



Water quality of Tehri dam reservoir and contributing rivers in the Himalayan region, India

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Abstract

In nature, the main resources for the availability of water are ponds, lakes, tanks, rivers, and shallow water basins. The water quality available in these water bodies is subjected for continuous change which is due to eutrophication of these water bodies. The water quality often becomes a problem to sustain it. The present investigation was undertaken to study water quality parameters of the Tehri dam reservoir and contributing rivers with an objective to indicate changes in the quality of waters in the contributing rivers and in the reservoir after impoundment and to suggest suitable measures to protect reservoir water quality. Temperature of Bhagirathi river water ranged between 16 and 28 °C while Tehri reservoir water showed it in between 29.5 and 32 °C. DO levels in the reservoir varied between 8.4 and 9.6 mg/L which are similar to river water (8.4–9.4 mg/L). Thus, there is no effect of impounding of river water on the DO which is sufficient for sustaining fisheries and other aquatic lives. Tehri dam reservoir water shows lower turbidity as compared to river water. River Bhagirathi had unique features of the presence of certain radioactive elements and specific groups of coliphages that are likely to maintain self-preservation of the water. DO, COD, BOD, heavy metals, radioactive elements, etc., were within permissible limits, as per categories ‘B’ and ‘C’, specified by CPCB for outdoor bathing and drinking water source with conventional treatment. However, such waters also fulfill categories ‘D’ and ‘E’, designated for propagating wildlife/fish and irrigation/cooling purpose, respectively. Biological parameters of phytoplankton and zooplankton were analyzed to determine the effect of impounding on the flora and fauna of reservoir, wherein plankton diversities in river and reservoir samples were comparable. The Palmer’s Pollution Index ranged between 3 and 5 for phytoplankton while Shannon–Wiener Diversity Index varied from 2 to 2.86 for zooplankton, indicating low to moderate productive waters.

Keywords DO · COD · BOD · Phytoplankton · Zooplankton · Palmer’s Pollution Index · Shannon–Wiener Diversity Index

Introduction

A large number of streams and rivers in India have been impounded to store the water for multipurpose beneficial uses like irrigation, fisheries, power generation, and drinking water supply. The ecosystem services of watercourses such as rivers and lakes directly or indirectly contribute to both human welfare and aquatic ecosystem (Costanza et al. 1997). Rivers also play an important role in the assimilation and transport of domestic and industrial wastewater, which represent constant pollution sources and agricultural runoff, which is temporal and commonly affected by climate (Vega

et al. 1998; Singh et al. 2004). Rivers are highly vulnerable to pollution; therefore, it is important to control water pollution, monitor water quality in river Basin (Simeonov et al. 2003), and interpret the temporal and spatial variations in water quality (Dixon and Chiswell 1996; Singh et al. 2004). Water resources are under pressure and are in danger because of potential pollution and contamination due to rapid industrialization, increasing population pressure, urbanization, modern agricultural activities, and other anthropogenic activities (Hatcher and McGillivray 1979; Huttly 1990; Agarwal et al. 2006; Singh et al. 2007). These activities trigger the rate of sedimentation of the reservoir bed characterized by silt and organic suspended material which initiates the process of eutrophication at a very early stage and show a deterioration of habitat quality. The study on water quality in third world countries shows that the eighty percent diseases are directly related to poor sanitation

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and water quality (Sharma et al. 1995). The maintenance of a healthy aquatic ecosystem is dependent on the physicochemical properties of water and the biological diversity (Ramulu and Benarjee 2013). The physicochemical means are useful in detecting effects of pollution on the water quality but changes in the trophic conditions of water are reflected in the biotic community structure including species pattern, distribution, and diversity (Kaushik and Saksena 1995). It is not possible to understand biological phenomena fully without the knowledge of water chemistry as the limnobiological and limnochemical components of the ecosystem. If we can find some correlations among these numerous parameters, however, the task of periodic monitoring of water quality may be facilitated to a good extent (Tiwari 1992).

The present study was undertaken to study water quality of the Tehri dam reservoir and contributing rivers with an objective to indicate changes in the quality of waters in the contributing rivers to identify impacts on river water quality through change in flow regime and discharge with comparative analysis of before and after the impoundment. The study will be helpful to identify the possible sources of contamination which exist in the catchment of the Tehri dam reservoir and contributing rivers which could negatively affect the water quality in the reservoir as well as downstream of the dam.

Materials and methods

Study area

The large multipurpose Tehri dam reservoir is located at the confluence of the Bhagirathi and Bhilangana rivers near old Tehri town, at about 80 km upstream from Rishikesh in Garhwal district of the northern state of Uttarakhand (Fig. 1). Both these rivers originate in the glaciers of the higher Himalayan region and flow through deep gorges, dense forests, and habitations alike. The source of river Bhagirathi is Gaumukh, while the Bhilangana originates from the Khatling glacier. The catchment area of the project is 7511 km². More than 25% of the area remains covered under perpetual snow.

Sampling and analysis

The water samplings were undertaken during March and June 2013. Sampling locations were identified in Tehri dam reservoir and along the Bhagirathi and Bhilangana rivers (Table 1). The water samples were collected from various locations in Tehri dam reservoir as well as from impoundment between Tehri dam reservoir and Koteshwar reservoir. Water samples from the reservoir were collected from about one foot from the surface of the reservoir. Samples from

river Bhagirathi and tributaries from the catchment and river near Rishikesh were also collected for the investigation. The water samples were analyzed for physico-chemical, bacteriological, and biological parameters, and heavy metals by following the standard methods (APHA 2012).

Results and discussion

Water quality during March 2013

During March 2013, the flow of river Bhagirathi was observed to be low in upstream, and accordingly water in the reservoir was apparently in stagnant condition. During this period, the inflow and outflow rates of water were visibly uniform. The reservoir could have developed monomictic thermal stratification because of sufficiently higher depth. However, analytical data of water samples, collected during March 2013, do not show any remarkable variations in water quality (Table 2) of upstream, downstream, and reservoir.

The upstream water samples showed variations of different parameters within the ranges of: pH 7.5–7.6, EC 102–160 $\mu\text{S}/\text{cm}$, turbidity 3–10 NTU, TDS 61–96 mg/L, total alkalinity 42–56 mg/L, total hardness 40–68 mg/L, sodium 3–5 mg/L, potassium 1–3 mg/L, nitrate 1–2 mg/L, chloride 8–10 mg/L, sulfate 3–20 mg/L, and chemical oxygen demand (COD) 2 mg/L.

The reservoir water showed variations of different parameters within the ranges of: pH 7.3–7.7, EC 102–130 $\mu\text{S}/\text{cm}$, turbidity 3–6 NTU, TDS 61–78 mg/L, total alkalinity 38–54 mg/L, total hardness 50–62 mg/L, sodium 2–3 mg/L, potassium 2–3 mg/L, nitrate 1 mg/L, chloride 8–16 mg/L, sulfate 5–8 mg/L and COD 1–4 mg/L.

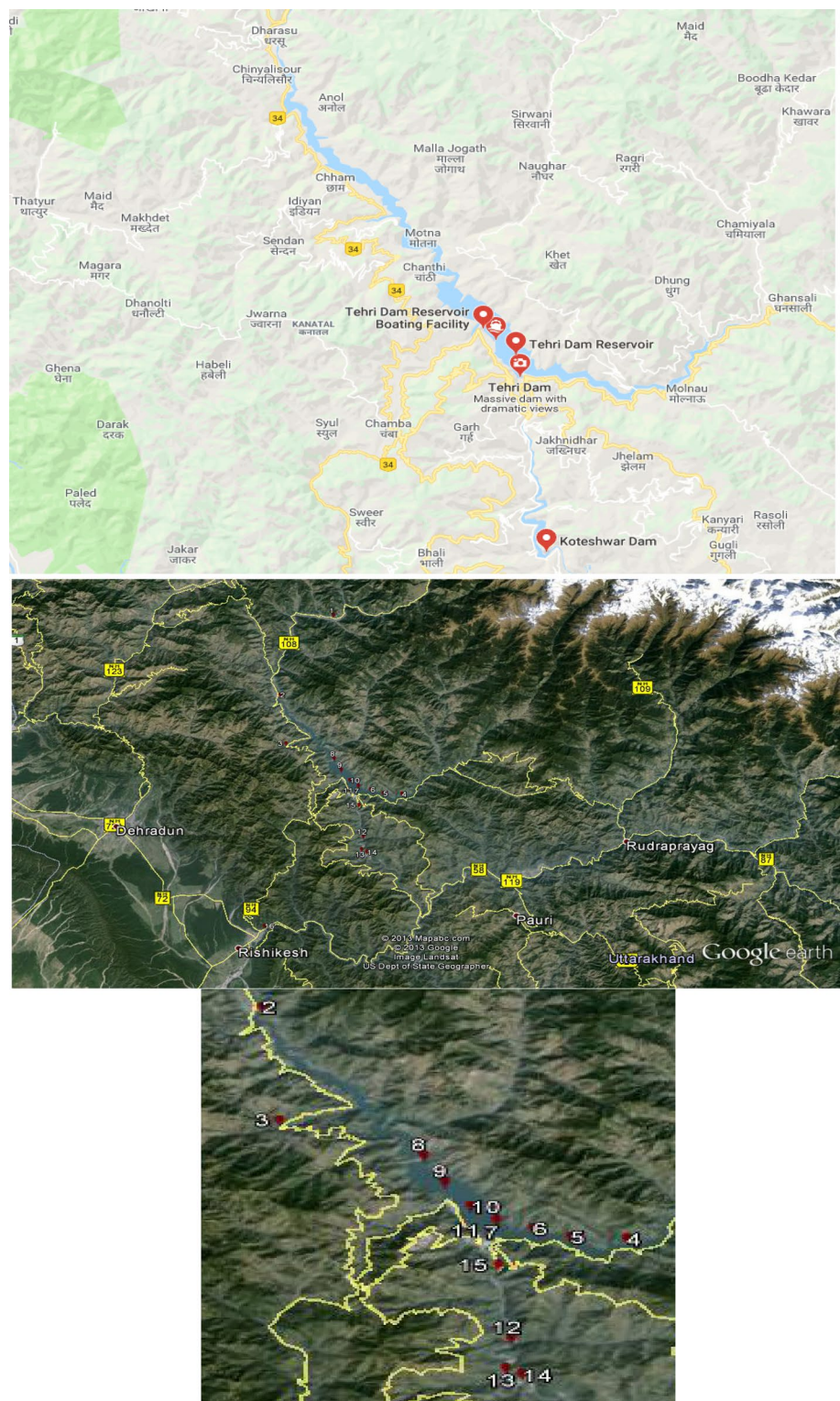
The downstream water samples showed variations of different parameters within the ranges of: pH 7.3–7.7, EC 115–150 $\mu\text{S}/\text{cm}$, turbidity 3–6 NTU, TDS 69–90 mg/L, total alkalinity 40–50 mg/L, total hardness 58–72 mg/L, sodium 3–4 mg/L, potassium 2–3 mg/L, nitrate 1–2 mg/L, chloride 9–11 mg/L and sulfate 7–22 mg/L. In this stretch, COD was recorded between 2 and 5 mg/L.

Since there was no remarkable variations in water qualities at different locations in upstream, downstream, and reservoir impoundment, water characteristics along the stretch of the river appeared to be relatively uniform during March 2013.

Water quality during June 2013

Water samples showed wide variations (Table 2) in certain characteristics among upstream, reservoir, and downstream during June 2013. In view of rainfall in the catchment area prior to sampling, flow of water was enhanced in upstream and downstream of the reservoir. Due to turbulence in flow

Fig. 1 Study area map with sampling locations



of water, water quality parameters like turbidity and pH showed site-specific variations. There was relatively high temperature and low turbidity noted in Tehri dam impoundment waters than those of Koteswar dam water and Bhagirathi river water samples.

The upstream water samples showed measurable variations of different parameters within the ranges of: pH 7.3–8.5, EC 108–122 $\mu\text{S}/\text{cm}$, turbidity 259–281 NTU except 1.6 NTU in location 3, TDS 65–73 mg/L, total alkalinity 36–60 mg/L, total hardness 54–60 mg/L, sodium 2–8 mg/L,

Table 1 Sampling locations' details (March and June 2013)

S. no.	Sampling locations	Latitude (N)	Longitude (E)	Altitude (m)
Upstream				
1	Bhagirathi river in Uttarkashi	30°43'54.0"	78°25'57.6"	1113
2	Bhagirathi river from Chinyalisour town on Uttarkashi road, 35 km before Uttarkashi	30°34'03.2"	78°19'39.8"	1028
3	Tributary of Bhagirathi near Kotigad village, ~40 km from Chamba on Uttarkashi road	30°28'25.6"	78°20'56.5"	915
Reservoir				
4	Bhagirathi river ~10 km upstream of confluence, near Pipaldali bridge	30°22'22.0"	78°33'21.7"	786
5	Bhilangana river ~6 to 6.5 km upstream of confluence	30°22'37.0"	78°31'50.7"	787
6	Bhilangana river ~3 km upstream of confluence downstream of Tipri village	30°22'57.9"	78°30'17.9"	784
7	Confluence of Bhagirathi and Bhilangana river	30°23'23.4"	78°29'02.5"	782
8	Bhagirathi river impoundment near Dobra bridge ~10 km from dam wall	30°26'37.5"	78°26'18.2"	787
9	Bhagirathi river impoundment upstream of Koti colony ~6 to 6.5 km from dam wall	30°25'19.8"	78°26'59.6"	783
10	Bhagirathi river impoundment (downstream) before Koti colony ~3 km from dam wall	30°24'06.4"	78°28'03.4"	781
11	Tehri reservoir near dam wall ~100 m from dam wall	30°22'51.7"	78°28'50.9"	758
Downstream				
12	Zero bridge 5 km downstream of Tehri dam wall	30°21'10.1"	78°29'05.9"	637
13	Water impounded toward Tehri dam, near Bhaso bridge	30°17'22.9"	78°29'17.0"	624
14	Water impounded between Tehri and Koteshwar reservoir	30°16'04.3"	78°29'25.0"	618
15	Downstream of Koteshwar dam (flowing river)	30°15'47.5"	78°30'03.7"	547
16	Ganga river near Ram Jhula, Rishikesh	–	–	–

potassium 1–3 mg/L, nitrate 1–3 mg/L, chloride 7–10 mg/L and sulfate 3–12 mg/L. Further, while DO was observed between 8.4 and 9.4 mg/L, COD was recorded within 4–14 mg/L, which is relatively higher as 20 mg/L at location 2. The total coliform (TC) was found to be relatively higher (3280–4240 CFU/100 mL) whereas the thermotolerant coliform (TTC) counts were found between 560 and 1080 CFU/100 mL.

The reservoir water showed measurable variations within the ranges of: pH 8.7–9.3, EC 117–122 μ S/cm, turbidity 4.3–13.2 NTU, TDS 70–73 mg/L, total alkalinity 48–54 mg/L, total hardness 60–64 mg/L, sodium 3–4 mg/L, potassium 2 mg/L, nitrate 1–2 mg/L, chloride 9–17 mg/L, and sulfate 6–10 mg/L. DO levels were observed between 8.4 and 9.6 mg/L, while COD was recorded between 3 and 13 mg/L. The TC counts were 135–665 CFU/100 mL whereas TTC count was recorded as 35 CFU/100 mL.

The downstream water samples showed measurable variations of different parameters within the ranges of: pH 6.9–8.2, EC 122–135 μ S/cm, turbidity 64–314 NTU, TDS 73–81 mg/L, total alkalinity 46–56 mg/L, total hardness 60–70 mg/L, sodium 3–4 mg/L, potassium 1–2 mg/L, nitrate 2–3 mg/L, chloride 8–15 mg/L, and sulfate 8–12 mg/L. DO and COD were observed between 6.8–9 mg/L and 2–11 mg/L, respectively. The TC and TTC counts were recorded between 460–3900 CFU/100 mL and 15–580 CFU/100 mL, respectively.

In Tehri dam water samples, DO is ranged between 8.4 and 9.6 mg/L, indicating no adverse impact due to

impounding of river water in the Tehri dam reservoir. In the upstream, DO values ranged between 8.4 and 9.4 mg/L due to turbulence, whereas in downstream, DO values declined up to 6.8 mg/L due to less turbulence, although such DO level is sufficient to thrive for fish and other aquatic biota.

Water quality of Tehri dam and associated rivers

To study water quality aspects of Tehri dam reservoir, water samples were collected from Tehri reservoir and from different locations of upstream and downstream of the reservoir. The temporal variations of water quality data with reference to selected parameters for summer seasons of the 3 years (2004, 2011, and 2013) are interpreted hereunder:

TDS

The TDS is a measure of the combined contents of all inorganic and organic substances present in water. The most common chemical constituents are calcium, magnesium, sodium, potassium, phosphates, nitrates, chlorides, and sulfate. When the TDS of the same source was observed apparently in the same ranges, it clearly indicates that water quality composition with respect to individual ions do not vary appreciably. The upstream location reveals that the TDS in water ranged from 101 to 104 mg/L and 61–101 mg/L, respectively, in 2004 and 2011. In the year 2013, the TDS of upstream water ranged from 65 to 73 mg/L. The downstream water during 2004 and 2011 showed that TDS ranged from

Table 2 Physico-chemical and microbiological characteristics of water

Parameters	Range in water quality parameters						Average			SD		
	Upstream		Reservoir		Downstream		March 2013	June 2013	March 2013			
	March 2013	June 2013	March 2013	June 2013	March 2013	June 2013					March 2013	June 2013
pH	7.5–7.6	7.3–8.5	7.3–7.7	8.7–9.3	7.3–7.7	7.3–7.7	7.5	8.35	7.5	8.35	0.1	0.85
Turb.	3–10	1.6–281	3–6	4.3–13.2	3–6	3–6	4.44	77.19	4.44	77.19	1.79	108.54
(EC)	102–160	108–122	102–130	117–122	115–150	115–150	125	121.31	125	121.31	17	5.97
TDS	61–96	65–73	61–78	70–73	69–90	69–90	74.81	72.75	74.81	72.75	10.06	3.56
T. hardness as CaCO ₃	40–68	54–60	50–62	60–64	58–72	58–72	59.25	61.75	59.25	61.75	8.13	3.99
Ca hardness as CaCO ₃	26–46	34–38	32–46	30–44	44–48	44–48	39.5	40.62	39.5	40.62	6.83	5.30
Mg hardness as CaCO ₃	14–22	16–22	12–26	18–32	14–26	14–26	19.75	21.12	19.75	21.12	4.78	3.86
Sodium	3–5	2–8	2–3	3–4	3–4	3–4	2.81	3.56	2.81	3.56	0.91	1.36
Potassium	1–3	1–3	2–3	2	2–3	2–3	2.13	1.69	2.13	1.69	0.5	0.60
T. alkalinity as CaCO ₃	42–56	36–60	38–54	48–54	40–50	40–50	45.75	50	45.75	50	5.74	5.06
Chloride	8–10	7–10	8–16	9–17	9–11	9–11	10.06	10.69	10.06	10.69	2.02	2.47
Fluoride	0.1–0.4	0.2	0.2	0.4	0.2–0.3	0.2–0.3	0.2	0.39	0.2	0.39	0.06	0.12
Sulfate	3–20	3–12	5–8	6–10	7–22	7–22	8.81	8.5	8.81	8.5	5.20	2.37
Nitrate	1–2	1–3	1	1–2	1–2	1–2	1.31	1.87	1.31	1.87	0.48	0.88
COD	2	4–20	1–4	3–13	2–5	2–5	3.12	8.69	3.12	8.69	1.55	4.92
Phosphate	–	0.17–0.28	–	0.02–0.13	–	–	–	0.11	–	0.11	–	0.07
Temp.	–	16–28	–	29.5–32	–	–	–	26	–	26	–	5.54
DO	–	8.4–9.4	–	8.4–9.6	–	–	–	8.49	–	8.49	–	0.93
TC CFU/100 mL	–	3280–4240	–	135–665	–	–	–	1160	–	1160	–	1481
TTC CFU/100 mL	–	560–1080	–	35	–	–	–	333	–	333	–	387

Unless mentioned, all values are expressed in mg/L; except pH, turbidity (NTU), EC electrical conductivity ($\mu\text{S}/\text{cm}$) and temp ($^{\circ}\text{C}$); CFU: TDS total dissolved solids; COD chemical oxygen demand; DO dissolved oxygen colony-forming unit; TC total coliforms; TTC thermotolerant coliforms

100 to 174 mg/L and 65–218 mg/L, respectively, compared to 73–81 mg/L during the year 2013. The TDS of Tehri dam reservoir ranged from 60 to 104 mg/L and 78 to 89.6 mg/L, respectively, in 2004 (prior to impoundment) and 2011, as compared to 70–73 mg/L during the year 2013. It was observed that TDS variation is negligible and overall water quality changes, during the span of the 10 years, are meager. It may be inferred that mass of water in dam is continuously replenished by river flow, thereby without affecting much the quality variation in reservoir water during different seasons.

DO

DO is an important parameter in defining the life supporting ability of water. Water quality data at upstream of Tehri reservoir reveal that the DO ranged from 12 to 12.2 mg/L and 9.6 to 10.7 mg/L, respectively, in 2004 and 2011. In the year 2013, DO ranged between 8.4 and 9.2 mg/L. Water quality at downstream of Tehri reservoir reveals that DO ranged from 15.9 to 20 mg/L and 6.4 to 10.9 mg/L, respectively, in 2004 and 2011, while during 2013, DO ranged from 6.8 to 9 mg/L. Tehri reservoir showed that the DO ranged from 13.5 to 17.7 mg/L and 6.4 to 10.7 mg/L, during 2004 (prior to impoundment) and 2011, whereas DO is in the range of 8.4–9.2 mg/L in 2013.

The above data from upstream, downstream, and Tehri reservoir impoundment indicate that DO was observed to be comparatively supersaturated in most occasions during 2004 (prior to impoundment), while in recent years (2011 and 2013), DO values (6.4–10.7 mg/L) were comparable and often supersaturated. After considering seasonal events, such as changes in lake water levels, volume of inflows and outflows, and presence of ice cover, etc., which also cause natural variation in DO concentrations, the DO levels never decreased below 6 mg/L during the last 10 years that indicate healthy state to thrive fish and other aquatic organisms. Accordingly, the water quality of this region is considered to be good.

COD

While upstream water quality data showed 5 mg/L of COD in 2004, it ranged between 1.6 and 8 mg/L in 2011 and 4 and 14 mg/L in 2013. However, it exceeded up to 20 mg/L in one location (6% of the samples). In the downstream, COD values ranged from 2 to 6 mg/L and 1.6 to 12 mg/L, respectively, in 2004 and 2011. In the present study, the values were observed in between 2 and 11 mg/L. Tehri dam location showed 5–7 mg/L and 10.4–18.4 mg/L COD in 2004 (prior to impoundment) and 2011, respectively. In the present study, COD value varied from 3 to 13 mg/L. Comparisons of COD values show that it never increased beyond 14 mg/L indicating that water is not polluted by any organic/

inorganic pollutants and apparently such condition is considered to be unpolluted.

Bacteriological quality

The variation in bacteriological water quality at upstream and downstream of the Tehri dam reservoir was evaluated using indicator bacteria TC and TTC CSIR-NEERI (2004, 2011, and 2013). In the upstream water, the TC count was 3280–4240 CFU/100 mL in 2013 during summer; while the variations among all the sampling points in 2004 and 2011 were 0–1000 and 300–3750 CFU/100 mL. However, the TTC count was maximum (160–3660 CFU/100 mL) in 2011, followed by 560–1080 CFU/100 mL in 2013 and 0–320 CFU/100 mL in 2004. In the downstream water, the TC and TTC counts were observed in 2011, i.e., 20–7000 CFU/100 mL and 15–6090 CFU/100 mL, respectively. In 2004, the TC and TTC counts were 1000–2200 CFU/100 mL and 600–1000 CFU/100 mL, respectively. In 2013, the TC counts were 460–3900 CFU/100 mL while TTC counts were in the lower range varying from 15 to 580 CFU/100 mL. The reservoir water quality showed wide variations with respect to different samplings undertaken in 2004, 2011, and 2013. In 2004, the TC and TTC counts were in the range of 800–1700 CFU/100 mL and 300–500 CFU/100 mL, respectively. The maximum TC and TTC load was in 2011, i.e., 20–18,000 CFU/100 mL and 10–10,500 CFU/100 mL, respectively. During 2013 summer sampling, the TC and TTC counts were 135–665 CFU/100 mL and 0–35 CFU/100 mL, respectively. The bacterial counts in the water bodies are attributed to anthropogenic activities nearby water bodies and inflow of domestic wastewater from the villages located in the catchment area in the rivers and reservoir.

It is evidenced that microbiological contamination in concerned water bodies has been enhanced gradually during the last 10 years. Rapidly increasing population, rising standards of living, and exponential growth of industrialization and urbanization have exposed the water resources, in general, and rivers, in particular, to various forms of degradation. In a study conducted by Semwal and Akolkar (2006), the variation in the water quality along the stretches of the course of these rivers to the continuous use of clean water for domestic purposes and runoffs from the places of open defaecation on the banks has been documented in detail. According to Agarwal and Rajwar (2010), the luxurious growth of bacterial population during summer and monsoon months is the outcome at the influx of washed organic matter in the reservoir from the surrounding forest areas. It is natural that the incoming nutrient load finds its way first to the surface, thereby encouraging bacterial proliferation during monsoon.

Heavy metals

Heavy metal analysis of water samples of reservoir was carried for arsenic, boron, cadmium, cobalt, chromium, copper, iron, manganese, nickel, lead, and zinc. Iron, manganese, and zinc were found in most of the water samples, while other heavy metals were either not detected or were present at negligible levels in water samples (Table 3). This is attributed mainly to the absence of industries in the catchment area and the non-release of industrial effluents in the catchment of rivers and reservoirs. The relatively higher concentration (up to 5.47 mg/L) of iron in water sample from Bhagirathi river near Uttarkashi city might be attributed to high turbidity of water containing iron and suspended particles due to anthropogenic activities in nearby city.

Biological parameters

Studies on biological aspects of an ecosystem are important in view of the conservation of environmental quality

and safety of natural flora and fauna. Assessing the impact of environmental stress on community structure serves as an efficient tool in management of a particular ecosystem. The biodiversity of phytoplankton and zooplankton was monitored during June 2013 by following standard protocol (APHA 2012).

Phytoplankton

The density, taxonomic composition, diversity indices, and list of genera were assessed and estimated (Table 4). Good levels of diversity of phytoplankton were observed in the reservoir and river waters indicating no remarkable effect of impounding of river water by Tehri dam to the aquatic ecosystem. In general, phytoplankton density is moderate in water samples. This may be attributed to excessive water current and turbidity of river waters. A similar trend was recorded during earlier investigations in the same area (NEERI 2004 and 2011). Phytoplankton density was observed between 1120 and 2408/mL. Five groups,

Table 3 Heavy metal content in water samples

Heavy metals	Concentration range							
	Upstream		Reservoir		Downstream		Average \pm SD	
	March	June	March	June	March	June	March	June
As	BDL–0.005	BDL–0.009	BDL–0.02	0.002–0.003	0.001–0.003	0.004–0.007	0.004 \pm 0.006	0.004 \pm 0.002
B	BDL–0.01	BDL–0.0	BDL–0.006	BDL–0.005	BDL–0.032	BDL–0.021	0.013 \pm 0.010	0.008 \pm 0.007
Cd	BDL–0.0	BDL–0.0	BDL–0.0	BDL–0.0	BDL–0.001	BDL–0.0	0.001 \pm 0	0.00 \pm 0.00
Co	BDL–0.001	BDL–0.009	BDL–0.0	BDL–0.0	BDL–0.0	BDL–0.0	0.001 \pm 0	0.004 \pm 0.003
Cr	0.002–0.01	BDL–0.005	BDL–0.04	BDL–0.002	BDL–0.003	0.001–0.002	0.006 \pm 0.010	0.003 \pm 0.001
Cu	BDL–0.009	BDL–0.016	BDL–0.006	0.001–0.004	BDL–0.005	0.001–0.004	0.005 \pm 0.003	0.005 \pm 0.004
Fe	0.04–3.68	0.006–5.47	0.001–0.52	0.084–0.4	0.033–0.53	0.004–0.005	0.395 \pm 0.889	1.23 \pm 1.73
Mn	0.001–0.07	0.001–0.4	BDL–0.019	0.024–0.13	0.002–0.02	1.08–2.31	0.013 \pm 0.017	0.088 \pm 0.107
Ni	BDL–0.004	BDL–0.013	BDL–0.0	0.001–0.003	BDL–0.001	0.051–0.11	0.002 \pm 0.001	0.003 \pm 0.003
Pb	BDL–0.004	BDL–0.028	BDL–0.003	BDL–0.001	BDL–0.002	0.002–0.005	0.003 \pm 0.001	0.008 \pm 0.010
Zn	0.02–0.07	BDL–0.057	0.06	0.013–0.042	BDL–0.066	0.015–0.035	0.032 \pm 0.035	0.030 \pm 0.014

BDL below detection limit (<0.0001 mg/L), all values are expressed in mg/L

Table 4 Density, diversity, and composition of phytoplankton in water samples (June 2013)

Variables	Data range			
	Upstream	Reservoir	Downstream	Average \pm SD
Density (no./mL)	0–1971	1646–2408	0–1534	1508 \pm 828
SWI	0–3.41	3.35–3.42	0–3.46	2.72 \pm 1.35
PPI	0–5	3–5	0–5	3 \pm 2
Chlorophyceae (%)	0–39	32–41	0–35	29 \pm 15
Cyanophyceae (%)	0–21	22–35	0–52	27 \pm 16
Bacillariophyceae (%)	0–25	15–28	0–19	15 \pm 9
Dianophyceae (%)	0–6	6–9	0–4	5 \pm 3
Cryptophyceae (%)	0–9	7–11	0–6	6 \pm 3

comprising 24 genera, were identified. Chlorophyceae was most dominant followed by Cyanophyceae. The highest density of 2408/mL and lowest density of 1120/mL were observed at samples 5 and 12, respectively. SWI values varied from 3.12 to 3.46 indicating good levels of diversity. Water temperature and nutrients are key factors for increasing the phytoplankton abundance and diversity (Nowrouzi and Valavi 2011). High species diversity, richness, and moderate to high individual counts are characteristics of undisturbed environments. PPI values varied from 3 to 5 indicating the absence of organic pollution. In samples 1, 2, and 16, phytoplankton could not be observed due to high turbidity and flow of water.

Zooplankton

Enumeration of zooplankton was undertaken by analyzing the samples for recording density, taxonomic compositions, diversity indices, and list of genera (Tables 5, 6). In general, zooplankton productivity was moderate due to water velocity, turbidity, and availability of natural feed. A similar trend

was recorded during earlier investigations in the same area (NEERI 2004 and 2011). Zooplankton density was observed between 1267 (sample 14) and 14,867/m³ (sample 4). Three groups, comprising of ten genera and one larva, were identified. Rotifera was the most dominant group followed by Copepoda. The rotifer genera are widely distributed in the world (Segers 2007; Ozge et al. 2010). The abundance of copepods may be related to water quantity, water movement, food availability, suitable environmental conditions for their growth and development. They are found in almost all water bodies and play an important role in ecological pyramids serving as food for fishes (Patel et al. 2013). Increases in zooplankton population summer might also be due to high photosynthetic activities in aquatic ecosystem. Shannon–Wiener Diversity Index (SWI) values varied from 2.00 to 2.86 indicating moderate levels of diversity. In samples 1, 2, and 16, zooplankton could not be observed due to high turbidity and flow of water.

Water quality monitoring plan

Anticipating any aberration of water quality parameters due to increased urbanization within the Tehri dam catchment area as well as alteration in natural phenomena, there is a need to monitor certain water characteristics at regular intervals. Accordingly, a water quality monitoring plan has been recommended (Table 7).

Table 5 Density, diversity, and composition of zooplankton in water samples (June 2013)

Variables	Data range			
	Upstream	Reservoir	Downstream	Average ± SD
Density (no./m ³)	0–3000	1600–14,867	0–2133	3350 ± 3965
SWI	0–2	2.13–2.86	0–2.51	1.98 ± 1.01
Rotifera (%)	0–51	35–59	0–53	37 ± 20
Cladocera (%)	0–7	13–29	0–22	13 ± 9
Copepoda (%)	0–42	25–50	0–46	31 ± 17

Table 6 List of plankton identified in water samples (June 2013)

Plankton group	Genera
Phytoplankton	
Chlorophyceae	<i>Ulothrix</i> sp.; <i>Chlorococcum</i> sp.; <i>Gloeocystis</i> sp.; <i>Cosmarium</i> sp.; <i>Ankistrodesmus</i> sp.; <i>Nephrocystium</i> sp.; <i>Pseudotetraspora</i> sp.; <i>Coelastrum</i> sp.; <i>Staurastrum</i> sp.
Cyanophyceae	<i>Microcystis</i> sp.; <i>Gloeocapsa</i> sp.; <i>Chroococcus</i> sp.; <i>Aphanocapsa</i> sp.
Bacillariophyceae	<i>Fragilaria</i> sp.; <i>Tabellaria</i> sp.; <i>Synedra</i> sp.; <i>Achnanthes</i> sp.; <i>Surirella</i> sp.; <i>Navicula</i> sp.; <i>Melosira</i> sp.; <i>Caloneis</i> sp.; <i>Cymbella</i> sp.
Dianophyceae	<i>Gymnodinium</i> sp.
Cryptophyceae	<i>Cryptomonas</i> sp.
Zooplankton	
Rotifera	<i>Keratella</i> sp.; <i>Philodina</i> sp.; <i>Filinia</i> sp.; <i>Asplanchna</i> sp.; <i>Euchlanis</i> sp.; <i>Trichocerca</i> sp.
Cladocera	<i>Moina</i> sp.; <i>Bosmina</i> sp.
Copepoda	<i>Cyclops</i> sp.; <i>Diaptomus</i> sp.; Nauplius larva

Table 7 Water quality monitoring plan

Hazardous event	Parameter (to monitor during at 3 years interval)	Existing status
Thermal stratification	Temperature at different depths	Temperature of reservoir ranges between 23.2 and 29.8 °C in summer and 16.5 and 18.2 °C in winter indicates minor thermal stratification
Soil erosion	Sediment analysis, TSS	Implemented catchment area treatment to check soil erosion and sediment build up in the reservoir
Lack of DO in hypolimnic layer may cause Fe and Mn to move from sediment to water column	DO, Fe, and Mn	Three-dimensional circulation prevails at all times because of temperature gradient. No possibility of permanent stagnation in reservoir
Flow of raw wastewater from surrounding settlements	Nitrates, phosphates, BOD, COD	COD values lie below 14 mg/L. This indicates that there is no remarkable impact of anthropogenic activities
Agricultural runoff	Nitrates, phosphates, pesticides	Implemented a catchment area treatment to check surface runoff and chemical build up in the reservoir
Ganga river water and sediments are known to have higher levels of radioactive elements	Radioactive uranium, thorium, potassium in water and sediment	The uniqueness of river Bhagirathi/Ganga lies in the sediment which is more radioactive. Such elements, at low dose, may have bactericidal property and can harbor and cause proliferation of coliphages which reduce and ultimately eliminate coliforms from the overlying water column
High concentration of nitrogen and phosphorus may cause growth of algae particularly cyanobacteria	Nitrates, phosphates, BOD, phytoplankton	Due to horizontal and vertical circulation in the reservoir, there are low concentrations of total nitrogen and phosphorus. The present condition does not alarm algal bloom
Lack of DO and low temperatures may cause negative impact on flora and fauna in the reservoir	DO, phytoplankton, zooplankton, Benthos Palmer Index, Shannon–Wiener Index	DO found to be greater than 6.8 mg/L. This ensures that self-purification capacity of River Bhagirathi is maintained. Further, the values of Palmer Index and Shannon–Wiener Index indicate low pollution and high diversity in reservoir
High load of fecal organisms may cause negative impact to humans	TC, FC, coliphages	Presence of bacteriophages in the river and reservoir is responsible for predating coliforms

Conclusion

Water quality of Tehri dam reservoir and contributing rivers in Himalayan region reveals that so far, there is no remarkable impact of anthropogenic activities, such as domestic, industrial or agricultural discharges, on the water quality of Tehri dam reservoir or River Bhagirathi. As a healthy aquatic ecosystem is dependent on the physico-chemical properties of water and the biological diversity, there is a need to maintain the water quality by adopting appropriate measures. Based on the water quality assessment of Tehri dam reservoir as well as the downstream and upstream of the reservoir, the water bodies can be classified under Classes

B and C. Water quality standards in India for “Designated Best Use and Guidelines for Irrigation Water Quality” are given in “Appendix”.

Appendix

See Table 8.

Table 8 CPCB classification for designated best use

SI	Parameter and unit	A	B	C	D	E
1	Taste	None	–	–	–	–
2	Odor	Unobj	–	–	–	–
3	Color (True) (Hazen unit)	10	300	300	–	–
4	pH (max) (min: 6.5)	8.5	8.5	8.5	8.5	8.5
5	Conductivity (25 °C) $\mu\text{S}/\text{cm}$	–	–	–	1000	2250
6	DO (mg/L) (minimum)	6	5	4	4	–
7	BOD (3 d, 27 °C) (mg/L)	2	3	3	–	–
8	Total coliforms (MPN/100 mL)	50	500	5000	–	–
9	TDS (mg/L)	500	–	1500	–	2100
10	Oil and grease (mg/L)	–	–	0.1	0.1	–
11	Mineral oil (mg/L)	0.01	–	–	–	–
12	Total hardness (mg/L as CaCO_3)	300	–	–	–	–
13	Chlorides (mg/L as Cl)	250	–	600	–	600
14	Sulfates (mg/L as SO_4)	400	–	400	–	1000
15	Nitrates (mg/L as NO_3)	20	–	50	–	–
16	Free CO_2 (mg/L)	–	–	–	6	–
17	Free NH_3 (mg/L as N)	–	–	–	1.2	–
18	Fluorides (mg/L as F)	1.5	1.5	1.5	–	–
19	Calcium (mg/L)	80.10	–	–	–	–
20	Magnesium (mg L)	24.28	–	–	–	–
21	Copper (mg/L)	1.5	–	–	–	–
22	Iron (mg/L)	0.3	–	50	–	–
23	Manganese (mg/L)	0.5	–	–	–	–

Class A—drinking water without conventional treatment but after disinfection. Class B—water for outdoor bathing. Class C—drinking water with conventional treatment followed by disinfection. Class D—water for fish culture and wildlife propagation. Class E—water for irrigation, industrial cooling, and controlled waste disposal

Unobj unobjectionable

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