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# Reviving Dying Springs: Climate Change Adaptation Experiments From the Sikkim Himalaya

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*Mountain springs emanating naturally from unconfined aquifers are the primary source of water for rural households in the Himalayan region. Due to the impacts of climate change on precipitation patterns such as rise in rainfall intensity, reduction in its temporal spread, and a marked decline in winter rain, coupled with other anthropogenic causes, the problem of dying springs is being increasingly felt across this region. This study was taken up in the Sikkim Himalaya, which has received limited attention despite being a part of the Eastern Himalaya global biodiversity hot spot. The objective of this study was to understand the basic characteristics of the springs and to demonstrate methods for reviving them. We found the rural landscape dotted by a network of microsprings occurring largely in farmers' fields, with an average dependency of 27 (±30) households per spring. The spring discharge generally showed an annual periodic rhythm suggesting a strong response to rainfall. The mean discharge of the springs was found to peak at 51 L/min during the postmonsoon months (September–November) and then diminish to 8 L/min during spring (March–May). The lean period (March–May) discharge is perceived to have declined by nearly 50% in drought-prone areas and by 35% in other areas over the last decade. The springshed development approach to revive 5 springs using rainwater harvesting and geohydrology techniques showed encouraging results, with the lean period discharge increasing substantially from 4.4 to 14.4 L/min in 2010–2011. The major challenges faced in springshed development were the following: identifying recharge areas accurately, developing local capacity, incentivizing rainwater harvesting in farmers' fields, and sourcing public financing. We recommend further action research studies to revive springs to advance the outcomes of this pilot study and mainstreaming of springshed development in watershed development, rural water supply, and climate change adaptation programs, especially in the Himalayan region.*

***Keywords:*** *Runoff; groundwater; recharge; watershed; rainwater harvesting; climate change adaptation.*

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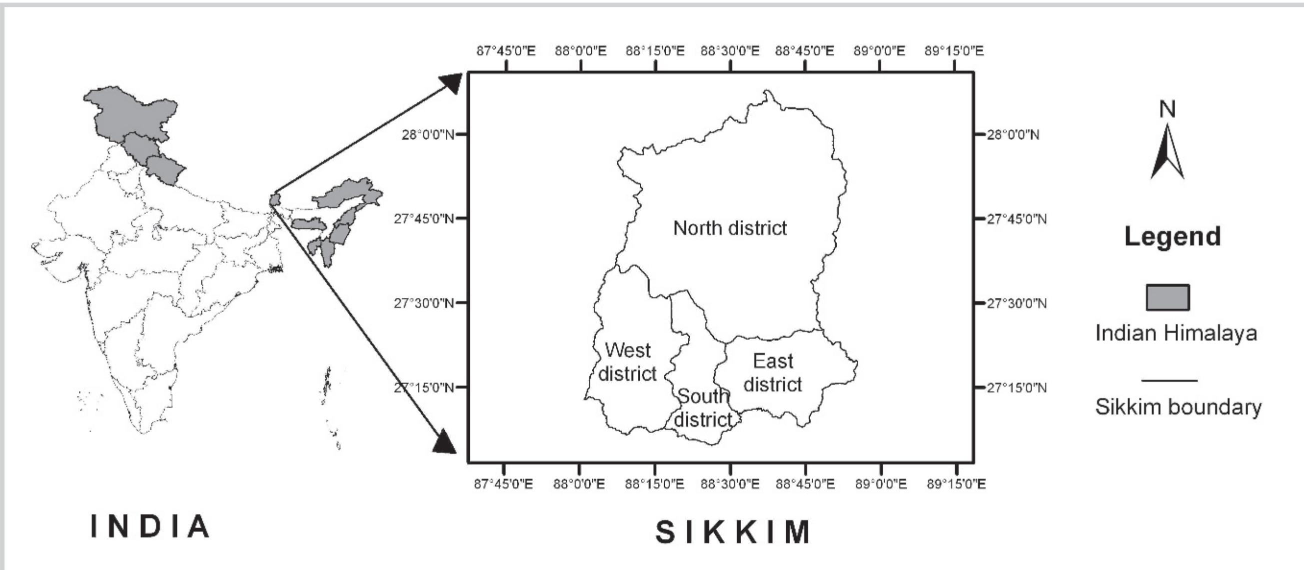
## Introduction

Sikkim (27°05′ to 28°07′N and 87°59′ to 88°56′E), wedged between Nepal and Bhutan, is a small state of India well known for its scenic beauty, immensely rich biological diversity, very diverse ecoclimatic conditions, and wide altitudinal variation (300–8598 m; Figure 1). Mount Khangchendzonga (8598 m), the third highest peak in the world, strongly governs the relief features of the state, which has a total geographical area of 7096 km$^2$. It is not only the highest but also the steepest landscape in the country, as the width of the Himalaya across its entire length is narrowest here (Schaller 1977). The annual mean rainfall, elevation, and slope show significant variation over short physical distances (Figure 2). Sikkim is a part of the Eastern Himalayan global biodiversity hot spot with 47% forest cover (Mittermeier et al 2004; Forest Survey of India 2009).

Water is the primary life-giving resource. Its availability is an essential component in socioeconomic development and poverty reduction (UNESCO-WWAP 2006). Though the Himalayan range is a source of countless perennial rivers, paradoxically the mountain people depend largely on spring water for their sustenance. The mountain springs, locally known as *Dharas,* are the natural discharges of groundwater from various aquifers, in most cases unconfined. In Sikkim, 80% of the rural households depend on spring water for their rural water security (Tambe et al 2009). Some of the springs are considered sacred, are revered as *Devithans,* and are protected from biotic interferences. With its history as a water surplus state with low population

**FIGURE 1** Map of Sikkim showing its location in India and as a part of the eastern Himalayan region. (Map by Sandeep Tambe)

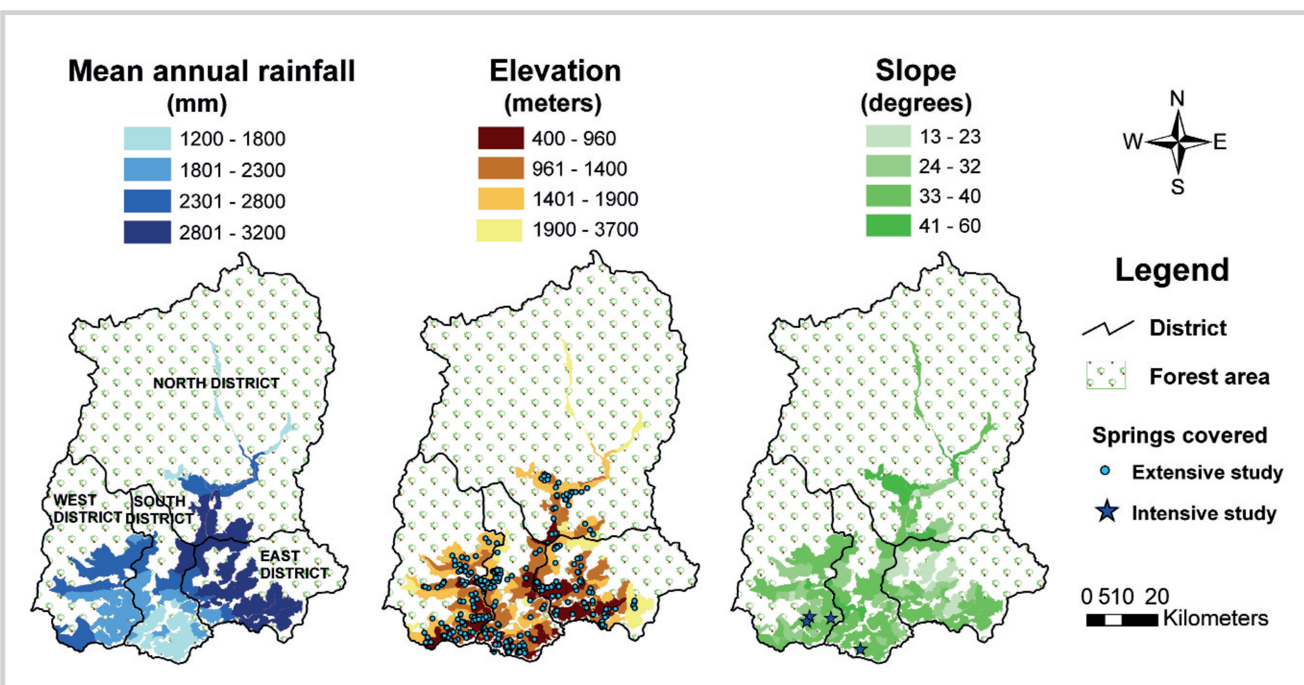



densities and high forest cover, artificial rainwater harvesting techniques for groundwater recharge were traditionally not prevalent. The rural households access water from springs mostly through gravity-based piped systems and sometimes manually.

## Sikkim geology

The geological setting of Sikkim has been mapped in detail by the Geological Survey of India (2007). This mapping indicates that the Sikkim Himalaya starts with a thin strip of rocks of the Gondwana group, which are

**FIGURE 2** Map showing the spatial variation in mean annual rainfall, elevation, and slope of Sikkim, along with the locations of the springs taken up for the extensive and intensive components of the study. (Map by Ghanashyam Kharel)





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overlaid by the Precambrian Daling group of rocks and exposed in the Rangit window in the southern part of the South and West districts. The Gondwana group of rocks is represented by a basal pebble slate (Ranjit Pebble Bed), followed by coal-bearing sandstone–shale horizons. The Daling group of rocks comprises quartz–chlorite–sericite phyllite, muscovite–biotite phyllite, slates, quartzose phyllite, and quartzites of the Gorubathan formation, and dolomite, limestone, and variegated phyllite of the Buxa formation. The Gondwana and Daling groups of rocks together constitute the Lesser Himalayan Domain (LHD). Systematic mapping reveals that most of the inhabited area is covered by the Daling group of rocks and particularly by the rocks of the Gorubathan formation. Further north, the Higher Himalayan Crystallines (HHC) occur, known as the Higher Himalayan Domain (HHD) (Das Gupta et al 2004). The different geotectonic domains of the Sikkim Himalaya are separated from one another by thrust faults (Acharya and Sastry 1979; Sinha-Roy 1982). The boundary between the LHD and the HHD is marked by the Main Central Thrust (MCT), which takes a sinusoidal turn in the Sikkim Himalaya (Das Gupta et al 2004).

## Literature review of spring-related studies

Intensive spring studies were taken up in the 1980s predominantly in the western Himalaya and focusing on aspects related to spring discharge in relation to rainfall patterns and catchment degradation (Singh and Rawat 1985; Singh and Pande 1989; Valdiya and Bartarya 1989, 1991; Bisht and Srivastava 1995; Sahin and Hall 1996; Negi and Joshi 1996, 2004). These studies showed that spring discharge was a function of both the rainfall pattern and the recharge area characteristics (Rai et al 1998; Negi and Joshi 1996; Negi et al 2001). At the same time, it was also found to be a function of the nature and character of the aquifers that feed many of these springs (ACWADAM and RMDD 2011).

These studies also indicate increasing instances of springs drying up or becoming seasonal. This has been attributed to growing impacts of population increase, erosion of the top soils, erratic rainfall patterns, deforestation, forest fires, and development activities (road building, building construction, etc) adversely impacting the spring catchments. Consequently, a limited amount of rainwater infiltrates to recharge the groundwater, thereby creating a hydrological imbalance.

Field experiments in the western Himalaya by Negi and Joshi (2002) to revive springs by adopting a spring sanctuary approach of developing the catchment using engineering, biological, and social measures showed promising results. This approach involves taking up artificial rainwater harvesting measures such as trenches, pits, check-dams, and plantation of native tree species in the spring recharge area, as well as protection by barbed wire fencing and minimizing of grazing and cutting of fuelwood and grass through social mobilization to create the effect of a spring sanctuary.

## Climate change as the new threat

Like many other places on Earth, the Himalaya are experiencing rapid climate change that is likely to significantly impact local ecosystems, biodiversity, agriculture, and human well-being (Chaudhary et al 2011). The weather has become unpredictable and erratic, snow is melting rapidly, and water sources are drying up (Sharma et al 2009; Chaudhary and Bawa 2011; Chaudhary et al 2011; Tambe et al 2011). As in many other parts of the world, there is a lack of spatially disaggregated meteorological records in Sikkim. Long-term, reliable data are available only for one station, Gangtok. Climate change-related studies based on the analysis of the data for this station, month-wise, season-wise, and annually from 1957 to 2005 indicate a trend towards warmer nights and cooler days, with increased rainfall except in winter (Seetharaman 2008; Ravindranath et al 2006, 2011). A comparison of long-term meteorological data available for Gangtok station (1957 to 2005), with the trend over the last 5 years (2006–2010), shows an acceleration of these patterns, as winters are becoming increasingly warmer and drier now, with October to February being the exceptionally dry period (Table 1) (Seetharaman 2008).

Perceptions of the local community captured in recent climate change studies in Sikkim (Tambe et al 2011) show that climate change impacts have resulted in a reduction in the temporal spread of rainfall and an increase in the intensity of rainfall, with a marked decline in winter rain. Community observations on recent climate change impacts indicate that in the subtropical belt (at altitudes of $<1000$ m) there is hardly any rainfall for the 6 months from October to March, resulting in frequent and ascending forest fires, drying of spring water sources, and decline in the production of winter crops and vegetables. More than three quarters of the local people in and around the adjacent Darjeeling Himalaya also believe that water sources are drying up, and 60% of them feel that there is less snow in the mountains than in the past (Chaudhary et al 2011). While catchment degradation has been identified as the main cause for the drying up of the springs in the last century, climate change is now emerging as the new threat in the 21st century. Drying up of mountain springs adversely impacts rural water security, and women have to reduce domestic use of water and travel longer distances to fetch water.

## Objectives of the study

Little is known about eastern Himalayan springs, although they play a vital role in ensuring rural water security. The objectives of the present study were twofold: first, to provide a better understanding of the basic characteristics of these springs by undertaking an extensive survey, and secondly, to use action research to explore whether these dying springs can be revived through a springshed development approach using geohydrology techniques.

**TABLE 1** Percentage of variation of monthly rainfall and maximum and minimum temperatures averaged for the years 2006 to 2010, in comparison with long period average for the period 1957–2005 for Gangtok station.[a)] (Adapted from Seetharaman 2008)

| Month | Rainfall (%) | Max temp (°C) | Min temp (°C) |
|---|---|---|---|
| Jan | −79 | 0.4 | 2.2 |
| Feb | −30 | 0.5 | 2.0 |
| Mar | −7 | −0.1 | 1.8 |
| Apr | 18 | −0.6 | 1.6 |
| May | −24 | 0.2 | 1.4 |
| Jun | −7 | −0.3 | 1.3 |
| Jul | −7 | −0.2 | 1.3 |
| Aug | 0 | −0.4 | 1.1 |
| Sep | −9 | 0.0 | 1.2 |
| Oct | −24 | −0.3 | 1.7 |
| Nov | −41 | −0.9 | 1.8 |
| Dec | −44 | −0.7 | 1.8 |
| Annual | **−9** | **−0.2** | **1.6** |

[a)]Min, minimum; Max, maximum; temp, temperature.

The springshed development approach further refines the spring sanctuary approach in using the underlying geology to identify the recharge area (known as the springshed), which often does not follow catchment or administrative boundaries. It involves mapping of the hydrogeological layout of the spring along with the conceptual model of the spring recharge area and aquifer. This springshed is then developed by artificial rainwater harvesting works to reduce the surface runoff and increase infiltration, thereby resulting in improved recharging of the spring aquifer. It is expected that the results of this action research will help to improve the designing of mountain springs revival.

## Methodology

### Description of the study area

The state comprises 4 districts: North, East, South, and West (Figure 1). Areas facing increasing incidences of drought are mostly in the south central part of the state located in the lower part of the South and West districts (Figure 2). This zone suffers from the following multiple vulnerabilities, all of which adversely impact the groundwater recharge:

- It is located in the rain shadow of the Darjeeling Himalaya and receives about 150 cm of annual rainfall, which is much less than the 250 cm received in other parts of the state.
- The annual rainfall is received in a concentrated spell of 4–5 months (June–September), with droughtlike conditions for 3–4 months (January–April).
- The steep physical terrain of the Rangit and Teesta river gorges results in high surface runoff and limited natural infiltration.
- Most of the villages are situated in the upper catchments, while the reserve forests are situated in the valley along the river bank, thereby reducing their rainwater harvesting potential.

### Collection of spring data

This study, undertaken from 2009 to 2011, has 2 components. In the extensive study we examined 270 springs to better understand their basic characteristics, while in the intensive study we explored the response of spring discharge to artificial recharge. The locations of the springs selected for the extensive and intensive study are shown in Figure 2.

The extensive study comprised a sample survey of springs distributed in the lower and middle hills in the 500- to 1800-m above sea level (masl) elevation zone in all 4 districts. We conducted a field survey using a standard questionnaire with the following parameters: Global Positioning System (GPS) reading (latitude, longitude, and elevation) of the spring source, land tenure, spring discharge, trend of lean period discharge over the last decade, and number of households dependent on the spring.

In the intensive study, the springshed development approach to revive 5 springs using rainwater harvesting and geohydrology techniques was adopted. The basic characteristics of the 5 springs selected for the intensive study are provided in Table 2.



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**TABLE 2** Basic characteristics of springs selected for artificial recharge.

| Spring name | Location | Elevation (m) | Geology | Land ownership | Spring type |
|---|---|---|---|---|---|
| Malagiri Dhara | Lungchok Kamarey GP, Melli Block | 975 | Phyllite | Private land | Depression |
| Aitbarey Dhara | Deythang GP, Kaluk Block | 1600 | Phyllite and quartzite | Community land | Fracture |
| Dokung Dhara | Takuthang GP, Kaluk Block | 1200 | Phyllite | Reserve forest | Depression |
| Nunthaley Dhara | Deythang GP, Kaluk Block | 1600 | Quartzite and phyllite | Community land | Depression |
| Kharkharey Dhara | Deythang GP, Kaluk Block | 1560 | Phyllite | Reserve forest | Fracture |

The science of groundwater, known as "hydrogeology," can lead us to a better understanding of aquifers, thus providing ways and means for their sustainable management. In mountain areas such as the Himalaya, high relief and complex geological structures play a vital role in the formation of these mountain aquifers. The extent and location of the spring recharge areas are completely governed by local geology and rock structure, often irrespective of catchment, administrative, or land use-related boundaries, many of which are "anthropogenic" divisions that are not always consistent with boundaries of natural resources such as groundwater. Hydrogeological mapping involves a detailed study of rocks, streams, and springs in the springshed. The type of rock(s) in an area, their attitude (dip and strike), the presence of openings, and the different structural features are the components that control the accumulation and movement of groundwater. In the Himalaya, the complexity of these components makes their study all the more important. The dip and strike of rocks forms the basis of geological mapping.

The springshed development approach involves the following processes: hydrogeological mapping of the springshed, delineation of the mountain aquifer, classification of the springs, secondary data collection and interpretation, identification of recharge area based on local geology and its structural setting, setting up of a monitoring system for periodic spring discharge data collection, planning of treatment measures in the recharge area with the help of community participation, and finally conceptual layout of the spring. Figure 3 illustrates the hydrogeological layout of a spring along with the conceptual model of the spring aquifer and the recharge area.

After the hydrogeological mapping, artificial recharge works were taken up in the recharge zone of the 5 selected springs, and we studied the impact of these structures on the lean period discharge. These works taken up on sloping lands consisted mostly of rows of staggered contour trenches (2 m × 0.8 m × 0.6 m) and percolation pits (2 m × 0.4 m × 0.6 m) with a vertical interrow spacing of 6 m and a few loose boulder check-dams (Figure 4A). In farmers' fields, an economic incentive in the form of horticulture and fodder plantation was also provided (Figure 4B). Recharge works consisted mainly of land-based activities, and drainage line measures were minimized due to the torrential stream flows resulting from intensive precipitation patterns and steep slopes. Springshed development was carried out in May 2010, and the spring discharge was measured on a monthly basis, during and after the intervention. The spring discharge during the dry season (March–May 2010) was taken as the baseline or control and was compared with the lean spring discharge (March–May 2011) after one season of groundwater recharge.

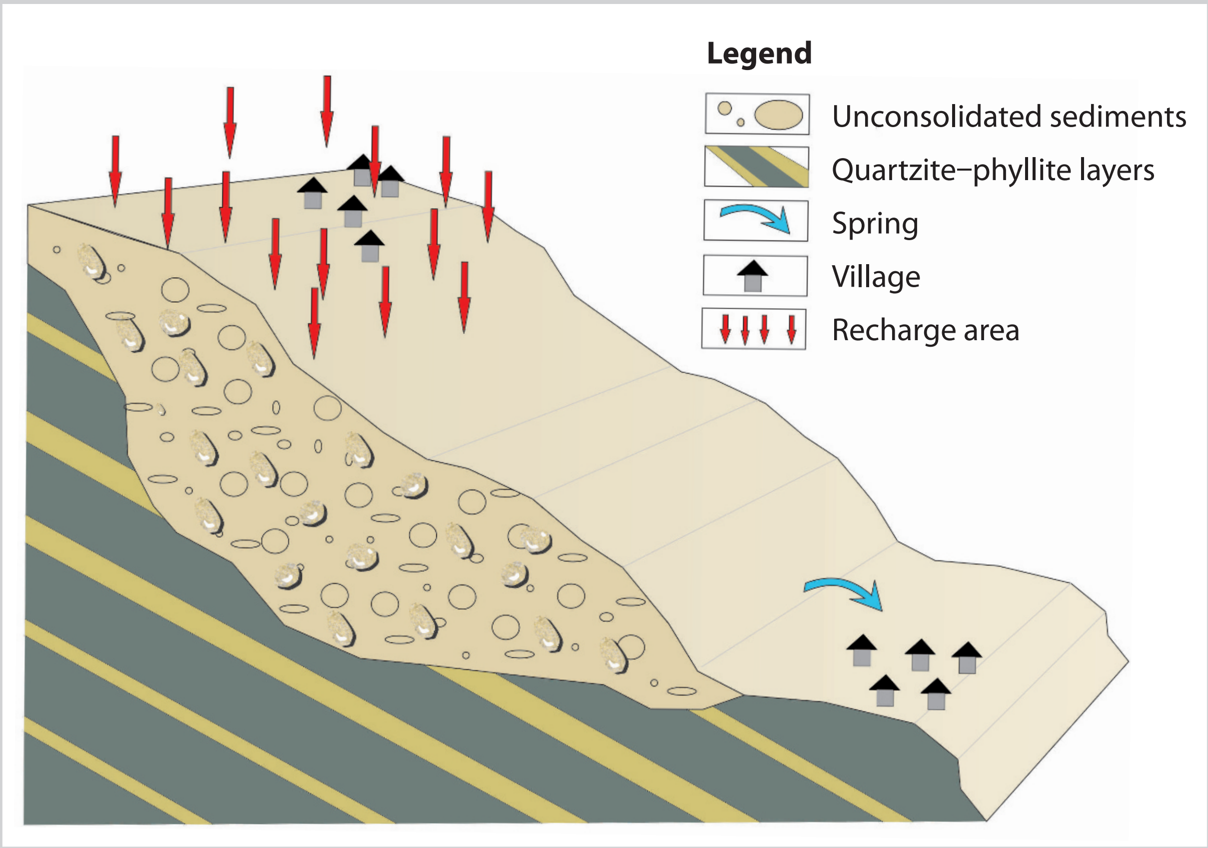
### Rainfall data recording

In 2010, 18 automatic weather stations (AWS) were installed with the help of the Indian Space Research Organization (ISRO), Department of Space, Government of India. The AWS records several weather parameters such as temperature, rainfall, humidity, radiation, wind velocity, wind direction, etc, and this weather information is directly uploaded to the website of the Department of Space, from where it can be accessed. Disaggregated rainfall data were obtained from the AWS that covered the intensive study sites.

### Limitations

In the extensive component of the study, while basic data for 270 springs were collected in the sample survey mode as a onetime effort, the seasonal spring discharge data were collected on a quarterly basis. On this count, while the springs of the drought-prone areas were covered adequately, those in other areas will have to be further supplemented especially in terms of lean season data. The AWS are located within a 5-km radius of the springs selected for the intensive study; however, in mountain terrain the rainfall variation is high, and having a rain gauge installed in the springshed itself will help in enhancing accuracy.

**FIGURE 3** Diagram showing the hydrogeological layout of a mountain spring along with the conceptual model of the spring aquifer and the recharge area. The springshed is made up of alternate layers of quartzite and phyllite rocks, which are overlaid by a thick deposit of unconsolidated sediments. The quartzite–phyllite layers prevent downward infiltration of groundwater, and the spring originates at the base, where the sediments become thinner and the surface slope is gentler. Thus, the unconsolidated sediments act as the aquifer to the spring, which is termed "depression spring." The recharge area of the aquifer lies in the upper reaches of the springshed in farmers' fields, where the slope is gentler and the village is located. (Diagram by Kaustubh Mahamuni)




In the intensive component, the quantity, temporal spread, and intensity of rainfall are exogenous factors that impact the spring discharge and bring in a factor of variability in the study. Although the study area received overall lesser lean period rainfall (March–May) in 2011 than in 2010, the early spring showers of 2011 (March–April) were higher and would have benefited the lean period spring discharge. The full impact of the artificial recharge work will be known only after 2–3 years, while the present study is based only on 1 year of data. Thus, the current study documents impacts through short-term data and needs to be supplemented through long-term monitoring (which is ongoing) and isotopic measurements (which are planned) to ascertain the correlation between geohydrological interpretation and interpretation from isotope techniques.

## Findings

### Extensive study

Most of the springs are located on private land (82%), and spring water is perceived as a public resource and shared freely downstream. An extensive network of about 20 small springs ensures rural water security of a village (Gram Panchayat Unit) with an extent of 7 $km^2$ and comprising 545 households with a population of 2700. On an average, 27 (±30) households, with a population of 135, are dependent on one spring, with the water piped to their houses through gravity flow. The typology of the springs was found to be mostly depression and fracture with contact springs and karst springs occurring only rarely.

The drought-prone areas have a narrower spread of annual rainfall, receiving only one half of the pre- and post-monsoon rainfall and little winter rain compared to the other areas (Figure 5A). The mean spring discharge peaked at 51 L/min during autumn (September–November), only to decline to 37 L/min during winter (December–February) and further diminish to 8 L/min during spring (March–May), followed by a spike to 42 L/min (June–August) during the monsoons (Figure 5A). The spring discharge follows an annual, periodic rhythm that is strongly dependent on the rainfall patterns with a distinct time lag at times. The perceived decline in the lean period spring discharge over the last decade is 48% in the drought-prone areas and 35% in the other areas.

### Intensive study

A total of 5 springs were selected in the drought-prone zone of the South and West districts. These springs have a


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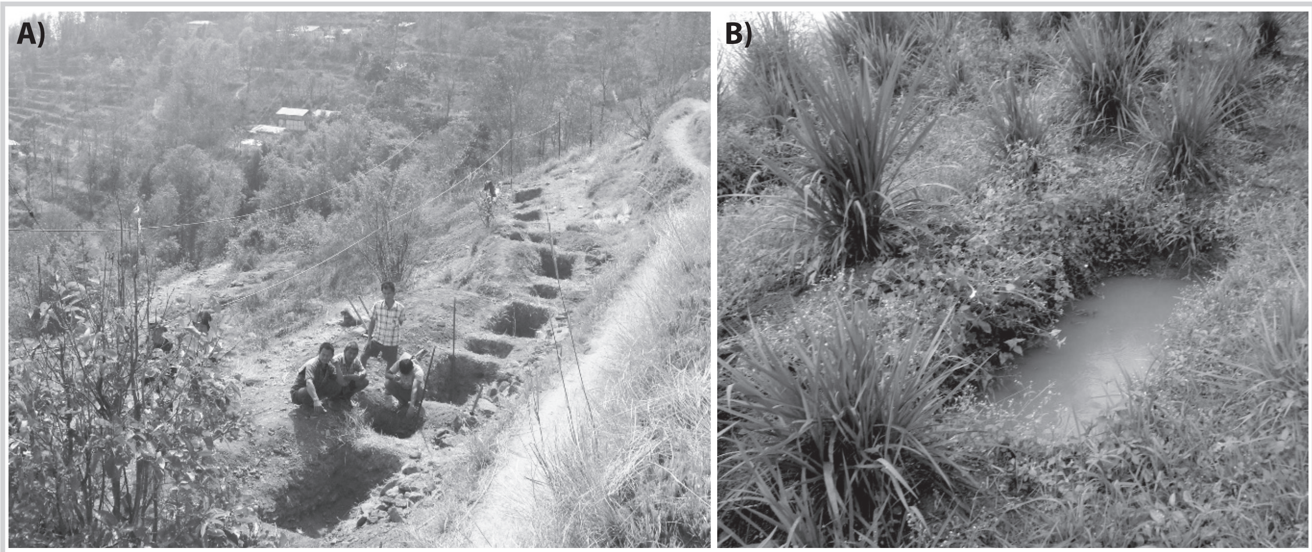
**FIGURE 4** (A) Artificial recharge structures consisting of rows of rectangular staggered contour trenches (2 m × 0.8 m × 0.6 m) with square pits in between for mandarin orange horticulture plantations under construction in privately owned sloping lands in the recharge zone of Malagiri Dhara, Lungchok Kamarey Gram Panchayat, South Sikkim (May 2010) (Photo by Suren Mohra); (B) surface runoff trapped in the trenches assisting in artificial groundwater recharge along with fodder plantation in the recharge zone of Dokung Dhara, Takuthang Gram Panchayat, Kaluk block, West Sikkim (August 2010). (Photo by Pem Norbu Sherpa)




depression and fracture typology and are located in the lesser Himalaya in the 975–1600 m elevation zone. The local geohydrology observed in these springsheds is low-grade metamorphic phyllite and quartzite rocks of the Daling group dipping north and northwest. Hydrogeological layout maps that provide the conceptual model of the spring aquifer and the recharge area were first prepared (Figure 3).

While Malagiri Dhara of Melli Block is located on private land, the other 4 springs of Kaluk Block occur on community or forest land (Table 2). The lag between the peak rainfall and the peak spring discharge varied from 0–2 months. The action research component to revive these 5 springs using rainwater harvesting and geohydrology techniques showed encouraging results, with the lean period discharge increasing substantially from 4.4 to 14.4 L/min (Table 3; Figure 5B–F). Independent assessments carried out by researchers based on the perceptions of the spring water users also confirm this significant increase in spring discharge (Laura Coulson, personal communication; http://sikkimsprings.org/dv/research/Final_Coulson%20.pdf, Richa Gurung, personal communication; http://sikkimsprings.org/dv/research/ Study%20of%20Richa%20Gurung.pdf). Probably, some of the locations benefited from a few early showers during the lean season (March–April) of 2011, which were absent during 2010. However, the overall premonsoon (March–May) rainfall in the year 2011 was less than that during 2010 (Table 3).

Springshed development of Malagiri spring in South Sikkim comprising staggered contour trenches and percolation pits in farmers' fields was incentivized by mandarin orange horticulture development along with broom grass fodder plantation as hedgerows. These plantations will provide additional income to the farmers and create incentives for springshed development in farmers' fields.

## Discussion

The Himalayan region is blessed with adequate rainfall, but an overwhelmingly high proportion of the same is restricted to the monsoon season and natural groundwater recharge is hampered by high levels of surface runoff. Rather than "gushing" surface water, groundwater oozing, trickling, and flowing in the form of mountain springs ensure water security for a sizeable part of the rural population. These springs are fed by groundwater and are largely recharged by rainwater infiltration. There is a growing perception that climate change impacts, manifested in the form of rising temperatures, more intense precipitation patterns, and longer winter droughts, have further reduced the natural groundwater recharge (Tambe et al 2011). This pattern of a shrinking monsoon season and the resulting drying up of natural springs and declining base flow of streams has been recently documented in the western Himalaya as well (Rawat et al 2011). In addition, recent studies in the adjacent Darjeeling hills indicate the perceived impact of climate change in the form of less snow in the mountains and intense but short episodes of rainfall that increase runoff, causing poor accumulation and recharge of water, thereby resulting in the drying up of water sources (Chaudhary et al 2011). In the present study we also found a near-universal community perception that the lean period spring discharge is declining at an alarming rate.

While spring water is perceived as a public resource, the majority of the springs and their recharge areas (not necessarily on the same slope as the spring) are located in privately owned farmers' fields. Paddy cultivation involving

**FIGURE 5** (A to F) Mean hydrograph of the springs and hydrograph of 5 springs showing the impact of artificial recharge (taken up from April to May 2010) on spring discharge, along with rainfall patterns from 2010 to 2011.

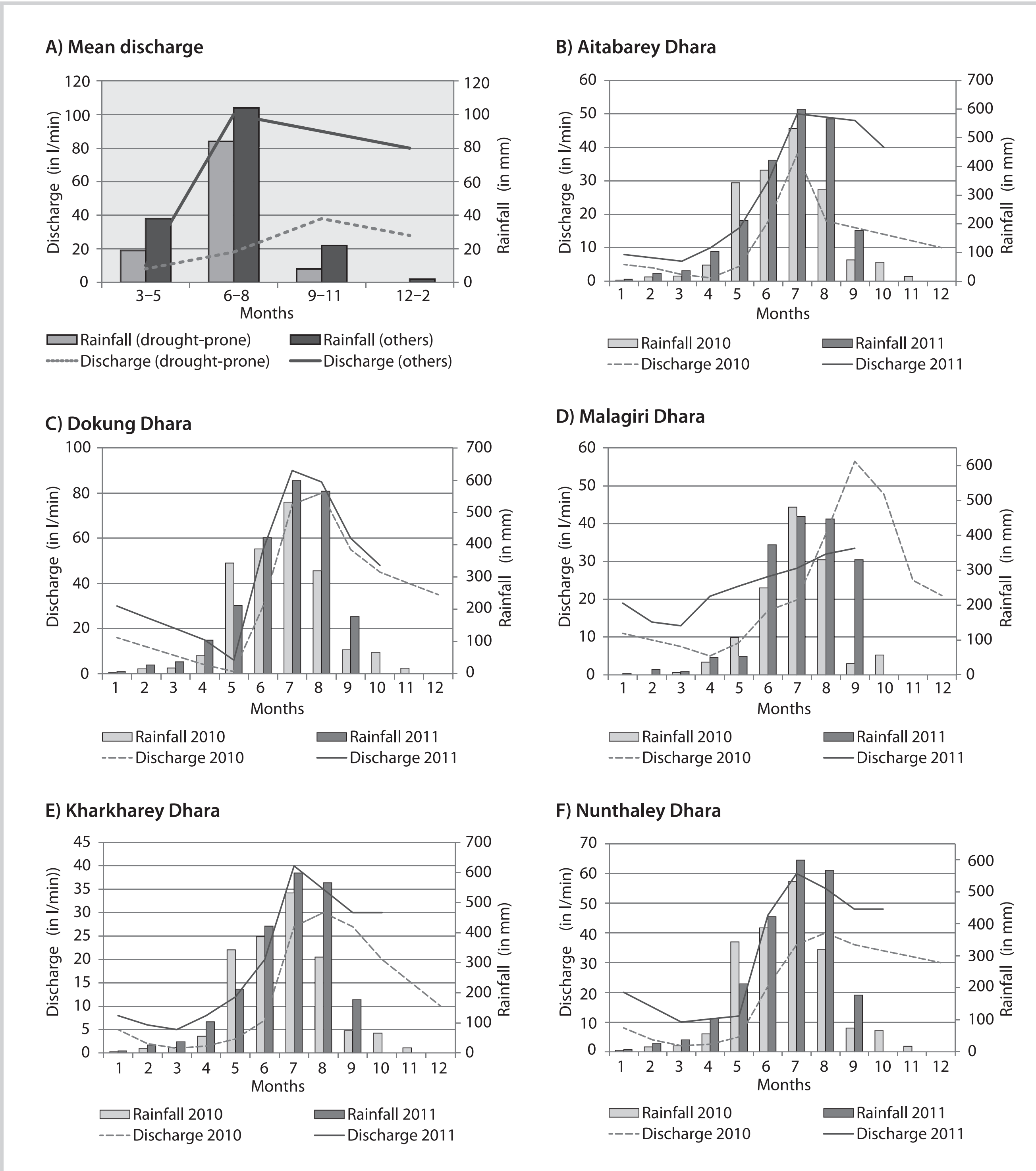


**TABLE 3** Impact of springshed development on the lean period discharge of springs.

| Spring name | Artificial recharge taken up | | Lean period rainfall (cm) | | Lean period spring discharge (L/min) | |
|---|---|---|---|---|---|---|
| | Area (ha) | Volume ($m^3$) | Mar–May 2010 | Mar–May 2011 | Mar–May 2010 | Mar–May 2011 |
| Malagiri Dhara | 13 | 841 | 15.1 | 11.3 | 7 | 20 |
| Aitbarey Dhara | 5 | 454 | 41.7 | 35.3 | 3 | 11 |
| Dokung Dhara | 7 | 349 | 41.7 | 35.3 | 4 | 17 |
| Nunthaley Dhara | 5 | 152 | 41.7 | 35.3 | 3 | 11 |
| Kharkharey Dhara | 5 | 222 | 41.7 | 35.3 | 2 | 8 |

flooding of the fields and terraced cultivation are ideal land use forms in the spring recharge area feeding their natural recharge. Wherever there is sloping land, the surface runoff is higher and there is scope for supplementing natural recharge through artificial techniques. With increasing fragmentation of landholdings, it is difficult to convince the small and marginal farmers to provide their lands for springshed development, unless some incentive-based mechanism is developed.

While constructing the artificial recharge structures is the easy part, the technical challenge lies in the accurate identification of the spring recharge area, taking into account the type, structure, and orientation of the rocks. There are 3 techniques based on watershed, geohydrology, and isotope that are currently in practice (Table 4). While the watershed technique is the traditional method of identifying the recharge area above the spring using the catchment approach, the geohydrology technique takes into account the type and structure of the rocks along with the nature and geometry of the underlying aquifers as well (Mahamuni and Upasani 2011). The isotope technique is based on the principle of variation in the isotopic composition of rainfall applied in combination with the previous 2 techniques (Shivanna et al 2008). In the current study, the geohydrology technique was adopted on account of its rapid approach, moderate level of complexity, and reasonably high degree of accuracy.

Resource mapping of the springs on a Geographic Information System (GIS) platform is essential to better understand this valuable resource, and the preparation of a village spring atlas has also been initiated. The data collected from the extensive component of the study have been made accessible online on the web portal www.sikkimsprings.org. This online database provides information on the location, GPS coordinates, land tenure, catchment status, water dependency of households, and discharge (supply/demand) of nearly 400 springs in Sikkim and is also linked to the Google Earth© platform.

## Conclusions and policy implications

With impacts of climate change and other anthropogenic causes, the problem of dying springs is palpable and visible across the Himalaya (Sharma et al 2009; Chaudhary and Bawa 2011; Chaudhary et al 2011; Tambe et al 2011). While catchment degradation was identified as the main cause for the drying up of the springs in the last century, climate change is now emerging as the new threat in the 21st century. There is a growing perception that changing rainfall patterns, attributed to climate change impacts, are adversely impacting spring discharge. Since rainwater is the only water available—and owing to its increasingly seasonal nature—the solutions will lie in storing rainwater either aboveground in natural or artificial reservoirs or underground in natural aquifers.

An integrated approach is needed to revive the whole landscape by taking up revival of hilltop lakes, critical streams, and springs and developing their catchment using rainwater harvesting watershed and springshed approaches. The springshed development approach further refines the spring sanctuary approach (Negi and Joshi 2002) by using geohydrology to identify the recharge area. In addition, an incentive mechanism is provided to the farmers (rather than barbed wire fencing), thereby facilitating the use of private lands and their conservation. This approach also differs significantly from watershed development (which adopts the catchment approach) in terms of scale, costs, duration, and treatment methods, as well as success indicators (Table 5). The most important factor is the inclusion of

**TABLE 4** Comparison of techniques for identifying the spring recharge area.

| Parameter | Technique for identifying the spring recharge area | | |
|---|---|---|---|
| | Watershed | Geohydrology | Isotope |
| Instrumentation | Low | Medium | High |
| Skills needed | Low | Medium | High |
| Costs involved | Low | Low | Medium |
| Time frame | 2–3 days | 3–5 days | 3 months |
| Accuracy | Medium | High | Very high |

the underlying geology, making it easier to base spring water management on a "geohydrological" rationale. Identification of recharge areas for springs is best rendered through a geohydrological approach, as real-world recharge spring systems do not always follow administrative or catchment boundaries.

We found that wherever springs are located in community- or government-owned lands, it was easier to undertake springshed development. Moreover, use of farmers' fields to take up the artificial rainwater harvesting works can be facilitated by providing horticulture and fodder plantations as an economic incentive. The major challenge lies in the accurate identification of the recharge area based on the principles of geohydrology, developing local level capacity, and sourcing public financing for springshed development. This springshed development approach to recharge groundwater to revive mountain springs holds promise for the Himalayan region. Water supply programs have traditionally received higher priority in public financing, but with the drying up of spring water sources, these schemes are faltering. The existing national integrated watershed management programs (http://dolr.nic.in/dolr/iwmp_main.asp), as well as the national rural drinking water programs (http://ddws.gov.in/NRDWP), may need to explore springshed development as a means to ensure sustainability of the spring water sources, especially in mountain areas. A positive step in this direction is a nationwide aquifer mapping exercise that is being planned along with mountain spring conservation for effective groundwater management.

The results of this study to revive springs show that it is possible to supplement the natural recharge of the spring aquifer by taking up artificial rainwater harvesting works in the recharge (springshed) area. The lean period spring discharge can be increased, resulting in enhanced rural water security of the local community in the dry season, thereby building resilience against climate change impacts. Considering the vital role springs play in ensuring rural water security in the Himalaya and their declining status, further action research studies need to be taken up to advance the lessons learned from this experiment. We recommend mainstreaming springshed development in programs related to watershed development, rural water supply, and climate change adaptation, especially in the Himalayan region.

**TABLE 5** Comparison of the design of watershed and springshed development programs.

| Parameter | Watershed | Springshed |
|---|---|---|
| Area coverage (ha) | 3000–5000 | 5–10 |
| Activities | Income generation, rainwater harvesting | Rainwater harvesting |
| Skills needed | Watershed, livelihoods | Geohydrology, watershed |
| Unit costs[a)] | INR 15,000 per ha | INR 30,000 per ha |
| Total cost[a)] | INR 40–60 million per watershed | INR 0.3 million per spring |
| Completion time | 5 years | 4 months |
| Outcome indicator | Multiple indicators | Discharge of spring |

[a)]1 INR = US$ 0.02.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