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SPATIAL VARIATION IN PHYTOPLANKTON DIVERSITY IN THE SABARMATI RIVER AT AHMEDABAD, GUJARAT, INDIA

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ABSTRACT

Biological assessment is a useful alternative for rating the ecological quality of aquatic ecosystems since biological communities integrate the environmental effects of water chemistry. Phytoplankton are assemblages of heterogeneous microscopic algal forms whose movement is more or less dependent upon water currents. To know the nature of species composition of phytoplankton and their significance, the present observations were made for a period of twelve months in the Sabarmati River, Ahmedabad, India from three selected sites, i.e. upstream (site 1), midstream (site 2) and downstream (site 3). The study revealed the occurrence of 48 species of phytoplankton; among these, 21 species of Chlorophyceae, 13 species of Bacillariophyceae, 11 species of Cyanophyceae and 3 species of Euglenophyceae were recorded. The algal flora of polluted water bodies showed the dominance of blue green algae and diatoms like *Oscillatoria, Anabaena, Microcystis, Navicula, Nitzschia, Synedra, Gomphonema* throughout the investigation. Many green algae like *Eudorina, Scenedesmus, Stigeoclonium* and *Ankistrodesmus* also occurred abundantly and frequently. Various indices such as Palmer's, Nygaard's and Shannon's biotic indices have been used for the assessment of diversity of phytoplankton. The calculated Palmer's values of sites 1 to 3 were 16, 35 and 41 respectively. Shannon-Weaver species diversity index (H') values for the three sites were S1: 2.04; S2:1.41; and S3: 1.16. The Nygaard's indices value showed oligotrophic nature of the water at S-1, while a eutrophic nature of fresh water was observed at S-2 and S-3.

Keywords: Phytoplankton, Sabarmati River, Diversity Index, water pollution

1. INTRODUCTION

Phytoplankton abundance in a water body reflects the average ecological condition and, therefore, it may be used as an indicator of water quality [1,2]. In natural waters such as oceans, lakes, rivers and swamps, the greatest amount of biological production is due to the smallest organisms, namely the plankton. These microscopic plants comprise communities that drift aimlessly with tides and currents, yet they incorporate and transfer large amounts of energy that they pass on to higher trophic levels. Thus communities of plankton, as distinct from those of swamp, forest, or grassland, support other communities of aquatic species and man [3].

Population pressure, urbanization, industrialization and increased agricultural activity have significantly contributed to the pollution and toxicity of aquatic ecosystems. Pollutants bring about a change not only in the physical and chemical quality of water but also modify the biotic components, resulting in the elimination of some probably valuable species. Chemical analyses of water provide a good indication of the quality of aquatic systems, but they do not integrate ecological factors such as altered riparian vegetation or altered flow regimes and, therefore, do not necessarily reflect the ecological state of the system [4]. Biological assessment is a useful alternative for assigning the ecological quality of aquatic ecosystems since biological communities integrate the environmental effects of water chemistry in addition to the physical and geomorphological characteristics of rivers and lakes [5].

The Sabarmati River is one of the four major rivers that traverse the alluvial plains of Gujarat. It rises in the Aravalli hills at a North latitude of 24°40' and East longitude of 73°20' in Rajasthan State at an elevation of 762 meters above mean sea level. The river is known to be under contamination menace by wastes derived from industrial sources, sewage and agricultural activities that alter the physico-chemical

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and biological properties and ecology of the biotic environment. Therefore, the present study is an attempt to record the changes in the community structure of phytoplankton in the Sabarmati River, a backbone of Ahmedabad city, from upstream to downstream in response to the changing physico-chemical environment.

2. MATERIALS AND METHODS

2.1. Study area

Ahmedabad is located at 23.03°N and 72.58°E at an average elevation of 53 meters above mean sea level and spans an area of 310 km². The Sabarmati River enters Ahmedabad near Hansol and passes through the center of the city with a stretch of approximately 20-25 km from north to south.

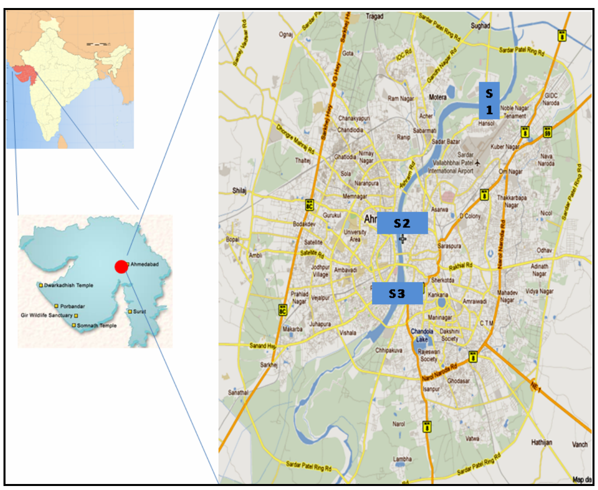

Figure 1 Site map of the study area

2.2. Sabarmati River

Three sites, namely Site-1 upstream - Indira Bridge (23°5'26"N and 72°37'47"E), Site-2 midstream-Gandhi Bridge (23°2'24"N and 72°34'24"E) and Site-3 downstream - Sardar Patel Bridge (23°0'40"N and 72°34'27"E) have been selected for the present work (Figure 1).

Site 1 is situated outside the main city near Kotarpur Village and is surrounded by agricultural fields, whereas Sites 2 and 3 are situated in the main city area and are approximately 4.5 km and 9 km away from Site 1, respectively. The work on the Sabarmati River Front Development is at a fast pace at Sites 2 and 3. It includes river dredging, construction of retaining walls, ghats, promenades, etc. These activities result in the influx of soil, cement and other particulate matter in the river, which affects the quality of the water and in turn leads to alteration in the plankton community. The water samples for physico-chemical and plankton analysis were collected on a monthly basis for the calendar year 2010-11.

2.3. Physico-chemical analysis

The water quality parameters such as temperature, pH and Dissolved Oxygen (DO) were measured *in situ.* Temperature was measured with a mercury-filled glass thermometer, pH with an EiE Instrument ATC model 132E pH meter and DO by the Winkler method. Other parameters, namely alkalinity, chloride, phosphate, sulfate and nitrate were measured in the laboratory with standard methods for the examination of water and wastewater [6,7].

2.4. Phytoplankton Analysis

The phytoplankton samples were collected using a 20μ mesh size planktonic net from approx. 1 m depth of the water column and were preserved in 4% formalin for further analysis. The water samples were allowed to sediment for microscopic identification of plankton. For quantitative analysis, one drop of sample was taken on a clean glass slide and phyto-plankton were counted by Lackey's drop count method, in which the coverslip was placed over a drop of water on the slide and the whole of the coverslip was examined by parallel overlapping strips to count all the organisms in the drop. About 20 strips were examined in each drop. The number of subsamples to be taken depended on examining 2 to 3 successive subsamples without any addition of unencountered species when compared to the already examined subsamples [6]. The results obtained are expressed as number of organisms per Liter of sample. The phytoplanktons analyzed were assigned to major groups, namely green algae (Chlorophyta), blue green algae (Cyanophyta), diatoms (Bacillariophyta) and Euglenophyta.

The identification of phytoplankta was carried out with the help of standard books and monographs [8-10]. Biodiversity indices were calculated using Palmer's algal index [11], Nygaard's trophic state indices [12] and the Shannon-Weaver diversity index to know the diversity of phytoplankton and pollution status of the Sabarmati River.

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Correlation coefficients (r) were calculated for phytoplankton density in relation to hydrochemical parameters using the Ky Plot Beta 2.0 version.

3. RESULTS

3.1. Water Quality Parameters

The average hydrochemical properties of water are given in Table 1. The surface water temperature of Sites 1-3 ranged between 18°C to 24°C. The temperature showed a gradual increase from the month of March till the onset of the monsoon season in July and gradually decreased from the rainy season to the post-monsoon months. The DO and pH of the water showed a highly positive correlation in river water (r = 0.860). The DO in the river water showed marked variation at different sites. The DO value at upstream S-1 ranged from 5 mg L^{-1} to 7.7 mg L^{-1} in the months of July and January, respectively. The DO level fell sharply downstream at Sites S-2 and S-3 with average values of 4.1 and 2.4 mg L^{-1}. The DO showed a negative correlation with temperature (r = -0.79), which confirms that at high temperature the solubility of oxygen in water decreases. The mean value of chloride varied between 41.5±9 to 102±16 mg L^{-1} in river water. The mean concentration of sulfate was found in the range of 1.4 to 8.0 mg L^{-1}. Sulfate exhibits positive correlation with nitrate and chloride, and negatively correlates with phosphate at the three river sites. A positive correlation between sulfate and chloride suggests that they are from similar sources [13].

Phosphate is present in natural waters as soluble phosphates and organic phosphates. In river water the mean values of phosphate ranged between 1.89±0.20 mg L^{-1} to 2.75±0.23 mg L^{-1} for all three sites. The phosphate concentration was high in the months of June and July (i.e. monsoon period), which could be attributed to agricultural runoff and discharge of water containing detergents, sewage water, storm water etc. from cities. Phosphate showed positive correlations with sulfate, nitrate and DO [14].

The concentration of nitrate varied from 0.18±0.11 mg L^{-1} to 0.36±0.04 mg L^{-1}. Nitrate showed negative correlation with DO and positive correlation with phosphate, sulfate and temperature. The spatial and temporal variation in nitrate represent the final product of the biochemical oxidation of ammonia [13]. Nitrate showed comparatively higher values in monsoon, which may be due to surface run-off from farms and storm water runoff into the river during early rain [15]. The elevated levels of nitrogen can cause eutrophication, which is observed in many shallow patches near the river bank [16]. Construction of reservoirs and dams also contributes to eutrophication as they decrease the flow velocities within a river [17].

The correlation coefficient of physico-chemical parameters and phytoplankton is summarized in Table 2. Analysis of the important parameters with the phytoplankton density showed a positive correlation of temperature with Cyanophyceae (r = 0.957), Bacillariophyceae (r = 0.904) and Euglenophyceae (r = 0.496), and DO with Cyanophyceae (r = 0.394) and Bacilariophyceae (r = 0.799). However, DO showed negative correlation with Euglenophyceae (r = -0.96). Oxidation of organic matter brings down the concentration of DO in water. Euglenophytes proliferate in environments poor in oxygen [18]. Furthermore, sulfate showed a positive correlation with Cyanophyceae (r = 0.371) and Euglenophyceae (r = 0.496). Nitrate also showed a positive correlation with Euglenophyceae (r = 0.56) and Bacillariophyceae (r = 0.778).

3.2. Phytoplankton

In the present study, the phytoplankton community in fresh water was represented by members of Chlorophyceae (Plates 1,2), Cyanophyceae (Plate 3), Bacillariophyceae (Plate 4) and Euglenophyceae (Plate 5) as represented in Table 3 and their sitewise occurrence is depicted in Table 4. The phytoplankton comprised 48 species, of which 21 species belong to Chlorophyceae, 13 species to Bacillariophyceae, 11 species to Cyanophyceae and 3 species to Euglenophyceae. The percentage distribution of phytoplankton is depicted in Fig 2A, 2B and 2C for Sites 1, 2 and 3, respectively.

Quantitative analysis of phytoplankton populations is summarized in Table 5. In the present study, the abundance of phytoplankton was highest during the pre-monsoon period, which could be attributed to more stable hydrographical conditions prevailing during summer months (Figures 3A, 3B and 3C).

The abundance of phytoplankton was lowered during the monsoon months when the water column was remarkably stratified to a large extent because of heavy rainfall, high turbidity caused by run-off, and decreased temperature and pH [19]. Chlorophyceae, Cyanophyceae and Euglenophyceae were found to be most abundant in the pre-monsoon season followed by the monsoon and post-monsoon seasons.

Palmer's index of pollution was calculated at the three sites for rating of water samples as high or low in organic pollution. The total score at Site 2 (midstream) and Site 3 (downstream) was greater than 20, indicating confirmed high organic pollution. The total score at Site 1 (upstream) was less than 20 indicating probable high organic pollution.

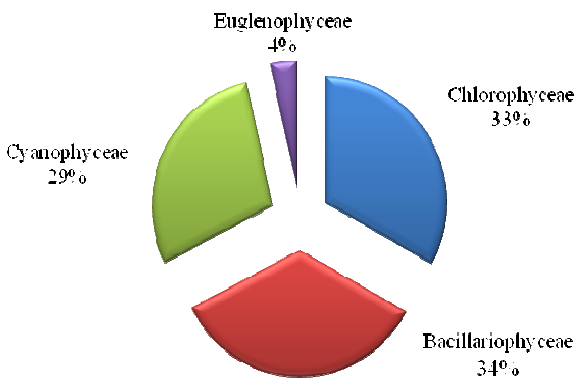


Figure 2A The species composition of different phytoplankton groups at Site 1

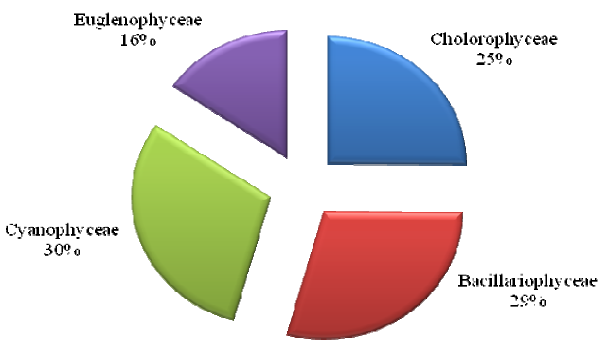


Figure 2B The species composition of different Phytoplankton groups at Site 2

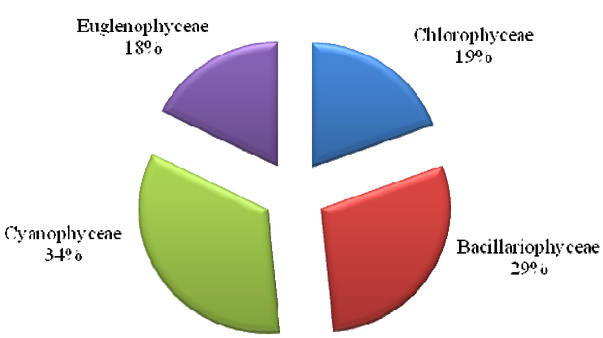


Figure 2C The species composition of different Phytoplankton groups at Site 3

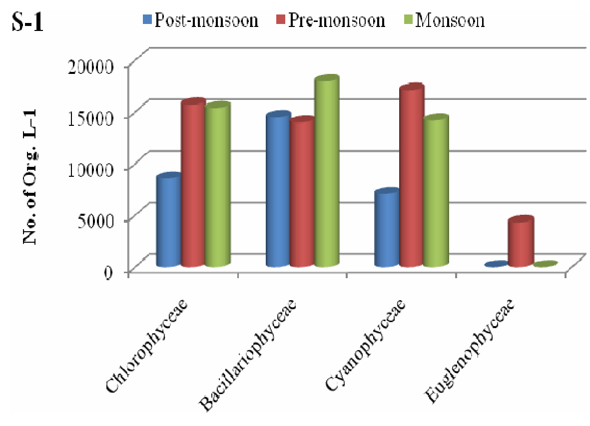


Figure 3A Seasonal variation in densities of different phytoplankton groups at Site 1

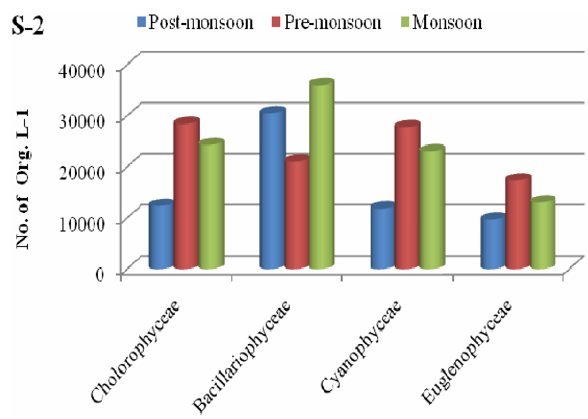


Figure 3B Seasonal variation in densities of different phytoplankton groups at Site 2

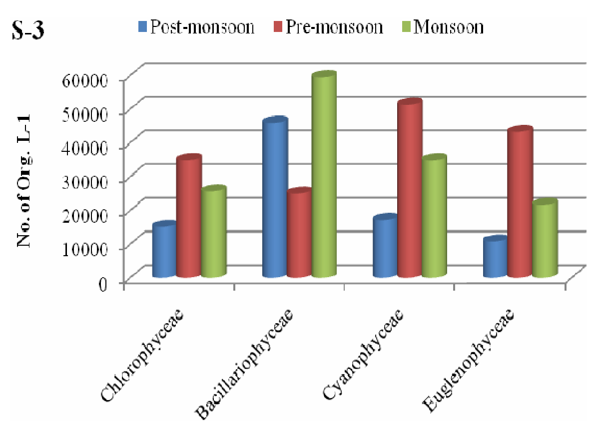


Figure 3C Seasonal variation in densities of different phytoplankton groups at Site 3

Plate - 1

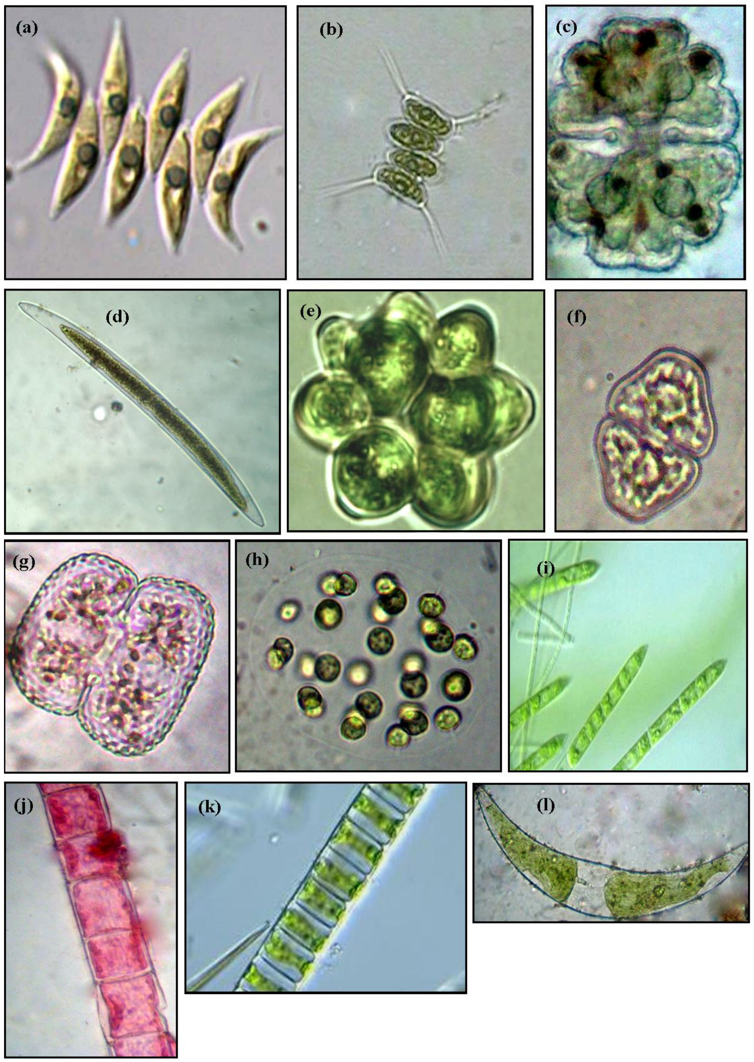
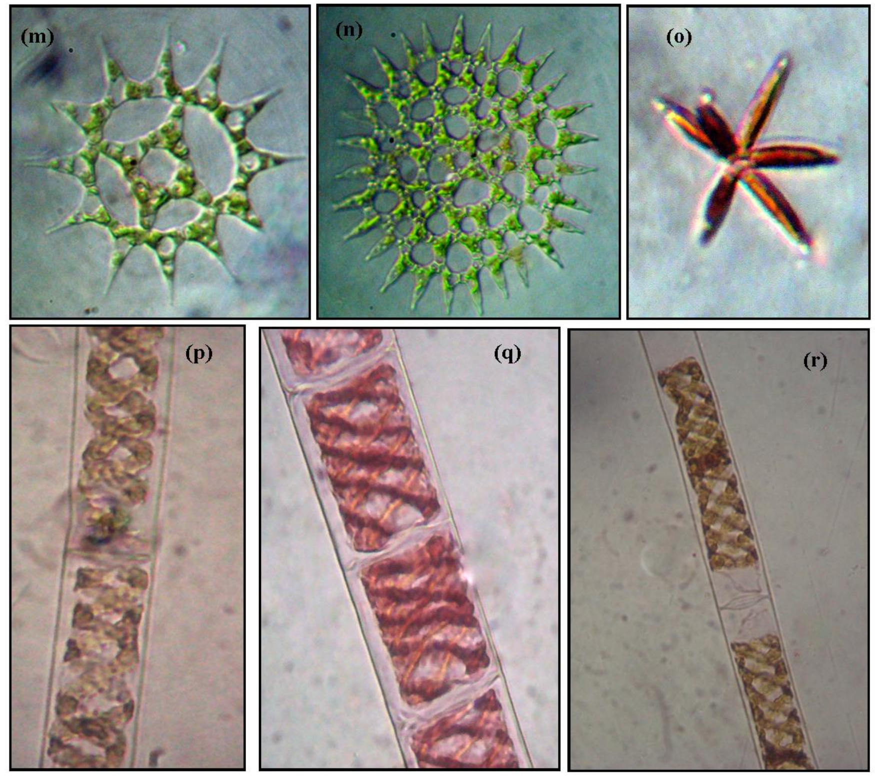


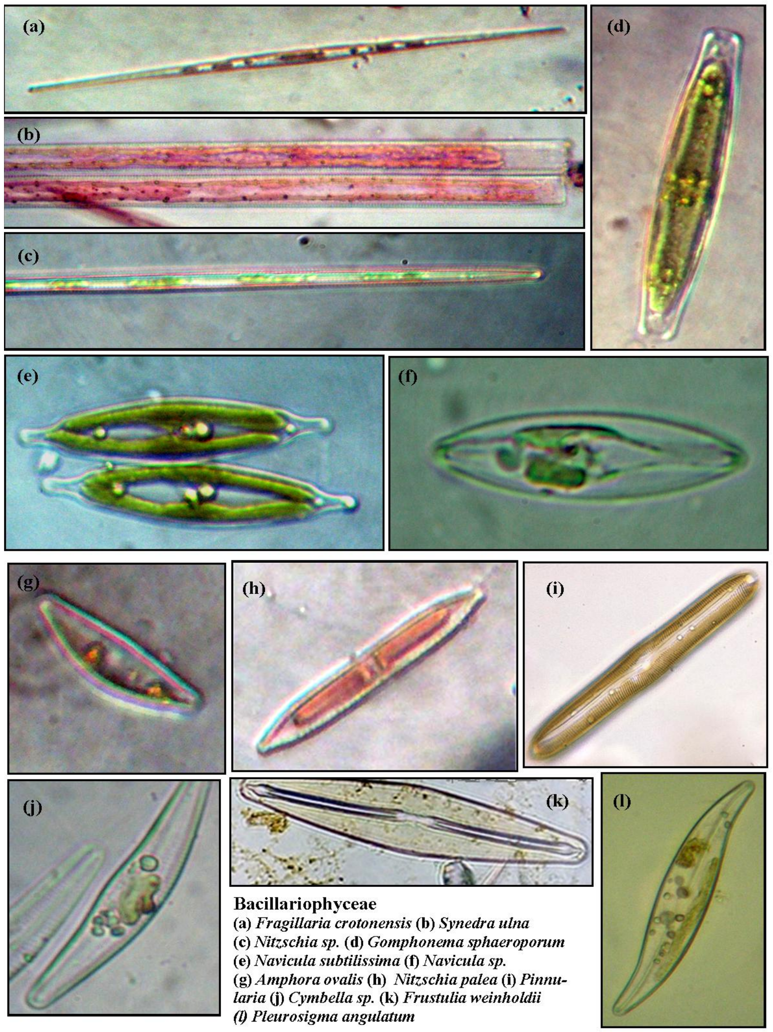
Plate - 2



Chlorophyceae

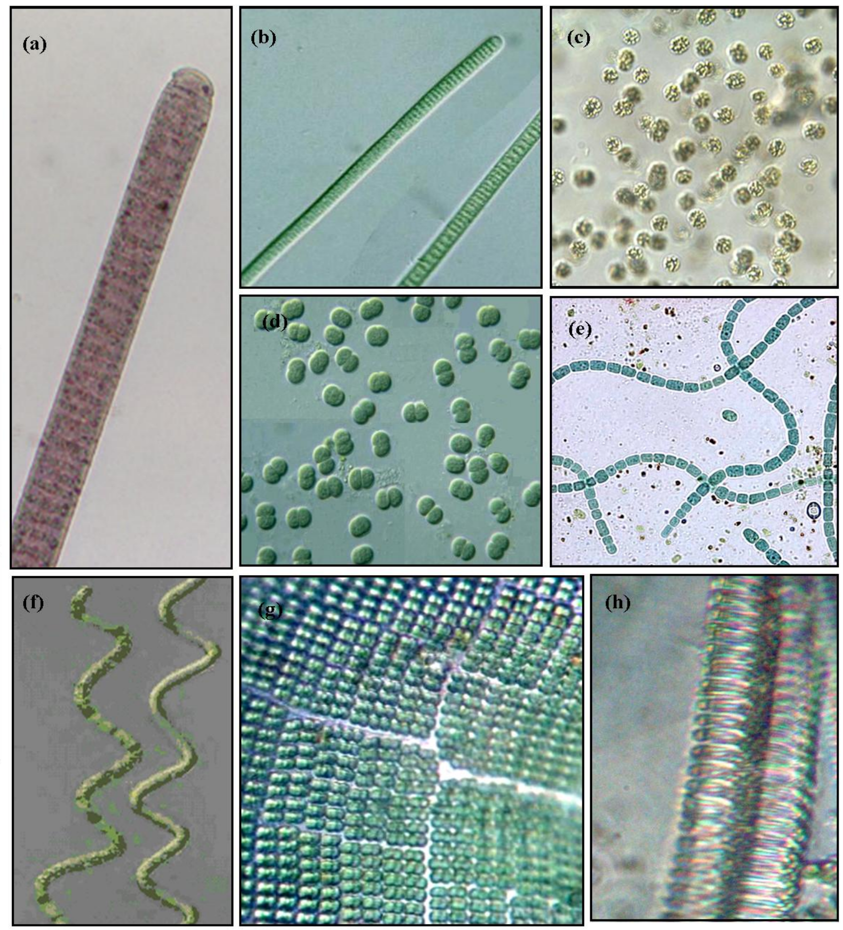
(a) ***Scenedesmus dimorphus*** **(b)** ***Scenedesmus quadricauda*** **(c)** ***Eustrum spinulosum*** **(d)** ***Closterium sp.*** **(e)** ***Coelastrum microsporum*** **(f)** ***Cosmerium granatum*** **(g)** ***Cosmerium obsoletum*** **(h)** ***Eudorina sp.*** **(i)** ***Stegioclonium tenue*** **(j)** ***Microspora willeana*** **(k)** ***Ulothrix zonata*** **(l)** ***Chlamydomonas closterium*** **(m)** ***Pediastrum simpex*** **(n)** ***Pediastrum duplex*** **(o)** ***Actinastrum hantzschii*** **(p)** ***Spirogyra rivularis*** **(q)** ***Spirogyra biformis*** **(r)** ***Spirogyra tuwensis***

Plate - 3



Bacillariophyceae
(a) *Fragillaria crotonensis* **(b)** *Synedra ulna* **(c)** *Nitzschia sp.* **(d)** *Gomphonema sphaeroporum* **(e)** *Navicula subtilissima* **(f)** *Navicula sp.* **(g)** *Amphora ovalis* **(h)** *Nitzschia palea* **(i)** *Pinnularia* **(j)** *Cymbella sp.* **(k)** *Frustulia weinholdii* **(l)** *Pleurosigma angulatum*

Plate - 4



Cyanophyceae
(a) *Oscillatoria subbrevis* **(b)** *Oscillatoria sancta* **(c)** *Microcystis aeruginos* **(d)** *Synechocystis crassa* **(e)** *Anabaena variabilis* **(f)** *Arthrospira platensis* **(g)** *Merismopedia tennusima* **(h)** *Spirulina sp.*

Table 1 Average values of physico-chemical parameters at three sampling sites with standard deviation; N= 36.

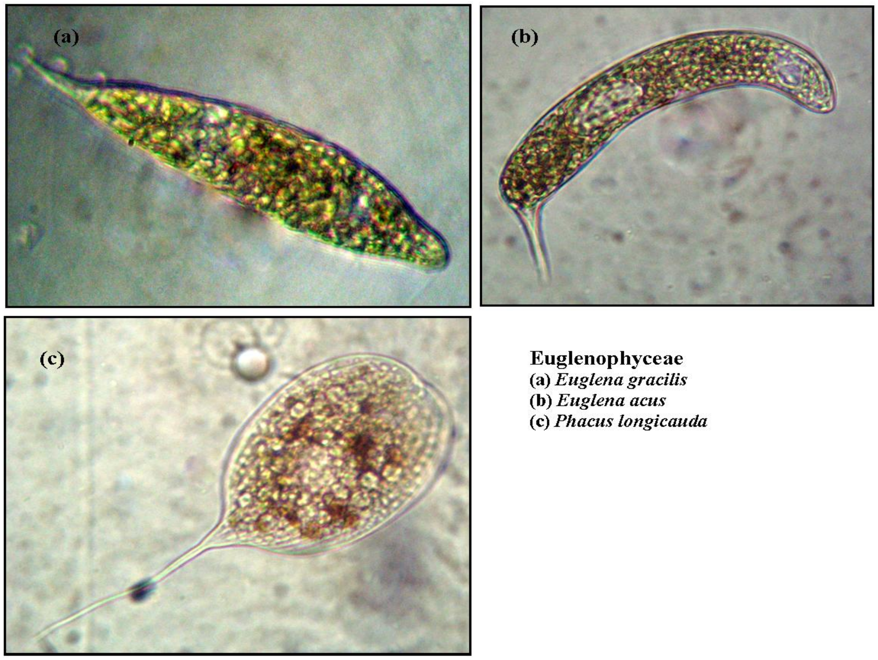
Sr. No.	Parameter	Site 1 Mean ± S.D.	Site 2 Mean ± S.D.	Site 3 Mean ± S.D.
1	pH	7.23 ± 0.28	7.03 ± 0.41	7.09 ± 0.50
2	DO	6.27 ± 0.89	4.06 ± 0.56	2.42 ± 0.87
3	Temperature	22.9 ± 2.9	23.7 ± 2.8	23.8 ± 2.9
4	T. Alkalinity	149.3 ± 29.3	161.3 ± 29.6	172 ± 26.8
5	Chloride	41.5 ± 8.9	80.6 ± 9.6	102.0 ± 15.7
6	PO_4	1.89 ± 0.20	2.20 ± 0.24	2.75 ± 0.23
7	SO_4	1.36 ± 0.03	1.57 ± 0.104	1.87 ± 0.12
8	NO_3	0.175 ± 0.108	0.30 ± 0.08	0.36 ± 0.04

Values are in mg/L except for pH and temperature (^oC). (Mean± Standard Deviation) [14]

Table 2 Correlation coefficients among hydrochemical parameters and plankton in the Sabarmati River

	pH	DO	Temp.	Alkalinity	Chlorides	PO_4^{3-}	SO_4^{2-}	NO_3^-	Chloro-phyceae	Cyano-phyceae	Bacillario-phyceae	Eugleno-phyceae
pH	1											
DO	0.907	1										
Temp.	-0.999	-0.916	1									
T. Alk.	-0.744	-0.956	0.758	1								
Chloride	-0.935	-0.997	0.942	0.932	1							
Phosphate	-0.563	-0.858	0.581	0.971	0.818	1						
Sulfate	-0.970	-0.981	0.975	0.883	0.993	0.745	1					
Nitrate	-0.959	-0.989	0.965	0.902	0.997	0.773	0.999	1				
Chlorophyceae	-0.946	0.694	0.957	0.459	0.654	0.452	-0.403	0.672	1			
Cyanophyceae	-0.946	0.394	0.957	0.766	0.365	0.538	0.371	-0.704	-0.07	1		
Bacillario-phyceae	-0.888	0.799	0.904	0.159	-0.328	0.292	-0.226	0.778	0.348	-0.05	1	
Euglenophyceae	-0.754	-0.960	0.777	0.598	-0.126	-0.309	0.496	0.56	0.128	0.911	-0.106	1

Plate - 5



Euglenophyceae
(a) ***Euglena gracilis***
(b) ***Euglena acus***
(c) ***Phacus longicauda***

Table 3 Phytoplankton of the Sabarmati River at Ahmedabad, India

Chlorophyceae	Bacillariophyceae	Cyanophceae
Scenedesmus sp	*Fragillaria crotonensis*	*Oscillatoria sancta*
Scenedesmus quadricauda	*Synedra ulna*	*Oscillatoria subbrevis*
Scenedesmus armatus	*Nitzschia palea*	*Synechocystis crassa*
Scenedesmus dimorphus	*Fragillaria intermedia*	*Microcystis aeruginosa*
Actinastrum hatzschii.	*Amphora ovalis*	*Anabaena ambigua*
Chlamydomonas closterium	*Frustulia weinholdii*	*Anabaena variabilis*
Closterium sp.	*Nitzschia amphibian*	*Arthrospira platensis*
Cosmerium granatum	*Pleurosigma angulatum*	*Merismopedia glauca*
Cosmerium obsoletum	*Cymbella cymbiformis*	*Merismopedia tuneiss*
Coelastrum microsporum	*Gomphonema sphaeroporum*	*Spirulina sp.*
Ulothrix zonata	*Pinnularia sp.*	*Spirulina major*
Microspora willeana	*Navicula cuspidate*	
Eudorina sp.	*Navicula subsolitaria*	Euglenophyceae
Pediatrum simplex		*Euglena acus*
Pediastrum duplex		*Euglena sp.*
Spirogyra rivularis		*Phacus longicauda*
Spirogyra hollandieae		
Spirogyra tuwensis		
Spirogyra biformis		
Eustrum spinulosum		
Stigeoclonium tenue		

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Table 4 Floristic diversity of phytoplankton at three sites of the Sabarmati River

Name of Species	(+ : present) (– : absent)		
	Site 1	**Site 2**	**Site 3**
Chlorophyceae			
Scenedesmus quadricauda	+	+	+
Scenedesmus armatus	+	+	+
Scenedesmus dimorphus	-	+	+
Ankistrodesmus sp.	-	+	+
Chlamydomonas closterium	-	+	+
Closterium sp.	+	+	+
Cosmerium granatum	+	+	+
Cosmerium obsoletum	-	+	+
Coelestrum microsporum	+	+	+
Ulothrix zonata	+	+	+
Microspora willeana	-	+	+
Eudorina sp.	+	+	+
Pediatrum simplex	+	+	+
Pediastrum duplex	-	+	+
Spirogyra rivularis	+	+	+
Spirogyra hollandieae	+	-	-
Spirogyra tuwensis	+	-	-
Spirogyra biformis	-	-	-
Eustrum spinulosum	+	+	-
Bacillariophyceae			
Synedra ulna	-	+	+
Nitzschia plea	+	+	+
Fragillaria crotonensis	+	+	+
Fragillaria intermedia	+	+	+
Amphora ovalis	+	+	+
Frustulia weinholdii	-	+	+
Nitzschia amphibian	-	+	+
Pleurosigma angulatum	+	+	+
Cymbella cymbiformis	+	+	+
Gomphonema sphaeroporum	-	+	+
Pinnularia sp.	+	+	+
Navicula cuspidate	+	-	-
Navicula subsolitaria	+	+	+

Table 4 (continued) Floristic diversity of phytoplankton at three sites of the Sabarmati River

Name of Species	**(+ : present) (– : absent)**		
	Site 1	**Site 2**	**Site 3**
Cyanophyceae			
Oscillatoria sancta	+	+	+
Oscillatoria subbrevis	+	+	+
Synechocystis crassa	-	+	+
Microcystis aeruginosa	-	+	+
Anabaena ambigua	+	+	+
Anabaena variabilis	-	+	-
Arthrospira platensis	+	-	-
Merismopedia glauca	+	-	-
Merismopedia tuneiss	-	+	+
Spirulina sp.	+	+	+
Spirulina major	-	+	+
Euglenophyceae			
Euglena acus	+	+	+
Euglena sp.	-	+	+
Phacus longicauda	-	+	+

Table 5 Phytoplankton density at three sampling sites of the Sabarmati River (Number of organism L^{-1})

Name of Species	**No. of org. L^{-1}**		
	Site 1	**Site 2**	**Site 3**
Chlorophyceae			
Scenedesmus quadricauda	8670^{*}	30330^{***}	41170^{***}
Scenedesmus armatus	1080	19500^{**}	36830^{***}
Scenedesmus dimorphus	-	26000^{**}	32500^{**}
Ankistrodesmus sp.	-	17330	34670^{***}
Chlamydomonas closterium	-	28170^{**}	43330^{***}
Closterium sp.	2170	30330^{***}	30330^{***}
Cosmerium granatum	21670^{**}	21670^{**}	21670^{**}
Cosmerium obsoletum	-	6500	6500
Coelestrum microsporum	2600^{**}	26000^{**}	26000^{**}
Ulothrix zonata	43330^{***}	8670^{*}	8670^{*}
Microspora willeana	-	36830^{***}	36830^{***}
Eudorina sp.	8670	26000^{**}	26000^{**}
Pediatrum simplex	21670^{**}	45500^{***}	45500^{***}
Pediastrum duplex	-	21670	21670

(Values significant at * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$)

Table 5 (continued) Phytoplankton density at three sampling sites of the Sabarmati River (Number of organism L^{-1})

Name of Species	No. of org. L^{-1}		
	Site 1	**Site 2**	**Site 3**
Spirogyra rivularis	43330***	21670**	21670
Spirogyra hollandieae	15166.67*	-	-
Spirogyra tuwensis	10833.33	-	-
Spirogyra biformis	-	-	-
Eustrum spinulosum	28170***	6500	-
Bacillariophyceae			
Synedra ulna	-	47670***	65000***
Nitzschia plea	8670	39000***	52000***
Fragillaria crotonensis	28170***	26000***	52000***
Fragillaria intermedia	36830***	36830***	56330***
Amphora ovalis	26000***	26000***	43330***
Frustulia weinholdii	-	36830***	58500***
Nitzschia amphibian	-	47670***	47670***
Pleurosigma angulatum	6500	15170*	26000**
Cymbella cymbiformis	4330	6500	36830**
Gomphonema sphaeroporum	-	26000***	36830***
Pinnularia sp.	10830	15170*	49830***
Navicula cuspidate	47670***	-	
Navicula subsolitaria	10830	30330***	21670**
Cyanophyceae			
Oscillatoria sancta	41170***	36830***	52000***
Oscillatoria subbrevis	21666.67**	28170***	52000***
Synechocystis crassa	-	6500	39000**
Microcystis aeruginosa	-	23830**	41170***
Anabaena ambigua	13000*	23000*	32500**
Anabaena variabilis	-	13000***	-
Arthrospira platensis	26000***	-	-
Merismopedia glauca	6500	-	-
Merismpedia tuneiss	-	21670	10830**
Spirulina sp.	32500***	42500***	49830***
Spirulina major	-	34670**	47666.67***
Euglenophyceae			
Euglena acus	4330	13000	19500*
Euglena sp.	-	6500	21670*
Phacus longicauda	-	10830	34670***

(Values significant at * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$)

In the present investigation, the dominance of Bacillariophyceae like *Navicula, Nitzschia, Gomphonema, Synedra* and *Fragilaria* was observed at Site 3. Similar observations were registered by [20], who gave a detailed account of dominant species of diatoms being used as indicators of water quality. In the present study, at upstream Site 1 green algal flora like *Zygnema, Spirogyra, Eustrum* and *Staurastrum* were observed, which are indicators of comparatively less polluted water as supported by refs. 21 and 22. The algal flora of polluted water bodies at Sites 2 and 3 showed the dominance of blue green alga and diatoms like *Oscillatoria, Anabena, Microcystis, Navicula, Nitzschia, Synedra, Gomphonema* etc throughout the investigation. Many green algae such as *Pandorina, Endorina, Scenedesmus, Stigeoclonium, Ankistrodesmus, Chlamydomonas, Pediastrum, Coelastrum,* also occured abundantly and frequently. The most pollution-tolerant species *Euglena, Oscillatoria, Navicula, Nitzschia, Stigeoclonium, Ankistrodesmus, Scenedesmus, Chlamydomonas,* were recorded to be maximal at Site 3, indicating the highest degree of organic pollution.

Many researchers extensively used Nygaard's (1949) indices to understand the quality criteria of water [7,23]. The Nygaard's trophic state indices for the three sites on the Sabarmati River are given in Table 6.

Nygaard's indices of different groups of algae, namely *Cyanophycean, Chlorophycean,* Diatoms, *Euglenophycean* as well as the Compound Index are used to get a meaningful evaluation of the extent of water pollution. The trophic state indices of Myxophycean at Sites 2 and 3 indicate a eutrophic nature of fresh water. While these indices showed the oligotrophic nature of the water at upstream Site 1, the trophic state indices of the *Chlorophycean* group at the three sites indicated the eutrophic nature of the water bodies. The trophic state indices of Diatoms indicated the oligotrophic nature of the water at Site 1 and eutrophic states at Sites 2 and 3. The trophic state indices of *Euglenophycean* at Site 1 showed the oligotrophic nature of the water, while the eutrophic nature of fresh water was observed at Sites 2 and 3. The Compound Index showed eutrophic water at Sites 2 and 3 on the Sabarmati River. Similar observations were made by earlier workers [24,25]. The degree of pollution based on the range of the Shannon and Weaver's species diversity index as prescribed by ref. 26 are shown in Table 7 along with values recorded in the present study. Site 1 showed values ranging from 2.0-3.0 indicating light pollution, whereas at Sites 2 and 3 the values ranged between 1.0-2.0, indicating moderate pollution.

Table 6 Nygaard's Trophic Status Indices and Shannon Diversity Index of the Sabarmati River

Nygaard's Index	Trophic status Indices Eutrophic Oligotrophic	Site 1	Site 2	Site 3
Cyanophycean	0.0-0.4 0.1-3.0	0.062	0.33	0.98
Chlorophycean	0.0-0.7 0.2-9.0	0.076	0.67	0.74
Diatoms	0.0-0.3 0.0-1.75	0.066	0.17	0.20
Euglenophycean	0.0-0.7 0.0-1.0	0.15	0.27	0.33
Compound	0.0-1.0 1.2-2.5	0.75	4.75	4.88

Table 7 Shannon's index and pollution level given by Biligrami (1988)

Shannon's Species Diversity	Pollution level	Present study values		
		Site 1	Site 2	Site 3
3.0-4.5	Slight			
2.0-3.0	Light	2.035		
1.0-2.0	Moderate		1.407	1.157
0.0-1.0	Heavy			

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Table 8 Pollution Tolerant Genera of Algae from Three Sites of the Sabarmati River (Palmer, 1969)

Algal Taxa/ Site	Pollution index	Site 1	Site 2	Site 3
Ankistrodesmus	2	-	2	2
Chlamydomonas	4	-	-	4
Chlorella	3	-	3	3
Closterium	1	1	1	1
Cyclotella	1	-	-	1
Euglena	5	-	5	5
Gomphonema	1	-	1	1
Microcystis	1	1	1	1
Navicula	3	3	3	3
Nitschia	3	-	3	3
Oscillatoria	5	5	5	5
Pandorina	1	-	1	1
Phacus	2	2	2	2
Phormidium	1	-	-	1
Scenedesmus	4	4	4	4
Stigeoclonium	2	-	2	2
Synedra	2	-	2	2
Total		16	35	41

4. DISCUSSION

Water quality parameters such as DO, pH, temperature, phosphate, sulfate and nitrate clearly influence the distribution of organisms and affect their fate in a riverine system [27]. The major inorganic nutrients required by phytoplankton for growth and reproduction are nitrogen (nitrite, NO_3^-, nitrite, NO_2^-, or ammonium, NH_4^+) and phosphorus (as phosphate PO_4^{3-}). Diatoms and silicoflagellates also require silica (SiO_2) in significant amounts. Other inorganic and organic nutrients may be required in small amounts. All of those nutrients are the limiting factors for phytoplankton productivity under most conditions. Temperature has a direct effect on certain chemical and biological activities of the organisms in aquatic media. The rise in temperature could be due to the fact that in winter the photoperiod is shorter and less intense than in summer [28]. DO and pH are indicators of good quality water, indicating various favorable conditions for high primary and secondary phytoplankton production. Dissolved oxygen (DO) is crucial for the survival of aquatic organisms and is also used to evaluate the degree of freshness of a river [29]. Chloride occurs naturally in all types of waters. High concentrations of chloride are an indicator of pollution due to organic wastes of animal or industrial origin. High values of chloride are troublesome in irrigation water and also harmful to aquatic life [21]. In the present study, the lower values of sulfate could be due to the fact that sulfate easily precipitates and settles in the river sediment [15]. Phosphate is a major nutrient for plankton growth; comparatively low values of phosphate were observed in the summer during the present investigation, which might be due to utilization of phosphate as nutrients by algae and other aquatic plants [30].

In the present study, the phytoplankton community in fresh water was represented by members of Chlorophyceae, Cyanophyceae, Bacillariophyceae and Euglenophyceae. Chlorophyceae was the dominant group at Site 1, followed by Bacillariophyceae, Cyanophyceae and Euglenophyceae. At Sites 2 and 3 the phytoplankton occurrence was in the order as Cyanophyceae > Bacillariophyceae > Chlorophyceae > Euglenophyceae throughout the study period. Philipose [31] has emphasized that natural factors like alkalinity, nitrates and phosphates are responsible for the luxuriant growth of Cyanophyceae. The group Bacillariophyceae was more abundant in the monsoon season and registered lower numbers in the pre-monsoon period. Similar observations were also made by ref. 32 during their study on a fresh water body in Tamilnadu.

According to ref. 33, most of the reservoirs in

India have three plankton pulses coinciding with the post-monsoon (October to November), winter (December to February) and summer (March to May) seasons, all within the dry season. During the wet months (June-August), flushing disturbs the standing crop of plankton. In order to apply biological means of determining the trophic status, Palmer's pollution indices of phytoplankton, Nygaard's phytoplankton quotient and Shannon and Weaver's species diversity values were calculated. The values of these three indices for the three sampling sites are given in Tables 2 and 8, respectively.

Palmer (1969) made the first major attempt to identify and prepare a list of genera and species of algae tolerant to organic pollution. Pollution-tolerant genera and species of four groups of algae from three sites were encountered as depicted in Table 8. Palmer (1969) has shown that genera like *Oscillatoria, Euglena, Scenedesmus, Chlamydomonas, Navicula, Nitzschia, Stigeoclonium, and Ankistrodesmus* are the species found in organically polluted waters as supported by refs. 25 and 34. Similar observations were recorded in the present investigation. It has been reported in ref. 35 that *Oscillatoria, Euglena, Chlorella* and *Ankistrodesmus* are typical inhabitants of heavily polluted waters [36] and that *Euglena* and *Oscillatoria* are highly pollution-tolerant genera. Moreover, species like *Euglena viridis, Euglena gracilis, Oscillatoria sp. and Oscillatoria tenuis* were also recorded with very high grade points on Palmer's scale. The pollution tolerance of *Stigeoclonium tenue* was already documented. This species is an indicator of organic pollution and tolerance to heavy metals, which is recorded in the present investigation [25,37]. *Stigeoclonium tenue* was also observed at the Sardar Patel Bridge (Site 3), which can be attributed to the inflow of domestic sewage. In the present investigation, at Gandhi Bridge (Site 2) and Sardar Patel Bridge (Site 3) phytoplankton were found abundant throughout the study and, even more interestingly, with a greater number of genera and species of pollution-tolerant algae with high Palmer's grade points, clearly indicating a high degree of pollution.

The first clear correlation between organic pollution and blue-green algae and the centric diatoms was given by ref 38. The planktonic forms *Pandorina, Scenedesmus, Navicula, Chlorella, Spirulina, Anabaena, Eudorina, Melosira, Closterium* and *Cosmarium* were observed in the present study as indicators of organic pollution-tolerant species. In the present investigation, the trend of increase in organic pollution from Site 1 towards the downstream of the Sabarmati River was observed, as was also supported by results of physico-chemical analysis of water. Similar observations were made by ref. 40 during their study of lakes and ponds in Dharwad.

Cyanophyta dominance and sometimes bloom are among the most visible symptoms of accelerated eutrophication of a water body [41]. It was also reported during the monsoon period mostly in ponds and reservoirs in Asia, where phytoplankton minima can be observed during the wet months [42].

5. CONCLUSIONS

Based on the present investigation it is possible to grade waters with reference to the degree of organic pollution using a synthetic approach. i.e. a consideration of the number of pollution indicator organisms of the different categories along with Nygaard's quotient that gives the community picture as well. However, before a precise system can be worked out, much more information regarding the tolerance of various algae to levels of pollution and critical evaluations of the phytoplankton of such polluted waters is needed. Moreover, as pointed out earlier, increasing urbanization and industrialization pose very serious threats from an ever-increasing quantity of effluents of all types being added to Sabarmati waters and lead to degradation of water and the aquatic community.

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