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Analysis of water environment changing trend in Bhagirathi tributary of Ganges in India

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ABSTRACT

While determining the quality of water for any water body, low, medium and high values of a parameter stand out to be a very important reference. Moreover, these values are used to decide various design parameters based on scientific aspects and its real applications around the world. In this research, determination of trend of water quality (WQ) status for Bhagirathi River was carried out at two sites, Uttarkashi and Tehri station (Tehri Zero point), for 18 WQ parameters and discharges. Preliminary analysis reveals that all parameter concentrations are below the standard permissible limit. No significant correlation was observed between any parameter with respect to discharge; however, out of 18 parameters, 14 were showing negative correlation indicating groundwater source and geological origin. Moreover, a strong correlation was found between 11 parameters at both sites. Seasonal Mann-Kendall test and Sen's slope method have been used to detect trend and to quantify its magnitude. Increasing trend in the concentration of 7 WQ parameters (Q, EC, K^+, Na^+, SO_4^{2-}, BOD and Na%) was observed while decreasing trend was observed for 8 parameters (TA, Ca^{2+}, HCO_3^-, Mg^{2+}, $NO_2 + NO_3$, o-PO_4^{3-}, DO and TH). Overall, WQ of Bhagirathi River was found to be good and hence is suitable for drinking and life-supporting activities.

Keywords: Water quality; Bhagirathi; Ganges; Mann-Kendall; Sen's slope; Trend analysis

1. Introduction

Rivers are an important source of fresh water to mankind with a share of only 2% of world's fresh surface water resources. Human civilizations have flourished near the source of water. The Ganges, one of the largest rivers of India, is a source of water to many cities located on its bank. It is one of the most densely populated river basins in the world, supporting 29 Class-I cities (population ≥ 100,000), 23 Class-II cities (population 50,000–99,999), 48 towns, and thousands of villages. Over 500 million people were estimated to be living in the entire Ganga river basin in 2000, and this number is expected to grow to over 1 billion by 2030 [1].

For human use, water must meet a certain standard. The general properties of river systems tend to reflect a combination of geomorphological attributes modified by a wide range of direct and indirect climatic and human influences. Water quality tends to degenerate gradually with human interventions, such as hydrological alterations [2], land use change [3], inputs from toxic chemicals and nutrients [4], and changes in other physicochemical properties of water [5,6], which cause a series of environmental problems such as shortage of drinking water [7], deterioration of aquatic ecological systems [8], and emergence of endemic diseases [9], etc. During the twentieth century, large dams considered as one of the most important and visible tools for the water resources management. Generally, dam construction affects the river continuum,

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water quality and self-purification capacity of reservoir water and below-dam segment but enforces little impact on that of downstream-flowing segment [10].

There is a growing concern about water quality and water resource management with changing environmental scenarios, especially given the increased demand for agricultural, domestic and industrial water. Such concerns have stimulated the Indian Government to develop management plans for the Ganga river system aimed at a long-term strategy to improve the environmental flow and address water quality issues.

More researchers are now focusing on the aspect of water quality in recent decades due to increased awareness and availability of long records of data. Many studies have reported the water quality of water resources across the world [11–14]. When studying on water quality, it is also important to study the trend as well along with it. Trend analysis determines whether the measured values of a water quality variable decrease or increase during a period of time. Hirsch et al. [15] proposed an adaptation of the non-parametric Mann-Kendall test to detect trends in seasonally varying water quality time series.

In streams, the concentrations of solutes vary from time to time. A major source of this variation is the stream discharge [16,17]. A strong relationship between solutes concentrations and discharge at different spatial and temporal scales has been identified for streams [18]. A load of water solutes is an important variable of water quality if interest focuses on storage of the water and its constituents. A load of relatively conservative constituents may be important where the monitoring station is upstream of a reservoir, lake or estuary where the water has a long residence time and the exposure to chemicals by aquatic organisms or populations that ingest the water is of concern [19]. Different models were proposed to describe the relationship between concentration discharge and load discharge [15–17,20]. These relationships give information on the variation of quality parameters due to discharge.

To evaluate long-term planning and management of streams/rivers, the statistical and trend analysis, as well as the relations between concentrations or loads and discharge are important steps to know the behavior, streamflow and the variation of water quality parameters.

The scope of this research is to identify water quality trend in the study stretch of Bhagirathi River. This work aims at highlighting: (1) the monthly time series of water quality parameters, (2) the existence of trends and the evaluation of the best-fitted trend models and (3) the relationships between concentration and loads of solutes with discharge. Using the information of natural trend in the water quality, water resource managers can make informed decisions for water resource management and cleaning of the Ganga River.

2. Study area and data used

The Bhagirathi River originates from the Gangotri Glacier at Gaumukh in the Himalayas at an elevation of nearly 3,892 m and traverses a length of about 205 km before it is joined by Alaknanda River and forms the Ganges. The main sources of water in the rivers are rainfall, sub-surface flow and snowmelt water from the Himalayas. Average annual rainfall varies between 1,000 to 1,500 mm (as per the IMD gridded [0.25 × 0.25] data set), with the western side of the region receiving less rainfall in comparison with the eastern side. Rainfall is concentrated in the monsoon months of June to October, low flow conditions in the Bhagirathi River, and its tributaries occur during the dry periods of November to May. Snowfall occurs at higher elevations during the winter months of December and January. The location of two sites is shown in Fig. 1, and their mean monthly temperature and precipitation are represented by Ombrothermic diagram shown in Fig. 2.

The map shows the Himalayan headwaters of the Bhagirathi River (as well as its course), the source stream of the Ganges River of the Indian subcontinent. That map, in turn, is based on the map of the region produced by the Surveyor General of India. The Uttarkashi point is high in the Himalayas at an elevation of 1,095 m. Tehri point is at 580 m elevation downstream of Uttarkashi after the confluence of Bhilangna into Bhagirathi River. Both the sites lie in the Uttarakhand state of India. The study area covers a large portion of snow and forest with very high slopes, i.e., mean of 57% to highest 337%. The towns in the study area come under the Tier IV to Tier VI categories, with the largest city Uttarkashi having a population of 16,500 (Census 2011).

Water quality data for 28 variables collected from Central Water Commission (CWC), Dehradun, for two sites at Uttarkashi (HO-445) and Tehri – Zero Point Bridge (HO-444) on Bhagirathi River, a tributary of Ganges from June 2003 to December 2013. As raw data sets usually suffer from drawbacks of gaps, wrong entries, and outliers, quality check was

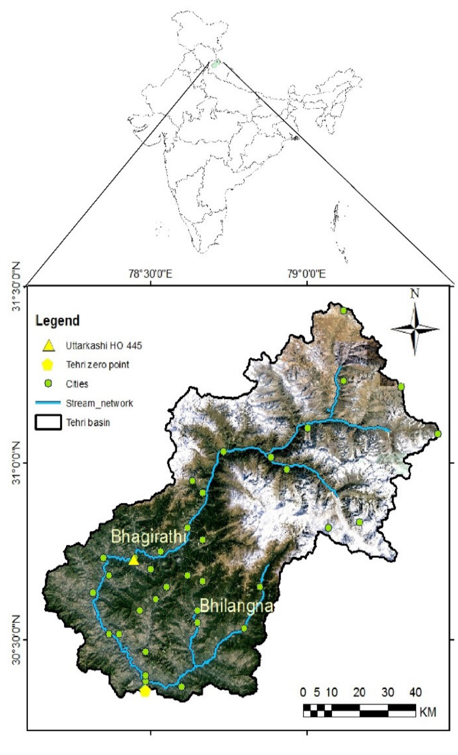

Fig. 1. Map showing location of study sites and stream network.

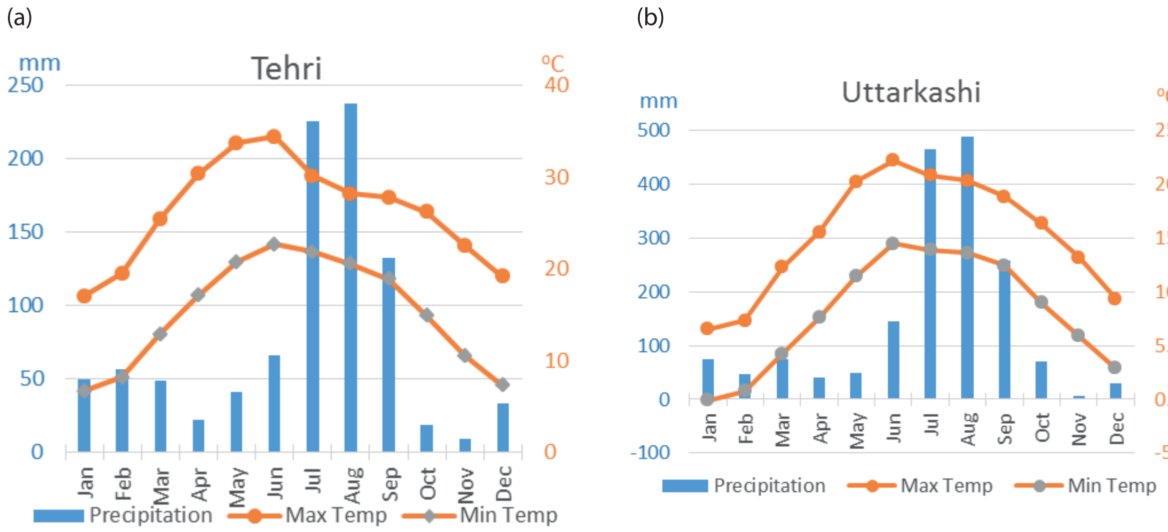

Fig. 2. Ombrothermic diagram of: (a) Tehri and (b) Uttarkashi.

done and depending on data quality; 19 variables (Q, EC, pH, T, TA, Ca^{2+}, Cl^-, F^-, HCO_3^-, K^+, Mg^{2+}, Na^+, $NO_2 + NO_3$, o-PO_4^{3-}, SO_4^{2-}, BOD_3^{27}, DO, TH and Na%) are selected for further analysis. The details of 19 variables, their symbols, units and standard values are given in Table 1.

3. Methodology

Some of the characteristics that complicate the analysis of water quality time series are non-normal distributions, seasonality, flow relatedness, missing values, values below the limit of detection and serial correlation. Parametric (assumes distribution) and non-parametric (distribution-free) analysis methods are regularly used by researchers for trend analysis. The Mann-Kendall test is suitable for cases where no seasonal or the other cycle is present in the data. Non-parametric 'seasonal Mann-Kendall (SK)' is one of the widely used test for trend analysis of monthly water quality data for monotonic trends that are suitable in the face of the complications listed above. The result of SK test reported in *p*-value. At 95% confidence level, *p*-value less than 0.05 represents a significant trend. Sen's slope gives the trend magnitude. Change in mean over time of the parameter is calculated using Sen's slope.

3.1. Seasonal Mann-Kendall test

The SK is a kind of non-parametric test, which can deal well with the missing values and seasonal changes in the data. It was put forward by Hirsch et al. [15] and widely used in water quality trend testing and analysis [21–23].

3.2. Theil and Sen's median slope

The slope of n pairs of data points was estimated using the Theil–Sen's estimator [24,25], which is calculated as follows:

$$Q_i = \frac{(x_j - x_k)}{(j-k)} \quad \text{for } i = 1,\ldots N \tag{1}$$

Table 1
Parameters used in the study, their units and standard permissible value

Parameters	Permissible value
Discharge Q, Cumec	–
Electrical conductivity EC, µmho/cm	300
pH	6.5–8.5
Water temperature T, °C	40
Total alkalinity (as $CaCO_3$) TA, mg/L	300
Calcium Ca^{2+}, mg/L	75
Chloride Cl^-, mg/L	250
Fluoride F^-, mg/L	1.0
Bicarbonate HCO_3^-, mg/L	200
Potassium K^+, mg/L	200
Magnesium Mg^{+2}, mg/L	30
Sodium Na^+, mg/L	200
Nitrite plus nitrate $NO_2 + NO_3$, mg/L	*45 (NO_3), 0.06 (NO_2), **1.0 (NO_2)
Ortho phosphate o-PO_4^{3-}, mg/L	<0.2
Sulfate SO_4^{2-}, mg/L	250*
Biochemical oxygen demand BOD_3^{27}, mg/L	5
Dissolved oxygen DO, mg/L	5
Total hardness (as $CaCO_3$) TH, mg/L	300
Percent sodium Na%	–

Source: Indian Standards Drinking Water specification IS 10500: 2012.
*Guidelines for drinking water quality, WHO (2009), Geneva.
** United States Environmental Protection Agency (2015).

where x_j and x_k are data values at times j and k ($J > k$), respectively. The median of these N values of Q_i is Sen's estimator of slope. If there is only one data in each time period, then:

$$N = \frac{n(n-1)}{2} \tag{2}$$

where n is the number of time periods. The median of the N estimated slopes is obtained in the usual way, i.e., the N values of Q_i are ranked by $Q_1 \le Q_2 \le \ldots \le Q_{N-1} \le Q_N$ and

$$\text{Sen's estimator} = \begin{cases} Q_{(N+1)/2} & \text{if } N \text{ is odd} \\ \frac{1}{2}\left(Q_{N/2} + Q_{(N+2)/2}\right) & \text{if } N \text{ is even} \end{cases} \quad (3)$$

3.3. Change magnitude as percentage of mean

Change percentage has computed by approximating it with a linear trend, i.e., change percentage equals median slope multiplied by the period length divided by the corresponding mean, expressed as a percentage (Pc) followed after Yue and Hashino [26].

$$\text{Percentage change} = \frac{\beta \times \text{length of year}}{\text{mean}} \times 100 \quad (4)$$

4. Results and discussion

4.1. Preliminary analysis

Preliminary analysis was performed using minimum, mean, maximum and standard deviation before trend analysis. The statistical measures of water quality variables at the Uttarkashi and Tehri stations used in the following analysis have been given in Table 2 and graphically represented in Fig. 3. The magnitude of the fluctuations in the discharge is much greater than the measured concentrations of water quality.

The monthly mean of Q, EC, pH, T, TA, Ca^{2+}, Cl^-, F^-, HCO_3^-, K^+, Mg^{2+}, Na^+, $NO_2 + NO_3$, o-PO_4^{3-}, SO_4^{2-}, BOD_3^{27}, DO, TH and Na% for Uttarkashi was found as 169.80 ± 199.03, 128.90 ± 27.27, 7.89 ± 0.34, 12.18 ± 2.77, 53.10 ± 12.34, 18.25 ± 6.71, 8.75 ± 2.46, 0.59 ± 0.42, 64.52 ± 15.39, 0.37 ± 2.23, 12.21 ± 4.59, 2.99 ± 1.25, 0.31 ± 0.13, 0.45 ± 0.25, 8.20 ± 1.80, 1.23 ± 0.11, 8.02 ± 0.79, 96.52 ± 33.60 and 7.47 ± 4.63, respectively, whereas for Tehri station was found as 260.09 ± 225.64, 133.35 ± 23.02, 7.90 ± 0.33, 14.84 ± 2.13, 54.35 ± 14.55, 18.65 ± 6.02, 9.18 ± 2.60, 0.65 ± 0.45, 66.70 ± 18.82, 0.56 ± 0.19, 12.69 ± 3.41, 3.06 ± 1.21, 0.37 ± 0.14, 0.46 ± 0.26, 8.48 ± 2.13, 1.21 ± 0.18, 8.26 ± 0.88, 98.68 ± 31.76, and 7.24 ± 4.52, respectively.

All the parameters found below permissible limit except pH and fluoride. After further analysis, pH was found above permissible limit (pH: 8.5) only for September 2010 at Uttarkashi station, whereas in December 2005 and January 2006 for Tehri station. Fluoride concentrations at both stations suddenly rise to 2 mg/L but then decreases gradually below the standard permissible limit. Rivers and lakes contain fluoride levels less than 0.5 mg/L, but groundwater, particularly in volcanic or mountainous areas, can contain as much as 50 mg/L [27]. Higher concentration of DO, a lower concentration of nutrients (N and P) and BOD come under the categories of good water quality in Bhagirathi River.

4.2. Exploratory data analysis

The data of the water quality parameters was graphically analyzed using Box-Whisker plot. It provides visual summaries of: (a) the centre of the data (the median = the centre line

Table 2
Basic statistics of parameters

Parameter	Uttarkashi				Tehri			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Q	1.9	805.4	169.80	199.03	1.85	1,082	260.09	225.64
EC	81	200	128.93	27.27	98	200	133.35	23.02
pH	6.40	9	7.89	0.34	7	8.90	7.90	0.33
T	5	17.50	12.18	2.77	8	19	14.84	2.13
TA	23	80	53.10	12.34	17	80	54.35	14.55
Ca^{2+}	6	31	18.25	6.71	8	31	18.65	6.02
Cl^-	4	15	8.75	2.46	3.8	17	9.18	2.60
F^-	0.05	2	0.59	0.42	0.05	2	0.65	0.45
HCO_3^-	23	80	53.10	12.34	17	80	54.35	14.55
K^+	0	0.80	0.37	0.23	0.1	1.10	0.56	0.19
Mg^{2+}	1.2	22	12.21	4.59	4.80	19.8	12.69	3.41
Na^+	0.70	7.20	2.99	1.25	0.70	7.2	3.06	1.21
$NO_2 + NO_3$	0.08	0.52	0.31	0.13	0.08	0.52	0.37	0.14
o-PO_4^{3-}	0.01	0.98	0.45	0.25	0.01	0.98	0.46	0.26
SO_4^{2-}	4.50	13.50	8.20	1.80	4.50	15.60	8.48	2.13
BOD_3^{27}	0.90	1.80	1.23	0.11	0.70	2	1.21	0.18
DO	5.80	9.60	8.02	0.79	6.10	10.20	8.26	0.88
TH	35	160	96.52	33.60	40	156	98.68	31.76
Na%	1	23	7.47	4.63	1	23	7.24	4.52

Note: Min: minimum value, Max: maximum value, and SD: standard deviation.

of the box); (b) the variation or spread (interquartile range = the box height); (c) the skewness (quartile skew = the relative size of box halves) and (d) presence or absence of unusual values (outliers and extreme values). Boxplots come handy for comparing attributes of data sets at several locations. Fig. 3 provides the boxplots of water quality parameters and discharge at Uttarkashi and Tehri stations. Results observed that parameter values at Uttarkashi and Tehri stations are almost in close agreement with each other. The boxplots of Q, EC, pH, T, F^-, K^+, Na^+, SO_4^{2-}, BOD, DO and Na% depart from a normal distribution not only in skewness but also by the number of outliers and the extreme values. Only values of orthophosphate (o-PO_4^{3-}) were close to normal distribution.

4.3. Correlation analysis

The concentration of water quality parameters in a freshwater body like river varies with time. The correlation of the parameters with the discharge is calculated to study the concentration-discharge relationship (Table 3). No significant correlation found between water quality parameters and discharge. Fourteen out of nineteen parameters are showing a negative correlation with discharge. It is due to the dilution effect of surface runoff, during periods of high runoff in the catchment, on the water of base flow [16]. Moreover, Inverse correlation shows that parameters have groundwater sources, whereas Na^+ have the surface water source. The temperature was highly positively correlated with the discharge,

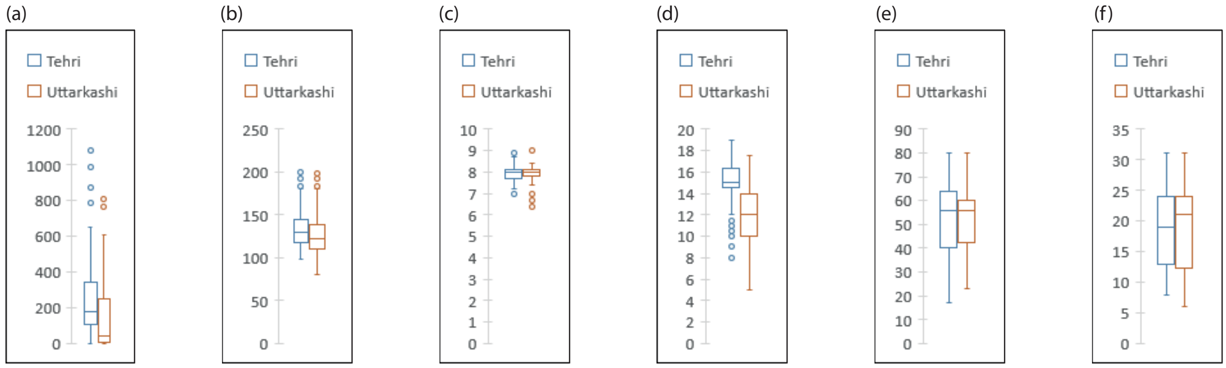

Fig. 3(A). Boxplots of: (a) Q, (b) EC, (c) pH, (d) T, (e) TA and (f) Ca.

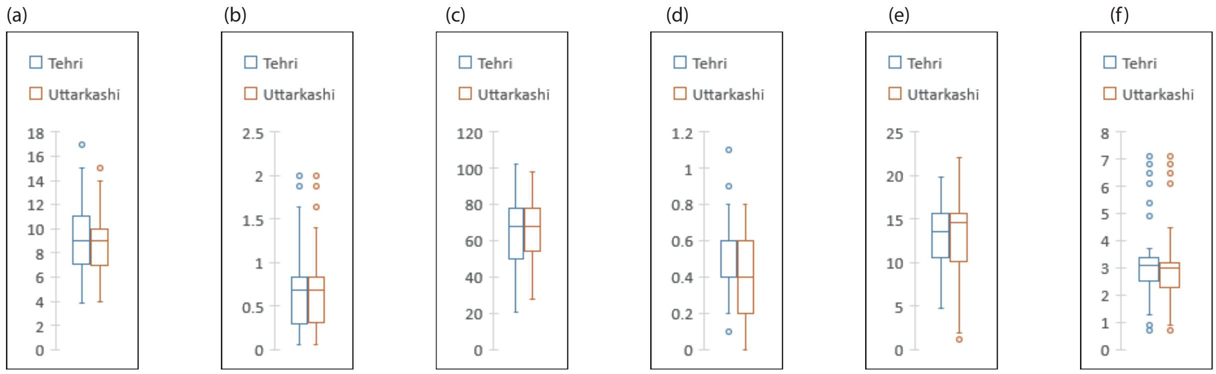

Fig. 3(B). Boxplots of: (a) Cl, (b) F, (c) HCO_3, (d) K, (e) Mg and (f) Na.

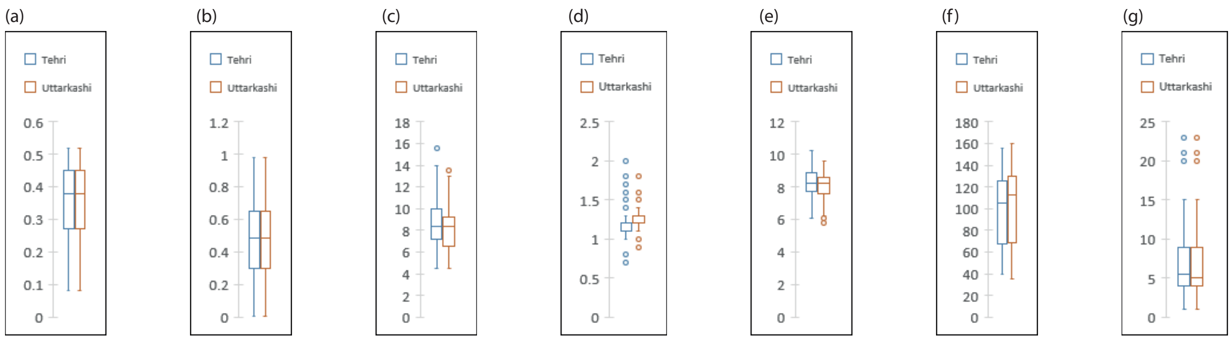

Fig. 3(C). Boxplots of: (a) $NO_2 + NO_3$, (b) P, (c) SO_4, (d) BOD, (e) DO, (f) total hardness and (g) Na%.

Table 3
Relationship between concentrations-discharge and between parameters among stations

Parameters	Correlation with discharge		Correlation of parameter between stations
	Uttarkashi	Tehri	
Q	–	–	0.63
EC	–0.02	0.05	0.72
pH	–0.11	–0.12	0.55
T	0.48	0.43	0.48
TA	–0.33	–0.21	0.92
Ca^{2+}	–0.23	–0.20	0.92
Cl^-	–0.38	–0.29	0.83
F^-	–0.25	–0.12	0.88
HCO_3^-	–0.35	–0.16	0.93
K^+	–0.11	0.09	0.74
Mg^{2+}	–0.37	–0.17	0.83
Na^+	0.19	0.14	0.97
$NO_2 + NO_3$	–0.47	–0.14	0.89
o-PO_4^{3-}	–0.23	–0.25	0.67
SO_4^{2-}	0.09	–0.05	0.88
BOD_3^{27}	–0.06	0.12	0.24
DO	–0.49	–0.27	0.30
TH	–0.32	–0.22	0.92
Na%	0.31	0.22	0.97

which is clearly evident as increase in the river discharge in the warmer months is due to high snowmelt and rainfall.

The correlation between above parameters at Uttarkashi and Tehri station is quite high. The highest correlation is observed for Na^+ and Na% (0.97) followed by HCO_3^- (0.93); Ca^{2+}, TA and TH (0.92); $NO_2 + NO_3$ (0.89); SO_4^{2-} and F^- (0.88) and Cl^- and Mg^{2+} (0.83), whereas lowest correlation is observed for BOD_3^{27} (0.24) and DO (0.30).

4.4. Trend analysis

The time series of 18 water quality parameters and the discharge of the Bhagirathi River at the Uttarkashi and Tehri station tested for the existence of a trend, by using the non-parametric SK test and Sen's slope. The *z*- and *p*-value (two-sided) of SK, Sen's slope and percentage change over time (10 years) for the examined time series (Table 4). The *z*-value indicates that there is a change in annual concentration for a constituent. With higher *z*-value, it is most likely that in the years to come, the parameter will continue to follow the same trend.

According to the results of SK (Table 4), the concentrations of parameters in the monthly time series of Q, pH, TA, Ca^{2+}, HCO_3^-, K^+, Mg^{2+}, Na^+, o-PO_4^{3-}, SO_4^{2-}, DO, TH and Na% changed over time at both the station. EC, $NO_2 + NO_3$ and BOD is showing trend only at Uttarkashi station while Cl^- is showing trend only at Tehri station, while all the parameters are showing the same direction of a trend at both the station, the direction of trend for pH reverses from positive at Uttarkashi to negative at Tehri. No trend observed at either station for T and F^-. Q, EC, K^+, Na^+, SO_4^{2-}, BOD and Na% are showing increasing trend whereas TA, Ca^{2+}, HCO_3^-, Mg^{2+}, $NO_2 + NO_3$, o-PO_4^{3-}, DO and TH are showing a decreasing trend.

The slight decrease in concentration of DO found at Tehri (–24.20%). Although, mean concentration observed at Uttarkashi as 8.02 ± 0.79 mg/L at Tehri as 8.26 ± 0.88 mg/L whereas the minimum concentration observed was 5.8 and 6.1 mg/L at Uttarkashi and Tehri station, respectively, which is close to the permissible limit (5 mg/L). If the present trend continues in future, there is a possibility that DO concentration can go down permissible limit during periods of high flows. Other parameters (Q, EC, K^+, Na^+, SO_4^{2-}, BOD and Na%), which are showing increasing trend and the percentage change over mean, are also quite high but mean, even maximum value of observed concentration was lower than the permissible limits, therefore, these parameters are of less concern to maintain the aesthetic value of the river in the future. The main concerning parameter is phosphorus (o-PO_4^{3-}) because it is rarely found in high concentrations in freshwaters. If it is present in an excess concentration, then it causes eutrophication or algal bloom [28]. In most natural surface waters, phosphorus ranges from 0.005 to 0.020 mg/L PO_4^{3-} [29]. From the Table 2, its concentration was observed as 0.45 ± 0.25 mg/L (mean ± standard deviation) at Uttarkashi, whereas 0.46 ± 0.26 mg/L at Tehri stations. Concentrations of o-PO_4^{3-} are decreasing with percentage change over time as –277.48 and –80.17 at Uttarkashi and Tehri station, respectively. The present trend is good, as it will reduce PO_4^{3-} concentration, which will inhibit the formation of algal bloom in future.

Temperature affects the density of water, solubility of constituents, pH, specific conductance, chemical reactions rate and biological activity in water. Major ions like Na^+, K^+, Cl^-, SO_4^{2-} and HCO_3^- naturally vary in surface and groundwater due to natural factors such as climatic, and geographical and catchment geology. K^+ is found to be low since rocks, which contain potassium, are relatively resistant to weathering. The presence of HCO_3^- influences the alkalinity and hardness of water. A stream or river's hardness reflects the geology of the catchment and sometimes provides a measure of the influence of human activity in a watershed. For example, sites that have active or abandoned mines nearby often have higher concentrations of iron ions (Fe^{2+}) in the water resulting in a very high degree of hardness. The parameter of TH in situ observation at Tehri station shows good relationship (in terms of % change) with Ca^{2+} and Mg^{2+} concentrations, indicating the impacts of physical and chemical weathering on local soil and rocks.

The amount of suspended and dissolved matter in freshwater bodies depends on the *Q*. Natural substances coming from erosion and its concentration can increase exponentially with increase in *Q*. Moreover, *Q* has strong seasonality with higher values during the monsoon and lower in winter, in the Bhagirathi River. Further, the rate of river flow gets significantly higher by the time it reaches Tehri. It was observed that the mean values of all the water quality parameters are increasing downstream at Tehri station. One of the possible explanations of higher loads at Tehri is that Bhilangna River is bringing high loads as Tehri is at the confluence of Bhilangna and Bhagirathi River or it can be

Table 4
Result of SK test, Sen's slope and percentage change over time

Parameters	Uttarkashi				Tehri			
	z-value	*p*-value	Sen's slope	% change	*z*-value	*p*-value	Sen's slope	% change
Q	**4.959**	**<0.001**	5.953	35.07	**3.486**	**<0.001**	**14.750**	56.71
EC	**3.857**	**<0.001**	2.000	15.51	0.000	**1**	0.000	0.00
pH	**2.110**	**0.035**	0.025	3.17	**–4.080**	**<0.001**	–0.033	–4.18
T	–1.420	0.157	–0.039	–3.20	0.906	0.365	0.000	0.00
TA	**–5.180**	**<0.001**	–2.687	–50.60	**–5.376**	**<0.001**	–3.000	–55.20
Ca^{2+}	**–6.480**	**<0.001**	–1.571	–86.07	**–6.807**	**<0.001**	–1.333	–71.49
Cl^-	–0.650	0.515	–0.012	–1.37	**–4.630**	**<0.001**	–0.400	–43.58
F^-	–0.830	0.406	–0.016	–26.89	–0.752	0.452	–0.015	–23.16
HCO_3^-	**–4.880**	**<0.001**	–3.167	–49.08	**–5.147**	**<0.001**	–3.492	–52.35
K^+	**7.462**	**<0.001**	0.050	134.49	**10.63**	**<0.001**	0.125	221.83
Mg^{2+}	**–9.930**	**<0.001**	–1.500	–122.80	**–9.700**	**<0.001**	–1.117	–88.02
Na^+	**11.830**	**<0.001**	0.383	128.20	**10.790**	**<0.001**	0.301	98.47
$NO_2 + NO_3$	**–2.370**	**0.018**	–0.016	–51.89	–1.386	0.166	–0.004	–10.85
o-PO_4^{3-}	**–3.540**	**<0.001**	0.125	277.48	**–6.085**	**<0.001**	–0.037	–80.17
SO_4^{2-}	**7.042**	**<0.001**	0.400	48.80	**9.411**	**<0.001**	0.525	61.92
BOD_3^{27}	**5.093**	**<0.001**	0.020	16.30	0.902	0.367	0.003	2.48
DO	**–2.030**	**0.043**	–0.055	–6.86	**–7.200**	**<0.001**	–0.200	–24.20
TH	**–10.000**	**<0.001**	–10.763	–111.51	**–8.911**	**<0.001**	–9.000	–91.20
Na%	**12.300**	**<0.001**	1.667	223.11	**12.030**	**<0.001**	1.250	172.57

Note: Boldfaced numbers indicate the significant values at 95% confidence level; $p < 0.05$ indicates that the Sen's slope is statistically significant.

due to lithology of the area. In the second scenario, there is high probability of increase in the concentrations of water quality parameters downstream, if physical and chemical weathering occurs on the local soil and rocks in future due to construction of storage dam and seasonal distribution of glaciers melt water [10,30].

5. Conclusion

The present study assesses the status of changing environment of water quality in Bhagirathi tributary of Ganges using non-parametric SK-test and Sen's slope estimator at the Uttarkashi and Tehri station. The monthly time series of 18 water quality parameters and discharge over 10 years (2004–2013) are used for the analysis. Significant correlation between parameters at these two sites suggests the same lithology in the study area. A negative correlation was observed between 14 parameters and discharges suggesting their geological origin. Trend analysis reveals concentrations of 7 parameters that are increasing but their values are quite low and even if the present trend continues over the years they are still of less concern. The parameter that is of great concern is phosphorus; further research should be done to understand its sources, which will inhibit the formation of algal bloom in future.

It is apparent that such information is very important for policy makers, and water resource engineers involved for making better decisions. The information is also useful in the context of the National River Conservation Plan, Ganga action plan under the National River Conservation Directorate, Ministry of Environment and Forest, Government of India.

There is a need for further investigate the effect of complicated temporal and spatial characteristics of the dam and land use land cover effect on the water quality in the study stretch to quantify anthropogenic intervention in the environment, which could cause changes in the water quality in the future.

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