Water quality assessment of sacred Himalayan rivers of Uttaranchal

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Mass bathing in sacred water bodies is an age-old ritual in India. Organized outdoor bathing is an important *in situ* utilization of water bodies, which demands water quality requirements for drinking as well as bathing purposes. Apart from this, the Himalayan rivers have a great potential for hydroelectric power generation due to altitudinal variations. The present study deals with water quality assessment of rivers in Uttaranchal, in view of their religious importance and ecological sustainability. Based on bio-monitoring assessment, biological water quality criteria have been evolved for rivers of Uttaranchal, indicating various beneficial uses of water quality and their respective levels of characteristics. Out of 60 stretches of 19 rivers, 41 stretches indicated clean water quality of Class 'A', five stretches were slightly polluted (class 'B'), six were moderately polluted (class 'C'), one stretch was highly polluted (class 'D') and there were altogether seven severely polluted (class 'E') stretches. The physico-chemical water quality in most of the rivers of Uttaranchal remained unchanged except of total dissolved solids, which ranged from 90.23 to 121.33 mg/l, total suspended solids varying from 126.5 to 236.5 mg/l and total alkalinity of 37.0 to 96.0 mg/l. Religious places have contributed significant levels of sulphates to water quality (1.66 to 20.0 mg/l). Traces of iron, zinc and copper metals in water and sediments have been observed in clean water quality stretches. Agricultural practices on the river bank may have considerable impact on contribution of pesticide residues such as total Endosulfan, Dieldrin and DDT. Open defecation is the most common activity on river banks, which has significant contribution towards the aesthetic water quality of rivers.

Keywords: Benthic macro-invertebrates, bio-assessment, bio-monitoring, diversity score, saprobic score.

THE Himalayan rivers have an important place in Indian culture and tradition. They are the lifeline of majority of population in cities, towns and villages and are considered sacred. During festivals, people take a holy dip in these rivers. Mass bathing in water bodies is an age-old ritual in India and an important in site utilization of water bodies, which demands water quality equally suitable to that required for drinking purposes. During bathing, the river water is also used for drinking (Aachman), irrespective of its water quality. The Water Prevention and Control of Pollution Act, 1974, is basically aimed to support the water quality of various designated-best-uses of water bodies. These beneficial uses of water bodies have been identified in terms of primary water quality criteria using a few physico-chemical parameters[1]. A considerable percentage of pilgrims visiting holy places for bathing, carry skin and other communicable diseases. Some of these pilgrims settle nearby river banks. Their daily routine near the water course becomes a constant source of contamination of the water bodies. The organic matter contribution during mass bathing is normally significant, as revealed by earlier studies. Apart from washing with detergents, pilgrims offer milk, curd, ghee, flowers, coins, idols, ashes of departed ones, body hairs and other religious materials into the water. Many a times such offerings are brought in polythene carry bags. In the absence of a proper disposable system, the polythene bags are dropped in the water or near the sides of the water body. These polythene bags, and other non-biodegradable materials remain either floating on the water surface or cover the river bed substratum, which is hazardous to aquatic life[1–9]. To restore and maintain the bathing water quality of rivers, critical parameters of total coliforms was selected as an indicator of aesthetic water quality of freshwater bodies such as: (a) 50 MPN/100 ml for drinking water sources after disinfection, (b) 500 MPN/100 ml for outdoor organized bathing and (c) 5000 MPN/100 ml for drinking water source with conventional treatment followed by disinfection. A series of investigations have been undertaken on deterioration of water quality at mass bathing places like Haridwar, Allahabad and Ganga Sagar for Kumbh and Ardh Kumbh respectively, during the years 1980, 1982, 1983 and 1986 (ref. 10). Similar studies were conducted in a closed aquatic system at Brahm Sarovar and Sannihit Sarovar, Kurukshetra during the solar eclipse on 23 September 1987 and on 11 August 1999 between 16.50 and 18.48 h (ref. 11). Pushkar Lake is a famous pilgrim centre in Ajmer. Studies have indicated that alteration in substratum of river bed due to mass bathing activities, has a significant influence on water quality in terms of change in biological composition of benthic macro-invertebrates inhabiting the rivers[12]. Water quality monitoring during pre-Simhastha Kumbh period as well as during mass bathing period in May 2004

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Table 1. Ecological assessment of various rivers in Uttaranchal

Range of saprobic score	Range of diversity score	Biological water quality	Biological water quality class	Indicator colour
7 and more	0.2–1.0	Clean	A	Blue
6–7	0.5–1.0	Slight pollution	B	Light blue
3–6	0.3–0.9	Moderate pollution	C	Green
2–5	0.4 and less	Heavy pollution	D	Orange
0–2	0.0–0.2	Severe pollution	E	Red

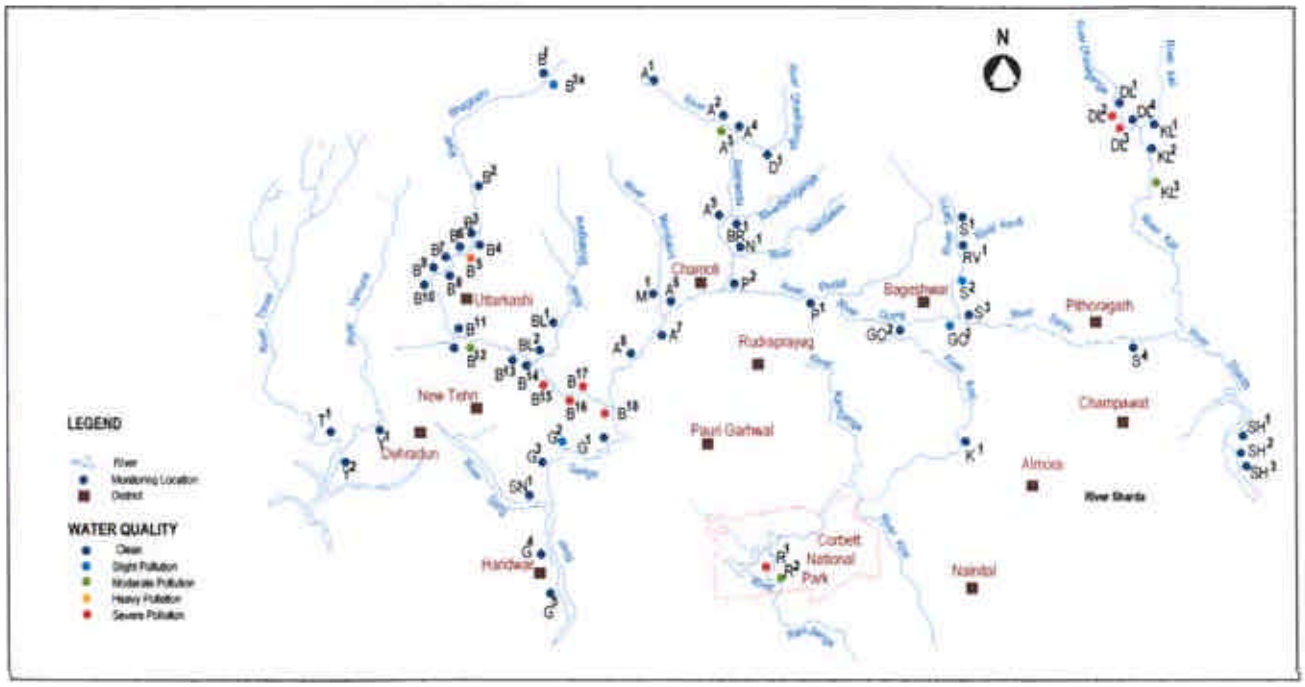

Figure 1. Map depicting sampling locations and biological water quality of rivers in Uttaranchal (2004–05).

Table 2. Average substratum composition of various rivers

Substratum type	Range of average % substratum composition
Boulder	0.0–63.3
Cobble	1.0–80.0
Pebble	5.0–37.0
Gravel	0.0–25.0
Sand	5.0–80.33
Silt	0.0–5.0
Clay	0.0–35.0
Detritus	0.0–1.25

at Ujjain have indicated elevated levels of total coliform and faecal coliform as well as BOD. The biological water quality depicted moderate to heavy pollution in various stretches of River Kshipra at Ujjain. Biological assessment relies on the fact that pollution of water bodies will cause change in physical and chemical environment of the water and that these changes will disrupt the ecological balance of the system. Thus, by measuring the extent of ecological upset, the severity of pollution can be estimated[2]. The Central Pollution Control Board (CPCB), Delhi established that the inclusion of bio-monitoring network, apart from physico-chemical parameters will enhance the water quality evaluation in a cost-effective manner. The benthic macro-invertebrates have been considered as the most suitable biological parameters for water quality evaluation. The present study deals with the ecological assessment of water quality of rivers in Uttaranchal in terms of its religious importance.

Table 3. Clean water stretches (class 'A') of rivers and tributaries in Uttaranchal

Rivers/tributaries	Location of river stretches	Taxa/families of benthic macro-invertebrates commonly collected from water bodies
Bhagirathi	Gangotri, District Uttarkashi	Ephemeroptera: Heptageniidae, Ephemerellidae, Pothaminthidae, Ephemeridae, Siphonuridae, Caenidae, Baetidae
	Downstream Lohari Nag-pala Hydroelectric Project	
	U/s Maneri Bhali, Phase-I, Near Jhulapul	
	Inlet Maneri Bhali, Phase-I, Keshavpuram	
	Outlet Maneri Bhali, Phase-I	Plecoptera: Perlidae, Nemouridae, Leuctridae, Capniidae, Taeniopterygidae, Perlodidae, Cryptoperla
	Inlet Maneri Bhali, Phase-II	
	2 km downstream Maneri Bhali, Phase II	
	Upstream Uttarkashi	Trichoptera: Hydropsychidae, Leptoceridae, Georidae, Sericostomatidae, Rhyacophilidae, Polycentropodidae, Philopotamidae, Brachycentridae, Hydroptilidae.
	Downstream Uttarkashi	
	Upstream Nagon Gadhera, Dharasu	
	Upstream Old Tehri, Malideval	
Nagon Gadhera	Downstream, Dharasu	Odonata: Libellulidae, Euphaeidae, Gomphidae
Bhilangana	Before confluence to River Bhagirathi at Kandal village (Old Tehri)	
Alaknanda	Badrinath, Second Hydel Project, Bamni 250 m upstream Vishnuprayag Barrage, access on NH-58	Hemiptera: Aphelocheiridae
	In front of Switch Yard, Downstream Power House of Vishnuprayag Hydroelectric Project	Coleoptera: Psephenidae, Dytiscidae, Gyrinidae, Hydrophilidae
	Birahi, after confluence of Birahiganga	
	Rudraprayag, opposite temple, upstream of sangam	Planaria: Planariidae
	Rudraprayag, after confluence to River, Mandakini, GMVN Guest House	
	Kaliyasaur, Near Dhari Devi Temple	Diptera: Blepharoceridae, Simulidae, Tipulidae, Chironomidae, Tabanidae
Dhauliganga	Tapovan village, Vishnugad barrage site District Joshimath	
Birahiganga	Birahi, before confluence to River Alaknanda, 6 km from Chamoli	Mollusca/Viviparidae, Lymnaeidae
Pindar	Meeng, near bridge	Megaloptera/Cordyladidae
	Karanprayag, before confluence to River Alaknanda	
Nandakini	Nandprayag, near bridge, before confluence to River Alaknanda	Hirudinea/Erpobdellidae, Hirudidae, Glossiphonidae
Mandakini	Before confluence to River Alaknanda 2 km from Tilwara, upstream Rudraprayag	Polychaeta/Gordiidae
Kosi	Jorasi, District Almora	
Dhauliganga	Baity village, 7 km upstream Dhauliganga barrage, District Pithoragarh	Oligochaeta/Oligichaetes
	Downstream of Dhauliganga barrage before confluence to River Kali, near Tawaghat	
Kali	2 km upstream Tawaghat on NH-29, 13 km from NHPC Guest House.	
	Upstream Power House, after confluence to River Dhauliganga at Tawaghat Distt. Pithoragarh	
Saryu	3 km from Loharkhet Micro Hydel Project near Tapt-Kund, Saling Udiyar	
	Maziakhet, 3 km from KMVN, downstream of Bageshwar	
	Ghat, before confluence to River Kali, District Pithoragarh	
Gomti	Kailasu, upstream Bageshwar before confluence to River Saryu	
Yamuna	Juddo village, near Panchayat Bhawan	
	Lakhwar Dam downstream Dak Pathar	
Ganga	Kaudiyala, Near Rafting Club	
	Downstream Veer Bhadra Barrage, Rishikesh	
Song	Near Satyanarayan Temple, 14 km from Haridwar	

Table 4. Slightly polluted stretches (class 'B') of rivers and tributaries in Uttaranchal

Rivers/tributaries	Location of river stretches	Taxa/families of benthic macro-invertebrates commonly collected from water bodies
Bhagirathi	Gangotri, District Uttarkashi (May 2005)	Ephemeroptera: Heptageniidae, Baetidae Ephemeridae, Ephemerellidae, Leptophlebiidae
Sharda	Upstream Tanakpur barrage, Hanumangadi, District Champawat	Plecoptera: Nemouridae, Perlidae.
Sarju	Harsila, downstream Kapkot	Trichoptera: Goeridae, Leptoceridae, Polycentropodidae, Hydropsychidae
Gomti	Kukarigad , upstream Bageshwar	Mollusca: Lymnaeidae
Ganga	Muni Ki Reti, Rishikesh	Coleoptera: Hydrophilidae, Dytiscidae, Psephenidae
		Hemiptera: Aphelocheiridae, Gerridae
		Diptera: Simulidae, Chironomidae
		Megaloptera: Corydalidae
		Crustacea: Grabsidae
		Hirudinea: Glossiphonidae

Table 5. Moderately polluted stretches (class 'C') of rivers and tributaries in Uttranchal

Rivers/tributaries	Location of river stretches	Taxa/families of benthic macro-invertebrates commonly collected from water bodies
Bhagirathi	Downstream Dharasu, after confluence of Nagon Gadhera	Ephemeroptera/Heptageniidae, Ephemeridae, Caenidae, Bactidae
Alaknanda	Downstream Vishnu Prayag barrage, opposite NH-58	Trichoptera/Rhycophilidae, Polycentropodidae, Hydropsychidae
Kali	Naya Basti, downstream Dharchula, District Pithoragarh	Odonata/Libellulidae, Euphaeidae, Gomphidae
Sharda	Upstream Tanakpur barrage, Brahmdev, District Champawat	Hemiptera/Nepidae
	Downstream Power House, Tanakpur, near NHPC rehabilitation village on NH-125, District Champawat	Coleoptera/Dytiscidae
		Diptera/Simulidae, Tipulidae, Chironomidae
		Megaloptera/Cordyladidae
Ramganga	Downstream Kalagadh barrage, Afjalgarh, Kalagadh	Mollusca/Thiaridae, Lymnacidae
		Hirudinea/Glossiphonidae, Hirudidae

Table 6. Heavily polluted (class 'D') and severely polluted stretches (class 'E') of rivers and tributaries in Uttaranchal

Rivers/tributaries	Location of river stretches	Taxa/families of benthic macro-invertebrates commonly collected from water bodies
Heavily polluted		
Bhagirathi	Maneri Bhali Phase-I, reservoir	Mollusca/Thiaridae
		Hemiptera/Corixidae
		Planaria/Planariidae
		Oligochaeta/Oligochaetes
Severely polluted		
Bhagirathi	Old Tehri, near Mosque	No families of benthic macro-invertebrates
	Downstream Tehri Dam, Zero point	
	Inlet of diversion tunnel, Tehri Hydro Development Corporation Ltd., Koteshwar	
	2 km upstream of Devprayag, near Hydel Colony, Bagwan	
Dhauliganga	Upstream Dhauliganga barrage near bridge, District Pithoragarh	
	Chirkila, Damsite, District Pithoragarh	
Ramganga	Upstream Kalagarh Dam, Dhikala, Corbett National Park, District Pauri Garhwal	

Table 7. Average physico-chemical water quality levels at various biological water quality classes of rivers in Uttaranchal

Parameter	Biological water quality class				
	A (Clean)	B (slight pollution)	C (moderate pollution)	D (heavy pollution)	E (severe pollution)
pH	7.259	7.365	7.23	7.23	7.36
Conductivity (u mho/cm)	151.96	172.75	175.0	165.0	164.28
TDS (mg/l)	90.23	121.33	120.0	98.0	107.20
TSS (mg/l)	126.5	236.5	–	–	–
Total alkalinity (mg/l)	76.5	69.0	96.0	37.0	62.8
Total hardness (mg/l)	65.0	73.0	73.25	61.0	79.0
Calcium (mg/l)	17.60	13.66	19.50	9.0	17.6
Magnesium (mg/l)	5.5	11.0	–	–	–
Chloride (mg/l)	8.88	20.0	14.0	9.0	8.8
Sulphate (mg/l)	11.529	9.66	1.66	20.0	16.82
Fluoride (mg/l)	0.175	0.126	NT	0.14	0.21
Nitrite-N (mg/l)	0.0053	0.035	NT	0.006	0.008
Nitrate-N (mg/l)	0.315	0.246	NT	NT	0.0532
NH_3-N (mg/l)	0.644	0.501	NT	0.22	0.0111
TKN-N (mg/l)	0.775	3.5	0.28	0.56	0.513
Sodium (mg/l)	2.31	–	1.13	–	2.0
Potassium (mg/l)	1.73	–	1.3	–	1.5
Phosphate (mg/l)	0.0366	0.068	0.0122	–	0.0654
Boron (mg/l)	0.406	0.406	–	–	–
COD (mg/l)	11.08	18.33	14.25	–	11.0
BOD (mg/l)	1.243	1.325	1.675	<1.0	<1.0
DO (mg/l)	9.671	9.19	9.84	12.87	9.936
Air temperature (°C)	21.69	23.83	24.08	21.5	26.34
Water temperature (°C)	15.32	17.41	14.66	14.0	16.0

NT, Not traceable.

Table 8. Average, minimum and maximum heavy metal residues in water of rivers in Uttaranchal

Biological water quality class	Biological water quality		Cadmium (mg/l)	Chromium (mg/l)	Copper (mg/l)	Iron (mg/l)	Nickel (mg/l)	Lead (mg/l)	Zinc (mg/l)
A	Clean	Average	NT	NT	NT	0.6621	NT	NT	0.16
		Minimum	NT	NT	NT	0.23	NT	NT	0.04
		Maximum	NT	NT	NT	1.43	NT	NT	0.19
B	Slight pollution	Average	–	–	–	–	–	–	–
		Minimum	–	–	–	–	–	–	–
		Maximum	–	–	–	–	–	–	–
C	Moderate pollution	Average	NT	NT	0.0233	1.613	NT	NT	1.276
		Minimum	NT	NT	0.02	0.32	NT	NT	0.16
		Maximum	NT	NT	0.03	2.82	NT	NT	2.26
D	Heavy pollution	Average	–	–	–	–	–	–	–
		Minimum	–	–	–	–	–	–	–
		Maximum	–	–	–	–	–	–	–
E	Severe pollution	Average	NT	NT	NT	3.86	NT	NT	0.143
		Minimum	NT	NT	NT	0.21	NT	NT	0.06
		Maximum	NT	NT	NT	10.73	NT	NT	0.22

NT, Not traceable.
–, Not done.

Human activities commonly observed along rivers of Uttarchanal

The following human activities were observed during sampling of rivers at various locations: Religious, tourism, bathing, washing, open defecation, cultivation, sand, stone and gravel recovery, stone crushing, road construction, mining, hydel activities, cremation; fishing, surface drainage, irrigation, drinking water intake, rafting, wildlife habitat, etc. Beside these human activities, the river ecology is significantly affected by landsliding and forest fire activities[13].

Table 9. Average, minimum and maximum heavy metal residues in sediments of rivers in Uttaranchal

Biological water quality class	Biological water quality		Cadmium (mg/g)	Chromium (mg/g)	Copper (mg/g)	Iron (mg/g)	Nickel (mg/g)	Lead (mg/g)	Zinc (mg/g)
A	Clean	Average	NT	0.00041	0.00187	7.97	NT	NT	0.125
		Minimum	NT	NT	0.002	0.660	NT	NT	0.016
		Maximum	NT	0.010	0.010	26.0	NT	NT	0.700
B	Slight pollution	Average	NT	NT	0.0006	11.98	NT	NT	0.091
		Minimum	NT	NT	NT	8.040	NT	NT	0.045
		Maximum	NT	NT	0.002	19.0	NT	NT	0.129
C	Moderate pollution	Average	NT	NT	NT	1.933	NT	NT	1.196
		Minimum	NT	NT	NT	0.970	NT	NT	0.220
		Maximum	NT	NT	NT	3.080	NT	NT	3.020
D	Heavy pollution	Average	–	–	–	–	–	–	–
		Minimum	–	–	–	–	–	–	–
		Maximum	–	–	–	–	–	–	–
E	Severe pollution	Average	NT	NT	0.0071	5.787	NT	NT	0.14
		Minimum	NT	NT	0.002	0.550	NT	NT	0.028
		Maximum	NT	NT	0.042	14.4	NT	NT	0.380

Table 10. Average, minimum and maximum pesticide residues in sediments of rivers in Uttaranchal

Biological water quality class	Biological water quality		Total BHC (ng/g)	Aldrin (ng/g)	Total Endosulfan (ng/g)	Dieldrin (ng/g)	Total DDT (ng/g)
A	Clean	Average	NT	NT	NT	NT	NT
		Minimum	NT	NT	NT	NT	NT
		Maximum	NT	NT	NT	NT	NT
B	Slight pollution	Average	NT	NT	NT	NT	NT
		Minimum	NT	NT	NT	NT	NT
		Maximum	NT	NT	NT	NT	NT
C	Moderate pollution	Average	NT	NT	NT	NT	NT
		Minimum	NT	NT	NT	NT	NT
		Maximum	NT	NT	NT	NT	NT
D	Heavy pollution	Average	NT	NT	NT	NT	NT
		Minimum	NT	NT	NT	NT	NT
		Maximum	NT	NT	NT	NT	NT
E	Severe pollution	Average	NT	NT	NT	NT	NT
		Minimum	NT	NT	NT	NT	NT
		Maximum	NT	NT	NT	NT	NT

Material and methods

There are more than a hundred religious places located on the bank of various rivers in Uttaranchal, as identified by Survey of India. The famous religious places of Char Dham at Yamunotri, Gangotri, Kedarnath and Badrinath are situated at the origin of major river systems of Yamuna, Ganga, Mandakini and Alaknanda respectively. Panch Prayag, namely Devprayag, Rudraprayag, Karanprayag, Nandprayag and Vishnuprayag are located at confluence of rivers such as Bhagirathi and Alaknanda, Mandakani and Alaknanda, Pindar and Alaknanda, Nandakini and Alaknanda, Alaknanda and Dhauliganga respectively. The water bodies on these locations are subjected to regular bathing activities throughout the year.

A total of 60 locations were selected on 19 river systems and tributaries in Uttaranchal (Figure 1). The sampling locations were selected based on various human activities practised in and around water bodies. Field studies were undertaken during the year 2004–05. To assess the actual health of water bodies, Biological Water Quality Criteria (BWQC; Table 1) developed by CPCB were used. Taking into account the saprobic and diversity scores of benthic macro-invertebrate families observed at different locations, the ecological assessment was made for various rivers of Uttaranchal (Table 1).

Table 11. Average, minimum and maximum pesticide residues in the waters of rivers in Uttaranchal

Biological water quality class	Biological water quality		Total BHC (ng/l)	Aldrin (ng/l)	Total Endosulfan (ng/l)	Dieldrin (ng/l)	Total DDT (ng/l)
A	Clean	Average	NT	NT	2.34	3.280	11.864
		Minimum	NT	NT	NT	NT	NT
		Maximum	NT	NT	32.76	45.93	92.94
B	Slight pollution	Average	NT	NT	NT	NT	NT
		Minimum	NT	NT	NT	NT	NT
		Maximum	NT	NT	NT	NT	NT
C	Moderate pollution	Average	NT	NT	16.41	11.075	91.20
		Minimum	NT	NT	NT	NT	NT
		Maximum	NT	NT	65.65	44.30	364.81
D	Heavy pollution	Average	NT	NT	NT	NT	NT
		Minimum	NT	NT	NT	NT	NT
		Maximum	NT	NT	NT	NT	NT
E	Severe pollution	Average	NT	NT	NT	NT	NT
		Minimum	NT	NT	NT	NT	NT
		Maximum	NT	NT	NT	NT	NT

The biological water quality of rivers in Uttaranchal State was compared with various levels of water quality characteristics.

Hydrological status of rivers on hydroelectric power projects in Uttaranchal

Studies have revealed that glacier-fed streams have more current velocity (0.68–2.5 m/s) than spring-fed streams (0.35–1.7 m/s) Hillstreams have a coarse bottom of boulders, rocks or pebbles. Substratum provides several biotypes, and thus is one of the most important factors that determines the quality and quantity of macrobenthos of streams and rivers[12]. Hydrological and sediment transport characteristics are two main fluvial parameters affecting the aggradation/degradation behaviour of the river systems[14].

Rivers in Uttaranchal are mostly running, eroding, turbulent, depositing and riffling due to altitudinal gradient and substratum composition. However, it is observed that on hydroelectric project sites, the natural river path is canalized into tunnels and the water body becomes stagnant at barrages. All these disturbances have drastically changed the ecological sustainability of rivers in the state. The average substratum composition of various rivers is shown in Table 2.

Results and discussion

Biological water quality

Studies carried out during the years 2004 and 2005 have clearly indicated that water quality of rivers in Uttaranchal is clean in most of the stretches (see Tables 13 and 14). Clean water stretches of class 'A' were identified in river Bhagirathi, Bhilangana, Alaknanda, Dhauliganga, Birahi Ganga, Pindar, Nandakini, Mandakini, Kosi, Dhauliganga (Pithoragarh district), Kali, Sarju, Gomti, Yamuna, Ganga and Song. The families of benthic macro-invertebrates collected from clean water quality stretches belonged to 13 taxa, i.e. Ephemeroptera, Plecoptera, Trichoptera, Odonata, Hemiptera, Coleoptera, Planaria, Diptera, Mollusca, Megaloptera, Crustacea, Hirudinea, Polychaeta and Oligochaeta (Table 3). The saprobic score of these taxa ranged from 7.0 to 9.0, with a diversity score range of 0.19 to 0.94. Slightly polluted stretches of class 'B' were observed in river Bhagirathi, Sharda, Saryu, Gomti and Ganga. The biological water quality in these stretches was indicated by the presence of families of benthic macro-invertebrates of taxa such as Ephemeroptera, Plecoptera, Trichoptera, Mollusca, Coleoptera, Hemiptera, Diptera, Megaloptera, Crustacea and Hirudinea. The saprobic score of class 'B' water quality ranged from 6.2 to 7.25, with a diversity score range of 0.08 to 0.85. Moderate pollution of class 'C' was observed in stretches of river Bhagirathi, Alaknanda, Kali, Sharda, and Ramganga. A total of nine taxa, i.e. Ephemeroptera, Trichoptera, Odonata, Hemiptera, Coleoptera, Diptera, Megaloptera, Mollusca and Hirudinea were identified in these stretches. Heavily polluted (class 'D') stretches were found in river Bhagirathi, i.e. in Maneri Bhali phase-1 reservoir only four taxa, i.e. Mollusca, Hemiptera, Planaria and Oligochaeta supported water quality. Severe pollution of class 'E' in rivers of Uttaranchal was indicated by total absence of biological establishment of benthic macro-invertebrates. These stretches belonged to rivers Bhagirathi, Dhauliganga and Ramganga, especially on various upstream and downstream locations of hydroelectric power projects (Tables 3–6).

Table 12. Bacteriological assessment of different water quality classes of rivers in Uttaranchal

River	Location of river stretches	Total coliform (nos/100 ml)	Faecal coliforms (nos/100 ml)
Class 'A'			
Bhagirathi	Lohari Nag – Pala	900.0	470.0
	Upstream Maneri Bhali Phase-1, Jhulapul	1300.0	110.0
	Outlet Maneri Bhali Phase-1	6300.0	90.0
	Maneri Bhali Phase-1	22,000.0	5500.0
Alaknanda	Badrinath, Second Hydel Project Bamni	5,10,000.0	1260.0
	Vishnuprayag HEP	80,000.0	5500.0
	Birahi	3,98,000.0	1,300.0
	Rudraprayag B/c Mandakini	11,000.0	2100.0
	Rudraprayag A/c Mandakini	12,100.0	2400.0
	Kaliasaur, Near Dhari Devi Temple	151000.0	6500.0
Mandakini	2 km before Tilwara, U/s Rudraprayag	11,90000.0	7700.0
Birahiganga	Birahi, District Chamoli	6,50,000.0	1670.0
Pindar	Karanprayag	3500.0	80.0
Nandakini	Nandprayag	11,000.0	1200.0
Dhauliganga	Baity, U/s Dhauliganga HEP	6200.0	1070.0
	Downstream Dhauliganga–Tawaghat barrage	23,000.0	1,100.0
Kali	2 km upstream Tawaghat	29,000.0	480.0
Yamuna	Lakhwar Dam, Juddo Village	86,00.0	230.0
	Dakpathar	45,000.0	5900.0
Dhauliganga	Tapovan, District Joshimath	900,000.0	1250.0
Saryu	Loharkhet, downstream Saling Udiyar	79,000.0	200.0
	Maziakhet, downstream Bageshwar	19,800.0	2110.0
	Ghat, District Pithoragarh	1,50,000.0	1800.0
Bhilangna	Ghouti, upstream Tehri Dam	2,50,000.0	1100.0
Kosi	Jorasi, District Almora	3700.0	90.0
Class 'B'			
Bhagirathi	Gangotri, upstream bridge	<1.0	<1.0
	Gangotri, downstream bridge	11,900.0	160.0
Sharda	Upstream Tanakpur barrage	48,000.0	1920.0
Sarju	Harsila, downstream Kapkot	62,000.0	440.0
Gomti	Kukarigad, upstream Bageshwar	9700.0	560.0
Class 'C'			
Kali	Naya Basti, District Pithoragarh	31,000.0	390.0
Class 'D'			
Bhagirathi	Maneri Bhali Phase-1 reservoir	1900.0	60.0
Class 'E'			
Bhagirathi	Inlet diversion tunnel, Koteshwar	13,900.0	250.0
	Upstream Devprayag	19800.0	4400
Dhauliganga	Upstream Dhauliganga barrage	7400.0	60.0
Ramganga	Upstream Kalagadh Dam, Dhikala, Corbett National Park	2500.0	90.0

Physico-chemical water quality

The biological water quality of classes A–E did not show significant change in the levels of physico-chemical characteristics (Table 7). The primary source of water in Uttaranchal for rivers is rainfall and snowmelt, which makes their composition an important component of river water chemistry. Total dissolved solids (TDS) in Himalayan rivers[3] ranged from 35 to 151 mg/l, which is similar to the present investigation (90.23 to 121.33 mg/l). It has been shown[10] that in upland hill streams, the range of bicarbonate alkalinity may vary from 28 to 76 ppm. The levels of total alkalinity in the present study ranged from 37.0 to 96.0 mg/l. In unpolluted hill streams, the range of NO_3-N has been reported to be nil to 0.13 ppm. Not much increase in levels has been observed in the present observation of rivers (NT, 0.315 mg/l and PO_4-P, 0.0122–0.068 mg/l). Similarly, in upland hill streams, BOD ranges have been reported from almost nil to around 3 ppm, which is higher compared to the present values of <1.0–1.675 mg/l. The DO values were reported to be lower, ranging from 8 to 12 ppm compared to present values of 9.19 to 12.87 mg/l.

Heavy metal and pesticide residues

Tables 8 and 9 depict various levels of trace metals in rivers belonging to clean water quality of classes A, C

Table 13. Bio-monitoring of rivers in Uttaranchal

River	Location of river stretches	Location code	Saprobic score	Diversity score	Biological water class quality	Biological water quality
Bhagirathi	Gangotri, District Uttarkashi	B1	8.0	0.42	A	Clean
			6.66	0.08	B	Slight pollution
	Lohari Nag Pala Hydroelectric Power Project	B2	7.28	0.35	A	Clean
	Upstream Maneri Bhali Phase-I, Jhulapul	B3	8.2	0.48	A	Clean
	Inlet Maneri Bhali Phase-I, Keshavpuram	B4	8.22	0.72	A	Clean
	Maneri Bhali Phase-I, reservoir	B5	4.25	0.33	D	Heavy pollution
	Outlet Maneri Bhali Phase-I,	B6	7.33	0.5	A	Clean
	Inlet Maneri Bhali Phase-II	B8	7.88	0.94	A	Clean
	2 km downstream Maneri Bhali Phase-II	B9	7.0	0.43	A	Clean
	Upstream Uttarkashi	B7	8.6	0.69	A	Clean
	Downstream Uttarkashi	B10	7.6	0.61	A	Clean
	Upstream Nagon Gadhera, Dharasu	B11	8.3	0.54	A	Clean
	Downstream Nagon Gadhera, Dharasu	B12	5.4	0.8	C	Moderate pollution
	Upstream Old Tehri, Malideval	B13	7.7	0.67	A	Clean
	Old Tehri, Near Mosque	B14	9.0	0.45	A	Clean
	Downstream Tehri Dam, Zero point	B15	0.0	0.0	E	Severe pollution
	Inlet of Diversion Tunnel, THDC Koteshwar	B16	0.0	0.0	E	Severe pollution
	2 km upstream Devprayag, Near Hydel Colony, Bagwan	B17	0.0	0.0	E	Severe pollution
Bhilangana	Ghonti, 26 km upstream Old Tehri	BL1	8.8	0.71	A	Clean
	Kandal village, Old Tehri, before Confluence to River Bhagirathi	BL2	7.56	0.39	A	Clean
Alaknanda	Badrinath, Second Hydel Project, Bamni	A1	8.5	0.85	A	Clean
	250 m upstream Vishnuprayag barrage	A2	7.85	0.54	A	Clean
	Downstream Vishnuprayag barrage	A3	6.4	0.271	C	Moderate pollution
	In front of Switch Yard, Downstream Power House of Vishnuparyag HEP	A4	8.22	0.408	A	Clean
	Birahi, after confluence of Birahiganga	A5	8.0	0.875	A	Clean
	Rudraprayag, opposite temple, U/S Sangam	A6	9.0	0.75	A	Clean
	Rudraprayag, after confluence of River Mandakini, GMVN	A7	7.7	0.63	A	Clean
	Kaliyasaur, near Dhari Devi Temple	A8	8.0	0.74	A	Clean
Dhauliganga	Tapovan village, Vishnugad barrage site, District Joshimath	D1	8.0	0.57	A	Clean
Birahiganga	Birahiganga, before confluence to River Alaknanad, 6 km from Chamoli	BR1	8.42	0.63	A	Clean
Pindar	Meeng, near bridge	P1	8.0	0.6	A	Clean
	Karanprayag, before confluence to River Alaknanda	P2	8.85	0.294	A	Clean
Nandakini	Nandprayag, near bridge, before confluence to River Alaknanda	N1	7.0	0.4	A	Clean
Mandakini	2 km before Tilwara, U/S Rudraprayag	M1	8.1	0.65	A	Clean
Dhauliganga	Baity village, 7 km upstream Dhauliganga barrage, District Pithoragarh, Dharchula	DL1	7.8	0.7	A	Clean
	Upstream Dhauliganga barrage, near bridge, Dharchula	DL2	0.0	0.0	E	Severe pollution
	Chirkila, damsite, District Pithoragarh	DL3	0.0	0.0	E	Severe pollution
	Downstream barrage, before confluence to River Kali, near Tawaghat	DL4	8.1	0.46	A	Clean
Kali	2 km upstream Tawaghat, 13 km from NHPC Guest House on NH-29	KL1	7.5	0.66	A	Clean
	Upstream Power House, after confluence of River Dhauliganga at Tawaghat	KL2	7.2	0.66	A	Clean
	Naya Basti, District Pithoragarh	KL3	4.8	0.85	C	Moderate pollution
Sharda	Brahmdev, upstream barrage, Tanakpur, District Champawat.	SH1	6.5	0.33	C	Moderate pollution
	Hanumangadi, Tanakpur, District Champawat	SH2	6.2	0.35	B	Slight pollution
	Near NHPC Rehabilitation village on NH-125, downstream Power House, Tanakpur	SH3	5.5	0.57	C	Moderate pollution

(*Cont…*)

Table 13. (*Cont…*)

River	Location of river stretches	Location code	Saprobic Score	Diversity Score	Biological water class quality	Biological water quality
Ramganga	Upstream Kalagarh Dam, District Pauri Garhwal, Dhikala, Corbett National Park	R1	0.0	0.0	E	Severe pollution
	Downstrem Kalagarh Dam, Afjalgarh	R2	3.6	0.7	C	Moderate pollution
Sarju	Lokarkhet Micro Hydel Project, downstream Saling Udiyar	S1	7.8	0.68	A	Clean
	Harsila, Downstream Kapkot	S2	6.9	0.85	B	Slight pollution
	Majiakhet, Downstream Bageshwar after confluence of River Gomti	S3	7.2	0.66	A	Clean
	Ghat, District Pithoragarh	S4	7.5	0.79	A	Clean
Gomti	Kukarigad, upstream Bageshwar	GO1	6.2	0.63	B	Slight pollution
	Kailasu, 12 km upstream Bageshwar	GO2	7.4	0.53	A	Clean
Kosi	Jorasi, District Almora	K1	7.5	0.65	A	Clean
Ganga	Kaudiyala, near Rafting Club	G1	7.2	0.75	A	Clean
	Rishikesh, Muni Ki Reti, opposite Gita Bhawan	G2	6.8	0.42	B	Slight pollution
Yamuna	Lakhwar Dam, NH-123, 2.5 km, from damsite, Juddo village, near bridge	Y1	8.3	0.45	A	Clean
	Dakpathar, near road bridge, Panchayat Bhawan	Y2	7.33	0.43	A	Clean

Table 14. Biological water quality criteria for rivers of Uttaranchal

Taxonomic group	Range of saprobic score (0–10)	Range of diversity score (0–1)	Biological water quality	Water quality class	Indicator colour
Ephemeroptera, Plecoptera, Trichoptera, Planaria, Odonata, Coleoptera, Diptera, Mollusca, Oligochaeta, Megaloptera, Hirudinea, Polychaeta	7.0–9.0	0.19–0.94	Clean	A	Blue
Ephemeroptera, Plecoptera, Trichoptera, Mollusca, Coleoptera, Hemiptera, Diptera, Megaloptera, Crustacea, Hirudinea	6.2–7.25	0.08–0.85	Slight pollution	B	Light blue
Ephemeroptera, Trichoptera, Megaloptera, Odonata, Hemiptera, Mollusca, Coleoptera, Diptera, Hirudinea	3.6–6.5	0.271–0.85	Moderate pollution	C	Green
Mollusca, Hemiptera, Planaria, Oligochaeta	4.25–4.6	0.33–0.37	Heavy pollution	D	Orange
No benthic macro-invertebrates	0.0–0.0	0.0–0.0	Severe pollution	E	Red

and E. Traces of chromium, copper, iron and zinc have been detected in sediments of most of the rivers. Pesticide residues of total Endosulfan, Dieldrin and total DDT have also been observed in the water quality of clean and moderately polluted stretches of rivers. However, none of the pesticide residues have been detected in sediments (Table 10). Studies have revealed that the biological community is strongly influenced by the physical and chemical environment in the sediment. Benthic macro-invertebrates living at the sediment–water interface are directly exposed to sediment-bound metals and pesticide residues. Thus presence of pesticide residues (Tables 10 and 11) in water quality of rivers did not have any significant impact on biological establishment of benthic macro-invertebrates.

Bacteriological water quality

Table 12 indicates that the bacterial contamination in rivers does not have much influence on the biological water quality of rivers. Total coliform in clean water quality stretches of class ‘A’ ranged from 900 to 11,90,000

nos/100 ml. Faecal contamination of river water is indicated by the presence of faecal coliform in the range of 80 to 7700 nos/100 ml. In slightly polluted river stretches, total coliform ranged from < 1.0 to 62,000 nos/100 ml and faecal coliform from < 1.0 to 1920 nos/100 ml. Compared to clean water quality, the number of total and faecal coliforms tend to reduce in biological water quality classes C–E (Table 12). This may be due to continuous use of clean-water river stretches for domestic purposes and run-offs from the places of open defecation on the banks. Other stretches are affected only due to change in hydrological conditions of the river.

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