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ECOLOGICAL DYNAMICS OF ALGAL COMMUNITIES IN THE BURHI GANDAK RIVER, MUZAFFARPUR, BIHAR

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Abstract

There are all kinds of organisms in any river which keep the aquatic ecosystem stable. Among these organisms, planktonic algae are special organisms that help in maintaining stability. But this stability will turn into instability when the level of nutrients increases in the river. Which indicates the pollution level in the water. A comprehensive analysis identified a total of 181 algae species, spanning 84 diverse genera. Within this dataset, the Chlorophyceae class encompassed 69 species, categorized into 38 distinct genera, while the Bacillariophyceae class comprised 67 species, organized into 23 different genera. Additionally, the Cyanophyceae class featured 32 species distributed among 17 distinct genera. Notably, the survey also documented 10 species from other algal classes. Remarkably, even in sections of the Burhi Gandak known for pollution, algae typically associated with clean water environments were present. This observation underscores the resilience and adaptability of certain algal species, challenging conventional expectations regarding their distribution in polluted habitats.

Keywords: *aquatic ecosystem, Organism, stability, algae species, Chlorophyceae, environment*

Introduction

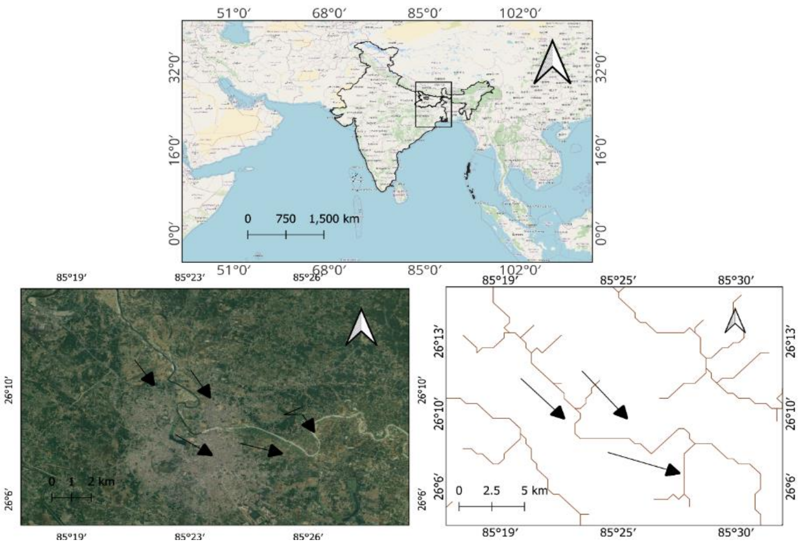
The river Burhi Gandak is a tributary of the Ganga River situated near the Muzaffarpur Originating in the terai area near Bishambharpur, West Champaran district, Bihar state, it takes its source from Chautarwa Chaur (Singh et al, 2018; Kumar and Prasad, 2022). This river is renowned for experiencing recurrent floods annually (Pradhan & Sahu, 2022). Understanding river ecosystems is challenging because these ecosystems are intricately shaped and influenced by a multitude of factors. The complexity arises from the sheer abundance of variables that can impact both the structure and functioning of these environments (Santos and Rocha, 1998). Phytoplankton, free-floating microscopic organism constituting the primary group of primary producers (chlorophyll bearing), is regarded as the primary food source for fish in the river (El-Sheekh et al. 2019, Paerl et al. 2007, S & R, 2015). Approximately 70% of the Earth's atmospheric oxygen is produced by phytoplankton (Negi & Rajput, 2013, Stephens et al. 2020). The population growth and community structure of periphytic algae in river streams are affected by light availability as another dominant abiotic factor (Hillebrand & Sommer, 1997, Zang et al. 2020). The algal spectrum characterizes the variety and abundance of algae in a particular ecological niche or environment. It is intricately connected to the overall water quality of the Burhi Gandak River, reflecting the river's ecological well-being and environmental state (Stevenson, 2014, Manzoor et al. 2021). The swift urbanization and socio-economic advancements have given rise to the occurrence of algal blooms in the Burhi Gandak River (Cheng et al. 2019, Prasad et al. 2009).

Elevated pollution levels in aquatic systems can lead to eutrophication, a process marked by the accelerated proliferation of phytoplankton through increased growth and reproduction. Thus, before contemplating the utilization of current river resources, a primary focus is on the study of plankton. In the analysis of algae bloom causes, three types of factors were considered: physical, chemical, and biological. Recently, researchers (Zhu et al, 2010) have predominantly focused on studying chemical factors to control algae blooms. Present investigations showed that the river Burhi Gandak is rich in nutrients due to the discharge of pollutants in the river, which results in the growth of phytoplankton, especially those belonging to Chlorophyceae, Bacilariophyceae, and Cyanophyceae.

The objective of this study was to evaluate the present state and short-term variations in phytoplankton and biomass within the river, with a specific focus on monitoring the monthly phytoplanktonic variations. Some previous work related to the algal spectrum were Gitelson (1992), Reynolds (1994), Leland and Porter, (2000), O'Farrell et al. (2002), Sabater et al. (2003), Lawrence et al (2008), Darki, (2009), Singh and Chaudhary (2011), Sunita et al. (2013), Rasool et al. (2014), Simić et al. (2015), Jang et al. (2016); Cheng et al. (2019), Wang et al. (2021).

Study Map

The present investigation was conducted over two years from 2021 to 2022. Three collection sites were chosen at Ashram Ghat, each situated a hundred meters apart. The urban municipal pollutants were directly released at Site B, making it the reference site. Two additional sites, namely A (downstream) and C (upstream), were selected at a distance of 100 meters from each other, where pollutants were not released. This research was designed to facilitate a thorough analysis and illustrate the impact of pollutants at a 100-meter distance for enhanced understanding.



Map drawn in QGIS showed the Burhi Gandak River in Muzaffarpur

Methods

Phytoplankton samples were obtained by pulling 150 liters of water through a plankton net, aided by a water sampler of known volume. Preservation of the collected samples was achieved by the addition of Lugol's solution.

Identification of different types of algae was based on the following works.

Prescott and Scott (1942), Desikachary (1959), Randhawa (1959), Prescott (1962), Philipose (1960), Suxena and Venkateswarlu (1968), Palmer (1980), Gonzalves (1946), Sarode and Kamat (1984).

Result and Discussion

The observed fluctuations in the total number of phytoplankton species across different sites (Table 1, 3 and Figure 1) and years provide valuable insights into the dynamic nature of aquatic ecosystems. The wide range of species, ranging from 90 to 131, underscores the complex interplay of monthly and seasonal variations, as well as inherent differences between the study sites (A, B, and C).

In the initial year, the temporal dynamics reveal notable peaks and troughs. December exhibited the highest species richness at sites A and B, while site C reached its maximum in January. These disparities persisted into the secondary year, where all sites displayed the highest species diversity in January. Conversely, September at site A and August at sites B and C marked the periods of lowest species count in the commencement year, while September emerged as the month of minimum diversity in the subsequent year for all three sites.

These variations likely stem from a multitude of factors, including seasonal changes, water temperature fluctuations, nutrient availability, and other environmental variables. The shift in peak species diversity from December to January between the two years suggests an intriguing temporal dynamic. The influence of environmental parameters on phytoplankton communities is evident. In May, marking the onset of the growing season, Khaliullina (2021) observed a fluctuation in the total number of planktonic algae species per sample at station 1 in the Volga River, ranging from several to 16 species.

The examination of average species counts across the two research years provides valuable insights into the comparative dynamics of phytoplankton communities at sites A, B, and C. Notably, site B consistently exhibited the highest average species count in both the initial and subsequent years, recording values of 115.33 and 105.58, respectively. Site A, with average counts of 107.75 and 104.91, followed closely behind, while site C consistently had the fewest species on average, with counts of 102.41 in the initial year and 107.5 in the subsequent year.

The recurrent pattern of site B boasting the highest diversity raises intriguing questions about the site-specific factors influencing phytoplankton populations. Water quality and habitat characteristics likely play pivotal roles in shaping the observed trends. The consistently lower average species count at site C suggests potential environmental constraints that may limit the diversity of phytoplankton in comparison to the other sites.

In a comprehensive two-year study spanning 2021 and 2022, monthly observations of green algae species were conducted across three diverse sites (A, B, C) along the Burhi Gandak River (Table 1, 3, and Figure 2). In the first year, the spectrum of green algae species at site A ranged from 35 to 50, while site B exhibited variability from 35 to 55, and site C displayed a range of 30 to 41. Moving into the second year, the species range shifted slightly, with site A recording 35 to 45, site B ranging from 31 to 56, and site C presenting a range of 29 to 54. Drawing a comparative analysis, Shehata et al. (2009) documented 38 taxa of the Chlorophyceae class in the Nile River. Temporal dynamics revealed that the maximum green algae species were observed in January during the initial year at site A, in December at site B, and again in January at site C. In the subsequent year, the peak was consistently observed in January across all sites. Conversely, the minimum species count occurred in September, June, and August in 2021, and 2022, it was September at sites A and C, and August at site B.

Over the course of the initial year, an examination of monthly observations revealed an average number of green algae species of 42.67 at site A, 43.58 at site B, and 36.5 at site C. In the subsequent year, these averages slightly shifted to 40 at site A, 43.75 at site B, and 43.33 at site C. The percentage composition of green algae in the debut year ranged from 36.19% to 45.19% at site A, 28.93% to 47.83% at site B, and 33.33% to 40.21% at site C. In the ensuing year, this composition exhibited variability from 35.40% to 40.95% at site A, 30.69% to 51.02% at site B, and 32.58% to 51.07% at site C. During the summer season, Khaliullina (2021) documented a noteworthy diversity among green algae, fluctuating from 29% to 44% until mid-August. Concurrently, blue-green algae exhibited diversity ranging from 29% to 50% until October.

In the study conducted over the years 2021 and 2022, the percentage dynamics of green algae species in the Burhi Gandak River exhibited notable seasonal and site-specific variations described in Tables 1, 3, and Figure 3. During the initial observational year, maximum percentages were recorded in April, August, and October in 2021, whereas in 2022, the peaks shifted to December, October, and November. Conversely, minimum percentages were observed in October and June at sites A and B, and in March, April, and August (with identical values) at site C in the initial year. In the subsequent year, the minimum percentages occurred in March, August, and September across all sites. Average percentages in the initial year were 39.52% at site A, 37.98% at site B, and 35.65% at site C, while in the second year, the averages shifted to 38.14% at site A, 41.44% at site B, and 40.41% at site C. The data underscores significant seasonal fluctuations, suggesting a strong influence of environmental factors such as temperature, pollutants, nutrient availability, and light on green algae growth and distribution. Notably, Site B consistently exhibited the highest species counts and average percentages, while Site C consistently had the lowest values, implying site-specific conditions may play a pivotal role in shaping green algae communities. Despite inter-year variations, the overall temporal patterns remained similar, with January consistently exhibiting higher values and September, June, and August associated with lower counts and percentages.

In the initial phase of Year One, the presence of blue-green algae species in the Burhi Gandak River exhibited dynamic ranges, spanning from 12 to 32 at site A, 18 to 37 at site B, and 18 to 32 at site C shown in Tables 1, 3 and Figure 4. This pattern persisted into the subsequent research period, with ranges of 19 to 32 at site A, 23 to 32 at site B, and 22 to 32 at site C. Drawing insights from Shehata et al. (2009) findings in the Nile River, 16 out of 90 taxa were classified under Cyanophyceae. In the initial year, peak blue-green algae species counts occurred in July at site A, June at site C, and in both July and January at site B. In the following year, peak values were observed in varying months across the sites. The annual averages for blue-green algae species in 2021 were 24.67 at site A, 31 at site B, and 29 at site C, with slightly different yet comparable values in 2022. The percentage composition of blue-green algae displayed variations from 12.63% to 31.37% at site A, 17.65% to 30.58% at site B, and 17.48% to 33.33% at site C during the initial year, and a broader range with generally higher percentages in the subsequent year. Monthly variations in maximum and minimum percentages shown in Tables 1, 3, and Figure 5 highlighted the influence of seasonal environmental factors on blue-green algae populations, with distinct patterns by site. Although there were inter-year variations, the overall stability in the total number of blue-green algae species (37) suggests a degree of ecosystem equilibrium, while the higher percentages in the second year may indicate evolving environmental dynamics. In August, the substantial rainfall occurrences likely played a role in mitigating the abundance of blue-green algae (BGA) by interrupting hydrological and light conditions essential for their proliferation (An and jones, 2000; Rigosi & Rueda, 2012; Ochumba and Kibaara, 1989). During the summer months, commencing in July, a significant restructuring of phytoplankton occurred, marked by the emergence of Cyanoprokaryota as the dominant presence (Dembowska et al, 2012).

In the initial year, the diversity of Diatom species in the Burhi Gandak River showcased dynamic ranges at sites A, B, and C, fluctuating from 26 to 51, 15 to 46, and 27 to 44, respectively shown in Table 2, 3, and Figure 6. This pattern continued into the subsequent year, with ranges of 22 to 43 at site A, 18 to 42 at site B, and 18 to 43 at site C. Aligning with Shehata et al. (2009) findings in the Nile River, where 36 out of 90 taxa were identified under the Bacillariophyceae class, the Burhi Gandak River exhibited a rich diversity of Diatom species. The initial Observational Year highlighted February at site A and January at sites B and C as months with the maximum number of Diatom species. In the subsequent year, this peak shifted to January at sites A and B and February at site C. Average counts of Diatom species in the inaugural year were 35.58 at site A, 36.08 at site B, and 34 at site

C, showing slight variations in the following year while maintaining a comparable range. The percentage composition of Diatom species demonstrated variations from 23.85% to 45.26% at site A, 16.30% to 44.12% at site B, and 28.57% to 38.39% at site C during the initial year and a narrower yet similar range in the subsequent year which was described in Figure 7. Khaliullina (2021) provided additional context, noting a significant increase in diatom composition from 40% to 71% in June. The Euglenophyceae species, observed in both years, exhibited ranges from 3 to 10 at site A, 5 to 10 at site B, and 2 to 9 at site C during the primary year, and 2 to 8 at all three sites in the subsequent year showed in Table 2, 4 and Figure 8. In the first year, peak values for Euglenophyceae were observed in various months at different sites, while the minimum values varied similarly between sites. In the second year, peak values were consistent in April, July, and October at all three sites, with minimum values in March and October. Average counts in the initial year were 6.44 at site A, 7 at site B, and 5 at site C, slightly lower in the following year across all sites. Percentage variations ranged from 2.97% to 7.93% at site A, 4.27% to 8.47% at site B, and 2.22% to 8.57% at site C in the inaugural year, and a slightly narrower range in the subsequent year which was described in Figure 9. The total number of Euglenophyceae species recorded during the observation period was 10, indicating some level of stability in the ecosystem. The data provides valuable insights into the seasonal and site-specific variations of Euglenophyceae species, emphasizing the influence of environmental factors such as temperature, light, and nutrient availability.

The rainy season floods amplified downstream alluvium, escalating sediment loads with silt and mud. Erosion effects, seen in exposed roots and collapsed riverbanks, influenced phytoplankton. Uniform turbidity patterns in autumn and winter across river sites suggested consistent light conditions, causing diminished light permeability and sediment infusion in plankton. The differences in percentages between the two sets of data suggest variations in algae populations between these conditions or locations (A, B, and C) during the first year.

The observed variations in the standard deviations (SD) of different phytoplankton groups over the course of two consecutive years provide insights into the dynamic nature of aquatic ecosystems. Notably, the SD of total phytoplankton exhibited fluctuations, decreasing from 9.4 to 7.40 in the initial year and subsequently increasing to 12.51 in the following year. This indicates a notable shift in the overall variability of phytoplankton biomass. Green algae, with SD values of 7.74, 5.88, and 6.29 in 2021, experienced a reduction in variability in 2022, with SD values of 3.02, 6.98, and 7.94. Blue-green algae, on the other hand, displayed a decrease in SD from 5.87, 4.84, and 3.91 to 4.47, 3.18, and 3.26 in the initial and subsequent years, respectively. Diatom and euglenoid SD patterns also exhibited changes over the two years. The fluctuations in SD suggest potential shifts in the ecological dynamics of these phytoplankton groups, reflecting environmental changes or ecosystem responses.

Tables 5, 6, 7, and 8 provided an overview of the variations in algae populations at three different sites over two years. The table lists three distinct species found at sites A, B, and C during both years of observation. To classify these species, they were categorized as 'dominant' if they were found in the highest numbers, 'frequent' if they were present in moderate numbers, and 'occasional' if they appeared in smaller quantities. The findings from the observation of the algal spectrum in the Burhi Gandak River reveal that the river's algal population was primarily characterized by three predominant classes: Chlorohyceae, Bacillariophyceae, and Cyanophyceae. throughout the two years of study.

Yong-jae (2004) recorded a total of 456 taxa which were composed of 136 genera, 427 species, 27 varieties, and 2 forma. 35 taxa observed by Ewa et al. (2013) belonging to 6 families. Ahmed et al. (2005) studied and observed approx. 29 genera belonging to 6 families. Efforts have been undertaken to identify particular types of algae that serve as indicators for specific water quality conditions. One of the pioneering initiatives in this regard was by Kolkwitz and Marsson in 1908, who introduced the concept of using the presence or absence of specific algal species to signify distinct water quality zones within river ecosystems. In the samples of the Pearl River from the rainy season, Huang et al. (2004) observed 130 species of phytoplankton, and in the dry season, 132 species were observed. Among them, in the rainy season, 82 species of diatoms, 39 freshwater and half-freshwater species, and 41 species of red tide organisms were found.

Shehata et al. (2009) studied the Nile River and identified 90 taxa during the observation period. 69 genera observed by Lam (1981). Saad (2008) observed monthly variation of phytoplankton community of Lake Manzala. According to this study, diatom is more dominant as cell biovolume with the annual relative abundance of 58.4%.

whereas chlorophyta was dominant based on cell number with the annual relative abundance of 76.22%. *Dyctiusphaerium pulchellum* is common at all polluted sites.

Various researchers, such as Palmer (1969), Govindan & Sundaresan (1979), Venkateswarlu, and Sampath Kumar (1982), Somashekar (1984), Saha et al. (1985), Manikya Reddy and Venateswarlu (1987), have extensively explored the use of algae as indicators of water pollution. Palmer's remarkable contribution to this field involved creating an exhaustive catalog that featured 60 genera and 80 species of algae known for their resilience to organic pollution. In the current study, we have identified some genera from Palmer's list, showcasing their descending order of tolerance to organic pollution: *Euglena, Oscillatoria, Chlamydomonas, Scenedesmus, Chlorella, Nitzschia, Navicula, Stigeoclonium, Synedra, Ankistrodesmus, Phacus, Phormidium, Melosira, Gomphonema, Cyclotella, Closterium, Spirogyra, Anabaena, Cryptomonas, Pediastrum, Fragilaria, Ulothrix, Surirella, Lyngbya, Oocystis, Merismopedia, Spirulina, Cymbella, Actinastrum, Coelastrum, Cladophora, Diatoma, Achnanthes, Pinnularia, Chlorococcum, Cocconeis, Cosmarium, Gonium, Tribonema, Selenastrum, Dictyosphaerium and Crucigenia.*

The presence and distribution of the above-mentioned algal taxa in the river have mild organic pollution at all the sites but specific site (B) receiving the effluents are more polluted as indicated by the increase in the number and individuals of the pollution tolerant forms.

The analysis of the river's spectrum revealed that certain algal species have a multifaceted impact, leading to issues such as corrosion, disruption of coagulation processes, generation of unpleasant taste and odor, as well as the potential for toxic effects.

The dominance of three major algal classes, namely Chlorophyceae, Bacillariophyceae, and Cyanophyceae, highlights their ecological importance within the river ecosystem. The river exhibits remarkable biodiversity with the presence of 181 distinct algal species belonging to 84 genera. Among these, Chlorophyceae is represented by 69 species across 38 genera, diatoms by 67 species spanning 23 genera, and blue-green algae by 32 species distributed among 17 genera. This diversity is crucial as it contributes to the overall ecological stability of the ecosystem and its ability to respond to various environmental stressors.

The categorization of algal species into 'dominant (D),' 'frequent (F),' and 'occasional (O)' groups provides a clear understanding of their prevalence and distribution. Such categorization helps in identifying key species that exert a more significant influence on the ecosystem compared to others. For instance, during specific months, the presence of dominant green algae such as *Ankistrodesmus falcatus* and *Chlorococcum humicola* underscores their importance in shaping the ecosystem's dynamics during those periods. In contrast, the prevalence of certain blue-green algae, like *Anabaena variabilis* and *Oscillatoria curviceps,* emphasizes their ecological significance within the river.

Seasonal variations in algal dominance underscore the dynamic nature of the river ecosystem. The fluctuations in the prevalence of specific algal species are likely influenced by environmental factors such as temperature, light availability, and pollutant discharge. Such temporal changes in algal composition can have cascading effects on the ecosystem, affecting water quality, nutrient cycling, and the overall health of aquatic life. Furthermore, the presence of certain uncommon species, especially within the Cyanophyceae and Bacillariophyceae classes, highlights the need for further investigation into their ecological roles and adaptations to the river environment. Uncommon species may possess unique traits or niches that are not readily apparent from their rarity, and further research could reveal their importance in the ecosystem.

The Chlorophyceae class in the observed samples revealed the presence of several noteworthy species. Among these, *A. hantzschii, Ankistrodesmus braunii, A. falcatus, Chaetophora elegans, Chara canescens, C. conductrix, C. turgidum, Cosmarium connatum, Dictyosphaerium pulchellum, Gloeocystis ampla, Hydrodictyon reticulatum, Oocystis elliptica, Protococcus viridis, and S. mjuscula* emerged as the most frequent species.

Within the blue-green algae category, dominant species included *A. variabilis, M. minima, M. tenuissima, Microcystis elabens, Nostoc calcicola, Gloeothece sp., Oscillatoria curviceps, O. limosa, Spirulina major, and Synechococcus elongatus.*

Frequent diatom species observed in the samples encompassed *Achnanthes affinis, Amphora ovalis, Cocconeis placentula, C. meneghiniana, D. ovalis, Fragilaria capucina, G. constrictum, G. sphaerophorum, M. juergensii, N. cocconeiformis, N. minuta, Nitzschia affinis, N. microcephala, and Synedra acus.*

Rojo et al. (1994) observed the same type of most frequent species, i.e., those reported in more than 50% of the total studies, in published data related to 67 rivers. *Cyclotella pseudostelligera* (Diatom) contributes to algal blooms in the Danube (Germany) (Steinberg et al, 1987). Lakshminarayana (1965) found *Aulacoseira granulata* contributing to blooms in the Ganga. *Chroococcus limneticus* in the river Guadalquivir contributes to eutrophication (Lopez Pera, 1987).

The Burhi Gandak River hosts a diverse range of algae, including clean water and pollution-tolerant species, as well as toxic algae. Interestingly, the distribution of these algae is not confined to specific areas. Clean water algae, which thrive in unpolluted environments, were also found in polluted sections of the Burhi Gandak. Similarly, pollution-tolerant algae were not exclusive to polluted sites; they were also present in areas that appeared unpolluted, although they were more abundant in polluted regions.

Many researchers have utilized algae as reliable indicators of water pollution. Moreover, the algal spectrum of the river highlighted the presence of algae that can cause various issues. For instance, there are "slime algae," such as *Spirogyra*, which can cause water discoloration, and algae like *Anabaena* which may introduce undesirable tastes and odors (Palmer, 1962). Anabaena can produce various odors depending on its concentration and state. In small quantities, it emits a subtle, grassy aroma. When present in larger amounts, it releases a more intense, pungent scent reminiscent of nasturtium. However, when *Anabaena* is heavily concentrated, especially if it's in a state of decay, it can generate a repugnant and unpleasant odor akin to a pigpen (Hale, 1930). Furthermore, toxic algae like *Microcystis* were identified, although specific problems only arise when these algae are present in substantial numbers (Carmichael, 1996). Additionally, we identified specific taxa with potential bioremediation capabilities, including *Anabaena, Ankistrodesmus, Chlorella, Chlamydomonas, Euglena, Fragilaria, Nostoc, Oscillatoria, Scenedesmus, Selenastrum, Spirulina*, and *Ulothrix*.
The same results were also observed by many researchers such as Chekroun et al. (2014), Khatiwada et al. (2020), and Sarmah and Rout (2020). These algae serve diverse functions, such as *Anabaena* ability to absorb radionucleotides like Co and Cs, *Ankistrodesmus* accumulation of cadmium, and *Chlorella* role in metal uptake, including cadmium, copper, iron, and zinc (Dhir, 2013).

Euglena was observed accumulating aluminum, zinc, manganese, copper, and lead, while *Fragilaria* could accumulate cadmium up to 2.25% of its dry weight. *Navicula* demonstrated an aptitude for accumulating cadmium and mercury, while Nostoc exhibited metabolism-dependent cellular uptake of copper. *Oscillatoria* and *Ulothrix* were involved in the accumulation of cadmium, mercury, and lead (Kaur and Bhatnagar, 2002).

Scenedesmus played a vital role in bioremediation, addressing issues like crude oil, n-alkanes, polycyclic aromatic hydrocarbons, and the removal of nitrogen from wastewater. *Selenastrum* was found to accumulate uranium, accounting for up to 1% of its dry weight (Hammed et al, 2016). *Spirulina* contributed to the removal of copper, mercury, cadmium, and ammonia nitrogen (Sayadi et al, 2019).

Table 1: Algal spectrum in 2021															
Month	Total number of species			Green algae						Blue Green algae					
				Number			percentage			Number			percentage		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
January	120	125	117	50	45	41	41.67	36	35.04	28	34	32	23.33	27.2	27.35
February	117	119	112	44	55	39	37.61	46.22	34.82	22	32	30	18.80	26.89	26.79
March	107	117	108	39	42	36	36.45	35.90	33.33	25	31	31	23.36	26.50	28.70
April	104	112	105	47	38	35	45.19	33.93	33.33	19	28	31	18.27	25	29.52
May	108	118	103	48	46	38	44.44	38.98	36.89	23	35	18	21.30	29.66	17.48
June	109	121	98	49	35	33	44.95	28.93	33.67	27	37	28	24.77	30.58	28.57
July	102	115	101	39	52	37	38.24	45.22	36.63	32	33	32	31.37	28.70	31.68
August	101	92	90	37	44	30	36.63	47.83	33.33	26	28	30	25.74	30.43	33.33
September	95	102	92	35	39	32	36.84	38.24	34.78	12	18	28	12.63	17.65	30.43
October	105	115	97	38	37	39	36.19	32.17	40.21	20	31	26	19.05	26.96	26.80
November	99	117	102	36	40	40	36.36	34.19	39.22	30	33	31	30.30	28.21	30.39
December	126	131	104	50	50	38	39.68	38.17	36.54	32	32	31	25.39	24.43	29.81
Average	107.75	115.33	102.42	42.67	43.58	36.5	39.52	37.98	35.65	24.67	31	29	22.860	26.85	28.41
SD	9.4	10.14	7.74	5.88	6.29	3.40	3.59	5.82	2.31	5.87	4.84	3.91	5.27	3.49	3.95

Table 2: Algal spectrum in 2021

Month	Diatom						Euglenoids					
	Number			Percentage			Number			Percentage		
	A	B	C	A	B	C	A	B	C	A	B	C
January	42	46	44	35	36.8	37.61	Nil	Nil	Nil	Nil	Nil	Nil
February	51	32	43	44.35	26.89	38.39	Nil	Nil	Nil	Nil	Nil	Nil
March	43	38	36	40.19	32.48	33.33	Nil	6	5	Nil	5.13	4.63
April	30	37	30	28.85	33.04	28.57	8	9	9	7.69	8.04	8.57
May	30	27	39	27.78	22.88	37.86	7	10	8	6.48	8.47	7.77
June	26	42	37	23.85	34.71	37.76	7	7	Nil	6.42	5.79	Nil
July	27	22	29	26.47	19.13	28.71	4	8	3	3.92	6.96	2.97
August	35	15	28	34.65	16.30	31.11	3	5	2	2.97	5.43	2.22
September	43	45	27	45.26	44.12	29.35	5	Nil	5	5.26	Nil	5.43
October	39	42	29	37.14	36.52	29.90	8	5	3	7.62	4.27	3.09
November	27	44	31	27.27	37.61	30.39	6	Nil	Nil	6.06	Nil	Nil
December	34	43	35	26.98	32.82	33.65	10	6	Nil	7.936	4.58	Nil
Average	35.58	36.08	34	33.150	31.11	33.05	6.44	7	5	6.04	6.08	4.96
SD	8.01	10.02	5.88	7.35	8.22	3.91	2.19	1.85	2.65	1.72	1.57	2.46

Table 3: Algal Spectrum in 2022

Month	Total number of species			Green algae						Blue Green algae					
				Number			percentage			Number			percentage		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
January	119	123	121	45	56	54	37.82	45.53	44.63	31	25	32	26.05	20.33	26.45
February	111	121	118	42	48	51	37.84	39.67	43.22	32	32	24	28.83	26.45	20.39
March	113	100	119	40	45	49	35.40	45	41.18	30	28	28	26.55	28	23.53
April	109	107	117	43	42	45	39.45	39.25	38.46	32	25	31	28.32	23.36	26.50
May	106	108	115	40	40	40	37.74	37.04	36.52	28	24	31	26.42	22.22	26.96
June	104	109	112	39	48	40	37.5	44.04	35.71	32	28	30	30.77	25.69	26.79
July	101	104	98	41	37	48	40.59	35.58	48.98	19	27	28	18.81	25.96	28.57
August	99	101	97	37	31	37	37.37	30.69	38.14	25	29	22	25.25	28.71	22.68
September	92	91	89	35	39	29	38.04	42.86	32.58	29	31	28	31.52	34.07	31.46
October	97	98	91	36	50	31	37.11	51.02	34.07	20	23	32	20.62	23.47	35.16
November	103	92	94	39	39	48	37.86	42.39	51.07	30	32	31	29.13	34.78	32.98
December	105	113	119	43	50	48	40.95	44.25	40.34	28	31	32	26.67	27.43	26.89
Average	104.92	105.58	107.5	40	43.75	43.33	38.14	41.44	40.41	28	27.92	29.08	26.58	26.71	27.36
SD	7.40	10.11	12.51	3.02	6.98	7.94	1.53	5.36	5.73	4.47	3.18	3.26	3.75	4.37	4.24

Table 4: Algal Spectrum in 2022

Month	Diatom						Euglenoids					
	Number			Percentage			Number			Percentage		
	A	B	C	A	B	C	A	B	C	A	B	C
January	43	42	35	36.13	34.15	28.93	Nil	Nil	Nil	Nil	Nil	Nil
February	37	41	43	33.33	33.88	36.44	Nil	Nil	Nil	Nil	Nil	Nil
March	41	25	40	36.28	25	33.61	2	2	2	1.77	2	1.71
April	26	35	35	23.85	32.71	29.91	8	5	6	7.34	4.67	5.13
May	32	40	39	30.189	37.04	33.91	6	4	3	5.66	3.70	2.61
June	33	33	42	31.73	30.28	37.50	Nil	Nil	Nil	Nil	Nil	Nil
July	39	32	18	38.61	21.15	18.37	3	8	4	2.97	7.69	4.08
August	34	35	35	34.34	34.65	36.08	3	6	3	3.03	5.94	3.09
September	22	18	28	23.91	19.78	31.46	6	3	4	6.52	3.30	4.49
October	34	23	20	35.051	23.47	21.98	7	2	8	7.22	2.04	8.79
November	34	21	22	33.010	22.83	23.40	Nil	Nil	Nil	Nil	Nil	Nil
December	34	32	39	32.381	28.32	32.77	Nil	Nil	Nil	Nil	Nil	Nil
Average	34.08	31.42	33	32.40	28.60	30.36	5	4.29	4.29	4.93	4.19	4.27
SD	5.85	8.02	8.81	4.57	5.97	6.15	2.31	2.21	2.06	2.29	2.08	2.31

Table. 5: List of overall algae in Burhi Gandak river

	Chlorophyceae (green algae)				
1	*Actinastrum gracilimum*	*O*	*36*	*Nitella tenuissima*	*D*
2	*A. hantzschii*	*F*	*37*	*Oedocladium sp.*	*D*
3	*Ankistrodesmus braunii*	*F*	*38*	*Oedocladium boscii*	*D*
4.	*A. convolutus*	*D*	*39*	*Oocystis elliptica*	*F*
5	*A. falcatus*	*F*	*40*	*O. pusilla*	*F*
6	*Aphanochaete repens*	*O*	*41*	*O. borgel*	*O*
7	*Chaetophora elegans*	*F*	*42*	*Pediastrum duplex*	*F*
8	*C. attenuata*	*C*	*43*	*Protococcus viridis*	*F*
9	*Chara canescens*	*F*	*44*	*Quadrigula quaternata*	*D*
10	*Characium ambiguum*	*O*	*45*	*Scenedesmus acuminatus*	*F*
11	*Chlamydomonas sp.*	*O*	*46*	*S. arcuatus*	*F*
12	*Chlorella vulgaris*	*O*	*47*	*S. bijugatus*	*D*
13	*C. conglomerata*	*O*	*48*	*S. denticulatus*	*O*
14	*C. conductrix*	*F*	*49*	*S. dimorphus*	*D*
15	*Chlorococcum humicola*	*D*	*50*	*S. longus*	*O*
16	*Cladophora fracta*	*D*	*51*	*S. obliquus*	*F*
17	*C. glomerata*	*D*	*52*	*S. quadricauda*	*F*
18	*Closterium rostratum*	*O*	*53*	*Sirogonium sp.*	*F*
19	*C. intermedium*	*D*	*54*	*Selenastrum gracile*	*D*
20	*C. turgidum*	*F*	*55*	*S. minutum*	*O*
21	*Coelastrum microporum*	*O*	*56*	*Spirgyra porticalis*	*F*
22	*Cosmarium connatum*	*F*	*57*	*S. mjuscula, Kuetz.*	*F*
23	*C. angulosum*	*F*	*58*	*S. communi*	*D*
24	*C. rugosum*	*D*	*59*	*Spirotaenia sp.*	*D*

25	*C. gonoides*	O	60	*Stigeoclonium lubricum*	O
26	*Crucigenia quadrata*	D	61	*S. subsecundum*	O
27	*Dictyosphaerium pulchellum*	F	62	*S. tenue*	O
28	*D. ehrenbergianum*	O	63	*Tetraedron minimum*	F
29	*Gloeocystis ampla*	F	64	*T. muticum*	D
30	*Gonium pectorale*	O	65	*Tetradesmus sp.*	D
31	*Hydrodictyon reticulatum*	F	66	*Ulothrix subconstricta*	D
32	*H. indicum*	D	67	*U. zonata*	F
33	*Kirchneriella lunaris*	O	68	*Uronema sp.*	O
34	*Mougeotia scalaris*	O	69	*Zygnema sp.*	D
35	*Mougeotiopsis sp.*	O			

Table. 6: List of overall algae in Burhi Gandak river ***Cyanophyceae (Blue-green algae)***					
1	Anabaena circinalis	F	17	*M. minima*	D
2	*A. constricta*	F	18	*M. tenuissima*	D
3	*A. variabilis*	D	19	*Microcystis elabens*	D
4	*Aphanocapsa pulchra*	O	20	*Nostoc calcicola*	D
5	*Coelosphaerium dubium*	O	21	*N. linckia*	O
6	*Chroococcus limneticus*	F	22	*Oscillatoria curviceps*	D
7	*C. Minor*	F	23	*O. limnetica*	O
8	*Dactylococcopsis*	F	24	*O. limosa*	D
9	*D. fascicularis*	F	25	*O. minima*	D
10	*Gloeothece sp.*	O	26	*O. princeps*	O
11	*Gloeotrichia natans*	F	27	*O. tenuis*	F
12	*Gomphosphaeria lacustris*	F	28	*Rivularia aquatica*	F
13	*Lyngbya baculum*	O	29	*Spirulina major*	D
14	*L. calcifera*	O	30	*S. subsalsa*	D
15	*L. lutea*	O	31	*Synechococcus elongatus*	D
16	*Merismopedia glauca.*	F	32	*Synechocystis pevalekii*	F

	Table 7: Bacilariophyceae (Diatom)				
1	*Achnanthes affinis*	F	21	*Fragilaria capucina*	F
2	*A. gibberula*	D	22	*F. intermedia*	F
3	*A. microcepala*	D	23	*F. Virescens*	O
4	*Actinella punctata*	O	24	*Gomphonema acuminatum*	O
5	*Amphora ovalis*	F	25	*G. augur*	***O***
6	*Caloneis amphisbaena*	O	26	*G. constrictum*	F
7	*C. siliculav*	F	27	*G. olivacium*	F
8	*Cocconeis placentula*	F	28	*G. sphaerophorum*	F
9	*Cyclotella glomerata*	F	29	*G. attenuatum*	F
10	*C. meneghiniana*	F	30	*Mastogloia smithii*	D
11	*Cylindrotheca gracilis*	O	31	*Melosira granulata*	F
12	*Cymbella aspera*	D	32	*M. islandica*	D
13	*C. tumida*	D	33	*M. juergensii*	F
14	*C. turgida*	D	34	*M. varians*	F
15	*C. ventricosa*	O	35	*Navicula anglica*	O
16	*Diatoma anceps*		36	*N. cocconeiformis*	F

17	*Diploneis elliptica*	O	37	*N. cryptocephala*	D
18	*D. ovalis*	**F**	**38**	*N. cuspidata*	F
19	*Eunotia formica*	O	39	*N. densestriata*	D
20	*Fragilaria capucina*	F	40	*N. dicephala*	F
41	*N. lucidula*	D	55	*N. tryblionella*	O
42	*N. microcephala*	O	56	*Neidium longiceps*	O
43	*N. minuta*	F	57	*Pinnularia divergens*	D
44	*N. pupula v. elliptica*	O	**58**	*P. finlandia*	D
45	*N. pygnaea*	O	59	*P. molaris*	F
46	*N. radiosa*	F	60	*Pleurosigma spencerii*	O
47	*Nitzschia affinis*	F	61	*Rhoicosphenia curvata*	F
48	*N. amphibia*	D	62	*Surirella angusta*	O
49	*N. apiculata*	D	63	*S. linearis*	D
50	*N. capitellata*	D	64	*S. ovalis*	D
51	*N. closterium*	D	65	*Synedra acus*	F
52	*N. frustulum*	O	66	*S. pulchella*	F
53	*N. microcephala*	F	67	*S. ulna*	F
54	*N. palea*	O			

Table. 8: List of other groups of algae in the Burhi Gandak river					
Others					
1	*Chromulina sp*	D	6	*E. minuta*	
2	*Cryptomonas erosa*	O	7	*E. spirogyra*	
3	*Euglena acus*	F	8	*Phacus pyrum*	
4	*E. ehrembergii*	O	9	*Tribonema bombycinum*	
5	*E. gracilis*	F	10	*Vaucheria sessilis*	

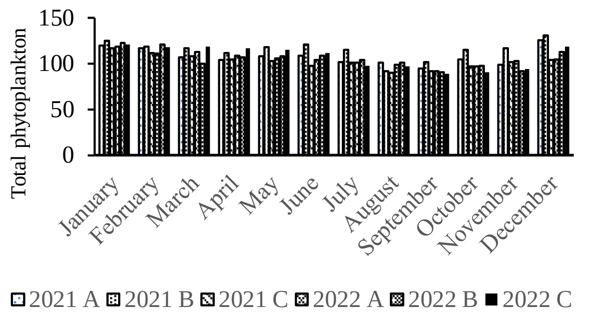


Figure 1: Total phytoplankton in 2021 and 2022

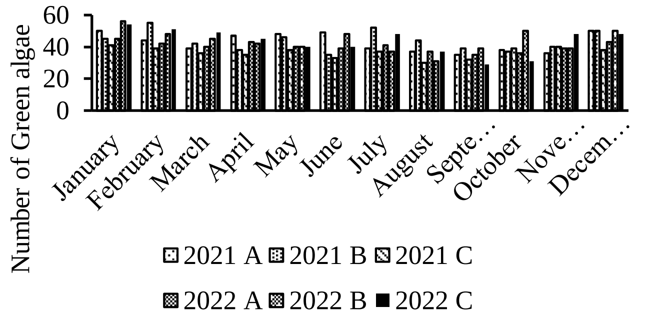


Figure 2: Number of Green algae in 2021 and 2022

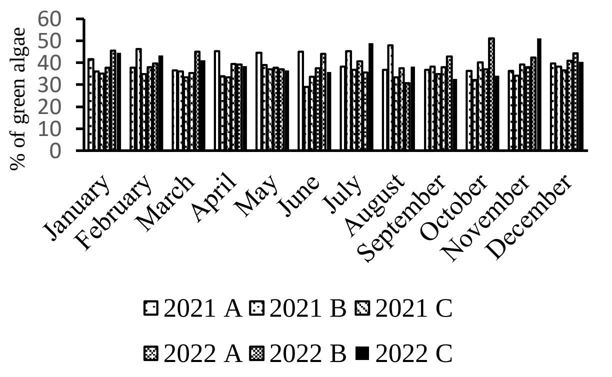


Figure 3: % of green algae in 2021 and 2022

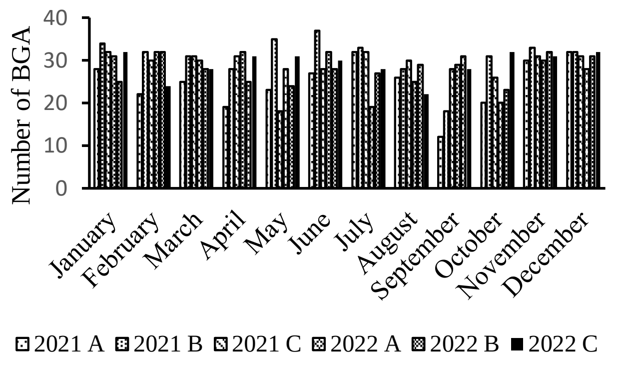


Figure 4: Number of Blue green algae in 2021 and 2022

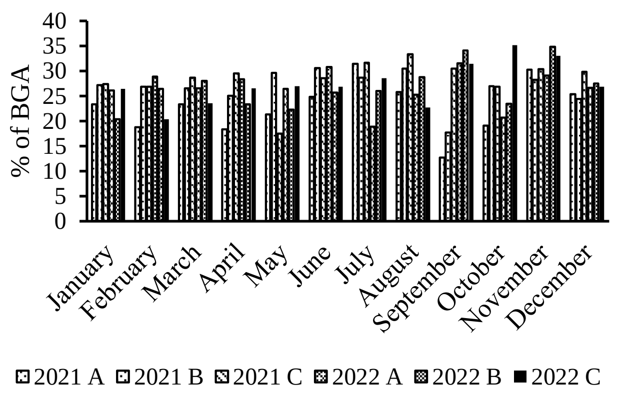


Figure 5: % of Blue green algae in 2021 and 2022

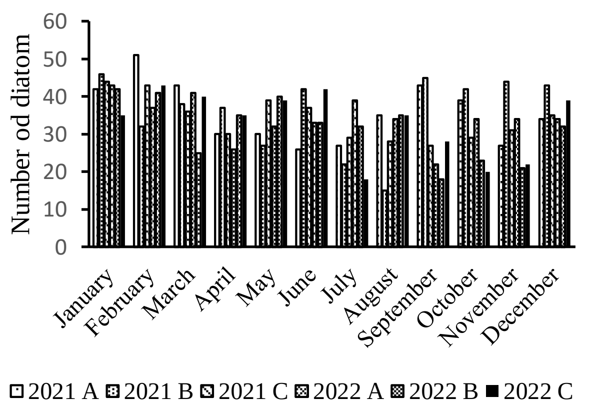


Figure 6: Number of diatom in 2021 and 2022

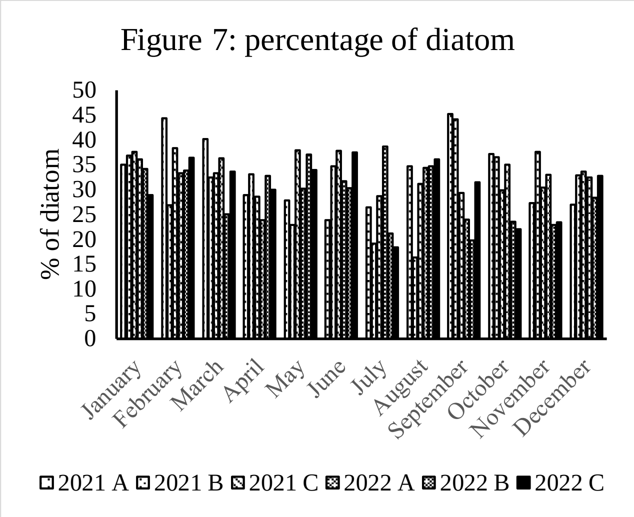


Figure 7: percentage of diatom
% of diatom
50
45
40
35
30
25
20
15
10
5
0
January
February
March
April
May
June
July
August
September
October
November
December
2021 A
2021 B
2021 C
2022 A
2022 B
2022 C

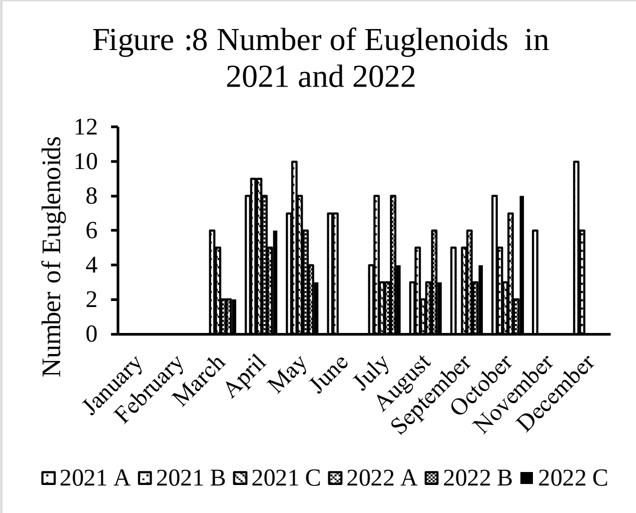


Figure :8 Number of Euglenoids in 2021 and 2022
Number of Euglenoids
12
10
8
6
4
2
0
January
February
March
April
May
June
July
August
September
October
November
December
2021 A
2021 B
2021 C
2022 A
2022 B
2022 C

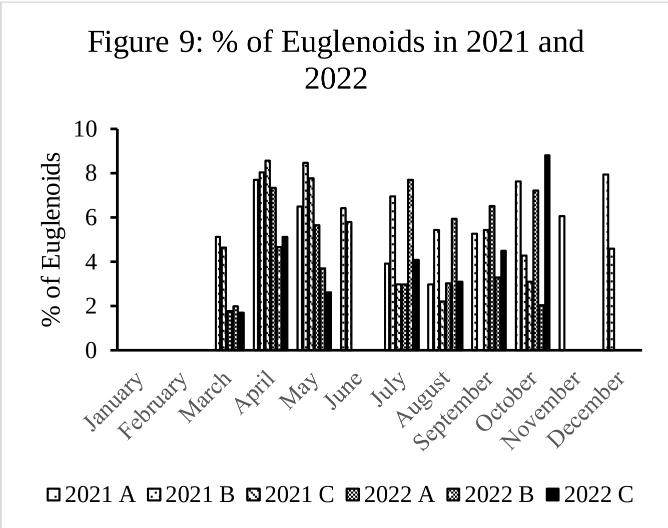
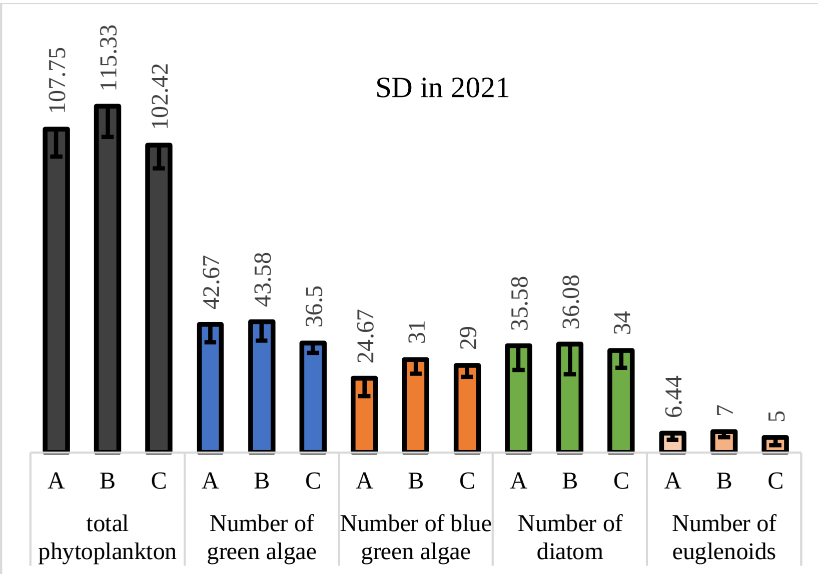
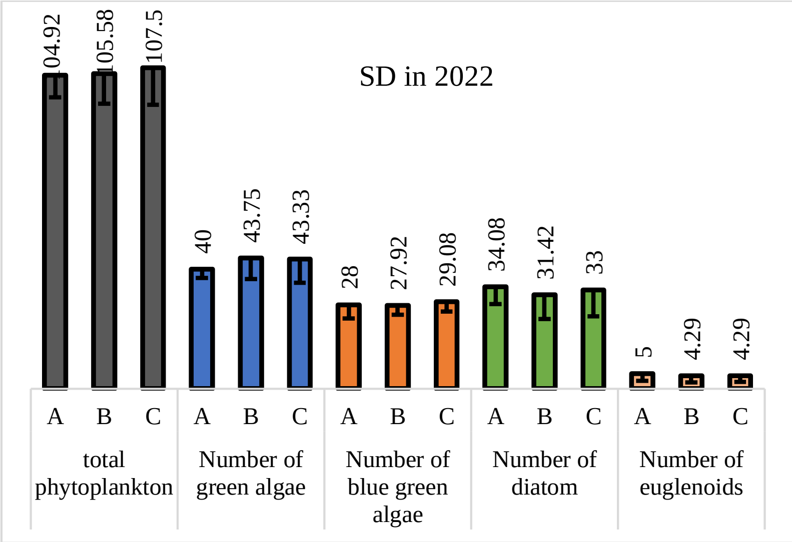


Figure 9: % of Euglenoids in 2021 and 2022
% of Euglenoids
10
8
6
4
2
0
January
February
March
April
May
June
July
August
September
October
November
December
2021 A
2021 B
2021 C
2022 A
2022 B
2022 C


SD in 2021
107.75
115.33
102.42
42.67
43.58
36.5
24.67
31
29
35.58
36.08
34
6.44
7
5
A
B
C
total phytoplankton
Number of green algae
Number of blue green algae
Number of diatom
Number of euglenoids



Conclusion

In this comprehensive two-year study of the Burhi Gandak River, an in-depth analysis of phytoplankton dynamics, including Chlorophyceae, Cyanophyceae, Diatom, and Euglenophyceae, was conducted across three distinct sites (A, B, C). The study revealed significant seasonal and site-specific variations in phytoplankton species composition, with clear patterns emerging over the observational years. Noteworthy findings include the dynamic shifts in species richness and diversity, influenced by factors such as seasonal changes, water temperature fluctuations, anthropogenic activities, and nutrient availability. The identification of dominant (D) and frequent (F)species within each algal class, coupled with the observation of specific site-related patterns, provides valuable insights into the complex interplay of environmental variables shaping phytoplankton communities. Additionally, the study contributes to the understanding of potential ecological indicators, such as algae tolerance to pollution and their role in bioremediation. The findings underscore the importance of continued research in elucidating the intricate relationships between phytoplankton and environmental factors, offering a foundation for informed water management and conservation efforts in river ecosystems.

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