REVIVING DYING SPRINGS: CLIMATE CHANGE ADAPTATION EXPERIMENTS FROM THE SIKKIM HIMALAYA

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ABSTRACT

Mountain springs emanating naturally from unconfined aquifers are the primary source of water for the rural households in the Himalayan region. With impacts of climate change, manifested in the form of rising temperatures, rise in rainfall intensity, reduction in its temporal spread with a marked decline in winter rain, 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 hotspot. 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 micro-springs occurring largely in farmer's 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 litres per minute during the post monsoon (sep-nov) and then diminish to 8 litres per minute during spring (mar-may). The lean period (mar-may) discharge is perceived to have declined by nearly 50% in drought prone areas and 35% in other areas over the last decade. The springshed development approach to revive five springs using rainwater harvesting and geohydrology techniques showed encouraging results, with the lean period discharge increasing substantially from 4.4 to 14.4 litres per minute during 2010-2011. The major challenges faced in springshed development were identifying recharge areas accurately, developing local capacity, incentivizing rainwater harvesting in farmer's fields and sourcing public financing. We recommend further action research studies to revive springs to advance the learnings of this pilot, and mainstreaming of springshed development in watershed development, rural water supply and climate change adaptation programmes, especially in the Himalayan region.

KEYWORDS: *Runoff; Groundwater; Recharge; Watershed; Rainwater harvesting, Climate change adaptation*

Naturally emanating springs are the main source of drinking water in mountains

Natural mountain springs are the primary source of drinking water for the rural households. Many of these springs are considered sacred and protected as “Devithans”

Sikkim (27^0 05’ to 28^0 07’ N latitudes and 87^0 59’ to 88^0 56’E longitudes) wedged between Nepal and Bhutan is a small and beautiful state of India well known for its scenic beauty, immensely rich biological diversity manifested by diverse eco-climatic conditions and wide altitudinal variation from about 300 m to 8598 m (Figure 1). Mount Khangchendzonga (8598m), 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 as shown in Figure 2. It is a part of the Eastern Himalaya global biodiversity hotspot with 47% forest cover (Mittermeier 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. Though the Himalayan range is a source of countless perennial rivers; paradoxically, the mountain people dependent largely on spring waters 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 and revered as *Devithans* and protected from biotic interferences. Being a historically water surplus state having low population densities and high forest cover, artificial rainwater harvesting techniques for groundwater recharge were traditionally not prevalent. The rural households access water from these springs, mostly through gravity based piped systems and sometimes manually.

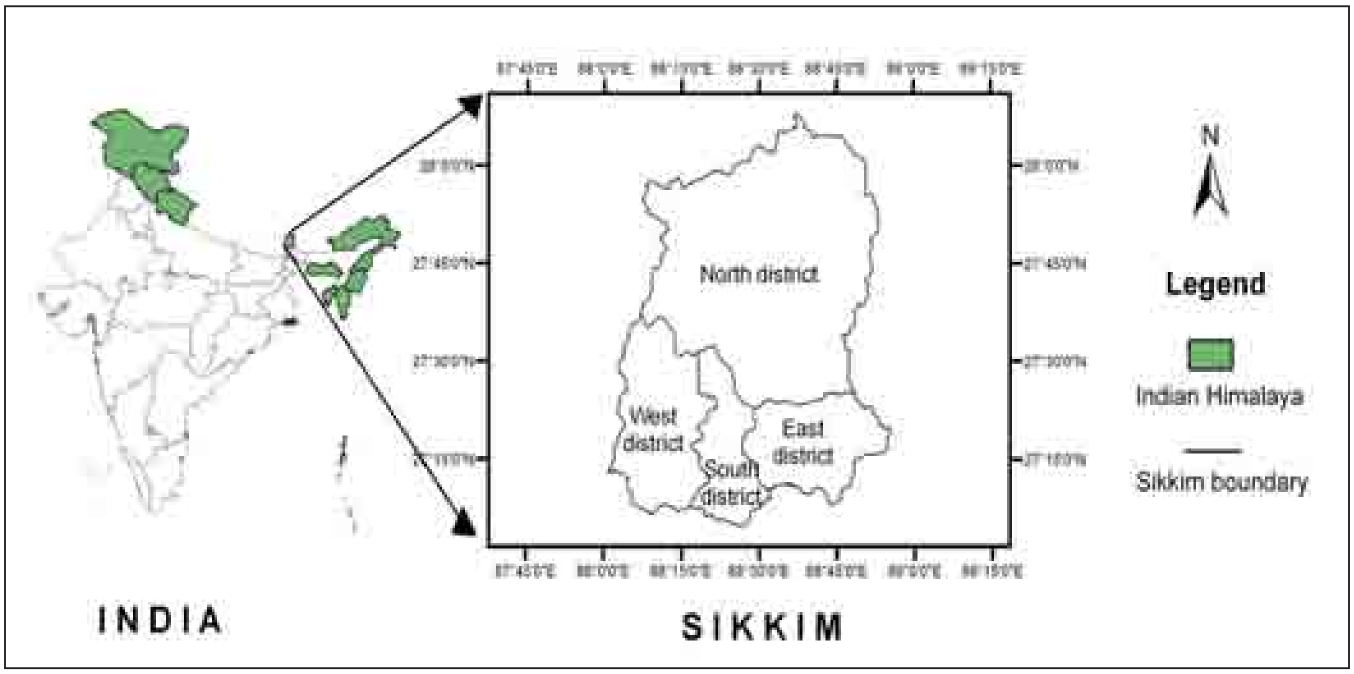


Figure 1: Inset map of Sikkim showing its location in India and as a part of the Indian Himalayan region

Sikkim Geology

The geological setting of Sikkim has been mapped in detail by the Geological Survey of India (GSI 2007). This mapping indicates that geologically the Sikkim Himalaya starts with a thin strip of rocks of the Gondwana group which are 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 are 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. Systematic mapping reveals that most of the inhabited area is covered by the Daling group of rocks and particularly by the rocks of Gorubathan formation. Further north, the Higher Himalayan Crystallines (HHC) occur (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 (Maura 2009).

Literature Review of Spring Related Studies

Intensive spring studies were taken up predominantly in the western Himalaya focussing 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; Valdiya and Bartarya 1991; Bisht and Srivastava 1995; Sahin and Hall 1996; Negi and Joshi 1996; Negi and Joshi 2004). These studies showed that the spring discharge was a function of both the rainfall pattern as well as the recharge area characteristics (Rai *et al.* 1998; Negi and Joshi 1996; Negi *et al.* 2001). At the same time, it is also 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 limited rainwater infiltrates to recharge the ground water, thereby creating a hydrological imbalance. Field experiments in the western Himalaya by Negi and Joshi (2002) to revive springs 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 like trenches, pits, check-dams and plantation of native tree species in the spring recharge area and protection by barbed wire fencing and minimizing grazing, cutting of fuelwood and grass with social mobilization to create the effect of a spring sanctuary.

Climate Change as the New Threat

The Himalayas, like many places on earth are experiencing rapid climate change that is likely to significantly impact local ecosystems, biodiversity, agriculture and human well-being (Chaudhary *et al.* 2011). 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*). Like in many other parts of the world, there is a lack of spatially disaggregated meteorological records in Sikkim. Long term, reliable data is 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; Ravindranath *et al.* 2011). Comparison of long term meteorological data available for Gangtok station (1957 to 2005), with the trend over the last five years (2006-10), shows an acceleration of these patterns, as winters are becoming increasingly warmer and drier now, with October to February being the exceptionally dry period (Seetharaman 2008).

Perception of the local community captured in the 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, an increase in the intensity, with a marked decline in winter rain. Community observations on recent climate change impacts indicate that in the subtropical belt (less than 1000 m) there is hardly any rainfall for the six 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-fourths 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 compared to the past (Chaudhary *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. Drying up of mountain springs adversely impacts rural water security and women have to reduce domestic use and travel longer distances to manually fetch water.

Present Study

Little is known about eastern Himalayan springs which play a vital role in ensuring rural water security. The objectives of the present study are twofold, first to provide a better understanding of the basic characteristics of these springs by undertaking an extensive survey and secondly in action research mode to explore if these dying springs can be revived by springshed development approach using geohydrology techniques. 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 better design the revival of mountain springs.

METHODOLOGY

Study Area Description

The state comprises of four districts, North, East, South and West. 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 average of 250 cm received in other parts of the state.
- The annual rainfall is received in a concentrated spell of 4-5 months (June-Sept), with drought like condition for 3-4 months (Jan-April).
- The steep physical terrain of the Rangit and Teesta river gorge results in high surface runoff and limited 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.

Spring Data Collection

This study undertaken during 2009-2011 has two components. In the extensive part we study 270 springs to better understand their basic characteristics, while in the intensive part we examine the response of spring discharge to artificial recharge. The location of these springs selected for the extensive and intensive study is shown in Figure 2. The extensive part comprised of a sample survey of springs distributed in the lower and middle hills in the 500 to 1800 m amsl elevation zone in all the four districts. We conducted a field survey using a standard questionnaire with the following parameters: GPS reading (latitude, longitude, elevation) of the spring source, land tenure, spring discharge, trend of lean period discharge over the last decade and household dependent.

While in the intensive study, the springshed development approach to revive five springs using rainwater harvesting and geohydrology techniques was adopted. Basic characteristic of the five springs taken up for the intensive study is provided for in Table 1. The science of groundwater known as 'hydrogeology' can lead us to a better understanding of aquifers, thus providing ways and means for its sustainable management. In mountain areas like the Himalayas, high relief and complex geological structure plays a vital role in the formation of these mountain aquifers. The extent and location of the spring recharge areas are completely governed by local

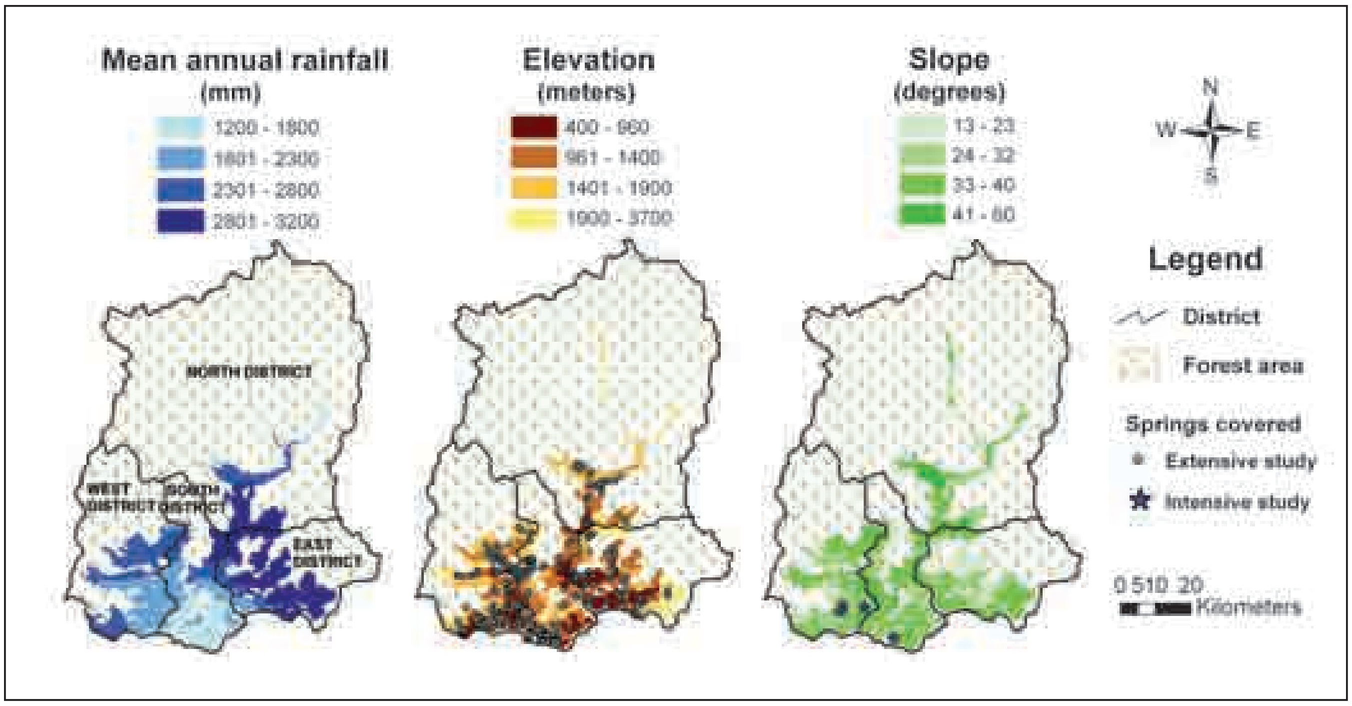


Figure 2: Map showing the spatial variation in mean annual rainfall, elevation and slope of Sikkim along with location of the springs taken up for the extensive and intensive components of the study

Table 1: Basic characteristics of springs selected for artificial recharge

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

geology and rock structure, often irrespective of catchment, administrative or landuse related boundaries many of which are "anthropogenic" divisions that are not always consistent with boundaries of natural resources such as groundwater. Hydrogeological mapping involves detailed study of rocks, streams and springs in the springshed. The type of rock(s) in an area, their attitude, openings present and the different structural features are the components that control the accumulation and movement of groundwater. In Himalayas, 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 namely 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 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 spring along with the conceptual model of the spring aquifer and the recharge area.

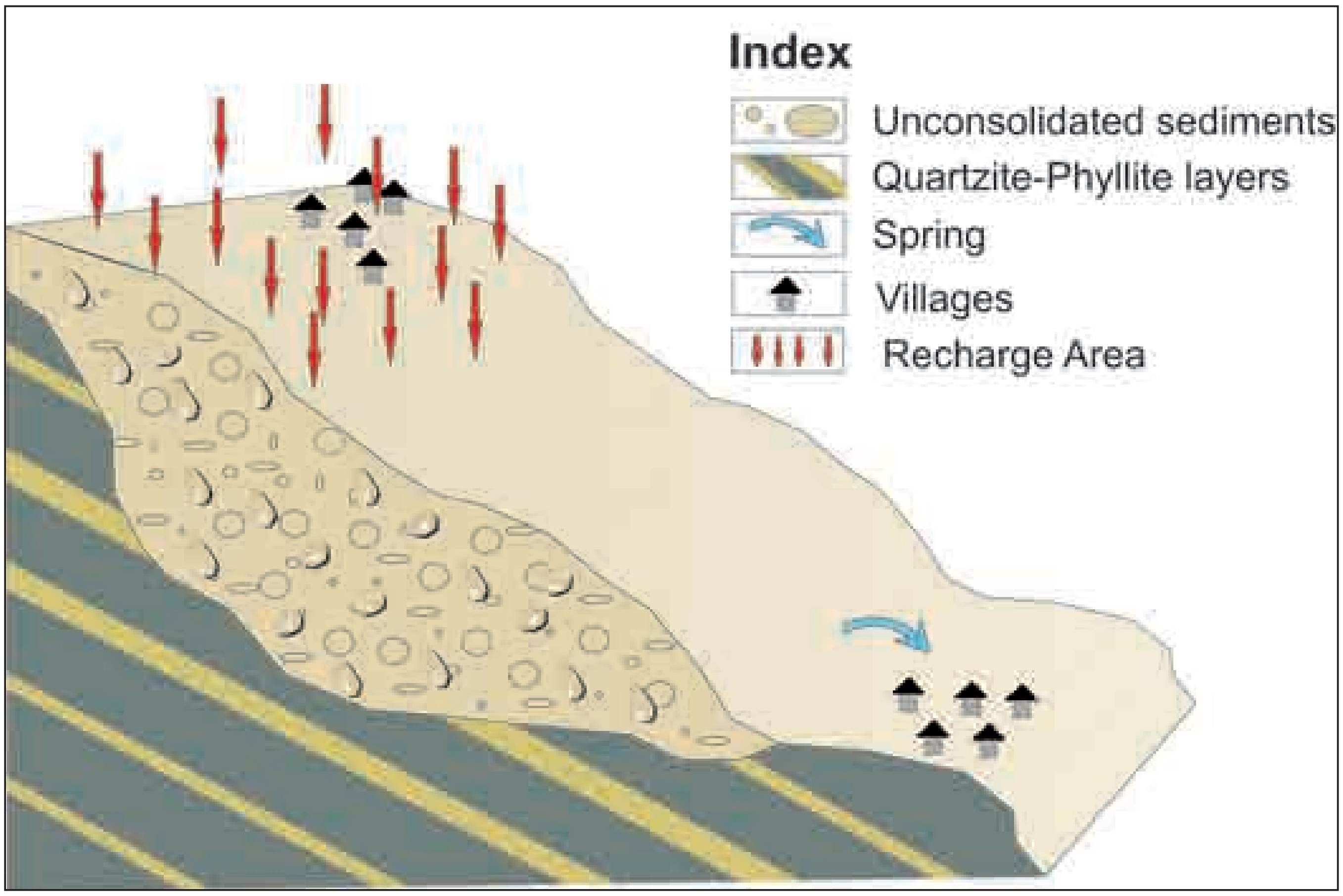


Figure 3: Map showing the hydrogeological layout of a mountain spring along with the conceptual model of the spring aquifer and the recharge area**.** The springshed is made up of alternate layers of quartzite and phyllite rocks which are overlaid by a thick deposit of unconsolidated sediments. The quartzite-phyllite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

Then the artificial recharge works were taken up in the recharge zone of the five selected springs and we studied the impact on their lean period discharge. These works taken up on sloping lands comprised mostly of rows of staggered contour trenches (2m x 0.8m x 0.6m) and percolation pits (2m x 0.4m x 0.6m) with a vertical inter-row spacing of 6m and a few loose boulder check-dams (Figure 4). In farmer's fields, economic incentive in the form of horticulture and fodder plantation was also provided (Figure 5). Recharge works comprised 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 (mar-may 2010) was taken as the baseline or control, and was compared with the lean spring discharge (mar-may 2011) after one season of groundwater recharge.

Figure 4: Artificial recharge structures comprising of rows of rectangular staggered contour trenches (2m x 0.8m x 0.6m) with square pits in between for mandarine orange horticulture plantations under construction in privately owned sloping lands in the recharge zone of Malagiri Dhara, Lungchok Kamarey Gram Panchayat, South Sikkim during May 2010

Figure 5: 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 during August 2010

Rainfall Data Recording

In 2010, 18 Automatic Weather Stations (AWS) were installed with the help of Indian Space Research Organization (ISRO), Department of Space, Government of India. The AWS records several weather parameters like temperature, rainfall, humidity, radiation, wind velocity, wind direction etc, and this weather information is directly uploaded in the website of Department of Space from where it can be accessed. Disaggregated rainfall data was obtained from these AWS which covered the intensive study sites.

Women now have to travel longer distances to fetch water, which increases their drudgery, while compromising their ability to perform other essential and livelihood functions

Limitations

In the extensive component of the study, while basic data of 270 springs was collected in sample survey mode as a onetime effort, the seasonal spring discharge data was collected on a quarterly basis. On this count, while the springs of the drought prone areas were covered adequately, those in other areas need to be further supplemented specially in terms of dry season data. The AWS are located within 5 km radius of the spring, however in mountain terrain the rainfall variation is high and having a rain gauge installed in the springshed itself will help in enhancing accuracy. In the intensive component, the quantum, pattern and intensity of rainfall are exogenous factors, which impact the spring discharge and bring in a factor of variability in the study. Though the study area received overall lesser lean period rainfall (mar-may) in 2011 as compared to 2010, however the early spring showers of 2011 (mar-apr) were higher and would have benefitted the lean period spring discharge. The full impact of the artificial recharge work will be known after 2-3 years, while the present study is based on one year's data. 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.

Drying water sources adversely affects rural water security with the households having to compromise on essential and livelihood functions to cope with the reduced supply

Labour camp established at 3000 metres in Maenam, South Sikkim to take up ground water recharge works in the upper catchment of Bermelli critical stream which is snow and rain fed and supplies drinking water to Namchi town

FINDINGS

Extensive Study

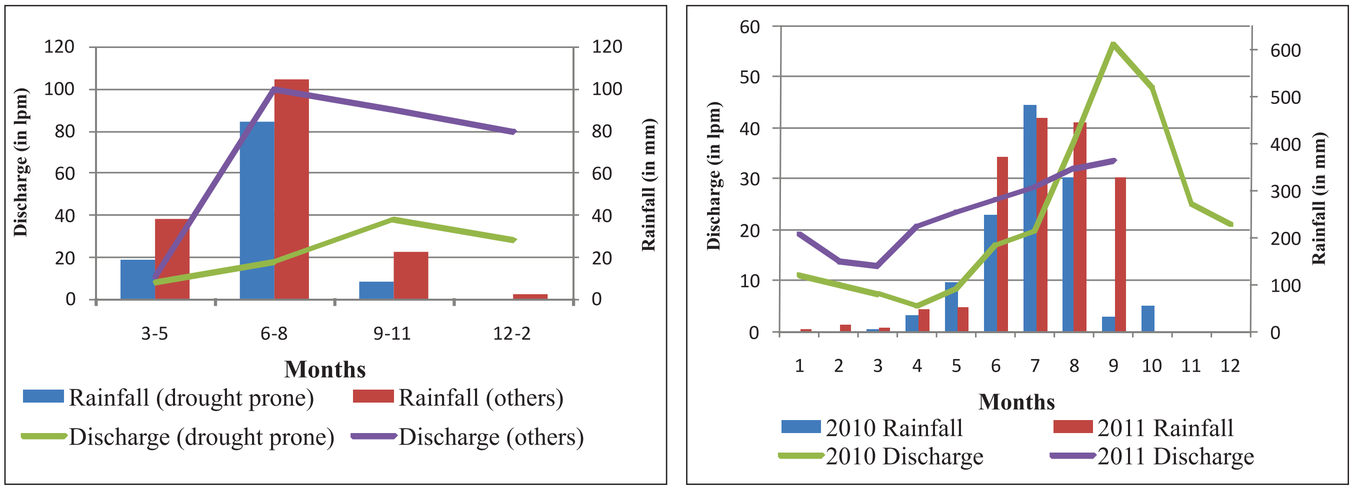
Most of the springs are located in private lands (82%) and spring water is perceived as a public resource and shared freely downstream. An extensive network of about 20 small springs ensured rural water security of a village (Gram Panchayat Unit) having an extent of 7 km^2 and comprising of 545 households with a population of 2700. On an average 27 (+ 30) households, having 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 a contact springs and karst springs occurring only rarely. The drought prone areas have a narrower spread of annual rainfall, receiving only half of the pre and post monsoon rainfall and little winter rain as compared to the other areas (Figure 6a). The mean spring discharge peaked at 51 litres per minute during autumn (sept-nov), only to decline to 37 litres per minute during winter (dec-feb) and further diminish to 8 litres per minute during spring (mar-may), followed by a spike to 42 litres per minute (jun-aug) during the monsoons (Figure 6a). The spring discharge follows an annual, periodic rhythm which 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

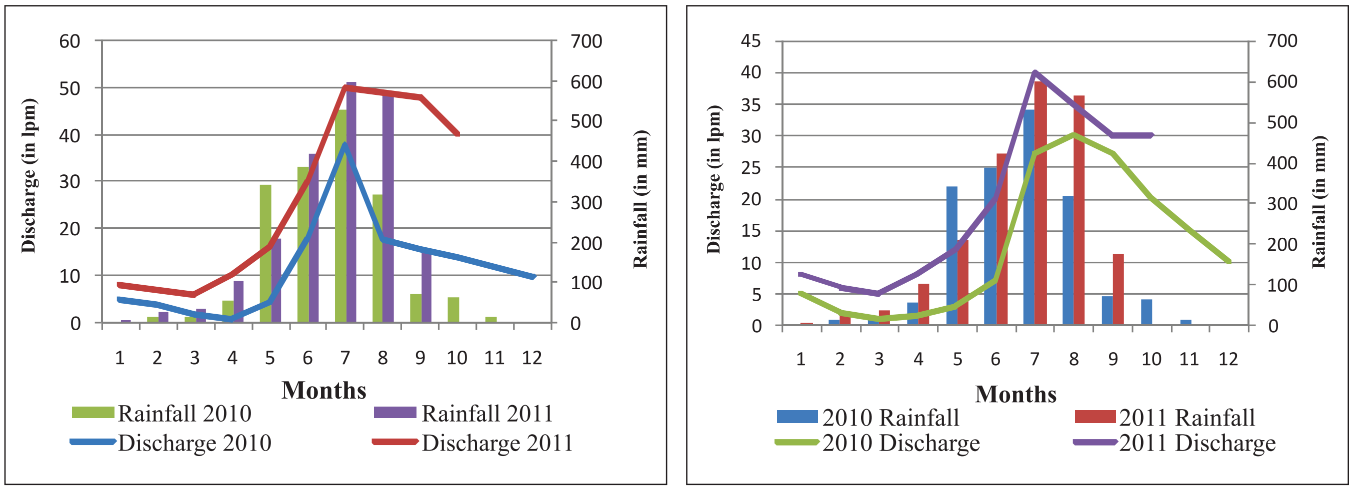
Five springs were selected in the drought prone zone of the South and West districts. These springs having depression and fracture typology, are located in the lesser Himalaya in the 975-1600 m elevation zone. The local geohydrology observed in these springsheds is low-grade metamorphic phyllite and quartzite rocks of

Figure 6: Mean hydrograph of the springs and hydrograph of five springs showing the impact of artificial recharge (taken up during Apr-May 2010) on spring discharge along with rainfall patterns during 2010-11

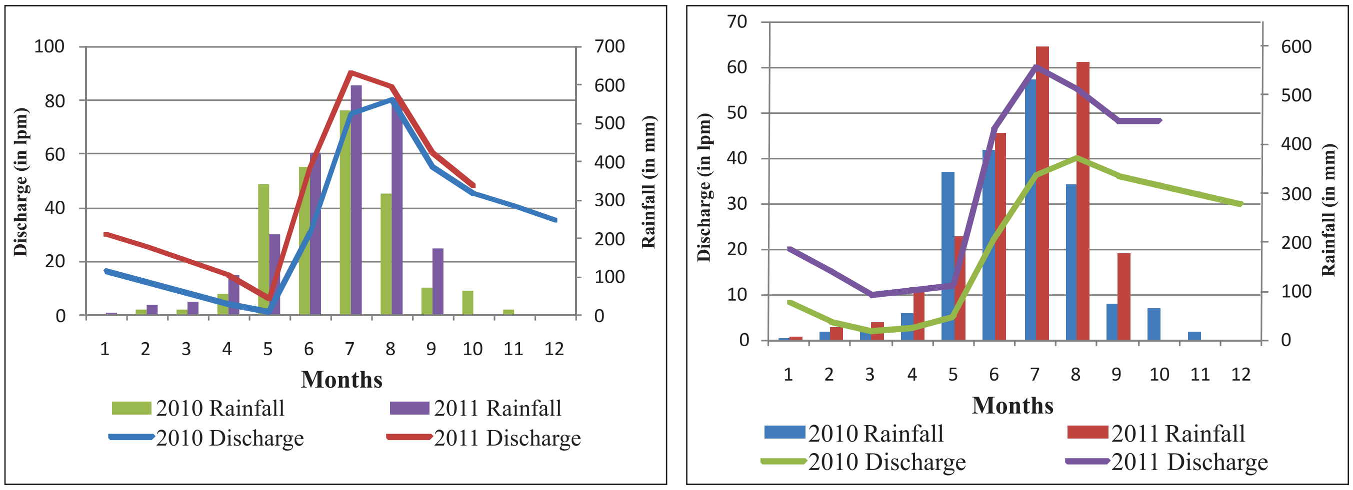
a) Mean Discharge **d) Malagiri Dhara**



b) Aitabarey Dhara **e) Kharkharey Dhara**



c) Dokung Dhara **f) Nunthaley Dhara**



the Daling group dipping north and north-west. Hydrogeological layout maps which 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 in private land, the other four springs of Kaluk block occur in community or forest land (Table 1). The lag between the peak rainfall and the peak spring discharge varied from 0-2 months. The action research component to revive these five springs using rainwater harvesting and geohydrology techniques showed encouraging results, with the lean period discharge increasing substantially from 4.4 to 14.4 litres per minute (Table 3, Figure 6). 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 pers. comm. http://sikkimsprings.org/dv/research/Final_Coulson%20.pdf, Richa Gurung pers. comm. 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 (mar-apr) of 2011, which were absent during 2010. However, the overall pre-monsoon (mar-may) rainfall in the year 2011 was less than that during 2010 (Table 2).

Table 2: 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** (litres per minute)	
	Area	**Volume (in cum)**	**mar-may 2010**	**mar-may 2011**	**mar-may 2010**	**mar-may 2011**
Malagiri Dhara	13 ha	841	15.1	11.3	7	20
Aitbarey Dhara	5 ha	454	41.7	35.3	3	11
Dokung Dhara	7 Ha	349	41.7	35.3	4	17
Nunthaley Dhara	5 Ha	152	41.7	35.3	3	11
Kharkharey Dhara	5 Ha	222	41.7	35.3	2	8

Team of young para-geohydrologists from Sikkim on an exposure visit to Uttarakhand to study the water conservation initiatives

DISCUSSIONS

The Himalayan region is blessed with adequate rainfall, but an overwhelmingly high proportion of the same is restricted to the monsoon season and adequate 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 to a sizeable chunk of the rural population. These springs are fed by groundwater and are largely recharged by rainwater infiltration. There is a growing perception that the climate change impacts, which manifest in the form of increase in temperatures, more intense precipitation patterns and longer winter drought, have further reduced the natural groundwater recharge (Tambe *et al.* 2011). This pattern of shrinking of the monsoon season and the resultant drying up of natural springs and declining discharge of streams has been recently documented in the western Himalayas as well (Rawat *et al.* 2011). Also recent studies in the adjacent Darjeeling hills indicate the perceived impact of climate change as - less snow in the mountains and intense but short episodes of rainfall increasing run-off, causing poor accumulation and recharge of water, thereby resulting in the drying up of water sources (Chaudhary *et al.* 2011). In the present study also we found a 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 farmer's fields. Paddy cultivation involving flooding of the fields and terraced cultivation are ideal landuse in the spring recharge area aiding in their natural recharge. Wherever there is sloping land, the surface runoff is higher and there is scope for supplementing the natural recharge using artificial techniques. With increasing fragmentation of these land holdings, it is difficult to convince the small and marginal farmers to provide their lands for springshed development, unless some incentive based mechanism is evolved. Springshed development of Malagiri spring in South Sikkim comprising of staggered contour trenches and percolation pits was incentivized by mandarin orange horticulture development along with broom grass fodder plantation as hedgerow. These plantations will help to provide additional income to the farmers.

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 three techniques based on watershed, geohydrology and isotope which are currently in practise (Table 3). 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 two 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.

Table 3: 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
Timeframe	2-3 days	3-5 days	3 months
Accuracy	Medium	High	Very high

Resource mapping of the springs on a 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 has been made accessible online in the webportal www.sikkimsprings.org. This online database provides information on the location, GPS coordinates, land tenure, catchment status, dependency, discharge (supply / demand) of nearly 700 springs of Sikkim and is also linked to the google earth platform.

CONCLUSIONS

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 the spring discharge. Since rainwater is the only water available, and owing to its increasingly seasonal nature, the solutions will lie in storing rainwater either above ground 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 hill-top lakes, critical streams and springs by developing their catchment using rainwater harvesting - watershed and springshed approaches. The springshed development approach further refines the spring sanctuary approach (Negi and Joshi 2002) in using geohydrology to identify the recharge area. 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, treatment methods as well as success indicators (Table 4). The most important factor is the inclusion of 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.

Table 4: Comparison of the design of watershed and springshed development programmes

Parameter	Watershed	Springshed
Area coverage	3000 - 5000 ha	5 - 10 ha
Activities	Income generation, Rainwater harvesting	Rainwater harvesting
Skills needed	Watershed, Livelihoods	Geohydrology, Watershed
Unit costs	Rs 15,000 per ha	Rs 30,000 per ha
Total cost	Rs 40 - 60 million per watershed	Rs 0.3 million per spring
Completion time	5 years	4 months
Outcome indicator	Multiple indicators	Discharge of spring during dry season

We found that wherever springs are located in community or government owned lands, it is easier to undertake springshed development. Also use of farmer's 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 lot of promise for the Himalayan region.

Water supply programmes 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 nation-wide aquifer mapping exercise which 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 Himalayas, and their declining status, further action research studies need to be taken up to advance the learnings of 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.

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