Environmental and Sustainability Indicators 9 (2021) 100093

Contents lists available at ScienceDirect

Environmental and Sustainability Indicators

journal homepage: www.journals.elsevier.com/environmental-and-sustainability-indicators/

Correlation of various water quality parameters and water quality index of districts of Uttarakhand

Vinod Kothari [a], Suman Vij [b], SuneshKumar Sharma [c], Neha Gupta [c,*]

[a] Department of Statistics, Shri Guru Ram Rai University, Dehradun, India
[b] Department of Commerce, Shri Guru Ram Rai University, Dehradun, India
[c] Himmotthan- an Associate Organization of Tata Trusts, Dehradun, India

ARTICLE INFO

Keywords:
Drinking water
WQI
Bacteriological
Statistical analysis
Correlation
Linear relationship

ABSTRACT

This study is based on hydrogeochemical and biological parameters and calculation of Water Quality Index (WQI) to assess water quality of a rural tract in five districts of Garhwal and Kumaon district of Uttarakhand, India. The drinking water quality parameters are pH, Total Hardness, Alkalinity, Turbidity, Iron (Fe), Chloride (Cl), Fluoride (F), Dissolved Solids (TDS), Sulphate (SO_4), Nitrate (NO_3), Calcium (Ca), Magnesium (Mg), Arsenic (As), conductivity, Total Coliform, Fecal Coliform and Total Residual Chlorine. It was observed that the physicochemical properties were as per BIS standards and found suitable for drinking purposes. However Bacteriological parameters i.e. Total coliform and Fecal coliform of some sampling sites ranged from 20 to 300 CFU/100 ml, which were higher than permissible limit (0 CFU/100 ml) as per BIS standards. Statistical analysis had been used to calculate the correlation coefficient of different parameters with WQI and the study showed significant linear relationship and the high correlation coefficient between different pairs of water quality parameters. The correlation matrix shows that total iron concentration, total coliform, and faecal coliform have a significant effect on Water quality index. Among these parameters, TDS has the highest correlation with conductivity, sulphate, and chloride ion concentration whereas turbidity significantly correlates with the presence of nitrate in drinking water.

Introduction

Uttarakhand is a northern Himalayan state in India having tremendous natural beauty and rich sources of water available from mountain springs. Even then, during summer, the availability of drinking water at hilly village clusters goes to the acute shortage. Mostly during summer and in the years of less rainfall, there is an acute shortage of water. People are dependent on the springs as the natural source of domestic water in Uttarakhand. Spring is a location at which water flows from an underground source of water to the surface. The water-retaining capacity of these underground water storage depends on geomorphology, hydrology, rock type, porosity and permeability of rocks and soil. These natural sub-surface waters are mainly a very rich source of minerals, calcium, magnesium, potassium, sulfur and iron (Leclerc and Moreau, 2002; Cabassud et al., 2001). Hence, spring water is considered as wholesome and adequate for drinking purpose. However, due to the increase in urbanization, Industrialization and tourism in Uttarakhand these water resources have been contaminated with both chemical and biological contaminants. Almost all the springs and water sources are contaminated with microbial contamination. The density of microbes increases at the springs or a natural water source when it is located near a village or in an area with extensive wildlife and animal populations. Community residing near theses springs and using this water for drinking purpose directly have adverse health effects. Microbial contamination mainly occurs in natural spring water due to infiltration of contaminated water through the soil to groundwater (A report and Industrial Deve, 2019). Runoff from rains, carry microbes present in the air, roads, dumped solid wastes, domestic and animal waste underground sun surface water and contaminate them (An et al., 2002). This microbially contaminated spring water is used for drinking purpose in these areas and creates a high health risk to rural communities in Uttarakhand. As Uttarakhand is the fastest-growing state, there is hugely increased in industrialization and tourism, about 36.35 million interstate tourists and 0.13 million foreign tourists visit Uttarakhand (A report and Industrial Deve, 2019). Thus, a burden to sustain this increasing demand for water usage is created. The peoples residing in the vicinity of industries are somehow, suffering from various water-borne diseases and water quality deterioration. To maintain water quality for drinking purpose is the major issue that has been

* Corresponding author. Himmotthan Society, India.
E-mail address: g21neha@hotmail.com (N. Gupta).

https://doi.org/10.1016/j.indic.2020.100093
Received 28 June 2020; Received in revised form 11 December 2020; Accepted 15 December 2020
Available online 17 December 2020

raised from the last few years. Though most of the household have access to treated water but simultaneously access to untreated water is also the highest in Uttarakhand when compared with the other States (Deepali, 2013; Uttarakhand at a glance, 2019; Ghalib and YaqubAl-Abadi, 2019).

The purpose of this study is to define the rate of degrading water quality and to provide information about the significant parameter affecting it. Some recommendations were made accordingly for the development of possible solutions to preserve water quality and targeted behaviour change programs to assist the community to overcome from a water-related disease. Water Quality Index (WQI) is the most effective tool to analyze the water quality of the particular area and to produce information regarding water quality in the simplest form to the general community, legislative/government and other decision-makers. WQI transforms the large and complex information of raw (Rothmaier et al., 1997) water quality data into a simplified and logical form with different categories of water quality that reflects the overall water quality status of the selected area (Uttarakhand at a glance, 2019) WQI is defined as, a rating reflecting the composite influence of different water quality parameters. It is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy-makers (Cabassud et al., 2001). The community can differently manage and utilize their available water sources for different purpose according to its water quality. Therefore, in the present study, an attempt has been made by Himmotthan society to assess the drinking water quality index of 117 villages, of five districts of Uttarakhand. The statistical analysis has been performed using standard methods, Karl-Pearson correlation coefficient (r) was calculated and correlation of different physicochemical parameters with WQI and with the statistical analysis deduces the significant effect of each parameter on water quality of available drinking water (Standard Methods for the, 1998; Almeida et al., 2012).

Traditionally water has always been managed by the rural community and treated water as forest or ecosystem subsidy. Water coming from springs and forest areas considered good quality by local community hence very little efforts were made to make the community awareness on water quality and issues associated with poor water consumptions and its treatments. However, due to higher water demand, it is useful to preserve water and make people aware of its wise use.

Material and methods

The study area consists of five districts i.e. Tehri Garhwal, Nainital, Chamoli, Rudraprayag, Bageshwar located in the state of Uttarakhand, India as shown in location map in Fig. 1. In Tehri Garhwal, three sampling sites were chosen, namely, Chamba, Bhilangna and Jaunpur. In Nainital district, Ramghar and Batalghat were the areas taken. These eight blocks were further divided into 117 sampling sites. Samples from all these sites were collected and sent to Uttaranchal Jal Sansthan laboratory, Dehradun and GBPHIED laboratory Kosi Katarmal Almora for physiochemical analysis. The collected water samples were analyzed in the laboratory for computing pH, Total Hardness, Alkalinity, Turbidity, Iron (Fe), Chloride (Cl), Fluoride (F), Dissolved Solids (TDS), Sulphate (SO4), Nitrate (NO3), Calcium (Ca), Magnesium (Mg), Arsenic (As), conductivity Total Coliform, Fecal Coliform and Total Residual Chlorine as per standard methodology as per latest, Indian, standard (IS:10500).

Sample collection: drinking water samples were collected from 117 sites of five different districts of the selected region of Uttarakhand. The water samples were collected in sterilized plastic sample collecting bottles and were brought to the laboratory in an icebox within 24 h to avoid unusual changes in water quality. Before the collection of sample water, all the bottles were washed thoroughly and rinsed thrice sample waters. Standard methods (APHA, 2005) for sample collection and preservation was followed. Testing methods used include titrimetric, colourimetric and atomic spectrophotometer as per standard methodology proposed by the American Public Health Association, 2007.

To understand and analyze the water quality of all the water sample, the WQI was used. WQI is defined as a relative influence and significance of various water quality parameters on the quality of water. The Indian standard specified for drinking water (BIS, 1991) was used for the

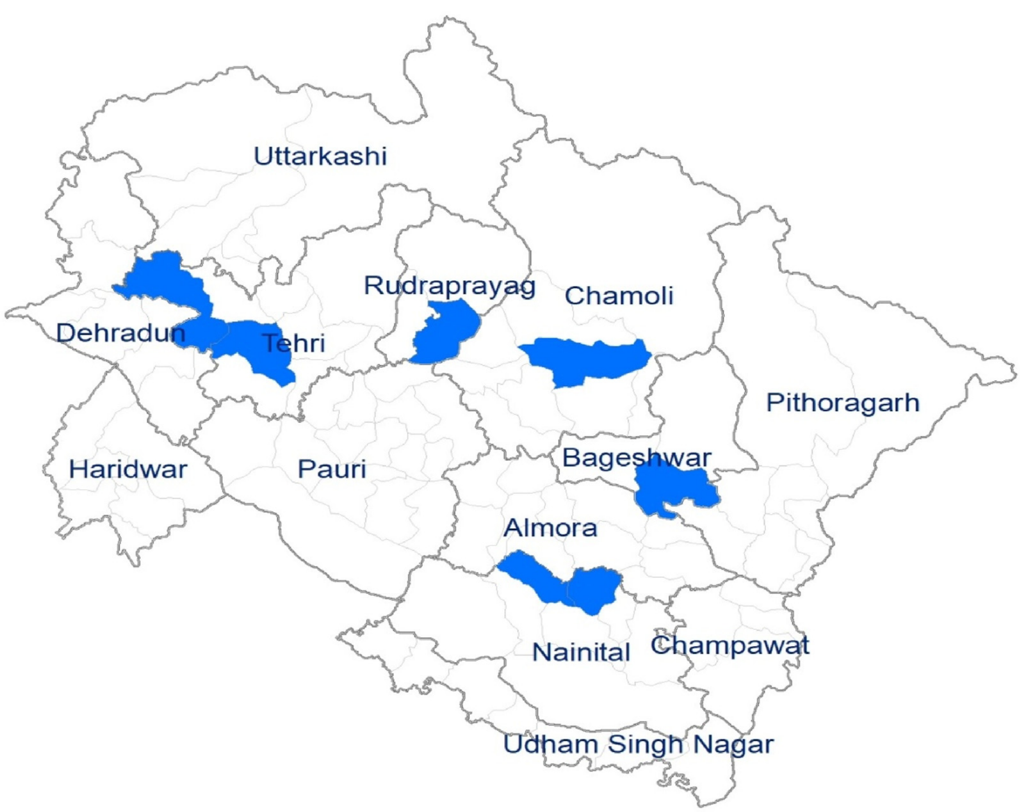

Fig. 1. Location map of the study area.

calculation of WQI (Standard Methods for the, 1998).

The WQI was computed through three steps:

First, each of the parameters was given a weightage level (wi) according to its relative contribution and significance in Uttarakhand specific water quality of drinking purposes and according to the predicated weightage given to each water quality parameter by WHO/CPCB. For each sample, a comparison study was done against the value calculated from results after lab testing with the desirable limit mentioned for each parameter by WHO/CPCB and accordingly weightage was given to each parameter by both by self-analysis of results and by comparing to predicted weightage by WHO/CPCB. A maximum of 5 weightage was given to nitrate, faecal and total coliform because according to data analysis it was observed that all other chemical parameters present in water were within the permissible limit. The only nitrate, faecal and total coliform presence was found to be the main cause of water contamination in this region. As the study area consists of mainly agriculture land the presence of nitrate in groundwater can easily be predicted and hence given more weightage. All other water quality parameters such as pH, TDS, total hardness, Alkalinity, turbidity, Cl, SO_4, F, Ca, Mg, Fe, arsenic, conductivity, residual chlorine and Mn concentration in water sample were assigned weightage based on their relative significance in the water quality evaluation.

Secondly, the relative weightage (Wi) of each water quality parameter was evaluated by using the equation given below:

$$\mathrm{Wi} = \sum_{i=1}^{n} \mathrm{wi}$$

Where, n is the number of parameters considered for the calculation of WQI and wi is the weightage calculated or assigned to each parameter, and. In the third step, a quality rating value (qi) for each water quality parameter was calculated by dividing its known concentration in each water sample after analysis by its standard permissible concentration mentioned according to Indian standard guidelines (BIS, 1991), and multiplied by 100 (Standard Methods for the, 1998):

$$\mathrm{qi} = (\mathrm{Ci}/\mathrm{Si}) * 100$$

Where.

Ci is the concentration of each water quality parameter in each water sample, and
Si is the concentration mentioned in Indian drinking water standard.

For computing WQI, the sub-index (SI) is then calculated for each water quality parameter, using the equation given below:

$$\mathrm{SIi} = \mathrm{Wi} * \mathrm{qi}$$

$$\mathrm{WQI} = \sum \mathrm{SI}$$

Third and the last step were to compute WQI values are classified into five categories:

- Excellent water (WQI $\leq$ 50);
- Good water (WQI = 50–100);
- Poor water (WQI = 100–200);
- Very poor water (WQI = 200–300);
- Water unsuitable for drinking (WQI $\geq$ 300)

Data Analysis: To identify the most significant parameter of water quality and its correlation with other parameters correlation matrix studies were done. In this study, the correlation matrix of 16 variables and WQI value for the 117 water samples was computed using excel 2007 software and is presented below in Table 10. Correlation analysis is a preliminary descriptive technique to estimate the degree of association among multiple variables involved in the study. Therefore, a correlation matrix was computed which shows the degree of a linear association between any two of the parameters, and measured by the degree of correlation as a coefficient (R). R-value is used to identify the highly correlated and interrelated water quality parameter and that may influence the water quality of the area. The value of R ranges from −1 to +1; R = +1, or near to one indicates a strongest positive linear correlation between two parameters compared and R = −1 or near to −1 reveals strongest negative linear correlation. Also, the correlation of each parameter with WQI was computed to study the linear association between each parameter with it. Thus, from the matrix, parameters significantly influence the level of water quality of an area is evaluated (Bhutiani et al., 2018; Bellizzi et al., 1999).

Results and discussion

The data of water samples collected from these blocks are summarized in Tables 1–10 below, which included parameters of pH, Total Hardness, Iron (Fe), Chloride (Cl), Fluoride (F), Dissolved Solids (TDS), Sulphate (SO_4), Nitrate (NO_3), Total Coliform, faecal coliform and Total Residual Chlorine.

pH: The concentration of hydrogen ion present in the solution is the measurement of pH of that solution. The permissible range of pH of Drinking water between 6.5 and 8.5 according to WHO. If the pH is below 6.5it is considered to be Acidic water tends to be corrosive to pipes and hand pumps. pH above 8.5 is Alkaline water and may tend to have a bitter or soda-like taste (Goon et al., 1986).

In this study, the pH values were recorded, in 117 sampling sites of all eight blocks presented in Table 2 below. The pH value in most of the water sample was observed to be under the permissible limit and all the water samples analyzed have a hydrogen ion concentration within the safe limit of 6.5–8.5 standard set by Indian standard (IS:10500). Only in two villages in Tehri district, that the collected sample water was found to be alkaline. Ragnar and Nainital water were found to be acidic as shown in Table 2 below:

Total Dissolved Solids (TDS): TDS of water is considered as the most important parameter to measure the quality of a water sample because it is directly correlated and affected by increased turbidity, hardness, alkalinity and conductivity of tested water sample. High concentrations of TDS, with limits value more than 300 mg/l is not suitable for drinking purposes. The acceptable range of TDS is 500 mg/l. In the present study, the value of TDS in the analyzed water samples varied between 23 and 755 mg/l, as shown in Table 3. High values of TDS 755mg/land 736 mg/l were observed at Saud and Kinsu villages of Tehri Gharwal which was above BIS permissible limit. The overall TDS values were found to be within the desirable limit (500 mg/l) for all sampling sites. Therefore, the drinking water is safe in terms of TDS (Table 2). High TDS influence the other qualities of water such as taste, hardness, corrosion properties, influences osmoregulation of freshwater organism (Prasad et al., 2019).

Total hardness (TH), alkalinity, conductivity, calcium and magnesium level: Measurement of bicarbonates, carbonates, sulphates and chlorides of calcium and magnesium dissolved in water contributes to the degree of hardness of water sample. The desirable limit of total hardness is 200 mg/l whereas the maximum acceptable limit is 600 mg/l. The hardness, alkalinity, conductivity calcium and magnesium ion concentration of analyzed water samples vary from 20 to 740 mg/l, 20–310 mg/l, 32–1179 mg/l, 16–256 mg/l and 4–84 mg/l respectively,

Table 1
pH analysis in the villages.

Name of District	Name of village	pH above/below the permissible limit
Tehri Gharwal	Doni pali	**10.27**
	Chamiyala	**8.56**
Nainital	Chapar	5.9
	Diyari	5.1
	Dhuthanedhar	6.4
	Lweshala	5.9
	Maunamal	5.8

Table 2
Name of the village with high hardness, alkalinity and TDS.

Name of District	Name of village	TDS mg/l above desirable limits	Hardness mg/l Above desirable limits	Alkalinity mg/l above desirable limits
Tehri Gharwal	Saud	755	740	310
	Kenri		338	393
	Nakot		346	272
	Kudiyal		372	256
	Kinsu	736	486	304
	Bansi		390	
	Rautu ki Bali		296	304
	Udarsu		330	342
	Bilori			254
Rudraprayag	Kund			280
	Chandrapur			300
	Ginwala			300
	Ghatgaad			290

Table 3
Name of villages with higher Calcium and Magnesium concentration.

Name of district	Name of village	Calcium concentration above the desirable limit	Magnesium concentration above the desirable limit
Rudraprayag	Kyunga	142	
	Ginwala	200	84.2
	Mathkhani	140	37.2
	Dolla		92
	Kund	180	84
	Chandrapur	256	47.15
	Haat	70	42.01
	Chinaroli	132	60
	Malkhola	136	50
	Dugdigad	140	42
	Simaldhara	125	70
	Murkula	120	40
Nainital	Khakar		39.5
	Supi		39.5
Bageshwar	Ghatagad		38
	Pagna		35.1
	kyunja		65.67

Table 4
Name of villages with Chloride concentration in water at the higher side.

Name of district	Name of Village	Chloride above 10 mg/l
Chamba	Saud	12
Tehri gharwal	Kinsu	14

Table 5
Name of villages with high fluoride concentration.

Name of District	Name of Village	Above desirable limits	Above permissible limits
Tehri Garhwal	Bahedigangar	1.16	
	Chamiyala	1.16	
	Bhenti	1.45	
	Fainda		**1.77**
	Lwani	1.31	
Rudraprayag	Mathkhani	1.48	

exceeding desirable limit (200 mg/l, 200 mg/l, 750 mg/l, 75 mg/l and 30 mg/l) but were below the permissible limits. The slightly higher limit of calcium level is observed in some villages of Rudraprayag, Nainital and Bageshwar respectively in Table 3. Even alkalinity, hardness and conductivity are higher in the villages of Rudraprayag district. Hardness in the water of some villages of Tehri Garhwal district is above the permissible limit (Table 3) (Bellizzi et al., 1999).

Chloride: Chloride concentration nationwide are mostly being due to anthropogenic, or human-caused factors. The presence of a high concentration of chloride ion in the water sample is directly proportional mixing of sewage water in a water source. It indicates improper sewage disposal or dumping of animal and solid waste in nearby areas of a water source, contamination of domestic effluents and linkage in septic tanks to

Table 6
Name of villages with microbial contamination in water samples.

Name of District	Name of village	Higher Coliform concentration (more than 0 CFU/100 ml)
Tehri Gharwal	Jakh	126
	Kothiyada	86
	Pakh	100
	Bahedigangar	120
	Koti	52
	Beleshwar	84
	Chamiyala I, II	80, 120
	Finda	70
Chamoli	Lwani	67
	Mathkot	69
	Santoli	64

Table 7
Name of villages with higher iron concentration.

Name of District	Name of Village	Iron above the permissible limit (0.3 mg/l)
Bagashwar	Ghatgaad	0.6
Rudraprayag	Malkhola	0.5
	Dugdigad	0.6
	Simaldhara	0.8
	Murkula	0.5
	Kemrigaon	0.4

Table 8
Relative weight of chemical parameters.

Chemical parameters	Indian Standard	wi	$Wi = wi/\sum wi$
pH	6.5–8.5	4	0.0702
TDS	500–2000	3	0.053
Turbidity	1–5	3	0.053
Total Alkalinity	200–600	3	0.053
Total Hardness	200–600	3	0.053
Fluoride	1–1.5	3	0.053
Nitrate	45	5	0.087
Sulphate	200–400	3	0.053
Calcium	75–200	3	0.053
Iron	0.3	3	0.053
Magnesium	30–100	3	0.053
Arsenic	0.05–0.01	1	0.017
Total Coliform, CFU/100 ml	0	5	0.087
Fecal Coliform,CFU/100 ml	0	5	0.087
Residual chlorine	0.2–1	2	0.035
Conductivity	750–2500	3	0.053
Chloride mg/L	250–1000	3	0.087

Table 9
Computation of water quality index (WQI) for district wise sample.

No of villages	WQI	Water type	Above permissible limit
61	Above 200	Very poor water	Total coliform, faecal coliform, alkaline water and fluoride
31	Above 100- 200	Poor water	Chloride, Alkalinity, Hardness and TDS Total coliform and faecal coliform
6	Above 50 -100	Good water	Acidic water and Total coliform and faecal coliform
15	Less than 50	Excellent water	A negligible amount of Microbial contamination

Table 10
Correlation Matrix of fourteen parameters of water quality.

	pH	TDS (mg/L)	Turbidity (NTU)	Total Alkalinity (mg/L)	Total Hardness (mg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Sulphate (mg/L)	Calcium (mg/l)	Iron (mg/L)	Magnesium (mg/l)	Total Coliform, Colonies/100 ML	Fecal Coliform, Colonies 100 ML	Conductivity	Chloride mg/L	WQI
pH	1															
TDS (mg/L)	0.2	1														
Turbidity (NTU)	0.01	−0.02	1													
Total Alkalinity (mg/L)	0.3	0.8	−0.03	1												
Total Hardness (mG/L)	0.2	0.8	−0.03	0.8	1											
Fluoride (mg/L)	0.2	−0.007	−0.04	0.1	−0.03	1										
Nitrate (mg/L)	−0.002	−0.095	0.8	−0.09	−0.06	−0.002	1									
Sulphate (mg/L)	0.24	0.9	−0.05	0.7	0.7	0.02	−0.1	1								
Calcium (mg/l)	0.3	0.4	−0.04	0.6	0.7	0.1	−0.05	0.4	1							
Iron (mg/L)	−0.3	−0.1	0.1	−0.2	−0.2	−0.4	0.06	−0.2	−0.4	1						
Magnesium (mg/l)	0.3	0.3	−0.1	0.4	0.6	0.2	−0.06	0.2	0.8	−0.6	1					
Total Coliform, Colonies/100 ML	−0.2	0.07	0.02	0.1	0.08	0.1	0.05	0.03	0.1	0.2	0	1				
Fecal Coliform, Colonies 100 ML	−0.02	0.02	0	0.03	0.06	−0.1	0.05	0.03	0.04	0.4	−0.1	0.2	1			
Conductivity	2	0.9	0.01	0.7	0.8	0.02	0.01	0.8	0.4	0.03	0.2	0.1	0.2	1		
Chloride mg/L	0.2	0.7	−0.01	0.6	0.6	0.1	−0.07	0.6	0.4	−0.4	0.4	−0.07	−0.14	0.6	1	
WQI	−0.2	−0.1	0.04	−0.1	−0.3	0.08	0.1	−0.1	−0.4	0.4	−0.5	0.4	0.2	0.01	−0.3	1

underground sub-surface water etc. The high content of chloride is mostly because of human activities. The permissible limit of chloride in drinking water is between 250 and 1000 mg l−1 (Asit Kumar and Surajit, 2015). The porosity of soil and permeability of rocks in the area also plays a key role in building up the chloride's concentration. In the present study, the results of chloride in all sampling sites range between 2.2 and 14 mg/L. As shown in Table 4.

Fluoride: Fluoride value is found to be ranging from 0.22 to 1.77 mg/l. From the data, it is evident that all the sampling sites were found in between the desirable limit of 1 mg/l and permissible limit of 1.5 mg/L as per Indian standard (IS:10500). Only in Bhilangna of Tehri Gharwal the fluoride level is on the higher side of the permissible limits. While 1.0 mg per litre (mg/l) of fluoride in drinking water is desirable for dental microbial protection and delay tooth decay and also help in maintaining bones strength, a value over 1.5 mg/l leads to dental and skeleton fluorosis. According to the Bureau of Indian Standards (BIS), the acceptable range for fluoride content is 1–1.5 mg/l. There are increased cases of dental fluorosis, yellowing of teeth, pain in shoulders and legs, and twisted and deformed bones and skeleton structure of community people affected by higher fluoride concentration in water (Ansari and Hemke, 2013; Divya et al., 2013). As shown in Table 5 below.

Sulphate (SO_4) and Nitrate (NO_3): Sulphate comes in groundwater from mineral deposits in the rocks in form of sulphates. They form oxides, in contact with water. Also, there is an infiltration of industrial effluents contaminated with sulphates. High levels of sulphate in the drinking water supply can impart bad taste. According to the guidelines of Indian standard (IS:10500) maximum permissible value 200–400 mg/l data presented in Table 6 represents that the sulphate values in all the 117 sampling sites ranged between 1 and 120 mg/l. The Nitrate value was observed as NO_3 in all the sampling sites and, ranged between 0.5 and 5.1 mg/l in all the sampling sites. Bacteriological contamination in water also correlated with the presence of an excess level of nitrate in the water. All drinking water sources available in these remote areas also should be tested for bacteriological contamination, particularly if the nitrate level exceeds the 10 mg/l. The presence of both nitrate and bacteriological contamination indicates possible microbial contamination from surface drainage, sewage systems, animal waste or some other source. Only at Chinaroli village of Chamba district show, the nitrate concentration is above 10 mg/l (Asit Kumar and Surajit, 2015).

Total coliforms and faecal coliform: The total and faecal coliform in all 117 sampling sites were found to have a range between 10 and 126 CFU/100 ml and 10–120 CFU/100 ml respectively.

Contaminated drinking water causes a health problem and leads to water-borne diseases. The major water-related diseases are diarrhoea, hepatitis, roundworm, hookworm infection, trachoma, guinea worm, schistosomiasis, leishmaniasis, lymphatic filariasis, cholera and malaria. Thus, poor environmental sanitation and water quality play an important role in spreading infectious diseases, which are presently emerging and creating a big public health problem. Total coliform and faecal coliform are an indicator of the presence of pathogens in drinking water and are unsuitable for drinking. If large numbers of coliforms are present in the water sample, there is a high probability that other pathogenic bacteria responsible for water-borne diseases will also be present in the water as evident in a water sample from Bilangna and Jaunpur region of Tehri Garhwal district (Bora and Goswami, 2017; Ghalib and YaqubAl-Abadi, 2019; Bhutiani et al., 2018). Data of faecal coliform and total coliform is mentioned in Table 6.

Total Residual Chlorine and Turbidity: Chlorination of drinking water in these areas and is used usually for decontamination and has several advantages as a disinfectant, including its comparative cheapness, effectiveness, and easy to manage, both in laboratories and in the field (Asit Kumar and Surajit, 2015). The residual chlorine value was not detected anywhere among all the 117 sampling sites.

Turbidity is defined or measured as the degree of cloudiness or muddiness of the water sample. It is a measurement of optical property that causes light to be scattered and absorbed by the water sample. Turbidity cannot be correlated with the concentration of suspended particles present in the water sample. Therefore, the turbidity was observed from 0.1 to 5.2 NTU. The observed values of turbidity were exceeding as per the guidelines of Indian standard (IS:10500),1 NTU in most of the water sample analyzed. Turbidity occurred due to the presence of soil, organic and inorganic matter, plankton, and other microscopic organisms.

Iron concentration: Groundwater usually contains more of these two minerals in these areas i.e. Fe and MN than surface water. Permissible and desirable limit of iron and magnesium in water is 0.3 mg/l and 0.1 mg/l respectively. The appearance of a reddish-brown precipitate in a water sample and near the tap and hand pump indicates the presence of a higher concentration of iron in water (Ansari and Hemke, 2013). The total iron concentration in all 117 sampling sites ranged from 0.01 to 0.08 mg/l. The iron in permissible range (0.3 mg/l) is mostly present in all Tehri Garhwal district and Rudraprayag district. In Ghatagad village of Bageshwar district, it is 0.6 mg/l above the permissible limit and in Rudraprayag district, in villages Chinaroli, Malkhola, Dudigad, Simaldhara and Murkula it ranges between 0.5 and 0.8 mg/l as shown in Table 7 below (Divya et al., 2013; Ramesh et al., 2010).

2. Calculation of WQI

For the calculation of water quality index above given method was used. Firstly, a weightage value is assigned to each parameter according to Data analysis of varies water quality parameters values of each water sample after testing in the lab and according to the weightage value already assigned by WHO and BIS to each parameter. Maximum weight 5 was assigned to nitrate, faecal and total coliform as most of the water sample collected for our research work are taken from springs and hand pumps which primarily contaminated with Coliform bacteria and organic waste of animal and domestic waste. It was also observed that all the other chemical parameters present in water samples were in permissible limit only faecal and total coliform presence was the main cause of water contamination; in this region. Other parameters such as pH, TDS, total hardness, Alkalinity, turbidity, Cl, SO_4, F, Ca, Mg, Fe, and MN were assigned weights between 1 and 5 based on their relative significance in the water quality. Calculated relative weight (wi) values of each parameter are given in Table 8.

In the next step, the Wi (relative weightage) was calculated by dividing each value of weightage for each parameter by sum of the value of weightage of all parameters.

Next, the WQI value was calculated by multiplying the sum value of relative weightage for all parameters with the summation of the Quality scale value of each parameter for all villages of the study area.

The WQI value and water type of all the water samples are presented in Table 9 below. The WQI ranges from 10 to 761.7 respectively. Most of the villages present in an area of Tehri Gharwal, Bhilangna, Bagashwar, Chamoli, Nainital and Ramgarh district had WQI above 100 and come under the category of poor and very poor quality of water that is not suitable for drinking purpose without treatment or filtrations. Only 15 villages have excellent water quality out of 117 villages and 6 villages have a good quality of water. The samples analyzed for WQI from villages of Ghat block of Chamoli district was less than 50 and come in the category of excellent water quality. The water that is supplied in these areas is of class A quality. In the majority of the cases, water contamination has been the remarkably high due presence of Total and Fecal coliform in water samples.

The computed WQI values were also compared with other areas as in Ballia district, Uttar Pradesh range from 66 to 74 and from 62 to 79, respectively and can be categorized into good quality type. And as mentioned the water needs 'Filtration and disinfection' treatment before use for drinking purpose. WQI indicates it may be due to higher values of TDS, total hardness, As F-, Cl^-, HCO_{3^-}, $_{NO3^-}$ $^-$ and SO_4 $^-$. Similarly, in another study of Haridwar District, Uttarakhand groundwater samples it was observed 5% groundwater samples qualified in the category of good water in whereas 21% of groundwater samples were found unsuitable for drinking purposes in West Bokaro coalfield, India. In another study on Haridwar WQI of mostly 95% of samples were qualified in the good and excellent category. The WQI of groundwater samples in the Bahraich district range from 45 to 1219, which shows that the groundwater for these locations falls under poor to the unfit category for the drinking purpose (Krishan et al., 2016; Singh et al., 2013, 2019; Tiwari et al., 2014).

Percentage Contribution to WQI and statistical analysis: A correlation matrix of fifteen parameters, namely, colour, EC, TDS, chloride, fluoride, total iron, total hardness, total alkalinity, calcium, magnesium, sulphate, Chloride, residual chlorine, conductivity, Fecal coliform, Total coliform, among themselves and with water quality index (WQI) was constructed and is shown in Table 10. TDS exhibited a significant positive linear correlation with sulphate (0.9), Total hardness (0.8), Total Alkalinity (0.8) and Conductivity (0.9) and moderate positive correlation with Chloride (0.7) as their R-value was near to one as shown below. Turbidity shows a significant positive correlation with Nitrate (0.8), and this can be explained as the soil present in this area mainly constitute high concentration domestic and animal waste and thus soil consists of high nitrate concentration. Due to runoff of rainwater and increase in soil erosion, there is increased turbidity in natural water sources. Soil concentration in water increases with rain and soil contains high nitrate hence turbidly and nitrate are interrelated (Mondal et al., 2010). Alkalinity and hardness both are moderately correlated with chloride (0.6) and Sulphate ion (0.6) concentration in water, and also conductivity is correlated to both Total Alkalinity (0.8) and Sulphate (0.8). A good positive correlation of WQI was noticed with Fecal coliform, Iron, and Total Coliform present in drinking water of almost all the sample taken and this was also analyzed during lab testing of the samples. The only count of faecal coliform and total coliform were above the desirable limit in most samples. Higher Fe concentrations in the hand pumps might have been the results of interaction of underground oxidized iron minerals with organic matters present and can be due to the dissolution of Fe_2CO_3 present in rocks at a low pH (Mondal et al., 2010; Applin and Zhao, 1989). Another reason for high Fe concentration may be due to the presence of microbial contamination and removal of dissolved oxygen by them, leading to reduced conditions and under theses reducing conditions, the solubility of Fe-bearing ores (siderite, marcasite, etc.) increases in water, leading to the increment in concentration of dissolved iron in groundwater (Richa et al., 2016).

Conclusions and recommendations

1. Mostly obtained results of tested water samples were within recommended limits of Bureau of Indian Standards (BIS) for physicochemical parameters. But the main parameter that has affected the water quality of this area is microbial contamination. The WQI index based on the physicochemical and biological parameters in 96 villages were very poor however in 21 villages WQI index ranked excellent or good quality, respectively. The regular use of microbially contaminated water for drinking purpose may create a health risk to the consumers. Therefore, there is a need for a regular investigation and establishing an operation and maintenance system for the quality of drinking water. Regular disinfectants as chlorine or boiling of water before use are highly recommended.
2. Environmental hygiene and sanitation practices should be improved. Many a time bacterial contamination may take place due to poor storage facilities. Water storage facilities generally contain high microbial contamination even when the source of water is good quality. An improved Point of Use system for potable water at the household level will reduce the chance of microbial contamination significantly.
3. Due to increase in population and number of households at village cluster infiltration of sewage, animal and domestic waste flow during monsoon towards the drainage line of the possible potable water system which translates furthering contamination. Hence it is recommended that recharge area of water sources should be protected from open defecation practices and livestock grazing and social fencing would be useful for recharge area protection from the faecal load.
4. The groundwater table is at a fixed level in plain but it is hard to analyze the water table in hills before laying of the toilet, it is highly recommended to build twin pit toilets using approved technologies. Using composting or installation of biogas plants for disposing of animal waste would be useful in these regions. Behaviour Change and awareness sessions towards protection of water sources, water quality monitoring and creating a database for available water sources will also help to monitor water quality and source sustainability.
5. Fluoride problem is observed at a single site; hence suitable fluoride treatment filters should be used. In a few sites, iron concentration was at a high level so appropriate filtration unit to remove iron on hand pumps can be installed. Site selection for hand pumps should be taken care off, presence of toilets or septic tanks in nearby locations should be prohibited and boring should as per approved norms.

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.

References

A Report, Industrial Development & Economics Growth in Uttarakhand, 2019.
Almeida, C., Gonzalez, S.O., Mallea, M., Gonzalez, P.A., 2012. Recreational water quality index using chemical, physical and microbiological parameters. Environ. Sci. Pollut. Res. Int. 19 (8), 300–411. https://doi.org/10.1007/s11356-012-0865-5/.
An, Y.J., Kampbell, D.H., Breidenbach, G.P., 2002. Escherichia coli and total coliforms in water and sediments at lake marinas. Environ. Pollut. 120, 277–284. https://doi.org/10.1016/s0269-7491(02)00173-2.
Ansari, K., Hemke, N.M., 2013. Water quality index for assessment of water samples of different zones in chandrapur city. Int. J. Eng. Res. Afr. 3, 233–237. https://doi.org/10.12691/ajwr-1-3-3.
Applin, K.R., Zhao, N., 1989. The kinetics of Fe(II) oxidation and well screen encrustation. Ground Water 168–174. https://doi.org/10.1111/j.1745-6584.1989.tb00437.x.
Asit Kumar, B., Surajit, C., 2015. Hydrogeochemistry and water quality index in the assessment of groundwater quality for drinking uses. Water Environ. Res. 87 (7), 607–617. https://doi.org/10.2175/106143015X14212658613956y.
Bellizzi, V., Nicola, L.D., Minutolo, R., Russo, D., Cianciaruso, B., Andreucci, M., Andreucci, V.E., 1999. Effects of water hardness on urinary risk factors for kidney stones in patients with idiopathic nephrolithiasis. Nephron 81 (1), 66–70. https://doi.org/10.1159/000046301.
Bhutiani, R., Ahamad, F., Tyagi, V., Ram, K., 2018. Evaluation of water quality of River Malin using water quality index (WQI) at Najibabad, Bijnor (UP) India. Environ. Conserv. J. 19, 191–201. https://doi.org/10.36953/ecj.2018.191228.
Bora, M., Goswami, D.C., 2017. Water quality assessment in terms of water quality index (WQI): case study of the Kolong River, Assam. India Applied Water Sci 7, 3125–3135. https://doi.org/10.1007/s13201-016-0451-y.
Cabassud, C., Burgaud, C., Espenan, J., 2001. Spring water treatment with ultrafiltration and stripping. Desalination 137, 123–131. https://doi.org/10.1016/S0011-9164(01)00210-7.
Deepali, J. Namita, 2013. Industrialization vs. Water quality: impacts on sanitation and hygiene in haridwar district. Sci. Int. 364–370. https://doi.org/10.1016/S0011-9164(01)00210-7.
Divya, D., Barataria, S.K., Khanna, P.P., 2013. Ionic sources and water quality assessment around a reservoir in Tehri, Uttarakhand, Garhwal Himalaya. Environmental Earth Sciences69 2513–2527. https://doi.org/10.1007/s12665-012-2076-2.
Ghalib, H., Yaqub, M., Al-Abadi, 2019. A Hydrogeochemical modelling and isotopic assessment of the quaternary aquifer at Ali al-Garbi Area in Misaan Governorate, South of Iraq. In: Advances in Sustainable and Environmental Hydrology, Hydrogeology. Hydrochemistry and Water Resources in Book, pp. 121–124.
Goon, A.M., Gupta, M.K., Dasgupta, B., 1986. Fundamental of Statistics, vol. I. The World Press Pv Ltd, Calcutta.
Krishan, G., Singh, S., Gurjar, G., Kumar, C.P., C Ghosh, N., 2016. Water quality assessment in terms of water quality index (WQI) using GIS in Ballia district, Uttar Pradesh, India. J. Environ. Anal. Toxicol. 6, 366. https://doi.org/10.4172/2161-0525.1000366.
Leclerc, H., Moreau, A., 2002. Microbiological safety of natural mineral water, FEMS Microbial. Rev 26, 207–222. https://doi.org/10.1111/j.1574-6976.2002.tb00611.x.
Mondal, N.C., Singh, V.S., Puranik, S.C., Singh, V.P., 2010. Trace element concentration in groundwater of pesarlanka island, krishna delta India. Environ. Monit. Assess. 163, 215–227. https://doi.org/10.1007/s10661-009-0828-6.
Prasad, M., Sunitha, V., Sudharshan Reddy, V., Suvarna, B., Muralidhara Reddy, B., Ramakrishna Reddy, M., 2019. Data on water quality index development for

groundwater quality assessment from Obulavaripalli Mandal, YSR district, A.P India. Journal Data of brief24 103–846. https://doi.org/10.1016/j.dib.2019.103846.
Ramesh, S., Sukumaran, N., Murugesan, A.G., Rajan, M.P., 2010. An innovative approach of drinking water quality index—a case study from southern Tamil nadu, India. Ecol. Indicat. 10, 857–868. https://doi.org/10.1016/j.ecolind.2010.01.007.
Richa, S., Manindra, M., Prashant, S., Rakesh, S., Rajendra, D.S., Pal, Krishna, Sanjan, G., 2016. Water quality evaluation of himalayan rivers of kumaun region, Uttarakhand. India Applied Water Sci 6, 137–147. https://doi.org/10.1007/s13201-014-0213-7.
Rothmaier, R., Weidenmann, A., Botzenhart, K., 1997. Transport of Escherichia Coli through the soil to groundwater traced by randomly amplified polymorphic DNA (RAPD). Water Sci. Technol. 35, 351–357. https://doi.org/10.2166/wst.1997.0758.
Singh, P.K., Tiwari, A.K., Mahato, M.K., 2013. Qualitative assessment of surface water of West Bokaro coalfield, Jharkhand by using water quality index method. International Journal of Geotech Research 5, 2351–2356. https://doi.org/10.21276/2455-295X.
Singh, S., Ghosh, N.C., Krishan, G., Kumar, S., Gurjar, S., Sharma, M.K., 2019. Development of indices for surface and groundwater quality assessment and characterization for Indian conditions. Environ. Monit. Assess. 191, 182. https://doi.org/10.1007/s10661-019-7276-8.
Standard Methods for the Examination of Water and Waste Water, twentieth ed., 1998. APHA, AWWA, WEF, Washington DC.
Tiwari, A.K., Singh, P.K., Mahato, M.K., 2014. GIS-based evaluation of water quality index of groundwater resources in West Bokaro coalfield, India. Curr. World Environ. 9 (3), 843–850. https://doi.org/10.12944/CWE.9.3.35.
Uttarakhand at a Glance, 2014-15 Central Electrical Authority, 2019. Forest department, Ministry of Tourism, Ministry of Statistic and Program implementation, Economic survey of Uttarakhand.