 DOI: https://doi.org/10.51220/jmr.v17i2.8

Groundwater Quality in Hilly Region of Uttarakhand with Particular Reference to Srinagar (Garhwal) and its Surrounding

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Received: 20.10.2022; Revised: 05.12.2022; Accepted: 11.12.2022

Abstract: The availability of safe drinking water is a basic necessity for the well-being of society. Physico-chemical characteristics of water significantly determine its quality and directly or indirectly influence the microbial growth. Only a selected studies have been done in the Garhwal region to ascertain the physico-chemical quality including heavy metals and bacteriological properties of the groundwater sources. The physico-chemical quality of groundwater sources used for drinking purposes in Srinagar and two adjacent areas i.e., Srikot and Chauras were analysed by collecting the water samples during pre-monsoon, monsoon and post-monsoon period in 2019. The parameters included water temperature, pH, dissolved oxygen (DO), free carbon dioxide (CO_2), total alkalinity (TA), total dissolved solids (TDS), electrical conductivity, total hardness (TH), turbidity and chloride, fluoride, nitrate and phosphate. On the basis of physicochemical analysis, it was recorded that the studied parameters lie within the desirable limit of BIS and WHO standards except alkalinity, turbidity and hardness which were found slightly higher throughout the study. Also, the water quality index (WQI) revealed that groundwater sources of region do not fall under good category of water and found to be unsuitable for drinking. Therefore, proper treatment of groundwater sources is required such as filtration, boiling, and other methods before being consumed by the people.

Keywords: Groundwater quality • Physico-chemical parameters • Water quality index (WQI)

Introduction

The availability of safe drinking water is the basic necessity for the maintenance of health of the society. The contamination of drinking water results in occurrence of many diseases in human and is globally acknowledged as a health hazard. Notably, only 2.5% of Earth's water is freshwater which serves most of life's needs (Shiklomanov, 1993), of this the groundwater is a significant water supply source and it constitutes around 30.1 percent of the total freshwater present on the earth’s surface. Precipitation of rainfall and surface water that seeps into the ground and moves through the soil and rock spaces is the main source of groundwater. It is filtered of many pollutants, including pathogenic microorganisms because of natural soil protection and filtering when it passes through silt, soil and rocks (Kistemann et al., 2002; Vaidya & Labh, 2017). Physicochemical characteristics significantly determine the quality of water because of their effect on growth of microbes and is influenced by a variety of environmental (hydrological condition, climate, topography, catchment area, lithology, erosion, etc.) and anthropogenic variables (Kurup et al., 2010; Damo & Icka, 2013; Rawal et al., 2018). Study of water quality variables is needed to ascertain whether it is safe for drinking purpose and also for developing methods to reduce to make it cleaner.

The Himalayan state of Uttarakhand is administratively divided into two regions namely Garhwal and Kumaun with 13 districts. The state abounds in freshwater resources like glaciers, rivers, springs and lakes etc., these water sources basically provide water to the people in hilly regions. At the same time, people in both urban and rural areas depend on groundwater because of its natural quality, as it doesn't need to be treated before being distributed. However, the

J. Mountain Res. P-ISSN: 0974-3030, E-ISSN: 2582-5011
Vol. 17(2), (2022), 85-95 DOI: https://doi.org/10.51220/jmr.v17i2.8

groundwater sources in aquifers of the mountains watershed of the Himalayan region are at risk of reduction due to anthropogenic activities and climatic stress (Ghimire et al., 2019).

National and international agencies like Bureau of Indian Standards (BIS, IS 10500: 2012) and World Health Organization (WHO, 2017) have issued guidelines for safe drinking water considering the value of the physicochemical parameters. Besides, in India, other organizations like Central Pollution Control Board (CPCB) and Indian Council of Medical Research (ICMR) have also prescribed the acceptable limit of various physicochemical parameters for drinking purposes.

In Uttarakhand, besides the local population, every year millions of people visit Badrinath and Kedarnath as well to other destinations. As result, the water sources in hilly region are adversely impacted. Therefore, for the suitability assessment of all potable water sources, it is mandatory to check the various physicochemical and microbiological parameters which may lead to many water-borne diseases. The present work undertakes a review of the available data on groundwater quality in the hilly region of Uttarakhand. Besides, the study also presents the data on physicochemical parameters of the groundwater sources (hand pumps) recorded in Srinagar township and its surrounding in Garhwal region of Uttarakhand.

Review

Studies on drinking water quality especially in the hilly region of Uttarakhand are scattered and very few. Mostly, isolated studies have been undertaken to assess the quality of drinking water sources in Kumaun and Garhwal region of the state. In one such study, assessment of the drinking water sources in 13 districts of Uttarakhand was attempted by Gupta et al. (2012). The study revealed that of the 156 samples analysed, 6.4% and 33.3% samples contained toxic metal ions more than the prescribed limits, respectively as per BIS and WHO standards.

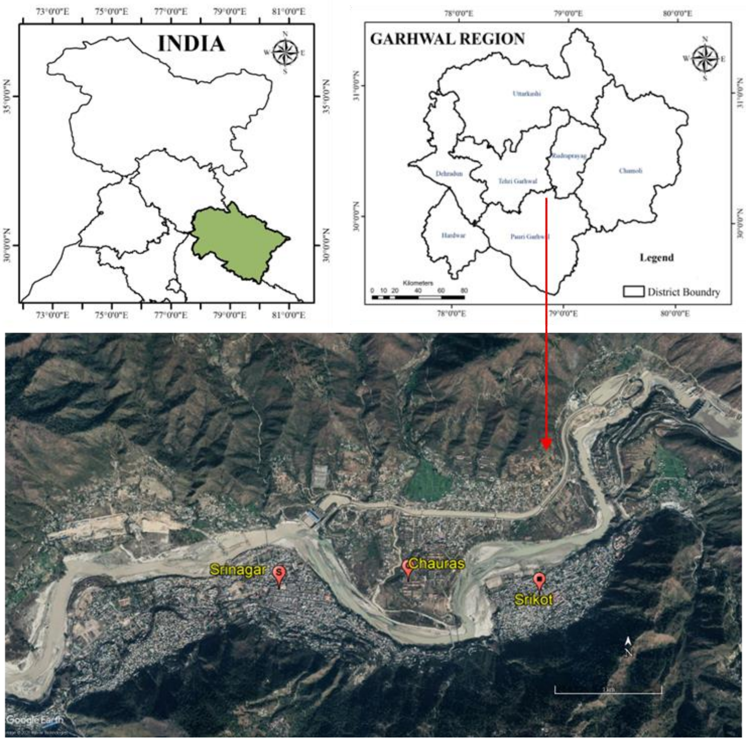

Figure 1: Location map of the study area

 DOI: https://doi.org/10.51220/jmr.v17i2.8

Recently, Kothari et al. (2021) evaluated the water quality of rural tracts in five districts of Uttarakhand - Tehri Garhwal, Nainital, Chamoli, Rudraprayag and Bageshwar by analysis of hydrogeochemical, biological parameters and Water Quality Index (WQI) determination. They found the physicochemical properties were suitable for drinking purposes as per BIS standards, however, the bacteriological parameters at few sampling sites were higher than BIS permissible limit.

Earlier, Jain et al. (2010)examined the groundwater for drinking and irrigation applications in District Nainital and found that 40 samples assessed during pre- and post-monsoon seasons had total dissolved solids concentration higher than the desirable limit in about 10% of the samples along with the alkalinity and hardness which also exceeded the desirable limit in 30% and 15 % of the samples respectively.

Different water sources including hand pumps in Tehri were analysed for major ion concentration and trace metals by Dudeja et al. (2013), they found that groundwater had higher ionic concentration than the other sources. In another study, a total of sixty samples of ground and surface water were tested for various physical and chemical parameters at twenty separate locations in Pauri district by Baunthiyal et al. (2015). The study recorded Iron content and total hardness in drinking water samples beyond the permissible levels of BIS standards during monsoon, winter and summer seasons.

Similarly, groundwater samples examined in Chporian village for physicochemical factors by Singh et al. (2019) reported that majority of the samples did not appear to be drinkable. Also, in the Kedar valley of Garhwal Himalayan area, samples of potable groundwater were analysed for levels of uranium and heavy metals as well as their health risk associated, and it was observed that the results were well within the respective safe ranges of advised guidelines (Prasad et al., 2019).

Materials and Methods

Study Area: Srinagar township is situated at 30.22° N, 78.78° E in District Pauri of Uttarakhand state (Fig. 1). This historic township, with an average elevation of 560 m asl is situated on the left bank of river Alaknanda, approximately 135 km from Haridwar on NH-58 enroute to Badrinath shrine. For drinking water requirements, the population of Srinagar and its surrounding area depends on municipal water supply from the river Alaknanda. However, during monsoon, the filtration of water become a challenge as the river water becomes highly turbid due to heavy rain fall in the upper Himalayan region, then the people also use groundwater sources present in the area.

According to Koppen's classification, the climate of area is categorised as subtropical to warm temperate (Rawat, 1992). In general, the pre-monsoon (April-June), monsoon (July-September) and post-monsoon (October-November) seasons are experienced during the year.

Sampling Procedure: In the present investigation, seven sampling sites were chosen in Srinagar and its two adjacent areas i.e., Srikot and Chauras (Fig. 2). The groundwater samples were collected in triplicates from all the sites during pre-monsoon, monsoon and post-monsoon seasons in 2019. Overall, 63 samples were collected throughout the study period. The sample bottles were thoroughly cleaned and rinsed with distilled water before collection. The sample were analysed for different physicochemical parameter namely temperature, pH, free CO_2, dissolved oxygen (DO), total alkalinity (TA), total hardness (TH), conductivity (EC), total dissolved solids (TDS), turbidity, chloride, fluoride, nitrate, phosphate and sulphate following standard methods outlined in Trivedy & Goel (1984) and APHA (2005). The physical parameters like temperature, pH, dissolved oxygen, free CO_2 and total alkalinity were determined on spot at the sampling site. Samples for determination of other parameters were brought to the laboratory for further analysis. Additionally, samples were sent to the laboratory of Indian Institute of Tropical Meteorology, New Delhi for the estimation of anions like chloride, fluoride, nitrate and sulphate by ion chromatography technique using Dionex ICS-2000 Ion Chromatography system.

Figure 2: Water sample collection sites: Handpumps at Srinagar (A), Srikot (B)and Chauras (C).

Water Quality Index (WQI) calculation

WQI is a rating exhibiting the overall effect of different water quality parameters (Ameen, 2019). It is a tool used to assess how separate metrics collectively affect the overall quality of water. Data on groundwater samples were employed for determination of water quality index (WQI) by means of the weighted arithmetic index (Ameen,2019) as established by Brown et al. (1972). BIS standards (IS 10500: 2012) were used to calculate WQI, however, in absence of BIS standards, other standards such as CPCB (Sharma & Kumar, 2017), ICMR (Sharma, 2014) were used. WQI was calculated using following equation:

$$WQI = \frac{\Sigma Q_n W_n}{\Sigma W_n}$$

Where, Q_n is the quality rating of n^{th} water quality parameter and W_n is the unit weight of n^{th} water quality parameter. The computed WQI values were there after grouped into five categories for determining the water quality status (WQS) as depicted in Table 1.

Table 1: WQI ranges, status, and possible use of the water sample (Brown et al., 1972).

WQI	Water Quality Status	Potential use
0–25	Excellent	Drinking, irrigation, and industrial
26–50	Good	Drinking, irrigation, and industrial
51-75	Poor	Irrigation and industrial
76–100	Very poor	Irrigation
> 100	Unsuitable for drinking	Proper treatment required before use

Results

The value of physicochemical parameters of all the groundwater samples analyzed during pre-monsoon, monsoon and post-monsoon seasons are depicted in Table 2. In the present investigation, the average temperature for groundwater ranged between 20.07±2.20 °C to

 DOI: https://doi.org/10.51220/jmr.v17i2.8

25.90±2.02 ℃ in post-monsoon and pre-monsoon respectively.

The pH value in all the samples varied between 7.18±0.37 and 7.79±0.43 which was well within the range (6.5-8.5) of BIS and WHO drinking water standards. The dissolved oxygen level ranged from 1.98±1.00 to 3.12±1.81 mgl^{-1}, which was low according to the CPCB's minimal recommended threshold for drinking water i.e., 6 mgl^{-1}. On the other hand, free carbon dioxide in groundwater was recorded to vary between 34.05±29.23 mgl^{-1} and 60.76±37.69 mgl^{-1}.

The total alkalinity in groundwater samples varied between 186.90±52.67 mgl^{-1} (pre-monsoon) and 274.52±81.29 mgl^{-1} (post-monsoon). The range of total hardness was recorded between 212.48±63.78 and 245.76±75.91 mgl^{-1}. The concentration of both i.e., TA and TH were found slightly higher than desirable range of BIS. The TDS ranged between 253.48±48.30 mgl^{-1} and 340.19±147.36 mgl^{-1} which were within the BIS desirable limit. While the EC ranged between 392.10±74.82 and 572.67±189.75 $\mu S.cm^{-1}$. Similarly, turbidity was found to vary between 3.90±3.79 NTU and 7.75±7.71 NTU which was quite higher than BIS prescribed limit.

The level of chloride was recorded between 2.60±2.84 mgl^{-1} and 4.48±1.84 mgl^{-1} in the groundwater samples which is far less than the limit of 250 mgl^{-1} set by BIS. Similarly, fluoride was found in the permissible limit range of BIS i.e., between 0.16±0.16 and 0.42±0.34 mgl^{-1} in groundwater. The nitrate concentration in groundwater was found to range between 4.87±4.66 mgl^{-1} and 14.27±9.61 mgl^{-1} which was also within the range of 45 mgl^{-1} as recommended by BIS. On the other hand, insignificant amount of phosphate was found in all the samples which ranged between 0.08±0.05 mgl^{-1} to 0.26± 0.23 mgl^{-1}. Likewise, very low concentration of sulphate (2.31±1.84 – 3.09±2.44 mgl^{-1}) was recorded in the groundwater during the present study.

Discussion

Groundwater is an important and crucial part of life support system. In hilly regions the groundwater sources are being used for drinking and other household purposes. There are various factors which define the quality of groundwater like the composition of recharge water, residence time and interaction between the soil, gas and rocks with which it comes into contact (Wavde & Shaikh, 2008).

Among the physicochemical parameters examined in present study, the temperature in groundwater samples ranged between 20.07±2.20 ℃ to 25.90±2.02 ℃ which may encourage the growth of microbes, changing the taste and odour of water. Although, no health-based recommendations are prescribed, the water's potability is enriched by its coldness, the idyllic temperature for potable water is between 6 and 15 °C (Delpla et al., 2009; Toure & Wenbiao, 2020).

The average pH value of all groundwater samples (7.18±0.37 - 7.79±0.43) was well within the ranges of BIS and WHO standards for different uses, like drinking water. Since CPCB's minimal recommended dissolved oxygen threshold for drinking water is 6 mgl-1,the DO concentration in groundwater samples was low (1.98±1.00 - 3.12±1.81 mgl-1). Although it has no effect on the health of the population consuming it but is accountable for several biological activities in the water (Chauhan et al., 2020). Similar DO levels in groundwater aquifers was also reported by Vyas & Sawant (2007), Kamboj et al. (2016), Saxena & Sharma, 2017 and Delkhahi et al. (2020). The respiration of aquatic life and the breakdown of dead organic materials are the main sources of free CO2 in water. Due to its underground interactions with soil, minerals, and bacteria, the groundwater aquifers may contain 10 to 100 times more CO2 than surface water (Wood & Hyndman, 2017).

Although CO2 would typically be stored in the groundwater for hundreds or thousands of years, this increase in CO2 causes increase in alkalinity and decrease of DO and pH in water samples (Delkhahi et al., 2020). Similar high free CO¬¬2 concentration (34.05±29.23-60.76±37.69 mgl-1) in groundwater samples was recorded during the present study. The concentration of ions that neutralize the hydrogen ion in water is referred to as alkalinity, with bicarbonate, carbonate, and hydroxide, being the most familiar components (Bozorg-Haddad et al., 2021). In the present study, the total alkalinity in groundwater was minimum (186.90±52.67 mgl-1) in pre-monsoon and maximum (274.52±81.29 mgl-1) in post-monsoon season. Higher values of CO2 observed in post monsoon season could be attributed to the increase in alkalinity of groundwater samples (Delkhahi et al., 2020).

Water hardness is a manifestation of the soil type and underlying geological formations as hard water often originates in regions with heavy topsoil and limestone deposits (Baunthiyal et al., 2015). Higher values of TH (212.48±63.78 - 245.76±75.91 mgl-1) in the present study may be due to carbonaceous or lime rich bed rock of the valley (Jain et al., 2010

Table 2: Statistical summary (Mean±SD) of the recorded physicochemical parameters at Srinagar and its surrounding and, recommended standards for calculating WQI and unit weight of individual parameters.

Parameters	Pre-monsoon	Monsoon	Post-monsoon	Standard	Recommending agency	Unit weight factor
Temperature (°C)	25.90±2.02	24.67±1.19	20.07±2.20	-	-	-
pH	7.18±0.37	7.22±0.36	7.79±0.43	6.5-8.5	BIS	0.050
DO (mgl^{-1})	3.10±1.85	3.12±1.81	1.98±1.00	6	CPCB	0.072
Free CO_2 (mgl^{-1})	34.05±29.23	46.10±43.58	60.76±37.69	-	-	-
TA (mgl^{-1})	186.90±52.67	243.10±36.52	274.52±81.29	200	BIS	0.002
TH (mgl^{-1})	212.48±63.78	245.76±75.91	223.19±71.87	200	BIS	0.002
TDS (mgl^{-1})	340.19±147.36	330.71±103.59	253.48±48.30	500	BIS	0.001
EC (μScm^{-1})	572.67±189.75	520.67±145.75	392.10±74.82	300	ICMR	0.001
Turbidity (NTU)	3.90±3.79	6.81±8.52	7.71±7.75	1	BIS	0.429
Chloride (mgl^{-1})	2.60±2.84	2.62±2.37	4.48±1.84	250	BIS	0.002
Fluoride (mgl^{-1})	0.16±0.16	0.31±0.28	0.42±0.34	1.0	BIS	0.429
Nitrates (mgl^{-1})	5.03±6.07	4.87±4.66	14.27±9.61	45	BIS	0.010
Phosphate(mgl^{-1})	0.14±0.11	0.26±0.23	0.08±0.05	-	-	-
Sulphate(mgl^{-1})	2.41±3.10	2.31±1.84	3.09±2.44	200	BIS	0.002

Singh et al., 2014; Khanam & Singh, 2014; Baunthiyal et al., 2015; Shekhar et al., 2016; Uniyal et al., 2018).

TDS in drinking water is frequently used for assessing and categorizing water quality as it increases the turbidity (Barakat et al., 2018; Kothari et al., 2021). Groundwater have a higher TDS and EC because of the interaction of water with soil and rock during the leaching process, further the EC of the water regulates the dissolved chemical concentration and mineral pollution (Barakat et al., 2018; Uniyal et al., 2018). In the current study, TDS in groundwater samples was recorded within the BIS and WHO desirable limits. Whereas, in absence of any health-based BIS or WHO recommendations for EC, the ICMR proposed limit up to 300 µScm^{-1} was considered and EC was found to be relatively higher in the groundwater samples in the study area. Similar values for TDS and EC has also been recorded by Jain et al. (2010), Dudeja et al. (2013), Singh et al. (2014), Uniyal et al. (2018) and Bhutiani et al. (2019).

During present investigation, high turbidity was recorded in monsoon and post-monsoon season as compared to pre-monsoon which might be due to the runoff during monsoon season (Baunthiyal et al., 2015) or may be due to corrosion of the iron pipes utilised in the facility (hand pumps). The presence of reddish-brown precipitate in water sample and near the tap/hand pump indicates higher concentration of iron in water or it could be due to the result of corrosion of metal from the facilities of the hand pump (Shittu et al., 2008; Toure & Wenbiao, 2020; Kothari et al., 2021). Higher level of turbidity in groundwater have also been observed by Khanam & Singh (2014) and Gupta & Chopra (2018).

Among the inorganic anions in water, chloride and fluoride were recorded well within the BIS permissible limit in groundwater samples. Fluoride commonly occurs in groundwater used for drinking with at concentrations less than the drinking-water standard for human health. Low levels of fluoride in drinking water can be helpful in preventing tooth decay, but it can be harmful to human health at higher concentrations (McMahon et al., 2020). Earlier, Jain et al. (2010), Dudeja et al. (2013), Goyal & Gupta (2016) and Uniyal et al. (2018) had also made similar observations for the groundwater sources.

In the present study, nitrate in groundwater was recorded within the desirable range of 45 mgl^{-1} set by BIS. However, the nitrate concentration was recorded highest (14.27±9.61 mgl^{-1}) during post-monsoon season, which could be attributed to leaching of domestic waste through soil into the groundwater with the runoff during monsoon season (Singh et al., 2014; Barakat et al., 2018).

All of sampling sites in the study area had relatively low phosphate (PO_4^{2-}) concentration (0.08±0.05 mgl^{-1} -0.26±0.23 mgl^{-1}). Phosphate concentration in groundwater was relatively low because phosphorus is absorbed/ fixed as aluminum or iron phosphate in acidic soil and as calcium phosphate in alkaline or neutral soil (Jain et al., 2010). Similarly, sulphate (SO_4^{2-}), another significant indicator of water quality that affects the flavour and odour of drinking water (Uniyal et al., 2018; Ameen, 2019), was recorded in low concentration (2.31±1.84 mgl^{-1} - 3.09±2.44 mgl^{-1}) in groundwater samples, which was well within the BIS desirable limit of 200 mgl^{-1}. Thus, the low concentration of four anions (nitrate, chloride, fluoride, and sulphate) as assessed by ion chromatography were within the drinking water desirable limit, which may be considered as a positive trait.

The primary objective of WQI is to transform the composite water quality data into an apparent information which could make the general public understand the condition of water sources of a location (Seth et al., 2016). For assessing the WQI, the weighted arithmetic index method developed by Brown et al. (1972) was employed. Eleven parameters (pH, DO, TA, TH, TDS, EC, turbidity, chloride, fluoride, nitrate and sulphate) were chosen to calculate WQI and

DOI: https://doi.org/10.51220/jmr.v17i2.8

the groundwater samples were evaluated for quality using BIS standards. Since the WQI displays the findings for the overall water quality instead of data for each metric, it is the most efficient method for communicating water quality.

Table 3: Water quality index (WQI) and classification of groundwater sources at Srinagar (Garhwal) and its surrounding.

Source	Pre-monsoon		Monsoon		Post-monsoon	
	WQI	Water quality	WQI	Water quality	WQI	Water quality
Groundwater	185.22	Unsuitable for drinking	323.35	Unsuitable for drinking	363.02	Unsuitable for drinking

The WQI determined the groundwater samples to be unsuitable for consumption during the study period (Table 3). Turbidity with highest Q_n value was the most significant parameter during all the seasons affecting the water quality to a large extent, otherwise all parameters fall under the desirable range. Increased turbidity during monsoon and post-monsoon season is understandable as due to surface runoff the rainwater also percolates to the groundwater table. WQI of groundwater samples was also found unsuitable during post-monsoon season in other regions of Uttarakhand (Panwar & Srivastava, 2012; Seth et al., 2014).

A review of the work done on the groundwater quality assessment in the hilly region of Uttarakhand clearly revealed lack of any comprehensive study. In the current study, majority of the physicochemical variables remained within prescribed limits of BIS standards, except turbidity, TA and TH which was above the desirable limit, but within the acceptable limit. However, on the basis of WQI, the groundwater samples were categorized as 'unsuitable for drinking'. Based on the findings of the present study, it could be inferred that mitigating the high turbidity by adopting suitable filtering methods, the water can be used for drinking and household purposes. Thereby, ensuring the provision of quality drinking water for improving human health by preventing the spread of water borne diseases.

Acknowledgement

The authors thankfully acknowledge the support extended for conduct of laboratory work by the Head, Department of Zoology, Hemvati Nandan Bahuguna Garhwal University, Srinagar-Garhwal. Fellowship provided by UGC, New Delhi to corresponding author is gratefully acknowledged.

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