Review Paper:

Hydrological Challenges and Water Management Strategies in the Uttarakhand Himalayas

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Abstract

The Himalayan Mountains are rich in springs as a vital source of groundwater and they are used for drinking water, agriculture and other domestic purposes. Some springs have been tapped with the public water supply system for providing raw water to villages, towns, cities and industries. In the last few decades, these sources have felt stress due to increasing population (demand), human interventions and climate factors. Some springs have only seasonal discharge and some are completely dried. Various efforts have been made by the Government and nongovernment organizations (NGOs) on the development of springsheds and management for the augmentation of discharge in the Himalayan region. In Uttarakhand, different Government (Peyjal Nigam, Jal Sansthan) and nongovernment (CHIRAG, HIMCON, Himalaya Sewa Sangh) organizations have been actively involved in the springshed development program over the past years.

Many recharge structures (Gully Plug, Deep recharge pit, Percolation pit, Contour trench) and scientific techniques (Isotopes, Remote sensing and GIS, Conceptual modelling and theoretical models) have been implemented at different sites of Uttarakhand. This study describes the technical assessments of the current status of springshed management in Uttarakhand and suggests the possibilities for increasing spring discharge through various scientific approaches.

Keywords: Conceptual modelling, Contour trench, Human interventions, Isotopes, Springshed management.

Introduction

A major proportion of the drinking water supply scheme in the mountainous parts of Uttarakhand is spring-based[2,3,19]. Springs can be considered the lifeline of mountain regions. Springs also form important cultural symbols and provide base flows to rivers which consequently help in maintaining the ecological balance in the Himalayan region[1]. There are five types of springs as per the hydrogeological classification: Depression Spring, Contact Spring, Fracture Spring, Fault Spring and Karst Spring[5]. Discharge from these water sources has decreased dramatically and poses a serious threat to secure water management in this region. Road-cutting, mining, building construction, landslides, climate change and especially erratic precipitation, are the major factors that affect spring discharges consistently [3,20,35].

Furthermore, the impacts of climate change on precipitation patterns, like as a rise in rainfall intensity, reduced rainfall over a year and its uneven spread and reduced infiltration capacity, along with anthropogenic causes, the problem of dying springs is being increasingly felt across the Himalayan region[1,15,17,25].

There are 21,363 habitations/ villages out of 39,202 habitations/ villages in Uttarakhand that have a drinking water facility. The rest 17,839 villages are facing challenges associated with water shortage, either due to the dried-up water sources or the failed drinking water projects[13]. It has been reported that the women and children are carrying water from a long-distance point source and this type of activity is very common in many regions of the Himalayas, especially in Uttarakhand. Due to this scarcity of water, some people use alternatives to collect water during the night and this phenomenon creates unclean water, inviting waterborne diseases[4]. In a survey of the Kumaun Himalayan region, it was mentioned that the 40% reduction in spring discharge over 35 years (1951 to 1986) was mostly attributed to changes in land-use patterns and vegetation[3].

In a hilly area, another problem related to water scarcity, mainly in the dry season, is water runoff; rainwater does not percolate into the soil to recharge groundwater sources. The mountainous rivers have 1000 times higher flow in the rainy season than in the dry season and show a “too little and too much water” disorder[35].

To overcome all the above problems related to water scarcity and increase water retention in weak, erosion-prone mountain watersheds, it is necessary to take steps for water management to obtain sustained discharge during the dry season. However, water management is related to the development of watersheds and their long-lasting maintenance.

Different types of studies and watershed interventions are performed in Uttarakhand to resolve the problem of water scarcity and augment of spring discharge. Meanwhile, the study to assess the impact and sustainability of these interventions is rare and inadequate. This review aims to provide the current status of springshed management in Uttarakhand and fill the knowledge gap, which may guide future research on springs in the Himalaya region.

Spring and springshed: A spring is a point source of groundwater discharge fed by the aquifers and spring water emerges as a trickle and flows onto the surface of the earth. The aquifer is a system of rocks capable of storing and transmitting sufficient quantities of water to the springs. Most springs emerge after rainfall and some are continuously flowing. The Himalayan and sub-Himalayan regions are characterised by complex geological systems, with highly deformed rocks[5].

The aquifers in this region generally extend from one valley to the next valley, depending on the rock structure[32], thus several programmes need to be modified by changing the 'ridge-to-valley' approach to a 'valley-to-valley' approach. Spring water is rich in minerals essential for living organisms (Fig. 1), called mineral springs. A spring with temperatures significantly higher than the surrounding area's air temperature is called a hot spring and is generally found in volcanic regions. Regions that feed multiple springs through a system of rock formations and can cover single or multiple watersheds, are known as springsheds.

Spring diversity in Uttarakhand: The occurrence of diverse topographical and climate factors has resulted in the significant biodiversity of springs. Sulfur springs have provided an important habitat for microbial communities and they represent a wide spectrum of microbial diversity. Rawat[26] observed the structure and function diversity at Sahastradhara spring.

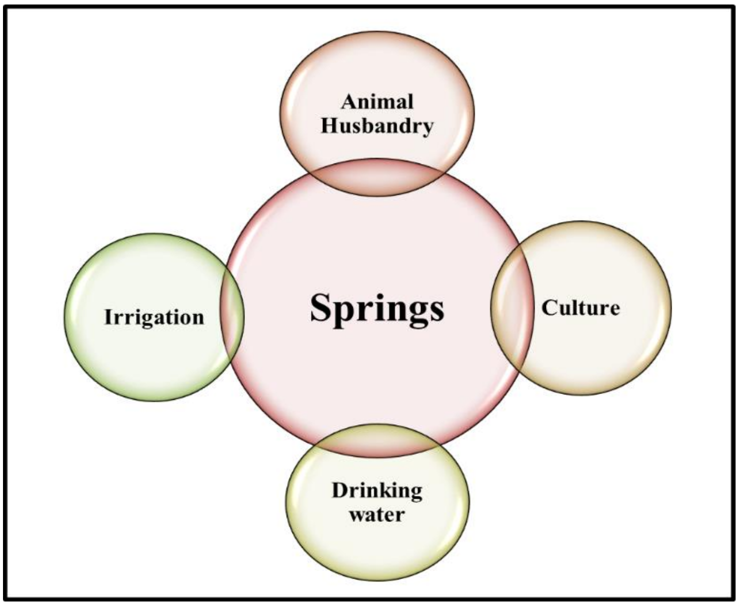

Figure 1: Socio-economic value of springs

Figure 2: Dry spring in Uttarakhand

Enrichment culture technique was used for observing the consequence of the microbial growth and activity with a particular time at different pH. Soil samples mixed with sulfur water had the maximum bacterial diversity i.e. protease producers (H' = 2.01; E1 = 0.64). A significant difference in the population count was also found in water and soil samples of Sahastradhara during the study. *Thiobacillus* was found to be the dominant microflora of sulphur water (34%) and soil mixed with sulphur water (20%). The temperature based microalgal and cyanobacterial diversity was also observed in two geothermal springs, namely Badrinath spring and Yamunotri spring of the Garhwal Himalaya[9]. The different morphotypes of *Synechococcus sp.* were found across the temperature gradient of 40 to 60 °C.

The *Mastigocladus laminosus* was found in Badrinath spring as the temperature ranged from 55 to 60 °C. Shannon's diversity index (H), which represented the cyanobacterial and microalgal diversity, also decreased drastically in this range. The Garhwal Himalayan region is especially rich in hot water springs and thermophilic microbial diversity was observed at many hot springs like Gauri Kund, Gangnani Kund and Tapovan Kund[11]. Simultaneously, the other hot springs, namely Surya Kund, Draupadi Kund and Yamunotri Tapt Kund, were found to be rich sources of thermophilic microbial diversity (bacteria, actinomycetes and fungi) and are alkaline in nature[12].

Factors that affect the discharge of springs in Uttarakhand

Climate change and poor watershed management have led to a decrease in discharge in many springs of the Uttarakhand Himalayan region[1]. Some studies have also concluded that the hydrological processes in the Himalayas are inadequate and management plans prepared from poor thought would not solve the problem of water scarcity in the lesser Himalayan region[3,10]. Nowadays, the weather has become unpredictable and irregular, with drastic changes in rainfall patterns. Snow is melting rapidly and water sources are drying up[27]. For example, during the period 1989-2018, both annual rainfall and rainy days show negative trends for Uttarakhand state[4]. Thus, assuming that rainfall has not declined but rainy days have declined, the number of dry days has increased during the monsoon. Along with this situation, the different anthropogenic causes have increased the problem of drying springs across the Himalayan region (Fig. 2).

Recharging of spring to mitigate the discharge: In the Mountain region, recharge is capable of mitigating the effects of climate change, but the natural limitations associated with springs need to be considered along with the improvement of access for supplying increased demand for different uses of groundwater[3,13,33]. For example, aquifers are natural bodies that possess limited storage and transmission capacities. These cannot be changed through any technological interventions. To resolve this, artificial recharge activities should be planned according to the natural recharge areas. Springs depend on the geohydrological conditions of the region. However, the recharge of water bodies alone cannot successfully resolve the water-related issues.

Thus, in the current scenario, like increasing population (demand), human intervention, changes in rainfall patterns and inadequate management framework of groundwater resources, it is required to implement specific effective plan on spring water management in the Himalayan Region. This plan should include the development of a science based, community-involved approach for long-term sustainability of the resource to manage the springs in the Himalayan region[8,14,33]. As per the guidelines of Jal Jeevan Mission, restoration and strengthening of springs should be done through the Compensatory Afforestation Fund Management and Planning Authority (CAMPA)[13].

Concept related to Springshed management: Despite springs being the lifeline of the mountainous regions of India, it has remained a blind spot in groundwater management. In mountains, the movement of groundwater is mainly through the fractures between the rocks. Hence, treatment plans for springs are based on their typology and hydrograph characteristics[35]. There are several challenges to sustaining spring discharge, resulting in continuous extinction of springs and spring-fed sources. Spring discharge is controlled by rainfall, land use, vegetation, grazing incidence and geomorphology of the recharge zone in a mountain watershed in Kumaun Himalaya[2].

Revival of springs in the Himalayan region for water security highlights the need for mainstreaming of springshed management with other developmental programmes at the State and national level to facilitate more merging with government schemes (e.g. MGNREGA, CAMPA, IWMP, SRLM)[2,18]. It is possible that some of the programmes may require modifying the guidelines to accommodate provisions for merging with springshed management activities.

Approaches for springshed management: The gradual changes in climate change, both rainfall and temperature and changes in patterns of land use and land cover have and will continue to affect the sustainability of aquifers and springs that emerge from them[3]. The geohydrology of a particular spring in the Himalayan region is extremely complex, further complicating the process in which water will infiltrate and recharge the aquifers[19]. Different techniques and empirical methods like pump test, water budget, tracers (dyes, Isotopes), spring hydrograph separation, kernel functions, mapping and conceptual model can be applied for the determination of spring geohydrology[5]. The isotopic technique has already been used for the determination of the recharge area of springs in the Chamoli district of Uttarakhand[30]. In another study, conceptual models were used to assist in the estimation of geohydrological controls on water resources in the Nainital district of Uttarakhand[10].

Table 1
Vital studies on spring hydrology in Uttarakhand and the methods/techniques used

S.N.	Catchment/Region	Methods/Techniques	Outcomes
1	Ranichauri watershed at Tehri Garhwal[34]	Spring hydrograph	Reduction in spring discharge is due to climatic factors
2	Gaucher springshed at Chamoli[30]	Isotopes	Identify recharge areas of springs for rainwater harvesting
3	Gaula Catchment at Kumaun, lesser Himalya region[3]	Water budget method	Providing quantified water inputs to estimate the recharge of springs
4	Water resources in Nainital[10]	Conceptual modelling	To assist in the estimation of geohydrological controls on water resources
5	Nainital Lake, Nainital[24]	Isotopes	Identification of the source of seepage
6	Hill Campus spring and Fakua spring, Ranichauri at Tehri Garhwal[27]	Artificial neural network (ANN) model	Measurement of Spring Flow
7	Hilly catchment of Tehri-Garhwal[22]	Fuzzy logic rule-based model (FLRBM)	Estimate the weekly spring flow in a hilly watershed
8	Chandrabhaga watershed at Tehri Garhwal[29]	Remote sensing and GIS techniques	Confirmation of the exact location of springs in a mountainous watershed and monitoring of Land use practices

Bartarya et al[3] used the water budget method to estimate recharge for springs in the Gaula catchment, located in the Kumaun Lesser Himalayan region in India. All instrumental techniques used in Uttarakhand so far are summarized in table 1. As a spring being groundwater, the principles of groundwater management and common-pool resources (CPR) apply to them as well[23]. A hydrogeological approach to spring-revival and springshed management, complemented by socio-ecological inputs, engineering surveys and a strong decentralised governance in mountain water security, makes springs resilient to climate variability and helps communities access water throughout the year and manage it better.

Community participation and hydrogeology are keys to the spring rejuvenation program[2,8]. The major challenges faced in the springshed development area are identifying recharge areas accurately, developing local capacity, incentivizing rainwater harvesting in farmers' fields and sourcing public financing[17]. In the present scenario, spring rejuvenation is based on valley-to-valley approaches, but the demerit of this rejuvenation work or recharge methods is inadequate for another valley. Therefore, to diminish these problems, focus on the various points is listed below:

a) The process generally starts with a field survey of the spring and the surrounding area.
b) Rock type and structures are mapped including strike and dip of formations and features and a geologic cross-section is developed.
c) Infrastructure, socioeconomic and other environmental data are collected.
d) Hydrologic monitoring of discharge and water quality is initiated.
e) Google Earth satellite imagery, topo map, or other sources are used to delineate the local watersheds and the field survey information is placed on the map.
f) Sustainable and integrated water resources management action plan for the revival and restoration of springs.
g) Implementation-oriented solutions for the provisioning of water to the mountain communities living in water-scarce areas.
h) Environmental restoration through springshed management.
i) Scientific and technological framework for adaptation and mitigation of climate change impacts.
j) Identifying existing or potential options and opportunities for enhancement and resource development and use.
k) Making and implementing decisions and finally, monitoring the impacts of those decisions.

Involvement of local authority and institutions: Civil society organizations (CSOs) and non-governmental organizations (NGOs) are actively contributing towards programmes to promote awareness of the importance of springs and to build capacities to protect, develop and manage “springsheds” across the country[7]. Many institutes and NGOs have actively participated in different springshed development programmes in Uttarakhand as listed in table 2. Himalaya Sewa Sangh (HSS) and Himalaya consortia for Himalayan Conservation (HIMCON), two voluntary organizations with the support of various national and international funding agencies, have undertaken the work of springs rejuvenation in the Garhwal Himalaya in the last two decades[7,28].

In Uttarakhand, many springs that the Central Himalayan Action Research Group (CHIRAG) has worked on, have shown distinct improvement in discharge. CHIRAG has taken steps towards understanding spring behaviour in greater detail. CHIRAG has treated and monitored 211 springs in 16 blocks spread over 8 districts of Kumaun and Garhwal regions so far[31].

Table 2
Key efforts related to the springshed management in Uttarakhand made by the Institute/ Organisation

S.N.	Institute/Organisation	Site/Region	Work performed	Key Findings
1	Central Himalayan Action Research Group[6] (CHIRAG)	Five springs (Balyali, Gajar, Bhadyan, Chopra, Nawal) at Nainital district	Construction of Khal and Contour Pits, Trench, Plantation, Terrace Bunding, levelling	Readily increase in discharge of Springs, Land for Cultivation having high moisture content. Improvement of the Hygiene of Villagers
2	Advanced Centre for Water Resources Development and Management (ACWADAM) and CHIRAG[20]	Kalsi Block, Dehradun	Plantation, Gully Plug, Deep recharge pit, Percolation pit, Contour trench	Readily increase in the discharge of Springs
3	Land and Water Resource Management Core Program, G. B. Pant Institute of Himalayan Environment and Development[16]	Dugar Gad micro watershed, Pauri-Garhwal	Trenches dug along contours, pits dug for plantation, Construction of barbed-wire fencing and mudstone walls	Increasing water availability during the dry season (April–June)
4	Himcon and Mahila Mangal Dal (MMD)[28]	Henwal river valley, Tehri Garhwal	Construction of Khals, Plantation and repair of the old water reservoir	Defunct or seasonal spring, having good discharge over the year

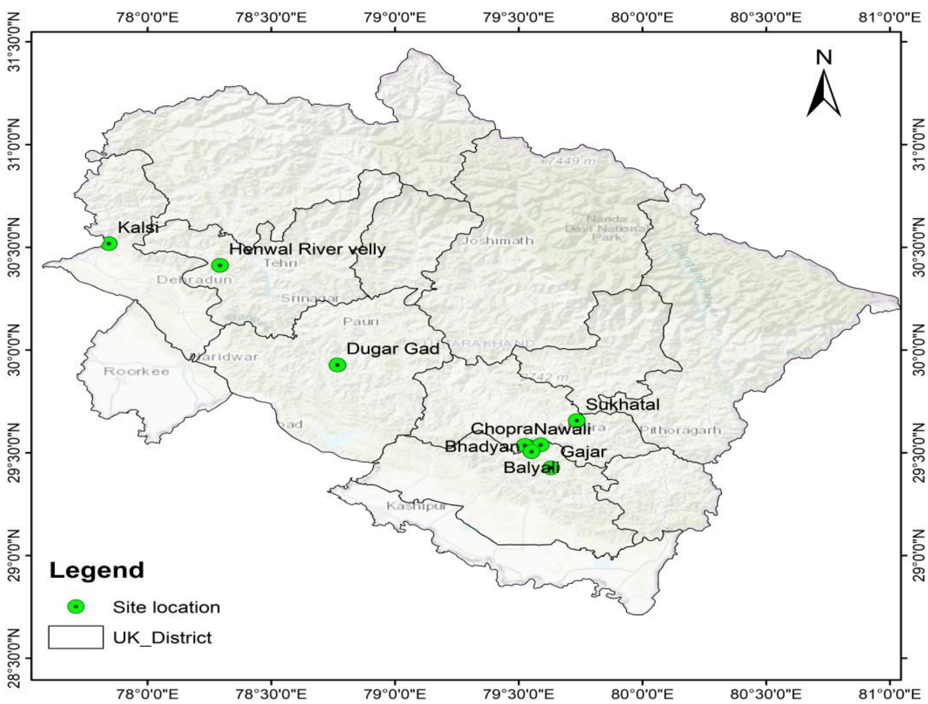

Figure 3: Spring rejuvenation sites in Uttarakhand

Case study

All places where the work related to the spring rejuvenation has been performed in Uttarakhand, are mentioned in fig. 3. A brief study of spring sanctuary development was done by Negi et al[16], in this recharge zone (18.5 ha) developed for reviving the spring present in Dugar Gad micro-watershed in the Pauri-Garhwal district in Uttarakhand[16]. The CHIRAG was involved in bringing hydrogeology to bear upon its work related to spring conservation and recharge in the Kumaon region of Uttarakhand. In another study, with the help of the Advanced Centre for Water Resources Development and Management (ACWADAM), CHIRAG developed a team of para-hydrogeologists, who mapped springsheds, monitored spring discharge and quality and identified a spring typology for the region of work that led to piloting recharge and demand management measures in over 100 springs in three districts of the Kumaon region[7].

The work also involved the institutionalization of springshed management in some villages. Their work was able to restore, to various degrees, the lean-season spring discharge and positively impact the summer water security of many habitations. The HIMCON and the Mahila Mangal Dal (MMD) have worked on the Henwal river valley in the central part of the Tehri Garhwal district of Uttarakhand[28]. The Henwal is a spring-fed river, which is revived by various interventions in the area, including the construction of new recharge structures called locally as khals.

A springshed developing work has been carried out in the Kalsi Block of Dehradun District. In this, two watersheds, Seligad and Dobragad have been selected for the study[20]. Many recharge activities were performed like plantation, contour trench, deep recharge pit and roof rain recharge pit etc.

Outcomes from the past springshed interventions and future aspects

In past decades, many interventions related to the spring rejuvenation and springshed management have been made in the Himalayan region[7]. Such types of approaches give a lesson and guidance for future planning and investment. Various studies are performed for evaluating the impact of springshed development programs on water availability, socio-economic and environmental conditions etc.[13,28,33]

First of all, the concept of 'spring sanctuaries' had been introduced by the Bartarya[2]. This study has a hypothetical suggestion for the development of the watershed model. The ideal model involves: water conservation by constructing storage tanks, improved irrigation canals and water supply lines, regular monitoring of water quality and involvement of the local community for sustainable protection of water sources.

A report of post program impact on the lives of the people in the Kumaon region prepared by the CHIRAG has revealed that recharge structures such as percolation ponds, khals, terrace levelling, terrace bunding and drainage have a positive impact on water availability[6]. These structures were very helpful for reviving the old and new springs and also increasing the dry season spring discharge.

However, the site-specific data are necessary to implement successful springshed interventions. The different scientific approaches like isotopic survey[30], conceptual modelling[10] and remote sensing and GIS measurements[25] are primarily investigations for collecting the site-specific data and aiding the preparation of monitoring and action plan.

In addition, the other interventions related to springshed development in Hilly areas are based on the hydrogeological survey, construction of recharge structures, monitoring of water quality and spring flow and skill development of a local community to combat the spring discharge and sustainability[5]. All informative studies show that any intervention related to the springshed development should be introduced after studying the fundamental hydrogeological principles of a particular area, to know about the physical, socio-economic benefits simultaneously. To this, a scientific validation of springshed development projects is very important to improve the efforts related to the spring rejuvenation and to gain confidence in future investments. Finally, with the above consideration, it is clear that future studies should be based on scientific data and should lead to the preparation of a simulation model on spring hydrology and estimation of aquifer properties. Springshed development should be followed after keeping in mind that it could solve the problem associated with incorporating future developments, population growth (demand) and climate change.

Conclusion

Springs are the main groundwater source in the mountain region for providing fresh water in rural as well as urban areas. But these point sources are going to shrink and feel environmental stress. The causes behind it are population growth (demand), erratic rainfall patterns, deforestation, forest fires, landslides and development activities. Inadequate knowledge, understanding and awareness of springs has further increased the problem while also inducing elements of conflicts like partiality in distribution and disorganized development.

Hence, there is an urgent need to restore and rejuvenate the spring for sustainable discharge. Watershed management and complete knowledge about the pattern of springs and their geohydrology can lead to the augmentation of spring discharge. The Government and non-government organisations are dealing with and connected to the spring rejuvenation programme, resulting in enhanced water security for the local community. These initiatives have created resilience against climate change impacts. For the successful and long-lasting initiatives, the socio-economic awareness of local stakeholders would be an important key in protecting and conserving springs.

Springs also represent an opportunity to hold capacity and recharge the plain and hill areas' drinking water. In the current review, almost all studies emphasized the need for active community participation in spring protection and recommended interventions such as artificial rainwater harvesting measures, collection of site-specific data, plantation and demarcation and protection of recharge zones from human activity. In conclusion, this work may also be helpful in future planning of watershed management and promote the study of springshed management.

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