Водные биоресурсы и среда обитания
2021, том 4, номер 3, с. 24–37
http://journal.azniirkh.ru, www.azniirkh.ru
doi: 10.47921/2619-1024_2021_4_3_24
ISSN 2618-8147 print, ISSN 2619-1024 online

Aquatic Bioresources & Environment
2021, vol. 4, no. 3, pp. 24–37
http://journal.azniirkh.ru, www.azniirkh.ru
doi: 10.47921/2619-1024_2021_4_3_24
ISSN 2618-8147 print, ISSN 2619-1024 online

УДК 581.526.325(282.253)(549.3)

PHYTOPLANKTON VARIABLES DYNAMICS IN THE HALDA RIVER (BANGABANDHU FISHERIES HERITAGE), CHITTAGONG, BANGLADESH

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Abstract. The Halda is a river ecosystem of major importance, well-suited for the natural spawning of major carps due to the unique physicochemical and biological properties of its water. The productivity of the Halda ecosystem mainly depends on the plankton density. The present study has been aimed at the determination of qualitative and quantitative density of the phytoplankton in the Halda River during a two-year period extending from January, 2017 to December, 2018. Phytoplankton density is a good indicator of the water quality of a river ecosystem. A total of 74 species of phytoplankton divided into 47 genera belonging to 6 phyla has been recorded. Bacillariophyta was the most dominant phylum of phytoplankton followed by Cyanobacteria, Chlorophyta, Miozoa, Charophyta, and Euglenozoa. The maximum phytoplankton density was recorded during the pre-monsoon period, and its minimum fell upon the post-monsoon period. The phytoplankton showed a positive significant relationship with transparency, total dissolved solids, conductivity, calcium, total hardness, and BOD_5 and an inverse significant relationship with water temperature. The water of the Halda River is organically polluted and eutrophic in its nature.

Keywords: Halda River, phytoplankton, pollution, Chittagong, Bangladesh

ДИНАМИКА ПОКАЗАТЕЛЕЙ ФИТОПЛАНКТОНА В РЕКЕ ХАЛДА (РЫБОХОЗЯЙСТВЕННОЕ НАСЛЕДИЕ БАГАБАНДУ), ЧИТТАГОНГ, БАНГЛАДЕШ

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Аннотация. Халда — важная речная экосистема, чьи уникальные физико-химические и биологические характеристики обеспечивают благоприятные условия для естественного нереста крупных карповых рыб. Продуктивность экосистемы Халды в значительной степени зависит от плотности планктона. Данное исследование было направлено на определение количественной и качественной плотности фитопланктона в реке Халда в течение двухлетнего периода, продолжавшегося с января 2017 по декабрь 2018 г. Плотность фитопланктона служит хорошим индикатором качества воды в речной экосистеме. Всего было обнаружено 74 вида фитопланктона, относившихся к 47 родам и входивших в 6 классов. Доминирующим классом фитопланктона был Bacillariophyta, за ним следовали Cyanobacteria, Chlorophyta, Miozoa, Charophyta и Euglenozoa. Максимальная плотность фитопланктона была зафиксирована в предмуссонный период, а минимальная — в послемусонный. Фитопланктон продемонстрировал статистически достоверную прямую зависимость от таких характеристик воды, как прозрачность, общая минерализация, проводимость, содержание кальция и общая жесткость, и достоверную обратную зависимость — от температуры воды. Вода в р. Халда загрязнена органическими веществами и по своей природе является эвтрофической.

Ключевые слова: р. Халда, фитопланктон, загрязнение, Читтагонг, Бангладеш

INTRODUCTION

The tidal River Halda, the sources for which are tidal waters and numerous streams originated in hilly area, is located in the southeastern region of Bangladesh; it is also well known as a major natural spawning ground of Indian major carp [1]. At present, it is considered as the "Bangabandhu Fisheries Heritage" of Bangladesh named after the father of the nation. The ecosystem of the Halda River is productive and suitable for various fish species, Gangetic dolphins, and other aquatic living organisms. In the Halda River, a total of 83 species of finfish and 10 shellfish have been recorded [2]. The river is mainly used by local fishermen for the collection of fertilized eggs of major carps. Its water is used for various purposes, i. e. agriculture, household activities, bathing, washing clothes, and transportation of local people; the main application of the downstream water after treatment is for drinking purposes by Chittagong City inhabitants. The productivity of any aquatic ecosystem depends on the physicochemical and biological parameters of water. Phytoplankters are the primary producers forming the first trophic level of the food chain of the freshwater ecosystem. Phytoplankton forms a vital source of energy in the freshwater environment. It initiates the freshwater food chain by serving as the source of nutrition for primary consumers, which include zooplankton, finfish, shellfish, and others [3]. Increases in river discharge are believed to decrease phytoplankton biomass by shortening its residence time and, consequently, reducing plankton's capacity to develop [4, 5]. Halda River directly receives untreated industrial wastes, agrochemicals, poultry litters, household wastes (solid and liquid forms) through its tributaries. Phytoplankton is widely used as an informative indicator of the water quality and pollution status of any ecosystem. Recently some notable research works on phytoplankton have been done at home and abroad by [6–15] for different water bodies. However, no detailed analysis has yet been conducted on the phytoplankton variables dynamics in the Halda River in its entirety. Therefore, the present study undertaken to determine the phytoplankton variables dynamics in the entire Halda River, known as the "Bangabandhu Fisheries Heritage" of Bangladesh, will be beneficial for its proper management.

MATERIALS AND METHODS

Investigated area: The Halda River is one of the important tributaries of the Karnafully River. It originates in Khagrachari Hill Ranges and crosses 88 km to meet with the Karnafully River at Kalurghat, Mohora point. The present study covered a two-year period, spanning from January, 2017 to December, 2018, and was conducted to analyze the variables dynamics of the phytoplankton in the Halda River in its entirety. For this purpose, the locations of three sampling stations were chosen from the lower to the upper reaches of the river (Fig. 1).

Station-1 is located at Nazirhat (latitude 22°37′59.38"N, longitude 91°47′32.71"E) in the upper reaches of the Halda River. It is 20 km upstream from Station-2.

Station-2 is located under the Halda Bridge of Satterghat (latitude 22°30′48.05"N, longitude 91°50′45.60"E) midstream of the Halda River. It is 20 km upstream from Station-3.

Station-3 is located under the Modunaghat Bridge (latitude 22°26′2.55"N, longitude 91°52′16.82"E) in the lower reaches of the Halda River. It is 5 km away from the Halda mouth.

Collection and preservation of phytoplankton samples:

Phytoplankton samples were collected from surface water at three sampling stations of the Halda River at monthly intervals; for this purpose, a 20 μm mesh size plankton net was used. After

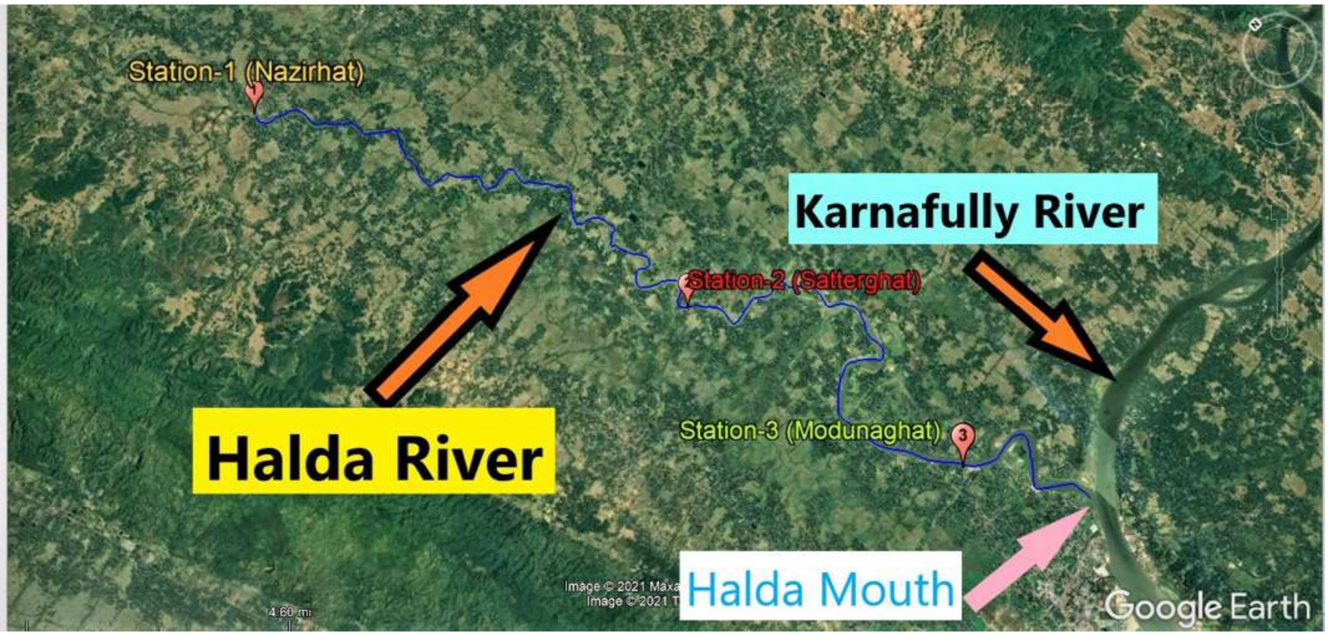

Fig. 1. Map showing the three sampling stations of the Halda River

Рис. 1. Карта трех станций отбора проб на р. Халда

collection, phytoplankton samples were preserved with 5 % formalin solution immediately in the field.

Analysis and identification of phytoplankton samples:

For the analysis of phytoplankton, a 1 ml sample was taken in the Sedgewick Rafter counting chamber and observed by using a binocular compound microscope (XSZ-107BN, China).

$$\text{No. of species} = \frac{C \times 1000}{L \times D \times W \times S} \ [16],$$

where C is the number of organisms counted, L is the length of each stripe (S-R cell length in mm), D is the depth of each stripe in mm, W is the width of each stripe in mm, and S is the number of stripes.

Identification of various genera and species of phytoplankton has been done according to the following books [17–22].

Different types of physicochemical parameters of the Halda River, i. e. air temperature, water temperature, transparency, total dissolved solids (TDS), conductivity, pH, dissolved oxygen (DO), free carbon dioxide (fCO_2), calcium (Ca^{++}), total hardness (TH), total alkalinity (TA), and biochemical oxygen demand (BOD_5), were analyzed during the study period. Air and water temperatures were measured by a mercury thermometer, transparency was measured by a 20 cm diameter Secchi disc, conductivity, pH, and TDS were measured by digital meters, DO, fCO_2, Ca^{++}, TH, TA, and BOD_5 were measured by following [16]. Statistical analysis was performed using Microsoft Excel 2013.

RESULTS AND DISCUSSION

Phytoplankton was analyzed both quantitatively and qualitatively. A total of 74 species of phytoplankton under 47 genera belonging to six phyla—namely Bacillariophyta, Charophyta, Chlorophyta, Cyanobacteria, Euglenozoa, and Miozoa—were recorded. Seasonal and monthly fluctuations in distribution and relative abundance of the total phytoplankton were highly pronounced. The study period has been divided into four timespans —pre-monsoon (February–April), monsoon (May–July), post-monsoon (August–October), and winter (November–January) seasons. During the study period, the mean values of different physicochemical parameters of the Halda River were analyzed to find out the significant relationship with the phytoplankton (Table 1). Table 2 shows the mean monthly and seasonal variations of the phytoplankton at the three sampling stations of the Halda River.

During a two-year study period extending from January, 2017 to December, 2018, at Station-1, the lowest mean density of the phytoplankton cells ($775.4546 \pm 548.3293/m^3$) was recorded in July, and the highest density ($14{,}152.04 \pm 15{,}079.05/m^3$) in December. The seasonal minimum mean density of the phytoplankton cells ($1{,}960.176 \pm 696.9914/m^3$)

Table 1. Mean values of various physicochemical parameters of the Halda River from January, 2017 to December, 2018

Таблица 1. Средние значения различных физико-химических параметров р. Халда с января 2017 по декабрь 2018 г.

Parameters Параметры	January Январь	February Февраль	March Март	Apr Апрель	May Май	June Июнь	July Июль	August Август	September Сентябрь	October Октябрь	November Ноябрь	December Декабрь
Air temperature (°C) Температура воздуха (°C)	21.67	25.33	25.30	30.45	32.50	30.17	29.67	29.17	27.67	25.50	28.00	21.84
Water temperature (°C) Температура воды (°C)	22.70	25.50	27.37	29.02	30.77	30.25	28.63	30.60	29.35	27.57	28.15	22.52
Transparency (cm) Прозрачность (см)	31.00	30.17	27.00	23.83	29.33	22.50	15.33	20.67	20.17	17.83	26.33	35.33
Conductivity (µS/cm) Проводимость (мкСм/см)	147.67	159.83	162.17	120.83	99.33	80.00	54.67	86.00	81.50	92.67	128.83	158.83
TDS (ppt) Общая минерализация (ччт)	0.06	0.07	0.07	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.06	0.06
pH	7.57	7.45	7.30	7.15	7.28	7.47	7.35	7.35	7.58	7.70	7.72	7.63
DO (mg/L) Растворенный кислород (мг/л)	10.07	5.38	8.13	5.00	4.98	5.02	4.30	4.80	4.92	6.52	7.88	6.98
fCO_2 (mg/L) Свободная углекислота (мг/л)	11.99	8.32	10.32	15.15	11.82	12.32	43.29	8.66	8.99	9.99	9.32	7.49
Calcium (mg/L) Кальций (мг/л)	11.47	11.62	10.69	7.21	6.01	4.41	5.74	4.41	5.75	5.34	10.55	9.34
Total hardness (mg/L) Общая жесткость (мг/л)	40.33	46.33	43.33	32.50	27.00	21.33	17.83	26.67	26.83	28.00	41.00	42.00
Total alkalinity (mg/L) Общая щелочность (мг/л)	45.67	49.50	49.67	45.50	55.00	43.33	51.17	52.67	36.17	42.67	43.00	50.83
BOD_5 (mg/L) $БПК_5$ (мг/л)	1.50	1.63	2.43	1.27	2.00	0.85	1.15	1.08	0.72	1.27	0.85	1.77

Table 2. Mean phytoplankton density at the three stations of the Halda River from January, 2017 to December, 2018
Таблица 2. Средняя плотность фитопланктона на трех станциях р. Халда с января 2017 по декабрь 2018 г.

Month Месяц	Station-1 Станция-1	Station-2 Станция-2	Station-3 Станция-3	Mean Среднее
January Январь	5557.424±4203.86	2455.606±548.33	4006.515±548.33	4006.515±1550.91
February Февраль	10597.88±11149.36	2843.333±1279.44	6591.363±5848.84	6677.525±3877.99
March Март	4071.136±4112.47	4846.59±5574.68	10404.02±1736.38	6440.582±3454.27
April Апрель	9822.423±11880.46	3554.166±1370.82	7948.407±7950.77	7108.332±3217.46
May Май	2843.333±3289.97	4717.348±274.16	6591.363±5848.84	4717.348±1874.02
June Июнь	3812.651±1553.60	1809.394±731.11	3295.682±1188.05	2972.576±1039.98
July Июль	775.4546±548.33	2455.606±2193.32	1550.909±731.11	1593.99±840.90
August Август	1163.181±365.55	1809.394±548.33	2390.985±274.16	1787.853±614.18
September Сентябрь	2455.606±1096.66	1938.637±182.78	2390.985±822.49	2261.743±281.68
October Октябрь	2261.742±639.72	1809.394±1827.76	2261.743±1736.38	2110.96±261.16
November Ноябрь	3683.409±639.72	2714.091±913.88	2455.606±182.78	2951.035±647.29
December Декабрь	14152.04±15079.05	7754.544±548.33	13376.59±12520.18	11761.06±3491.34

was recorded during the post-monsoon period and the maximum density (8,163.813±3,565.507/m^3) during the pre-monsoon period. At Station-2, the lowest mean density of the phytoplankton cells (1,809.394±1,827.764/m^3) was recorded in June, August, and October, and the maximum density (7,754.544±548.3288/m^3) in December. The seasonal minimum mean density of the phytoplankton cells (1,852.475±74.61848/m^3) was recorded during the post-monsoon period, and the maximum density (3,748.03±1,015.602/m^3) during the pre-monsoon period. At Station-3, the lowest mean density of the phytoplankton cells (1,550.909±731.106/m^3) was recorded in July, and the maximum density (13,376.59±12,520.18/m^3) in December. The seasonal minimum mean density of the phytoplankton cells (2,347.904±74.6179/m^3) was recorded during the post-monsoon period, and the maximum density (8,314.597±1,932.527/m^3) during the pre-monsoon period.

In the Halda River, the lowest mean density of the phytoplankton cells (1,593.99±840.9038/m^3) was recorded in July, and the highest mean density (11,761.06±3491.339/m^3) in December (Table 2). The seasonal minimum mean density of the phytoplankton cells (2,053.519±242.1106/m^3) was recorded during the post-monsoon period, and the maximum density (6,742.146±338.5328/m^3) during the pre-monsoon period (Table 2). Higher temperature during the pre-monsoon period enhanced the rate of decomposition, which caused an increase in phytoplankton abundance. As a result, the water became rich in nutrients, and thus the rate of photosynthesis increased. This finding coincides with the findings of [6, 23–25] for various water bodies. Phytoplankton showed a positive significant relationship with transparency ($r=0.79$, $P<0.01$), TDS ($r=0.64$, $P<0.05$), conductivity ($r=0.75$, $P<0.01$), Ca^{++} ($r=0.51$, $P<0.1$), TH ($r=0.64$, $P<0.05$), and BOD_5 ($r=0.59$, $P<0.1$) and an inverse significant relationship with water temperature ($r=-0.59$, $P<0.1$). It contradicts the findings of [15] for the Halda River due to the time factor and variation of sampling stations.

Bacillariophyta:

The Bacillariophyta was the most dominant phylum of phytoplankton that represented 35.12 % of the total phytoplankton abundance during the study period (Table 3). A total of 28 species of bacillariophytes under 18 genera was recorded, where *Surirella* was the dominant genus followed by *Nitzschia, Pinnularia, Cyclotella,* and *Tabellaria* (Table 4). The dominance of bacillariophytes with following genera—*Navicula, Nitzschia, Melosira, Fragilaria, Pinnularia,* and *Synedra*—was reported by [9, 11, 13, 26–28] for various water bodies. The lowest mean density of the bacillariophyte cells (193.864/m^3) was recorded at Station-1 in July, and the highest mean density (8,077.652/m^3) at Station-1 in December (Fig. 2). The seasonal minimum mean density of the bacillariophyte cells (732.374/m^3) was recorded at Station-2 during the post-monsoon period, and the maximum density (4,135.757/m^3) at Station-1 during the winter period (Fig. 2, 3). In the Halda River, the minimum mean density of the bacillariophyte cells (280.03/m^3) was recorded in July, and the maximum density (4,372.702/m^3) fell on December (Table 3). The seasonal minimum mean density of the bacillariophyte cells (646.212±21.540/m^3) was recorded during the post-monsoon period, and its maximum (2,268.922±1,824.503/m^3) fell on the winter period (Table 3). The highest number of bacillariophytes species was recorded in the winter period due to an adequate amount of dissolved oxygen, as well as favorable pH and alkalinity. The present finding is congruent with the works of [11, 13, 26, 29, 30] for various water bodies. Due to their short regeneration time and sensitivity to ecological factors, bacillariophytes can be used as bio-indicators for water quality evaluation [31, 32]. Bacillariophytes showed a positive significant relationship with transparency ($r=0.73$, $P<0.01$), conductivity ($r=0.64$, $P<0.05$), TH ($r=0.54$, $P<0.1$), and TDS ($r=0.50$, $P<0.1$) and an inverse significant relationship with water temperature ($r=-0.58$, $P<0.1$) (Table 5).

Cyanobacteria:

The Cyanobacteria was the second dominant phylum of phytoplankton, comprising 29.63 % of the total phytoplankton abundance (Table 3). A total of 10 species of cyanobacteria under 6 genera was recorded, where *Oscillatoria* was the dominant genus followed by *Spirulina, Phormidium, Anabaena, Microcystis,* and *Merismopedia* (Table 4). Patra and Azadi [15] reported cyanobacteria to be the second dominant group of phytoplankton in the Halda River, with following genera—*Microcystis, Oscillatoria, Lyngbya, Anabaena, Nostoc,* and *Rivularia*. The prevalence of cyanobacteria was also reported by [10, 33] for various water bodies due to different ecological and geographical variations. The lowest mean density of the cyanobacteria cells (258.4848/m^3) was recorded at Station-1 in July and August, and the highest one (3,683.408/m^3) at Station-3 in December (Fig. 2, 4). The seasonal minimum mean density of the cyanobacteria cells (452.3484/m^3) was recorded at Station-1 during the post-monsoon period, and the maximum mean density (2,671.01/m^3) at Station-3 during the pre-monsoon period (Fig. 2, 4). In the Halda River, the minimum mean cells density of this phylum (473.8888/m^3) was recorded in August, and its maximum (2,757.171/m^3) fell on December (Table 3). The seasonal minimum mean cells density of this phylum (538.510± 93.892/m^3) was recorded during the post-monsoon period, and its maximum (1,744.773±373.712/m^3) fell on the pre-monsoon period (Table 3). The cyanobacteria had the highest abundance during the pre-monsoon period due to high levels of temperature, TDS, hardness of water, conductivity, BOD_5, and abundance of food. The present finding is similar to the findings of [11, 23, 25, 29, 34] for various water bodies. High density of cyanobacteria indicates a high pollution load and nutrient-rich conditions [3, 35]. Cyanobacteria showed a positive significant relationship with BOD_5 ($r=0.78$, $P<0.01$), TDS ($r=0.68$, $P<0.05$), transparency ($r=0.76$, $P<0.01$), conductivity ($r=0.73$, $P<0.01$), TH ($r=0.61$, $P<0.05$), and Ca^{++} ($r=0.53$, $P<0.1$) and an inverse significant relationship with water temperature ($r=-0.56$, $P<0.1$) (Table 5).

Chlorophyta:

The phylum Chlorophyta represented 25.12 % of the total phytoplankton abundance (Table 3). A total of 10 species of chlorophytes under 7 genera were identified, where *Pediastrum* was the dominant genus followed by *Volvox, Ankistrodesmus,* and *Scenedesmus* (Table 4). The prevalence of chlorophytes in various river ecosystems was also reported by [6, 12, 25, 29, 36–38].

The lowest mean density of the chlorophytes cells (0/m^3) was recorded at Station-1 in July, and the highest one (4,588.105m^3) was recorded at Station-3 in December (Fig. 2, 4). The seasonal minimum mean density of the chlorophytes cells (236.9444/m^3) was

Table 3. Density of different phytoplankton groups in the Halda River from January 2017 to December 2018

Таблица 3. Плотность клеток различных групп фитоплактона в р. Халда с января 2017 по декабрь 2018 г.

Groups Группы	January Январь	February Февраль	March Март	Apr Апрель	May Май	June Июнь	July Июль	August Август	September Сентябрь	October Октябрь	November Ноябрь	December Декабрь	Total, % Всего, %
Cyanophytes Синезеленые водоросли	990.8585	1830.934	2067.879	1335.505	1507.828	796.9949	775.4544	473.8888	495.4292	646.2121	624.6716	2757.171	29.62963
Chlorophytes Зеленые водоросли	947.7777	1464.747	1421.666	1895.555	603.1312	689.2927	107.702	344.6464	689.2929	366.1868	538.5101	3058.737	25.12271
Charophytes Десмидиевые	172.3232	129.2424	107.702	107.702	215.404	150.7828	86.1616	64.6212	86.1616	215.404	86.1616	21.5404	2.989737
Bacillariophytes Диатомовые	1313.964	1701.692	1357.046	2692.55	1249.343	926.2371	280.0252	667.7524	646.2122	624.6717	1120.101	4372.702	35.11825
Miozoans Динофлагелляты	236.9445	775.4543	947.7777	323.106	215.404	86.1616	107.702	0	107.702	64.6212	86.1616	0	6.113342
Euglenophytes Эвгленофиты	107.702	0	43.0808	64.6212	0	129.2424	43.0808	0	0	64.6212	21.5404	21.5404	1.026327

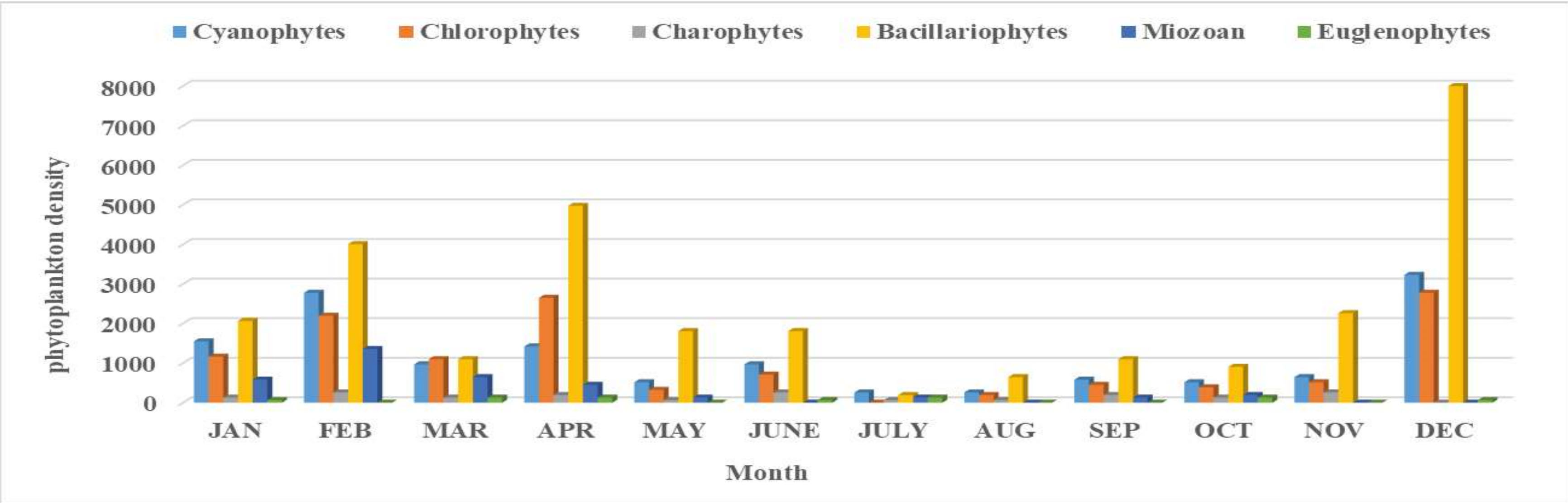

Fig. 2. Mean cells density of different groups of phytoplankton at the Station-1 of the Halda River from January 2017 to December 2018

Рис. 2. Средняя плотность клеток различных групп фитопланктона на Станции-1 р. Халда с января 2017 по декабрь 2018 г.

Table 4. Phytoplankton species recorded in the Halda River from January 2017 to December 2018

Таблица 4. Виды фитопланктона, обнаруженные в р. Халда с января 2017 по декабрь 2018 г.

1. Bacillariophyta	*Spirogyra varians* (Hassall) Kützing, 1849
Aulacoseira granulata (Ehrenberg) Simonsen, 1979	*Spirogyra minuticrassoidea* Yamagishi, 1963
Asterionella formosa Hassall, 1850	*Staurasstrum gracile* Ralfs ex Ralfs, 1848
Coscinodiscus radiatus Ehrenberg, 1840	*Zygnema circumcarinatum* Czurda, 1930
Cyclotella atomus Hustedt, 1937	**3. Chlorophyta**
Cyclotella meneghiniana Kützing, 1844	*Ankistrodesmus falcatus* (Corda) Ralfs, 1848
Cylindrotheca closterium (Ehrenberg) Reimann & J.C. Lewin, 1964	*Eudorina elegans* Ehrenberg, 1832
Cymbella lanceolata C. Agardh, 1830	*Pediastrum boryanum* (Turpin) Meneghini, 1840
Fragilaria crotonensis Kitton, 1869	*Pediastrum duplex* Meyen, 1829
Frustulia maoriana H. Lange-Bertalot & T. Beier, 2007	*Pediastrum simplex* Meyen, 1829
Gyrosigma acuminatum (Kützing) Rabenhorst, 1853	*Pachycladella zatoriensis* (Bednarz & Mrozinska-Webb) Komárek, 1979
Melosira varians C. Agardh, 1827	*Scenedesmus opoliensis* P.G. Richter, 1895
Navicula tripunctata (O.F. Müller) Bory in Bory de Saint-Vincent, 1822	*Ulothrix aequalis* Kützing, 1845
Nitzschia longissima (Brébisson) Ralfs in Pritchard, 1861	*Volvox aureus* Ehrenberg, 1832
Nitzschia sigmoidea W. Smith, 1853	*Volvox globator* Linnaeus, 1758
Nitzschia seriata Cleve, 1883	**4. Cyanobacteria**
Pinnularia gibba Ehrenberg, 1843	*Anabaena circinalis* Rabenhorst ex Bornet & Flahault, 1886
Pinnularia viridis Ehrenberg, 1843	*Microcystis flosaquae* (Wittrock) Kirchner, 1898
Pinnularia streptoraphe Cleve, 1891	*Merismopedia tenuissima* Lemmermann, 1898
Surirella elegans Ehrenberg, 1843	*Oscillatoria brevis* Kützing ex Gomont, 1892
Surirella robusta Ehrenberg, 1841	*Oscillatoria* sp. Vaucher ex Gomont, 1892
Surirella splendida Ehrenberg, 1834	*Oscillatoria limosa* C. Agardh ex Gomont, 1892
Surirella tenera W. Gregory, 1856	*Oscillatoria princeps* Vaucher ex Gomont, 1892
Surirella minuta Brébisson ex Kützing, 1849	*Phormidium favosum* Gomont, 1892
Synedra famelica Kützing, 1844	*Spirulina platensis* (Gomont) Geitler, 1925
Tabellaria flocculosa (Roth) Kützing, 1844	*Spirulina maxima* (Setchell & N.L. Gardner) Geitler, 1932
Tabellaria fenestrata (Lyngbye) Kützing, 1844	**5. Euglenozoa**
Triceratium favus Ehrenberg, 1839	*Euglena acus* (O.F. Müller) Ehrenberg, 1830
Ulnaria ulna Compère, 2001	*Euglena sociabilis* P.A. Dangeard, 1902
2. Charophyta	*Euglena gracilis* G.A. Klebs, 1883
Closterium setaceum Ehrenberg ex Ralfs, 1848	*Euglena viridis* (O.F. Müller) Ehrenberg, 1830
Closterium praelongum Brébisson, 1856	*Lepocinclis acus* (O.F. Müller) B. Marin & Melkonian, 2003
Closterium acerosum Ehrenberg ex Ralfs, 1848	*Phacus longicauda* (Ehrenberg) Dujardin, 1841
Cosmarium margaritum Wolle, 1881	*Phacus acuminatus* A. Stokes, 1885
Desmidium swartzii C. Agardh ex Ralfs, 1848	*Phacus cordatus* (Pochmann) Zakryś & Lukomska, 2015
Docidium ehrenbergii Ralfs, 1848	*Strombomonas octocostata* S. Péterfi
Euastrum crassum Ralfs, 1848	**6. Miozoa**
Micrasterias americana Ehrenberg ex Ralfs, 1848	*Ceratium furca* Claparède & Lachmann, 1859
Mougeotia scalaris Hassall, 1842	*Ceratium hirundinella* (O.F. Müller) Dujardin, 1841
Pleurotaenium ehrenbergii (Ralfs) De Bary, 1858	*Dissodinium elegans* (Pavillard) Matzenauer, 1933

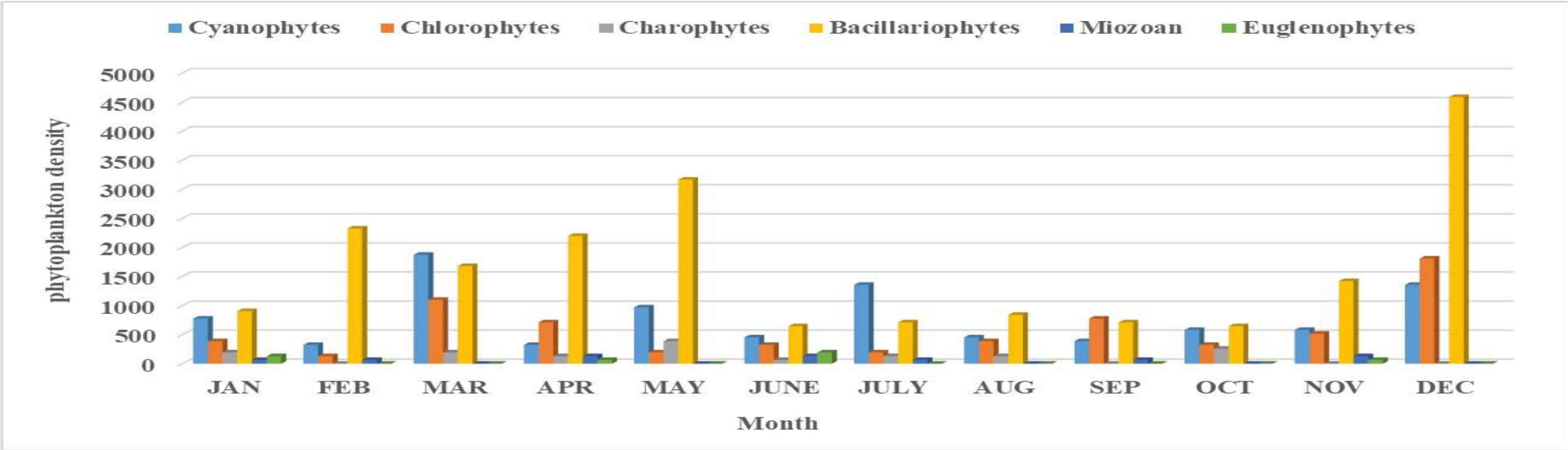

Fig. 3. Mean cells density of different groups of phytoplankton at the Station-2 of the Halda River from January 2017 to December 2018

Рис. 3. Средняя плотность клеток различных групп фитопланктона на Станции-2 р. Халда с января 2017 по декабрь 2018 г.

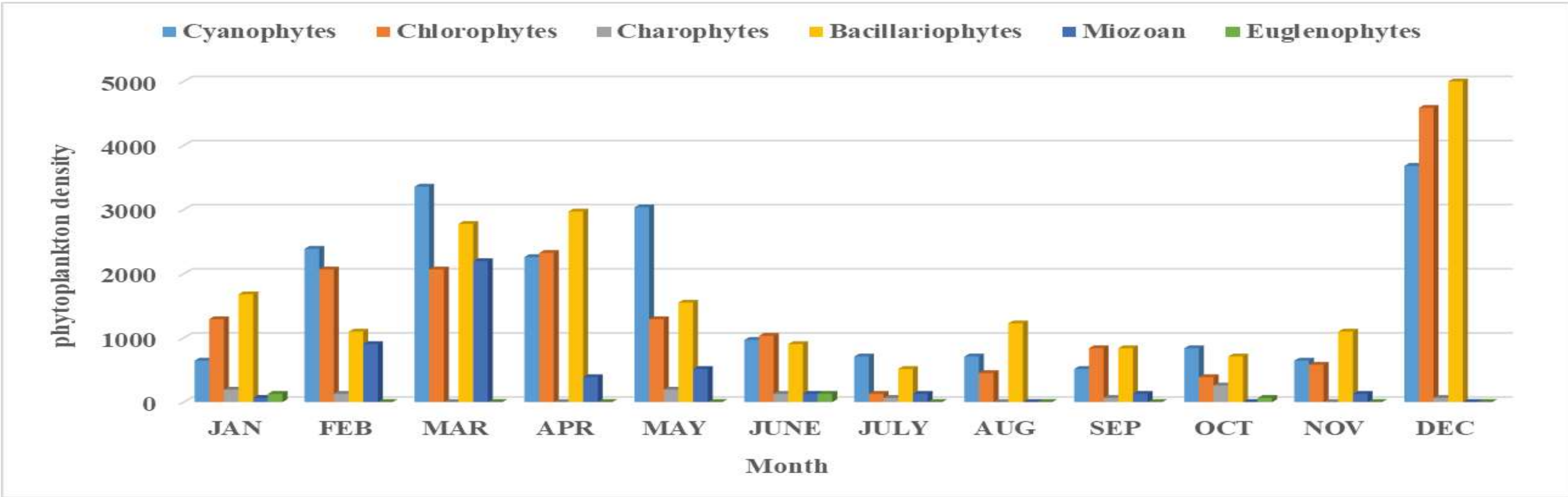

Fig. 4. Mean cells density of different groups of phytoplankton at the Station-3 of the Halda River from January 2017 to December 2018

Рис. 4. Средняя плотность клеток различных групп фитопланктона на Станции-3 р. Халда с января 2017 по декабрь 2018 г.

Table 5. Correlation coefficient for different phytoplankton groups and different physicochemical parameters of the Halda River waters from January 2017 to December 2018

Таблица 5. Коэффициент корреляции различных групп фитоплактона с различными физико-химическими параметрами вод р. Халда с января 2017 по декабрь 2018 г.

Parameters Параметры	Air temp. Темп. воздуха	Water temp. Темп. воды	Trans. Прозр.	Cond. Пров.	pH	DO РК	fCO_2 Своб. CO_2	Ca^{++}	TDS Общ. мин.	TH Жест.	TA ОЩ	BOD_5 $БПК_5$
Cyanophytes Синезеленые водоросли	-0.42	-0.56*	0.76***	0.73***	-0.17	0.22	-0.21	0.53*	0.68**	0.61**	0.48	0.78***
Chlorophytes Зеленые водоросли	-0.50*	-0.61**	0.72***	0.72***	-0.05	0.23	-0.35	0.47	0.58*	0.61**	0.15	0.45
Charophytes Десмидиевые	0.18	0.17	-0.08	-0.13	-0.02	0.10	-0.08	-0.12	-0.19	-0.18	-0.04	0.17
Bacillariophytes Диатомовые	-0.41	-0.58*	0.73***	0.64**	-0.01	0.19	-0.32	0.40	0.50*	0.54*	0.22	0.38
Miozoans Динофлагелляты	-0.18	-0.17	0.29	0.60**	-0.40	0.22	-0.13	0.59*	0.68**	0.57*	0.19	0.66**
Euglenophytes Эвгленофиты	-0.14	-0.16	-0.10	-0.06	0.06	0.33	0.14	-0.05	-0.02	-0.18	-0.30	-0.15

Significance level: **** — P <0.001, *** — P <0.01, ** — P <0.05, * — P <0.1
Уровень достоверности: **** — P <0,001, *** — P <0,01, ** — P <0,05, * — P <0,1

recorded at Station-2 during the monsoon period, and the maximum density (2,154.04/m^3) was found at Station-3 during the pre-monsoon and winter periods (Fig. 3, 4). In the Halda River, the lowest mean cells density of this phylum (107.702/m^3) was recorded in July and the highest one (3,058.737/m^3) in December (Table 3). The seasonal minimum mean cells density of this phylum (466.709±313.879/m^3) was recorded during the monsoon and post-monsoon periods, and the maximum density (1,593.989±262.050/m^3) fell on the pre-monsoon period (Table 3). The present finding coincides with the findings of [11, 13, 25, 26, 29, 34]. The highest abundance of chlorophytes was recorded during the pre-monsoon period due to a sufficient amount of DO, suitable pH, and high temperature. Chlorophytes showed a positive significant relationship with transparency ($r=0.72$, $P<0.01$), conductivity ($r=0.72$, $P<0.01$), TDS ($r=0.58$, $P<0.1$), and TH ($r=0.61$, $P<0.05$) and an inverse significant relationship with water temperature ($r=-0.61$, $P<0.05$) and air temperature ($r=-0.50$, $P<0.1$) (Table 5).

Miozoa:

The phylum Miozoa comprises 6.11 % of the total phytoplankton abundance (Table 3). A total of 3 species of miozoans under 2 genera were recorded, where *Ceratium* was the dominant genus followed by *Dissodinium* (Table 4). Dixit and Sharma [6] reported 2 species of miozoans under the genus *Gymnodonium* in the Gomti River, and 1 species of miozoan under the genus *Ceratium* was recorded by [27, 39] in Kshipra River and Kwa River respectively. The lowest mean density of the miozoan cells (0/m^3) was recorded at Stations 1, 2, and 3 during March, May, June, August, October, November, and December, and the highest density (2,197.121/m^3) was found at Station-3 in February (Fig. 2–4). The seasonal minimum mean cells density of this phylum (21.5404/m^3) was recorded at Station-2 during the post-monsoon period, and the maximum density (1,163.182/m^3) was found at Station-3 during the pre-monsoon period (Fig. 3, 4). In the Halda River, the lowest mean cells density of this phylum (0/m^3) was recorded in August and December, and the highest density (947.7777/m^3) fell on March (Table 3). The seasonal minimum mean cells density of this phylum (57.441±54.209/m^3) was recorded during the post-monsoon period, and the maximum density (682.113±322.627/m^3) fell on the pre-monsoon period (Table 3). A similar findings were also reported by [40] for the Tapi estuarine area. The cells density of the Miozoa is very low as compared to Bacillariophyta, Cyanobacteria, and Chlorophyta, which could be attributable to the oligotrophic preferences of dinoflagellates and their competition with diatoms [41]. Miozoans showed a positive significant relationship with TDS ($r=0.68$, $P<0.05$), BOD_5 ($r=0.66$, $P<0.05$), conductivity ($r=0.60$, $P<0.05$), Ca^{++} ($r=0.59$, $P<0.1$), and TH ($r=0.57$, $P<0.1$) (Table 5).

Charophyta:

The phylum Charophyta comprises 2.99 % of the total phytoplankton abundance (Table 3). A total of 14 species of charophytes under 11 genera were recorded, where *Closterium* was the dominant genus followed by *Spirogyra, Zygnema, Mougeotia, Cosmarium, Micrasterias,* etc. (Table 4). Ali *et al.* [42] reported the presence of 28 species of charophytes under the 7 genera—*Spirogyra* as the dominant genus followed by *Chara, Closterium,* and *Zygnema*—in the low water, Charsadda, Pakistan. Ozer *et al.* [43] recorded the presence of 9 species of charophytes under *Closterium, Spirogyra, Cosmarium*, and *Penium* genera in the Melen River. The lowest mean density of the charophyte cells (0/m^3) was recorded at Stations 1, 2, and 3 in February, March, April, August, September, November, and December, and the highest density (258.4848/m^3) was found at Station-3 in February, June, and November (Fig. 2–4). The seasonal minimum mean density of the charophyte cells (43.0808/m^3) was recorded at Station-3 during the pre-monsoon period, and the maximum density (193.8636/m^3) was found at Station-1 and Station-2 during the pre-monsoon and monsoon periods (Fig. 2–4). In the Halda River, the lowest mean cells density of this phylum (21.5404/m^3) was recorded in December, and the highest density (215.404/m^3) fell on May and October (Table 3). The seasonal minimum mean cells density of this phylum (93.342±75.647/m^3) was recorded during the winter period, and the maximum density (150.783±64.621/m^3) fell on the monsoon period (Table 3). Charophytes showed no significant relationship with any of the parameters (Table 5).

Euglenozoa:

The Euglenozoa is the least dominant phylum represented by 1.03 % of the total phytoplankton abundance (Table 3). A total of 9 species of euglenophytes under 4 genera were recorded, where *Euglena* was the dominant genus followed by *Phacus*, *Lepocinclis,* and *Strombomonas* (Table 4). Dixit and Sharma [6] reported the presence of 3 species of euglenophytes under the genera *Euglena* and *Phacus* in the Gomti River. The lowest mean density of the euglenophyte cells (0/m^3) was recorded at Stations 1–3 in February–May, in July, and in August–December, and the highest density (193.8636/m^3) was found at Station-2 in June (Fig. 2–4). The seasonal minimum mean cells density of this phylum (0/m^3) was recorded at Station-2 and Station-3 during the post-monsoon period, and the maximum density (86.1616/m^3) was found during the pre-monsoon period (Fig. 3, 4). In the Halda River, the lowest mean cells density of this phylum (0/m^3) was recorded in February, May, August, and September, and the highest density (129.2424/m^3) was found in June (Table 3). The seasonal minimum mean cells density of this phylum (21.540±37.309/m^3) was recorded during the post-monsoon period, and the maximum density (57.441±65.807m^3) was found during the monsoon period (Table 3). The present finding coincides with the findings of [23, 25, 26, 42] for various river ecosystems. The density of euglenophytes was the highest during the monsoon period due to the entry of nutrients through the influx of household sewage from the tributaries of the Halda River. Euglenophytes showed no significant relationship with any of the parameters (Table 5).

CONCLUSION

From the present study, it can be concluded that diverse groups of phytoplankton are present in the Halda River in the following order: Bacillariophyta> Cyanobacteria> Chlorophyta> Miozoa> Charophyta> Euglenozoa. Bacillariophytes and cyanophytes were the most abundant ones—both quantitatively and qualitatively. The abundance of bacillariophytes and cyanophytes is a good indicator of pollution and eutrophication of any water body. The occurrence of certain pollution tolerant species from genera *Microcystis, Nitzschia, Navicula, Oscillatoria, Scenedesmus, Ankistrodesmus, Fragilaria, Euglena,* and *Phacus* clearly indicate organic pollution [44, 45], which is consistent with the present study. In this case, the water body of Halda can be defined as organically polluted and eutrophic in its nature. It could be induced by various anthropogenic activities: washing clothes, bathing, discharge of human and animal excreta, disposal of garbage, etc. Industrial and household effluents, as well as certain harmful wastes are being directly dumped into the Halda River through its tributaries. Therefore, immediate and continuous monitoring of the water quality and phytoplankton dynamics should be ensured to protect this ecosystem from severe pollution in order to enhance the fishery in the Halda River.

ACKNOWLEDGEMENTS

I am very grateful to my supervisor Prof. Dr. Mohammad Ali Azadi and co-supervisor Prof. Dr. Munira Nasiruddin for their kind cooperation during this research work.

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Поступила 04.08.2021

Принята к печати 11.09.2021