Phytoplankton Diversity in Sharavati River Basin, Central Western Ghats

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Phytoplankton is one of the most rapid detectors of environmental changes Pollution stress reduces the number of algal species but increases the number of individuals Phytoplankton composition was assessed in 16 localities of the Sharavati River basin A total of 216 species belonging to 59 genera (belonging to Bacillariophyceae, Desmidials, Chlorococcales, Cyanophyceae, Dinophyceae, Euglenophyceae and Chrysophyceae) were recorded. During the sampling, 100, 117 and 110 species of phytoplanktons were recorded in collection-I, II and III respectively. Species composition was almost uniform in all the three collections. Species compositions as well as population of diatoms were more in streams, while that of desmids was more in reservoir water. Species diversity and species richness were not uniform in any of the stations and in any of the three collections. Various pollution indices showed the oligotrophic nature of the reservoir waters with slight organic pollution in stream waters.

Key Words: Phytoplankton diversity, Sharavati river, Central western ghats

Introduction

Population pressure, urbanization, industrialization and increased agricultural practices have significantly contributed to the pollution and toxicity of aquatic ecosystems. Pollutants bring about a change not only in physical and chemical quality of water but also modify the biotic components, resulting in the elimination of some, probably valuable, species. Eutrophication of our natural ecosystems due to sewage disposal and other human activities has become a common feature these days It is, therefore, necessary to monitor the trophic level of the aquatic habitats either by chemical or biological methods. Attempts have been made by many workers to decide the trophic status of water bodies based on phytoplankton groups or species. Microscopic suspended algae or phytoplankton occur in different forms, such as unicellular, colonial or filamentous, which are mainly photosynthetic in nature Zooplankton were found to graze on these phytoplankton

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Phytoplankton is one of the most rapid detectors of environmental changes due to their quick response to toxins and other chemicals. Pollution stress reduces the number of algal species but increases the number of individuals. A marked change in the algal community severely affects the species diversity (Biligrami, 1988). Eutrophication or organic pollution of aquatic ecosystem results in replacement of algal groups. It has been observed that many species are sensitive to the nutritional loading, but equally good numbered are pollution tolerant. A number of reports are available on pollution-indicating or pollution-tolerant algal species. Similarly, a good number of indices have also been evolved to determine the trophic level of fresh water ecosystems like Nygaard's algal indices, Shannon and Weiner's species diversity indices and Palmer's algal pollution index.

Certain species of phytoplankton grow luxuriantly in eutrophic waters while some species cannot tolerate waters that are contaminated with organic or chemical wastes. Some of the species that indicate clean waters are *Melosira islandica, Cyclotella ocellata* and *Dinobryon*. The pollution indicating plankton includes *Nitzschia palea, Microcystis aeruginosa* and *Aphanizomenon flosaquae*. The latter two species have been found to produce toxic blooms and anoxic conditions. Some algae were found to cause noxious blooms in polluted water that tastes bad with intolerable odor. Plankton adapt quickly to the environmental changes because of their short lifecycles. Their standing crop and species composition indicate water quality. Plankton influence on factors such as pH, color, taste and odor. This is mainly because of the small size and great numbers. Often their scant distribution along with their transient nature cannot be totally relied upon for assessing the water quality (APHA, 1985).

Algae are said to be simple plants inhabiting various kinds of habitats. Generally, they are present in almost all natural water bodies. The nutrient-deficient natural water harboring low populations of algae, on addition of nutrients, increases the growth of algae. The water appears dark green on excessive algal growth or the algal blooms. These water blooms occur in highly enriched waters, especially that receiving sewage waste (Trivedy and Goel, 1984).

In the present work an attempt has been made to assess the distribution pattern of phytoplankton in Sharavati River Basin. Comparative study of various stations of the reservoir (lacustrine ecosystem) and streams (lotic ecosystem) is unique. This type of study is new to the Sharavati River basin. As the area of the Linganamakki reservoir is about 2,000 sq. km, it is quite possible that there could be some difference in phytoplankton composition among the different reservoir stations. Similarly, as the streams selected for this study are feeding this reservoir and are flowing from different areas of the catchment, there is a possibility of change in the phytoplankton composition in these streams.

Further, as these streams are flowing through the different regions of Western Ghats and feeding the Linganamakki reservoir there could be a difference in species composition, diversity, richness and dominance of phytoplankton between reservoir and streams. Thus, the study was intended to know the diversity status of phytoplankton among these aquatic ecosystems.

The specific objectives are:

- To study species composition and their differences between the stations of reservoir and streams;
- To study the population and bloom of phytoplankton among these stations;
- To study species diversity, richness and dominance; and
- To assess the trophic status of each station of the reservoir and streams using phytoplankton group, genera and species as a measure

Materials and Methods

For this purpose, phytoplankton sampling was made on monthly basis for three months during October-December at the following representative stations as shown in Table 1. Stations 1, 2, 3, 4, 5, 6 and 14 are for streams and Stations 7, 8, 9, 10, 11, 12, 13, 15 and 16 are for the reservoir. In streams, there were disturbances like cattle bathing and cloth washing while in reservoir there were no such activities.

In each sampling station, phytoplankton collection was made towing a net made up of bolting silk net No. 25 for five minutes. Sedimentation of phytoplankton was made in 4% formaldehyde. Algal monographs of Hustedt (1976) and Prescott (1982) were followed to identify the phytoplankton. Drop count method of Trivedy and Goel (1984) was followed for enumeration of phytoplankton and they are expressed as organisms per litre (O/mL). Nygaard (1949); Palmer (1980); and Biligrami (1988) were applied for trophic studies.

Table 1: Representative Stations

Sl. No.	Stations	October Collection-I	November Collection-II	December Collection-III
1	Sharavati-I	//	//	//
2	Sharavati-II	//	//	//
3	Sharmanavati	//	//	//
4	Keshvapur	//	//	//
5	Haridravati	//	//	//

(Contd..)

Table 1: Representative Stations (..contd)				
Sl. No.	Stations	October Collection-I	November Collection-II	December Collection-III
6.	Nandiholé	"	"	"
7.	Muppanae	"	"	"
8	Talakalale	"	"	"
9.	Dam outlet	"	"	"
10.	Reservoir center	"	"	"
11	Volagere	"	"	"
12.	Yenneholé	"	"	"
13.	Huraliholé	"	"	"
14	Sampekai	"	"	"
15.	Madenur	–	"	"
16.	Nittur	–	"	"

Results and Discussion

Different aquatic ecosystems of Sharavati River basin showed rich and diverse phytoplankton population (Appendix I) In the collections phytoplankton belonged to Bacillariophyceae (diatoms), Desmidials (desmids), Chlorococcales, Cyanophyceae, Dinophyceae, Euglenophyceae and Chrysophyceae. During the study, 216 species belonging to 59 genera were recorded. Stationwise list of phytoplankton for all the three collections are given in Appendix II

Collection-I

During first sampling, 100 species belonging to 37 genera were recorded. Of these, 48 species belonged to Bacillariophyceae, 38 to Desmidials, 8 to Chlorococcales, 3 to Cyanophyceae, 2 to Euglenophyceae and 1 to Dinophyceae Qualitative dominance of the phytoplankton in this collection was in the order of Bacillariophyceae > Desmidials > Chlorococcales > Cyanophyceae > Euglenophyceae > Dinophyceae In this collection, population of Desmidial member *Staurastrum multispiniceps* was highest (58,944/mL) in Station-7 (Muppane) of the reservoir Among streams, population of Bacillariophyceae member *Synedra ulna* was highest (35,136/mL) in Station-5 (Haridravati main tributary).

Collection-II

In this collection, 117 species were recorded from 49 genera Bacillariophyceae dominated with 49 species, followed by Desmidials with 44, Chlorococcales with 14, Cyanophyceae with 5, Chrysophyceae with 3, and Dinophyceae with 2 species. Qualitative dominance was in the order of Bacillariophyceae > Desmidials > Chlorococcales > Cyanophyceae > Chrysophyceae > Dinophyceae. Among streams population of *Gomphonema longiceps*, a Bacillariophycean was highest (21,568/mL) in Station-6 (Nandiholé—minor tributary), while among reservoir waters in Station-16 (Nittur), population of *Dinobryon sertularia* was highest (4752/mL).

Collection-III

During this collection, 110 species of phytoplankton belonging to 48 genera were recorded. Of these, 41 species belonged to Bacillariophyceae, 39 to Desmidials, 16 to Chlorococcales, 9 to Cyanophyceae, 2 species each to Dinophyceae and Chrysophyceae, and a single species to Euglenophyceae. Qualitative dominance was in the order of Bacillariophyceae > Desmidials > Chlorococcales > Cyanophyceae > Dinophyceae = Chrysophyceae > Euglenophyceae. Between both the waters of streams and reservoir, population of *Navicula viridula* was highest in Station-1 (Sharavati-I, 27,728/mL) and Station-12 (Yenneholé, 5,648/mL).

The distribution pattern of phytoplankton was almost similar in all the collections. However, the highest species were recorded in collection-II with 117 species and lowest in collection-I with 100 species. During collection-III, 110 species were recorded. From Tables 2.1, 2.2 and 2.3 it is clear that, in general in all the streams (Stations 1-6 and 14)

Table 2.1: Phytoplankton Composition in Collection-I

Family		Stations													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Diatoms	Genus/L	8	6	8	6	5	4	2	–	3	2	2	5	3	5
	Species/L	18	8	11	9	9	6	2	–	3	2	2	8	3	5
Desmidials	Genus/L	1	2	2	–	1	1	7	5	3	6	7	8	6	–
	Species/L	1	2	2	–	1	1	17	10	8	11	15	12	12	–
Cyanophyceae	Genus/L	–	1	–	–	–	1	1	1	–	1	–	1	1	–
	Species/L	–	1	–	–	–	1	1	1	–	1	–	1	1	–
Chlorococcales	Genus/L	2	2	–	–	1	1	–	1	–	–	1	2	–	–
	Species/L	2	2	–	–	1	1	–	1	–	–	1	2	–	–
Dinophyceae	Genus/L	–	–	–	–	–	–	1	1	–	–	–	–	–	–
	Species/L	–	–	–	–	–	–	1	1	–	–	–	–	–	–
Euglenophyceae	Genus/L	–	–	1	1	1	–	–	–	–	–	–	–	–	–
	Species/L	–	–	1	1	1	–	–	–	–	–	–	–	–	–
Total	**Genus/L**	**11**	**11**	**11**	**7**	**8**	**7**	**11**	**8**	**6**	**9**	**10**	**16**	**10**	**5**
	Species/L	**21**	**13**	**14**	**10**	**12**	**9**	**21**	**13**	**11**	**14**	**18**	**23**	**16**	**5**

Table 2.2: Phytoplankton Composition in Collection-II

Family		Stations															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Diatoms	Genus/L	9	8	7	8	7	7	4	4	3	5	4	2	3	7	5	3
	Species/L	12	17	9	11	11	13	4	6	3	5	4	2	3	11	8	3
Desmidials	Genus/L	1	1	1	1	1	3	5	5	2	4	4	7	5	2	5	7
	Species/L	1	2	1	1	1	3	9	9	3	11	6	11	7	2	11	13
Cyanophyceae	Genus/L	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1
	Species/L	2	1	1	1	1	1	1	1	1	1	1	1	1	1	2	1
Chlorococcales	Genus/L	2	2	2	1	1	1	1	1	2	1	1	4	1	3	2	1
	Species/L	2	2	2	1	1	1	1	1	2	1	1	4	1	4	2	1
Dinophyceae	Genus/L	–	–	–	–	–	–	–	1	–	–	1	–	2	–	1	–
	Species/L	–	–	–	–	–	–	–	1	–	–	1	–	2	–	1	–
Chrysophyceae	Genus/L	–	–	–	–	–	–	–	–	–	–	–	1	1	–		1
	Species/L	–	–	–	–	–	–	–	–	–	–	–	1	2	–	–	2
Euglenophyceae	Genus/L	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	Species/L	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Total	**Genus/L**	**14**	**12**	**11**	**11**	**10**	**12**	**11**	**12**	**8**	**11**	**11**	**15**	**13**	**13**	**15**	**13**
	Species/L	**17**	**22**	**13**	**14**	**14**	**18**	**15**	**18**	**9**	**18**	**13**	**19**	**16**	**18**	**24**	**20**

Bacillariophyceae (Diatoms) species dominated while in all the waters of reservoir (Stations 7-13, 15, and 16) Desmidials predominated during all the collections From the stationwise list of diatoms (Appendix II) it is clear that *Gomphonema longiceps, Navicula viridula, Synedra ulna, Surirella ovata* and many species of diatoms almost commonly occurred in all the streams Similarly, species of desmids like *Staurastrum limneticum, S freemanii, S multispiniceps, Arthrodesmus psilosporus, Triploceros gracile* and *Xanthedium perissacanthum* almost commonly occurred in all the stations of the reservoir during all the three collections Thus, the distribution pattern of diatoms and desmids indicates that species composition was almost similar in streams and reservoir waters during all the collections.

Cyanophyceae and Chlorophyceae members distributed uniformly in streams and reservoir waters, but Dinophyceae and Euglenophyceae were scantly distributed Chrysophyceaen members did not occur during collection-I. During collection- II and III, they were recorded from reservoir waters with 2 species of *Dinobryon*

Bacillariophycean members—*Anomoeoneis sphaerophora, Gyrosigma attenuatum, G gracile, Gomphonema lanceolatum, G. longiceps, Navicula viridula, Nitzschia obtusa, N. palea,*

Table 2.3: Phytoplankton Composition in Collection-III

Family		Stations															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Diatoms	Genus/L	8	6	6	6	7	6	4	4	5	4	3	2	5	4	4	8
	Species/L	16	11	9	7	11	9	5	4	5	5	3	3	5	4	5	14
Desmi-dials	Genus/L	1	1	2	1	1	4	4	3	5	4	7	6	3	4	6	3
	Species/L	1	1	2	1	1	5	13	8	16	6	10	11	4	5	10	3
Cyano-phyceae	Genus/L	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1
	Species/L	1	1	1	1	2	1	1	1	1	1	1	2	1	1	1	1
Chloro-coccales	Genus/L	1	1	1	3	2	1	1	2	1	2	1	1	2	1	1	2
	Species/L	1	1	1	3	2	1	1	3	1	2	1	1	2	1	1	2
Dino-phyceae	Genus/L	–	–	–	–	–	–	–	1	1	1	2	1	1	1	1	–
	Species/L	–	–	–	–	–	–	–	1	1	1	2	1	1	1	1	–
Chryso phyceae	Genus/L	–	–	–	–	–	–	1	–	–	–	1	1	1	–	1	1
	Species/L	–	–	–	–	–	–	1	–	–	–	1	2	1	–	1	2
Eugleno-phyceae	Genus/L	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
	Species/L	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–
Total	**Genus/L**	**11**	**9**	**10**	**11**	**12**	**13**	**11**	**11**	**13**	**12**	**15**	**13**	**13**	**11**	**14**	**15**
	Species/L	**19**	**14**	**13**	**12**	**16**	**17**	**21**	**17**	**24**	**15**	**18**	**20**	**14**	**12**	**19**	**22**

Pinnularia lundii, P. maharashtrensis, Surirella ovata, Synedra acus and *S. ulna*—were common to all the three collections. Desmidial members common to all the three collections were *Arthrodesmus psilosporus, Closterium ehrenbergii, Cosmarium decoratum, Desmidium baileyi, Staurastrum limneticum, S. freemanii, S. multispinceps, S. peristephes, S. tohopekaligense* and *Triploceros gracile.*

Chlorococcalean members—*Eudorina elegans, Muogeotia punctata, Pediastrum simplex,* and *Spirogyra rhizobrachialis*—were common in all the three collections. One Dinophycean member, *Ceratium hirundinella* and one Cyanophycean member, *Microcystis aeruginosa* were common in all the three collections.

Most of the other species of Diatoms, Desmids, Cyanophycean and Chlorococcalean were common to either collection-I and II or I and III or II and III, indicating almost similar species composition in all the three collections.

Algal Bloom

Generally blooms are formed under limnological conditions favoring high fertility at the water surface. Commonly, a bloom of algae forms a scum on the surface or gives distinct coloration to the water. Tables 3.1, 3.2 and 3.3 show the population of different algal

Table 3.1: Population (O/mL) of Phytoplankton in Collection-I

Family	Stations													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Bacillariophyceae	5,792	5,456	2,624	1,696	61,792	5,632	2,240	–	7,616	928	896	6,592	912	1,616
Desmidials	16	240	64	–	112	16	161,184	43,024	11,872	53,440	28,304	5,488	19,568	–
Chlorococcales	128	256	–	–	32	16	–	256	–	–	320	176	–	–
Cyanophyceae	–	288	–	–	–	16	864	336	–	256	–	864	288	–
Dinophyceae	–	–	–	–	–	–	1,136	704	–	–	–	–	–	–
Euglenophyceae	–	–	16	32	128	–	–	–	–	–	–	–	–	–
Total	**5,936**	**6,240**	**2,704**	**1,728**	**62,064**	**5,680**	**165,424**	**44,320**	**19,488**	**54,624**	**29,520**	**13,120**	**20,768**	**1,616**

Table 3.2: Population (O/mL) of Phytoplankton in Collection-II

Family	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bacillariophyceae	512	3,360	1,536	752	4,144	24,720	336	944	1,024	144	160	464	624	20,576	512	512
Desmidials	16	96	144	16	16	48	416	448	192	352	240	5,552	992	48	544	736
Chlorococcales	2,432	32	32	16	16	16	16	96	32	16	16	432	16	160	48	16
Cyanophyceae	32	32	16	16	32	48	16	32	16	16	16	128	16	64	48	16
Dinophyceae	–	–	–	–	–	–	–	16	–	–	32	–	64	–	32	–
Chrysophyceae	–	–	–	–	–	–	–	–	–	–	–	416	8,048	–	–	5,072
Total	**2,992**	**3,520**	**1,728**	**800**	**4,208**	**24,832**	**784**	**1,536**	**1,264**	**528**	**464**	**6,992**	**9,760**	**20,848**	**1,184**	**6,352**

Table 3.3: Population (O/mL) of Phytoplankton in Collection-III

Family	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Bacillariophyceae	29,664	4,720	3,184	400	448	2,464	752	192	208	928	208	352	528	17,920	1,392	6,704
Desmidials	32	32	48	32	16	144	656	400	544	336	464	1,520	528	160	592	160
Chlorococcales	16	32	16	48	48	16	16	80	16	32	16	16	64	16	16	96
Cyanophyceae	16	32	16	16	48	16	16	16	16	16	16	176	32	16	16	32
Dinophyceae	-	-	-	-	-	-	-	256	48	96	272	848	384	16	176	-
Euglenophyceae	-	-	-	-	-	16	-	-	-	-	-	-	-	-	-	-
Chrysophyceae	-	-	-	-	-	-	2,272	-	-	-	1,360	6,448	2,032	-	608	2,880
Total	**29,728**	**4,816**	**3,264**	**496**	**560**	**2,656**	**3,712**	**944**	**832**	**1,408**	**2,336**	**9,360**	**3,568**	**18,128**	**2,800**	**9,872**

groups in three collections. It is clear here that the population of Bacillariophyceae (diatoms) is almost high in streams (Stations 1-6 and 14) to that of desmids in reservoir waters (Stations 7-13, 15 and 16). However, none of the phytoplankton, representing either Bacillariophyceae or Desmidials, formed bloom during any of the three collections. Their individual population was not enough to form a scum on the surface to give distinct coloration to the water to form the algal bloom. However, *Gomphonema longiceps* predominated in Station-6 of collection-II, and *Navicula viridula* predominated in Station-14 of collection-II and Stations 1 and 14 of collection-III overall other phytoplankton. Population of Cyanophycean and Chlorococcalean species were very low. Dinophycean and Euglenophycean occurrence was scanty with negligible population. Chrysophycean species occurred only in collection-II and III with dominance in some stations. *Dinobryon sertularia* dominated in Station-13 and 16 of collection-II and Stations 7, 11, 12 and 13 of collection-III

Species Diversity

Tables 4.1, 4.2, and 4.3 reveal the diversity status of phytoplankton during I, II and III-collections. From these Tables, it is clear that species diversity is not uniform in any station in any of the collections. This is mainly because of the non-uniformity in the occurrence of species and their population in these stations during all the collections

Table 4.1: Diversity Status of Phytoplankton in Collection-I

Parameter	Stations													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Total Individuals	371	390	169	108	3,879	355	10,339	2,770	1,218	3,414	1,845	820	1,298	101
Total Species	21	13	14	10	12	9	21	13	11	14	18	23	16	5
Species Richness	3.25	2.01	2.53	1.92	1.33	1.36	2.16	1.51	1.4	1.59	2.26	3.27	2.09	0.86
Shannon-Diversity	2.44	2	1.67	2.03	1.27	1.37	1.96	1.85	1.84	2.24	2.37	2.69	2.15	1.09
Simpson-Dominance	0.11	0.19	0.33	0.16	0.39	0.31	0.2	0.22	0.21	0.12	0.12	0.09	0.17	0.47
Simpson-Diversity	0.88	0.8	0.66	0.83	0.6	0.68	0.79	0.77	0.78	0.87	0.87	0.9	0.82	0.52

Table 4.2: Diversity Status of Phytoplankton in Collection-II

Parameter	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total Individuals	187	220	108	50	263	1,552	49	96	79	33	29	437	610	1,303	74	397
Total Species	17	22	13	14	14	18	15	18	9	18	13	19	16	18	24	20
Species Richness	3.05	3.89	2.56	3.32	2.33	2.31	3.59	3.72	1.83	4.86	3.56	2.96	2.33	2.37	5.34	3.17
Shannon-Diversity	0.86	2.29	1.99	1.97	1.79	0.66	2.43	2.11	1.08	2.75	2.42	1.97	1.19	0.93	2.85	1.16
Simpson-Dominance	0.66	0.17	0.17	0.2	0.2	0.75	0.11	0.23	0.55	0.07	0.09	0.24	0.48	0.62	0.07	0.56
Simpson-Diversity	0.33	0.82	0.83	0.79	0.79	0.24	0.88	0.76	0.44	0.92	0.9	0.75	0.51	0.37	0.92	0.43

Table 4.3: Diversity Status of Phytoplankton in Collection-III

Parameter	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total Individuals	1,858	301	204	31	35	166	232	59	52	88	146	585	223	1,133	175	617
Total Species	19	14	13	12	16	17	21	17	24	15	18	20	14	12	19	22
Species Richness	2.39	2.27	2.25	3.2	4.21	3.12	3.67	3.92	5.82	3.12	3.41	2.98	2.4	1.56	3.48	3.26
Shannon-Diversity	0.41	1.37	1.94	2.01	2.59	2.17	1.57	2.45	3.07	2.21	1.69	1.57	1.66	0.15	2.21	2.46
Simpson-Dominance	0.87	0.45	0.17	0.21	0.09	0.14	0.4	0.12	0.05	0.14	0.35	0.38	0.34	0.95	0.15	0.11
Simpson-Diversity	0.12	0.54	0.82	0.78	0.9	0.85	0.59	0.87	0.94	0.85	0.64	0.61	0.65	0.04	0.84	0.88

From Table 4.1, it is clear that in general, total individuals are low in almost all the streams and high in almost all the waters of reservoir. Among all the stations total individuals are highest in Station-7 (10,339) and lowest in Station-14 (101) Total species is high (23) in Station-12 with highest species richness (3.27) and Shannon diversity values (2.69), which is evident from the low Simpson dominance value and high evenness index value in Station-12. On the other hand, in Station-14 species richness and Shannon diversity values are low (0.86 and 1.09 respectively) with high Simpson dominance (0.47) and low evenness index value (0.52).

From Table 4.2, it is clear that in general, in the waters of streams and reservoir total individuals are almost low as compared to collection-I. Total individuals are lowest (49) in Station-7 where it was high during I-collection. Highest individuals were recorded in Station-6 (1,552). Total species is high (24) in Station-15 with highest species richness (5.34) and Shannon diversity values (2.85), which is evident from the low Simpson dominance and high evenness index values. Total species is lowest (9) in Station-9 with lowest species richness (1.83) and almost lower Shannon diversity value (1.08) However, lowest (0.66) Shannon diversity is in Station-6 with highest Simpson dominance (0.75) and lowest evenness index values (0.24).

Table 4.3 indicates that the total individual value is highest (1,858) in Station-1 and lowest (31) in Station-4. Total species is high (24) in Station-9 with highest species richness (5.82) and Shannon diversity (3.07) values. Lowest species richness value is in Station-14 (1.56) with lowest Shannon diversity (0.14), which is evident from the higher Simpson dominance (0.95) and lower evenness

Table 4.4: Average Diversity Status of Phytoplankton in all the Three Collections

Parameter	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Total Individuals	805	304	160	63	1,392	691	3,540	975	450	1,178	604	614	710	846	124	507
Total Species	19	16	13	12	19	15	19	16	15	16	16	21	15	12	22	21
Species Richness	2.94	2.72	2.44	2.81	2.62	2.26	3.14	3.05	3.01	3.19	3.07	3.07	2.66	1.59	4.41	3.21
Shannon-Diversity	1.23	1.88	1.86	2	1.88	1.4	1.98	2.32	1.99	2.88	2.16	2.07	1.66	0.72	2.53	1.81
Simpson-Dominance	0.54	0.27	0.22	0.19	0.22	0.4	0.23	0.19	0.27	0.37	0.18	0.23	0.33	0.68	0.11	0.33
Simpson-Diversity	0.44	0.72	0.77	0.8	0.76	0.59	0.75	0.8	0.72	0.88	0.8	0.75	0.66	0.31	0.88	0.65

index (0.04) values. Vice versa was true with Station-9 where the Shannon diversity is high (3.07) with low Simpson dominance (0.05) and high evenness index values (0.94).

Table 4.4 reveals the average diversity status of phytoplankton of all the three collections. This table shows the highest population (3,540) in Station-7 and lowest (63) in Station-4. Highest number of species is in Station-15 (22) with highest species richness (4.41) and highest Shannon diversity (2.53) values, which are indicated by low Simpson dominance (0.11) and high evenness index values (0.88). Lowest number of species is in Station-14 (12) with lowest species richness (1.59) and Shannon diversity (0.72) and with the highest Simpson-dominance (0.68) and lowest evenness index values (0.31). From Table 4.4, it is also clear that species richness and species diversity values are almost high in the waters of reservoir as compared to waters of streams. This might be due to the higher number of species (24 species) of *Staurastrum*, a desmidial member, which might have resulted in higher species diversity value in reservoir waters.

From the Tables 4.1, 4.2 and 4.3, it is clear that the Stations 7 and 1, which harbored the highest and lowest total individuals respectively during collection-I had almost low and high total individuals during collection-II and III. Similarly, during collection-II, Station-6, which harbored highest total individuals, showed lower population during collection-I and III. This indicates that the growth and distribution patterns of phytoplankton are not uniform during all the collections. Further, as compared to collection-II and III, total individuals were high during collection-I. It might be because of the rains during the month of September just prior to collection-I during October, which might have added nutrients to the waters along with runoff water from surrounding catchment areas

Thus, from the above discussion about species diversity of phytoplankton in various stations of streams and reservoir, it is clear that diversity and species richness were not uniform in any stations during all the three collections. However, during collection-I, total population was highest in reservoir waters as compared to streams. It might be because of the higher nutrient load in stagnant waters of reservoir (due to rain just before collection-I, which might have resulted in higher population of Desmidials in these waters In general, the requirement of dissolved oxygen for the growth of many diatom species is well-documented In the present study, in stream waters, higher population of diatoms coincided with the higher dissolved oxygen, as oxygen is generally high in stream (flowing) waters compared to reservoir waters. The studies of Venkateshwarlu (1970) and Sheavly and Marshal (1989) who found that diatoms prefer well-aerated waters that are rich in dissolved oxygen are in support of the present observation. Rao (1977) has observed dissolved oxygen favoring different species of diatoms, which is also found to be true for diatoms in the present study

On the other hand, reservoir waters showed lower species composition as well as population of diatoms. It may be due to their slight stagnant nature where dissolved oxygen content is less as compared to streams. However, in reservoir waters desmid species predominated. Generally, paucity of desmids is seen in the organically polluted waters. Waters supporting luxuriant growth of Desmidials have been found to be chemically distinct from those harboring other members of algae (Hegde, 1985). The present study is on par with these observations, since desmids predominated in reservoir waters, which might have had lower organic pollution On the other hand, stream waters harbored lower desmid population indicating probable evidence of organic pollution as compared to the waters of reservoir.

Trophic Status

In order to apply biological means of determining the trophic status Shannon and Weaver's species diversity values, Nygaard's phytoplankton Quotient and Palmer's pollution indices of phytoplankton were calculated for the three collections of phytoplankton

Nygaard (1949) has given ratios for plankton communities to decide the trophic status (Table 5).

For oligotrophic lakes of Denmark, investigated by Nygaard (1949), the values for Cyanophycean, Chlorococcales, Diatom, Eugleninae and Compound quotients were 0.0-0.4; 0.0-0.7; 0.0-0.0; 0.0-0.2 and 0.0-1.0 respectively. For eutrophic lakes, the values of these quotients were 0.8-3.0; 0.7-3.5; 0.2-3.0; 0.0-0.2 and 2.0-8.75 respectively

Table 5: Nygaard's Trophic Status Index

Index	Calculation
Cyanophycean Quotient	$\frac{\text{Cyanophyceae}}{\text{Desmideae}}$
Chlorococcalean Quotient	$\frac{\text{Chlorococcales}}{\text{Desmideae}}$
Diatom Quotient	$\frac{\text{Centric Diatoms}}{\text{Pennate Diatoms}}$
Euglenophycean Quotient	$\frac{\text{Euglenophyta}}{\text{(Cyanophyceae + Chlorococcales)}}$
Compound Quotient	$\frac{\text{(Cyanophyceae + Chlorococcales + Centric Diatoms + Euglenophyta)}}{\text{Desmideae}}$

The ∞ value indicates the absence of algal quotient representing groups in that collection. For example, for the calculation of Diatom Quotient both pinnate and centric diatoms should be present in a particular sample. Since centric diatoms were not collected in any of the three collections, the diatom quotient value is ∞.

Tables 6.1, 6.2 and 6.3 indicate the Nygaard's phytoplankton quotient values. From Table 6.1, it is clear that almost all the values are very low to represent the eutrophic nature of the water. However, in some Stations 1, 3, 4, 5 and 6, the values were above the values given by Nygaard for oligotrophic waters. In Station-1, Chlorophycean and Compound quotient values, in Station-2 Compound quotient value, in Stations 3 and 4 Euglenophycean quotient values, in Station-5 Chlorophycean, Euglenophycean and Compound quotient values and in Station-6 Cyanophycean, Chlorophycean and Compound quotient values exceeded the values given for oligotrophic nature of water. Interestingly, all these Stations represent the streams. All the waters of reservoir show the oligotrophic nature as their quotient values are in between the values given by Nygaard for oligotrophic water. Similarly, from Table 6.2, it is clear that stream waters are slightly eutrophicated, as in Station-1 Cyanophycean, Chlorophycean and Compound quotient values, in Station-3 Chlorophycean and Compound quotient values and in Stations 4 and 5 Cyanophycean and Chlorophycean quotient values exceeded the values given for oligotrophic nature of water. Similar to collection-I, the Nygaard's phytoplankton values are in the range of oligotrophic nature in collection-II also, in all the reservoir waters.

Table 6.3 almost confirms the findings of collection-I and II as the stream waters in collection-III are also eutrophic in nature. In Station-1 Cyanophycean, in Station-2 Chlorophycean, in Station-4 Cyanophycean, Chlorophycean and Compound quotient values and in Station-5 Cyanophycean, Chlorophycean and Compound quotient values have exceeded above the oligotrophic values. On the other hand, waters of the reservoir are in between the values given for oligotrophic waters. Thus, it is clear from Nygaard's pollution index that stream waters are slightly eutrophic in nature as compared to reservoir waters. Generally, waters of streams with rapid flow carry organic matter from the soil. In the present study, stream waters might have carried the organic matter from the soil

Table 6.1: Nygaard's Phytoplankton Quotient in Collection-I

Family	Stations													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Cyanophycean Quotient	∞	0.5	∞	∞	∞	1	0.05	0.1	∞	0.09	∞	0.08	0.08	∞
Chlorophycean Quotient	2	∞	∞	∞	1	1	∞	0.1	∞	∞	0.06	0.16	∞	∞
Diatom Quotient	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Euglenophycean Quotient	∞	∞	1	1	1	∞	∞	∞	∞	∞	∞	∞	∞	∞
Compound Quotient	2	1.5	0.5	1	2	2	0.05	0.2	∞	0.09	0.06	0.25	0.08	∞

Table 6.2: Nygaard's Phytoplankton Quotient in Collection-II

Family	Stations															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Cyanophycean Quotient	2	0.5	∞	1	1	0.33	0.11	0.11	0.33	0.09	0.16	0.09	0.14	0.5	0.18	0.07
Chlorophycean Quotient	2	2	2	1	1	0.33	0.11	0.11	0.66	0.9	0.16	0.09	0.14	2	0.18	0.07
Diatom Quotient	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Euglenophycean Quotient	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Compound Quotient	4	1.5	3	2	2	0.66	0.22	0.22	1	0.18	0.18	0.33	0.28	2.5	0.36	0.15

Table 6.3: Nygaard's Phytoplankton Quotient in Collection-III

Family	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Cyanophycean Quotient	1	1	0.5	1	2	0.2	0.076	0.12	0.062	0.166	0.1	0.18	0.25	0.2	0.1	0.33
Chlorophycean Quotient	1	1	0.5	3	2	0.2	0.076	0.375	0.062	0.33	0.1	0.09	0.5	0.2	0.1	0.66
Diatom Quotient	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Euglenophycean Quotient	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
Compound Quotient	2	2	1	4	4	0.4	0.153	0.5	0.125	0.5	0.2	0.27	0.75	0.4	0.2	1

and the decomposed dried leaves of surrounding trees, resulting in the slight eutrophic nature of the waters. It is quite natural that in reservoir waters, the organic matter brought from runoff water during rains settles down to the bottom in the winter season. This might be the reason for the lower organic pollution and oligotrophic nature of the reservoir waters as the collections of phytoplankton were made during the winter season.

Biligrami (1988) has given the degrees of pollution based on the ranges of Shannon and Weiner's species diversity (Table 7).

Table 7: Shannon's Index and Pollution Levels

Species Diversity	Pollution Level
3.0-4.5	Slight
2.0-3.0	Light
1.0-2.0	Moderate
0.0-1.0	Heavy

From Table 8, it is clear that in general species diversity values of almost all the stations are in the range of moderate or light pollution level. As per the pollution ranges given by Biligrami (1988), waters of Stations 1, 2, 4, 10, 11, 12 and 13 during collection-I, waters of Stations 2, 7, 8, 10, 11 and 15 during collection-II, and waters of Stations 4, 5, 6, 8, 9, 10, 15 and 16 during collection-III show light pollution level with species diversity ranging between 2.0 and 3.0. While waters of Stations 3, 5, 6, 7, 8, 9 and 14 during collection-I, waters of Stations 3, 4, 5, 9, 12, 13 and 16 during collection-II, and waters of Stations 2, 3, 7, 11, 12 and 13 during collection-III show moderate pollution level (Species diversity ranges between 1.0 and 2.0)

Table 8: Shannon-Weiner's Diversity Values

Stations	Phytoplankton Collections			
	I	II	III	Average
1	2.44	0.86	0.41	1.23
2	2.00	2.29	1.37	1.88
3	1.67	1.99	1.94	1.86
4	2.03	1.97	2.01	2.00
5	1.27	1.79	2.59	1.88
6	1.37	0.66	2.17	1.4
7	1.96	2.43	1.57	1.98
8	1.85	2.11	2.45	2.32
9	1.84	1.08	3.07	1.99
10	2.24	2.75	2.21	2.88
11	2.37	2.42	1.69	2.16
12	2.69	1.97	1.57	2.07
13	2.15	1.19	1.66	1.66
14	1.09	0.93	0.14	0.72
15	–	2.85	2.21	2.53
16	–	1.16	2.46	1.81

In collection-II and III, stream waters show heavy pollution load in some stations. In collection-II waters of Stations 1, 6 and 14 and in collection-III waters of Stations 1 and 14 had heavy pollution load with the species diversity ranging between 0.0 and 1.0. Only the waters of Station-9 in collection-III had slight pollution level with the species diversity 3.07

From the average species diversity values, it is clear that almost all the waters of the streams show moderate pollution level, while almost all the reservoir waters show light pollution level.

Thus, from the above discussion, it is clear that waters of only Stations 3 and 10 show uniformity, i.e., moderate and light pollution level from collection-I to/and collection-III. Remaining waters during different collections show either light or moderate pollution level. Thus, the pollution level was not uniform in almost all the stations. It is in between the light and moderate pollution level with heavy pollution load in few stations of streams.

Another popular work on pollution aspect is of Palmer (1980), who has listed top 8 pollution tolerant genera, the *Euglena, Oscillatoria, Chlamydomonas, Scenedesmus, Chlorella, Nitzschia, Navicula* and *Stigeoclonium* and top 9 species *Ankistrodesmus falcatus, Euglena* *viridis, Nitzschia palea, Oscillatoria limnosa, Oscillatoria tenuis, Pandorina morum, Scenedesmus quadricauda, Stegioclonium tenue* and *Synedra ulna*. Further, he has given the algal pollution indices developed for use in rating water samples for high or low organic pollution (based on 20 genera and 20 species). In analysis of a water sample, all of the 20 genera and species of algae that are present are recorded separately. An alga is 'present' if there are 50 or more individuals per ml. The pollution index factors of the algae present are then totalled. A score of 20 or more for a sample is taken as evidence of high organic pollution, while a score of 15-19 is taken as probable evidence of high organic pollution. Low figures indicate that the organic pollution of the sample is not high.

Algal Genera Index

Tables 9.1, 9.2 and 9.3 reveal Palmer's genera index values. From Table 9.1, it is clear that all the stations with a score of less than ten except Stations 5 and 13 are said to be less polluted. Stations 5 and 13 with scores of 12 and 13 come nearer to the point of suspected pollution. Similarly, collection-II and III with scores less than ten are indicating low organic pollution in all the stations (Tables 9.2 and 9.3). Thus, Palmer's pollution index values of all the three collections are not exceeding the score given by Palmer (1960) for the high organic pollution or the probable evidence of organic pollution. Thus, the waters of all the stations during collection-I, II and III showed low organic pollution.

Algal Species Index

Out of the 20 algal species reported by Palmer, *Synedra ulna* and *Nitzschia palea* occurred in some of the stations of collections-I and III. In collection-II along with these two species

Table 9.1: Palmer's Pollution Index of Algal Genera in Collection-I

Genera	Stations													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Gomphonema	1	1	1	1	1	–	–	–	1	1	1	1	1	1
Navicula	3	3	3	3	–	3	3	–	–	3	–	3	–	3
Nitzschia	3	3	–	3	3	3	3	–	–	–	–	3	–	3
Synedra	2	2	2	2	2	2	–	–	2	–	2	2	–	–
Closterium	–	–	–	–	1	–	–	–	–	–	–	1	–	–
Euglena	–	–	–	–	5	–	–	–	–	–	–	–	–	–
Microcystis	–	–	–	–	–	–	–	–	–	–	–	1	1	–
Ankistrodesmus	–	–	–	–	–	–	–	–	–	–	–	2	–	–
Total Score	9	9	6	9	12	8	6	0	3	4	3	13	2	7

Table 9.2: Palmer's Pollution Index of Algal Genera in Collection-II

Genera	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gomphonema	1	1	1	1	1	–	–	1	1	1	1	1	1	1	1	–
Navicula	3	–	3	–	–	3	3	3	3	–	–	–	–	3	3	3
Nitzschia	–	3	–	–	3	3	–	–	–	–	–	–	–	3	–	–
Synedra	–	2	2	2	2	2	–	2	–	–	–	–	–	2	–	–
Closterium	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–
Microcystis	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–
Ankistrodesmus	–	–	–	–	–	–	–	–	–	–	–	2	–	2	–	–
Scenedesmus	–	–	–	–	–	–	–	4	–	–	–	4	–	–	–	–
Melosira	–	–	–	–	–	–	1	–	1	–	1	–	1	–	–	1
Total Score	4	6	6	3	6	8	4	10	5	1	2	8	3	11	4	4

Table 9.3: Palmer's Pollution Index of Algal Genera in Collection-III

Genera	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Gomphonema	1	1	1	1	1	1	–	–	1	1	–	–	–	–	1	1
Navicula	3	3	3	–	3	3	–	–	–	3	3	–	3	3	3	3
Nitzschia	3	–	3	3	–	3	–	–	–	–	–	–	–	–	–	3
*Synedra*2	2	2	–	2	2	–	–	–	–	–	–	–	2	–	2	
Closterium	–	–	–	–	–	1	–	–	–	–	–	–	1	1	–	–
Microcystis	–	–	–	–	–	1	–	–	–	–	–	1	–	–	–	–
Pandorina	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–
Melosira	–	–	–	–	–	–	1	1	1	1	1	1	1	–	1	1
Total Score	9	6	9	5	6	11	1	1	2	5	4	2	5	6	5	10

Ankistrodesmus falcatus also occurred in some stations Some other species like *Pandorina morum* and *Scenedesmus quadricauda*, even though occurred in some of the stations, are discarded due to their lower number (less than 50 per mL.).

Tables 10.1, 10.2 and 10.3 reveal Palmer's species index values. From these Tables, it is clear that the total score of none of the stations of all the three collections exceeded the total score given by Palmer for high organic pollution This indicates that waters of all the stations during all the three collections had low organic pollution.

From the species composition and growth of phytoplankton in various streams and reservoir it is clear that waters of both streams and reservoir were below the level of high organic pollution. High pollution indicating organisms were very less in these aquatic ecosystems and the score of their presence did not show the range of Palmer's total score of high organic pollution

Table 10.1: Palmer's Pollution Index of Algal Species in Collection-I

Genera	Stations													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Synedra ulna	3	3	3	3	3	3	–	–	3	–	–	–	–	–
Nitzschia palea	–	–	–	–	–	–	–	–	–	–	–	–	–	5
Total Score	3	3	3	3	3	3	–	–	3	–	–	–	–	5

Table 10.2: Palmer's Pollution Index of Algal Species in Collection-II

Genera	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Ankistrodesmus falcatus	–	–	–	–	–	–	–	–	–	–	–	3	–	3	–	–
Synedra ulna	–	3	3	–	3	3	–	3	–	–	–	–	–	3	–	–
Nitzschia palea	–	5	–	–	–	5	–	–	–	–	–	–	–	–	–	–
Total Score	–	8	3	–	3	8	–	3	–	–	–	3	–	6	–	–

Table 10.3: Palmer's Pollution Index of Algal Species in Collection-III

Genera	Stations															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Synedra ulna	3	–	3	–	3	3	–	–	–	–	–	–	–	–	–	3
Nitzschia palea	–	–	–	–	–	5	–	–	–	–	–	–	–	–	–	5
Total Score	3	–	3	–	3	8	–	–	–	–	–	–	–	–	–	8

By applying various pollution indices, it is clear that in general waters of both streams and reservoir are oligotrophic in nature, as there is no high organic pollution load in these waters. However, there is a slight difference in the results of different pollution indices. Nygaard's pollution index showed slight eutrophic quality for stream waters and oligotrophic for reservoir waters. While pollution index based on Shannon diversity showed no difference between streams and reservoir waters on the basis of oligotrophic and eutrophic natures. Results of this index indicated slight eutrophication and oligotrophication in both the waters of streams and reservoir. Palmer's genera as well as species pollution index showed no heavy load of organic pollution in any of the waters of both the streams and reservoir. According to Palmer (1980) *Melosira islandica* and species of *Dinobryon* are clean water indicators. The occurrence of *Melosira islandica* in stream waters and *Dinobryon calciformis* and *D. sertularia* in reservoir waters clearly indicate that both the waters are clean. Thus, there is no heavy organic pollution load in any of the waters of both streams as well as reservoir of Sharavati River basin.

As all the stations of streams and reservoir are away from disturbances from cities and industries, presently there is no heavy organic pollution in these water bodies. However, in future, in case of any pollutants like domestic and industrial wastes, there will be a threat to the indigenous phytoplankton. Phytoplankton are the primary producers, on which many higherlevel organisms like zooplankton and other aquatic higher animals are directly or indirectly dependent. So, these contaminations may change their environment and affect the food chain. Due to this, the organisms which were in equilibrium with habitat earlier, will be unable to cope with the changed environment and may disappear slowly.

Conclusion

The biological examination of the stream and reservoir ecosystems of Sharavati River basin showed a rich and diverse phytoplankton population. Desmids predominated in reservoir waters while diatoms in streams. Species diversity is not uniform either in streams or in reservoir waters. From various pollution indices, it is clear that the waters of reservoir are in oligotrophic nature, even though the streams showed slight organic pollution. The study emphasizes the requirement of proper conservation of phytoplankton—the primary producers, on which most of the higher aquatic organisms are dependent. ▩

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