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RESEACH ARTICLE

WILEY

Impact of the dams on water and plankton quality of the River Ganga (Gangotri to Vindhyachal)

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Abstract

The river Ganga originates from Gangotri and travels approximate 1,300 km to Vindhyachal, bypassing through a series of dams. Water quality parameters including temperature, pH, dissolved oxygen, alkalinity, chloride, biological oxygen demand, dissolved organic matter, and nutrients were studied from various centers of the river Ganga from Gangotri to Vindhyachal (24 centers). Specific conductivity increased gradually from Maneri above barrage area and reached maximum at Kanpur as the river receives industrial and domestic effluents near Kanpur. Allahabad, Haridwar, and Vindhyachal sampling points were found to be affected by anthropogenic influences. A chloride as well as Myxophyceae were maximum at Kanpur, which indicated that maximum organic pollution at Kanpur plankton population and composition were much more affected by temperature and nutrients than by the construction of dams. However, the pattern of release of water affected the accumulation of nutrients in surface water, which impacted the quality of planktonic fauna and flora. The upper stretch was dominated by diatoms and the middle stretch by green and blue-green algae as the accumulation of nutrients exhibited eutrophic conditions. Near the source, diatoms like *Eunotia, Achanthes, Cymbella, Diatoma, Tabellaria* were found to be dominant but as river moves toward downstream, species of *Synedra, Melosira,*

Nitzchia, and Cyclotella became abundant. The study revealed how water quality deteriorated by the construction of each dam. Therefore, when making policy for a dam on any river it is important to maintain at least one stream of the original water flow. The whole river should not be blocked at any point/place or at least 50% of original water should flow continuously to sustain the biodiversity and quality of water, otherwise after traveling a few kilometers through dams, a river will lose its originality.

KEYWORDS

diversity, Ganga, plankton composition, the impact of dams, water policy

1 | INTRODUCTION

The river Ganga originates from Gangotri and travels 1,300 km up to Vindhyachal. The river Ganga is commonly known as Bhagirathi in the stretch Gangotri to Devprayag. The entire stretch of river Ganga (mainstream) can be viewed into three segments that is, upper Ganga from Gaumukh to Haridwar, middle Ganga from Haridwar to Varanasi and lower Ganga from Varanasi to Ganga Sagar. These three segments differ in their geomorphology, ecology, and rheology. In the way, Ganga passes through a series of dams and various physical changes or habitat alterations. These changes affected water quality in a minor way but its cumulative effect becomes visible from Farrukhabad onward. The scenario becomes poorest at Kanpur. Dilution of Ganga water with the river Yamuna improves its water quality slightly. Multiple stresses affect aquatic ecosystem adversely by changing physical, chemical, and ecological status causing changes in species composition, ecosystem structure, and function as well as biodiversity (Rajvanshi et al., 2012). Water quality of the river Ganga is observed continuously under various projects of CIFRI (Anonymous, 1967–2018). Biological assessment is a useful alternative for assessing the ecological quality of aquatic ecosystem because biological contribution integrates the environmental effects of river water (Segner et al., 2014). To assess water quality and the impact of environmental change, many groups of organisms have been studied. Previous work of upper stretch is limited to the fish and epilithic diatoms only (Nautiyal et al., 2013a, 2013b, 2013c; Nautiyal et al., 2000; Singh et al., 1994). Plankton occupies the base level of a food chain that leads up to commercially important fisheries. Thus here changes in water quality and plankton productivity of the river Ganga after originating from Gangotri and passing through a series of dams were studied.

2 | MATERIALS AND METHODS

Samples were collected during summer (2015) and winter (2016) from various centers of the river Ganga *viz* Gangotri, Maneri above barrage 1, Maneri above barrage 2, Maneri below barrage, Tehri jheel, Tehri zero point, Chinyalisaur, Srinagar above barrage (ab), Srinagar below barrage (bb), Alaknanda, Bhagirathi, their Confluence at Deoprayag, Haridwar above barrage (ab), and below barrage (bb), Bijnore above and below barrage, Narora above and below barrage, Kannauj, Kanpur above barrage (Bithoor) and below barrage, Farukhabad, Allahabad (Prayagraj), and Vindhyachal. Plankton samples were collected using

bolting silk net no. 25 by filtering 50 liters water and fixed in 4% formalin solution in 50 ml tubes for qualitative and quantitative analysis in the laboratory. Samples were analyzed using the methodology proposed by Welch (1952). Analysis of water quality parameters was performed by using (APHA, 2005). Water quality and plankton samples were collected at the same time and place. Palmer pollution index, based on algal genera, was calculated according to Palmer (1969).

3 | STUDY AREA

Gangotri—Represents near-natural and pristine conditions and steep bed with rocks and boulders. Deep gorges have slight distributed pollution due to wastes from eating-joints on the Gangotri-shrine. The problem of sanitation is most important.

Maneri above barrage—Modified to impoundment. Riverine environment shifting to the lacustrine environment. Slight pollution due to domestic activities. High eutrophication potential.

Maneri below barrage—Modified fluctuating flows depending upon power generation. Riverbed consisting of small stones and pebble. River in the form of combination of riffles and pools. Slight pollution due to domestic activities.

Tehri jheel—Modified to impoundment. Riverine environment shifting to the lacustrine environment. Slight pollution due to domestic activities. High eutrophication potential. Potential for release of greenhouse gases due to the decomposition of submerged biomass in the lake.

Tehri zero point—Substantially modified fluctuating flows depending upon power generation at Tehri power plant. The Riverbed consisting of small stones and pebble. River in the combination of riffles and pools. Slight pollution due to domestic activities.

Deoprayag—Flow augmented due to confluence of Bhagirathi with Alaknanda. Hydroelectric projects under construction/proposed on Alaknanda and its tributaries may further influence hourly variation inflow.

Haridwar—Riverbed consisting of large and small pebble with some boulders and sand. Slight pollution due to domestic activities, bathing, and other cultural/religious activities. Riverine ecosystem under stress due to frequent fluctuations in flow and water quality (e.g., temperature and turbidity).

Bijnor—Low flow during non-monsoon period. Wide flood plain and sandy bed with some pebbles. Moderate pollution due to domestic and agricultural activities. Subsequently flow modified through the discharge of Ramganga waters through feeder canal.

Narora—Extremely low flows during the non-monsoon period. Only occasional releases of water during the non-monsoon period. Sandy bed and significant degradation of river water quality.

Kannauj, Bithoor, and Kanpur—Low flows during the non-monsoon period. Only occasional increase in flows during non- monsoon period. Wide flood plain, sandy bed, and extensive degradation of river water quality due to domestic and industrial wastes.

Allahabad and Vindhyachal—Significant degradation of river water quality due to use of excessive pesticides. Several important major and mega religious/cultural conglomeration held on the riverside. Discharge of domestic and some industrial wastes. The slight increase in flow is because of the combination with of a major tributary, Yamuna.

4 | RESULTS

As the river flows from Gangotri to downwards, increase in all nutrients like bicarbonate ions, chloride, specific conductivity, TDS, calcium, and magnesium, were recorded maximum in

Kanpur to Vindhyachal area, which is also supported by plankton abundance in summer and winter seasons in the river Ganga. Details of each parameter (Tables 1 and 2) at all the centers are presented here.

4.1 | Temperature (°C)

Air temperature ranged from 2.5°C (Gangotri) to 25.5°C (Deoprayag, Maneri - 23.5°C) in winter and from 17 Gangotri to 40 (Allahabad & Deprayag) in summer. Water temperature ranged from 1.7°C (Gangotri) to 17°C (Deop and 16.8 Tehri Jheel) in winter and from 5°C (Gangotri) to 35.5°C (Allahabad) in summer, with a maximum temp in upper stretch (24°C) noticed in Tehri jheel. During both the seasons, Tehri jheel revealed higher temp which may be due to topography of the jheel. The temperature of the water is dependent on altitude, topography, and type of source.

4.2 | pH

In winter pH ranged from 7 (Gangotri, and Maneri) to 8.1 (Allahabad), while in summer it ranged from 6.7 (Gangotri) to 8.1 (Allahabad, Vindhyachal, Bithoor).

4.3 | Transparency (cm)

In winters water was transparent in upper stretch (Gangotri to Haridwar), being maximum at Deoprayag 131 cm, while in the lower stretch it ranged from 12.5 cm, Narora Ab to 56 cm (Vindhyachal). In summer it ranged from 20 cm in Bijnore bb to 60 cm in Vindhyachal.

4.4 | CO_2 (ppm)

Carbon dioxide ranged from 9 ppm (Narora up) to 0 (Farukhabad toVindhyachal) in winter and from 10 ppm (Haridwar up)) to 0 (Bithoor to Vindhhyachal) in summer.

4.5 | HCO_3 (ppm)

A gradual increase in HCO_3 from Gangotri to Vindhyachal was noticed as bicarbonates ranged from 8 ppm (Gangotri) to 198 ppm (Vindhhyachal) in winter and 28 ppm (Gangotri) to 153 ppm (Kanpur) in summer.

4.6 | Cl (ppm)

Cl ranged from 8.5 ppm (Gangotri) to 42.5 ppm (Vindhyachal) in winter and from 4.2 ppm (Gangotri & Maneri) to 93.7 ppm (Bithoor) in summer. In the upper stretch, a highest value for bicarbonate was noticed in Tehri jheel (11 ppm in summer and 26 ppm in winter).

TABLE 1 Physico-chemical parameter of water of River Ganga in summer

Place	Temperature(^{0}C)		CO_2	CO_3	$BiCO_3$	Cl	DO	BOD	Sp. Conductivity	TDS	Total Hardness	Ca	Mg	PO4	Si	D.O.M
	Air	Water	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(μs/cm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
Gangotri	17	5	3	0	28	4.26	8.8	0.48	75	42.89	36	9.62	2.9	0.05	0.3	0.98
Maneri I(AB)	25	12	3	0	40	4.26	9.23	0.64	99.21	56.26	52	12.83	4.84	0.03	0.3	0.98
Maneri II(AB)	22	13	3	0	30	4.26	9.28	1.12	99.55	56.67	48	12.83	3.87	0.03	0.4	0.75
Maneri (BB)	25	14	3	0	48	7.1	9.28	1.85	143.4	81.38	68	20.84	3.86	0.07	0.5	0.53
Chinyali saur	35	18	3	0	42	8.52	10.72	1.92	124.2	71.69	60	20.84	1.92	0.03	0.3	0.45
Tehri jheel	28	24	4	0	60	9.94	10.88	2.08	144.9	82.69	72	22.44	3.86	0.05	0.6	0.68
Tehri 0 point	27	18	4	0	54	11.36	7.2	2.24	130.6	74.52	64	20.84	2.89	0.05	0.5	0.6
Shringar (AB)	36	19	3	0	70	9.94	9.12	1.13	155.8	88.68	76	22.44	4.86	0.04	0.3	0.53
Shrinagar (BB)	36	21	3	0	64	8.52	9.6	1.3	136.8	78.02	64	20.84	2.89	0.02	0.4	0.83
Devprayag 0 point	42	18	2	0	54	7.1	8.8	1	142.3	81.3	68	20.84	3.86	0.02	0.3	0.23
Devprayag (Bhagarati)	40	20	2	0	64	7.1	9.12	1.14	139.4	79.61	60	16.03	4.84	0.02	0.2	0.6
Devprayag (Alknanada)	40	20	2	0	44	7.1	9.12	1.14	149.3	85.34	80	19.24	7.75	0.03	0.3	0.38
Haridwar AB	38	22.5	10	0	60	7.1	8.48	1.44	157.2	89.73	76	20.84	5.81	0.04	0.6	0.6

(Continues)

TABLE 1 (Continued)

Place	Temperature(^{0}C)		CO_2	CO_3	$BiCO_3$	Cl	DO	BOD	Sp. Conductivity	TDS	Total Hardness	Ca	Mg	PO4	Si	D.O.M
Haridwar BB	38	21	10	0	68	7.1	8.48	1.44	151.7	86.01	64	17.64	4.84	0.05	0.4	0.6
Bijnor AB	34.5	25.5	8	0	70	9.94	5.92	1.76	88.1	107	82	15.23	10.67	traces	0.2	1.65
Bijnor BB	35.5	22	7	0	64	8.52	7.04	0.88	150.5	86.05	88	4.81	18.46	traces	0.3	0.49
Narora AB	25	28	5	0	78	9.94	5.76	1.12	167.7	96.14	76	19.24	6.78	traces	0.3	0.23
Narora BB	24.5	27.5	4	0	66	8.52	6.48	1.36	170.6	96.86	78	18.44	7.75	0.01	0.5	0.3
Farrukhbad	32	28	0	6	106	12.78	6.56	2	240.2	137.4	110	7.21	22.35	0.02	0.6	0.19
Kannauj	36.5	31.5	0	8	137	24.14	6.8	3.12	338.1	193.1	132	12.02	24.77	0.03	0.2	0.94
Bittur	39	31.5	0	13	142	93.76	6.88	2.08	353.1	201.5	118	14.43	19.91	0.05	0.7	0.71
Kanpur	38	31	0	8	153	82.36	6	3.76	513.5	291.7	130	18.44	20.39	0.03	0.6	1.65
Allahabad	40.5	33.5	0	10	143	51.12	9.92	3.2	460.2	263.4	120	19.24	17.47	0.1	0.7	1.84
Vindhychal	38	31	0	13	137	61.06	8.16	7.16	304	481.8	275.9	20.8	21.64	0.02	0.2	0.68

Note: AB = above barrage, BB = below barrage

TABLE 2 Physico-chemical parameter of water of River Ganga in winter

Place	Temperature(^{0}C)		pH	CO_2	CO_3	$BiCO_3$	Cl	DO	BOD	Sp. Conductivity	TDS	Total Hardness	Ca	Mg	PO4	Si	D.O.M
	Air	Water		(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(μs/cm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)
Gangotri	2.5	1.7	7	7	0	8	8.52	10.72	0.32	105.1	62.52	52	10.42	6.41	0	0.3	1.8
Maneri I(AB)	9.9	6	7	1	0	46	9.94	11.2	0.8	170.5	100.3	80	19.24	7.76	0	0.6	0.23
Maneri II(AB)	10	7	7.1	1	0	52	12.78	11.36	0.8	174.4	99.53	88	17.64	10.67	0	0.6	0.38
Maneri (BB)	23.5	8.6	7.9	2	0	54	11.36	11.04	1.44	180.5	100.6	88	22.44	7.75	0	0.6	0.6
Chinyali saur	22.9	14.5	7.8	2	0	47	11.36	10.4	1.6	170.9	98.64	84	19.24	8.72	0	0.6	0.75
Tehri jheel	14.8	16.8	7.7	2	0	56	12.78	6.4	0.8	159.7	90.89	72	17.64	6.78	0	0.6	0.75
Tehri 0 point	20.1	16.2	7.6	2	0	57	26.98	6.88	0.16	100.7	56.96	48	11.22	4.85	0	0.6	0.75
Shringar (AB)	18.2	12.2	7.6	2	0	76	8.52	11.1	2.46	189.4	109.3	100	20.84	11.64	0	0.6	0.53
Shrinagar (BB)	13.5	11.3	7.6	2	0	74	8.52	11.52	2.22	171.8	98.64	92	24.05	7.75	0	0.6	0.45
Devprayag (confluence)	25.5	13.4	7.84	3	0	70	11.36	10.4	1.44	160	90.78	84	23.25	6.29	0	0.4	0.64
Devprayag (0 point)	31	17	7.76	3	0	56	9.94	8.8	1.28	103.1	60.11	68	17.64	5.81	0	0.6	0.53
Haridwar AB	31	12.4	7.3	3	0	76	14.2	10.4	1.34	178.6	102.4	84	24.05	5.81	0	0.6	0.53
Haridwar BB	15.2	15.8	7.45	3	0	80	12.78	11.2	2	199.2	112.6	96	27.25	6.77	0	0.6	0.72

(Continues)

TABLE 2 (Continued)

Place	Temperature(^{0}C)		pH	CO_2	CO_3	$BiCO_3$	Cl	DO	BOD	Sp. Conductivity	TDS	Total Hardness	Ca	Mg	PO4	Si	D.O.M
Bijnor AB	14	14.4	7.6	3	0	62	11.36	10.4	2	152.7	87.12	74	17.64	7.27	0	0.7	0.6
Bijnor BB	11.4	15.2	7.5	6	0	86	11.36	7.2	1.28	224.5	129	102	28.06	7.74	0	0.4	0.56
Narora AB	13.4	14.6	7.5	9	0	86	9.94	8.16	1.12	208.6	119.2	94	24.85	7.75	0	0.3	0.56
Narora BB	9.6	14	7.6	5	0	80	9.94	9.92	1.12	209.5	119.6	92	24.05	7.75	0	0.5	0.64
Farrukhbad	10.1	14.3	7.5	5	0	78	11.36	9.44	1.28	211.4	120.3	92	24.85	7.26	0	0.6	0.56
Kannauj	12.8	13.8	7.7	6	0	78	9.94	9.84	1.52	220.5	125.9	98	24.85	8.72	0	0.6	0.6
Bittur	15.1	14.3	8	0	3	125	19.88	9.52	1.68	337.9	192.8	136	35.27	11.62	0	0.7	1.05
Kanpur	16.9	15.2	7.8	0	4	128	29.82	9.68	1.76	344.3	196.5	132	36.07	10.16	0	0.7	0.86
Allahabad	12.8	14.3	8.1	0	8	146	32.66	11.04	2.56	406.7	232.2	148	33.67	15.51	0	0.3	1.61
Vindhychal	13.4	15.2	7.7	0	4	198	42.6	7.2	2.24	501.5	287.1	166	38.48	16.93	0	0.5	1.43

Note: AB = above barrage, BB = below barrag

4.7 | DO (ppm)

DO ranged from 6.2 ppm (Tehri Jheel) to 11.3 ppm (Maneri) in winter and 5.7 ppm (Narora ab and Bijnore ab) to 10.8 ppm (Tehri jheel and Chinyalisaur) in summer. The decline in oxygen was noticed from Bijnore to Kanpur and then improved at Allahabad and Vindhyachal. Almost all the centers depicted good values of dissolved oxygen except Tehri jheel, Bijnore ab, and Narora ab. In a sluggish condition of the river, there is less turbulence and oxygen is not so readily absorbed from the air or oxygen produced by green plants is being used up decaying living things.

4.8 | BOD (ppm)

BOD ranged from 0.3 ppm (Gangotri) to 2.5 ppm at Allahabad in winters and from 0.4 ppm (Gangotri) to 7.6 ppm (Vindhyachal) in summer. Increase in BOD at Vindhyachal may be due to confluence with the Yamuna as the latter has high organic load and is still polluted at Allahabad.

4.9 | Conductivity (µs/cm)

Conductivity ranged from 100.7 us/cm (Tehri zero point) to 501 us/cm (Vindhyachal) in winter and from 75 us/cm (Gangotri) to 513 us/cm (Kanpur) in summer.

4.10 | Hardness (ppm)

Hardness ranged from 48 ppm (Tehri 0 point) to 166 ppm at Vindhyachal in winter and from 36 ppm (Gangotri) to 275 ppm (Vindhyachal) in summer.

4.11 | Ca (ppm)

Ca ranged from 10.4 ppm (Gangotri) to 38.4 ppm (Vindhyachal) in winter and from 4.8 ppm (Bijnore bb) to 22.4 ppm at Tihri Jheel in summer. Calcium concentration was higher in winter compared to summer.

4.12 | Mg (ppm)

Mg was minimum (4.8 ppm) in Tihri zero point (below tehri jheel) and maximum (16.9 ppm) in Vindhyachal, during winter and in summer it ranged from 1. 9 ppm (Chinyalisaur) to 24.7 ppm (Kannauj). Mg increased from Bijnore to Vindhyachal.

4.13 | Dissolved organic matter (ppm)

Dissolved organic matter was the maximum at Allahabad, with 1.6 ppm in summer and 1.8 ppm in winter.

4.14 | Plankton abundance and composition

Plankton was contributed by all the major algal groups of phytoplankton and Zooplankton. Diatoms formed the largest group, greens the second major constituent with large no. of species, while the blue-green algae formed the third, in order of abundance. The phytoplankton has proved to be eutrophic and polymixic in nature (Laxminarayana, 1965).

4.15 | Upper stretch

In the upper stretch, plankton abundance ranged from 30 μl^{-1} Gangotri to 690 μl^{-1} (Tehri jheel). Percentage contribution of Bacillariophyceae ranged from 42% (Tehri jheel) to 100% (most of the centers). Chlorophyceae ranged from 15% (Deoprayag confluence) to 55% (Maneri ab1). Myxophyceae ranged from 10% (Bhagirathi) to 11.6% (Tehri jheel). Other groups were absent in the upper stretch and were present in Tehri Jheel only (Table 3). Plankton composition of Tehri jheel is presented in Figure 1.

4.16 | Middle stretch

In the middle stretch, plankton population ranged from 145 μl^{-1} (Haridwar ab) to 3,280 μl^{-1} (Vindhyachal). Bacillariophyceae ranged from 10.8% (Kannauj) to 93.8%(Haridwar). Chlorophyceae ranged from 6.0% (Haridwar) to 60.8% (Kannauj) and Myxophyceae ranged from 6.8% (Narora bb) to 30.2% (Allahabad.). Euglenaceae was present at Allahabad only (1.1%). Dianophyceae was present at Kannauj, Kanpur ab and bb centeres and recorded as much as 1.7%, 1.4% and 1.1% respectively. Rotifers ranged from 1.5% (Allahabad) to 8.2% (Kanpur) and Crustaceans from 0.4% (Vindhyachal) to 7% (Bijnore ab) as depicted in Table 4. Plankton composition of Kanpur and Vindhyachal is presented in Figures 2 and 3.

TABLE 3 Plankton abundance (μ/l) and composition (%) in the river Ganga (average value summer and winter)

Centers	A	B	C	D	E	F	G	H	I	J	K	L
Bacillariophyceae %	100	90	100	100	42	100	100	100	100	75	90	85
Chlorophyceae %	0	10	0	0	24	0	0	0	0	25	0	15
Myxophyceae %	0	0	0	0	11.6	0	0	0	0	0	10	0
Euglenophyceae %	0	0	0	0	8	0	0	0	0	0	0	0
Dianophyceae %	0	0	0	0	4.3	0	0	0	0	0	0	0
Crustacean %	0	0	0	0	7.3	0	0	0	0	0	0	0
Rotifera %	0	0	0	0	1.4	0	0	0	0	0	0	0
Protozoa %	0	0	0	0	1.4	0	0	0	0	0	0	0
total plankton μ/l	30	100	135	55	690	180	210	45	105	40	50	65

Note: ab = above barrage, bb = below barrage, A- Gangotri, B- ab Maneri 1, C- ab Maneri 2, D- bb Maneri, E- Teheri jhel, F- Teheri zp, G- Chinyalisaur, H- ab Srinager, I- bb Srinager, J- Alaknanda, K- Bhagirathi, L- Deoprayag confluence.

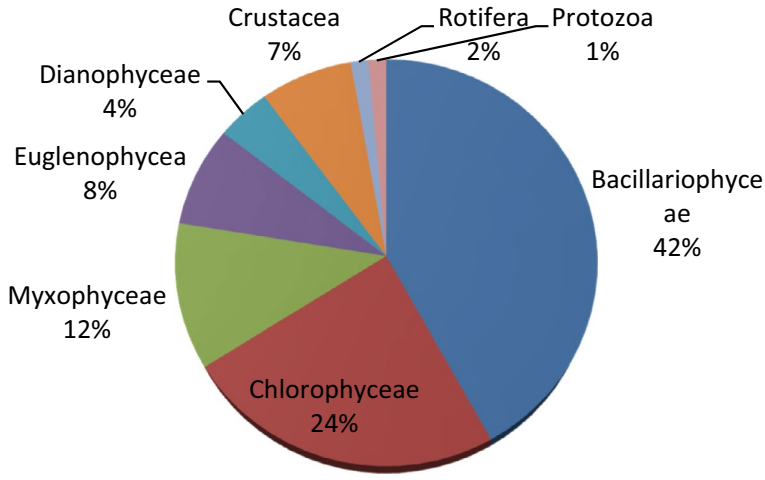

FIGURE 1 Plankton composition of Tehri Jheel-showing impact of stagnation

4.17 | Diversity and palmer pollution Index

In the year of study total 66 genera were recorded (Bacillariophyceae 16, Chlorophyceae 22, Myxophyceae 9, Euglphyceae 3, Dianophyceae. 2, Rotifera 7, Crustacea, Protozoa 2). Near the source diatoms like *Eunotia, Achanthes, Cymbella, Diatoma,* and *Tabellaria* were found to be dominant but as a river moves toward downstream species of *Synedra, Melosira, Nitzchia, and Cyclotella* became abundant. Green algae showed a wide range of adaptability and were abundant in middle stretch places (Cairns et al., 1972). This can be noticed from Figure 4, that palmer pollution index score (summer) ranged from 5 (ab Maneri) to highest 40 in the middle stretch (Kannauj, Bithoor, Kanpur). However, Tehri jheel and Srinagar above barrage centers also revealed above 20 scores in the summer season.

5 | DISCUSSION

Construction of dam affected water quality slightly or much difference in water quality parameters of above and below barrage areas could not be recorded. But this can be noticed that in the above barrage areas, Chlorophyceae contribution was higher, while in below barrage areas Bacillariophyceae contribution was higher. Oligotrophic (fewer nutrients) water has sparse plant plankton, as fertility increases diatoms dominate, and then green algae, finally blue–green algae. These can become very abundant at some seasons, and water tends to become more eutrophic. This situation is similar to the case of plankton abundance at Kannauj, Bithoor, and Kanpur. Plankton composition of Tehri dam and Kanpur above barrage, in the stretch, studied. Ganga water quality started improvement at Vindhyachal by dilution with the Yamuna river water. Climate-induced changes in plankton production are in terms of plankton communities, biodiversity, and species distribution, which had an effect on other aquatic life like fishes. Summer dominant planktonic species were recorded in winter also. *Melosira* species and *Brachionus* species which were recorded previously in middle stretch only are observed in upper stretch also especially in Tehri jheel. In the river Ganga, previously dominant species had declined and species with warm water affinities (e.g., Chlorophycean- Chlorococcales) like *Ankisrodesmus, Scenedesmus, Actinastrum, and Pediastrum* etc. are moving to replace the species. There has been a north word shift in the distribution of many plankton species. Climate warming (50%

TABLE 4 Plankton abundance (μ/l) and composition (%) in the river Ganga (average value summer & winter)

Centers	A	B	C	D	E	F	G	H	I	J	K	L
Bacillariophyceae %	91.8	93.1	36.9	70	59.7	65.9	24.3	10.8	27.7	30.6	47.7	69.2
Chlorophyceae %	8.2	6.9	44.5	16.6	29.8	27.4	60.4	60.8	52	27.9	19.2	19.7
Myxophyceae %	0	0	8.4	10	10.4	6.6	15.2	17	52	29.7	30.3	10.6
Euglenophyceae %	0	0	0	0	0	0	0	0	0	0	1.1	0
Dianophyceae %	0	0	0	0	0	0	0	1.7	1.4	1.1	0	0
Crustacea %	0	0	7.5	0	0	0	0	1.7	0	2	0	0.4
Rotifera %	0	0	2.5	0	0	0	0	7.8	3.1	8.4	1.5	0
Protozoa %	0	0	0	0	0	0	0	0	0	0	0	0
total plankton u/l	185	145	595	150	335	455	1,440	2,940	2035	1715	2,260	3,280

Note: ab = above barrage, bb = below barrage, A- Haridwar ab, B- Haridwar bb, Bijnor ab- C, Bijnor bb- D, E- Narora ab, F- Narora bb, G- Farrukhabad, H- Kannauj, I- Kanpur ab, J- Kanpur bb, K-Allahabad, L-Vindhyachal.

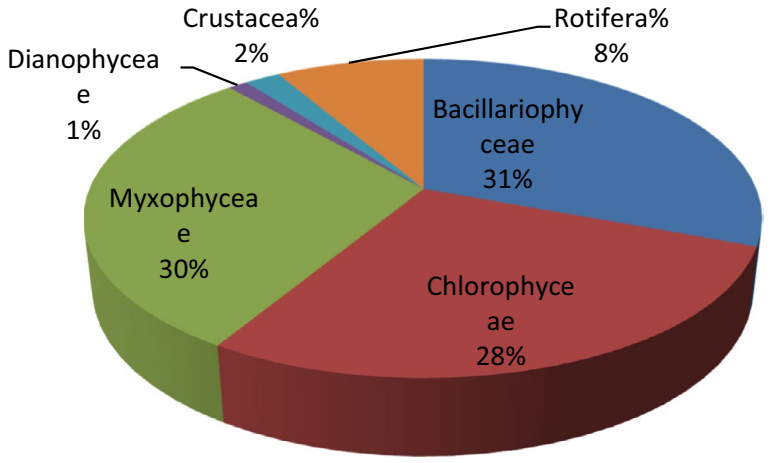

FIGURE 2 Plankton composition at Kanpur showing anthropogenic impact by increased Myxophyceae contribution

natural and 50% anthropogenic) will increase the diversity in cooler regions with changed distribution and abundance. Hence future warming is likely to alter the geographical distribution of primary and secondary producers, affecting aquatic ecosystem functions like O_2 production, carbon utilization, and biogeochemical cycle (Winder & Sommer, 2012).

Some dams are constructed for electricity generation (Maneri and Tehri), and some for irrigation purpose (Haridwar, Narora, Bijnore). Stagnation affected water quality as reflected by the increase in specific conductivity at Maneri lower barrage. During the coursing river Ganga receives city sewage, industrial effluents (Haridwar, Kanpur, Kannauj). and agriculture runoff (Farrukhabad). Ganga water quality is also influenced by adjoining tributaries (Sinha et al., 1997). Specific conductivity increased gradually from Maneri above barrage area and reached on maximum near Kanpur as river receives industrial and domestic effluents near Kanpur (above and below). Furthermore, Allahabad and Vindhyachal centers are affected by anthropogenic influences as both are religious places. Presence of free CO_2 at Haridwar above and below barrage in summer (10 ppm) signifies reduced phytoplankton activity and thereby

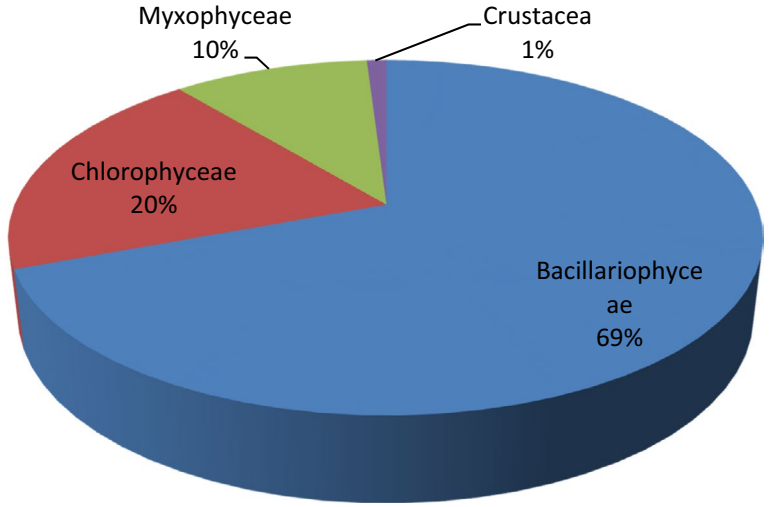

FIGURE 3 Plankton composition at Vindhyachal showing Increase in Bacillariophyceae contribution

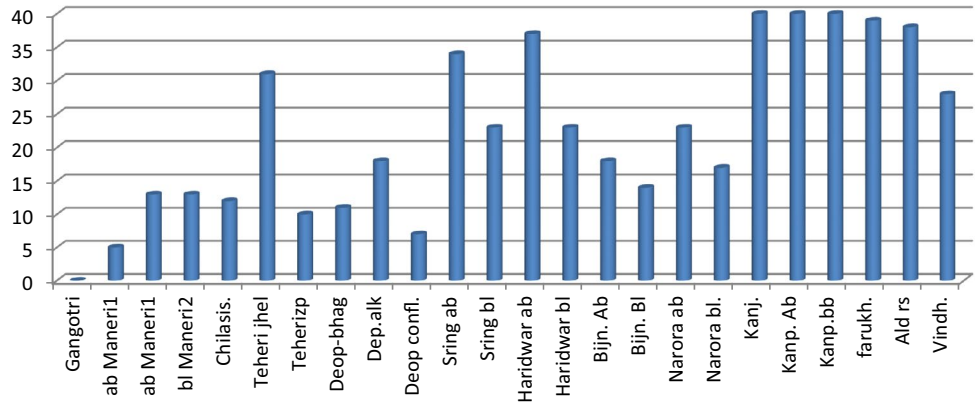

FIGURE 4 Palmer algal genera pollution index showing organic pollution in the middle stretch

reduced CO_2 utilization. Bicarbonate, hardness, and TDS were recorded maximum in Vindhyachal and contributed toward the maximum abundance of plankton also. Chloride was noticed maximum at Kanpur and Myxophycae also, both indicated maximum organic pollution at Kanpur above barrage are in the period of study. A positive Correlation of plankton productivity with total alkalinity and correlation of specific conductivity with Myxophyceae toward pollution was noticed.

6 | CONCLUSION

As river move from source (Gangotri) to plane areas (middle stretch) accumulation or increase of nutrients was noticed which affected the growth of primary producers. In all aquatic ecosystems, phytoplankton growth depends on water temperature, light, and nutrient availability. In our studies also, plankton population was much affected by temperature and nutrients compared to the construction of dams. Changes in the phytoplankton population/composition were evident more concerning physical than to chemical conditions of the river. Changes in water level, transparency, and temperature affected the growth of phytoplankton. In the upper stretch flow was the major driving force for plankton abundance but in lower stretch higher temp and anthropogenic activities played imp role and function as driving force. But the composition was influenced by the construction of dams as stagnation favored the growth of green algae. However, the pattern of release of water affected the accumulation of nutrients in surface water, which had impacted the quality of planktonic fauna and flora. This it can be concluded that the factors that control river biota are current speed, the type of substratum, the temperature, the amount of oxygen, the hardness of the water, and finally the geographical position of the river.

The study also revealed that how water quality deteriorated by the construction of each dam. Therefore, when making policy for a dam on any river it is important to maintain at least one stream of the original water flow. The whole river should not be blocked at any point/place or at least 50% of original water should flow continuously to sustain the biodiversity and quality of water, otherwise after traveling few kilometers through dams, a river will lose its originality.

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