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Water quality of springs and lakes in the Kumaon Lesser Himalayan Region of Uttarakhand, India

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ABSTRACT

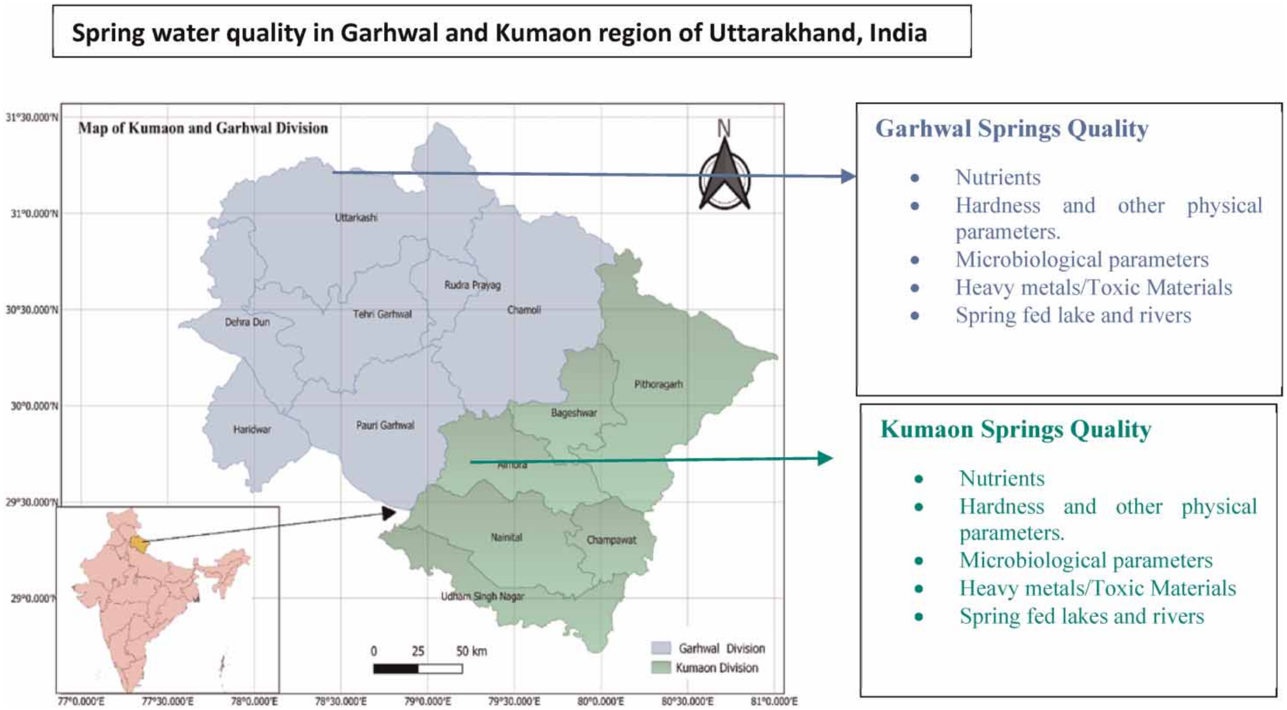
The scarcity of drinking water has become a bitter reality in many countries. The gap between demand and supply of water has been increasing exponentially year by year. Deforestation, vigorous use of groundwater for agricultural practices, and pollution of our present water resources such as rivers, lakes, and wells are triggering the freshwater scarcity problem. Ninety percent of people in Uttarakhand depend on springs for their daily life activities. In such a case, the quality and quantity of spring water should be a prime topic to be focussed on. In the Kumaon region of Uttarakhand, spring water quality is good but there is an issue with its availability, especially in summer. This review paper details the studies that have been conducted on nutrient status, hardness, heavy metals, and the presence of microbiological diversity in spring water. It also uncovers information on some critical springs, geological settings of their aquifers, and the steps that have been adopted to rejuvenate the spring. Some other measures have been carried out by the government and local communities for springs' revival and their improvement in discharge rate, including the construction of percolation pits, contour trenches, check dams, and improvement of water resources. It has been observed among the analyzed sample that the Kumaon region is dominated by arsenic, cadmium, chromium, and lead, whereas aluminum, barium, cobalt, and manganese are more in the Garhwal region. Apart from springs, this review paper also reveals the physicochemical characteristics of the spring-fed rivers and lakes of the Kumaon region.

Key words: geological settings, hardness, heavy metals, nutrients, rejuvenation of spring

HIGHLIGHTS

- Compiled all the water quality data on spring and spring-fed rivers of Uttarakhand at a single place.
- Compared the spring water quality of Kumaon and Garhwal regions.
- Compiled the work that has been done in Uttarakhand region for spring rejuvenation.
- The water-related problem of local people of Uttarakhand has been addressed.
- Remote sensing tool was applied for spatial distribution of organic and heavy metals.

GRAPHICAL ABSTRACT



1. INTRODUCTION

1.1. Background

Millions of people in the Himalayan region mainly depend on springs for their water sources. Rainwater that percolates into the underground aquifers is the main source of the water in the spring. Both rural and urban communities rely on springs to meet their drinking, agricultural, and domestic water needs (Jasrotia *et al.* 2018). Apart from this, springs also contribute to providing water for base flow in rivers, support vegetation, and wildlife springs. In the Himalayas, springs also have religious and cultural significance. Although the Himalayan area is considered a site of water resources (Singh *et al.* 2017), at the same time it is a stressed area in terms of water accessibility (Adimalla & Taloor 2020). Uttarakhand, a Himalayan state of India, comprises two regions, namely Garhwal and Kumaon. There are seven districts in Garhwal and six in Kumaon (Figure 1). Uttarakhand is a hilly state and the abode of several holy rivers and hundreds of small and big rivers. The sources of these rivers are glaciers of the western Himalayas and springs. The source of springs in the hilly regions is mainly from seepage water which flows through the shallow weathered and fractured zones. The diverse geology and physiography of the Himalayan region give rise to several springs, which according to their nature are locally called Naula, Dhara, and Bawdi. The study of their sources and characteristics is vital for their sustainability. Springs provide safe and perennial drinking water to the river and support the local ecosystem. The spring sources in Uttarakhand have ranged from a minimum of 0.82 to a maximum of 6.55 m^3/day and fall under the seventh and eighth categories of the Meinzers 1918 spring classification (Arora 2016). The fluvial originating springs have the highest rate of about 405×10^3 l/d, whereas the colluviums originating springs have a flow rate of 7.2×10^3 l/d (Negi & Joshi 2004). Variation in spring discharge has been noticed in those springs that are followed by rainfall and have rapid infiltration. The quality of Himalayan rivers and springs has been deteriorating year by year due to several anthropogenic activities, including disposing of untreated and treated effluents, poorly managed drainage systems, and dilapidated sewerage systems (Inventory & Revival of Springs, NITI Aayog 2017). It has been estimated (NITI Aayog 2017) that in Uttarakhand, out of a total of 16,973 villages, there are 594 with springs, i.e., only 3.5% of total villages. Seventy-seven percent of Uttarakhand's population reside in the high attitudinal hilly regions, of which 90% depend upon the natural spring water for their daily activities (Jain *et al.* 2010). Villages and hamlets in the high altitudes

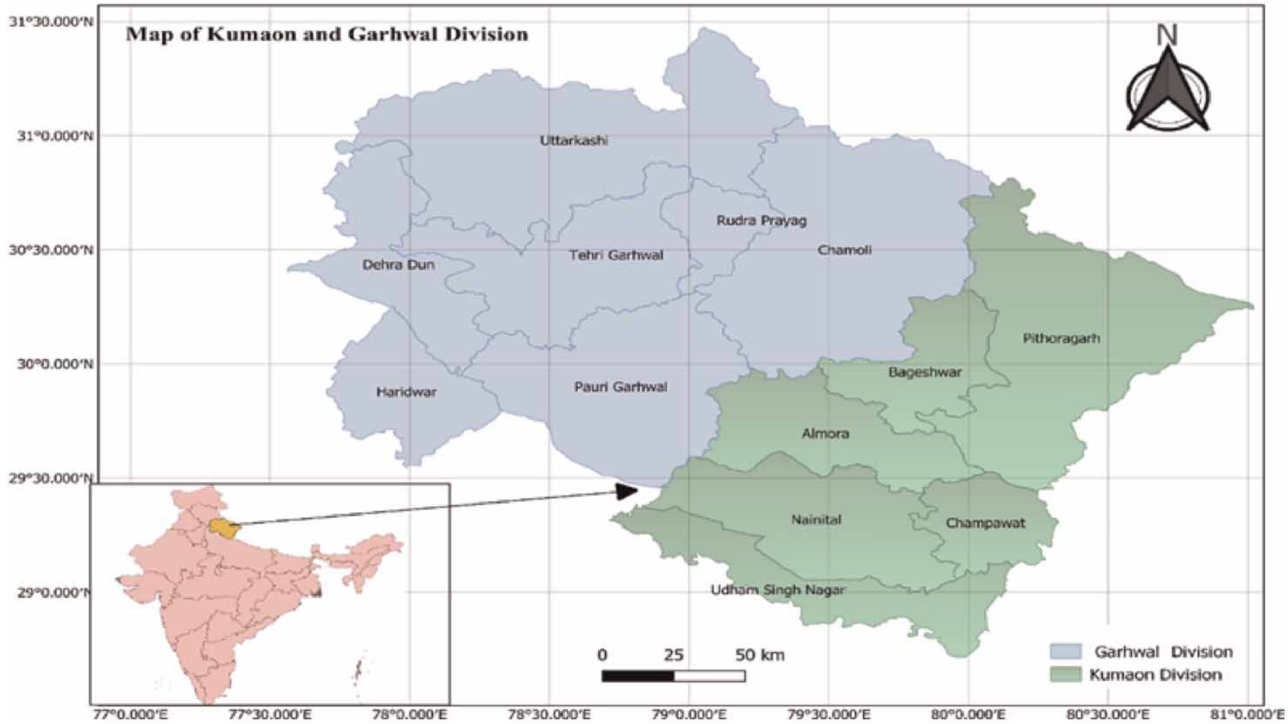


Figure 1 | Kumaon and Garhwal divisions of Uttarakhand.

are at a great disadvantage as most of the freshwater flowing through streams originating in the Himalayas is not readily accessible to them.

In Kumaon Himalayan regions, these springs are the main source of water for drinking irrigation and other household purpose, as well as springs, also serving as an integral part of hill ecology. Despite that, sometimes there is an acute shortage of water in hills due to uneven distribution in space, especially in summers (Agarwal *et al.* 2014). The dependency of hill communities on springs makes their conservation and rejuvenation a basic demand.

Deforestation, fluctuation in rainfall patterns, changes in land cover and land-use patterns, and forest fires are the factors behind the drying of springs. It has been observed that the aquifers are depleting which is the root cause of the declining water discharge from the Himalayan springs. The quality of water in springs is also deteriorating which is even more disturbing. The hydrological study of springs revealed that the water holding capacity of the reserve forest is higher in comparison to the other landscapes. It has been also observed by Joshi (2006) that the settlements, the open grazing, deforestation, and mismanaged agricultural activities affect the spring recharge capacity. Spring water is widely used for irrigation purposes in the Kumaon region. The quality of spring water also affects crop growth, as its chemical constituents provide the nutrients to the crops for their growth and development. Deterioration in spring water quality parameters also affects qualitative agriculture production (Bhandari & Joshi 2013).

1.2. Significance of research

Springs are the lifeline of the Kumaon region and are derived from seepage water. These resources are changing from perennial to seasonal and have been largely ignored. Due to urbanization, unsystematic sewage disposal, inefficient wastewater treatment methods, and the water quality of springs are affected. This research highlights the untouched part of springs' water quality parameters. Among surface water, spring water is usually considered safe for drinking (Batool *et al.* 2018). Water quality of springs directly or indirectly affect its environment – the human and animal health, crop, and plants production – and hence it must be free from toxic material. The analysis of water quality as per the prescribed norms of Drinking Water Standards is essential to understand the status and extent of pollutant loads being consumed by the mass population, which may otherwise be detrimental to their health. On 2 June 2017, the NITI Aayog took the initiative and founded five working groups for sustainable development in the hilly areas of the Himalayan region. 'Inventorization and

Rejuvenation of Springs in the Himalayan region for Water Security' was one such thematic area identified by the NITI Aayog. Some agencies/institutions have participated in this group that includes designators of the Central Ground Water Board (CGWB), Advanced Centre for Water Resources Development, Rural Management and Development Department (RM&DD), Ministry of Environment Forest and Climate Change (MoEF&CC), Management (ACWADAM), Pune, International Centre for Integrated Mountain Development (ICIMOD), Kathmandu and Department of Land Resources (DoLR), Government of India (GoI), and Government of Sikkim. Similarly, this research helps in analyzing the water quality status of Kumaon's spring region, to restore the quality and vitality of all the springs. The profile of water quality can also be used as reference data by researchers, scientists, and social scientists working in the water sector for analysis, testing, training, and awareness. Information on water resources, their suitability for use, and sustainability are necessary for sustainable development and spatial planning at nearby villages of that area.

2. SPRINGS' WATER QUALITY

Uttarakhand receives 90% supply of potable water from springs and rivers (indiawaterportal.org/). In the Kumaon region of Uttarakhand, 60% of rural people depend on natural springs for water supply. The traditional sources of spring water are locally known as Chal, Khals, Naulas, and Gharats (Sharma 2016). Springs are derived from rainfall patterns and the hydrogeology of that area. However, increased anthropogenic interference like deforestation, land-use pattern changes, sanitation, population growth as well as climate change are influencing the availability, quality, and quantity of spring water. Numerous studies conducted worldwide and in India (Fonollosa *et al.* 2016; Barakat *et al.* 2018; Chen *et al.* 2019; Taloor *et al.* 2020). Pande & Singh 1989 on spring water and its hydrochemical characteristics have claimed that reductions in spring water discharges are due to losses in the indigenous oak forest coverage and its partial replacement by pine. Other factors which are behind the substantial decrease in spring water include overall forest cover depletion and construction activities.

2.1. Nutrients

Nainital lake basically originates from spring. An investigation has been performed by Pant *et al.* (1980) to reveal the quality of water in Naini lake. It was found that since 1954, the total hardness and concentration of nitrate-nitrogen are consistently increasing. In 1954, ammoniacal nitrogen concentration was low and has increased eight-fold up to 1974. The same enhancement has been observed in nitrate concentration of which there was only a trace in 1954.

A study has been conducted by Bhandari & Joshi (2013) to propose a quality profile of springs of the study area for irrigation. Water from 54 springs in Almora has been sampled from rural areas as well as from urban localities for analyzing pH, electrical conductivity (EC), total dissolved solids (TDS), Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, and SO_4^{2-} for irrigational water during pre-monsoon, monsoon, and post-monsoon seasons. Also, some irrigation quality parameters like sodium adsorption ratio (SAR), residual sodium carbonate (RSC), soluble sodium percentage (SSP), salinity, magnesium hardness (MH), and permeability index (PI) are analyzed. All springs were found good for irrigation quality parameters. They used the Wilcox diagram and categorized the water resources into C1S1 (low–low) which covered 98% of springs and C2S1 (medium–low) classes (Bhandari & Joshi 2013). They also concluded that the SAR values of 99% samples were below 10 and categorized as S1 level. Their study revealed that about 82% of the water of spring resources in pre-monsoon, 95% of the water of spring resources in monsoon, and 95% of the water of spring resources in post-monsoon are good for irrigation.

The work on the quality of water in some springs of Almora has also been done by G.B. Pant Institute of Himalayan and development Kosi Katramal, Almora (Nayal & Sati 2007)). This study says that minimum amounts of calcium (11–71 mg/l) and magnesium (9 mg/l) were found in Teendhara and Chatwapipal springs, respectively; however, maximum concentrations of calcium (71 mg/l) and magnesium (24 mg/l) were reported in Bhaktiyana spring. It was observed that sulfate, nitrate, and chloride were absent in Karas spring water, and their maximum concentration was found in Bhaktiyana spring. The detailed study is shown in Table 1. The trace numbers of heavy metals have also been analyzed and among them, the concentration of Fe is found to be maximum (0.753–9.218 μg/l), followed by Cu (0.119–0.995 μg/l), Pb (0.0016–0.138 μg/l), and As (0.061–1.166 μg/l). As per the Indian Bureau of Standards, all the water quality parameters are found to be within the safe limits of drinking water (Table 1).

The study of springs at different parts of the Kosi basin, including the Garhwal and Kumaon regions by Joshi (2006), revealed that nitrate concentration was high. It was also identified that a badly managed drainage system and old sewage disposal methods resulted in an increased level of Na^-, Cl^-, F^-, NO_3^-, and sulfate. Drinking water is always a subject of concern among public health. Springs are the main source of drinking water and for other household purposes. A study on nine

Table 1 | Presence of some nutrients in sampled springs of the Almora region

Nutrients	BIS (2012) limit	Maximum	Minimum
Calcium	AL 75 mg/l PL 200 mg/l	71 mg/l (Bhaktiyana)	11 mg/l (Teendhara)
Magnesium	AL 30 mg/l PL 100 mg/l	24 mg/l (Bhaktiyana)	9 mg/l (Chatwapipal
Sulfate	AL 200 mg/l PL 400 mg/l	116 mg/l (Bhaktiyana)	0 (Karas)
Nitrate	AL 45 mg/l PL no relaxation	21 mg/l (Joshimath)	0(Karas)
Chloride	AL 250 mg/l PL 1,000 mg/l	18 mg/l (Bhaktiyana)	0 (Teendhara)

AL, acceptable limit; PL, permissible limit.

sampled sites at the Pithoragarh district of the Kumaon region (Patni *et al.* 2018) revealed that all the nutrients present in spring water were within the permissible limit assigned by the BIS10500 (Table 2). This water can be used by the dwellers simply by boiling and filtering it.

2.2. Hardness and other physical parameters

Joshi (2006) measured the hydrological behavior and dynamics of the springs at different parts of the Kosi basin, including the Garhwal region and Kumaon region. Water quality was tested for eight springs. The water quality testing and analysis were carried out for the samples that were collected in winter (January), summer (June), and rainy (August) seasons of the years 1998 and 1999. The samples were studied and analyzed for parameters such as pH and EC, TDS, dissolved oxygen (DO), Ca^{2-}, Mg^{2-}, Na^{-}, Cl^{-}, F^{-}, and SO_4^{-2}. The study revealed that springs in the forest and the less populated areas had lower EC, cationic, TDS anionic concentrations, which makes them suitable for drinking purposes, whereas springs that were found at cultured or irrigated land had high concentrations of EC, nitrate, and low DO.

Dharas and Naulas are generally found in high altitudinal regions. This type of spring emerges where impermeable layers intersect with the groundwater table. Mostly unconfined aquifers have the flow of water under gravity. Singh *et al.* (2014) studied five springs of the Srinagar Garhwal region. Their study showed that there was a fluctuation in different water quality parameters as shown in Table 3.

All the parameters were within the probability range of APHA and WHO indicating the good quality status of water for drinking and other household consumption for the people of the region.

Table 2 | Average concentration of nutrients found in sampled springs in Pithoragarh

	Nitrate conc. (mg/l)		Sulfate conc. (mg/l)		Phosphate conc. (mg/l)	
	Desirable limit <45 mg/l		Desirable limit=200–400 mg/l		Desirable limit=0.1 (mg/l)	
Sampled sites	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post- monsoon
HudkanaDhara	<0.1	<0.1	1	1	0.01	0.22
Mahadev Dhara, GIC	18.4	18.4	1	3	0.06	0.02
Rai Dhara Rai, Pithoragarh	<0.1	<0.1	1	4	0.17	0.17
GurnaDhara	<0.1	<0.1	1	1	0.1	0.1
Mahadev Dhara, Visad	<0.1	<0.1	1	2	<0.001	0.06
Mahadev Dhara, Market	11.8	11.8	45	53	0.23	0.01
MarhDhara	10.6	14.4	22	21	2.19	2.24
Subterranean spring, Chaira	7.9	15.1	10	13	0.05	<0.01
Subterranean, spring, Satsiling	1.6	1.6	20	3	0.8	0.86

Table 3 | Mean value of various physicochemical properties of the water of the five springs of Srinagar Garhwal

S. no.	Parameter	Spring name Kolundhara	Beegadhara	Kamleshwardhara	Hanuman Mandir Dhara	Kothardhara	SD
1	pH	6.9	6.9	6.9	7.1	7.2	0.14
2	Conductivity (μS/cm)	595.51	515.89	684.01	530.46	509.68	73.72
3	Temperature (°C)	20.69	21.25	21.5	21.25	20.69	0.37
4	DO (mg/l)	2.9	2.5	2.8	3.05	3.2	0.27
5	Chloride (mg/l)	58.38	57.5	67.88	59.13	59.5	4.21
6	Total hardness (mg/1)	245.88	220.25	267.13	211.19	218.25	23.37
7	Nitrate (mg/1)	4.45	6.25	7.5	6.13	8.75	1.68

SD, standard deviation.

Hardness in water is due to the presence of calcium and magnesium ions. Although there is a weak correlation between water hardness and its impact on human health, it should be under the permissible limit. An investigation has been carried out by Gaur *et al.* (2011) in five regions: Uttarakhand–Haridwar, Dehradun, Vikasnagar, Mussorie, and Dakpatthar. They observed that the presence of total hardness and other physical parameters like pH, alkalinity, TDS at different studied sites were under the permissible limit (Table 4).

The CGWB has done a lot of work on testing the groundwater and surface water quality in the Bageshwar district, and 63 samples were collected from the random site of springs for inventory. In its published report, it has been mentioned that the average concentration of bicarbonates in 63 sampled sites varied from 18 to 232 mg/l, the EC recorded shows an increase from 50 to 670 μS/cm. The total hardness of 10–290 mg/L in groundwater (as $CaCO_3$) was reported in the Bageshwar district, which was low and under the permissible limit, indicating the suitability of that spring water for domestic use. A lot of investigations have been performed by the CHIRAG in the Kumaon region of Uttarakhand. Their work on testing the physicochemical is summarized in Table 5 (Spring atlas 2015, CHIRAG) which concludes that the water at the below-mentioned places is of excellent quality.

2.3. Microbiological parameters

The water quality of two natural water springs, i.e., Raj Naula and Badi Naula located in the Kosi river catchment area of the Almora city in Kumaon Himalaya (Uttarakhand), has been investigated by Sati & Paliwal 2008. The physical, chemical, and

Table 4 | Physicochemical characteristics of water samples in five regions of Garhwal Uttarakhand

Parameter	BIS (2012) standards (mg/l)	Haridwar	Vikasnagar	Mussoorie	Dehradun	Dakpatthar
pH	6.5–9.2	7.25	7.0	7.4	7.2	7.1
Alkalinity	Desirable 200 mg/l, Permissible 600 mg/l	275	328	336	322	322
Total hardness (TH)	Desirable 300 mg/l Permissible 600 mg/l	252	282	329	290.5	272
TH (as Ca^{2+})	Desirable	206.5	212	249	290.5	208
TH (as Mg^{2+})	500 mg/l	45.5	70	80	40.5	64
TDS	Permissible 2,000 mg/l	682.5	567.5	551	548	548
Suspended solid (SS)	Desirable 250 mg/l	16.5	22	18	22	20
Chloride	Permissible 1,000 mg/l	153.5	196.0	121.0	289.0	185.0
Sulfate	Desirable 200 mg/l Permissible 400 mg/l	197.5	153	130	170	132

Table 5 | Physicochemical characteristics of water sample in Kumaon region

Sampled sites	pH Acceptable limit 6.5–8.5	TDS (mg/l) Acceptable (500 mg/l) Permissible (2,000 mg/l)	Total hardness (mg/l) Acceptable (200 mg/l) Permissible (600 mg/l)
DhargaraDhara, Bageshwar	7.32	320	156
GhatgarhDhara, Nainital	6.4	110	80
Salkuli Naula,	7	200	96
Kulgarh naula, Nainital	7.52	170	96
Mounatalladhara, Nainital	6.4	110	96
Dansil naula, Naintal	6.4	110	48

biological characteristics of the water of these springs occurring in the heavily populated area were analyzed. A significant decline in the water quantity and quality has been noticed in both the springs, whereas Raj Naula spring water had higher ranges of deterioration in comparison to Badi Naula. Both the water bodies were contaminated with coliform bacteria. The presence of coliform bacteria indicated the occurrence of organic pollution in both the studied water bodies.

Kumar & Sharma (2019) studied the microbiological diversity and physicochemical attributes of two hot water springs, namely Ringigad and Saldar in the Garhwal region of Uttarakhand. The microorganisms isolated from the spring samples were *Brevibacillus*, *Bacillus*, *Geobacillus* and *Streptococcus*, along with four archeal and three fungal strains in Ringigad spring and three archaeal and three fungal strains in Saldar spring. Some bacterial profiles of genera of *Bacillus* and *Paenibacillus* was also found in Tapovan hot water spring in Joshimath in Garhwal (Ranawat *et al.* 2016). A piece of information on the presence of bacteria, protozoa, and other pathogens on groundwater seems to access microbial risk and inform system-based management of drinking water (Ashbolt 2015). A thorough study on microbial assessment has been carried out by Rawat & Joshi (2019) on 16 springs located along National Highway-58 from Rishikesh to Badrinath. The study revealed the presence of *Salmonella*, *Shigella*, *Vibrio*, and *Pseudomonas* in spring water. The Most Probable Number (MPN) index for coliforms was above the permissible limit and water from most of the springs cannot be considered completely safe for direct human consumption. To check the potability of spring water, an investigation was performed by Chauhan *et al.* (2020) at the springs of the Sumari village of the Pauri Garhwal district. They observed that at different sites the range of coliform was from 1 to 12 which is more than the prescribed limit of zero as per the BIS10500. The highest coliform count of 12/100 ml was found in the studied area. The observation has shown that there was some source of fecal matter that was contaminating the drinking water at the site. Fecal contamination of 320/l in Dhargara Dhara in the Raikholi village at Bageshwar was observed by the CHIRAG (Spring atlas, CHIRAG).

2.4. Heavy metals/toxic materials (such as arsenic and fluoride)

Heavy metals/toxic metals are very stable elements and are found in trace amount; they cannot be metabolized by the body and thus can be very toxic. The presence of these elements in some springs at Haridwar, Dehradun, Dakpatthar, Vikasnagar, and Mussorie of the Garhwal region of Uttarakhand has been studied by Gaur *et al.* (2011). Table 6 shows the heavy metal concentration of water at different sites. It had been observed that the content of the Pb at all the five regions was higher than the BIS permissible limits and the content of Mn, Ba, Cu, Co, Fe was within the permissible limit of the BIS standards for drinking water.

3. SPRING-FED LAKE WATER QUALITY

A study was carried out by Sharma & Bradely (2014) on the water quality characteristics of Naini lake situated in the Kumaon region of Nainital. The upper side of the lake is called Mallital and the lower side is called Tallital (Figure 2) by the local people. This lake originates from spring, and it is an important water body as far as local tourism is concerned. For this purpose, water samples from two different points were collected – one was from the highly polluted (Mallital) and another was from the least polluted (Tallital) areas. It had been done to identify the actual level of pollution in the lake in four different seasons (January, April, July, and October). The collected samples were analyzed at different physical and chemical parameters. The turbidity, EC, heavy metal (lead, iron, and copper), and total alkalinity concentration were found to be

Table 6 | Heavy metal concentration in spring water samples in five regions of Uttarakhand

Heavy metals	BIS acceptable limit (mg/l)	BIS permissible limit (mg/l)	Haridwar	Vikasnagar	Mussoorie	Dehradun	Dakpatthar
Manganese	0.1	0.3	0.052	0.058	0.054	0.053	0.054
Aluminium	0.03	0.2	0.056	0.058	0.056	0.056	0.056
Barium	0.7	No relaxation	0.075	0.078	0.079	0.079	0.078
Cadmium	0.003	0.01	0.131	0.132	0.133	0.133	0.130
Chromium	.05	0.05	0.094	0.096	0.096	0.096	0.098
Cobalt	–	–	0.060	0.062	0.064	0.064	0.060
Copper	0.05	1.5	0.022	0.022	0.021	0.021	0.018
Iron	1.0	1.0	0.066	0.068	0.062	0.067	0.064
Lead	0.01	No relaxation	0.084	0.090	0.088	0.088	0.090

Figure 2 | Mallital and Tallital parts of Naini lake at Nainital (www.nainitaltourisim.com).

above the desirable limit (Table 7) of the prescribed national and international standards in all four seasons at both Mallital and Tallital.

Inaotombi & Gupta (2014) did an investigation on Lake Sattal, in the Nainital district of the Kumaon region of Central Himalaya, from 2011 to 2012 to identify the changes in the water quality of the lake in the last 30 years and to find out the trophic status of the lake so that the utility of the lake for human consumption and fish production could be determined. Lake Sattal is a warm monomictic water body with a high DO concentration. About three decades ago, it was in an oligotrophic state. It has been found that the concentration of phosphorous has increased 60 times as compared to the previous study. The increased concentration of phosphorous and nitrogen in water is responsible for its eutrophication. These could be attributed to changes in the land-use patterns, extensive land clearance, agriculture, suburban development, and other biotic activities in the catchment. The data on various parameters of water quality like turbidity, metallic content, fluoride, nitrogen (0.08 mg/l in the eastern basin and 0–0.07 mg/l in the western basin during the 2-year study), phosphorous (0.02–0.14 mg/l in the eastern basin and 0.01–0.16 mg/l in the western basin) were also under the desirable limit for human consumption after proper treatment.

It has been observed that after adopting several efficient methods to purify Naini lake, including Lake Bank Infiltration (Dash *et al.* 2008) and cleaning programs by the Government of India, the water quality of the lake has improved. The physicochemical and microbial quality of some springs in the Naini lake basin of the Kumaon region of Uttarakhand were assessed by Maindoli *et al.* 2018. Seventeen springs located in the lake basin of Nainital were selected for sample collection.

Table 7 | Water quality parameters of Nainital lake for all four seasons

	Nainital lake (Mallital)			Nainital lake (Tallital)		
	For all four seasons			For all four seasons		
Parameter	Maximum	Minimum	Mean ± Standard deviation	Maximum	Minimum	Mean ± Standard deviation
PO_4^{-3} (mg/l)	0.18	0.09	0.143 ± 0.046	0.16	0.09	0.123 ± 0.036
Temp (°C)	22.00	17.00	19.5 2.08	22.00	18.00	20.50 ± 1.73
DO (mg/l)	8.60	7.90	8.20 ± 0.29	7.20	4.00	5.77 ± 1.39
pH	8.20	7.20	7.55 ± 0.47	8.20	7.40	7.75 ± 0.34
BOD (mg/l)	3.50	2.80	3.25 ± 0.046	4.80	3.80	4.25 ± 0.41
Turbidity (NTU)	16.00	6.00	10.25 ± 4.64	18.00	6.00	10.50 ± 5.25
Total hardness (mg/l)	290.00	192.00	250.00 ± 41.53	392.00	112.00	241.5 ± 125.9
Alkalinity (mg/l)	278.00	230.00	253.50 ± 21.56	154.00	120.00	142.00 ± 15.05
TDS (mg/l)	422.00	375.00	400.00 ± 23.05	582.00	359.00	443.25 ± 98.29
TSS (mg/l)	390.00	286.00	338.00 ± 44.92	412.00	258.00	341.25 ± 68
Cl (mg/l)	18.00	11.00	14.50 ± 2.88	19.00	14.00	16.750 ± 2.62
EC (μS/cm)	580.00	500.00	536.00 ± 33.62	550.00	500.00	525.00 ± 28.86
Na (mg/l)	3.20	2.42	2.79 ± 0.40	3.30	2.89	3.14 ± 0.18
K (mg/l)	14.57	11.80	12.82 ± 1.20	11.24	10.27	10.57 ± 0.45
Pb (mg/l)	0.34	0.24	0.28 ± 0.04	0.27	0.21	0.23 ± 0.02
Cu (mg/l)	0.24	0.14	0.19 ± 0.04	0.22	0.18	0.20 ± 0.02
Fe (mg/l)	0.73	0.62	0.68 ± 0.04	0.79	0.64	.70 ± 0.06
Zn (mg/l)	0.08	0.03	0.06 ± 0.02	0.07	0.02	0.04 ± 0.02

The water samples were collected thrice during 2017 and a total of 15 parameters were analyzed, namely DO, pH, total hardness, Mn, Fe, BOD, TDS, Ca, F, PO_4-P, NO_3-N, NH_3-N, NO_2-N, Cu, and Zn. The results were analyzed (Table 8). The analysis on the above-mentioned parameters concluded that water qualities of almost all springs were either within the acceptable or within the permissible limit of the Indian Standard Institution (ISI) for human consumption.

Choudhary *et al.* (2009) found after assessing biogeochemical records of paleoenvironment changes in Nainital lake that total organic carbon (TOC) concentration varied from 1.0 to 3.5 g/m^2/year. The sediments were anoxic with low nitrogen (0.10–0.30 g/m^2/year) and high sulfur flux (0.37–1.0 g/m^2/year), and such fluctuation in N, S, and TOC is due to several microbial processes dominated by denitrification and sulfate reduction. As per the report of CGWB-2010, the Cd concentration was prominent as 1,000 mg/l in Nainital lake, whereas the prescribed limits for drinking water by the BIS standards and WHO guidelines are 10 and 3 mg/l, respectively.

4. SPRING-FED RIVER WATER QUALITY

The major rivers of Uttarakhand originate from springs. Some investigations on water quality assessment of different rivers of Uttarakhand (Sati & Paliwal 2008; Paliwal & Sati 2009; Semwal & Jangwan 2009; CPCB 2010; Bhandari & Joshi 2013) have been reported. A study was conducted by Seth *et al.* (2016) on the Gola River which originates mainly from the lesser Himalayan region. It is a spring-fed river and source of water for the Haldwani and Kathgodam regions. The following water quality parameters were observed: i.e., total hardness 570 mg/l, alkalinity 461 mg/l, chloride 25 mg/l, sodium 4.31 mg/l, potassium 2.07 mg/l in pre-monsoon; and 135, 115, 10.2, 3.97, and 1.49 mg/l in post-monsoon.

An investigation on seasonal variation in physicochemical variables in spring-fed Kosi river at the Almora region has been carried out by Selakoti & Rao (2015). They observed a maximum value of 10.5 mg/l in January and a minimum of 8 mg/l in August, and the highest level of alkalinity observed is 75 mg/l in December, whereas the lowest recorded is 56 mg/l. The chloride concentration was highest at 5.5 mg/l in July and the lowest was at 3.2 mg/l. The maximum and minimum ranges of nitrate concentration were observed between 0.006 and 0.015 in Sharda River (Naganyal & Saxena 2019). Mixing of

Table 8 | Physicochemical parameters of water quality of various springs in Naini lake basins of Kumaon Himalaya

S. no	Springs	DO mg/l	pH	Total hardness ($CaCO_3$) mg/l	Mn mg/l	Fe mg/l	BOD mg/l	TDS mg/l	Ca mg/l	F mg/l	Phosphorus (PO_4-P) mg/l	Nitrate (NO_3^-N) mg/l	Ammonia (NH3-N) mg/l	Nitrite (NO_2-N) mg/l	Total Copper (Cu) mg/l	Zinc (Zn) mg/l
1	Near Satyanarayan Mandir Kilbury Road	2.5	7.0	230	0.15	0.01	1	198	190	0.08	0.06	0.128	0.02	0.00	0.00	0.01
2	Near Nishant Hostel	2.6	7.5	515	0.01	0.20	1.5	185	102	0.12	0.09	0.238	0.71	0.001	0.06	0.01
3	Chunadhara	2.1	7.0	480	0.01	0.0	0.8	561	101	0.46	0.11	0.880	0.71	0.003	0.10	0.01
4	Near Main pump House	2.2	7.2	520	0.01	0.01	1.5	397	165	0.53	0.20	0.860	0.11	0.000	0.06	0.01
5	Near Bhotiya Bandh	2.1	7.5	190	0.01	0.02	1.5	421	106	0.32	0.12	0.550	0.32	0.009	0.00	0.01
6	Nainital to Haldwani Road (Near Krishnapur)	2.1	7.5	270	0.10	0.1	1	236	33	0.33	0.10	0.332	0.05	0.000	0.08	0.015
7	Near Ramlila Grounnd	1.8	7.2	490	0.15	0.1	1	420	31	0.45	0.12	0.477	0.45	0.001	0.08	0.015
8	Near Jiwaji Cottage	3.6	7.2	510	0.02	0.2	1	379	55	0.39	0.34	0.496	0.15	0.003	0.04	0.015
9	Sipaidhara	6.2	7.2	460	0.02	0.14	0.5	224	54	0.42	0.07	1.010	0.07	0.003	0.08	0.012
10	Dogaun	6.31	7.0	150	0.01	0.20	0.8	415	55	2.60	0.05	0.48	0.21	0.004	0.12	0.012
11	Gufa Mahadev upper	6.5	7.5	420	0.015	0.21	0.5	276	112	0.36	0.08	0.327	0.15	0.00	0.08	0.01
12	Gufa Mahadev Lower	4.15	7.5	370	0.012	0.15	0.6	263	66	0.33	0.16	0.640	0.07	0.001	0.16	0.01
13	Tur TurDhara	8.2	7.5	520	0.013	0.12	1.0	351	43	0.37	0.14	0.407	0.37	0.001	0.06	0.015
14	Saraswati School Veerbhati	8.5	7.0	450	0.011	0.0	1.5	505	65	1.13	0.16	0.540	0.28	0.003	0.24	0.01
15	Saraswati School upper	2.5	7.0	520	0.02	0.20	1.2	475	85	0.73	0.17	0.545	0.17	0.062	0.06	0.01
16	Kelakhan belt	2.6	7.0	490	0.01	0.01	1.2	263	190	1.02	0.06	0.310	0.33	0.000	0.04	0.01
17	Seepage water near Saraswati School	2.8	6.5	520	0.01	0.01	1.3	250	31	1.47	0.11	0.267	0.36	0.007	0.14	0.15

industrial waste, development activities, and geological mixing are responsible for contaminating the ground and surface water in the Kumaon and Garhwal region of Uttarakhand. An investigation was done by Dobhal *et al.* (2012) on drinking water sources (rivers and some springs) in some districts of Kumaon, Uttarakhand for four toxic metal ions, i.e., arsenic, cadmium, chromium, and lead. The water samples from gadheras and tube wells were analyzed and they observed that at major districts of the Kumaon region, the Cd has exceeded the prescribed limit of 3 mg/l (WHO). Cr and Pb were also present but were under the prescribed limit (Table 9).

Based on reviewed information (given in Annexure), it has been observed that there are differences between the presence of heavy metals in the Kumaon and Garhwal regions of Uttarakhand. This may be because of the formation of the geology of both regions. Based on collected data, the Spatial Data Modular (SDM) tool of QGIS has been used to portray the spatial distribution of heavy metals in the springs of Kumaon and Garhwal regions of Uttarakhand (Figure 3).

With the help of SDM model tools, it can be summarised that among the sampled spring presence of aluminium, barium, cobalt, and manganese is more in the Garhwal region as compared to Kumaon while the Kumaon region is dominated by arsenic, cadmium, chromium, and lead. Cu and Fe concentrations range between 0.048 and 0.191 mg/l and less than 0.158 mg/l, respectively. Cu is distributed in Nainital, Bageshwar region with some part of Garhwal region, i.e., Chamoli, Rudraprayag, and Pauri Garhwal. The presence of iron has been noticed equally in both regions.

5. OPTIONS FOR SPRING WATER TREATMENT

For thousands of years springs have been the source of water for both human beings and the ecosystem. Traditionally, spring water is considered pure and clean, due to the natural filtering that occurs during infiltration and movement of spring water through deep and shallow aquifers. But due to increased anthropogenic activities, the discharge and quality of spring water have been deteriorating. There can be different methods to purify the lake and aquifers, one of which is phytoremediation by floating raft as shown in the study performed by Kholiya & Roy (2015). This technique proved very beneficial in reducing the growth of aquatic weed as well as reducing sulfate, COD, and BOD. It was found that it is also helpful in controlling the *E. coli* population of lakes and can help in improving the DO of the water body.

Another effective method to mitigate spring water depletion is spring shed management. It includes various aspects of water management, ranging from hydrology to governance of natural resources. The first step in this regard was taken by

Table 9 | Average concentration of heavy metals in water resources of Kumaon

Districts		BIS limit (mg/l)	WHO (1984) limit (mg/l)	Avg. concentration (mg/l)
Nainital	Arsenic	10	10	0.33
	Cadmium	10	03	3.17
	Chromium	50	50	0.17
	Lead	50	50	43
Almora	Arsenic	10	10	0.17
	Cadmium	10	03	3.33
	Chromium	50	50	ND
	Lead	50	50	30.17
Pithoragarh	Arsenic	10	10	0.17
	Cadmium	10	03	6.00
	Chromium	50	50	ND
	Lead	50	50	41.7
Bageshwar	Arsenic	10	10	1.00
	Cadmium	10	03	3.83
	Chromium	50	50	4.00
	Lead	50	50	38.67
Champawat	Arsenic	10	10	0.67
	Cadmium	10	03	3.50
	Chromium	50	50	ND
	Lead	50	50	35

ND, not determined.

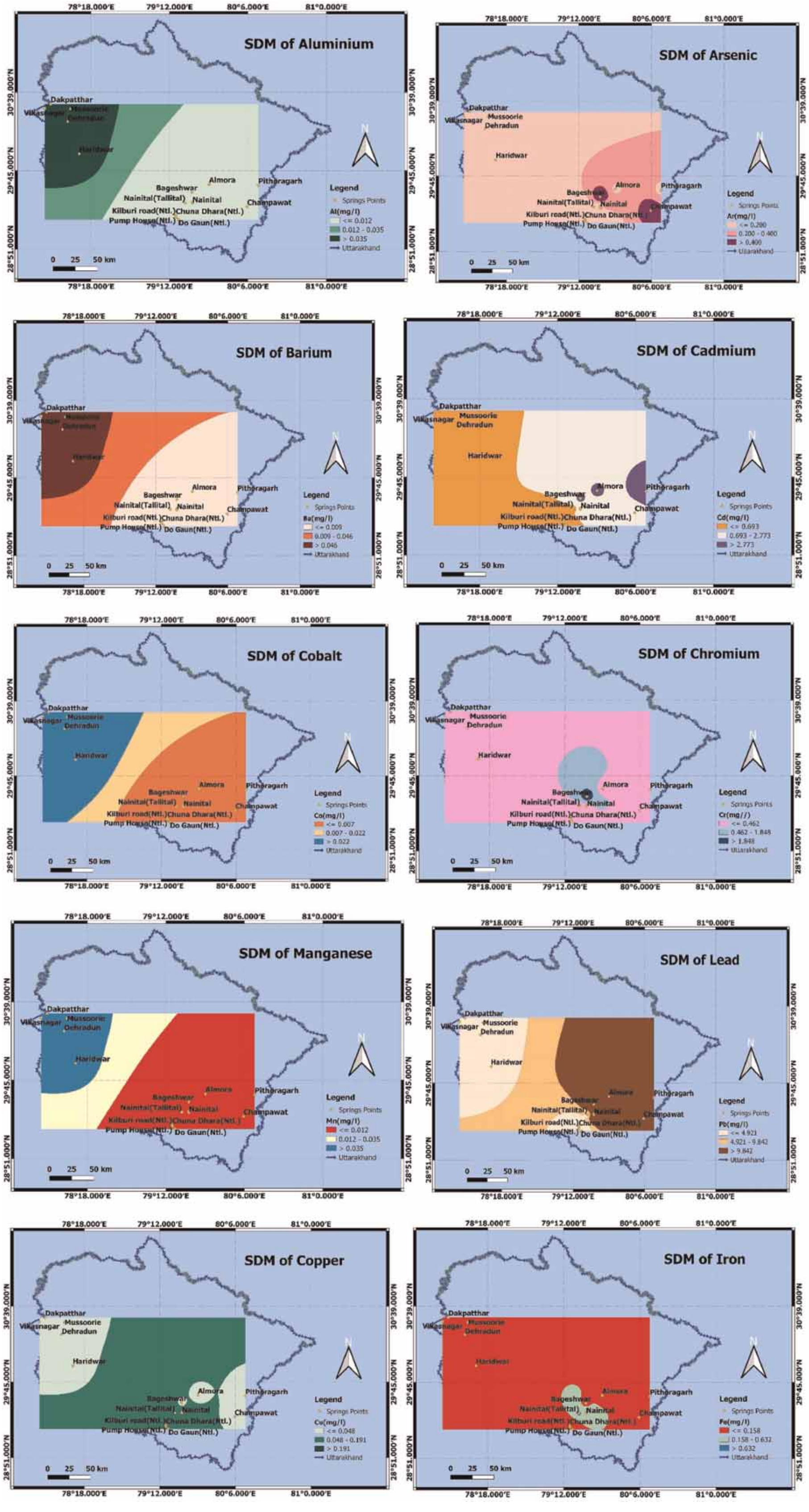


Figure 3 | Spatial distribution of heavy metals in Kumaon and Garhwal regions.

the Dhara Vikas Programme by the Rural Management and Development department (RM& DD), Government of Sikkim; now the same concept is also applied in Uttarakhand. The CHIRAG, in collaboration with ALSTOM, NABARD, ARGHYAM, IIT Roorkee, and ACWADAM, has treated and monitored 211 springs in eight districts of Kumaon and Garhwal regions. The science behind spring shed management revolves around a nine-step methodology. The nine steps are shown in Figure 4. A similar approach has been preferred by the Nepal government in collaboration with the International Centre for Integrated Mountain Development (ICIMOD) and ACWADAM for the revival of their springs (Shrestha *et al.* 2017).

Also, the CHIRAG has started a project to recharge two springs under the Kosi river rejuvenation campaign in Hawalbag and Taluka block in 2018–2019 in partnership with the Chief Development Officer (CDO) of Almora (Spring atlas of Uttarakhand, 2018–2019).

An integrated approach of spring with community management of groundwater resources would be effective for the revival of springs. Involvement of the community and nearby people in the development, monitoring, and maintenance of springs is essential and is an achievable task, as there are cultural and religious beliefs that motivate people to protect springs.

Various recharge activities can be adopted to rejuvenate the springs. Recharge activities proposed in the area are contour trenches, percolation pits, khals, check dam plantation, and direct seed sowing. The selection of treatment activities is based on the slope of that area.

6. IDENTIFICATION OF KNOWLEDGE GAPS

6.1. Extent of water quality data collection

Springs get neglected in the larger context of rivers, aquifers, and watersheds. This is a reason for great apprehension as it is key to identify the large gaps in practice and policy in planning any strategy in spring water management in India. Naturally, spring water emerges on the surface, which may be the reason for its not getting that much attention. However, so-called development and management of water resources have been occurring only in a flat area or area having gentle slopes and many studies have focussed only on the water quality of rivers and lakes of the Garhwal region while a few studies have been carried out successfully on the water quality of springs in some parts of the Kumaon region, Uttarakhand. Major springs of these regions are still unexplored. The work on biological parameters of the water quality of springs is still unreported.

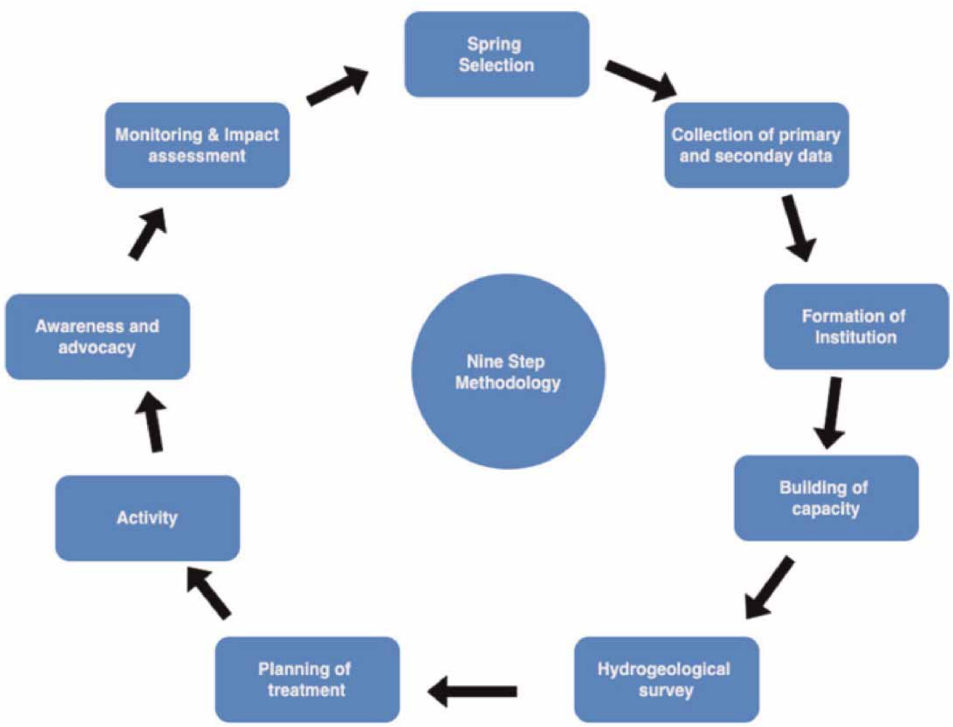


Figure 4 | Nine-step methodology of the CHIRAG for spring rejuvenation (NITI Aayog 2017).

6.2. Water quality parameters tested

The quality of water received from springs is also a matter of great concern. As it is a vital source for drinking and other household purposes, it is necessary to know the quality of spring water before its consumption or for agricultural purposes. In Uttarakhand, DAV (PG) College Dehradun, Uttarakhand Jal Sansthan (UJS), and Uttarakhand State Council for Science and Technology (UCOST) are working in collaboration for sketching of water quality map of Uttarakhand as per BIS specification of water quality parameters and APHA guidelines. They covered all 13 districts of Uttarakhand and tested 27 physical, chemical, and biological parameters. But they mostly covered rivers, lakes, and at some places, groundwater sources, i.e., tube well hand pumps. The CHIRAG has analyzed the water quality parameters, but it covered only 7–8 parameters (pH, TDS, total hardness, salinity, chloride, iron, nitrate, and fecal coliform). Some other important nutrients like phosphate, sulfate, calcium, etc., and biological parameters (microbial diversities) are still unexplored. The testing of heavy metals is also necessary, as its trace amount above the permissible limit can be deleterious. The presence of heavy metals (like As, Cd, Pb) is also undetected in most of the springs, especially in the Kumaon region.

6.3. Treatment options

It is well known that springs represent groundwater discharge. Downward percolation or infiltration of water through rain and snow melting in high altitude regions recharge the spring. This water is clean and pure as it is percolated and filtered during infiltration. Water finds places deep underneath the rocks and is stored there, after which it moves to the surface again. Springs are recharged and discharged processes of aquifers that should be understood and protected by local communities. But the biggest irony is that people are not very aware of the way to store the spring water. Also, we do not have scientific knowledge about the functioning of springs. It is not included in the mainstream of education like wells and other aspects of groundwater. The extent of Himalayan aquifers, their hydrological behavior, and geometry seem to have large variations in spring behavior, and the basic structure of springs is somewhat as shown in Figure 5.

The CHIRAG (NGO) has done a lot of study and exploration into springs in the Kumaon region of Uttarakhand. Some features of critical springs and their treatment methods adopted in the Kumaon region are as follows.

6.3.1. Some critical springs of the Kumaon region with its geology, recharge area, and treatment option

Dhargara spring: This spring is in the Raikholi village of the Bageshwar district of Uttarakhand. This spring is situated at 20.75°N and 79.80°E at an elevation of 1,550 m above the mean sea level with an average rainfall of around 1,350 mm annually. Villagers of this area are highly dependent on this spring, especially in summer.

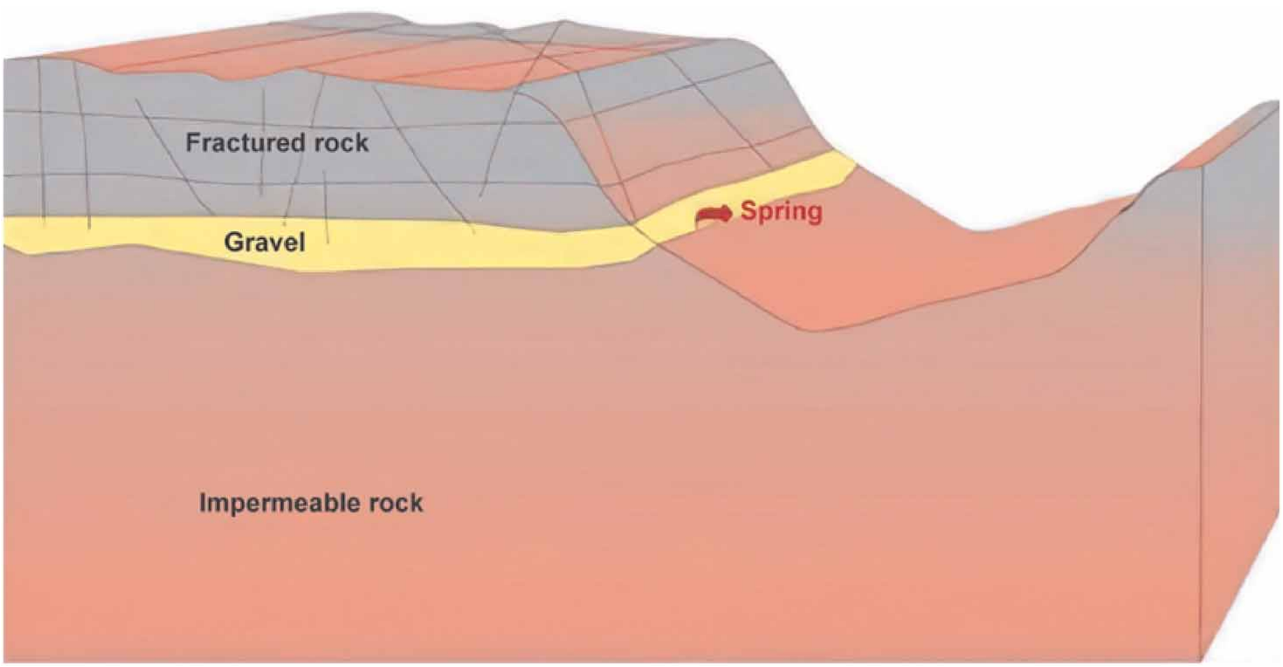


Figure 5 | Conceptual layout of a spring with its hydrogeological settings (NITI Aayog 2017).

This spring is underlined with dolomite with dip direction towards the northeast and strike run along the northeast to the southeast axis. The average value of the dip mount is 30°. Through the sedimentary rocks water oozes out from the aquifers and this spring is categorized as a Karst spring (Figure 6). Dhargara spring had its recharge area at the southwest slope of the spring. The total recharge area identified was 2.5 ha.

Only 2 ha of a total of 2.5 ha was recharged by making contour trenches check dams and pits. The method adopted for this purpose was based on the basis of slope and type of soil in the recharge area. The impact of this intervention was noticed. In July 2014–June 2015, the rainfall was 2,226 mm while the discharge rate of this spring was 10.66 liter per minute (lpm). After adopting methods for its revival, the discharge rate of 13.13 lpm was observed on 15 July–16 June despite a 34% reduction in annual rainfall in the previous year (Mehra & Kulkarni 2018).

GhatgarhDhara: This spring is situated in the Chattola village in Ramgarh block of district Nainital in Uttarakhand. This spring lies at 29.466°N and 79.58°E at the elevation of 1,850 m above mean sea level. The average annual rainfall of this area is around 1,200 mm annually. The geology of this spring consists of schist and water oozes out from the unconsolidated colluvial deposit. The dipping of the rock bed is 25° with a strike along the northwest–southeast direction. The discharge of this spring is influenced by the two major fractures, i.e., one is along the northeast (NE)–southwest (SW) axis and another set runs along the NE–SW axis (Figure 7).

The recharge area of Ghatgarh falls in private agricultural land and some part of it falls under oak forest and lies on the southwest slope. The identified recharged area was 3 ha with a 26.8% slope. The treatment plant was adopted for the revival of the spring including terrace leveling, percolation pits, Khals, and improvement of water reservoir. The structure for treatment purposes was constructed by the local community under the Uttarakhand Jal Samiti. This spring was in critical

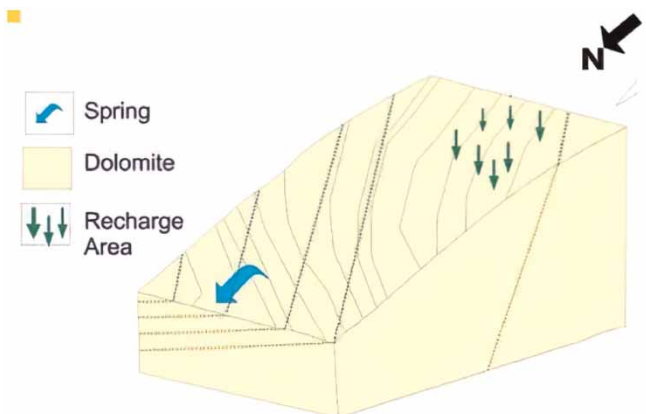


Figure 6 | Layout of Dhargara spring (Mehra & Kulkarni 2018).

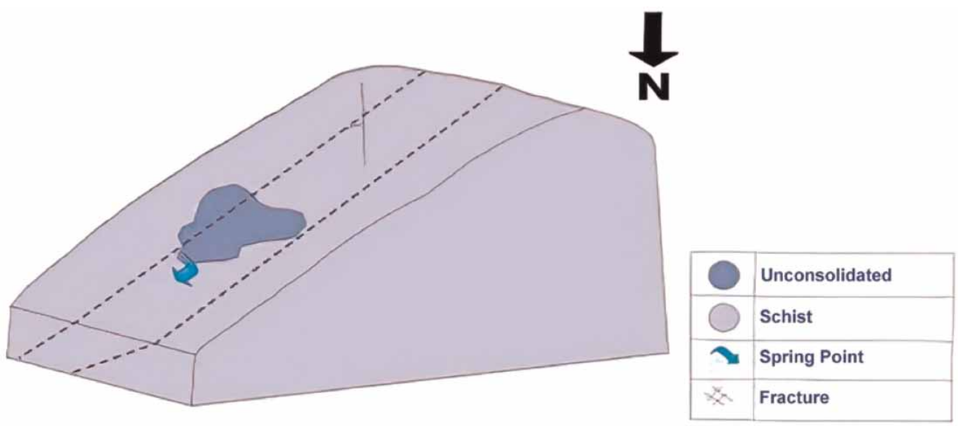


Figure 7 | Geological layout of Ghatgarh spring (Mehra & Kulkarni 2018).

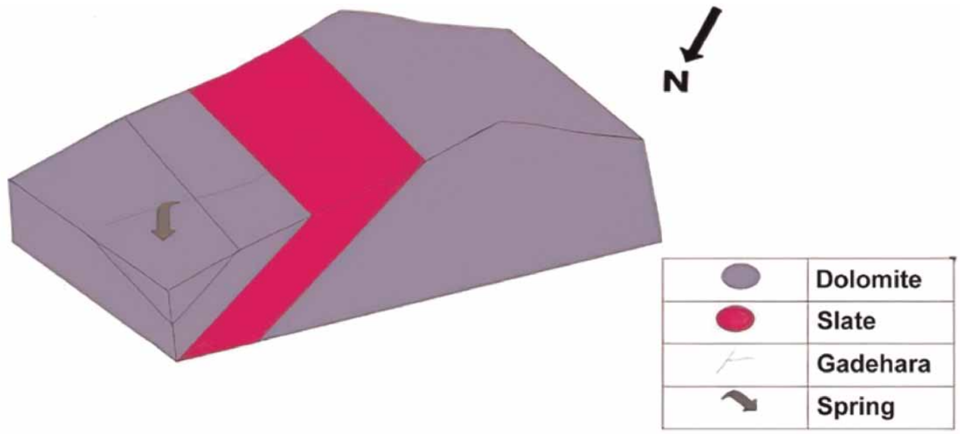


Figure 8 | Geological layout of Naghar spring (Mehra & Kulkarni 2018).

condition, on the verge of completely drying. The discharge rate of spring water in 2016 was only 1.77 lpm but by taking revival measures the discharge rate became 2.81 lpm even in the summer region (Mehra & Kulkarni 2018).

Naghar Naula (Spring): This spring is in the Bageshwar district of Uttarakhand at 29.78°N and 79.77°E with an average elevation of 1,800 m above mean sea level. The average annual rainfall of this area is around 1,350 mm. This spring is dominated by dolomite and slate having a dip direction in the northeast at 40°. The strikes fall along the northwest to southwest axis. This spring comes under the Karst system (Figure 8).

The estimated recharge area of this spring was 7 ha, and falls in Khakar and Joshigaon village. The aspect of this recharge area was in the northeast direction with a 21.2% slope. For recharging this spring, the main challenge was the availability of land. The estimated recharge area of this spring was 12 ha. For rejuvenation of this spring contour trenches, Khals and percolating pits were constructed. The discharged rate was increased from 2.23 lpm in 2016 to 10.66 lpm in 2017 by adopting the above techniques for the revival of spring (Mehra & Kulkarni 2018).

7. CONCLUSION

It is necessary to know the aquifers feeding them. However, one of the biggest gaps in our knowledge system is that we are more focussed on the systematic functioning of springs on the supply side rather than the engineering behind the function of aquifers.

There are significant impacts of climate change and anthropogenic activities, which are responsible for the drying and deterioration of springs' discharge and their quality. This makes their management and treatment a challenging task for the future. Although the CHIRAG with other institutions has been working on the retrieval of Kumaon springs by making trenches, pits, contour check dams, etc. as per the slope of that area and geohydrology of springs, there is still a need for involvement of the nearby community to protect these springs. It requires a basic knowledge of spring shed management among the local people and researchers which is lagging. The fast and efficient technologies for treating the springs are still unexplored.

CONFLICT OF INTEREST STATEMENT

The authors are not affiliated with or involved with any organization or entity with any financial or non-financial interest in the subject matter.

ANIMAL TESTING

Animals are neither harmed, nor their services used in this study.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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