	-	-	-	-
N. stagnorum (Rabenhorst) Grunow	F	+	-	-	R	+	-	-	-	-	-	-	-	-
Hantzschia amphioxys (Ehrnberg) Grunow	R	+	-	-	-	-	-	-	-	-	-	-	-	-
Family: Surirellaceae														
Surirella capronioides Gandhi	-	-	-	-	F	+	F	+	R	+	-	-	-	-
S. subsalsa W. Smith	-	-	-	-	R	+	-	-	-	-	-	-	-	-

F = Frequency, A = Abundance; Frequency: C = Common, R = Rare, F = Frequent; Abundance (No. of cell/l): 10^0 - 10^2 = +, 10^2 - 10^4 = ++, 10^4 - 10^6 = +++.

Obali, 2010) in the stream as a whole. Sampling stations along the effluent drain Telnala were highly infested with two pollution tolerant centric genera *Melosira* and *Cyclotella*, two species of *Cymbella* (*C. cymbiformis* and *C. gracilis*) and two *Synedra* species (*S. tabulata* and *S. ulna*) where total oil content was high.

Chlorophyceae was the second largest phytoplanktonic algal class as recorded in the stream in the present study. *Scenedesmus* was the dominant genus with nine species. Palmer's pollution tolerant Chlorophycean genera *viz. Chlorococcum*, *Eudorina*, *Pandorina*, *Ankistrodesmus*, *Coelastrum* and *Scenedesmus* were common in sampling sites S1 to S5 along the Telnala with moderate to high abundance (Table 1). Though desmids have low tolerance with regard to polluted water (Mahadev *et al.* 2010), 8 species belong to *Closterium*, *Cosmarium* and *Staurastrum* were found common in all the stations along the Telnala. *Closterium* and *Cosmarium* of the family Desmidaceae are reported to be pollution tolerant genera by Palmer (1969). Singh and Gaur (1989) also recorded desmids in oil refinery effluent receiving stream.

Among Cyanophyceae, the abundance of *Microcystis flos-aquae*, *Chroococcus varius, Aphanothece bullosa, Coelosphaerium kuetzingianum*, *Cyanosarcina burmensis, Merismopedia punctata* and *Oscillatoria tenuis* were recorded high at the sampling stations S1 to S4 which indicated their resistance capacity to refinery effluent. Only 20 taxa of Euglenophyceae were reported from the stream (Table 1). Highest congregation of *Euglena* were reported at and around S5 which was also the confluence of Telnala with natural stream that carrying little agricultural wastes. Enhancing of euglenoid abundance in the point might be attributed to high inorganic phosphate and nitrate content of the water samples (Table 2). Lowest representation of euglenoiods at S1 indicated that they are quite sensitive to refinery waste and escape away due to high effluent concentration.

There were oscillations in ranges of the parameters in different stations of the stream (Table 2). The water temperature ranged from 13.62^0C at S6 to 31.62^0C at S1 (Table 2). The pH of the stream water was acidic during summer to alkaline in winter. Maximum pH recorded was 9.4 at S1 during winter and the minimum was 5.52 at S6 during summer. Conductivity showed a wide variation in all the seven stations from 35.4 µS/cm at study site S6 to 392.2 µS/cm at S1. The concentration of DO was recorded in the range of 2.14 mg/l at S3 to 8.78 mg/l at S6. The lower values of DO except at S6 indicated polluted status of the entire stream (Sheela *et al*. 2011 and Lekwot *et al.* 2012). Free CO_2 ranged from 1.89 mg/l at S7 to 21.70 mg/l at S1. Higher values of BOD were found at stations S2 to S4. COD ranged from 46.8 mg/l at station S6 to 216.8 mg/l at S1. The maximum concentration of inorganic phosphorus (4.99 mg/l) and nitrate (2.63 mg/l) were recorded at the station S6. Receiving of agricultural runoff from the adjoining fields might be attributed for overall higher values of the inorganic phosphorus and nitrate at S6. Highest values phenol and TOC recorded at S1 (phenol 1.18 mg/l and TOC 17.99 mg/l) and showing gradual decreasing trend towards natural stream (Table 2).

Phytoplankton abundance is an important indicator of water pollution (Haldar *et al.* 2014). It is regulated by physical, chemical and biological characteristics of the water body (Goldman and Horne 1983). The annual mean values of phytoplankton abundance at the different sampling stations were ranged from 38.42×10^3 cells/l at S1 to 363.43×10^3 cells/l at confluence point S5 (Table 2). There was a significant temporal variation in abundance of phytoplankton observed in the stream (Fig. 2). The luxuriant growth of phytoplankton was observed during the late monsoon to post monsoon months (August to October 2011), while the lowest abundance value was recorded during winter months (December 2011 to January 2012).

Table 2. Water quality in seven sampling stations of Digboi refinery effluent receiving stream.

Parameters	Sampling stations						
	S1	S2	S3	S4	S5	S6	S7
Temp.	19.84 - 31.36	17.38 - 29.96	16.52 - 30.28	15.88 - 29.48	15.2 - 28.72	13.62 - 27.5	14.8 - 28.78
pH	6.35 - 9.4	6.09 - 9.1	5.98 - 8.94	5.87 - 8.64	5.88 - 8.8	7.52 - 8.79	6.11 - 8.94
Conductivity (µS/cm)	148.2 - 392.2	72.2 - 377.2	49.8 - 301	34.2 - 303.2	115.2 - 340.2	35.4 - 219.8	70 - 297
Turbidity (NTU)	12.6 - 88.6	8 - 59.2	9.4 - 45.8	5.8 - 41.4	11.2 - 62.4	7 - 85.4	10.6 - 104.2
DO (mg/l)	2.34 - 4.32	2.42 - 4.8	2.14 - 4.48	2.32 - 4.66	3.28 - 5.42	4.12 - 8.78	3.58 - 8
Free CO_2 (mg/l)	6.27 - 21.70	4.45 - 19.77	4.82 - 17.70	4.31 - 16.06	3.58 - 14.72	3.08 - 14.32	1.89 - 13.16
BOD (mg/l)	1.64 - 3.98	2.53 - 5.62	2.61 - 6.7	2.67 - 5.73	1.87 - 4.78	1.63 - 4.7	1.54 - 5.12
COD (mg/l)	56 - 216.8	72.6 - 189.2	89 - 161.6	71.2 - 173	49 - 189.2	26.8 - 205.4	46.8 - 221.6
Inorganic PO_4 (mg/l)	0.68 - 1.83	0.70 - 1.73	0.59 - 1.93	0.45 - 2.19	0.97 - 4.17	1.22 - 4.99	0.73 - 3.82
Nitrate (mg/l)	0.54 - 1.37	0.63 - 1.79	0.59 - 1.38	0.49 - 1.91	0.86 - 2.27	1.15 - 2.63	0.65 - 2.14
Phenol (mg/l)	0.84 - 1.18	0.48 - 0.87	0.42 - 0.72	0.39 - 0.66	0.12 - 0.37	ND	0.12 - 0.37
TOC (mg/l)	6.75 - 17.99	3.03 - 14.81	1.81 - 11.52	1.44 - 12.17	0.61 - 10.99	0.30 - 3.13	0.65 - 6.51
Phytoplankton abundance ($\times 10^3$ cells/l)	38.42 - 103.77	77.59 - 183.82	95.38 - 286.00	135.48 - 315.32	189.48 - 363.43	108.68 - 285.74	136.17 - 311.85

Pearson's correlation coefficient analysis made it evident that there were strong interactions between pH, inorganic phosphorus, nitrate, phenol and total oil content with that of phytoplankton in the stream (Table 3). Increased inorganic phosphorus and nitrate content in water enhanced the phytoplankton abundance, whereas, a significantly negative relationship was observed with that of pH, phenol and total oil content in the Telnala as well as in the stream.

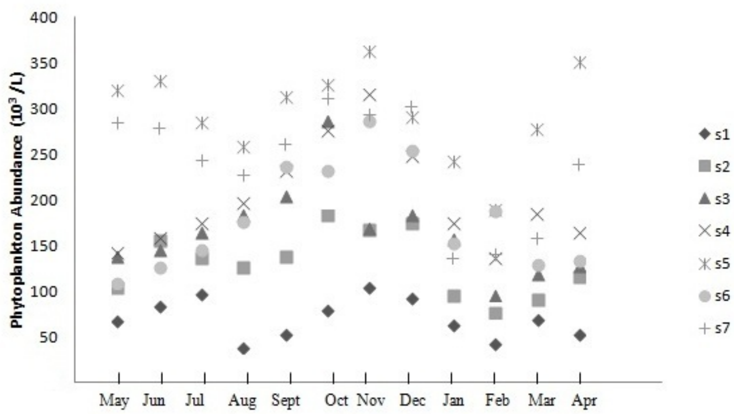

Fig. 2. Temporal variations of phytoplankton abundance at seven sampling stations along Digboi refinery effluent stream.

Table 3. Pearson correlation coefficients between water quality parameters of Digboi refinery effluent receiving stream with phytoplankton abundance during the study period.

Parameters	Phytoplankton abundance
Temperature	–0.028
pH	–0.290**
Conductivity	–0.158
Turbdity	0.022
DO	0.092
Free CO_2	–0.128
BOD	0.094
COD	–0.163
Inorganic PO_4	0.191*
NO_3	0.217*
Phenol	–0.650**
TOC	–0.600**

*p < 0.05; **p < 0.01.

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