Applied Biological Research 26(2): 233-245; (2024)
DOI: 48165/abr.2024.26.01.27

WATER QUALITY ASSESSMENT AND STATUS OF PHYTO- AND ZOO-PLANKTON OF HIMALAYAN BHAGIRATHI RIVER IN UTTARKASHI, UTTARAKHAND (INDIA)

Mahidhar Prasad Tiwari*[1] and Poonam Tiwari[2]

[1]*Department of Chemistry, Government Post Graduate College Uttarkashi, 249 193, Uttarakhand (India)*
[2]*Department of Zoology, Government Post Graduate College, New Tehri 249 192, Uttarakhand (India)*
*****e-mail: *mptiwari90@gmail.com*

(Received 26 December, 2023; accepted 7 May, 2024)

ABSTRACT

Rivers are important source of fresh water which is important for the sustenance and welfare of the society. The present study deals with the assessment of water quality parameters and with the population of phyto- and zoo-plankton of Himalayan Bhagirathi river in Uttarkashi, Uttarakhand (India). The samples were collected from the study area during summer, monsoon, and winter seasons for water quality and phyto- and zoo-plankton analysis. The air temperature, depth temperature, pH, total alkalinity, total dissolved solids (TDS), dissolved oxygen (DO), turbidity, free CO_2, electric conductivity (EC), biological oxygen demand (BOD) and total hardness were determined. The study revealed that DO was maximum in winter (12.35 ± 0.25 mg L^{-1}) and minimum in June to September (9.75 ± 0.25 mg L^{-1}). The Bhagirathi water contained maximum DO in colder month, followed by a gradual decrease to its lowest value during June to September. BOD, an important indicator of pollution status of a water body, was high during summer perhaps due to low discharge at river. BOD was high in monsoon (4.4 ± 0.14 mg L^{-1}) and low in winter (1.5 ± 0.14 mg L^{-1}). The study revealed low river flow during winter. *Bacillariophyceae* was maximum (442 units L^{-1}) in February and minimum (18 units L^{-1}) in July. *Chlorophyceae* was maximum (80 units L^{-1}) in January and minimum (6 units L^{-1}) in August, while *Myxophyceae*was maximum (34 units L^{-1}) in February and minimum in June and *Xanthophyceae* was not recorded at this site. The maximum number of zooplankton genera was observed during winter and minimum in rainy season. The study showed that there is an urgent need to have proper water management in rainy and summer seasons so as to restore the water quality of this river.

Keywords: Himalayan ecosystem, phytoplankton, river health, water quality, zooplankton

INTRODUCTION

Bhagirathi river originates from Gaumukh glacier in Himalayan mountains at an elevation of 3892 m masl and is a source of water supply for drinking and irrigation purposes to the Uttarakhand state of India. The rapid increase in population has rapidly increased the demand for clean water globally (Vliet *et al.*, 2021). Rivers meet various needs of human civilization, improve the quality of climate and landscape, and support the flora and fauna (Sharma, 2008). Since water of Bhagirathi river is potable, it is necessary to check its quality and monitor the factors affecting its quality. The water quality of Bhagirathi river mainly depends on the local environment, anthropogenic activities (such as industrial, domestic, agricultural and mining operations), etc. Several parameters provide basis for judging the water suitability for its specified uses and for improving the existing conditions. The parameters monitored to measure the water quality include temperature, dissolved oxygen, pH, conductivity, turbidity, total dissolved solids (TDS), biological oxygen demand (BOD), chloride, etc. The various parameters of drinking water quality are regulated on the basis of the recommendations of Bureau of Indian Standards: 10500 (2012).

The river Bhagirathi is perennial in nature as it receives all the three types of water inputs *viz*., snow melt runoff, rain runoff and groundwater (Mane *et al.*, 2005). The measurement of seasonal variation in water quality parameters over time is a significant component for evaluating the temporal variation of river pollution due to natural or anthropogenic inputs from point and non-point sources (Rani *et al*., 2011; Shetty *et al.*, 2013). Bhagirathi river is one of the biggest source of water which caters to the needs of Uttarkashi area. In river Bhagirathi, large number of streams such as Ashi, Ganga, Indrawati and Badethi are combined in different places, which cater to the different needs of the city. The Bhagirathi River, coursing through the heart of Uttarakhand, holds both spiritual and practical significance. It weaves a tale of culture, spirituality, and sustenance, captivating all who encounter its majestic flow. Preserving this sacred river and its surrounding ecosystem is not just a responsibility but a privilege, ensuring that the Bhagirathi remains an enduring symbol of India's natural and cultural heritage. The importance of river is not only for its socio-cultural perspective, but also for various livelihood and economic activities for the people living around the basin. Improving the health of this river has been a growing debate in India since last decade, mainly in terms of its quality and quantity (Matta and Uniyal, 2017). The river is facing multi-dimensional issues like, flow disturbance, water pollution, climate influences, habitat and biodiversity conservation (Kaushal *et al.*, 2019). The water pollution has become a global threat for developing countries due to the climate change, rapid urbanization, agricultural runoff and industrialization (Rana *et al.*, 2017; Matta *et al.*, 2018c). More than two hydroelectric power projects have been built in river, which discharge their waste into the water bodies, thus deteriorating the water quality of Himalayan rivers. Dam construction can cause damage to river basins, including changes in downstream flow, changes in river species and other organisms, and material sedimentation. Degradation of river ecosystems has a direct impact on aquatic biodiversity. Such changes in ecology have led to the fragmentation of river communities, which either disappear or shift to other locations (Rawat and Agarwal, 2015). Large dams and reservoirs cause changes in water temperature, water chemistry, and disrupt the migration of aquatic life forms (McAllister *et al.*, 2001). Dam has a major impact on fish populations, migrations and other fish movements. Fishes suffer major damage during their transit through hydraulic turbines or over spillways (Tiwari and Tiwari, 2022).

The development of river systems through dams has emerged as one of the important valuable tools for managing water resources (Mull *et al.*, 2018). Dams promote social and economic development of the state and country through power generation, water supply and flood control (Hussain *et al.*, 2012). The scale of socio-economic activities, urbanization, industrialization, and hydropower production have major impact on water resources (Kurbatova *et al.*, 2005) which, in turn, impact water quality and aquatic biodiversity. Dams influence natural river flow and the flow is generally less than the normal flow. These changes may adversely affect the habitats of micro-organisms and plants. The phytoplankton are the primary producers of water bodies and the main source of food directly or indirectly for various animal groups. The efficiency of water body depends on the quantity of planktons in it (Guy, 1992). Plankton populations serve as a consistent tool for bio-monitoring the status of pollution in the river bodies (Mathivanan *et al.*, 1995). Some studies on water quality assessment of different rivers of Uttarakhand have previously been reported (Sati and Paliwal, 2008; Semwal and Jangwan, 2009; CPCB, 2010; Bhandari and Joshi, 2013). However, literature survey has revealed that meagre work has been done on water quality assessment based on phyto- and zoo-plankton of river Bhagirathi (Poonam, 2019; Mahidhar, 2020; Tiwari, 2022). Phytoplankton are important biological component to maintain and balance aquatic ecosystems (Hambright *et al.*, 2006). Some phytoplankton provides reliable information about the state of pollution of water bodies. Therefore, they are considered a reliable indicator of water quality. Such monitoring is useful for controlling the physicochemical and biological conditions of water. In last few decades, physicochemical factors have mainly been found responsible for the processes influencing the development of phytoplankton communities (Akbey *et al.*, 1999, Peerapornpisal *et al.*, 2011). These components vary over space and time (Mane *et al.*, 2006). Natural concentrations of environmental variables are majorly influenced by human interference with nature (Kulshrestha *et al.*, 2006). The objective of present study was to assess the water quality of Bhagirathi river by analysing seasonal variations in physicochemical parameters as well as determine the effect of water quality on population of phyto- and zoo-plankton in the study area.

MATERIALS AND METHODS

Study area

The first study site was in Maneri, district Uttarkashi ($30^0$44'16" N, $78^0$32'22" E). Maneri village is located on the bank of river Ganges (Bhagirathi) 13 km upstream from Uttarkashiand 165 km from Rishikesh. The second site was downward near the Rishiram School approximately 2 km away from Uttarkashi ($30^0$42'36" N;78^0 24'7" E) [Fig. 1]. The distance between the two sites is 15 km. The present study was conducted from August 2022 to July 2023. Regular monthly sampling was done at each site. All the physicochemical parameters, and zoo- and phyto-plankton were recorded at the same time during different days to minimize the time dependent variations of each site. The time of sampling at both the sites was between 9.00 to 11.00 am on different days of month. Some physicochemical

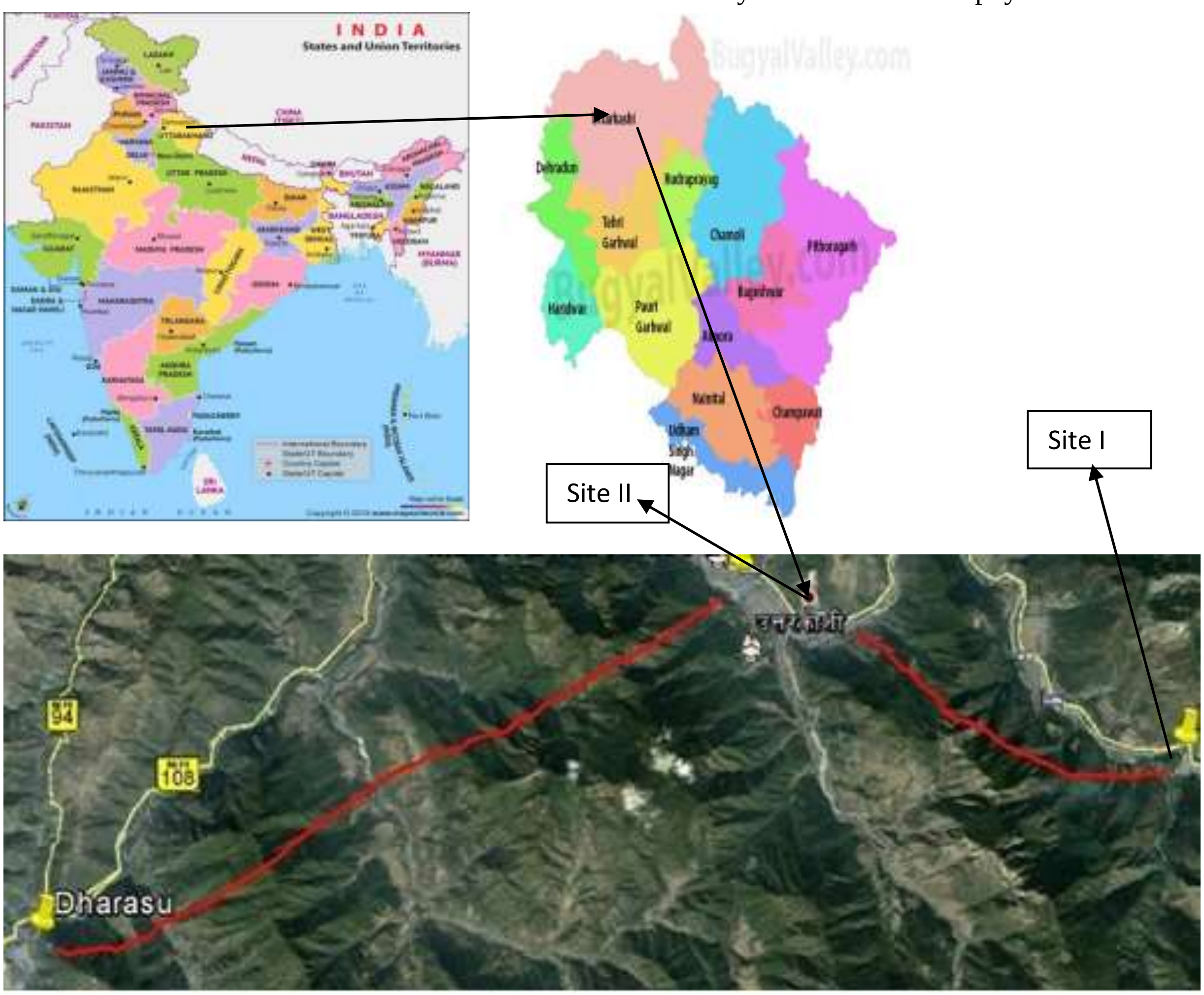

Fig. 1: The map showing the sampling sites (site 1 & site II) of Bhagirathi river in Uttarakhand (India)

parameters were measured on spot and the rest were analysed in the laboratory of the Department of Chemistry, RCU, GPG College, Uttarkashi, Uttarakhand (India).

Geology of the study area

The study area has different types of rock formations, *i.e.* white and cream coloured quartzite grading into talc-chlorite schist's along the thrust and migmatites, augengneisses, garnetiferous mica-schist's and amphibolite's. The rock types in the area are quartzite.

Physicochemical parameters

Monthly sampling was done for obtaining the data on physicochemical environment of the sites. Standard methods as outlined by Welch (1952), Trivedi and Goel (1986), and APHA (1995) were followed. Readings were taken in triplicates. Temperature was measured using a mercury thermometer with a graduated scale. The water samples were taken in a beaker from the sites and then its pH was determined at study site using an electronic pH meter (Hanna pocket pH meter; model H-196-107). Modified Winkler's method was adopted for the analysis of DO concentration. Free CO_2 in water was estimated by titrating the sample with strong alkali of pH 8.3. Alkalinity is the expression of total quantity of base (usually in equilibrium with carbonates and bicarbonate) that can be determined by titration with strong acid (Hutchinous, 1975). The conductivity of water samples was measured with the help of a water and soil analysis kit (Systronics, model 460E; manufactured by Environmental and Scientific Instrument Co. Haryana, India). The total dissolved solids (TDS) of water samples were measured with the help of a water and soil analysis kit. The turbidity of water samples was determined by using a digital nephelo-turbidity meter (Systronic, model 132). Turbidity of samples was expressed as nephalometric turbidity unit (NTU). BOD of water was determined by incubation method (APHA, 1995).

Assessment of phytoplankton population

The phytoplankton population was estimated at both the sites. At each site, 100 L water (in buckets of 10 L each) was filtered through plankton net and the planktons were collected in glass tube and fixed in 5% formalin. In laboratory, 1 mL preserved phytoplankton sample was diluted with 100 mL distilled water and centrifuged at 1500 rpm for 20 min to concentrate the planktons for quantitative analyses. A Hensen-Stempel pipet was used to take 1 mL aliquots into Sedgwick-Rafter counting chamber (Microscope world, BSW-15). Each cell was then examined under an inverted compound microscope (500X) for identification and count of each phytoplankton. Primary taxonomic reference used for the identification of phytoplankton were Needham and Needham (1962), Ward and Whipple (1992), APHA (1998) and the population densities were calculated as per Welch (1952).

$$n = \frac{\mathrm{a\ x\ c}}{\mathrm{L}}\ x\ 100$$

Where n = No. of plankton $L^{-1}$of original water (unit L^{-1}); a = average number of plankton in all counts in counting unit of 1 mm^3 capacity; C = volume of original concentration in counting cell); L = volume of original water expressed in L.

Assessment of zooplankton population

The estimation of zooplankton population was done at both the sites. Sampling was done through-out the study period by pouring 10 L water through a plankton bucket with mesh apertures of 50 mL. The entire sample was immediately fixed with 4% formalin solution. The identification and enumeration were done in Sedgwick-Rafter counting cell. The identification of zooplankton species was done as per Needham and Needham (1962), Ward and Whipple (1992), and APHA (1998). Zooplankton were identified under a microscope (Microscope world, SKU: HS-3800) (500X). The total number of plankton in 1 L water sample was calculated using the formula of Santhanam *et al.* (1989).

$$N = \frac{\mathrm{n\ x\ v}}{\mathrm{V}}$$

Where: N = Total No. of organisms L^{-1} water filtered, n = No of organisms counted in 1 mL sample, v = Volume of concentrated sample (mL), V = Volume (mL) of total water filtered L^{-1}.

Data analysis

The data of phyto- and zoo-plankton density, and water quality parameters were analysed by principal component analysis (PCA). PCA of standardized water quality and phyto- and zoo-plankton parameters were performed by origin software.

RESULTS AND DISCUSSION

The average air temperature recorded was maximum (27.8ºC) in monsoon season and minimum (20.6°C) in winter season in Bhagirathi river at site I. The average depth temperature was maximum (15.8°C) in monsoon and minimum (9.23°C) in winter season (Fig. 2). The average air temperature was maximum (30.8°C) in monsoon and minimum (20.8°C) in winter season. The average depth temperature was maximum (17.4°C) in monsoon and minimum (9.9°C) in winter season (Fig. 3). The lower water temperature in winter season in the study area may be attributed to the infrequent rainfall

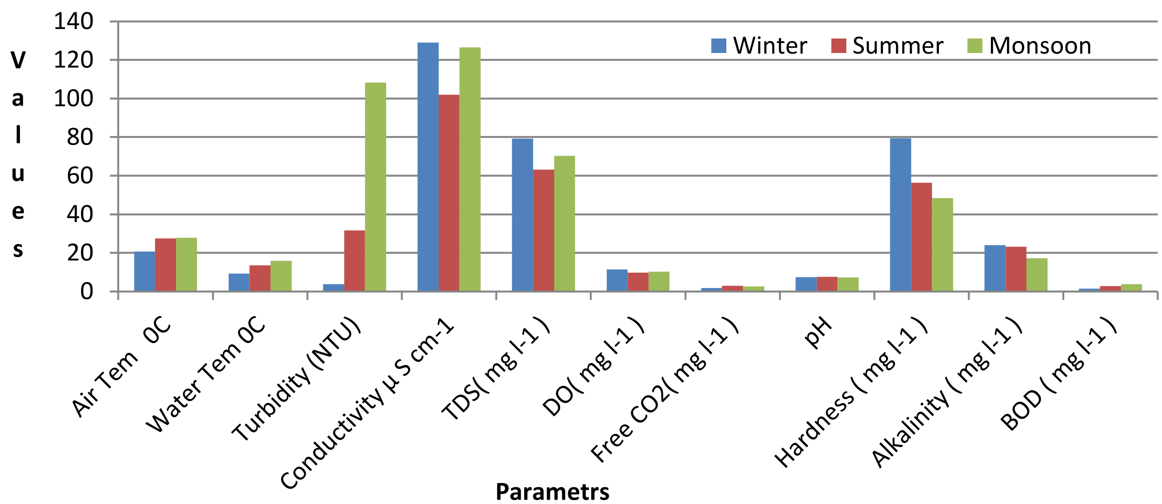

Fig. 2: Mean seasonal variation in physicochemical parameters of Bhagirathi river at site I

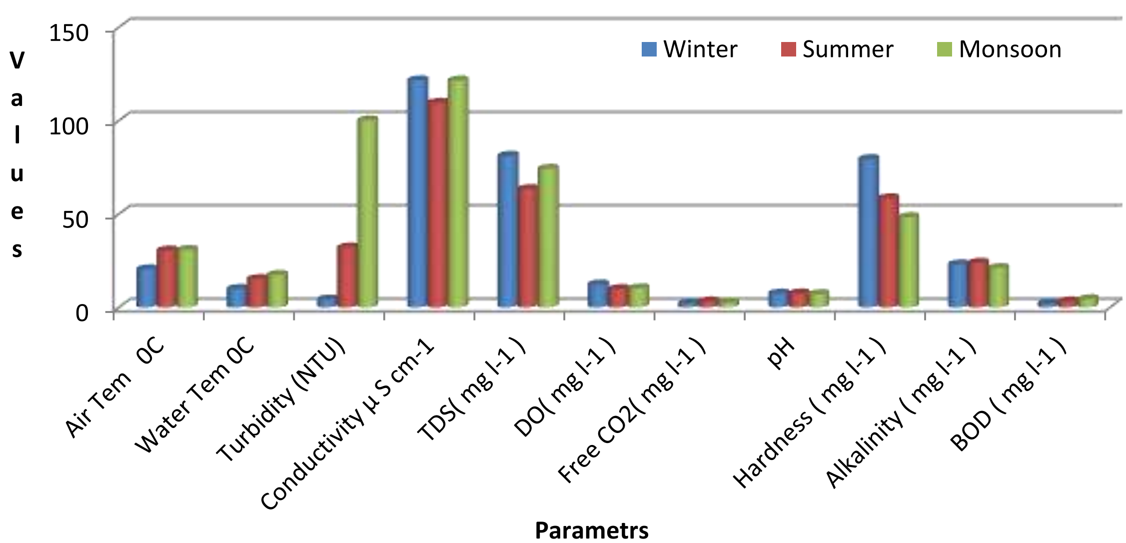

Fig. 3: Mean seasonal variation in physicochemical parameters of Bhagirathi river at site II

and cold weather conditions. The higher temperature in April and May was related to the longer photoperiod bright sunshine dry wind conditions. Turbidity was maximum (108.23 ± 0.56 NTU) in monsoon and minimum (3.75 ± 0.20 NTU) in winter at site I (Fig. 2). Turbidity was maximum (100.12 ± 0.56 NTU) in monsoon and minimum (4.23 ± 0.13 NTU) in winter at site II (Fig. 3). The turbidity of river Bhagirathi water was lowest during November to March which gradually increased from May to September This was due to the rising atmospheric temperature which resulted in melting of glaciers thereby increasing the water level of the river. Higher turbidity was due to the construction activities and mixing of muck into the water. Same result was obtained by NTPC report (2011) and NEERI July (2011).

The electrical conductivity (EC) was higher (129.06 ± 0.20 µ S cm^{-1}) in winter and lower in summer (102 ± 0.23 µ S cm^{-1}) at site I (Fig. 2). The EC value was higher (121.6 ± 0.20 µ S cm^{-1}) in winter and lower in summer (109.6 ± 0.23 µ S cm^{-1}) at site II (Fig. 3). Higher conductivity was observed in all sampling site in winter and lower conductivity in summer. This is due to low level of water in dry season. This may be due to low volume of water which brought about concentration effect. Ovie and Adeniji (1994) reported a similar trend in Shiroro lake, while NEERI (2011) reported almost similar results in Bhagirathi river. The TDS was maximum (79.23 ± 0.23 mg L^{-1}) in winter and minimum in summer (63.1 ± 0.13 mgL^{-1}) at site I (Fig. 2). The TDS was maximum (81.2 ± 0.23 mg L^{-1}) in winter and minimum in summer season (63.4 ± 0.52 mg L^{-1}) at site II (Fig. 3). The average DO was maximum (11.31 ± 0.21 mg L^{-1}) in winter and minimum (9.75 ± 0.25 mg L^{-1}) in summer season at site I (Fig. 2). The DO was maximum (12.35 ± 0.25 mg L^{-1}) in winter and minimum (9.85 ± 0.29 mg L^{-1}) in summer season at site II (Fig. 3). The river had maximum DO in colder month followed by a gradual decrease to its lowest value in June to September. The higher concentration during colder months is due to low water temperature, low turbidity and less photosynthetic activities of green algae, which grow over submerged stones and rocks (Badola, 2009). Free CO_2 in river water was maximum (3.0 ± 0.01 mg L^{-1}) in summer and minimum (1.82 ± 0.013 mg L^{-1}) in colder months at site I (Fig. 2). CO_2 was maximum (3.2 ± 0.01 mg L^{-1}) in summer and minimum (2.02 ± 0.13 mg L^{-1}) in winter at site II (Fig. 3). The increase in CO_2 concentration at the onset of rainy season may be due to anaerobic decomposition of organic materials. The higher mean observed at both sites could be attributed to lesser population density of photosynthesis plankton, a process which tends to remove CO_2 from the surrounding system. This is in agreement with those of Boyd (1979) and (Wade, 1987). Similar observations were reported by Agarwal (2009). The free CO_2 showed negative correlation with DO.

The average BOD was maximum (3.78 ± 0.14 mg L^{-1}) in monsoon and minimum (1.5 ± 0.14 mg L^{-1}) in winter season at site I (Fig. 2). The average BOD was maximum (4.4 ± 0.14 mg L^{-1}) in monsoon and minimum (2.02 ± 0.14 mg L^{-1}) in winter at site II (Fig. 3). BOD is the amount of O_2 required by living organisms engaged in the utilization and ultimate destruction or stabilization of organic water (Hawkes, 1993). BOD serves as an important indicator of pollution status. BOD of water samples in Bhagirathi river was higher in monsoon and low in winter (Kumar *et al*., 2010; Sati *et al*., 2011). Pattnaik (2018), Tiwari *et al*. (2019), and Tiwari *et al.* (2022) have reported higher BOD during summer due to low river discharge. In present study, the water pH in the study sites ranged from 7.0 to 7.9. The pH increased during summer but decreased in monsoon. Maximum BOD during summer may be attributed to the increased photosynthesis by algal blooms leading to the precipitation of carbonates of calcium and magnesium from bicarbonates thus causing higher alkalinity. Similar results were reported by Kumar *et al.* (2010). Water hardness is due to the presence of bicarbonate, sulphate, chloride and nitrates of Ca and Mg (Kumar *et al.,* 2010). Total water hardness in river was maximum in winter and minimum in monsoon. The results are in line with Ayoade *et al.* (2009) and NEERI (2011). Alkalinity is the measure of the capacity of water to neutralize a strong acid; and alkalinity in water is generally imparted by the salts of carbonate silicates together with the hydroxyl ions in free state (Trivedi and Goyal, 1986). In present study the alkalinity was maximum in summer and minimum in monsoon at both the sites. NTPC (2011) have reported high alkalinity during summer and lower in monsoon.

The qualitative and quantitative analysis of phytoplankton was done from July 2022 to June 2023 which showed wide variation. *Bacillariophyceae* was maximum 440 units L^{-1} in March and minimum (34 units L^{-1}) in July. *Chlorophyceae* was maximum (66 units L^{-1}) in February and minimum (6 units L^{-1}) in August, while *Myxophyceae* was maximum (34 units L^{-1}) in February and minimum in monsoon (Fig. 4). *Bacillariophyceae* was maximum in February and minimum in July; while *Chlorophyceae* was maximum in January and minimum in August. *Myxophyceae* was maximum in December and minimum in June (Fig. 5). *Xanthophyceae* was not recorded at any of the sites studied. Phytoplankton are the primary producers in water bodies and the main source of food (directly or indirectly) for various animal groups. The productivity of any aquatic water body depends on the amount of plankton present in water body (Guy, 1992). The pollution status of aquatic bodies depends on the plankton population (Mathivanan and Jayakumar, 1995). The density of phytoplankton and their associations with water quality have been used as biological indicators (Nwankwo and Akinsoji, 1992; Lee, 1999; Nwankwo *et al.*, 2003). Seasonal variations in phytoplankton density are as a result of complex interplay of physical, chemical and biological processes which indicate the diversity richness in the ecosystem (Bansal *et al.*, 1989). Plankton have survived the ecological individuality and have served as a water quality indicator (Saha *et al.*, 2000). Joshi *et al.* (1996) reported maximum phytoplankton density during winter and minimum in rainy season in a study site in Ganges near Haridwar. Joshi *et al.* (1993) in their study on phytoplankton production in snow-fed river Bhagirathi in Garhwal Himalaya yielded maximum plankton in December-February and minimum in July-August. Agarwal *et al.* (2005) reported maximum phyto-plankton diversity in Bhilangana river in winter and minimum in monsoon. The variations observed may be due to the variations in water temperature, velocity and turbidity which impact phytoplankton in winter months. Winters provide favourable environment for the growth of plankton and other biotic communities. In present study 36 genera of phytoplankton were observed during the entire study period. The phytoplankton were represented by *Bacillariophyceae* (21), *Chlorophyceae* (9), and *Myxiphyceae* (6).

Eleven genera of zooplankton were found at

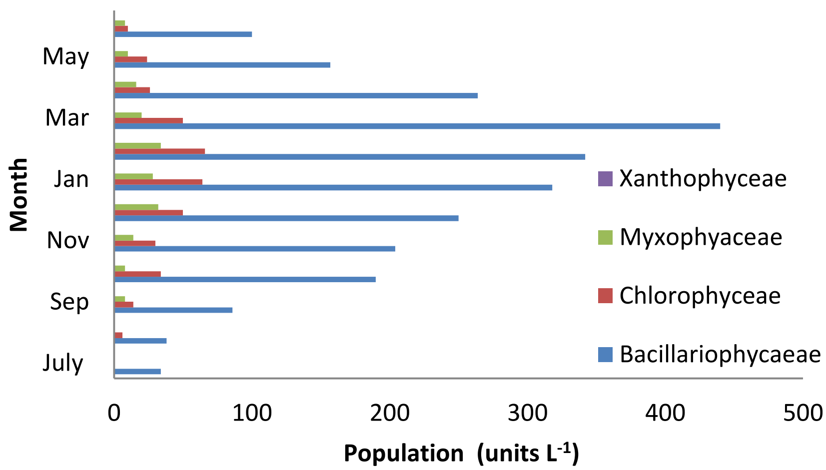

Fig. 4: Monthly variation in phytoplankton population (unit L^{-1}) of Bhagirathi river at site I

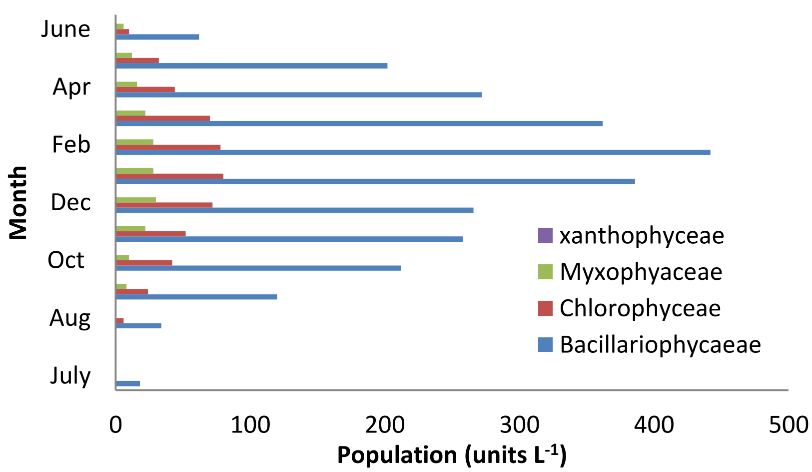

Fig. 5: Monthly variations in phytoplankton population (unit L^{-1}) of Bhagirathi river at site II

both the sites during the entire study period with zooplankton communities belonging to Cladocera (3 genera), Protozoa (2 genera), Copepoda (4 genera) and Rotifer (2 genera). The maximum number of zooplankton genera were noted in winter season and minimum in rainy season (Fig. 6 & 7). Similar findings were reported by Abdus *et al.* (1995) and Kumar (2001). Ahmed *et al. (*2009) and Gautam *et al*. (2011) reported fluctuation in zooplankton diversity due to the seasonal changes in Keetham lake at Agra and in river Gomati at Lucknow.

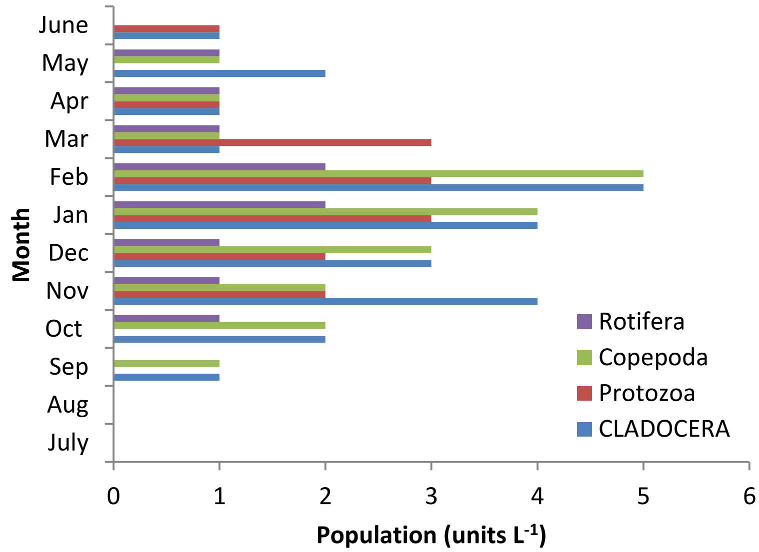

Fig. 6: Monthly recorded of zooplankton population (unit L^{-1}) of Bhagirathi river of site I

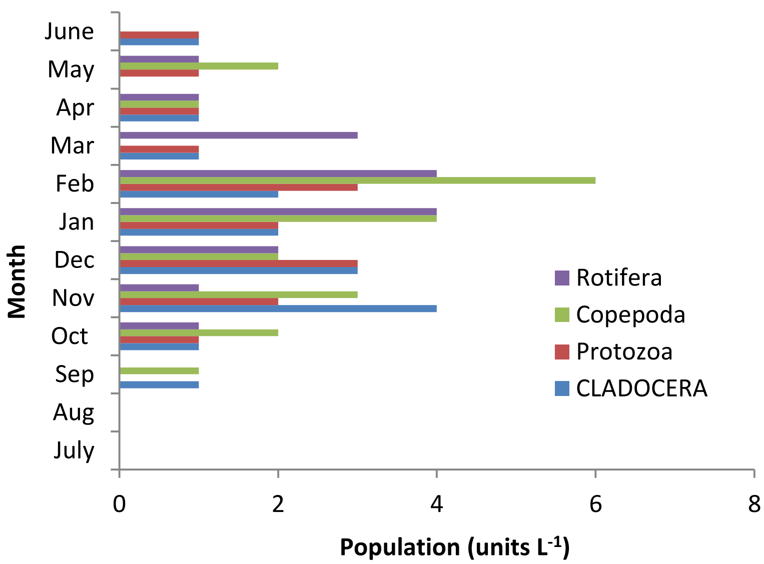

Fig. 7: Monthly recoded of zooplanktons population (unit L^{-1}) of Bhagirathi river of site II

The water quality, zooplankton and phytoplankton are related to each other. These interactions are directly or indirectly subject to the complex influences, some of which result in quantitative changes. Wei (2022) and Oparaku *et al.* (2022) showed that DO, temperature, total alkalinity, pH, phosphate, and nitrogen influence the growth of zooplankton. Das *et al.* (1996) showed relationship between zooplankton and physicochemical parameters such as densities, pH, alkalinity, nitrate and phosphate. Nutrient availabilities influence the abundance of Rotifer and Copepoda (Kumar *et al.* 2004). Ojha *et al.* (2007) reported that zooplankton did not always follow the fluctuation of physico-chemical parameters. Importance of zooplankton as fish food (Nickolsky, 1999) and as an indicator of water quality (Sladeck, 1983) are well known. Water temperatures between 10-29°C are suitable for zooplankton development (Kaushik *et al.*, 1992) and species diversity of zooplankton are very much low in fresh water in comparison to marine water (Lehman, 1988). Zooplanktons are important food item of many omnivorous and carnivorous fishes.

The Eigen values of principal component analysis (PCA) of water quality and phyto- and zooplankton variables showed that the 1st and 2nd principal component (PC1 & PC2) explained 76.95 and 23.05% of total variation at site I, and 75.15 and 24.83% of total variation at site II, respectively (Table 1; Fig. 8 & 9). PC1 axis was positively correlated with phytoplankton, zooplankton, DO, TDS, conductivity and pH; and negatively correlated with BOD, water temperature, and turbidity in site I and II. Additionally, the PC2 axis was positively correlated with BOD, and turbidity but negatively correlated to hardness. These results indicate that with DO, TDS, electric conductivity and alkalinity are good for phyto- and zoo-plankton.

Table 1: Coefficients of principal components (PC) of some water quality parameters and phyto- and zoo-plankton variables in Bhagirathi river at site I and site II

Extracted Eigen vectors	Site 1		Site II	
	Coefficients of PC1	Coefficients of PC2	Coefficients of PC1	Coefficients of PC2
Bacillariophyceae	0.23866	-0.25505	0.27119	-0.11938
Chlorophyceae	0.27632	-0.01720	0.27842	-0.04716
Myxiphyceae	0.27522	-0.04813	0.27764	-0.05945
Xanthophycea	0	0	0	0
Rotifera	0.27559	-0.04064	0.27842	-0.04716
Copepoda	0.26173	0.16280	0.26626	0.14923
Protozoa	0.27122	-0.09813	0.27966	-0.01065
Cladocera	0.27178	0.09281	0.27358	0.10150
Water temperature	-0.27645	-0.00813	-0.27966	-0.01083
Dissolved oxygen	0.22172	0.30180	0.25260	0.20912
Turbidity	-0.24796	0.22346	-0.25199	0.21135
Hardness	0.27570	0.03792	0.27971	-0.00637
Alkalinity	0.22941	-0.28196	0.14347	-0.41787
Biological oxygen demand	-0.27272	0.08303	-0.27456	0.09317
Total dissolved solids	0.19560	0.35703	0.16049	0.39869
CO_2	-0.20334	-0.34231	-0.18368	-0.36712
Electric conductivity	0.07624	0.48560	0.06084	0.47512
pH	0.15349	-0.42019	0.16574	-0.39212

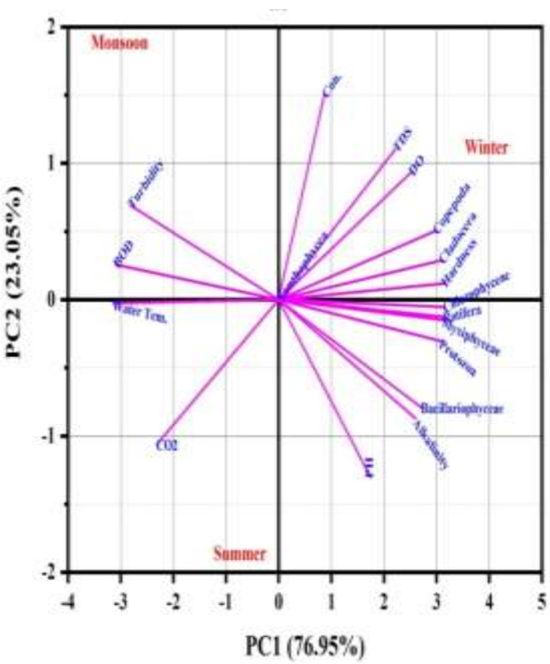

Fig. 8: Biplot of Different variable showing variations in water quality parameters and phyto- and zoo-plankton populations in Bhagirathi river at site I

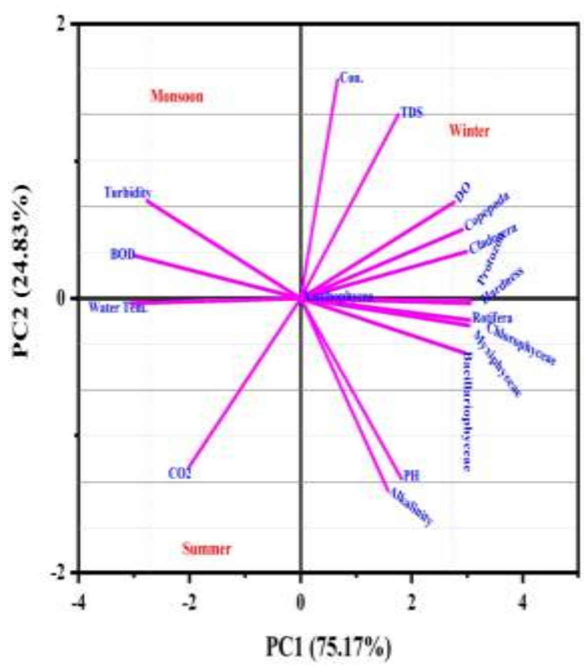

Fig. 9: Biplot of different variable showing variation in water quality parameters and phyto- and zoo-plankton populations in Bhagirathi river at site II

Conclusion: The physicochemical parameters of the study area was near the standard values in winter but varied from standard values in monsoon season and summer. The study showed the water is not healthy for drinking in monsoon season due to run-off of organic matter into Bhagirathi river. The nutrients and water quality parameters undergo seasonal changes and the values showed slight variations in all the seasons. The changes in physicochemical properties of water appear due to the seasonal variations and anthropogenic activities. The fauna population was maximum during the winter season and minimum during the monsoon mainly because of less turbidity in winter months. Zooplankton, phytoplankton and water quality are interrelated to each other. River Bhagirathi at these sites seems to have tremendous healing potential whereas on the other sited the river ecology is damaged due to the disproportionate water release from the hydro-electric power project into main river channel. However, this recovery might be limited to few cycles and immediate steps need to be taken in order to restore the ecological balance – mainly after the construction of dam walls of hydro-electric power projects. An integrated approach involving each stakeholder is required or the conservation and management of aquatic biodiversity of Bhagirathi.

Acknowledgement: Authors are grateful to the Govt.PG College Uttarkashi, Uttarkhand for providing research facilities required to carry out this work.

REFERENCES

Abdus Saboor and Altaff, K. 1995. Qualitative and quantitative analysis of zooplankton population of tropical pond during summer and rainy season. *Journal of Ecobiology,* **7**(4): 269-275.

Agarwal, N.K. and Thapliyal, B.L. 2005. Pre-impoundment hydrological study of Bhilangana river from Tehri dam reservoir area in Uttaranchal. *Environmental Geochemistry,* **8**: 143-148.

Ahmad, T. and Sharma, A.K. 2009. A study of fresh water protozoans with special reference to their abundance and ecology. *Journal of Applied and Natural. Science,* **1**(2): 166-169.

Akbay, N., Anul, N., Yerti, S., Soyupak, S. and Yurteri, C. 1999. Seasonal distribution of large phytoplankton in Keban dam reservoir. *Plankton Research*, **21**(4): 771-787.

APHA. 1995. *Standard Method for the Examination of Water and Waste Water*. American Public Health Association, American, Water Works Association and Water Environment Federation, Washington, USA.

Arora, S. and Keshari, A.K. 2021. Dissolved oxygen modelling of the Yamuna river using different ANFIS models. *Water Science Technology,* **84**: 3359-3371.

Ayoada, A.A., Agarwal, N.K. and Chandola, A. 2009. Changes in physicochemical features and plankton of two regulated high altitude rivers Garhwal Himalaya, India. *European Journal of Scientific Research*, **27**(1): 77-92.

Baig, A.A., Mahmood, Q., Nawab, B., Hussain, A. and Nafees, M. 2010. Assessment of seasonal variation in surface water quality of Chitral river, North West Frontier Province (NWFP), Pakistan. *World Applied Science Journal,* **9**(6): 674-680.

Bhandari, N.S. and Joshi, H.K. 2013. Quality of spring water for irrigation in the Almora district of Uttarakhand, India. *Chinese Journal of Geochemistry,* **32**: 130-136.

BIS. 2012. *Specification of Drinking Water. IS: 10500*. Bureau of Indian Standards, New Delhi, India.

Boyd, C.E. and Lichthoppler, F. 1979. *Water Quality Management in Pond Fish Culture*. Research and Development Series No. 22 (Project AID/DSAN-g 0039). International Center for Aquaculture, Agriculture Experiment Station, Auburn University, Auburn, Alabama, USA.

Bu, H., Tan, X., Li, S. and Zhang, Q. 2010. Temporal and spatial variations of water quality in the Jinshui river of the South Qinling Mts., China. *Ecotoxicology and Environmental Safety,* **73**(5): 907-913.

CPCB. 2010 *Status of Water Quality in India*. [*www.cpcb.nic.in/ WQSTATUS_REPORT2010.pdf*].

Dewan, S., Ali, M. and Islam, M.A. 1977. Study on the size and pattern of feeding of fries and fingerlings of three major carps, e.g. *Labeorohita* (Ham), *Catlacatla* and *Cirrhinamrigala*. *Bangladesh Journal of Agriculture Science* ,**2**(2): 223-228.

Gautam, R. and Gautam, R.K. 2011. Zooplanktons diversity at Sursarovar (Keetham) lake, Agra. *Aquaculture*, **12**(1): 73-77.

Guy, D. 1992. *The Ecology of the Fish Pond Ecosystem with Special Reference to Africa*. *volume 72*. Pergamon Press, Oxford, UK. [*ISBN: 978-90-481-4132-6*].

Hambright, K.D. and Zohary, T. 2006. Phytoplankton species diversity control through competitive exclusion and physical disturbances. *Limnology and Oceanography,* **45**(1): 110-122.

Hawkes, H.A. 1993. *The Ecology of Waste Water Treatment.* Pergamon Press, Oxford, UK.

Hossain, F., Degu, AM. and Yigzaw, W. 2012. Climate feedback–based provisions for dam design, operations, and water management in the 21st century. *Journal of Hydrological Engineering,* **8**: 837-850.

Ismael, A.A. and Dorgham, M.M. 2003. Ecological indices as tool for assessing pollution in E1-Dekhaila harbour (Alexandria, Egypt). *Oceanologia,* **45**: 121-131.

Jakhar, P. 2013. Role of phytoplankton and zooplankton as health indicators of aquatic ecosystem: A review. *International Journal of Innovative Research Studies,* 12: 490-500.

Joshi, B., Bisht, R. and Joshi, N. 1996. Planktonic population in relation to certain physicochemical factors of Ganga canal at Jawalapur (Hardwar). *Himalayan Journal of Environment and Zoology,* **10**(2): 75-77.

Joshi, B., Pathak, J., Singh, Y., Bisht, R. and Joshi, P. 1993. On the physicochemical characteristics of river Bhagirathi in the upland of Garhwal Himalaya. *Himalayan Journal of Environmental Zoology,* **7**: 69-75.

Kannan, V. and Job, S.V. 1980. Diurnal depth wise and seasonal changes physicochemical factors in Sathior reservoir. *Hydrobiologia,* **70**: 103-117.

Kaushal, N., Babu, S., Mishra, A., Ghosh, N., Tare, V., Kumar, R., Sinha, P.K. and Verma, R.U. 2019. Towards a healthy Ganga - Improving river flows through understanding trade offs. *Frontiers in Environmental Science,* **7**: 83. [*https://doi.org/10.3389/fenvs.2019.00083*].

Kaushik, S., Agarkar, M.S. and Saxena, D.N. 1992. Distribution of phytoplankton in riverine waters in Chambal area, Madhya Pradesh. *Bio nature,* **12**: 1-7.

Khanna, D.R. and Singh, R.K. 2000. Seasonal fluctuation in plankton of Suswariver at Raiwala (Dehradun). *Environment Conservation Journal*, **1**(2-3): 89-92.

Kulshrestha, H. and Sharma, S. 2006. Impact of mass bathing during Ardhkumbh on water quality. *Journal of Environmental Biology*, **27**: 437-440.

Kumar, A., Bisht, B., Joshi, V., Singh, A. and Talwar, A. 2010. Physical, chemical and bacteriological study of water from rivers of Uttarakhand. *Journal of Human Ecology,* **32**(3): 169-173.

Kumar, A., Tripathi, G. and Ghosh, P. 2004. Status of freshwater in 21st century: A review in water pollution assessment and management. (eds. A. Kumar and G. Tripathi), Daya Publishing House, New Delhi, India.

Kumar, K.S. 2001. The fresh water zooplankton of some lakes in Dharmapuri district Tamilnadu. *Journal of Aquatic Biology*, **16**: 5-10.

Kurbatova, I. 2005 Response of microorganism zooplankton to acidification. *Nature of Science Biology*, **1**: 100-108.

Lee, R.E. 1999. *Psychology*. Cambridge University Press, New York, USA.

Lehman, J.J. 1988. Ecological principals affecting community structure and secondary production by zooplankton in marine and fresh water environments. *Limnology Oceanography*, **33**: 913-945.

Mane, V.R., Chandorkar, A.A. and Kumar, R. 2005. Prevalence of pollution in surface and ground water sources in the rural areas of Satararegion, *Asian Journal of Water, Environment and Pollution,* **2**: 81-87.

Mathivanan, V. and Jayakumar, S. 1995. The studies on plankton fluctuation in a reservoir of Annamalaingar. **In**: *Proceedings of the National Symposium on Recent Trends in Indian Wildlife Research*. A.V.C. College, Mayilduthurai, Tamilnadu, India.

Mathivanan, V., Vijayan, P., Sabhanayakam, S. and Jeyachitra, O. 2007. An assessment of plankton population of Cauvery river with reference to population. *Journal of Environmental Biology*, **l28**: 523-552.

Matta, G. and Uniyal, D.P. 2017. Assessment of species diversity and impact of pollution on limnological conditions of river Ganga. *International Journal of Water*, **11**(2): 87-102.

Matta, G., Kumar, A., Naik, P.K., Tiwari, A.K. and Bendtsson, R. 2018c. Ecological analysis of nutrient dynamics and phytoplankton assemblage in the Ganga river system, Uttarakhand. *Taiwan Water Conservation,* **66**(1): 1-12.

McAllister, D., Craig, N., Davidson, J., Murray, D. and Seddon, M. 2001 *Biodiversity Impacts of Large Dams*. Background Paper No. 1. IUCN/ UNEP/ WCD. [*www.researchgate.net/ publication/255643683_Biodiversity_Impacts_of_Large_Dams*].

Mul, M., Pettinotti, L., Amonoo, N.A., Bekoe-Obeng, E. and Obuobie, E. 2018. Dependence of riparian communities on ecosystem services in Northern Ghana. International Water Management Institute (IWMI). Colombo, Sri Lanka. [*doi: 10.5337/2018.201*]

NTPC. 2011. *Environmental Assessment Report: India: Assessment of Cumulative Impact of Hydropower Projects in Alakanda and Bhagirathi Basins*. Wildlife Institute of India, India

Nwankwo, D. and Akinsoji, A. 1992. Epiphyte community of water hyacinth, *Eichhornia crassipes* (Mart.) Solms in coastal waters of South Western Nigeria. *Archiv fur Hydrobiologie*, **124**(4): 501-511.

Nwankwo, D.I., Onyema, I.C. and Adesalu, T.A. 2003.A survey of harmful algae in coastal waters of south-western Nigeria. *Journal of Nigerian Environmental Society*,**1**(2): 241-246.

Ojha, P., Mandloi, A.K. and Dube, K.K. 2007. Diel variations of physicochemical parameters influence zooplanktons fluctuations in a small irrigation reservoir. Bamoo, Jabalpur, MP. *Journal for Natural Conservation*, **19**(2): 375-385.

Oparaku, N.F. and Andog, F.A. 2022. The effect of physicochemical parameters on the abundance of zooplankton of river Adada, Enugu. *Journal of Fresh Water Ecology,* **37**(1): 35-56.

Ovie, S.I. and Adeniji, H.D. 1994. Zooplankton and environmental characteristic of Shiroro at the extremes of its hydrological cycle. *Hydrobiologia*, **286**: 175-182.

Pattnaik, S. 2018. Assessment of water quality of Bhagirathi river using water quality index. *International Journal of Emerging Technologies and Innovative Research*, **5**(1): 365-376.

Peerapornpisal, Y., Sonthichai, W., Somdee, T., Mulsin, P. and Rott, E. 1999. Water quality and phytoplankton in the Mae Kuang Udomtara reservoir, Chiang Mai, Thailand *Journal of Science Faculty of Chiang*, **26**(1): 25-43.

Qicai, L. 2011. Influence of dams on river ecosystem and its countermeasures. *Journal of Water Resource and Protection*, **3**(1): 60-66.

Rana, R.S., Singh, P., Kandari, V., Singh, R., Dobhal, R. and Gupta, S. 2017. A review on characterization and bioremediation of pharmaceutical industries' wastewater: An Indian perspective. *Applied Water Science,* **7**: 1-12.

Rani, N., Sinha, R.K., Prasad, K. and Kedia, D.K. 2011. Assessment of temporal variation in water quality of some important rivers in middle Gangetic plain, India. *Environmental Monitoring & Assessment.* **174**: 401-415.

Rawat, U.S. and Agarwal, N.K. 2015. Biodiversity: Concept, threats and conservation. *Environment Conservation Journal*, **16**(3): 19-28.

Saha, S.B., Bhattacharya, S.B. and Choudhary, A. 2000. Diversity of phytoplanktons of a sewage pollution brackish water tidal ecosystem. *Journal of Environmental Biology*, **21**(1): 9-14.

Sanatham, R., Velayutham, P. and Jegatheesan, G. 1989. *A Manual of Fresh Water Ecology*. Daya Publishing House Delhi, India.

Sarkar, K. and Chayudhari, A. 1999. *Limnological Research in India* (1stedn.). Daya Publishing House, New Delhi, India.

Sati, A., Sood, A., Sharma, S., Bisht, S. and Kumar, V. 2011. Bacterial indicators of faecal pollution and physiochemical assessment of tributaries of Ganges river in Garhwal Himalayas, India. *Materials and Geo-environment*, **58**(2): 129-142.

Sati, S.C. and Paliwal, P.C. 2008. Physicochemical and bacteriological analysis of Kosi river water in central Himalaya. *Pollution Research,* **27**(1): 179-183.

Semwal, N. and Jangwan, J.S. 2009 Major ion chemistry of river Bhagirathi and river Kosi in Uttarakhand Himalaya. *International Journal of Chemical Science*, **7**(2): 607-616.

Sharma, M.P., Singal, S.K. and Patra, S. 2008. Water quality profile of Yamuna river. India. *Hydro Nepal*, **3**: 1-6.

Shetty, S., Tharavathy, N.C., Lobo, R.O., and Shafakatullah, N. 2013. Seasonal variation in the physicochemical characteristics along the upstream of Tungabhadra river, Western Ghats, India. *The International Journal of Plant, Animal and Environmental Sciences,* **3**(1): 242-246.

Sladeck, V. 1983. Rotifers as indicators of water quality. *Hydrobiology*, **100**: 169-201.

Tiwari, M.P. and Tiwari, P. 2020. Assessment of water quality status and zooplanktons of river Bhagirathi in Uttarkashi. *Journal of Water and Environmental Nanotechnology,* **5**(1): 92-101.

Tiwari, P. and Tiwari, M.P. 2022 Evaluation of water quality and dam for sustaining the fish population dynamics. *Applied Water Science,* **12**: 233. [*https://link. springer. com/ article/ 10. 1007/ s13201-022-01728-x*]

Tiwari, P., Tiwari, M.P., Madhu, T. and Ashish, T. 2019, Water quality status of Bhagirathi river and fish populations of Uttarkashi, Uttrakhand. *International Journal of Recent Scientific Research,* **6**: 32936-32940.

Trivedi. R.K. and Goyal, P.K. 1986. *Chemical and Biological Methods for Water Pollution Studies.* Environment Publication, Karad, Maharashtra., India.

Van Vliet, M.T., Jones, E.R., Flörke, M., Franssen, W.H., Hanasaki, N., Wada, Y. and Yearsley, J.R. 2021. Global water scarcity including surface water quality and expansions of clean water technologies. *Environmental Research Letter,* **16**: 024020. [*https://iopscience.iop.org/article/ 10.1088/1748-9326/abbfc3*].

Wei, Y., Ding, D., Gu, T., Jiang, T., Qu, K., Sun, J. and Cui, Z. 2022. Different responses of phytoplankton and zooplankton communities to current changing coastal environments. *Environmental Research*, **215**: 114426. [*https://www.sciencedirect.com/science/article/pii/ S0013935122017534*].

Welch, P.S. 1952. *Limnology*. McGraw Hill Book Co. Inc., New York, USA.