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Nature rejuvenation: Long-term (1989–2016) vs short-term memory approach based appraisal of water quality of the upper part of Ganga River, India

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ABSTRACT

The deteriorating water quality (WQ) of the sacred north-flowing perennial Indian River, Ganga was a serious concern in recent decades for population adjoining to the river and policy planners. The present evaluation attempts to assess the long-term (1989–2016) physiochemical characteristics of WQ of river Ganga at five upstream locations (Uttarkashi, Tehri, Rudraprayag, Devprayag, and Rishikesh) of Uttarakhand, India using comprehensive pollution index (CPI) and environmetrics (PCA and CA). These methods were used to categorize, summarize expensive datasets, and grouping the similar polluted areas along the river stretches. The WQ of river at all the locations were within the good category and most of the physiochemical parameters were well within their acceptable limit for drinking WQ. Considerably, CPI demonstrated the river WQ was in slight pollution range (CPI: 0.40–1.00) in the year 2007 and 2015 at all the five locations. The positive correlation coefficient (R^2 > 0.50) among NO_2+NO_3, Ca, Na, B, and K indicates the significant contribution of organic and inorganic salts through runoffs from catchments due to weathering of rocks. PCA confirmed the input source of nutrients in the river from both natural and anthropogenic sources. Moreover, the upstream WQ assessed was found to be good as compared to the severely polluted downstream region. Due to COVID-19 and shutdown in the country, reduction of pollution load in the river was observed due to the rejuvenation capability of river Ganga. This information can assist the environmentalist, policymaker, and water resources planners & managers to prepare strategic planning in advance to maintain the aesthetic and cultural value of Ganga river in future.

1. Introduction

Water resources and quality of freshwater are the foremost basic need of flourishing ecological diversity and sustainable development. The rapid growth of human population, urbanization, and industrialization have stimulated the over-extraction of water from the freshwater sources (e.g., river, lakes) for various purposes of the daily demands of

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water (Mishra et al., 2016; Misaghi et al., 2017). Moreover, the untreated waste water containing organic and inorganic compounds are generated from the domestic households, industries, agricultural runoffs, and are being discharged in the surrounding water bodies (Sharma et al., 2016; Cao et al., 2020) resulting in deterioration of water quality (WQ). The shortage of freshwater availability and deterioration of WQ has assisted in extinction of biotic communities and put excess pressure on ecology leading to disturbing the ecosystem (Singh et al., 2019, 2020a). Contrarily, the consumption of polluted water causes several health hazards to mankind (WHO and UNICEF, 2017; Cabral-Pinto et al., 2019, 2020). Approximately 80% of human population in India suffers from water-borne diseases, resulting in the annual death of about 600,000 persons from diarrhoea (Conaway, 2015). The loss of life and huge pressure on ecology due to polluted and insufficient water has alarmed for the grim situation and warrant immediate actions and strategy for conservation and rejuvenation of water resources. Ecological integrity could be enhanced by maintaining e-flows (ecological flow) in the Ganga River, reduced industrial discharges and following discharge standards guidelines of central pollution control board (CPCB) and WHO which will further enables self-rejuvenation. Keeping in view the above and increasing rate of urbanization and pollution loading (especially nutrients, heavy metals, organic matters) in the river, necessary corrective measures should be taken in advance to reduce future deterioration of WQ in the river.

India with diverse ecology has a large number of freshwater rivers, lakes, wetlands, and ponds in different parts of the country. The Ganga, the National River of India, is a perennial river fed by snowmelt and ice-melt almost round the year, originates at the confluence of Rivers Alaknanda and Bhagirathi at Devprayag in Himalaya and traverses a course of 2525 km, has a large number of tributaries joining during the course, flows south in the northern part of India into the Bay of Bengal (IAAD, 2017). Himalaya contains several rivers including a few sacred (Ganges is one of them), lakes and wetlands, and supports distinct biodiversity along with the water bodies and provides various services to the inhabitants of the river bank. Ganga basin is the largest river basin in India constituting 26% of the geographic area of the country and along with the river's tributaries supports for thousands of years for material, spiritual and cultural sustenance to about 43% of country's population (IAAD, 2017) inhabiting in 30 cities, 70 towns, and thousands of villages along the vicinity of the fertile river basin of the river (Nandi et al., 2016). Expanding and unplanned urbanization, industrialization, expansion of agriculture, destruction of forests, abstraction of water for irrigation and industry, lack of proper investment in water quality infrastructure, and governance problems have detrimental impacts on water quality (IAAD, 2017). Moreover, numerous drainage discharges almost 1 billion litres of untreated wastewater daily into the river Ganga, resulting in deteriorating WQ (CPCB, 2013). The degrading water quality challenge infiltration of rainwater and abstraction of surface and groundwater in excess and thereby disturbing the hydrological cycle with reducing perennial flow in the rivers and streams (Khan et al., 2019), resulting in unconditional urban flooding in the river basin (Haritash et al., 2016; Almeida and Dias, 2016).

Water supports productive activities and has competitive demand leading to very meagre flow in the rivers and streams for sustaining environmental concerns (CPCB, 2017). The river water crisis is critical for sustaining the population and therefore government of India implemented the Ganga Action Plan I (GAP-I) in year 1985 with the support of many voluntary indigenous and international organizations (Hamner et al., 2006). The GAP-I with budgetary support of over US$33 million aimed to achieve development of new and renovation of existing sewage treatment plants (STPs) in urban areas, expansion of sewerage systems to disconnected areas, and construction of electric crematorium at the bank of the rivers (Birol and Das, 2010). GAP-I was facilitated for reduction in amount of direct discharge of wastewater into river, however, WQ of the river was remained a challenge and even was not suitable for bathing (Tare et al., 2003). Therefore, GAP-II was initiated in year 1993 with target to manage the pollution load of three main tributaries of river Ganga (e.g., Yamuna, Gomti, and Damodar), and 25 towns (population of >100,000) that remained untargeted in GAP-I (Das and Tamminga, 2012). GAP-II was also unable to reduce the load primarily due to the lack of strategic planning and less involvement of stakeholders (Ching and Mukherjee, 2015). In 2015, the Integrated Ganga Conservation Mission as an umbrella programme "*Namami Gange*" was initiated by Union government with the aim of integrating previous and currently ongoing initiatives for the rejuvenation of the river and its tributaries with a budgetary provision of Rs 20,000 crore for the year 2015–2020, however, the planned target could not be achieved due to delay in implementation (IAAD, 2017).

Various scientific evaluations have been made during recent years to evaluate the quality of water along the course of the river Ganga and provide various contrasting features of the river water. The result of primary information on WQ in the state of West Bengal confirms the suitability of the Ganga water river for irrigation purposes (Mandal et al., 2018). However, presence of emerging pollutants as mesoplastics (size >5 mm) and microplastics (size <5 mm) particles in the sediment of river Ganga downstream was observed in the eastern basin from Buxar to Fraserganj (Sarkar et al., 2019). The metal concentration in river water was evaluated and found in excess as observed while analysing the concentration of Fe and Cr in river water, sediments, plants, and fishes of the river Ganga in Kanpur area posing severe risks to human health (Kumar et al., 2019a,b). Seasonal variation in WQ of river Ganga was found to be excellent in winter, acceptable in summer and polluted in monsoon seasons at Haridwar city due to uneven discharge of wastewater, interference of tourists, and active self-cleansing property of river (Kamboj and Kamboj, 2019). The self-cleaning property of river Ganga is due to the presence of bacterial species (belonging to genus *Escherichia, Pseudomonas, and Enterobacter*), and diversity of bacteriophages in the river water (Dwivedi et al., 2020). Numerous evaluations of WQ of the river Ganga has been made with varied results with potential explanations such as for WQ (Singh et al., 2020b), impact of climate change on river hydrological dynamics (Jain and Singh, 2020), pollution mapping, and categorization (Trombadore et al., 2020). However, a comprehensive study of WQ assessment using long term data of physiochemical and biological parameters has not been reported in the upstream of the river Ganga. The lack of long term evaluation restricts the visualization of changing WQ at one side and reduces opportunities to facilitate enabling conditions for management of water crisis (Tripathi and Singal, 2019). Considering the lack of information about temporal changes in the WQ and thereby refraining for developing the suitable policies, the present study is focused to analyse the long-term variation in WQ of river Ganga at the site of culturally important upstream regions (i.e., Uttarkashi, Tehri, Rudraprayag, Devprayag and Rishikesh) of Uttarakhand, India. Attainment of this purpose is formulated on the premise to classify the overall WQ of the river with respect to the suitability of water for human consumption purposes and to identify the major contaminants that imbalance the WQ of river Ganga. The data sets for physiochemical and biological parameters were collected on monthly basis during the years 1989–2016 for achieving the objective. Primarily, the comparative analysis of individual parameters to the standards prescribed at the regional and international scale is performed to identify the WQ for anthropogenic purposes. Moreover, the available datasets are used to evaluate water quality indices (WQI) as comprehensive pollution index (CPI) to classify the overall water pollution in the form of single numeric value. Several WQI is available to classify the overall water quality of a freshwater body for anthropogenic uses (Kumar et al., 2017a,b; Khan et al., 2019; Panwar et al., 2020), however, CPI a comprehensive numeric evaluation method for evaluation of surface water pollution was preferred for being a concise aggregation of various WQ parameters. Furthermore, the application of environmetrics like Principal component analysis (PCA), and hierarchical cluster analysis (HCA) was applied to identify the loading source of pollutants and similarity of pollution among the sampling locations. The government of India has formed an administrative body called as National Mission for Clean Ganga (NMCG) under the Ministry of Jal Shakti to look after the planning and implementation of projects related to rejuvenation of river Ganga that involves national and international organizations. The result of the present study would provide information to NMCG, environmentalists, policy-makers, water resource planners, and managers to understand the sources of pollution, pollutions sites, and making strategic mitigation plan to maintain the aesthetic values of the river.

2. Materials and methods

2.1. Details of study locations

River Ganga is one of the sacred freshwater bodies of India, flows in northern part of the country. Two Himalayan rivers are known as Bhagirathi and Alaknanda covers 200 km and confluence at Devprayag in Uttarakhand and carries the name called "river Ganga" in its flow pathway after this confluence. Bhagirathi originates from Himalayan Gangotri glacier located at an elevation of 7138 m amsl, in Uttarkashi district, while Alaknanda originates near the holy shrine of Badrinath, located at an elevation of 3300 m in Chamoli district of Uttarakhand, India. Since Devprayag, river Ganga flows downstream through the mountainous region for about 220 km before entering in the plain at Haridwar district of Uttarakhand. Further, river Ganga covers about 2290 km of downstream flow stretch across the states of Uttar Pradesh, Bihar, and West Bengal of India and finally merges into the Bay of Bengal (Kumar et al., 2017a,b). In addition to a strong cultural presence among the residents of India specially the Hindus, the river has diverse ecological relevance and contributes huge support to the Indian economy. Each city and ghats located along the stretch of river Ganga have religious significance, as being either as a spot for temples or for cremation place, thereby attracting the pilgrims from all over the country and globe (Pandey and Yadav, 2017). The river receives a huge amount of partially/untreated wastewater from domestic, industrial, and agriculture sectors along the stretch from its origin at Gomukh (Tripathi and Singal, 2019; Mishra and Maiti, 2019; Mishra et al., 2020). Considering the importance of river, entrance of wastewater, and land-use patterns, surface water monitoring, and assessment were carried out in the upstream region of river Ganga and its main tributaries.

The variation in temperature of the study areas remains in the range from 0 to 46 °C. In pre-monsoon (summer) and monsoon season, average temperature at upstream, midstream, and downstream was found to be 20–25 °C, 25–27 °C and 27 to >30 °C, respectively, while during post-monsoon season (winter), the average temperature at upstream, midstream and downstream was 13–15 °C, 15–18 °C and 18 to >20 °C, respectively (CWC, 2012).

2.2. Data collection, assessment and processing

The water quality data (Jan 1989 to Jan 2016) were collected from the five major locations, as Uttarkashi, Tehri, Rudraprayag, Devprayag, and Rishikesh. These locations were part of the Himalayan mountain region. The details of the data collection sites are reported in Table 1 with their respective locations in Fig. 1. In this study, the sub-surface water samples were collected from the selected sampling locations during the day time between 10:00–11:00 am, on the first day of every month from January 1989 to January 2016 for evaluations of the physicochemical parameters like pH, dissolved oxygen (DO), electrical conductivity (EC), and surface water temperature (WT) using portable analytical instruments. The details are provided in supplementary table S1. The composite water samples were filled in three acid-rinsed airtight plastic containers of 500 mL volume at each location, which were further stored at 4 °C temperature without freezing to avoid unpredictable changes in quality before analysis. Among three contained samples, one sample was fixed in biochemical oxygen demand (BOD) bottle for the analysis of BOD, while other two contained samples (kept

Table 1
Details of water sampling location in river Ganga.

Code	Sampling location	River	Latitude	Longitude	Elevation (m)	Catchment (km^2)
S1	Uttarkashi	Bhagirathi	30°43’45” N	78°26’47” E	1095	4055
S2	Tehri Zero Point Bridge	Bhagirathi	30°22’40” N	78°28’39” E	580	7208
S3	Rudraprayag	Alaknanda	30°18’00” N	78°59’35” E	895	9031
S4	Devprayag (G)	Ganga	30°08’24” N	78°35’47” E	443	19600
S5	Rishikesh	Ganga	30°06’08” N	78°18’15” E	327	21794

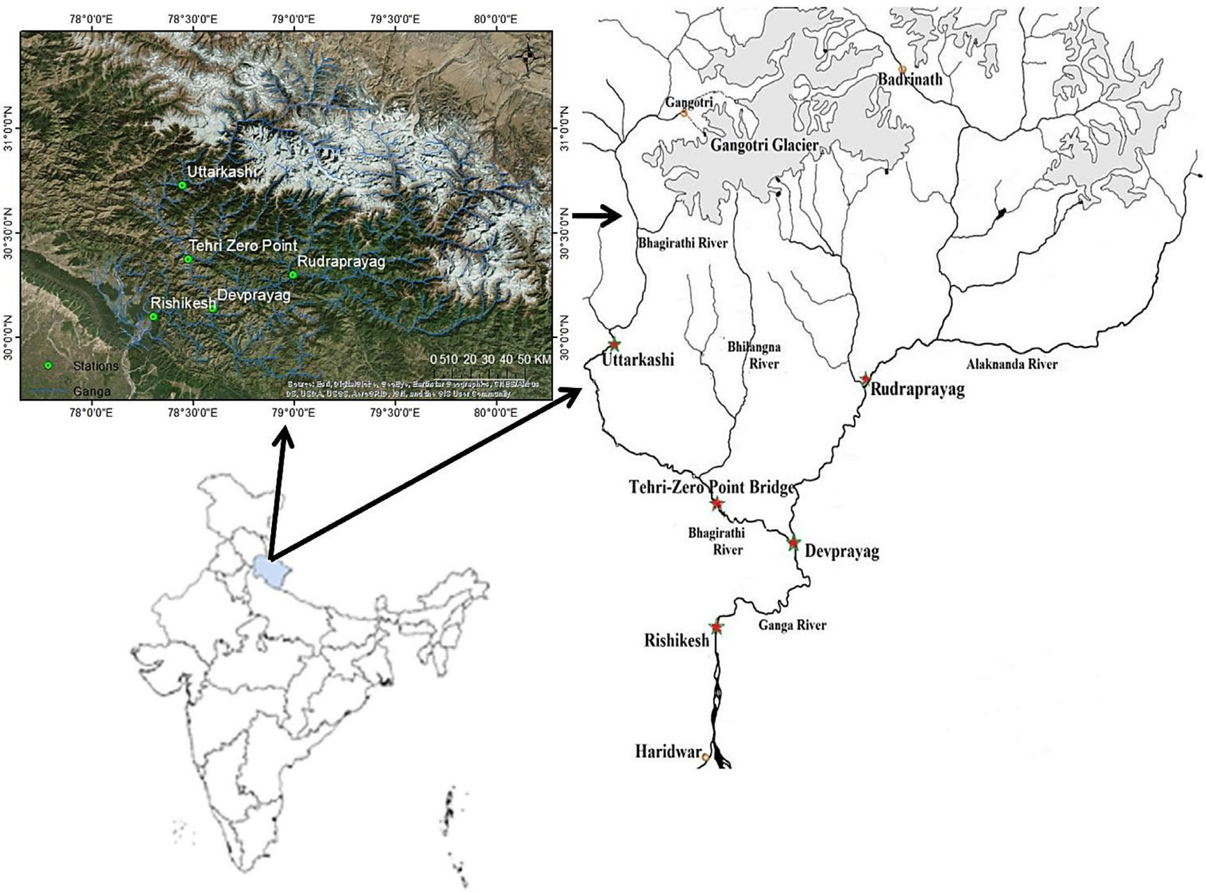

Fig. 1. Map of water sampling location in the river Ganga.

unfixed) were used for the analysis of other water quality parameters. The contained samples were transported to the laboratory within 24 h for experimental analysis. The experimental analysis of water quality parameters was performed in triplicate as per the procedure reported in APHA (2011) and the mean value of observations was estimated. The experimental procedure followed for analysis of physicochemical parameters with their abbreviation, measurement unit, and the numeric value of standard acceptable limit in drinking water, prescribed by BIS 2012 and WHO 2017, is provided in supplement table S1. The water quality data obtained during laboratory analysis were provided by Central Water Commission (CWC; http://india-wris.nrsc.gov.in), a body of Ministry of Jal Shakti under Government of India to carry out river water pollution assessment in this study. Real-time data of water quality in the river Ganga at downstream regions during April 2020 has been taken from CPCB (2020) and used to see the effect of water quality during country lockdown (COVID-19) at downstream locations.

2.3. Assessing water quality responses

In order to identify the variable parameters that affect the river WQ, the data obtained during laboratory analysis of water samples were compared with respect to their respective standard acceptable limit (SAL) value. Based on that, the collected WQ data were used to evaluate the CPI to classify the overall WQ status of river Ganga in single numeric terms at a particular sampling location in the respective month. The CPI is evaluated based on those parameters whose SAL has been prescribed as per BIS (2012) and WHO (2017). Parameters like DO, pH, BOD, EC, COD, alkalinity, total dissolved solids (TDS), total hardness (TH), and chloride were used to evaluate the index value. The mathematical equations (Eqs. (1) and (2)) of CPI are expressed below:

$$PI_i = \frac{C_i}{S_i} \tag{1}$$

$$CPI = \frac{1}{n}\sum_{i=1}^{n} PI \tag{2}$$

where PI represents sub-pollution index of *i*th parameter of water quality, C_i represents concentration value of *i*th parameter obtained during laboratory analysis of collected water samples, S_i represents SAL of *i*th parameter for drinkable water, and n is the total number of WQ parameters. The WQ status classified by CPI value and ranges from 0 to 2.0 and divided into five classes for indicating respective WQ status as 0–0.20 (excellent quality); 0.21–0.4 (good quality); 0.41–1.00 (slightly polluted quality); 1.01–2.00 (moderately polluted quality); $\geq$ 2.01 (severely polluted quality).

In order to standardize the large dataset of WQ parameters, the mean, median, kurtosis, skewness, population standard deviation, and Z-test values were calculated, which were further used to assess the comparative responses of different sampling locations on a common scale. As the focus of the study is on overall response across the sampling locations, the Z test value is used to centre all year's (January 1989 to January 2016) monthly data on their mean value to reduce the influence of any individual year data, which might have high average raw values of a particular parameter that unduly affect statistical analysis (Spears et al., 2015). The datasets were used to perform the statistical analysis to identify the root causes of WQ deterioration of river Ganga.

2.4. Statistical techniques

The statistical analysis of WQ parameters was performed through the HCA and PCA using SPSS, version 16.0 software. For HCA, a mean value of all year's monthly data of each parameter was evaluated and used to construct cluster of sampling locations that depicts the similarity in pollution load among the sampling locations. Further, PCA was performed using raw data of WQ parameters for each sampling location to identify the most influential parameter of water quality deterioration and to predict the sources of pollution in the river (Tripathi and Singal, 2019).

3. Results and discussion

The physicochemical characteristics of water in river Ganga were assessed at five upstream locations on the first day of each month from January 1989 to January 2016. The descriptive statistics of parameters (like DO, pH, EC, BOD, TA, F, B, Ca, Mg, Cl, SO_4, Na, K, NO_2+NO_3, and WT) obtained from the analysis of water samples were represented as Box–Whisker plots (Figs. 2 and 3). The mean of individual parameter was estimated based on all sampling months along with median, kurtosis, skewness, and Z-test values (Table 2).

The onsite measurement of pH value falling in the range of 6.4–9.0, 7.0–8.9, 6.3–8.8, 6.3–9.9, and 7.0–10.2 at locations S1, S2, S3, S4, and S5, respectively, with overall mean value of ∼8.0 and median value of ∼8.00–8.08 at all sampling locations. The maximum value of pH (>8.5) was obtained in January 2010 at all locations, while it remained stable within the SAL (pH 6.5–8.5) in other months. The WQ parameters WT and EC were within the SAL at all locations in sampling period, with maximum values ranging from 18 to 27 °C, and 266 to 491 μS/cm, respectively. The minimum concentration of DO was 5.8, 6.1, 5.73, 5.69, and 3.85 mg/L, while the maximum BOD concentration was 2.49, 4.06, 2.88, 3.54, and 50.10 mg/L at S1, S2, S3, S4, and S5 locations, respectively. The lower concentration of DO < SAL (5 mg/L) and higher concentration of BOD > SAL (5 mg/L) at location S5 were obtained in summer and monsoon months. The location S5 is an important tourist destination and attracts huge tourists resulting in the excessive anthropogenic hindrance in terms of bathing, river rafting, and other recreational activities in monsoon months. Notably, the overall median concentration of DO and BOD were obtained as ∼8 mg/L and ∼1.2 mg/L at all sampling locations. In addition, input of agricultural and forest runoff from the catchment in monsoon month were the major causes of decline in DO with increase in BOD concentration in the river at location S5. According to CPCB (2020), if the pH and EC of surface water lie within $6 \leq pH \geq 8.5$, BOD $\leq$ 3 mg/L, DO $\geq$5 mg/L and EC <2000 μS/cm, the water could be considered suitable for bathing, and irrigation purposes, but require conventional treatment for using for drinking ((Kumar and Gupta, 2020). The concentration of TA, Cl, Mg, and SO_4 was observed within their SAL at all sampling locations at each month.

Until February 1991, the concentration of fluoride in the river was estimated above the SAL value of 1 mg/L, while it became within SAL from March 1991 to January 2016 at all sampling locations. The improvement in WQ was due to decline in F concentration indicating the reduction of fluoride contaminated wastewater directly discharged into the river. The reduction is attributed to the impacts of GAP-II (Tripathi and Singal, 2019). Mean and median concentration of B was obtained within the SAL value of 0.50 mg/L during the sampling period. However, during the monsoon season in year 2011, the maximum B concentration of 1 ± 0.10, 1.1 ± 0.10, 0.44 ± 0.2, 0.60 ± 0.1, and 0.40 ± 0.2 mg/L were observed at sampling locations S1, S2, S3, S4, and S5, respectively. The mean and maximum

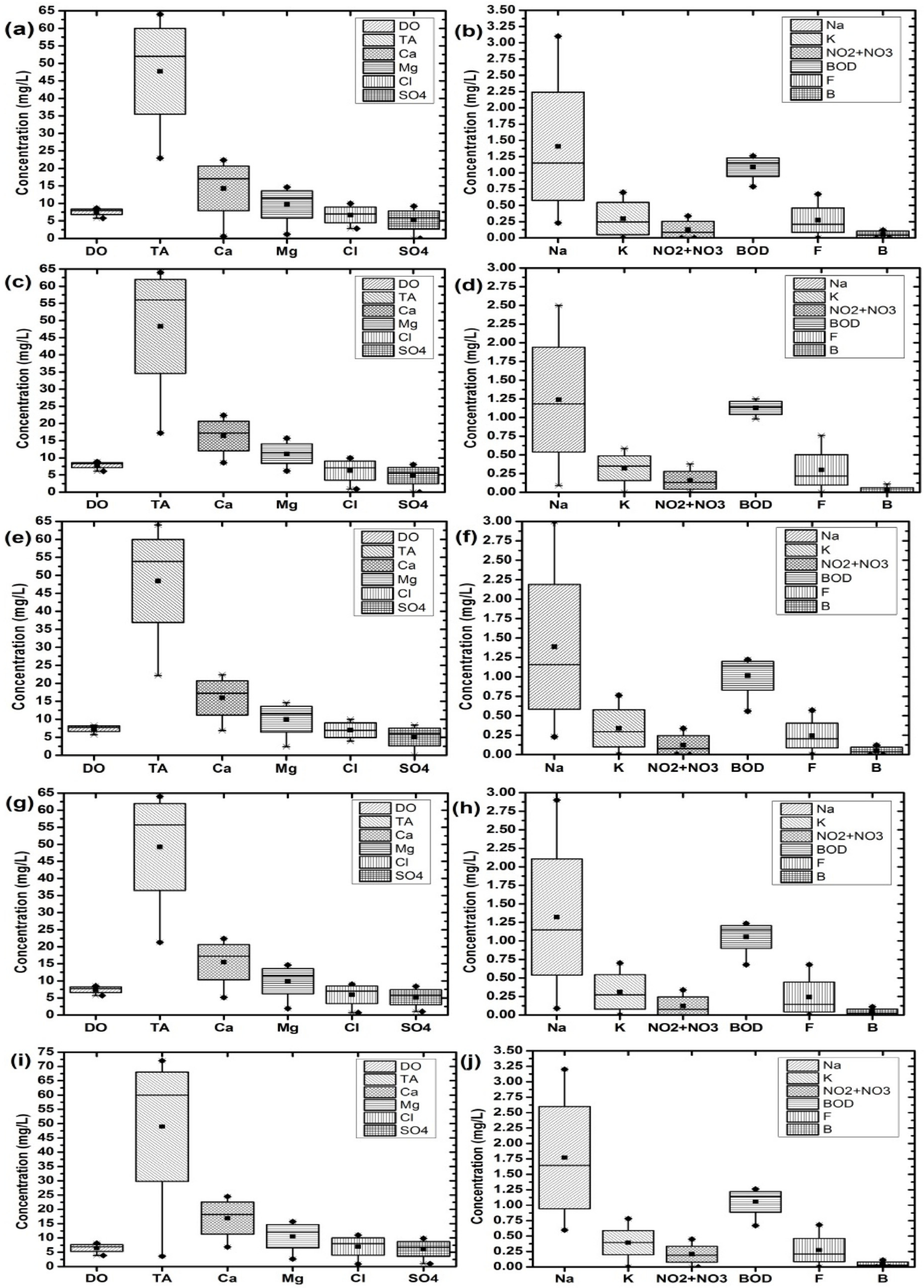

Fig. 2. Box–Whisker plot of physiochemical parameters of water quality at various locations: (a and b) Uttarkashi; (c and d) Tehri; (e and f) Rudraprayag; (g and h) Devprayag; (i and j) Rishikesh.

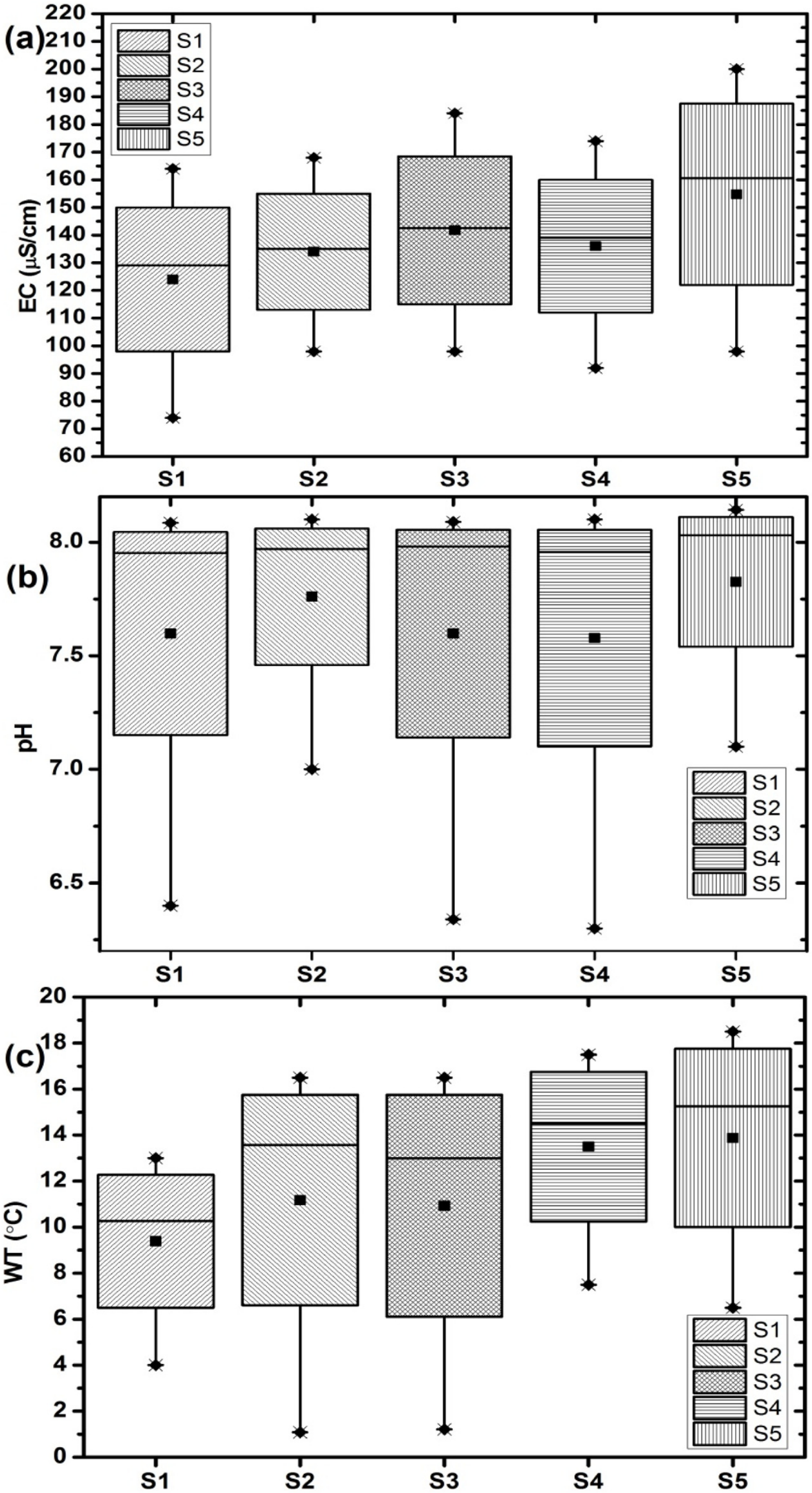

Fig. 3. Comparative Box–Whisker plot of parameters at various locations: (a) electrical conductivity (EC); (b) pH; (c) surface water temperature (WT).

Table 2
Statistical summary of physiochemical parameters in the river Ganga during January 1989 to January 2016.

		DO	pH	EC	BOD	TA	F	B	Ca	Mg	Cl	SO_4	Na	K	NO_2+NO_3	WT
S1	Overall mean	8.24	7.95	145.55	1.21	55.42	0.53	0.09	18.36	12.12	8.27	8.08	2.31	0.93	0.21	11.30
	Median	8.13	8.00	136.00	1.20	56.00	0.28	0.07	18.92	12.51	8.00	6.48	1.38	0.39	0.17	11.55
	Kurtosis	1.85	7.63	0.99	13.92	−0.11	3.98	18.57	−0.14	0.18	1.72	5.52	21.64	3.85	48.65	−0.41
	Skewness	0.44	−1.81	1.08	3.07	−0.39	2.07	3.85	−0.10	−0.42	0.91	2.22	3.54	2.29	4.91	−0.29
	SD	0.73	0.07	1201.25	0.04	121.68	0.40	0.02	31.50	16.23	7.85	31.28	5.44	2.34	0.06	7.23
	z value	−0.07	−0.04	0.00	0.34	−0.01	−0.04	0.07	0.00	0.00	−0.03	−0.01	0.02	−0.04	0.22	0.01
	P(Z<=z) one-tail	0.47	0.48	0.50	0.37	0.50	0.49	0.47	0.50	0.50	0.49	0.50	0.49	0.49	0.41	0.50
S2	Overall mean	8.52	7.96	156.32	1.22	57.17	0.61	0.05	18.68	12.99	8.24	6.36	1.76	0.44	0.23	14.18
	Median	8.44	8.02	142.00	1.18	60.00	0.28	0.01	19.00	12.54	8.16	6.48	1.38	0.39	0.18	15.00
	Kurtosis	1.08	2.94	11.87	79.98	0.68	2.61	61.33	−0.35	−0.71	0.01	0.72	11.73	16.28	−0.65	0.68
	Skewness	0.11	−1.26	3.07	7.23	−0.53	1.80	7.13	−0.11	0.22	0.26	0.02	2.15	2.53	0.43	−0.94
	SD	0.47	0.07	2633.20	0.06	114.78	0.51	0.12	29.31	9.93	5.89	5.91	1.10	0.11	0.03	9.16
	z value	−0.11	0.16	0.00	0.26	0.00	0.05	0.07	0.00	−0.03	−0.01	0.02	−0.01	−0.15	−0.09	0.00
	P(Z<=z) one-tail	0.46	0.44	0.50	0.40	0.50	0.48	0.47	0.50	0.49	0.50	0.49	0.50	0.44	0.46	0.50
S3	Overall mean	8.07	7.98	166.57	1.20	57.81	0.54	0.07	19.11	12.51	8.17	7.93	2.38	0.92	0.20	13.81
	Median	8.00	8.02	154.00	1.18	56.00	0.25	0.07	19.00	12.54	8.00	6.70	1.38	0.39	0.15	15.00
	Kurtosis	0.67	12.20	14.89	18.51	5.95	142.80	4.76	−0.09	0.41	1.92	4.48	5.84	5.47	0.66	−0.37
	Skewness	0.58	−2.33	3.30	3.53	0.90	10.29	1.72	0.18	−0.38	0.97	2.11	2.35	2.58	0.82	−0.67
	SD	0.99	0.06	3495.98	0.05	13.37	1.15	0.01	30.68	15.50	7.29	29.30	5.78	2.44	0.03	10.88
	z value	−0.02	0.28	0.00	0.28	−0.01	−0.06	0.29	−0.01	−0.02	−0.01	0.00	0.01	−0.05	0.04	−0.02
	P(Z< = z) one-tail	0.49	0.39	0.50	0.39	0.50	0.48	0.39	0.50	0.49	0.50	0.50	0.50	0.48	0.49	0.49
S4	Overall mean	8.00	7.97	156.19	1.23	56.87	0.47	0.07	19.65	12.44	7.86	7.82	2.46	0.91	0.20	15.32
	Median	8.00	8.01	146.00	1.18	59.84	0.21	0.05	18.92	12.54	7.99	6.48	1.31	0.39	0.15	16.00
	Kurtosis	−0.04	11.92	0.11	26.84	0.22	2.34	20.35	54.55	18.39	2.68	6.26	12.06	4.48	1.20	0.08
	Skewness	−0.07	−1.47	0.83	4.68	−0.65	1.78	3.37	6.33	2.00	0.96	2.32	3.16	2.35	1.07	−0.25
	SD	0.70	0.10	1300.00	0.87	156.64	0.36	0.01	111.23	21.16	8.00	6.48	8.20	2.30	0.04	9.40
	z value	−0.07	−0.23	0.00	0.05	0.00	−0.07	−0.45	0.01	0.02	0.01	0.01	0.03	0.06	−0.35	0.09
	P(Z< = z) one-tail	0.47	0.41	0.50	0.48	0.50	0.47	0.33	0.50	0.49	0.50	0.50	0.49	0.48	0.36	0.46
S5	Overall mean	7.40	8.05	177.08	1.40	61.32	0.50	0.06	24.02	13.30	9.14	8.89	2.85	0.99	0.27	15.93
	Median	7.15	8.08	176.00	1.18	64.00	0.25	0.05	20.64	13.58	9.00	7.60	2.00	0.40	0.22	16.50
	Kurtosis	−0.14	11.57	1.13	310.58	1.17	2.57	4.25	17.00	−0.26	15.71	5.47	6.42	6.01	−0.02	−0.51
	Skewness	0.24	0.75	0.72	17.47	−0.31	1.82	1.45	4.05	−0.10	2.37	2.20	2.47	2.61	0.58	−0.36
	SD	1.15	0.07	1636.80	7.51	247.90	0.36	0.00	415.60	19.90	12.90	32.26	7.78	2.15	0.03	12.37
	z value	0.04	0.22	0.00	−0.03	0.03	0.02	0.53	0.00	−0.02	0.00	0.01	0.00	−1179.76	0.02	−0.01
	P(Z< = z) one-tail	0.49	0.41	0.50	0.49	0.49	0.49	0.30	0.50	0.49	0.50	0.49	0.50	0.00	0.49	0.50

SD: Standard deviation; all the WQ values has been given in mg/L except pH (unit less), EC (μS/cm) and WT (°C).

Table 3
Comprehensive pollution index at various locations in river Ganga since 1989 to 2016.

Sampling year	CPI (Pre-monsoon)					CPI (Monsoon)					CPI (Post-monsoon)				
	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5	S1	S2	S3	S4	S5
1989	0.31	0.39	0.44	0.51	0.52	0.34	0.44	0.45	0.41	0.53	0.37	0.38	0.36	0.33	0.53
1990	0.51	0.33	0.30	0.36	0.51	0.50	0.55	0.54	0.50	0.55	0.41	0.53	0.53	0.51	0.52
1991	0.37	0.44	0.42	0.44	0.46	0.40	0.39	0.39	0.39	0.36	0.39	0.38	0.40	0.40	0.38
1992	0.33	0.38	0.40	0.39	0.40	0.38	0.36	0.35	0.35	0.36	0.39	0.37	0.41	0.38	0.38
1993	0.33	0.40	0.38	0.36	0.42	0.36	0.32	0.32	0.28	0.34	0.40	0.33	0.35	0.34	0.36
1994	0.34	0.39	0.40	0.38	0.42	0.36	0.37	0.33	0.34	0.36	0.40	0.34	0.36	0.38	0.34
1995	0.34	0.39	0.39	0.39	0.39	0.34	0.35	0.32	0.33	0.36	0.33	0.32	0.33	0.35	0.34
1996	0.35	0.36	0.36	0.38	0.38	0.31	0.36	0.32	0.34	0.35	0.37	0.35	0.34	0.35	0.36
1997	0.32	0.38	0.36	0.38	0.40	0.35	0.36	0.29	0.33	0.34	0.35	0.35	0.34	0.36	0.35
1998	0.32	0.37	0.34	0.36	0.36	0.34	0.35	0.30	0.32	0.33	0.36	0.35	0.32	0.34	0.32
1999	0.33	0.38	0.34	0.37	0.38	0.35	0.36	0.32	0.34	0.32	0.34	0.35	0.34	0.36	0.34
2000	0.33	0.38	0.36	0.37	0.38	0.36	0.35	0.30	0.34	0.35	0.41	0.36	0.36	0.36	0.35
2001	0.41	0.41	0.40	0.40	0.40	0.42	0.42	0.36	0.38	0.39	0.44	0.41	0.39	0.40	0.37
2002	0.39	0.47	0.42	0.46	0.41	0.38	0.40	0.37	0.37	0.37	0.42	0.37	0.38	0.36	0.35
2003	0.37	0.40	0.42	0.41	0.39	0.37	0.40	0.36	0.36	0.37	0.41	0.38	0.37	0.36	0.32
2004	0.37	0.39	0.42	0.41	0.37	0.36	0.42	0.39	0.37	0.39	0.40	0.39	0.39	0.35	0.36
2005	0.41	0.41	0.41	0.39	0.40	0.39	0.40	0.39	0.37	0.44	0.41	0.38	0.40	0.39	0.38
2006	0.43	0.43	0.45	0.43	0.40	0.49	0.43	0.40	0.53	0.54	0.53	0.46	0.41	0.47	0.64
2007	0.49	0.54	0.43	0.50	0.67	0.47	0.48	0.49	0.48	0.51	0.47	0.48	0.51	0.50	0.47
2008	0.37	0.46	0.46	0.46	0.45	0.41	0.45	0.40	0.33	0.42	0.42	0.38	0.36	0.38	0.38
2009	0.38	0.43	0.39	0.39	0.40	0.38	0.49	0.39	0.37	0.42	0.39	0.40	0.37	0.37	0.36
2010	0.35	0.39	0.40	0.39	0.40	0.35	0.36	0.38	0.33	0.38	0.38	0.33	0.34	0.34	0.34
2011	0.44	0.38	0.39	0.37	0.37	0.41	0.45	0.39	0.35	0.37	0.40	NA	0.38	0.34	0.34
2012	0.31	NA	0.34	0.35	0.33	0.38	0.32	0.38	0.31	0.33	0.37	NA	0.40	0.34	0.31
2013	0.34	NA	0.35	0.38	0.41	0.37	NA	0.40	0.34	0.37	0.38	NA	0.40	0.37	0.43
2014	0.35	NA	0.35	0.39	0.42	0.39	NA	0.42	0.37	0.39	0.43	NA	0.46	0.40	0.40
2015	0.45	NA	0.77	0.42	0.46	0.47	NA	0.52	0.50	0.74	NA	NA	NA	0.47	0.52

NA — not assessed.

value of Ca concentration were within the SAL value of 75 mg/L at locations S1, S2, and S3 during the sampling period. Although, the mean value of Ca concentration at location S4 and S5 were obtained as 19.65 and 24.02 mg/L during the sampling period, but the maximum Ca concentration was above the SAL during monsoon months in the year 2006 for both locations. The concentration of NO_3+NO_2 in river water was found in the range of 0.2–7.0 mg/L, and was lower than the SAL (NO_3:45 mg/L). The comparative analysis of WQ datasets with their corresponding SAL values reveals that the WQ of river Ganga was suitable for human use after conventional treatment. Our results were within the SAL and supported by Kumar et al. (2010) based on physiochemical characteristics (i.e., DO, BOD, COD, and TA) of WQ in river Ganga at Devprayag and Rudraprayag. Similar to the present estimate, the physiochemical and heavy metal (Pb, Cu, Zn, and Ni) concentration was found to be either absent or within the SAL with alkalinity (Na+ K) type at Rishikesh (Haritash et al., 2016).

In order to ensure the variability and statistical significance of data, the raw water quality data was used to evaluate kurtosis, skewness, and z-test values of individual parameters. At location S1, the kurtosis of parameters pH, BOD, F, B, SO_4, Na, K, and NO_2+NO_3 were found to be >3, meaning heavier tails than a normal distribution. The kurtosis of parameters TA, Ca, and WT were evaluated as −0.11, −0.14, and 0.41, respectively indicating the flatter peaks and lighter tails than the normal distribution. The negative skewness of −1.81, −0.39, 0.10, −0.42, and −0.29 were obtained for parameters pH, TA, Ca, Mg, and WT, respectively, indicating the tail of the left side of the distribution is fatter or longer than the tail on the right side. The z-value was zero for parameters EC, Ca, and Mg and positive for parameters BOD, B, Na, NO_2+NO_3, and WT, while negative z-value for others that signifies the raw score below the mean average. Similarly, the kurtosis, skewness, and z-value of parameter datasets were also evaluated at locations S2, S3, S4, and S5. Comparatively, a wide variation in kurtosis value of parameters BOD, B, Cl, Na, K, and NO_2+NO_3 was obtained at all locations indicating variable input of nutrients through wastewater or surface runoff discharge at different locations. Moreover, it is required to draw meaningful information, and classify the overall water pollution status at respective sampling locations in the river.

3.1. Evaluation of water quality index

CPI was estimated to classify the water pollution status at upstream region of river Ganga from 1989 to 2016. In order to present the seasonal water quality status, mean CPI value was evaluated using monthly CPI data for pre-monsoon, monsoon, and post-monsoon seasons and reported in Table 3. The range of the CPI were from 0.41–1.0, meaning the slightly polluted WQ during the pre-monsoon at location S1 (1991, 2001–02, 2005, 2006–07, 2011, and 2015), at location S2 (1991, 2002, 2005–09, and 2015), at location S3 and S4 (1989, 1991, 2002–08, and 2015), at location S5 (1989–94, 2002, 2007–08, and 2013–15); monsoon season at location S1 (1990, 2001, 2006–08, 2011, and 2015), at location S2 (1989–90,

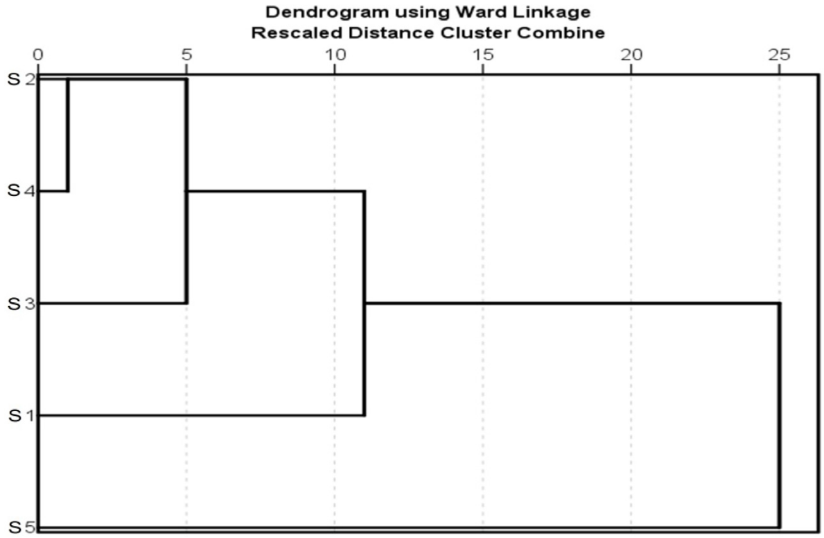

Fig. 4. Dendrogram of water quality based on Ward method.

2001–04, 2006–09, 2011 and 2015), at location S3 (1989–90, 2007, 2014, 2015), at location S4 (1989–91, 2006–07, 2015), and at location S5 (1989–91, 2005–09, 2015); and post-monsoon at location S1 (1990, 2000–03, 2005–08, 2014–15), location S2 (1990, 2001, 2006–07, 2015), location S3 (1990, 1992, 2006–07, 2014–15), location S4 (1990, 2006–07, 2015), location S5 (1989, 2006–07, 2013, 2015). Considerably, the good quality of water was observed in other sampling periods at all locations.

The comparative analysis of the CPI reveals that all sampling locations were slightly polluted during the pre-monsoon season in year 1991, 2002, 2007, and 2015 and in the year 1990, 2007, and 2015 during the monsoon season, and in the year 2006–07, and 2015 during the post-monsoon season. In general, CPI results reveal that the WQ in river has been slightly polluted during all the sampling months in year 2007, and 2015 at all the locations. Thus, the assumptions revealed from the comparative analysis of WQ parameters with their SAL value are found to be viable based on CPI results. In this study, CPI results revealed that the conventionally treated river water could be used for drinking purposes. The early evaluation of the WQ based on the nine locations of river Ganga between Haridwar city to Garhmukteshwar during the year 2014–2015 using CPI method reported 2.71 and 2.82 for pre- and post-monsoon seasons, respectively, signify severely polluted water unsuitable for human use (Chaudhary et al., 2017). Contrary to this, WQ of the river Ganga at Allahabad (Prayagraj) based on CPI was poor quality (Sharma et al., 2014). Moreover, in order to identify the similarity and dissimilarity of WQ among the sampling locations, statistical cluster analysis was performed using the hierarchical cluster analysis (HCA).

3.2. Hierarchical cluster analysis

The overall mean datasets of WQ parameters were used for cluster analysis using the HCA through Ward method. The agglomeration resulted into two clusters in HCA and represented by the dendrogram plot (Fig. 4).

In cluster one, the sampling locations S1 and S2 were grouped, and cluster two contains S2, S3, S4, and S5. Considerably, location S2 was found in both the clusters, which might be due to the impact of their geomorphologic position and wastewater discharge from both the point and non-point sources. The first cluster signifies input of wastewater into the river and can be mainly from the natural sources; however, the second cluster contained the impact of both anthropogenic and natural hindrances in the river. Most of the sampling locations of downstream regions were grouped in the second cluster confirming the input of wastewater through runoffs from the catchment (forest cover and agricultural area). The changing trends in aquatic environment of river Ganga at locations Uttarkashi and Tehri Zero point were investigated through evaluating the correlation between WQ datasets and the discharge and found good category of water (Kumar et al., 2017a,b). Therefore, the results indicate the dilution effect of surface runoffs in the catchment area due to the base flow. Further, a Pearson correlation coefficient and PCA were performed to identify the source of nutrients in the river Ganga so that mitigation strategies could be suggested in advance to maintain the safeguard of WQ for human consumptive use.

3.3. Relationships between the water quality parameters

The inter-relationship of parameters indicates the input sources or pathways of nutrient-loaded wastewater, thereby alters the water characteristics in a water body (Ray et al., 2018). The Pearson correlation coefficient of WQ parameters was estimated to understand the pathway and input source of nutrients in the river using raw WQ datasets for each sampling location (*see supplement Table S2–S6*). At location S1, the positive correlation coefficient was estimated between K-SO_4 (0.86), K–Na (0.75), Na-SO_4 (0.71), B-SO_4 (0.54), B–Na (0.46), B–K (0.54), TA-Ca (0.51), TA-Mg (0.51), Ca–Mg (0.43), EC-TA (0.41), EC-F (0.30), EC-Mg (0.39), pH-TA (0.37), pH-Ca (0.36), and pH-Mg (0.26), however, a negative correlation coefficient was found between DO–WT (−0.39), Mg-K (−0.57), Mg-SO_4 (0.46), Mg–Na (0.39), EC-K (−0.34), EC-Na (−0.22), and EC-SO_4 (−0.28). At location S2, the positive correlation was found between K-SO_4 (0.90), Na-SO_4 (0.84), Na–K (0.87), Na–Ca (0.74), Na-Cl (0.63), TA-K (0.65), TA-Cl (0.62), TA-Ca (0.83), TA-Na (0.80), TA-SO_4 (0.60), and TA-NO_2+NO_3 (0.43) with negative correlation coefficient between DO-Ca (−0.59), BOD-DO (−0.51), DO-TA (−0.52), Na-DO (−0.48), K-DO (−0.40), and DO–WT (−0.46). At location S3, the positive correlation was observed between K-SO_4(0.88), Na-SO_4 (0.78), Ca–Na (0.75), Na–K (0.76), Ca-NO_2 +NO_3(0.61), Na-Cl (0.54), B-SO_4(0.57), B–K (0.56) and negative correlation coefficient was observed between DO–WT (−0.44), WT–pH (−0.26), EC-Ca (−0.28), EC-SO_4 (−0.29), EC-Na (−0.29), EC-K (−0.21), B-Mg (−0.32), Mg–K (−0.37). At location S4, the positive correlation was found between Na-SO_4 (0.77), K-SO_4 (0.75), Na–K (0.68), Na-Cl (0.60), BOD-Na (0.67), Ca–Na (0.56) and the negative correlation coefficient was observed between Mg–K (−0.53), DO–WT (−0.41), EC-Na (−0.47), EC-B (−0.41), and Mg–B (−0.40). At location S5, the positive correlation was found between Na-SO_4 (0.76), K-SO_4 (0.86), Na–K (0.84), Na–Ca (0.62), Na–B (0.53), Na–K (0.55), Na-TA (0.61), TA-Ca (0.63) and the negative correlation coefficient was obtained between DO–WT (−0.62), Mg–K (−0.45), F-SO_4 (−0.41), and pH–BOD (−0.39). During the comparative analysis, negative correlation between DO–WT, and pH–BOD at all the sampling locations were found which signifies that the river water tends to be slightly polluted, loaded with organic nutrients. Negative correlation between DO-TA signifies that increased concentration of inorganic salts (in form carbonate and bicarbonate ions with the SO_4, Cl, and NO_2+NO_3 anions), resulting into interference with the solubility of oxygen (Sharma et al., 2014). The positive correlation among NO_2+NO_3, Ca, Na, B, and K signify the significant contribution of organic and inorganic salts through runoffs from the surrounding natural weathering in mountainous resulting the river water alkaline (Mahmoodabadi and Arshad, 2018). The positive correlation coefficients among the WQ datasets indicate their significant mutual dependency, actual nutrients characteristics, and common input sources (Singh et al., 2020c).

3.4. Identifying the drivers of water quality responses

PCA was performed through varimax normalized rotation method using WQ datasets to validate the relationship between parameters and to further identify the input source of nutrients for WQ. The rotation of the PCs was performed to elucidate an easy and relevant portrayal of the loading factors by adjusting the significant contributor (Dutta et al., 2018). Primarily, scree plot of WQ datasets was constructed to estimate the number of components obtained during the PCA (Fig. 5). For location S1, the scree plot indicates the major break after second component, which reveals that the first two components could produce more meaningful information about the loading of nutrients in the river water (Supplementary figure S1(a)). The component eigen-values curve in scree plot has dropped after the fourth component which indicates that four components might be useful for better interpretation of nutrient loading. Similarly, scree plots curves indicating component eigen-values obtained from the datasets at locations S2, S3, S4, and S5 have resulted into 4, 6, 5, and 5 PCs, respectively for these locations (Supplementary figure S1(b–e)).

All the PCs have eigen-value >1 with a cumulative variance of 63.39%, 75.35%, 80.64, 74.53%, and 77.74% for datasets of location S1–S5, respectively. Moreover, the Kaiser–Meyer–Olkin (KMO) and Bartlett's test of sphericity of datasets were estimated before performing the component analysis. The KMO values of 0.69, 0.69, 0.70, 0.66, and 0.65 with Bartlett's test of sphericity (degree of freedom: 105; and zero significance), the Chi-square values of approximately 815.12, 1009.81, 865.04, 1211.26, and 691.14 were estimated for WQ datasets of all five locations S1–S5, respectively, which signify the suitability of datasets for PCA. The PCA component's value and commonalities of datasets are reported in Table 4. All the PCs have high loading of different parameters (Fig. 5) leading to better insight into the hydrochemical and biological interpretation.

PCA for location S1 was resulted into four PCs with PC1 having 26.49% variance explained with higher positive loading for K, SO_4, Na, Cl, DO, and BOD. PC2 has positive loading of all parameters except F and WT. The positive PC value of 0.62 for F was obtained in PC3, while WT was positively loaded in PC3 (PC value of 0.25), and PC4 (with highest PC value of 0.65). In PC2, Ca, TA, Mg, Cl, NO_2+NO_3, and pH exhibit their highest positive loading. The highest positive loading of Cl (0.59) was obtained in PC3, while loading of BOD (0.47) and EC (0.24) were obtained in PC4. PCs for location S2 resulted into four PCs, where PC1 with variance of 37.97% exhibits the highest positive loading of Na, TA, K, Ca, SO_4, Cl, WT, and B, which indicates that the river receives a huge amount of runoffs water from agriculture and forest cover areas. The highest positive loading of parameters BOD and EC was obtained in PC2, while the highest positive loading of parameters Mg, NO_2+NO_3, and pH was found in PC3. Considerably, the parameters DO and F exhibits the highest positive loading in PC4. PCs for location S3 was defined by six PCs, with the highest positive loading of parameters Na, K, SO_4, Cl, Ca, and B were found in PC1 with the variance 29.72%, while the highest positive loading of parameters Mg, NO_2+NO_3, DO, TA and EC, parameter WT, parameter pH, and parameter BOD were obtained in PC2, PC3, PC4, PC5, and PC6, respectively. PCs for location S4 resulted into five PCs, where the parameters Na, K, SO_4, BOD, Cl, Ca, and B exhibits highest positive loading in PC1 with the variance 28.16%, while the highest positive loading of the parameters Mg, TA, NO_2+NO_3, and EC, F and WT, pH, and DO were obtained in PC2, PC3, PC4, and PC5, respectively. PCA for location S5 was based on five PCs, where the parameters Na, K, SO_4, BOD, Cl, Ca, B, and TA exhibits the highest positive loading in PC1 with variance 29.85%, while the highest positive loading of the parameters Mg, NO_2+NO_3, and EC, WT, DO and pH were obtained in PC2, PC3, PC4, and PC5, respectively.

Table 4
Principal component matrix and Communalities of physiochemical parameters analysed during January 1989 to January 2016.

	PC	IEV	Variance %	Cumulative %	Na	K	SO_4	BOD	Cl	Ca	B	Mg	TA	NO_2+NO_3	EC	F	WT	DO	pH
S1	1	3.97	26.49	26.49	0.78	0.92	0.85	0.10	0.26	−0.21	0.64	−0.72	−0.48	−0.10	−0.51	−0.36	−0.21	0.14	−0.21
	2	2.56	17.04	43.54	0.28	0.13	0.32	0.33	0.54	0.75	0.17	0.47	0.64	0.54	0.19	−0.09	−0.41	0.22	0.45
	3	1.55	10.34	53.87	0.04	0.00	0.00	0.33	0.59	−0.16	0.29	0.17	−0.08	0.08	0.24	0.62	0.25	−0.42	−0.52
	4	1.43	9.52	63.39	0.04	0.05	0.08	0.47	−0.03	0.08	−0.31	0.04	−0.06	0.28	−0.18	−0.56	0.65	−0.48	0.09
	Communalities				0.69	0.87	0.84	0.45	0.71	0.64	0.62	0.76	0.65	0.38	0.39	0.83	0.70	0.47	0.52
S2	1	5.70	37.97	37.97	0.94	0.85	0.83	0.40	0.68	0.84	0.55	0.05	0.88	0.45	0.21	−0.30	0.46	−0.65	0.21
	2	2.30	15.31	53.27	−0.08	−0.38	−0.37	0.53	0.27	0.28	−0.27	0.61	0.21	0.34	0.58	0.52	−0.26	−0.2	−0.52
	3	2.02	13.44	66.72	−0.04	−0.19	−0.04	−0.12	0.11	0.17	−0.23	0.65	0.01	0.61	−0.56	−0.43	−0.44	0.09	0.60
	4	1.30	8.64	75.35	0.08	0.05	0.12	−0.44	0.33	−0.07	0.49	0.07	0.08	0.14	0.04	0.59	−0.26	0.52	0.06
	Communalities				0.90	0.90	0.84	0.65	0.65	0.81	0.67	0.80	0.82	0.71	0.70	0.89	0.54	0.74	0.68
S3	1	4.46	29.72	29.72	0.92	0.81	0.88	0.51	0.67	0.81	0.58	−0.06	0.34	0.46	−0.28	0.02	0.02	0.17	0.25
	2	2.21	14.75	44.47	−0.14	−0.45	−0.27	0.12	0.31	0.29	−0.28	0.80	0.36	0.60	0.26	0.26	−0.42	0.41	0.2
	3	1.69	11.26	55.73	0.00	0.08	0.00	−0.27	0.25	−0.18	0.33	0.00	0.65	−0.11	0.68	0.46	0.25	−0.40	−0.27
	4	1.54	10.27	66.00	0.17	0.00	−0.07	0.41	0.09	0.13	−0.52	0.32	−0.32	0.08	0.02	0.21	0.68	−0.57	0.04
	5	1.16	7.70	73.70	−0.11	0.13	0.09	0.06	−0.08	−0.17	−0.04	−0.07	0.01	−0.22	−0.05	0.47	−0.29	−0.21	0.82
	6	1.04	6.94	80.64	0.01	0.06	−0.06	0.52	0.09	−0.12	−0.19	−0.13	0.23	−0.23	0.47	−0.57	−0.11	0.00	0.17
	Communalities				0.90	0.88	0.86	0.80	0.63	0.82	0.83	0.77	0.81	0.69	0.83	0.87	0.80	0.73	0.88
S4	1	4.23	28.16	28.16	0.95	0.81	0.84	0.62	0.60	0.55	0.46	−0.35	0.22	0.32	−0.51	−0.31	0.24	−0.06	−0.12
	2	3.09	20.59	48.75	0.09	−0.25	−0.05	0.27	0.50	0.53	−0.35	0.75	0.71	0.64	0.61	0.22	−0.44	0.34	0.28
	3	1.57	10.47	59.22	0.00	−0.06	−0.11	−0.02	0.40	−0.21	0.27	0.03	0.30	−0.04	0.15	0.76	0.44	−0.5	−0.39
	4	1.21	8.04	67.26	−0.11	0.24	0.24	−0.45	0.02	−0.04	0.43	−0.33	0.15	0.02	0.25	0.19	−0.54	−0.15	0.38
	5	1.09	7.26	74.53	0.03	−0.04	−0.15	0.05	0.05	−0.03	0.45	0.08	−0.26	0.08	−0.16	0.27	−0.35	0.59	−0.46
	Communalities				0.92	0.79	0.81	0.66	0.77	0.64	0.79	0.79	0.74	0.53	0.75	0.82	0.86	0.74	0.6
S5	1	4.48	29.85	29.85	0.93	0.85	0.78	0.44	0.45	0.73	0.57	−0.19	0.68	0.19	0.24	−0.14	0.37	−0.47	−0.25
	2	2.45	16.35	46.19	−0.06	−0.35	−0.29	0.40	0.31	0.45	−0.41	0.83	0.44	0.63	0.35	0.17	−0.41	0.09	−0.12
	3	1.91	12.74	58.94	−0.02	−0.20	−0.40	0.07	0.13	−0.17	0.15	0.02	0.28	−0.39	0.33	0.82	0.43	−0.6	0.27
	4	1.46	9.71	68.64	0.13	0.20	0.16	−0.41	0.09	−0.04	0.03	−0.02	0.38	−0.11	0.28	0.15	−0.33	0.52	0.75
	5	1.36	9.10	77.74	0.07	−0.07	0.04	−0.39	0.43	−0.02	0.38	0.27	−0.11	0.36	−0.74	0.31	0.00	−0.07	0.09
	Communalities				0.88	0.93	0.88	0.68	0.51	0.77	0.67	0.79	0.88	0.74	0.91	0.84	0.60	0.86	0.72

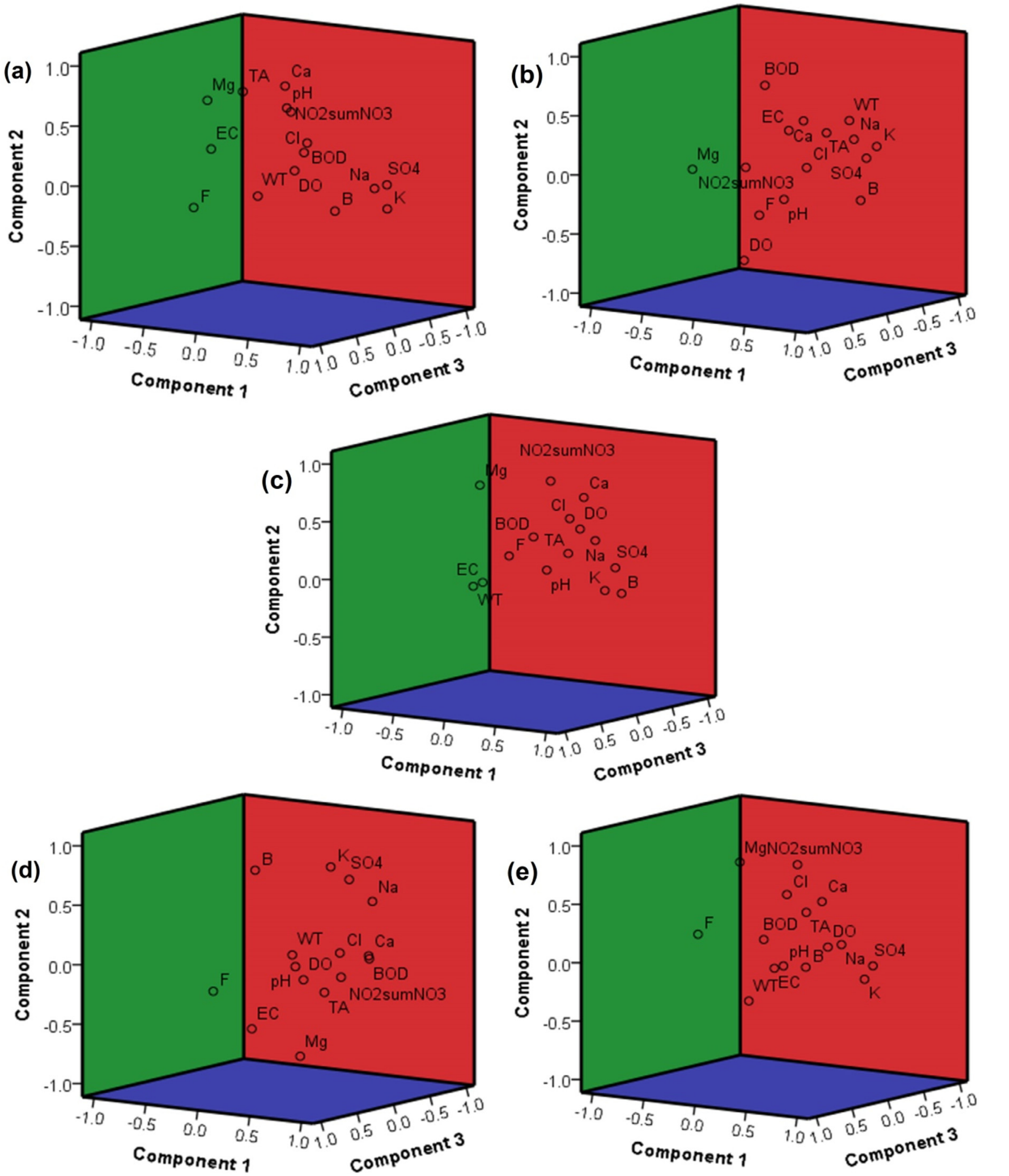

Fig. 5. Component loadings plot of water quality at various location: (a) Uttarkashi; (b) Tehri; (c) Rudraprayag; (d) Devprayag; (e) Rishikesh.

The parameters loading in PC1 governed the nutrient input source from natural sources, while positive loading of parameters in PC2 defined the nutrient input through direct discharge of partially or untreated treated domestic or industrial wastewater into the river (Mishra and Kumar, 2020; Kumar et al., 2018). During the comparative analysis of parameters loading in PCs at all locations, it was noted that the parameter K, SO_4, Na, and Cl were positively loaded in PC1, which signified the input of their salts from both natural source through runoff or landslides and anthropogenic agricultural activities (where use of chemical herbicides, fertilizers, pesticides, and mining operations occurs) (Dalakoti et al., 2018). In this study, the trend of parameters loading in different PCs was found to be almost similar at all locations. Loading of parameters in PC2 was due to the input of nutrients specifically from the anthropogenic activities including agriculture, while parameters loading in the PC3, PC4, PC5, and PC6 were defined based on the input from the natural sources (Rajkumar et al., 2018). The upstream Ganga river basin's catchment area (lies in active Himalayan Mountain) is mainly covered by forest and agriculture land with scarce industrial setup compared to the downstream plain areas with dense industrial setup. Therefore, the surface runoff and landslide due to weathering of parent materials often occur in the area, which might be the major input source of nutrients in the river Ganga. Researchers across the domain have investigated the water characteristics of river Ganga all along the stretch (Table 5).

The river water quality in the upstream region (from Uttarkashi and Tehri Zero Point Bridge via Devprayag to Rishikesh) has been reported to be good and safe for human consumption. The observations and findings in this study also supported the similar water characteristics at these locations. Compared to the upstream region, the downstream region (plain area from Haridwar to Kolkata) of river Ganga is found to be highly polluted due to excessive anthropogenic hindrance, large input of domestic and industrial wastewater into the river (Kumar et al., 2018, 2019a,b).

3.5. Effect of countrywide lockdown on the water quality of river Ganga

In order to control infectious spread of pandemic flue disease caused by the pandemic Coronavirus (COVID-19), the government of India implemented the lockdown of country since 24th March 2020. During the lockdown period, human life comes to a standstill and all the major industrial activities (except medical and food industries) were shutdown (Yunus et al., 2020). For decades, water pollution along the stretch of river Ganga has been a prime concern and a matter of research that is reported by numerous researchers in the literature (Table 5). Based on the literature available, the major cause of water pollution has been identified as direct discharge of partial or untreated wastewater from industries located in the basin of river Ganga and its tributaries. During the lockdown, since all the anthropogenic activities were prohibited and closed down for weeks, it was expected that pollution load could decrease in the environment (Yunus et al., 2020). According to CPCB (2020) real-time WQ analysis of river Ganga, it is observed that the WQ is improvised and found suitable for life-supporting purposes in the studied stretch (CPCB, 2020).

Previously, the river Ganga water at sampling locations like Haridwar city, Kanpur city, Varanasi city, Prayagraj, and others were found to be severely polluted (DO <3 mg/L, unsuitable biotic environment) in every month and seasons as well, reported by Mishra et al. (2009), Chaudhary et al. (2017) and others. Considerably, the WQ at these locations becomes suitable for human use as the parameters like BOD, DO, EC, pH, WT, Cl, COD, F, NO_3, and K are found within their permissible limit during the lockdown period in April 2020 (Table 6). Moreover, river Ganga has self-assimilative or purification capability, which seems to be enhanced during the recent lockdown period (Dwivedi et al., 2020). The results of WQ in preceding years were compared and it is observed that the aim of rejuvenation of river Ganga could not be achieved with GAP-I and GAP-II, however, during lockdown, the WQ was improved significantly and become suitable for human consumptive use. Therefore, it can be inferred that if the discharge of industrial effluent and wastewater in river Ganga would be checked, the river would rejuvenate herself. Moreover, this study draws further attention to the WQ of the river after the upliftment of the lockdown once the industrial activities will be resumed and the pollutants along with the wastewater will eventually be discharged into the river. Therefore, it is suggested that appropriate and stipulated actions should be implemented immediately to reduce the risk of environmental damage to the sacred river Ganga ecosystem with maintaining ecological health. Present study will act as a reference to the water planners & managers, governors, environmentalists, and policy-makers to take strategic mitigation plan to maintain the aesthetic and cultural value of the river.

4. Conclusions

The long-term study estimates the WQ of river Ganga based on the physiochemical parameters at the five upstream locations of Uttarakhand, India using CPI, PCA, and HCA to categorize the WQ into different classes for understanding the hydrochemistry and cluster of similar water quality status. The values of physiochemical parameters were within the acceptable limits signified good WQ of the Ganga river and suitable for life-supporting purposes after conventional treatment. PCA revealed the enrichment of K, SO_4, Na, and Cl in the river through the runoffs and discharge from natural sources (i.e., surface runoff from catchment, weathering of rocks, and landslides). Comparative analysis of upstream WQ with the downstream locations revealed that downstream river water is severely polluted. The prime sources of river WQ deterioration were discharge of domestic, industrial, and agricultural wastes at the downstream of River Ganga and contamination from local villages into the river water. During the country lockdown due to pandemic Coronavirus disease (COVID-19), the WQ at downstream region was improved and became suitable for life support purposes. It is found that the self-cleansing property of river was enhanced and rejuvenated during lockdown period, which has been troublesome tasks to achieve in decades.

This study yields the valuable information of different indices and multivariate statistical techniques in the investigation and explanation of the compound datasets in recognizing contaminant sources, and in understanding dissimilarities in water quality for better designing of action plans for river rejuvenation. The rejuvenation should be achieved by reducing

Table 5
Comparative analysis of water quality in river Ganga all along the stretch.

Location (District)	Parameters	Methodology	Observed water quality status	Source
Uttarkashi and Tehri Zero point	Physiochemical	Comparison with SAL value and statistical analysis	Good water quality, safe for human use	Kumar et al. (2017a,b)
Devprayag and Rudraprayag	Physiochemical and bacteriological	Comparison with SAL value	Good water quality, safe for human use	Kumar et al. (2010)
Rishikesh	Physiochemical and heavy metals (Pb, Cu, Zn, Ni)	Comparison with SAL value Langelier saturation index, Ryznar stability index	Good water quality	Haritash et al. (2016)
Haridwar	Physiochemical	Weighted arithmetic water quality index method	Poor water quality	Bhutiani et al. (2016)
Haridwar to Garhmukteshwar	Physiochemical and heavy metals (Fe, Cu, Cr, and Zn)	Water quality index evaluation method	Severely contaminated due to heavy metals, indicate human health risk	Chaudhary et al. (2017)
Fatehgarh and Kannauj	Physiochemical and bacteriological	Comparison with SAL value	• Poor water quality • High level of coliforms	Malik et al. (1995)
Kanpur				
Varanasi	Physiochemical and bacteriological	Comparison with SAL value	• High level of faecal contamination. • Polluted and not safe for human use	Mishra et al. (2009)
Varanasi	Heavy metals (Zn, Cu, Cd, Pb, Cr) and bacteriological	Comparison with SAL value	• Heavy metals concentration above permissible limit, microbial and faecal pollution, • Polluted, health hazard risk	Rai et al. (2010)
Mirzapur	Heavy metals (Cd, Co, Cu, Fe, Mn, Ni, Pb and Zn)	Comparison with SAL value	Heavy metals concentration above permissible limit, polluted water.	Sharma et al. (1992)
Allahabad (Prayagraj)	Physicochemical	Water quality index evaluation method	Poor quality of water	Sharma et al. (2014)
Patna	Physiochemical	Comparison with SAL value	Moderately polluted, not suitable for human use	Rai et al. (2011)
Kolkata	Physiochemical and heavy metals (Fe, Mn, Cu, Zn, Pb, Cd, Cr, and Ni)	Comparison with SAL value	• Rich in Mn, Zn, and Cu • Not suitable for human use	Aktar et al. (2010)
Uttarkashi to Rishikesh	Physiochemical	• Comparison with SAL value • Water quality index evaluation method • Statistical analysis	Good water quality, suitable for human use after conventional treatment	In this study

Table 6
Physiochemical characteristics of WQ in the river Ganga at downstream regions during April 2020.

Parameters	Units	Permissible limit (River)	Analysed values				
			Bathing Ghat, Kanpur city	Narora, Uttar Pradesh	Varanasi, Uttar Pradesh	Murshidabaad, West Bengal	Howrah bridge, West Bengal
BOD	mg/l	$\leq$ 3	1.20	2.17	1.89	1.65	0.59
DO	mg/l	$\geq$ 5	8.42	8.51	8.18	8.22	5
pH	Unit less	6.5 - 8.5	7.67	7.68	7.64	7.78	7.65
WT	°C	$\leq$ 35	23.2	23.9	23.6	26.8	27.5
COD	mg/L	< 10	7.04	9	9.23	3.36	9
Total suspended solid	mg/L	< 10	10	8	9	9	9
Nitrate	mg/L	< 10	0.74	0.89		1.42	2.4
Turbidity	NTU	$\leq$ 30	25	25	24	25	20.09

livestock activities and domestic discharge around the river, discharge of wastewater otherwise; over pollution have the potential effect on the human population leading to socio-economic disaster. These determinations should be considered for future planning and management of the river for realizing the potential ecosystem services to the inhibiting population along the river.

CRediT authorship contribution statement

Amit Kumar: Conceptualisation, Data analysis, Preparation of the first draft, Proofread the final version of manuscript and agreed for publication. **Saurabh Mishra:** Conceptualisation, Data analysis, Preparation of the first draft, Proofread the final version of manuscript and agreed for publication. **A.K. Taxak:** Data collection, Extraction, Formal analysis, Proofread the final version of manuscript and agreed for publication. **Rajiv Pandey:** Proofread the manuscript and agreed for publication. **Zhi-Guo Yu:** Proofread the manuscript and agreed for publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Appendix A. Supplementary data

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