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Assessment of Water Quality for Drinking Purpose in District Pauri of Uttarakhand, India

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Abstract The water quality of Pauri District of Uttarakhand, India has been assessed during pre- and post-monsoon seasons to express the suitability of water for drinking purposes. The values of turbidity and iron exceed the permissible limit prescribed by Indian Standards for drinking purpose. Some sites were also contaminated with large number of total and fecal coliform bacteria. Piper diagrams exhibit that all water samples fall in Ca-Mg-HCO_3 hydrochemical facies and show the nature of carbonate hardness during both seasons. Based on the seasonal variation, the concentrations of most of the parameters considerably decreased during post-monsoon season and show the dilution effect of rain water in monsoon season. Water quality index describes the suitability of all sources for drinking purpose with 'Good' and 'Excellent' water quality during pre- and post-monsoon seasons, respectively.

Keywords: *Drinking water quality, Piper diagrams, Water quality index, Uttarakhand, Pauri district, India*

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1. Introduction

In Uttarakhand, a large portion of population lives in the hilly areas and about 90 % of the rural population depends upon the natural water sources for their daily water demand [1,2]. Due to the topography and high slops of the state, the drinking water supply department is mainly dependent on surface water sources to meet the rising demand of water. Therefore, economic, agricultural and social activities within Pauri district require urgent need to maintain the status of water sources. The water quality analysis is a most important part of hydrogeological investigations to quantify the composition of chemical characters. The factors influencing the water quality are the degree of weathering of rocks, topography of ground, seasonal variation, and discrepancy in monsoonal rainfall [3]. Besides, the rapid growth of population, higher demand of agricultural products, unplanned urbanization, over exploitation of water sources and other anthropogenic activities on the ground also led to the deterioration of surface water quality [1,4,5].

The main problematic issue of hilly region is the bacterial contamination generating due to direct or indirect discharge of municipal waste in river system owing to the slope factor [6]. These coliform contaminations particularly fecal coliform, seriously affect the human health and entail the major water borne diseases such as diarrhea, cholera, typhoid, schistosomiasis etc. [7]. Water Quality Index (WQI) is the most effective tool to convey the water quality information in the simplest form to the general public and legislative decision makers [8]. WQI transforms the large and complexed information of raw water quality data into a simplified and logical form with different categories of water quality that reflects the overall water quality status [9]. It has become a central theme of many national and international environmental agencies in various countries to determine water quality status of any source for various uses and for comparative purposes between different stations [10,11]. Numerous studies have used the various indices to predict the water quality of different regions for drinking and other uses [12,13,14]. Brown et al. in 1972 [12] have proposed an unambiguous method for communicating this information to everyone concerned by using simple, stable, consistent, and reproducible unit of water quality index method. Where as in 2006, Lumb et al. [13] employed the Canadian Water Quality Index to suggest the water quality of the Mackenzie-Great Bear sub-basin of Canada, which impacted by high turbidity and total (mostly particulate) trace metals due to high suspended sediment loads during the open water season.

Drinking water quality has emerged as major issue requiring immediate attention. Hence, regular monitoring of water quality is necessary to determine the pollution level of ground and surface waters. None of the agencies so far conducted any monitoring programme for quality of water resources of Pauri district of Uttarakhand. Therefore, till now no monitoring data has been generated for major drinking water sources of Pauri district. However, we have compared the water quality of river Alaknanda at Srinagar and river East Nayar at Satpuli in Pauri district of Uttarakhand with the water quality of river bank filtrate obtained from RBF wells established adjacent to these rivers for physico-chemical and bacteriological parameters [2]. The present study has been conducted to determine the concentration of hydrochemical constituents of drinking water sources of Pauri district in Uttarakhand state of India and compared with Indian Standards related to its suitability for drinking purposes. The study reveals the seasonal variation in water quality of selected sources during pre- and post-monsoon seasons of the year. In the study, piper diagrams indicate the presence of major ions in water sources due to the dissolution of mineral ions from rocks of mountains. Water Quality Index (WQI) describes the suitability of selected six water sources for drinking purpose and communicates the information related to water quality to the concerned citizens and policy makers.

2. Materials and Methods

2.1. Study Area

Pauri Garhwal, an important district of Uttarakhand state in India, covers an area of 5,230 km^2 and situated between latitude 29° 45’ to 30°15’ N and longitude 78° 24’ to 79° 23’ E [15]. According to census 2011, the total population of the district has reached upto 6,86,527 [16]. Besides Alaknanda, Nayar River is the major river of the district and is one of the major tributaries of Alaknanda, which is called Nayar after the confluence of Eastern and Western Nayar at Satpuli. Average annual rainfall in the district is 2180 mm, where about 90 percent is generally concentrated over the monsoon. Soils of the region have been formed either through pedogenetic processes or transported soils. The pedogenetic soils are formed by long duration of exposure to atmospheric factors, physical and chemical weathering and rock slides. Such types of soils are derived from granite gneissic, schistose and phyllite rocks. These soils obtained high percentage of silica from their parent body, while the soils formed from the limestone are rich in calcium carbonate. The transported soils are carried and deposited by the streams. The brown forest soil contains very high percentage of organic matter.

2.2. Methodology

Six major drinking water sources of Pauri district namely Srinagar (Alaknanda River) (site no.1), Satpuli (Madhuganga River) (site no.2), Buganio (Gadoli Gadhera) (site no.3), Ghodikhal (Kevru Gadhera) (site no.4), Maithana Gaon (Gazald Gadhera) (site no.5) and Kanskheit (Adwani Gadhera) (site no.6) were selected as water sampling sites (Table 1). The GPS co-ordinates were collected from each site by using GPS system (Make: Garmin, Taiwan; Model: GPSmap 76CSx) along with temperature of water (using mercury thermometer). The GPS co-ordinates with elevation above Mean Sea Level (MSL) and temperature of selected sites are summarized in Table 1.

Table 1. Description of Water Sampling Sites of Pauri District

Site No.	Sampling Site (Source)	Latitude	Longitude	Elevation (in Meter)	Temperature (in °C)
1	Srinagar (Alaknanda River)	30° 13' 12.4"N	78° 47' 53.7"E	526	21.0
2	Satpuli (Madhuganga River)	29° 55' 09.0"N	78° 42' 42.0"E	570	25.5
3	Buganio (Gadoli Gadhera)	30° 08' 57.5"N	78° 48' 21.6"E	1143	23.5
4	Ghodikhal (Kevru Gadhera)	30° 06' 44.1"N	78° 46' 06.8"E	1561	22.0
5	Maithana Gaon (Gazald Gadhera)	30° 10' 01.2"N	78° 44' 34.2"E	1320	08.0
6	Kanskheit (Adwani Gadhera)	30° 04' 19.3"N	78° 43' 19.7"E	1819	20.5

These sources are being used for drinking water supply in the district through water supply department of the state (Uttarakhand Jal Sansthan) to cater the mass population of the district. Water samples were collected from each site during pre-monsoon (April-May) and post-monsoon (October-November) seasons of the year 2011. Grab sampling was preferred for sample collection.

Water samples were collected in high-density polyethylene ‘Tarson’ brand bottles after 2-3 times rinsing with the sample. For trace metal analysis, water samples were collected in acid-leached polyethylene bottles and preserved by adding ultra pure nitric acid (5 ml/l) to minimize the adsorption and precipitation by reducing pH <2. While for bacteriological analysis, samples were taken in sterilized Tarson bottles covered with aluminum foils. pH and turbidity parameters were measured on site while for other parameters, water samples were brought to the laboratory at 4°C in sampling box. Sample preservation and physico-chemical analysis were performed as per standard methods of APHA [17]. Colorimetric analysis was performed by UV-VIS spectrophotometer of Merck, Germany (Model: Pharo300). Metal ion concentrations were determined using flame atomic absorption spectrometer (FAAS) of Varian (Australia; Model AA240) [18]. All the chemicals and reagents of analytical grade were purchased from Merck, India. Analytical grade water from Millipore water purification system (Make: Millipore, USA; Model: Elix and Synergy) was used for the preparation of all standards and solutions.

3. Results and Discussion

The detailed discussion of analysed physico-chemical characteristics of collected water samples from Pauri district is presented under the Table 2. These results are also compared with Bureau of Indian Standard IS 10500 [19] recommended for drinking purpose.

3.1. Turbidity and pH

The turbidity values fluctuated from 1.0 to 24 NTU and 7.8 to 9.8 NTU, respectively during pre- and post-monsoon seasons. Site no.1 (i.e. Srinagar) has higher turbidity value as 24 NTU than the permissible limit of 5 NTU during pre-monsoon season. The higher turbidity values in water sources of Pauri district has also been verified by the monitoring study of Govt. of India [20,21]. The pH values ranged from 7.10 to 8.26 and from 7.38 to 7.87 during pre- and post-monsoon seasons, respectively. The pH values in all drinking water sources were found within the recommended limit of BIS as 6.5 to 8.5.

Table 2. Hydrochemical data of water samples of Pauri district

Parameters	BIS Standard		Water Quality Data			
	Desirable limit	Permissible limit	Minimum	Maximum	Average	SD
Turbidity, NTU	1	5	1.0 (7.8)	24 (9.8)	9.8 (8.8)	7.6 (0.9)
pH	6.5-8.5	No relaxation	7.10 (7.38)	8.26 (7.87)	7.76 (7.71)	0.40 (0.20)
Total hardness, mg/l	200	600	41 (21)	152 (69)	75 (38)	39 (18)
Alkalinity, mg/l	200	600	27 (18)	114 (52)	53 (32)	31 (14)
TDS, mg/l	500	2000	68 (49)	236 (116)	119 (74)	59 (28)
Calcium, mg/l	75	200	9.45 (4.45)	36 (15)	18 (10)	9.3 (4.0)
Magnesium, mg/l	30	100	4.28 (1.8)	15 (7.39)	7.30 (3.35)	3.9 (2.1)
Sodium, mg/l	-	-	2.86 (2.62)	3.87 (6.73)	3.22 (4.62)	0.40 (1.5)
Potassium, mg/l	-	-	0.88 (0.39)	1.72 (2.43)	1.17 (1.18)	0.30 (0.84)
Chloride, mg/l	250	1000	12 (08)	18 (12)	15 (10)	2.40 (1.7)
Fluoride, mg/l	1.0	1.5	0.34 (0.05)	0.43 (0.23)	0.40 (0.14)	0.04 (0.10)
Sulphate, mg/l	200	400	ND (ND)	18 (12)	6 (3)	8.8 (4.8)
Nitrate, mg/l	45	No relaxation	0.4 (0.6)	3.4 (1.4)	1.4 (0.9)	1.1 (0.3)
Iron, mg/l	0.3	No relaxation	0.104 (0.073)	0.364 (1.777)	0.218 (0.514)	0.09 (0.70)
TC, Colonies/100ml	Absent	Absent	Absent (Absent)	160 (09)	48 (1.5)	66 (3.7)
FC, Colonies/100ml	Absent	Absent	Absent (Absent)	75 (Absent)	13 (Absent)	31 (Absent)

ND: not detected; SD: standard deviation; The values given in parenthesis indicate post-monsoon data.

3.2. Total Hardness and Alkalinity

The range of total hardness were found in between 41 to 152 mg/l and 21 to 69 mg/l, respectively during pre- and post-monsoon seasons for all the samples falling within the desirable limit of 200 mg/l of BIS. Alkalinity values in the analyzed water samples were obtained from 27 to 114 mg/l and 18 to 52 mg/l, respectively during pre- and post-monsoon seasons. The results show that all concentrations were found to be within the desirable limit of 200 mg/l.

3.3. Total Dissolved Solids (TDS)

TDS values fluctuated from 68 to 236 mg/l and 49 to 116 mg/l, respectively in pre- and post-monsoon seasons. TDS content in all the samples were well within the desirable range of 500 mg/l of BIS.

3.4. Calcium and Magnesium

The calcium contents in water samples ranged within 9.45 to 36 mg/l during pre-monsoon season and 4.45 to 15 mg/l during post-monsoon season. The magnesium content varied from 4.28 to 15 mg/l and 1.80 to 7.39 mg/l, respectively for pre- and post-monsoon seasons. The results indicate that no site exceeded the concentration of calcium and magnesium from their desirable limits as per BIS 10500 of 75 and 30 mg/l, respectively.

3.5. Sodium and Potassium

The values of sodium were quite lower in analysed water samples, which fluctuated from 2.86 to 3.87 mg/l and 2.62 to 6.73 mg/l, respectively in pre- and post-monsoon seasons. The sodium values in all samples were well within the prescribed limit of WHO as 20 mg/l. The potassium ion concentration oscillated within 0.88 to 1.72 mg/l during pre-monsoon season and 0.39 to 2.43 mg/l during post-monsoon season. BIS and WHO have not prescribed any limit for potassium ions in drinking water but it is useful for total ionic balance as well as important nutrient for human body. The seasonal variations for potassium ion were negligible during study.

3.6. Chloride and Fluoride

The chloride concentrations were found from 12 to 18 mg/l and 8 to 12 mg/l in analysed samples during pre- and post-monsoon seasons. Fluoride concentration ranged from 0.34 to 0.43 and 0.05 to 0.23 mg/l, respectively during pre- and post-monsoon seasons. No sample exceeded the desirable limit of 250 mg/l for chloride and 1.0 mg/l for fluoride.

3.7. Nitrate and Sulphate

The values of nitrate were confined between 0.4 to 3.4 and 0.6 to 1.4 mg/l, respectively during pre- and post-monsoon seasons. Nitrate concentration in water samples of all sites were well within the prescribed limit of 45 mg/l. The sulphate concentration fluctuated in a limited range of ND (not detected) to 18 mg/l in pre-monsoon season and ND to 12 mg/l in post-monsoon season. The collected concentrations of sulphate were much lower than the desirable limit of sulphate as 200 mg/l.

3.8. Iron

In the drinking water samples, the iron content was from 0.104 to 0.364 mg/l and 0.073 to 1.777 mg/l, respectively during pre- and post-monsoon seasons. The maximum concentrations of iron as 0.364 mg/l and 1.777 mg/l were recorded at Srinagar (Alaknanda River) sampling site no.1 during both pre- and post-monsoon seasons. These concentrations of iron were higher than the permissible limit of 0.3 mg/l, which is further confirmed by another study [21].

3.9. Bacteriological (Total Coliform and Fecal Coliform) Analysis

In the bacteriological assessment of water sources of study area, total coliform were recorded from absent to 160 colonies/100ml during pre-monsoon season. While in post-monsoon season, these organisms were recorded as 9 colonies/100ml at Srinagar (Alaknanda River) sampling location. Fecal coliform counts were found as 75 colonies/100ml only at Srinagar sampling site during pre-monsoon season, while in post-monsoon season, all sites were free from any fecal contamination. In the study, higher total and fecal coliform contaminations were noted only at Srinagar sampling site (Site no.1).

4. Water Quality Classification Using Piper Trilinear Diagram

Piper trilinear diagrams (Piper, 1944) were prepared to classify the water quality of selected sources of study area [22]. The diagram classified the hydrochemical facies in account of prominent ions contributed the water quality. These diagrams graphically represent the chemical equilibrium between cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) and anions (Cl^{-}, SO_4^{2-}, CO_3^{2-} and HCO_3^{-}) in water samples and also describe the presence of main contributor ions and chemical reactions taking place in the water. The diagram composed of two lower triangles of cations and, anions and middle quadrilateral. Quadrilateral or diamond shape indicates the combined distribution of both ions (cations and anions) and final water type of sources. Such diagrams may describe various hydrochemical processes like base cation exchange, cement pollution, mixing of natural waters, sulfate reduction, saline water (end-product water) and other related hydrochemical problems.

In present study, water quality of selected sites during pre- and post-monsoon seasons has been characterized using Piper diagrams (Figure 1). These diagrams represent that water quality of all selected sources is predominantly influenced by Ca^{+2}, Mg^{+2} and HCO_3^{-} ions i.e. Ca-Mg-HCO_3 hydrochemical facies during both pre- and post-monsoon seasons. These plots represent the equal dominance of alkaline earth metals and weak acid and thus water quality shows the nature of carbonate hardness.

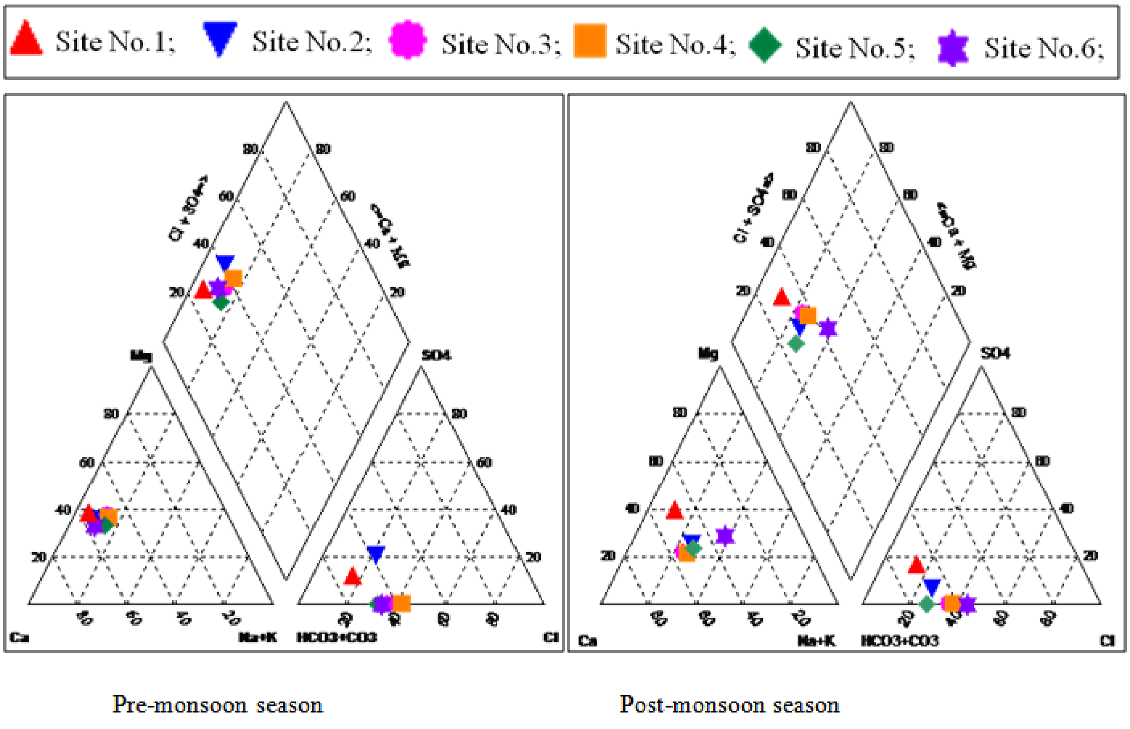

Figure 1. Piper diagram showing water quality classification of study area

5. Suitability of Water for Drinking Purpose Using Water Quality Index

Weight Arithmetic Water Quality Index Method was employed in determining the water Quality Index for assessing the suitability of water sources for drinking purpose. Such WQI has been extensively used for surface and groundwater quality assessment, mainly in different regions of India and also outside [9,23,24,25]. The index classifies the water quality based on the purity of sample by using the most commonly measured water quality parameters. This index was computed by using the following steps:

In the first step, water quality parameters including TDS, HCO_3, Cl, SO_4, NO_3, F, Ca, Mg, Na and K were selected to summarize the water quality, which indicate the considerable impact in the regions.

In the second step, quality rating or subindex (q_i) is computed for each of the parameter by using the given expression:

$$q_i = \left(V_{actual} - V_{ideal}\right) / \left(V_{standard} - V_{ideal}\right) \text{ x } 100$$

Where, V_{actual} is the estimated value of i^{th} parameter in the analysed water sample; V_{ideal} is the ideal value of this parameter in pure water. The ideal value is zero for all parameters except pH =7.0 and $V_{standard}$ is the recommended standard value of i^{th} parameter given in Table 2.

In the third step, the unit weight (W_i) for each water quality parameter was determined by using the following formula:

$$W_i = K / S_i$$

Where, S_i is standard value of i^{th} parameter recommended by BIS; K is the proportionality constant which is calculated by using the following equation:

$$K = 1/\left(\Sigma 1/S_i\right)$$

In the final step, the overall WQI is calculated by using following formula:

$$WQI = \Sigma q_i W_i / \Sigma\ W_i$$

The water quality ratings on the basis of index value for this WQI are summarized in Table 3.

Table 3. Water quality rating and index values

WQI value	Water quality rating	Grading
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very poor water quality	D
>100	Unsuitable water quality	E

Table 4. WQI values and relative description of water samples

S. No.	Sampling site	Pre-monsoon season			Post-monsoon season		
		WQI value	Description	Grade	WQI value	Description	Grade
1	Srinagar	33.74	Good	B	22.51	Excellent	A
2	Satpuli	36.42	Good	B	10.06	Excellent	A
3	Buganio	30.52	Good	B	5.31	Excellent	A
4	Ghodikhal	35.92	Good	B	19.50	Excellent	A
5	Maithana Gaon	37.75	Good	B	10.06	Excellent	A
6	Kanskheit	37.98	Good	B	11.93	Excellent	A

The results of WQI method during pre- and post-monsoon seasons are summarized in Table 4. The values of WQI ranged from 30.52 to 37.98 during pre-monsoon season and from 5.31 to 22.51 in post-monsoon season. All water samples in pre-monsoon season indicate the 'Good' water quality with 'B' grade, whereas in post-monsoon season, all samples were of 'Excellent' water quality with 'A' grade water. The lowering of results in post-monsoon season shows the dilution effect of rain water in monsoon season. Overall results conclude that water samples of all sites of Pauri district were found suitable for drinking purpose during both pre- and post-monsoon seasons.

6. Conclusion

Major drinking water sources in Pauri district are surface water sources. The quality of surface water varies from one season to another season due to the heavy rainfall of the region. The water quality of major surface water sources of study area has been assessed for drinking uses by analyzing various physico-chemical and bacteriological parameters during pre- and post-monsoon seasons. The ranges of turbidity and iron are significantly varying in surface water and exceed the desirable as well as permissible limits of BIS specification. Coliform contamination in surface water is also high. Piper diagrams indicate the dominancy of calcium, magnesium and bicarbonate ions in all the selected samples i.e. Ca-Mg-HCO_3 water type. Water Quality Index (WQI) reveals the 'Good' and 'Excellent' water quality during pre- and post-monsoon seasons, respectively. The results of the study confirm the suitability of all selected water sources for drinking purposes. But, regular monitoring is required to determine the pollution load with follow up treatment of water to improve the water quality, which is being used for drinking purpose.

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