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RAINFALL DEPENDENCY AND WATER QUALITY ASSESSMENT OF SPRINGS OF THREE VILLAGES OF RUDRAPRAYAG DISTRICT: AN ANALYSIS OF VEINS OF UTTARAKHAND HIMALAYA

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Abstract
A spring is a crevice in the substrate that forms naturally and allows water to pour out directly from the earths subsurface. Every major river in the country has a system of springs that serve as a symbolic representation of its source. But this very fundamental source of many resources is in peril. The problem is mainly related with the reduced discharge rate of water from the spring. The reason of truncate discharge rate is variability in the rainfall pattern in the recharge area due to the climate change over the years.To ensure the quality and security of the public's water supply, regular quality assessments of drinking water sources are required. In consequence, this study not only analyse the rainfall dependency of springs but also evaluated the spring water quality for drinking, using water quality index (WQI), in three villages, namely Jakhnoli, Dharyaanj and Sidhsaudh, located in Jakholi block of Rudraparayag district, Uttarakhand. The ten foremost physiochemical parameters that regulate water quality—Nitrate, Fluoride, Iron, pH, Turbidity, Chloride, Residual Chlorine, Magnesium, sulphate, and Hardness—were investigated to ensure compliance with guidelines defined by the Bureau of Indian Standards IS: 12500:2012. Total eight springs were identified in the region. After examining the data, it became apparent that all of the indicators pointed to acceptable water quality, making it ideal for drinking. The spring water quality (WQI ranges from 6.17-17.96) in the three settlements is of A grade Excellent according to the WQI standard value. It is concluded in the study that the discharge rate of springs of Jakhnoli villages (.01-.33L/sec) is the lowest amongst the three studied villages. However, because of its low discharge and great reliance on rainfall, condition of spring water is getting more detrimental.

Keywords: Spring water, Raifall dependency, Water supply; Physicochemical parameters, Water quality index

1. Introduction

Springs are majorly the natural opening in the ground from where the water flows naturally and feed the major streams of the rivers in the lean period. Natural springs make up even less than 0.03% of the world's total freshwater at any particular time

(Agarwal et al., 2012). Communities in hilly areas have relied on springs to supply water for generations, not just in the Himalayan region but in all the hilly regions of India. Although there are no official statistics on the number of springs in India, yet the estimate is between two to three million (Negi and Joshi, 2004). There is a need for an organizational structure to discover springs in the Indian Himalayan Region (IHR) being most fragile and consequently require pressing deliberation for regeneration, conservation, and improved conduct (Agarwal et al., 2012).

For sustaining life on this earth, water is the basic unit for every individual that nature has provided us. But water has been depleted day by day and in turn, now it becomes a scarce commodity due to its increasing usage and also quality of water is depleting continuously through various anthropogenic activities. The diminished number of the springs in IHR has been prompted by interplay of biophysical (such as weather fluctuations and changes in land use) and socioeconomic causes (Negi and Joshi, 2004). In today's era, it is now becoming a global problem (Water scarcity) and the major demand is for the maintenance of clean drinking water.

Water scarcity has become an alarming reality in many parts of the world. Identifying the spatial distribution of groundwater looks to be the most likely natural resource that could change this outcome. The provision of pristine water for drinking to a staggering 1.5 billion individuals by the end of the following decade represents one of India's foremost concerns as the country's water economy is under tremendous strain.

Across the IHR, various studies have discovered that spring discharge has decreased and water quality has deteriorated dramatically (Bharti et al., 2014; Chapagain et al., 2019). Secluded studies in various regions of the IHR attribute the decline in spring discharge to population growth, development activities (Chapagain et al., 2019; Chimmwal et al., 2022), rapid urbanization (Glazier, 2014), climate change and variability (ICIMOD, 2015; Jeelani, 2008), and land use and land cover changes (Chapagain et al., 2019; Glazier, 2014). The socio-economic drivers are the results of the Himalayas' booming population and accelerating social and economic growth (Joshi, 2006; Kumar, 1997). These factors cause supply-side processes to be constrained in the spring systems while also creating demand-side pressures. A worrying number of biophysical and socioeconomic factors have an impact on water quality. Climate change and the Neo tectonics movement are two examples of external biophysical influences. Internal biophysical causes include LULC alterations (Tiwari, 2008). Additionally, socioeconomic internal elements include population growth, human economic development, and changes in way of life, while socioeconomic external ones include the expansion of a significant mountain town and tourism strategy.

Along with the water quality and its scarcity, there is also a major problem of the discharge rate in the Indian Himalayan region (Chimmwal et al., 2022). Variations in rainfall in the recharge area, or more specifically, fluctuations in the amount of rainwater that is able to permeate the ground and replenish the groundwater, are the main causes of variations in spring water flow (Rai et al., 1998). Periodic (monthly) changes brought on by sporadic significant rainfall, typically during the rainy season, are superimposed on this variability (Valdiya and Bartarya, 1991; Tiwari, 2008). Water starts to seep through the soil layer after it rains (Tambe et al., 2011, 2012). Groundwater is released more quickly because springs and seepage can release more water when it is recharged (Mahamuni and Kulkarni, 2012). The water table is lowered, its gradient is diminished, and the pressure in pore spaces is diminished due to the high discharge rate.

The overall quality of drinking water has an extensive effect on public health; hence, efficient surveillance and complete evaluation of community drinking water systems are critical to protecting society's good health (Li and Smith, 2009). Environmental change, lithological effect on topography, and hydrodynamic risks, on the contrary hand, are primary causes of water pollution (Uddin et al., 2021). Population growth, altered land uses, related infrastructure projects, and climate change have all contributed to the reduction of spring flows, the seasonalization of permanent springs, and the total drying up of seasonal springs (Barquín and Scarsbrook, 2008). Recent years have seen sightings of enhancement of elements from sewage, agriculture, and other land utilisation patterns polluting springs (Katz et al., 2001). The geomorphological context of natural springs determines their environmental conditions, whereas the aquifer and nascent surface topography control discharge, temperature, water chemistry, substrate, habitat stability, and organic material concentrations (Ameen, 2018). The chemical properties of spring water are critical for municipal, agricultural, and drinking water supply (Jebreen and Ghanem, 2015).

The changing climate and its implications on the environment and natural springs have been tracked in the Himalayas as an upsurge in temperature, variations in sporadic precipitation, and alterations in stream flow patterns (ICIMOD, 2015; Bharti et al., 2014).

Investigation into natural spring systems and notably the creation of a database on water resources with a primary focus on determining the current circumstances of the natural springs (highly advised by the NITI Aayog) have not been prepared for Jakholi block yet. This research explores the features of natural springs in terms of their distribution, discharge rate of spring water (January 2021-December 2022) and its dependency on raifall and their water quality assessment, based on fieldwork from the Jakholi Block.

2. Material and methods

Description of study area

The Himalayas cut through Uttarakhand, originally known as Uttranchal, in northern India. The area of the present study is Jakholi block of district Rudraprayag, which lies in the Garhwal Himalaya of Uttarakhand. Uttarkhand lies in the northern part of India with 13 districts. Rudraprayag district almost enshroud a precinct about 2439 sq.km and it comprise of three subdivision viz. Jakholi, Rudraprayag and Ukhimath and three development blocks viz Ukhimath, Augustmuni and Jakholi. The elevation of Jakholi Block ranges from 575mt to 3637mts. As per Indian meteorological department, the average annual rainfall in the study

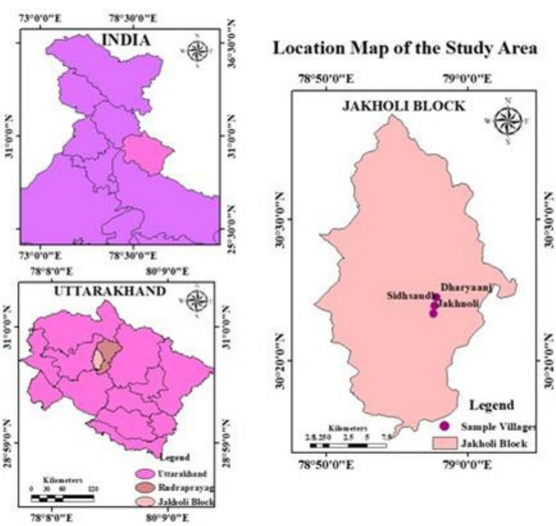

Fig. 1. Location Map of Study Area

area is 1800 mm. Climate is subhumid and is characterized by hot summer and pleasant monsoon and cold seasons. The geomorphology of the region is characterised by dissected hills and alluvial plains. The geology of the study area is dominated by quartzite, gniess and granite.

The current study is conducted in three villages of Jakholi block named Jakhnoli, Dharyaanj and Sidhsaudh (Fig. 1). There is urgent need of spring water management as they are facing the issue of reduced discharge rate.

Methodology

Inventory and Database of springs

In order to gather data regarding the springs, multiple walks were taken across the communities with the locals. The positions of the springs were recorded using the Global Positioning System (GPS Garmin 64s), and additional data about the spring was obtained by talking to people in the neighbourhood. A sociological data base of the springs was compiled via a questionnaire survey. The respondents were members of the local community and the village pradhan (village representative), who served as a representation of the populace.

In January, February and September of 2021 as well as April, June, and November of 2022, the field was surveyed. The discharge data has been collected every two weeks with the help of residents of the adjacent communities. The discharge of the springs has been measured three times using a measuring beaker and stopwatch, and an average of these measurements has been implemented in the study to determine how rainfall influences spring water flow in the study region. Additionally, the data from Climate Research Unit 4.01 (High resolution gridded data) was used to derive the raifall data. (University of East Angilia). To demonstrate the dependence of springs on rainfall, hydrographs of the invented springs for two years have been constructed using rainfall information and monthly discharge rate.

To fulfill the objective of water quality assessment, water samples from the springs were collected in clean 1 liter polythene bottles during pre monsoon period (months of February and April, 2022). The total eight springs are taken for assessing the physical, chemical attributes. Samples were analysed for following ten physio chemical parameters: Nitrate, Fluoride, Iron, pH, Turbidity, Chloride, Residual Chlorine, Hardness, magnesium and sulphate. To test pH and turbidity of the samples, respective digital meters were used and for the remaining parameters, titration method was employed using respective reagents. The samples were analyzed as per instructions given in the water testing kit by OCTOPUS Inc (An ISO 9001:2015 Company).

Calculating WQI

The BIS-recommended (Bureau of Indian Standards) water quality requirements for WQI were combined into a single number and then standardized across all of the evaluated parameters. All of these physical and chemical properties coexist in various ranges and are articulated using several standard measuring units [Rao et al., 2010]. For the assessment of the WQI in the study area, a total of 10 parameters were determined and analyzed.

Weighted Airthmetic Water Quality Index (WAWQI) has been used in the study. The Weighted arithmetic Mean is a formula of calculating an average value where particular values are given more significance through different weights. The use of Weighted Mean is significant in data analysis, weighted differential, and integral calculus systems. [Ramakrishnia et al., 2009; Balan et al., 2012]. Following steps were employed to calculate WAWQI:

1. Acquire data pertaining to several physico-chemical water quality factors.
2. Use the formula to determine the proportionality constant “K” value.

$$K = 1/\{\Sigma 1/Sn\}$$

Sn acceptable standard for the nth parameter

Table 3. The standard Value of WQI using weighted arithmetic WQI Method

WQI	Grade	Status
0-25	A	Excellent
26-50	B	Good
51-75	C	Poor
76-100	D	Very Poor

Source: Brown et al. (1972)

3. If there are n parameters, compute the quality rating for the nth parameter (Qn). Utilising a formula: **(Vn-Vo / Sn-Vo) x 100 = Qn**
4. Compute the nth parameters' unit weights.

Wn= K/Sn

4. The following formula was used to calculate the WQI:

WQI =∑QnWn/ ∑Wn

Qn, and Wn are the quality rating scale and unit weight, respectively.

Where Vo is the ideal value of pure, Sn is the standard value of the nth parameter, and Vn is the estimated value of the parameter in the analyzed water.

After calculating the Water quality Index of the samples, it was analysed as per the values given in table 3.

3. Results and discussion

Database of springs

Using a GPS device, eight springs were tracked and mapped for the purpose of this study. The database of newly found springs is shown in Table 1. With the use of the spring names listed in Table 1, springs in Figure 2 may be recognised.

The mapped springs were subsequently investigated to gather information on their discharge, public perception, social conflicts, and governance challenges associated with them.

A sociological data base of the springs invented can be accessed in Table 2. It demonstrates that the people are extremely reliant on all eight springs in order to satisfy their drinking and household needs. From the table 2, it can be concluded that the discharge

Table 1. Database of invented springs

S.No.	Spring Name	Village	Latitude	Longitude	Elevation (ft)
1.	Malya Dhara	Dharyaaj	30°24'50.97"N	78°57'47.29"E	5421
2.	Mulya Dhara	Dharyaaj	30°24.86'N	78°57.80'E	5384
3.	Bamad Dhara	Sidhsaudh	30°23.929'N	78°57.659'E	5417
4.	Katgola	Sidhsaudh	30°23.989'N	78°57.706'E	5307
5.	Chauki	Sidhsaudh	30°24.15'N	78°57.53'E	5230
6.	Naini	Sidhsaudh	30°23.89'N	78°57.55'E	5445
7.	Dhara	Jakhnoli	30°23.348' N	78°57.546' E	5304
8.	Dhara II	Jakhnoli	30°23.388' N	78°57.574' E	5252

Source: Field Survey

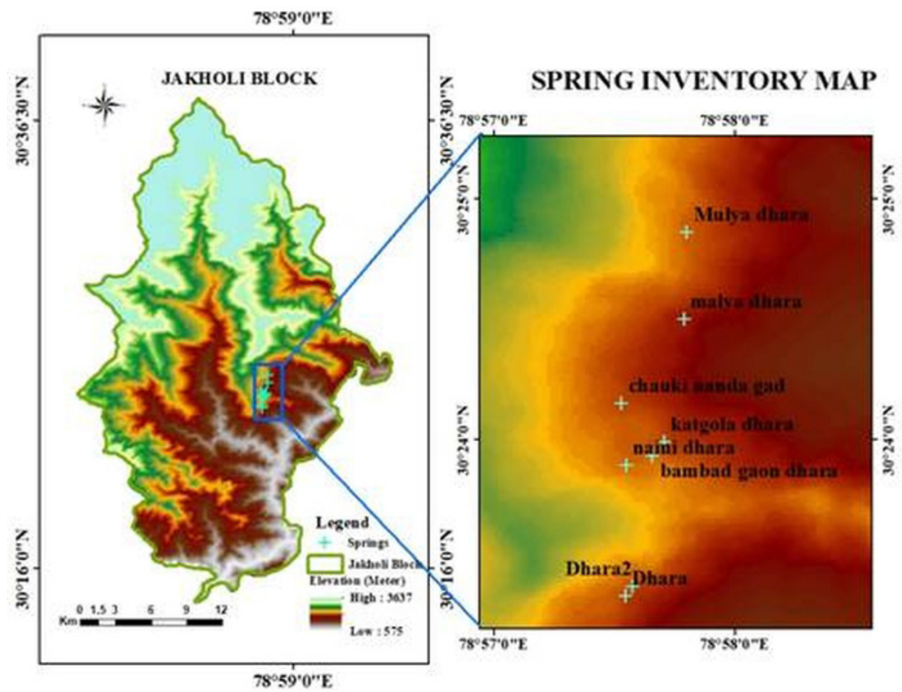

Fig. 2. Spring Inventory Map

Table 2. Social Database of the springs

Spring Name	Dependency[1] (High, Medium , Low)	Use (Drinking, Domestic, Irrigation, others)	Decrease in the spring flow in last 3decades (Perception based)	Water conflicts	Seasonality of the spring	Spring managing Body
Malya Dhara	Low (12-15 HH[2])	Domestic, Irrigation	Decreased	No	Perennial	None
Mulya Dhara	High (35-40 HH)	Drinking, Domestic	Decreased	Yes	Perennial	Gram* Panchayat
Bamadgaon Dhara	High (40-42HH)	Drinking	Decreased	Yes	Seasonal	Gram Panchayat
Katgola	High(38-40)	Drinking, Domestic	Decreased	No	Perennial	Gram Panchayat
Chauki	High (45-50)	Drinking, domestic	Decreased	No	Perennial	Gram Panchayat
Naini	Medium (22-25HH)	Drinking	Decreased	No	Perennial	Gram Panchayat
Dhara	High (50-52HH)	Drinking, irrigation	Decreased	Yes	Perennial	Gram Panchayat
Dhara II	Medium (20-22HH)	Drinking, Domestic	Decreased	No	Perennial	Gram Panchayat

Source: Field Survey
[1]Dependency refers to the number of households depends on the springwater.
*It is a governing institution at village level.
[2]Household

rate of the springs has been declined in past few years. Locals claim that the bamadgaon dhara has reduced its discharge by more than 50%. During lean months, its flow diminishes, placing strain on the region's other springs, which are already highly dependent.

Influence of rainfall on discharge of springs

In the Uttarakhand Himalayas, a region distinguished by its rocky topography and intricate hydrological processes, precipitation has a substantial impact on discharge patterns [Valdiya and Bartarya, 1991]. The interplay between rainfall and runoff is the most substantial factor influencing the flow of spring water. Quick and strong runoff on a steep slope causes little rainfall permeation, which is detrimental for spring recharging. On the other hand, a region with favourable rainfall permeability characteristics (permeable soil, a moderate slope, and rocks with high porosity and transmissivity) corresponds to a high springshed recharge.

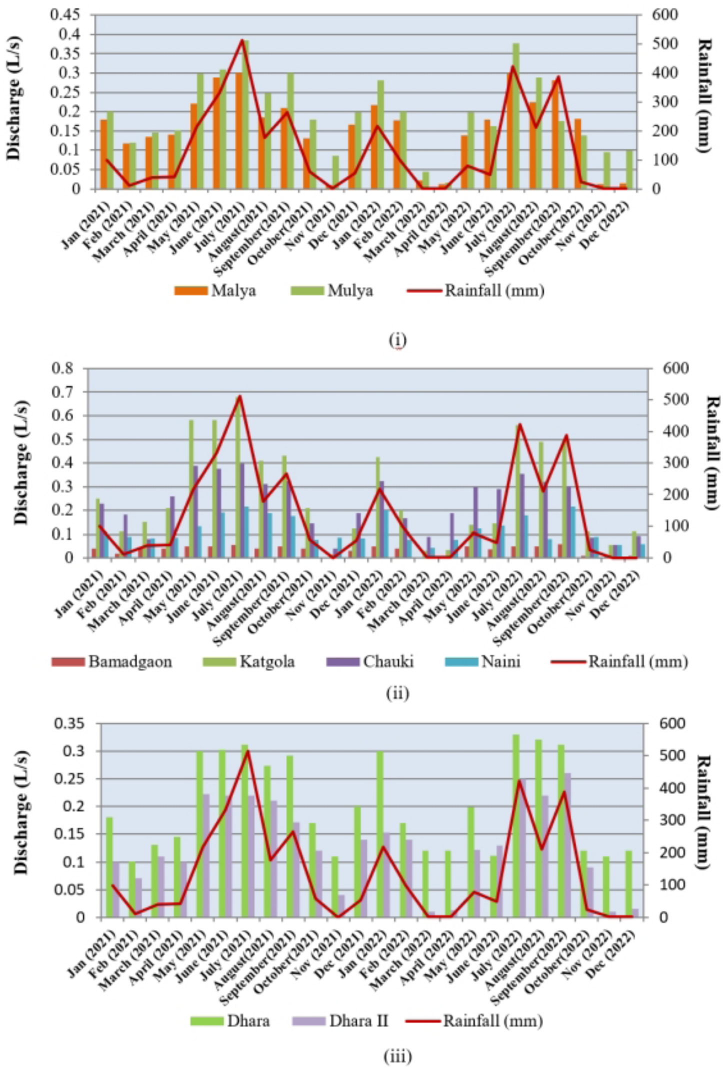

Fig. 3. Hydrograph of Springs of (i) Dharyaaj Village (ii) Sidhsaud Village (iii) Jakhnoli Village

Evaluation of Spring Flow

Water Discharge Pattern: Hydrographs (In Fig 3) show a correlating link between spring discharge and rainfall. The maximum discharge and variability was recorded by Katgola of Sidhsaud village, while the lowest discharge was seen by Bamadgaon Dhara of same village (In Fig 4). Rainfall and spring stimulation are easily associated. When there is little rainfall, this reaction decreases. The analysed springs exhibit varied degrees of immediate response to rainfall, with the springs in Jakhnoli village and Katgola of Sidhsaud exhibiting the highest response, indicating that their recharge region is responsive to rainfall and has suitable hydrogeology.

Q2 in the Fig. 4. represents median of the discharge data of the springs, which is least for bamangaon spring (0.041L/Sec) and highest for Chauki spring (0.244L/Sec).

The fact that Bamadgaon Dhara responded to rainfall the least indicates that the springshed of the spring has poor infiltration and low transmissivity.

The research work of Agarwal et al. (2012); Bharati et al (2014) ;Chapagain et al. (2019); ICIMOD (2015) and Mahamuni and Kulkarni (2012) has analysed that there is high dependency of the mountain springs on rainfall.

Water Quality Assessment

The proportions of major dissolved chemicals found in water are influenced by various factors such as geological rock type, weathering processes, and human activities. Chimmwal (2022); Ramakrishna et al. (2009); Rao et al. (2010); Shighut et al. (2017) has evaluated the Water Quality Indexing Method to evaluate suitabilty of water.

By means of physicochemical evaluation, the concentrations of the dissolved compounds in water can potentially be resolute [Barakat et al., 2018]. Therefore, the study aims to examine water samples of springs of various villages in the Jakholi block for 10 different physicochemical parameters.

A solution's pH indicates how acidic or alkaline it is. It is undeniably possible to use a body of water's pH as a critical measure to assess its level of pollution and water quality (Al-Jiburi and Al-Basrawi, 2013). All of the springs' pH levels are between 6-7, which is lower than the permissible limit set by BIS 2012, or 8.5. Turbidity measures the relative purity of the water by identifying the presence of suspended organic and mineral particles as well as color-producing substances (Shigut et al. , 2017). The average value of turbidity ranged from 0-2 Nephelometric Turbidity Units[NTU]. Alkaline earth metals like magnesium and calcium that are dissolved in water, together with other divalent cations

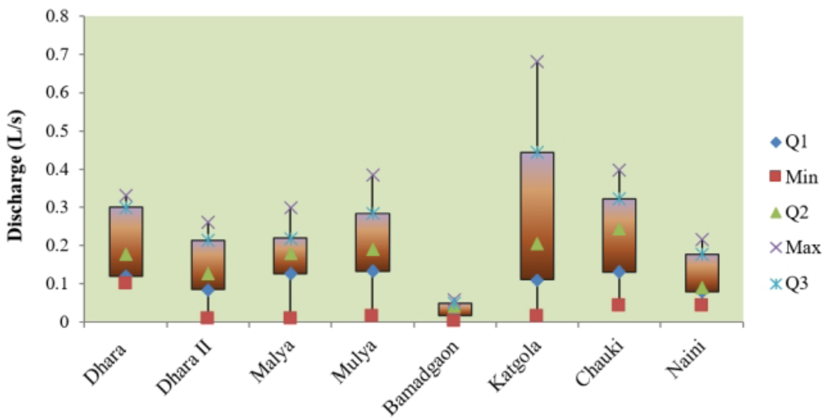

Fig. 4. Discharge Data of the Springs

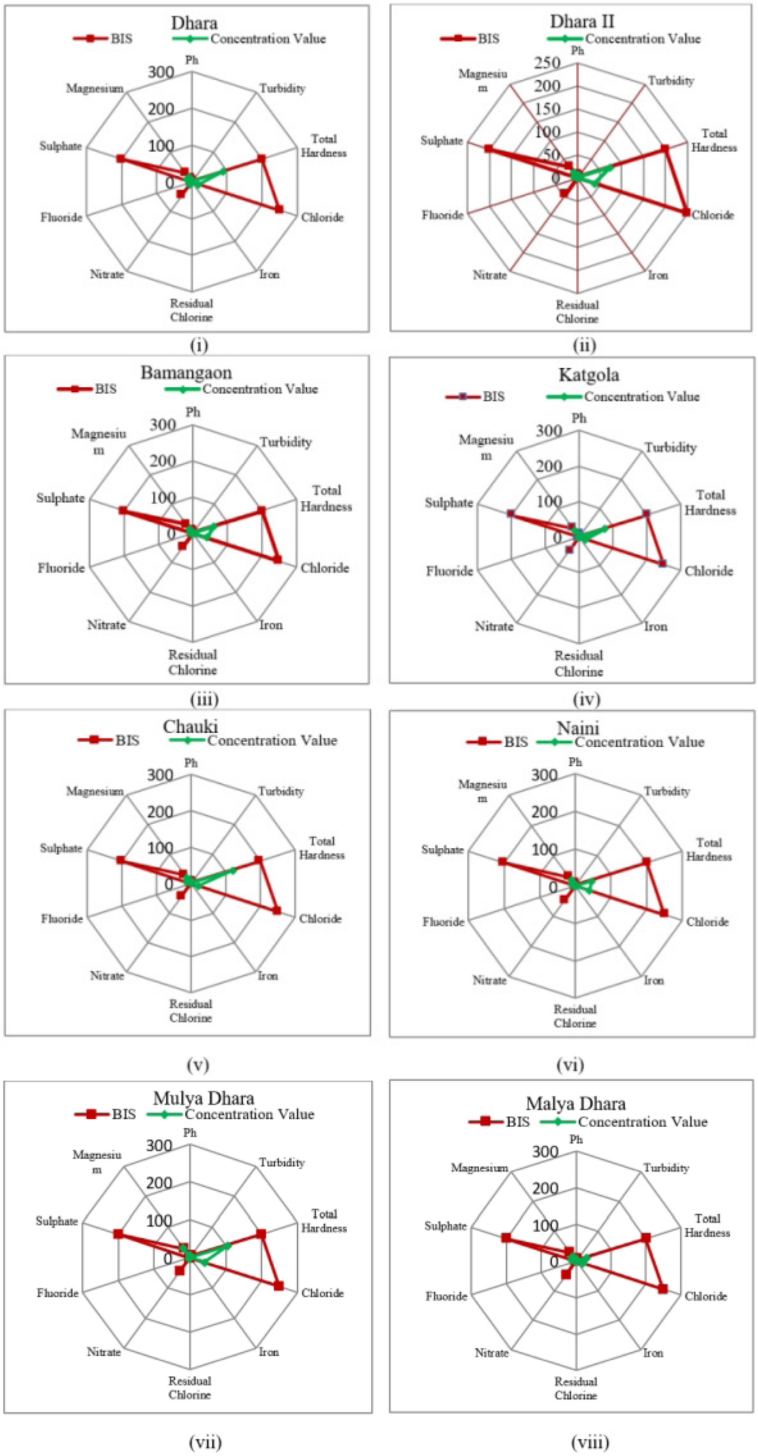

Fig. 5. Radar Graph showing physio-chemical parameters of springs [(i), (ii),(iii),(iv),(v),(vi),(vii),(viii)]
Source: Primary Data and BIS (12500:2012) Report

that add to the total concentration, are the key contributors to the creation of hardness [Barakat et al., 2018]. The spring water samples' average total hardness content spanned the range of 30 to 120 mg/L.

The examination of all the spring water indicated very low chloride content. The typical concentration varied between 20 and 40 mg/l. Chloride (Cl-) levels in groundwater are affected by geological weathering, leaching from rocks, household wastewater, irrigation runoff, agricultural usage, and other natural and man-made activities (Barakat et al., 2018). The average value of the fluoride (F-) concentration in spring water ranged from 0 to 0.6 mg/L, which is likewise quite low. The major mineral sources for sulphate, which naturally occurs in water, include gypsum and other common mineral sources. The samples' average sulphate content ranged from 0 to 15 mg/L. In all of the water samples, the average nitrate (NO_3^-) content was relatively low and ranged from 0 to 10 mg/L. Magnesium (Mg_2^+) in the samples ranged in mean value from 14 to 30 mg/L. All spring water samples studied had an average iron concentration that varied from 0 to 0.1mg/L. The taste and odour that much chlorine may produce may deter people from drinking the water. All of the springs had zero residual chlorine content. It is evident from the radar graph that every Physicochemical parameter is within the permissible limit established by BIS 12500:2012 (Fig. 5). The spring water quality in the three settlements is of A grade Excellent according to the WQI standard value (Fig. 6).

4. Conclusion

By means of this study, an effort has been attempted to compile a database of springs that have been located, indicating a heavy reliance on the spring for drinking reasons.A study of spring discharge and its relationship to precipitation reveals various spring characteristics.The earliest feasible regeneration of springs of Jakhnoli village and katgola and chauki spring of sidhsaud is declared by their high rainfall dependability. Additionally, due to their least dependence and restricted water flow, bamangaon and naini spring are fragile and endangered springs, and their revival is imperative. The springs' reliability will enhance if a little quantity of storage is constructed to accommodate the local water demand during the dry season (Feb-April). The diminishing health of Bamadgaon spring is not only putting others prings of the region under undue burden from the population, but it is also making gender vulnerability more vulnerable.

Despite the vital function springs possess in the Himalayas, they face a variety of perils, many of which are societal in provenance. The outcomes of the present research demonstrated that the springs have potable

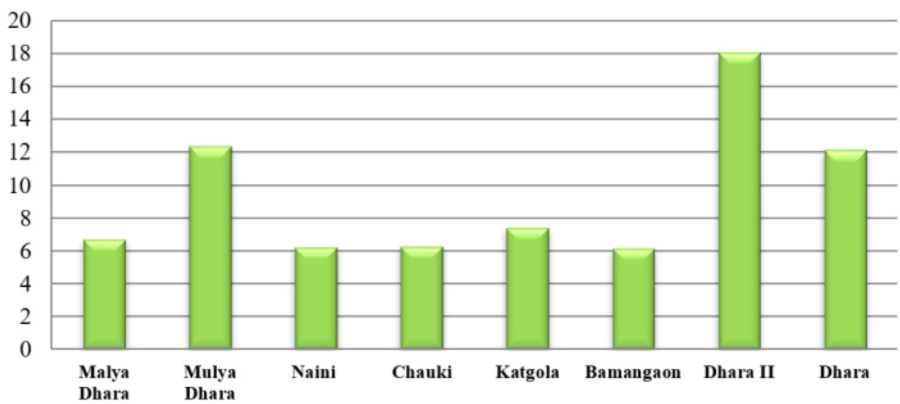

Fig. 6. Water Quality Index of springs

water quality. Even if spring water is showing indications of degradation, a sizable section of the population continues to utilise it for domestic purposes like drinking and washing, which need prompt care. Thus, in order to ensure better management of this water resource, it is necessary to conduct awareness campaigns about the significance of springs in the community.

The issue of drying up water sources is not resolved by merely campaigns; instead, it should be supplemented by locating recharge zones and putting rainwater collection techniques in place. Together, this will uphold high water quality and enhance water outflow, resolving the challenges of both quantity and quality in managing water resources.

5. Refrences

Agarwal, A.- Bhatnaga, N. K.- Nema, R. K.- Agrawal, N. K. (2012): Rainfall Dependence of springs in the Midwestern Himalayan Hills of Uttarakhand. Mt. Res. Dev: 446–455.

Al-Jiburi, H. K. - Al-Basrawi, N. H. (2013): Hydrogeological map of Iraq, scale 1: 1000 000. Iraqi Bulletin of Geology and Mining: 17–26.

Balan, I. N. – Shivakumar, M.- Kumar, P.D.M. (2012): An assessment of ground water quality using water quality index in Chennai, Tamil Nadu, India. Chron Young Sci. : 146–150

Barakat, A- Meddah, R. – Afdali, M.- Touhami, F. (2018): Physicochemical and microbial assessment of spring water quality for drinking supply in Piedmont of Béni-Mellal Atlas (Morocco). Physics and Chemistry of the Earth Parts A/B/C: 39–46.

Bharati, L. – Gurung, P- Jayakody, P. - Smakhtin, V. - Bhattarai, U.(2014): The projected impact of climate change on water availability and development in the Koshi basin, Nepal. Mountain Research and Development, 34(2) : 118–130.

BIS (2012). Indian standards specifcations for drinking water (second revision). Bureau of Indian standards, IS:12500, New Delhi

Brown, R.M. – Mccleiland, N. J. – Deiniger, R.A. (1972): Water quality index – crossing the physical barier, Proc. Int. Conf. on water pollution research, Jerusalem 1972 : 787-797.

Chapagain, P. S. – Ghimire, M. – Shrestha, S. (2019): Status of natural springs in the Melamchi region of the Nepal Himalayas in the context of climate change. Environment, Development and Sustainability. 21(1) : 263–280.

Chimmwal, M. (2022): Water quality of springs and lakes in the Kumaon Lesser Himalayan Region of Uttarakhand, India, Journal of Water and Health Vol (20) No 4, 738

Glazier, D.S. (2014): Springs. In Reference Module in Earth Systems and Environmental Sciences; Elsevier: Amsterdam, The Netherlands.

ICIMOD. (2015): Reviving the drying springs reinforcing social development and economic growth in the Midhills of Nepal. Kathmandu: ICIMOD.

Jeelani, G. (2018): Aquifer response to regional climate variability in a part of Kashmir Himalaya in India. Hydrogeol. J. 16: 1625–1633.

Joshi, B.K. (2006): Hydrology and nutrient dynamics of spring of Almora-Binsar area, Indian Central Himalaya: Landscapes, practices, and management. Water Resour. 33: 87–96.

Kumar, K. - Rawat, D.S.- Joshi, R. (1997): Chemistry of springwater in Almora, Central Himalaya, India. Environ. Geol. 31: 150–156.

Mahamuni, K.- Kulkarni, H.(2012): Groundwater Resources and Spring Hydrogeology in South Sikkim with Special Reference to Climate Change. In Climate Change in Sikkim-Patterns, Impacts and Initiatives; Arrawatia, M.L., Tambe, S., Eds.; Government of Sikkim: Gangtok, India: pp. 261–274.

Negi G.C.S. - Joshi V. (2004): Rainfall and spring discharge pattern in two small drainage pattern catchment in the western Himalayan mountain, India, The Environmentalist. 24: 19-28

Rai R.N.- Singh K.A.- Solanki R.C. (1998): A case study of water flows of some hill springs of Sikkim. Indian Journal of Soil Conservation 16(1):52–56.

Ramakrishniah, C.R. – Sadashivaiah, C. – Ranganna, G (2009): Assessment of water quality index for the groundwater in Tumkur Taluk. E-J Chem. 6(2):523–530

Rao, C.S.- Rao, B.S.- Hariharan, A- Bharathi, N.M. (2010): Determination of water quality index of some areas in Guntur district Andhra Pradesh. Int J Appl Bio Pharm Tech I 1:79–86

Shigut, D. A. - Likhnew, G. - Igre, D. D. - Tanweer, A. (2017): Assessment of physico-chemical quality of borehole and spring water sources supplied to Robe Town, Oromia region, Ethopia. Applied Water Science, 7(1), 155–164

Tambe, S. - Arrawatia, M.L. - Bhutia, N.T. - Swaroop, B. (2011): Rapid, cost-effective and high resolution assessment of climate-related vulnerability of rural communities of Sikkim Himalaya, India. Curr. Sci. 101: 165–173.

Tambe, S. - Kharel, G. - Arrawatia, M.L. - Kulkarni, H. - Mahamuni, K. - Ganeriwala, A.K. (2012): Reviving Dying Springs: Climate Change Adaptation Experiments From the Sikkim Himalaya. Mt. Res. Dev. 32: 62–72.

Tiwari, P. (2008): Land use changes in Himalaya and their impacts on environment, society and economy: A study of the Lake Region in Kumaon Himalaya, India. Adv. Atmos. Sci. 25: 1029–1042.

Valdiya, K.S. - Bartarya, S.K. (1991): Hydrogeological studies of springs in the C atchment of the Gaula River, Kumaun Lesser Himalaya, India. Mt. Res. Dev. 11:

239–258.