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Inventorization and Socio-Hydrological Assessment of Springs in Bhimtal and Okhalkanda Blocks, Nainital District, Uttarakhand, India

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Abstract- This study aims to inventory springs in the Bhimtal and Okhalkanda Block of the Nainital district in Uttarakhand. It will involve field surveys, mapping using GPS technology, and measuring various hydrological parameters. Socio-economic surveys and GIS analysis will also be conducted. The results will provide insights for effective water resource management and conservation strategies, contributing to the sustainable development and conservation of these important water sources in the Kumaon region.

Keywords – *Inventorization, springs; Kumaun Lesser Himalayan Region; hydrology; socio-environmental significance; water resource management; conservation.*

I. INTRODUCTION

A. Background

The Indian Himalayan Region, often referred to as IHR, is a part of the Himalayas that is found in the Republic of India and comprises seven states and union territories: Ladakh, Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, West Bengal, and Arunachal Pradesh. The area has a variety of flora and fauna and is in charge of delivering an abundance of water to the inhabitants. Over 50 million people reside in the IHR and depend on these mountains for their survival. Most of the rivers in Northern India flow from the Himalayan region, where they are either nourished by glacier melt or the numerous springs scattered across the steep terrain. Therefore, perennial rivers like the Indus, the Ganga, and the Brahmaputra rely heavily on the Himalayas, which are fittingly known as "the water tower of the earth."

Springs are believed to be manifestations of God by most of the people in the mountains. These are groundwater stored in aquifers that emerge as a point source in the form of surface water. According to studies, both the pattern of rainfall and the characteristics of the recharge area influence spring discharge [1]-[3]. It is also believed that aquifer characteristics play a part in springs' discharge. More than half of the population of the Himalayan region relies on springs for their daily consumption as they are considered clean and pure due to the natural filtering that occurs during infiltration and their movement through aquifers. They are not only needed for fulfilling the water demand of people but are of utmost importance to sustain the base flow of rivers and rich biodiversity and ecosystems in the Himalayas.

People have been seen to prefer to live close to the resources they require for survival throughout history. Global population growth has increased the demand for fresh/usable water, and over the past decades, a severe decline in the quantity and quality of accessible freshwater has become a major problem in the IHR region. To meet the demand for fresh water in various sectors, there is enormous stress on groundwater resources as surface water pollution is increasing day by day. This has resulted in a decrease in water level as demand has taken over the supply of water. Since the Himalayas provide water to millions of people in the highlands and lowlands, little attention has been given to investigating and protecting these perennial springs. Further, with the increasing push for development, anthropogenic activities are posing threats to the stability of such Himalayan ecosystems and, therefore, making natural resources such as groundwater/springs constantly susceptible to changes. It is observed through studies that deforestation, grazing, and trampling by livestock, soil erosion, forest fires, and development activities such as roads, mining, construction, etc, reduce infiltration capacity, due to which there are fewer chances of groundwater being recharged as water does not percolate into the soil [4]. Due to susceptibility to several changes caused due to both natural dynamism and anthropogenic interventions and the fragile nature of the Himalayan ecosystem, it is vital to recognize spring water depletion as a nationally pertinent problem and address it immediately [5].

In the Himalayas, spring water is of major socioeconomic significance to the nearby populations and the surrounding area. It is an essential supply of clean drinking water for the populations living in the Himalayas. The consistent availability of clean, pure spring water supports the local population's well-being and health. Since the people in the mountains heavily rely on agriculture, it also plays a crucial role in irrigation systems. As a result, spring water supports agriculture by offering a dependable source of water for raising animals, cultivating crops, and preserving forest ecosystems. This helps the farmers to make a living and contributes to the overall food security of the region. The pristine beauty and purity of spring water attract tourism, which also generates income and employment opportunities for local communities residing in the Himalayas, contributing to their social well-being. As is known, the Himalayas are noted for having a large number of spring-fed rivers and streams, and these water sources are used to produce hydroelectric power. This gives both urban and rural communities access to energy, improving the quality of life for the local population and fostering economic growth. In addition, it should not be forgotten that spring water requires not just an understanding of the underlying geology and surface hydrology, but also a keen understanding of traditional practices and culture around springs, both of which have significant socioeconomic and governance dimensions. Springs are often considered sacred and are associated with various rituals and practices; therefore, this helps preserve local customs and contributes to the identity and heritage of the communities. Springs in the Himalayas harbor unique ecosystems and are often hotspots of biodiversity. The preservation of spring water and the surrounding ecosystems supports the region's ecosystem services, including water purification, climate management, and ecological balance. It is therefore important to note that the sustainable management and conservation of spring water resources are crucial to ensure their continued socio-economic benefits for the Himalayan communities and the surrounding regions.

An insufficient database on springs makes them more vulnerable to drying. It is also a cause for great concern, as it has led to significant gaps in practice and policy in developing a strategic national response to spring water management in India. The lack of a brief description of springs makes monitoring and conserving them difficult. Henceforth, the inventorization of springs creates a baseline information database on their status, including their location, environmental settings, seasonal flow patterns, water quality characteristics, management, use, and ownership [6]. Systematic inventory precedes assessment, planning, implementation of action, and monitoring in a structured resource management strategy. Efficient, interdisciplinary inventory protocols are also essential for improving understanding of spring ecosystem ecology, distribution, status, and conservation [7].

B. Scope and Limitations

The inventory of springs will help identify and categorize different types of springs in the region, including perennial springs, seasonal springs, and intermittent springs. This would also help in collecting data on the springs, including their discharge patterns, water quality, and socio-economic significance. Mapping the springs with the help of a Geographic Information System will be useful in creating a comprehensive spatial database, and also, with the help of an inventory of springs, one can monitor and conserve the springs that are on the verge of drying.

Some limitations may slow down the process of inventorying springs in the Himalayan region. Since some springs are in remote or inaccessible areas, it becomes challenging to reach and survey them, thereby limiting the collection of data. As we know, the springs' flow rate varies throughout the season, so one needs to monitor the springs in multiple seasons to capture their dynamics accurately. Factors such as weather conditions and limitations of survey equipment may hinder the accuracy of data collection. Also, the limitations of financial resources, expertise, and time may affect the quality of the inventory. Since the inventory of springs requires the engagement of the local people and stakeholders who possess traditional knowledge, it may restrict the inventory's comprehensiveness without their participation.

II. Materials and Methods

A. Study Area

In Uttarakhand, the Nainital district lies in the Kumaun division. It is located approximately between 78° 51′ 11.34″ and 79° 58' 23.06″ east longitude and 28° 58' 31.84″ and 29° 36' 45.19″ north latitude. The total population of the district is 9,54,605 as per the 2011 census. The geographical area of the district is 4,251 Sq. Km. [8].

Nainital district has a mild to moderate climate, which is indicative of its meteorological conditions. Summer precipitation in Nainital district is substantially more than winter precipitation. The yearly average temperature in Nainital is 17.1 °C. There is about 1903 mm of precipitation annually.

The research area (Figure 1) is in the Nainital district's Bhimtal Block and Okhalkanda Block. In this research, seven springs are examined, four of which are in the Bhimtal block and the other three in the Okhalkanda block. The villages Baret, Syuda, Murkuriya Haidakhan, and Bhoriya were covered in the Bhimtal Block, and the villages Talla Logar, Malla Logar, and Patrani were covered in the Okhalkanda Block. Springs in Bhimtal Block provide baseflow to the Gaula River, and springs in Okhalkanda Block provide baseflow to the Logar River, a tributary of the Gaula River.

The south-central portion of Kumaun is drained by the Gaula, a Lesser Himalayan River. The elevation of the 600 km2 Gaula catchment region (29°17'36" - 29°27'48": 79° 49'20" - 79° 26' 21") varies from 500 to 2610 m above MSL. The studied area is part of the middle Miocene Siwalik belt, which is made up of mudstones and sandstones [9].

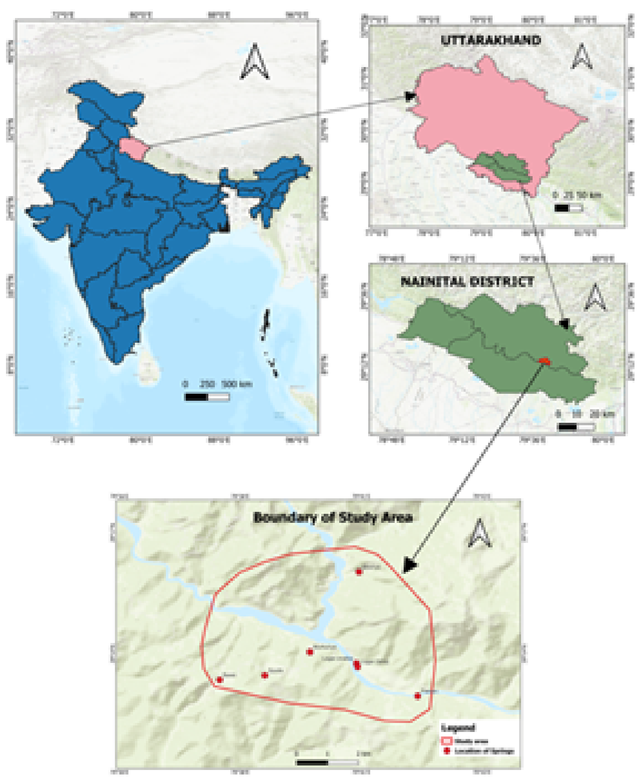

Figure 1. Location of the Study Area (Bhimtal and Okhalkanda Block, Nainital District)

This area was chosen for research because there has not been much research done in this area, which could be owing to monsoon season road bottlenecks that take months to clear (Figure 2), and because most of the people in this area rely on spring water for drinking and domestic purposes. As a result, there is a need to research and develop methods to identify the quantity and quality of spring water. The various springs studied are located at varying elevations in the lesser Himalayan region and are used in various ways (private, agriculture, irrigation, forest, etc.).

Figure 2. A landslide during the monsoon obstructed the major route

B. Field Survey

A total of 7 spring sites for abstracting samples were selected from the Bhimtal and Okhalkanda blocks of the Nainital district. Spring discharge observations started from the onset of Winter (January) 2022. The samples for water quality testing were taken in January 2024 for the winter season, April 2023, and October 2023, respectively, during the summer and post-monsoon seasons.

The Bhimtal block, with a total of 108 villages, has a total population of 52,403. The springs investigated in this block are located at villages Baret (BS1), Syuda/ Suera (BS2), Murkuriya (BS3), and Bhoriya (BS4). There is a total of 107 villages in the Okhalkanda development block of the Nainital district, with a total population of 48,337. The springs located in this block are at villages Logar Talla (OS5), Logar Malla (OS6), and Patrani (OS7).

The samples were then placed in 1-liter standard sample bottles for storage. Using a time-volume method, the discharge of all spring water sources was quantified on-site during the sample period. Following that, each sample was put into a sample bottle and transported to the lab of Uttarakhand Council of Biotechnology, Haldi, Uttarakhand, for a thorough examination of its physico-chemical characteristics.

C. Spring Discharge Measurements

The discharge of mountain springs is never constant. It varies significantly throughout the year. Furthermore, spring discharge varies significantly throughout the season depending on the environmental conditions. Diminishing spring discharge has become one of the main concerns in a few locations of the Nainital district. As a result, methodologies for testing and analysing spring discharge variation must be developed. The stopwatch-container method, or time-volume method, as described below, is used for measuring the discharge of the spring in this study.

The Stopwatch-Container method is used when the spring in any region flows following a certain trajectory through a locally engineered material like bamboo or pipe. A known volume container and a stopwatch/timer are required in this method. The sample is collected directly by placing the known volume container (bucket) vertically below the spring flow and starting the stopwatch immediately. Stop the watch as soon as the bucket fills up. Suppose a spring takes time ‘t’ minutes to fill up the ‘V’ liter container. Then, discharge ‘Q’ is calculated as:

$$\text{Discharge (Q)} = \frac{\text{Volume (V)}}{\text{Time (t)}} \text{ lit/min} \quad (1)$$

D. Spring Mapping using QGIS

Quantum GIS, or QGIS, is a free open-source software used for various GIS (geographic information system) applications. Its applications include the analysis of spatial data as well as the creation, editing, and extraction of graphical maps. The study region was turned into a shapefile using QGIS 3.22.4 software. Each place was identified by its elevation, latitude, and longitude using the Global Positioning System (GPS) device. From then on, the shapefile layer was updated with a delimited text layer that included the springs' latitude and longitude locations. Additionally, a Digital Elevation Model (DEM) of the area was created, and terrain analysis was done. The elevation data of a landscape expressed in relation to a datum is called a digital elevation model (DEM). Elevation data analysis, computation, and manipulation are frequent uses for DEMs. It is widely used to detect various properties of the terrain, such as aspect, elevation, and slope, as well as to locate various terrain features, such as drainage networks, watersheds, and so on. Raster data—raster grids of elevation data—are obtained from the National Remote Sensing Centre (NRSC), the Bhuvan portal, and the Indian Geo-platform of the Indian Space Research Organization (ISRO) to generate a digital elevation model (DEM). The Bhuvan portal provides 30m digital elevation data from Cartosat-1.

E. Physico-chemical Testing of Spring Water

Spring water is inexpensive and high quality, but once the groundwater emerges as a spring, it loses its natural protection provided by the overlying rock layers and therefore becomes more vulnerable to contamination threats from surface and atmospheric conditions. The increasing human population has led to urbanization and other development activities, which have resulted in the degradation of the quality of groundwater. It is believed by a huge number of people that spring water contains the perfect blend of minerals within a matrix of clean water. The myth that spring water is healthy is not entirely true, as it picks up natural minerals as well as any naturally occurring metals, some of which can cause serious harm. The study of spring water quality is vital as it determines the water quality in that area and allows us to plan for any spring water treatment if required.

1) Physico-chemical parameters for assessing water quality

i. Physical parameters: Turbidity and Total dissolved solids (TDS).

ii. Chemical parameters: pH, Electrical Conductivity (EC), Total Dissolved Solids, Alkalinity, Chloride, Hardness, Potassium, Sodium, Residual Free Chlorine (RFC), Fluoride, Iron, Sulphate, Nitrate, Calcium, Magnesium, Dissolved Oxygen.

2) Methods

Each water sample was tested in the laboratory of the Uttarakhand Council for Biotechnology, Haldi, Uttarakhand. A few water quality parameters (pH, Total Dissolved Solids, and Electrical Conductivity) were tested in each spring. These field parameters were tested on-site as they are sensitive to the groundwater environment and can change with time and temperature. Therefore, for better and more accurate assessment, they were tested in situ. The other remaining parameters were tested using water analysis testing kits, which were available in the lab. The samples for water quality testing were taken in April and October of 2023, respectively, during the summer and post-monsoon seasons, and in January 2024 for the winter season.

To collect spring water samples, polyethylene (plastic) narrow-neck containers of one-litre volume were used. The containers were soaked with HNO3 (nitric acid) of pH < 2 and left for one day. These HNO3-soaked containers were thoroughly washed using distilled water before being taken to the spring site. These containers were washed using the spring water on the site before collecting the samples. Each container was marked with a unique sample ID such as BS1, BS2, BS3, BS7, and OS4, OS5, OS6 (where 'B' represents Bhimtal Block, 'O' represents Okhalkanda Block, and 'Sn' represents samples; here 'n' is the number of sites visited first). The spring water in the containers was filled up to the brim, and the lid was tightly closed, such that no air was present in the container for better preservation of the samples. The collected samples were kept in a cool and dark place to avoid any changes in the quality.

F. Community Perception and Cultural Significance

Springs have high cultural and religious significance in the lives of the mountain people in the Himalayas. Water, specifically from the natural springs, plays an important role in all stages of life for the communities of Kumaun as well as the Garhwal Himalayas, from birth to death. The springs are worshipped, and before performing any prayer ritual near the spring, the area around it is cleaned, and one cannot go near the spring while wearing any form of footwear. It is believed that after giving birth to a child, the mother and the infant are impure, so there is a ritual performed in the Kumaun region where, after 21 days of giving birth, both are sprinkled with spring water in this ceremony to make them pure. After marriage, the newlyweds are taken directly to the nearby spring of the husband's village, where they perform the rituals, which involve pouring water from a small copper vessel, and then the bride offers it to the elders of the house. When someone dies in the community, to ward off negative energy, people bathe themselves in spring water to purify themselves [10]. This disseminates the key role of the springs in their religious and cultural lives. Although the springs may be communally protected, they are still being controlled in some aspects, as there is still a mindset of discrimination, even around water, based on the caste system, a product of post-Vedic philosophy [10]. The people of the Kumaun region have allocated the springs to the lower-caste community depending on their location or the quality of water. This issue of social inequality persists with the new generation as well.

The inhabitants of the research area relied entirely on these water resources. However, spring water has varied as a result of road building and climate change, forcing communities to rely on piped water supplies as well. The base flow for the Gaula River is formed by the springs in the villages of Baret, Syuda, and Murkuriya; the villages of Logar Malla, Logar Talla, Patrani, and Bhoriya form the base flow for the Logar River. During this procedure, some of the villagers were interviewed, and some basic questions on the availability of spring water, its influence on health, and its cultural value were posed.

III. RESULT

A. Digital Elevation Model (DEM) Analyses

A Digital Elevation Model (DEM) is a digital representation of land surface elevation relative to a certain reference datum. DEMs help determine various terrain attributes, such as elevation at specific points, slope, and aspect. They can also be used to identify terrain features, such as drainage basins and channel networks. In this study, the DEM of the area is identified (Figure 3), as well as the spring location and its elevation above mean sea level (Table 1), which ranges from 682 meters to 1932 meters, indicating moderately to highly rugged terrain. A standard deviation of 251 meters suggests significant elevation variation, which may impact water flow direction and velocity, spring discharge zones, and land use suitability. The DEM serves as an input layer for generating maps of slope (Figure 4), contour (Figure 5), aspect (Figure 6), and hillshade (Figure 7).

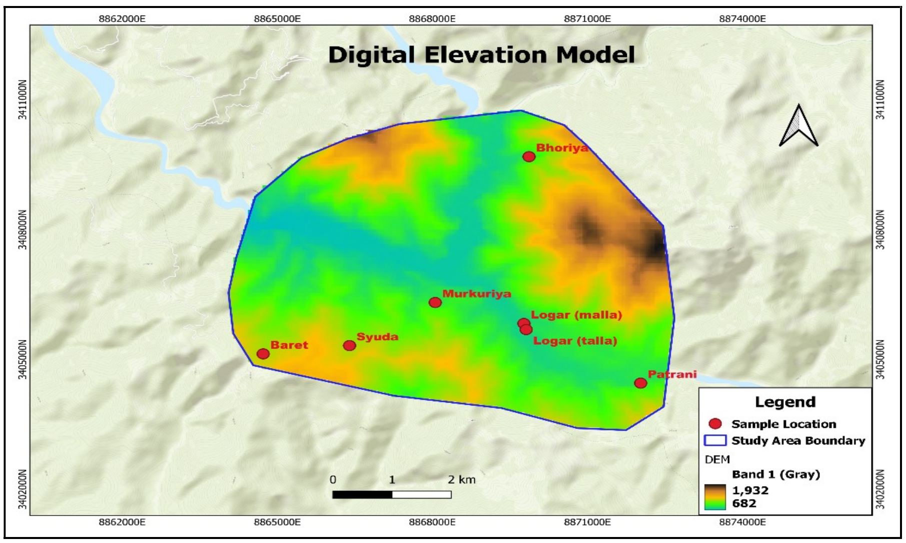

Figure 3. Digital Elevation Model of the Study Area (Bhimtal and Okhalkanda Block)

Table 1 - Elevation values of Sample Location

Spring Name	Spring ID	Elevation (m)
Baret	BS1	1179
Syuda	BS2	1131
Murkuriya Haidakhan	BS3	901
Logar (Malla)	OS4	805
Logar (Talla)	OS5	805
Patrani	OS6	900
Bhoriya	BS7	885

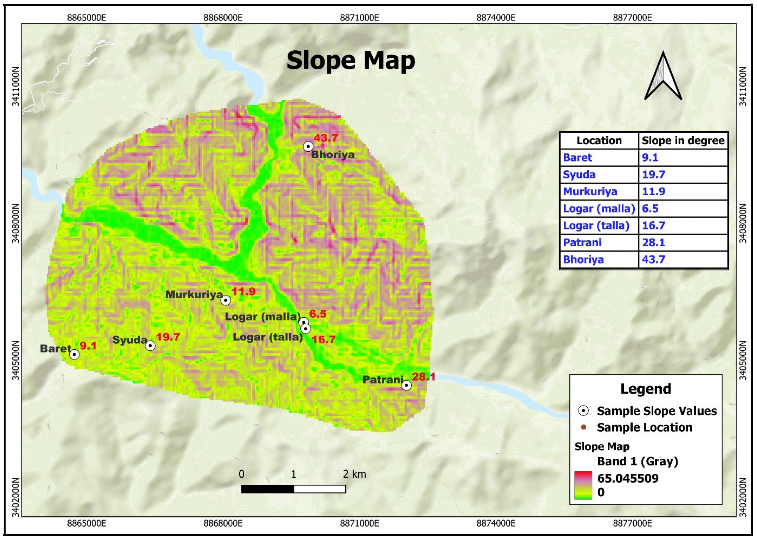

Figure 4. Slope Map of the Study Area (Bhimtal and Okhalkanda Block)

One of the most significant morphological characteristics that aid in understanding the surface configuration of the terrain is the slope, which is the degree of inclination of the surface [11]**.** The landscape becomes more pronounced with higher slope values, while it appears flatter with lower slope values. The slope map indicates that the slope of the study area ranges from 0° to 65°. The green area represents a flatter region, whereas the pink and red areas indicate steeper regions. The slope map analysis (Table 2) reveals that the spring samples indicate certain locations, such as Logar (Malla) and Baret, are situated in low-slope areas (less than 10°). This makes them favorable for groundwater recharge and consistent spring discharge. In contrast, Bhoriya, with a slope of 43.7°, and Patrani, at 28.1°, are located in steeper zones. In these areas, reduced infiltration and increased runoff can limit groundwater recharge, resulting in lower or seasonal spring yields.

Table 2 -Slope Value of Spring Sample Location

Location	Slope (°)	Interpretation
Baret (BS1)	9.1	Gentle
Syuda (BS2)	19.7	Moderate slope
Murkuriya Haidakhan (BS3)	11.9	Gentle to moderate
Logar (Malla) (OS4)	6.5	Flat to gentle
Logar (Talla) (OS5)	16.7	Moderate slope
Patrani (OS6)	28.1	Steep
Bhoriya (BS7)	43.7	Very steep

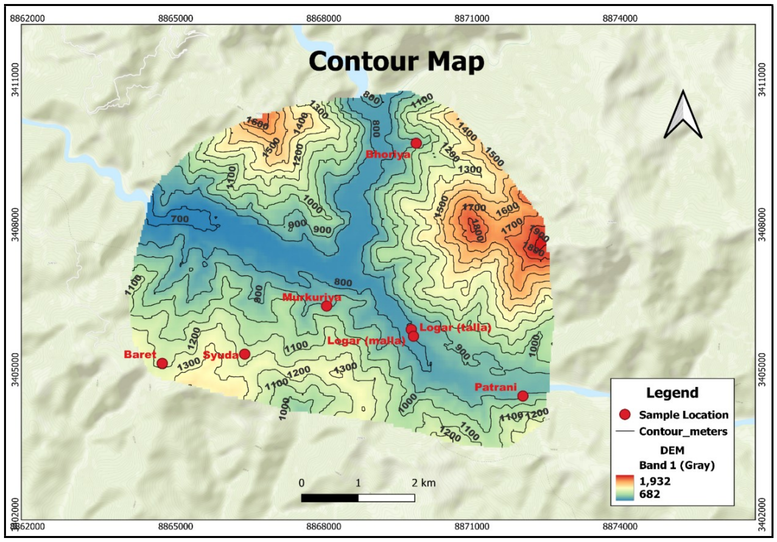

Figure 5. Contour Map of the Study Area (Bhimtal and Okhalkanda Block)

Contour maps use contour lines, that is, lines connecting points of equal elevation, to show the elevation of the terrain at various positions on the map. The contour map displays hills and valleys, as well as the steepness or gentleness of the slopes [12]. The contour map of the study area provides vital insights into the topographic characteristics that significantly influence hydrological processes, especially spring occurrence and discharge behavior. The map was generated using Digital Elevation Model (DEM) data and delineated with contour lines at consistent elevation intervals, illustrating the variation in terrain across the defined study area boundary.

The study area exhibits a rugged topography, with elevation values ranging approximately from 700 meters to over 1600 meters above the base level, as indicated by the contour lines. The contour lines form closed loops and sharp bends, denoting hilly or mountainous terrain. Steeper slopes are evident where contour lines are densely packed, particularly near Patrani, Murkuriya, and Logar (Malla). In contrast, wider spacing between contour lines indicates gentler slopes, especially near Bhoriya and downstream of the drainage.

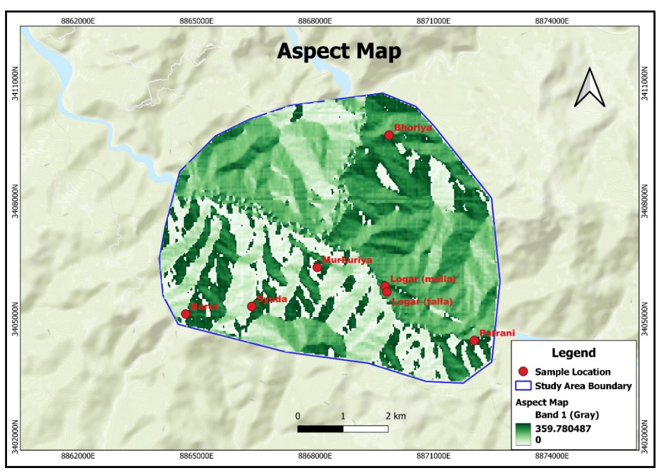

Figure 6. Aspect Map of the Study Area (Bhimtal and Okhalkanda Block)

Slope orientation, commonly referred to as aspect, is measured in degrees from 0 to 360° in a clockwise direction. Here, 0° (and 360°) indicates north, 90° represents east, 180° signifies south, and 270° indicates west. Table 3 presents the direction classification rules [13] used for creating aspect maps. It significantly influences microclimatic conditions such as solar radiation, evaporation, vegetation type, and groundwater recharge potential [14]. The aspect map was generated using the Digital Elevation Model (DEM) of the study area to examine its relationship with spring discharge. After the analysis in QGIS, the aspect value and its direction presented in Table 4 are correlated with the spring discharge potential of each spring.

Table 3 -Direction Classification Rules used

Aspect (°) Range	Direction
337.5 – 22.5	North
22.5 – 67.5	Northeast
67.5 – 112.5	East
112.5 – 157.5	Southeast
157.5 – 202.5	South
202.5 – 247.5	Southwest
247.5 – 292.5	West
292.5 – 337.5	Northwest

Table 4 -Aspect value of the Springs and their respective direction

Spring Name (Spring ID)	Aspect Value (in degrees)	Direction
Baret (BS1)	329.93	Northwest
Syuda (BS2)	31.56	Northeast
Murkuriya Haidakhan (BS3)	3.184	North
Logar Malla (OS4)	239.03	Southwest
Logar Talla (OS5)	223.97	Southwest
Patrani (OS6)	329.57	Northwest
Bhoriya (BS7)	349.52	North

The analysis of spring aspect values indicates a clear link between slope orientation and spring discharge behavior. Springs like Murkuriya Haidakhan (BS3) and Bhoriya (BS7) face north (3.18° and 349.52°), benefiting from cooler, shaded conditions that promote groundwater recharge and consistent flow. Syuda (BS2), facing northeast (31.56°), also receives early sunlight while avoiding intense afternoon heat, supporting stable discharge. In contrast, Logar Malla (OS4) and Logar Talla (OS5) face southwest (239.03° and 223.97°), experiencing higher sun exposure, increased evaporation, and likely lower discharge. Northwest-facing springs like Baret (BS1) and Patrani (OS6) (329.93° and 329.57°) are in a transitional zone, retaining moderate moisture and potentially showing intermediate discharge levels influenced by rainfall and catchment features.

Overall, the aspect analysis suggests that north- and northeast-facing springs are more favorable for sustained and higher discharge. In contrast, southwest-facing springs may be more prone to seasonal variability and lower flow, primarily due to increased solar radiation and evaporation.

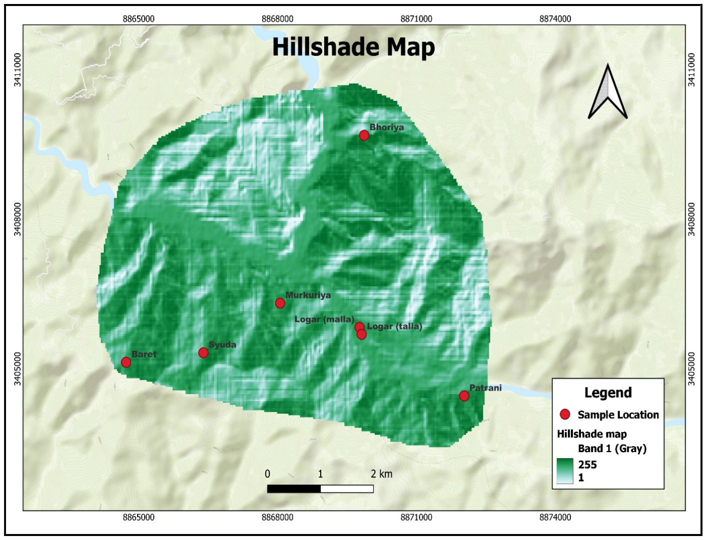

Figure 7. Hillshade Map of the Study Area (Bhimtal and Okhalkanda Block)

The hillshade map (Figure 7) provides a visually enhanced representation of the terrain in the study area, derived from the Digital Elevation Model (DEM), and it does not give any quantitative value [15]. Hillshading simulates the illumination of the landscape by the sun, allowing better perception of topographic variations such as ridges, valleys, and slopes. This map was generated by applying a default sun azimuth of 315° (northwest) and an elevation angle of 45°, which are standard parameters to mimic typical late afternoon lighting conditions.

The color gradient on the map indicates varying terrain exposure to sunlight. Brighter areas represent sun-facing slopes, while darker areas correspond to shaded terrain, often found on north-facing or steep concave slopes [16]. These variations are critical for understanding surface runoff behavior, soil moisture retention, and vegetation distribution.

B. Spring Discharge Measurement

In the study area, a total of seven springs in the Bhimtal block and Okhalkanda block were studied, and their discharges were measured.

The stopwatch-container, or simply the time-volume method, was used for the measurement. The spring discharge of the study area ranges from 2.1 lit/min (BS3) to 68 lit/min (OS5) in Jan 2022, 2.8 lit/min (BS3) to 66 lit/min in Feb 2022, 2 lit/min (BS3) to 61 lit/min (OS5) in Mar 2022, 1.5 lit/min (BS3) to 60 lit/min (OS5) in Apr 2022, 1.4 lit/min (BS1 and BS3) to 51 lit/min (OS5) in May 2022, 1.2 lit/min (BS1) to 58 lit/min (OS5) in Jun 2022, 1.6 lit/min (BS1) to 53 lit/min (OS5) in Jul 2022, 1.2 lit/min (BS3) to 53 lit/min (OS5) in Oct 2022, 1.9 lit/min (BS3) to 57 lit/min (OS5) in Nov 2022, 3 lit/min (BS3) to 60 lit/min (OS5) in Dec 2022.

3.3 lit/min (BS3) to 63 lit/min (OS5) in Jan 2023, 3 lit/min (BS3) to 60 lit/min (OS5) in Feb 2023, 1.8 lit/min (BS3) to 57 lit/min (OS4) in Mar 2023, 1 lit/min (BS3) to 42.5 lit/min (OS4) in Apr 2023, 1 lit/min (BS1) to 46 lit/min (OS4) in May 2023, 0.8 lit/min (BS1) to 60 lit/min (OS5) in Jun 2023, 0.7 lit/min (BS1) to 52 lit/min (OS5) in Jul 2023, 3 lit/min (BS3) to 70 lit/min (OS5) in Oct 2023, 1.8 lit/min (BS3) to 56 lit/min (OS5) in Nov 2023, 2.8 lit/min (BS3) to 61 lit/min (OS5) in Dec 2023.

2.2 lit/min (BS2) to 72 lit/min (OS5) in Jan 2024, 1 lit/min (BS2) to 71 lit/min (OS5) in Feb 2024, 1.1 lit/min (BS2) to 67 lit/min (OS5) in Mar 2024, 0.8 lit/min (BS2) to 62 lit/min (OS5) in Apr 2024, 0 lit/min (BS2) to 59 lit/min (OS5) in May 2024, 0 lit/min (BS2) to 57 lit/min (OS5) in Jun 2024, 0.8 lit/min (BS2) to 55 lit/min (OS5) in Jul 2024, 2 lit/min (BS3) to 61 lit/min (OS5) in Oct 2024, 4.7 lit/min (BS1) to 69 lit/min (OS5) in Nov 2024, and 4.9 lit/min (BS1) to 76 lit/min (OS5) in Dec 2024.

The minimum discharge was observed at the spring BS2 (0 lit/min) in May and June 2024, and the maximum was at spring OS5 (76 lit/min) in Dec 2024.

Data for spring discharge in the Bhimtal and Okhalkanda blocks for January through July 2022 and for October through December 2022 are presented in Table 5, while spring discharge data for January through July 2023 and for October through December 2023 are provided in Table 6. Spring discharge data for January through May 2024 and for October through December 2024 are available in Table 7. No data was collected for August and September due to road blockages caused by heavy rainfall. Variations in discharge during different months for the years 2022, 2023, and 2024 are illustrated in Figures 8, 9, and 10, respectively.

Table 5- Spring discharge data (in liters per minute) for each month from January to July and October to December, 2022

Spring ID	Jan-22	Feb-22	Mar-22	Apr-22	May-22	Jun-22	Jul-22	Oct-22	Nov-22	Dec-22
BS1	4.4	3.8	3.3	1.8	1.4	1.2	1.6	3.5	3.6	4
BS2	18	22	13	4.2	3.5	6.2	5.5	12.5	20	17
BS3	2.1	2.8	2	1.5	1.4	1.8	1.7	1.2	1.9	3
OS4	48	45	45	32	35	30	25	41	43	45
OS5	68	66	61	60	51	58	53	53	57	60
OS6	29	20	10.2	4.5	4.1	4.3	3.9	34	29	19
BS7	25.5	24	17.8	15.6	12.3	10	10	27	30	32

Table 6 -Monthly Spring discharge (in liters per minute) from January to July and October to December, Year 2023

Spring ID	Jan-23	Feb-23	Mar-23	Apr-23	May-23	Jun-23	Jul-23	Oct-23	Nov-23	Dec-23
BS1	4.7	3.5	4	1.5	1	0.8	0.7	4	3.8	4.2
BS2	22	26	18	5	4	6	5.8	14	28.5	20
BS3	3.3	3	1.8	1	1.9	2.5	2.2	3	1.8	2.8
OS4	52	49	57	42.5	46	38	26	42	38	44
OS5	63	60	55	16.5	43	60	52	70	56	61
OS6	28	19	12	2	2.1	2.6	2	30	25	27
BS7	38	39	31	28.5	22	17	18	32	26	30

Table 7 - Monthly Spring discharge (in liters per minute) from January to July and October to December, Year 2024

Spring ID	Jan-24	Feb-24	Mar-24	Apr-24	May-24	Jun-24	Jul-24	Oct-24	Nov-24	Dec-24
BS1	4.1	4	2.7	2.1	1.8	1.6	1.5	3.8	4.7	4.9
BS2	2.2	1	1.1	0.8	0	0	0.8	2.5	5.2	6
BS3	2.9	2.5	2.2	1	0.8	1	1.2	2	7.1	7.6
OS4	43	40	33	28	24	22	24	32	47	49

OS5	72	71	67	62	59	57	55	61	69	76
OS6	30	21	8.4	7	6.2	6	5.8	6.9	7.6	9.3
BS7	13	9	4.6	2.7	2.6	2.9	2	8.9	10.3	14.1

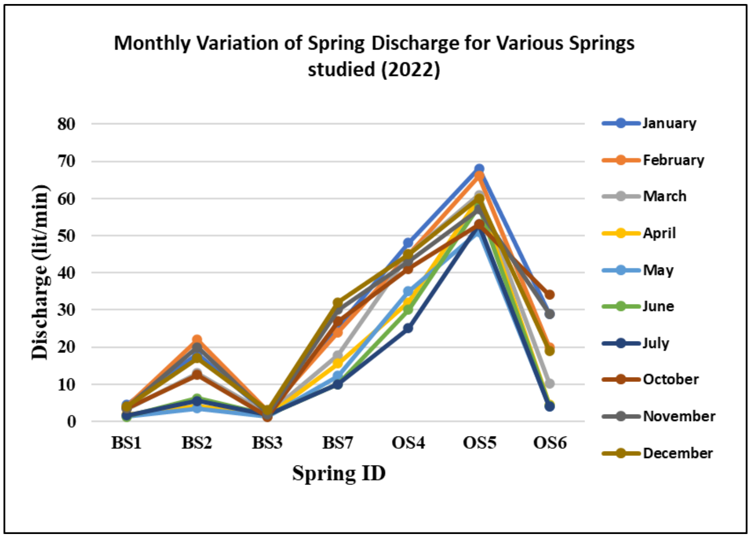

Figure 8. Monthly Variation in Spring Discharge for Various Springs Studied (2022)

The line chart illustrates the monthly variation of spring discharge for different springs during 2022 (Figure 8). Overall, substantial variation is observed among the springs, with OS5 exhibiting the highest discharge across all months, peaking at approximately 68 lit/min in January and remaining consistently high throughout the year. OS4 also shows relatively high discharge values, while BS3 records the lowest discharge, remaining below 3 lit/min for most months. Mid-range discharges are observed for BS2 and BS7, both displaying seasonal fluctuations, with higher values in the post-monsoon and winter months (October–December) compared to the pre-monsoon period (April–June). OS6 shows moderate discharge levels with a distinct drop during the summer months. Most springs demonstrate an increasing trend from the lean summer months toward the post-monsoon and early winter months, reflecting the influence of seasonal precipitation and recharge patterns on spring flow.

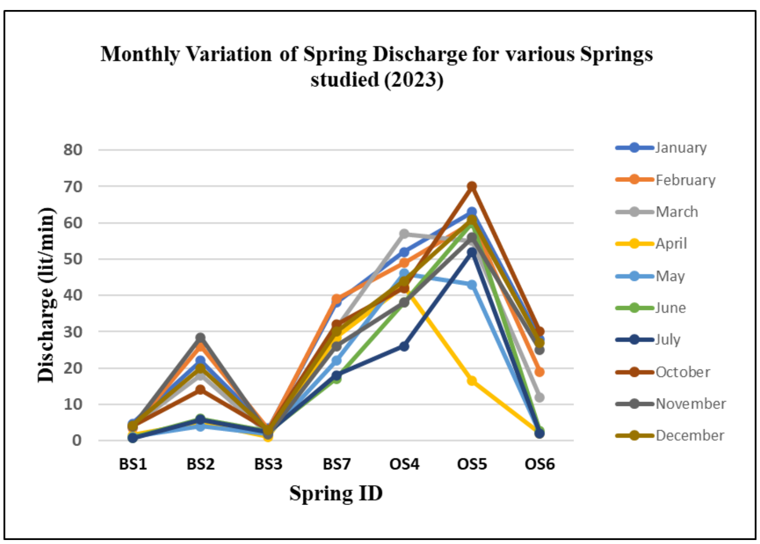

Figure 9. Monthly Variation of Spring Discharge for Various Springs Studied (2023)

The line chart depicts the monthly variation of spring discharge for different springs in 2023 (Figure 9). As in the previous year, OS5 recorded the highest discharge values, peaking at around 70 lit/min in October and remaining elevated throughout most months. OS4 also exhibited consistently high discharge, with peak flows during the pre-monsoon months of March–May and again in the post-monsoon season. BS3 maintained the lowest discharge values, generally below 3 lit/min across all months. BS2 and BS7 displayed moderate discharges, with noticeable increases during the post-monsoon and winter months compared to summer. OS6 maintained moderate flow levels, with declines in the dry summer months (April–June) and recoveries in the post-monsoon period. Seasonal fluctuations were evident across most springs, reflecting climatic influences on groundwater recharge, with lean flows during the dry months and higher flows following the monsoon season.

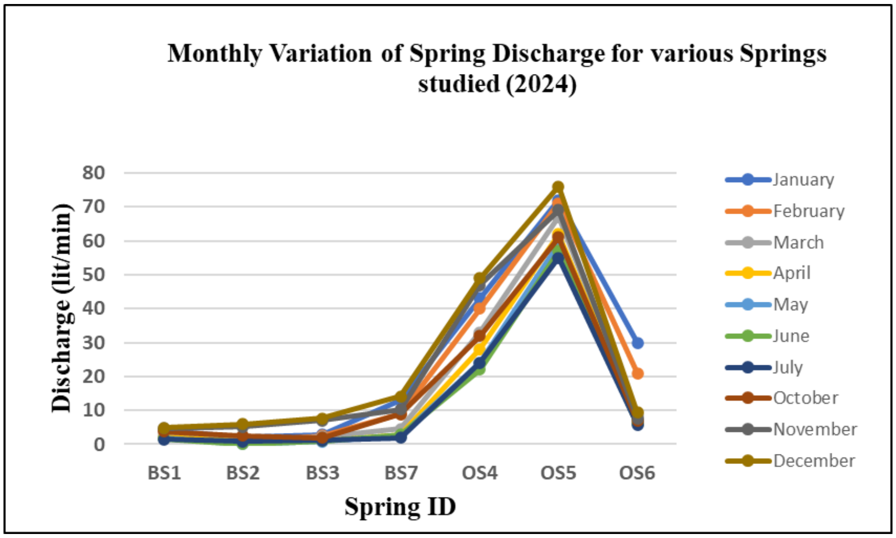

Figure 10. Monthly Variation of Spring Discharge for Various Springs studied (2024)

The line chart (Figure 10) illustrates the monthly variation of spring discharge for different springs in 2024. OS5 again recorded the highest discharge values, peaking at around 75 lit/min in December and maintaining high flows throughout most months. OS4 also showed strong discharge levels, with peaks during the post-monsoon and early winter months. In contrast, BS1, BS2, and BS3 recorded significantly lower discharges, with the majority of the year's discharges mostly below 5 lit/min, indicating reduced water availability compared to other springs. BS7 exhibited moderate flows, with a gradual increase from the summer months toward the post-monsoon period. OS6 displayed moderate to low flows, with minimal seasonal fluctuation compared to other springs.

Overall, 2024 discharge patterns were characterised by the dominance of OS5 and OS4, subdued flows in BS-series springs, and a general trend of increased discharge during the post-monsoon and early winter months, reflecting the seasonal recharge effects.

C. Community Perception

Conducting interviews with residents provides valuable insights into the current status of spring water in their area. In this study, a few questions were asked of the people of the rural community known for its reliance on natural springs as a primary water source. The responses highlighted a blend of concerns, observations, and experiences that collectively paint a comprehensive picture of the spring water situation.

Many of the older residents reminisced about the days when the springs flowed abundantly throughout the year. “Back then, we never worried about water shortages,” recalled Kunwar Singh, a 70-year-old farmer and resident of Murkuriya village. He believes that after the construction of the concrete storage tank, there has been a noticeable decline in the water emerging from the springs. However, this trend has been attributed to several factors, including forest fires, deforestation, construction of roads, a decrease in rainfall, and increased water usage by the growing population.

Kamla Devi, an old woman who has lived in the village named Baret all her life, expressed her concerns about the changing water quality and shortages of the number of springs in the area. “The water used to be crystal clear, and the people didn’t have to walk miles to fetch water,” she said while collecting water in a container. “Now, it's often muddy, and we have to boil it before using it for drinking or cooking.” Several other residents echoed this sentiment, noting that sediment and pollutants have become more common, likely due to upstream agricultural activities and inadequate management practices.

Young adults in the community, such as 23-year-old Ajay Kumar, a resident of a village named Syuda surprised by the sudden diminishing of the spring in their area, discuss the impact of these changes on their daily lives. “We have to travel farther to fetch water, and sometimes we depend on water trucks provided by the local government,” he explained. This situation has led to increased expenses and time commitments for families, particularly affecting children who might be late for school or have less time for homework due to water-fetching duties.

A resident of the village of Bhoriya named Sudesh Singh also opened a restaurant next to the spring and talked about how the changing climate has a negative impact on spring discharge. He remembers prior years when there had been minor seasonal spring discharge fluctuations, but the emergence of irregular rainfall, extended summer seasons, and insufficient rainfall during winters have all contributed to the decline in spring flow. In response to a question concerning the springs' cultural and religious significance, he stated: "The springs were worshipped as they were the only source of drinking water supply for the entire village. After marriage, the groom and bride's headgear (having God’s picture on it), or mukut in Hindi, was placed near the spring as it showed a sign of respect. The guy seated next to Sudesh adds that most young people in the next generation have left their villages to make a living, and over time, they have become unaware of the importance that the springs in the villages have.

Despite these challenges, the community remains resilient. Local leaders are actively seeking solutions, including collaborating with NGOs such as the Central Himalayan Rural Action Group (CHIRAG), which has been monitoring the springs in Murkuriya and Logar Malla. With the help of NGOs and other government organizations, better waste management systems and initiatives to educate residents about water conservation can be adopted.

IV.DISCUSSION

Springs, in simple language, are the ecosystems where the groundwater is exposed, which then typically flows from the Earth’s surface. Traditionally, spring water is considered clean and pure due to the natural filtering that occurs during infiltration and its movement through aquifers. For that reason, half of the population of the Kumaun region of the Indian Himalayan Region (IHR) consumes it directly and depends on it completely for their daily water requirements. Spring water is noted to be susceptible to changes caused due to both anthropogenic and natural activity, because of which the magnitude of the problem is exemplified by the high dependency of the Himalayan population on spring water on one hand and the deteriorating status of springs on the other. An insufficient database on springs makes them more vulnerable to drying. It is also a reason for great concern as it has led to significant gaps in practice and policy in developing any strategic national response to spring water management in India. It should not be forgotten that spring water requires not just an understanding of the underlying geology and surface hydrology, but also a keen understanding of traditional practices and culture around springs, both of which have significant socioeconomic and governance dimensions. Henceforth, the inventorization of springs creates a baseline information database providing essential data on the distribution and status of springs, or else it will be difficult to plan, design, and manage spring water in a region without an exhaustive database.

The current study uses some areas of the Bhimtal and Okhalkanda block of the Nainital District, Uttarakhand, India, as the study area. The mapping of the springs was done using QGIS software, followed by the Digital Elevation Model (DEM) for terrain analysis, such as slope, aspect, contour, and hillshade maps of the study area. The DEM shows that the spring BS1 lies at an elevation of 1179 m above mean sea level (m.s.l), BS2 at an elevation of 1131 m above m.s.l, BS3 at an elevation of 901 m above m.s.l, OS4 at an elevation 805 m above m.s.l, OS5 at an elevation of 805 m above m.s.l, OS6 at an elevation of 900 m above m.s.l, and BS7 at an elevation of 885 m above m.s.l. According to the research area's slope map, the OS6 spring is located on the steepest hill, and the OS4 spring is located on a gentler slope than the rest. The slope's orientation is established with the aid of an aspect map. As a result, it shows that the springs at Baret (BS1), Syuda (BS2), and Logar (Malla) (OS4) face north-west (NW) directions, the springs at Murkuriya (BS3), Bhoriya (BS7), and Patrani (OS6) face north (NW) directions, and spring at Logar (Talla) (OS5) face South (SW) directions. The contour map of the study area reveals that all the springs lie on gentle slopes.

The spring discharge was measured on-site using the time-volume method or stopwatch-bucket method. The discharge data for the years 2022, 2023, and 2024 indicated a significant fluctuation in the flow from the seven springs located in various villages within the Bhimtal and Okhalkanda blocks of Uttarakhand, India. It is concerning to note that in 2024, the springs in the village of Syuda dried up in May and June (summer), leaving the residents reliant on piped water supplies and springs from faraway locations. The NGO CHIRAG is also keeping an eye on the spring in Murkuriya, which is about to dry up. The folks disclosed that there has not been any precipitation since the start of 2024, which has caused significant alterations in spring discharge and the subsequent drying out of springs. It was also observed that the reduction in spring quantity was a result of road building as well. Despite having no rainfall in 2024, the Logar (Talla) spring showed no major variation in discharge, and Logar (Malla) also showed slight variation, which was not a matter of concern for the people living in the area. The quantity of spring water at Logar (Talla) is sufficient to run a water mill all year round to produce flour, and the spring at Logar (Malla), which is being monitored by NGO CHIRAG, is used for various purposes such as drinking water, washing clothes, and irrigation. The presence of a naturally occurring pond uphill and the surrounding trees may be the cause of the village of Logar's springs' minimal or non-existent fluctuation. The study of spring water quantity thereby revealed that the highest average discharge, 68 lit/min, 70 lit/min, and 76 lit/min in all three years 2022, 2023, and 2024 respectively were found in Spring ID OS5 i.e., Logar (Talla), and the lowest average discharge of 1.2 lit/min in the year 2022 was found at Spring ID BS1 and BS3 i.e., Baret and Murkuriya Haidakhan respectively, 1 lit/min in the year 2023 at Spring ID BS1 and BS3 i.e., Baret and Murkuriya Haidakhan respectively and 0 lit/min in the year 2024 at Spring ID BS2 i.e., Syuda.

Springs are believed to be manifestations of God by most of the people in the mountains. They are known to be high in minerals and pure in nature; therefore, they are directly consumed by the people residing in the Himalayas. With the rapid growth of the population and an increase in anthropogenic activities, a sense of doubt arises when the quality of water, as it can impact the health of people. To check the quality of the seven spring waters collected from the study area, physico-chemical parameters such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Alkalinity, Chloride, Hardness, Residual Free Chlorine (RFC), Turbidity, Fluoride, Iron, Sulphate, Nitrate, Calcium, and Magnesium were analysed. The water samples from each site were placed in 1-liter standard sample bottles for storage. Following that, sample bottles were brought to the laboratory of the Uttarakhand Council of Biotechnology, Haldi, Uttarakhand, for a thorough examination of their physico-chemical characteristics. The three seasons for which the spring water samples were analysed were summer (April 2023), post-monsoon (October 2023), and winter (January 2024). Since all parameters fell within the acceptable bounds set by [17] and [18], the results indicate a favorable outcome for each of the three seasons.

Speaking with locals provides important information about the state of spring water in their community today. The viewpoints of a rural community that relies primarily on natural springs for its water supply were investigated in this study. The worries, perceptions, and experiences that emerged from the interviews together paint a picture of the springs' condition. To ensure accurate data gathering, develop a sense of ownership, build trust, and advance sustainable water management methods, community engagement in spring water inventorization is essential. Involving locals makes the process more thorough, context-specific, and efficient in resolving difficulties and maximizing the community's assets.

V.CONCLUSION

Springs are natural systems where groundwater surfaces and flows, often considered clean due to natural filtration through aquifers. In the Kumaun region of the Indian Himalayan Region (IHR), around half the population relies on spring water for daily needs. However, these springs are vulnerable to changes from human activity and natural factors, and the lack of comprehensive data exacerbates this issue. The gaps in data lead to poor water management practices and policies.

Understanding springs requires knowledge of geology, hydrology, traditional practices, and cultural significance. This study focuses on springs in the Bhimtal and Okhalkanda blocks of Nainital District, Uttarakhand, India. Using QGIS software and the Digital Elevation Model (DEM), the study mapped terrain features and spring locations, noting that springs lie at elevations between 682 and 1932 meters above sea level, indicating moderately to highly rugged terrain. The slope and aspect maps helped identify that springs face various directions and generally lie on gentle slopes.

Spring discharge data from 2022 to 2024 showed fluctuations, with some springs drying up during the dry months of 2024, forcing locals to rely on piped water. The Murkuriya Haidakhn spring is nearly dry, monitored by NGO CHIRAG. In May and June 2024, the minimum discharge was observed at spring BS2 (Syuda), which was dried to 0 lit/min. The maximum discharge recorded in December 2024 was 76 lit/min at spring OS5 (Logar Talla), likely due to an uphill pond and surrounding trees.

Physico-chemical analysis of water quality across different seasons in 2023-2024 indicated that all parameters met WHO and IS standards. Engaging local communities in spring water inventory processes is crucial for accurate data collection and fostering sustainable water management practices. This involvement helps tailor solutions to specific community needs and leverages local knowledge for better resource management.

Resilient springs require the implementation of efficient conservation measures. Some of the conservation measures that must be used for effective spring monitoring to save springs for future generations are understanding the hydrology of springs, regular water quality monitoring, conducting regular biodiversity assessments, protecting the land surrounding the springs, involving the local community in spring monitoring and conservation efforts, and putting legal frameworks in place to protect springs from pollution, over-extraction, and changes in land use.

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