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 and a marked decline in winter rain, the problem of dying springs is being increasingly felt across this region. The objective of this study is to better understand the springs and to demonstrate methods for reviving them. The study area is dotted with 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 shows a periodic annual 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 action research experiment 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 climate change adaptation programmes, especially in the Himalayan region.

Keywords: runoff; groundwater; recharge; watershed; rainwater harvesting.

1 Introduction

Sikkim 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. 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 in shown in Figure 1. In the north, the state forms international boundary with Tibetan Autonomous Region of China, while in the south it is bordered by the state of West Bengal. The state is the catchment of river Teesta which originates from the extreme north. 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). These springs considered sacred and revered as *Devithans* were 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 by fetching water manually by women and children.

1.1 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 with occasional plant fossils equivalent to the Damuda formation of the Indian Peninsular shield. 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 which together comprise 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 Gorubathan formation. Further north, the Higher Himalayan Crystallines (HHC) occur, and are 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 & 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. The rocks of this area have been subjected to more than one phase of deformational episodes. Three generations of fold movement have been established in Sikkim (Maura, 2009). Although the regional geology is quite clear in the case of Sikkim, local variations abound. The local diversity in lithology and structure govern the occurrence and movement of groundwater within aquifers feeding springs (ACWADAM & RM&DD, 2011). Groundwater occurs in largely disconnected localized bodies under favourable geological conditions, such as jointed, fractured zones in various lithological units, weathered zones in the phyllite, schist, gneisses and quartzite. Ground water naturally oozes out from springs from major rock groups namely Chungthang, Darjeeling, Daling and the Gondwana (Misra, 2010).

1.2 Literature Review of Spring Related Studies

The discharge of these springs is a function of both the rainfall pattern as well as the recharge area characteristics (Rai *et al.*, 1998; Negi & 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 & RM&DD, 2011). Springshed is defined as the area of land which influences the discharge of the spring. This area depends upon not only the geometry and morphology of the surface catchment but also upon the geometry, spread and outcrop of underlying rocks that constitute the aquifer feeding the spring. Over the last decade increasing instances of springs drying up or becoming seasonal with reduction in the lean period discharge has been reported. With growing impacts of population increase, erosion of the top soils, erratic rainfall patterns, deforestation, forest fires and development activities (road building, building construction etc) springsheds which earlier comprised of well-forested catchments are increasingly being reduced to a few trees or bamboo clumps. Consequently limited rainwater percolates down creating a hydrological imbalance in some of the watersheds. It has been estimated that less than 15% of the rainwater is able to percolate down to recharge the springs, while the remaining flows down as runoff often causing floods. Over the last three decades, intensive spring studies were taken up predominantly in the western Himalaya focussing on aspects related to spring discharge in relation to catchment degradation and rainfall patterns (Singh & Rawat, 1985; Singh & Pande, 1989; Valdiya & Bartarya, 1989; Valdiya & Bartarya, 1991; Bisht & Srivastava, 1995; Sahin & Hall, 1996; Negi & Joshi, 1996; Negi & Joshi, 2004). The findings of these studies indicate that spring discharge shows a strong response to rainfall pattern and a healthy catchment is necessary to ensure good health of the springs. Field experiments in the western Himalaya to revive springs using engineering, biological and social measures have shown encouraging results (Negi & Joshi, 2002).

1.3 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. Weather has become unpredictable and erratic, snow is melting rapidly, and water sources are drying up (Sharma *et al.*, 2009; Chaudhary & Bawa, 2011; Chaudhary *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 indicates 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 few years (2006-09), shows an acceleration of these patterns, with winters becoming increasingly warmer and drier now (Table 1). Recent 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. The subtropical villages, especially those in the drought-prone zone are most vulnerable due to an increased outbreak of pests, diseases and weeds and the drying up of spring water sources (Figure 2). More than three-fourths of the local people believe that water sources are drying up, and 60.2% 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.

1.4 Present Study

The present study highlights the importance of springs as a primary source of water for the rural households across the Himalayas, and the alarming rate at which their lean period discharge is declining especially over the last decade. During the 20th century, several studies taken up mostly in the western Himalaya highlight the impact of rainfall patterns and catchment health on spring discharge. Climate change is now emerging as the new threat to springs and we demonstrate springshed development to revive springs as a viable climate change adaptation measure. Little is known about eastern Himalayan springs and this study tries to bridge this gap. The objectives of this present study are twofold, first to provide a better understanding of the basic characteristics of the eastern Himalayan springs by undertaking an extensive survey and secondly in action research mode we experiment if these dying springs can be revived by artificial rainwater harvesting. It is expected that the results of this action research will help to better design the revival of mountain springs and to also mainstream this approach as a climate change adaptation intervention.

2 Methodology

2.1 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 1). 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, with drought like condition for 3-4 months.
- 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.

2.2 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 (Figure 1). 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, artificial recharge works were taken up in the recharge zone of five selected springs and we examine the impact on their lean period discharge. Basic characteristics of these springs are provided in Table 2. Artificial recharge measures were taken up in the recharge area on sloping lands and 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 3). In farmer's fields, incentive in the form of horticulture and fodder plantation was also provided (Figure 4). 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 which formed the baseline, and the spring discharge was measured on a monthly basis before, during and after the intervention. The spring discharge during the dry season (mar-may 2010) was taken as the baseline for this project, and was compared with the lean spring discharge (mar-may 2011) after one season of groundwater recharge. Funding for the springshed development was sourced from the national flagship programme – Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA).

2.3 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 MOSDAC 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.

2.4 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 lean season data. Though the AWS are located within 5 km radius of the spring, however in mountain terrain the rainfall variation is high, hence in future having a rain gauge installed in the springshed itself will help in enhance accuracy. In the intensive component, the quantum, pattern and intensity of rainfall is an extraneous factor, which impacts the spring discharge and brings 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 longer-term monitoring (which is ongoing) and isotopic measurements (which are planned) to ascertain the correlation between geohydrological interpretation and interpretation from isotope techniques.

3. Findings

3.1 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 few contact springs and karst springs occurring only rarely. The drought prone areas have a narrower spread of the annual rainfall, receiving only half of the pre and post monsoon rainfall and little winter rain and as compared to the other areas (Figure 3). The mean spring discharge spiked to 42 litres per minute (jun-aug) during the monsoons and 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) (Figure 5). 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. The spring discharge follows a periodic annual rhythm which is strongly dependent on the rainfall pattern with a distinct time lag at times.

3.2 Intensive Study

Five springs were selected in the drought prone zone in 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 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 6). 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 2). 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 7-11). 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., Richa Gurung pers. comm.). While it is acknowledged that some of the locations benefited from a few early showers during the lean season (mar-apr) of 2011, which were absent during 2010.

4 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. Also rather than “gushing” surface water, groundwater oozing, trickling and flowing in the form of mountain springs ensures 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 by a few months 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 Khangchendzonga landscape show 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 that there is 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. The springshed development of Malagiri spring in South Sikkim was incentivized by supplementing the artificial recharge works of staggered contour trenches and percolation pits with mandarin orange horticulture development along with broom grass fodder plantation as hedgerow. These plantations will help to provide additional income to the farmers while aiding in springshed development as well. The investment in springshed development in this case would get enhanced from Rs 30,000 to Rs 65,000 per ha.

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 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 & 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 off its rapid approach, moderate level of complexity and reasonably high degree of accuracy.

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 currently under updation, provides information on the location, GPS coordinates, land tenure, catchment status, dependency, discharge (supply / demand) of nearly 400 springs of Sikkim and is also linked to google earth.

5 Conclusions

With impacts of climate change and other anthropogenic causes, the problem of dying springs is palpable and universally visible across the 3,000 km length of the Himalaya. 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. 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 programme differs significantly from the watershed development programme in terms of scale, costs, duration, treatment methods as well as success indicators (Table 5). 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.

We found that wherever the springs are located in community or government owned lands, it is easier to undertake springshed development. In private lands, a win-win situation needs to be explored by supplementing rainwater harvesting works with horticulture and fodder development which serve the dual purpose of livelihood support as well as a vegetative measure for springshed development. 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 approach of rainwater harvesting to recharge groundwater to revive mountain springs holds lot of promise for the whole 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, and there is felt need to revive the springs using an augmentation approach. Considering the vital role springs play in ensuring rural water security in the Himalayas, and their declining status, we recommend further action research studies to revive springs to advance the learning's of this pilot, and mainstreaming springshed development in climate change adaptation programmes, especially in the Himalayan region.

Acknowledgements

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Tables

Table 1: Percentage variation of monthly rainfall, maximum and minimum temperature averaged for the years 2006 to 2009, in comparison with long period average (LPA) for the period 1957-2005 for Gangtok station (Source: K. Seetharaman, pers. comm.)

Month	Rainfall (%)	Max Temp (^0C)	Min Temp (^0C)
Jan	-73	-0.1	2.1
Feb	-19	0.3	2.0
Mar	-25	-0.3	1.5
Apr	7	-0.6	1.4
May	-26	0.1	1.4
Jun	-8	-0.4	0.9
Jul	-10	-0.2	1.4
Aug	0	-0.3	1.0
Sep	2	-0.2	1.0
Oct	-40	-0.3	1.5
Nov	-24	-1.0	1.6
Dec	-39	-0.7	2.1

Table 2: 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

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** (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

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

Table 5: 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

Figure captions

Figure 1: Map showing the spatial variation in mean annual rainfall, elevation and slope of Sikkim (Tambe *et al.*, 2011)

Figure 2: Map of climate related vulnerability of rural communities of Sikkim, India (Tambe et *al.*, 2011)

Figure 3: 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 4: 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

Figure 5: Hydrograph showing the mean discharge of springs in the drought prone areas as compared to other areas along with rainfall pattern during the year 2010

Figure 6: Map showing the hydrogeological layout of spring along with the conceptual model of the spring aquifer and the recharge area

Figure 7: Hydrograph of Aitabarey Dhara, Kaluk block, showing the impact of artificial recharge on spring discharge along with rainfall patterns during 2010-11

Figure 8: Hydrograph of Malagiri Dhara, Melli block, showing the impact of artificial recharge on spring discharge along with rainfall patterns during 2010-11

Figure 9: Hydrograph of Dokung Dhara, Kaluk block, showing the impact of artificial recharge on spring discharge along with rainfall patterns during 2010-11

Figure 10: Hydrograph of Nunthaley Dhara, Kaluk block, showing the impact of artificial recharge on spring discharge along with rainfall patterns during 2010-11

Figure 11: Hydrograph of Kharkharey Dhara, Kaluk block, showing the impact of artificial recharge on spring discharge along with rainfall patterns during 2010-11

Figures

Figure 1: Map showing the spatial variation in mean annual rainfall, elevation and slope in the inhabited portion of Sikkim, along with the springs studied for the extensive and intensive components (Tambe *et al.*, 2011)

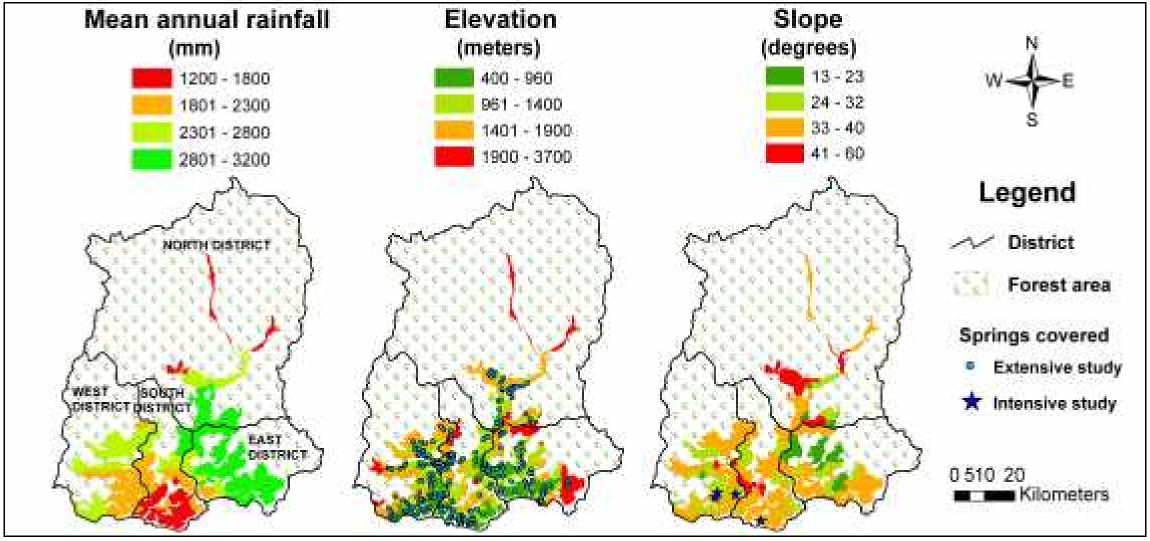
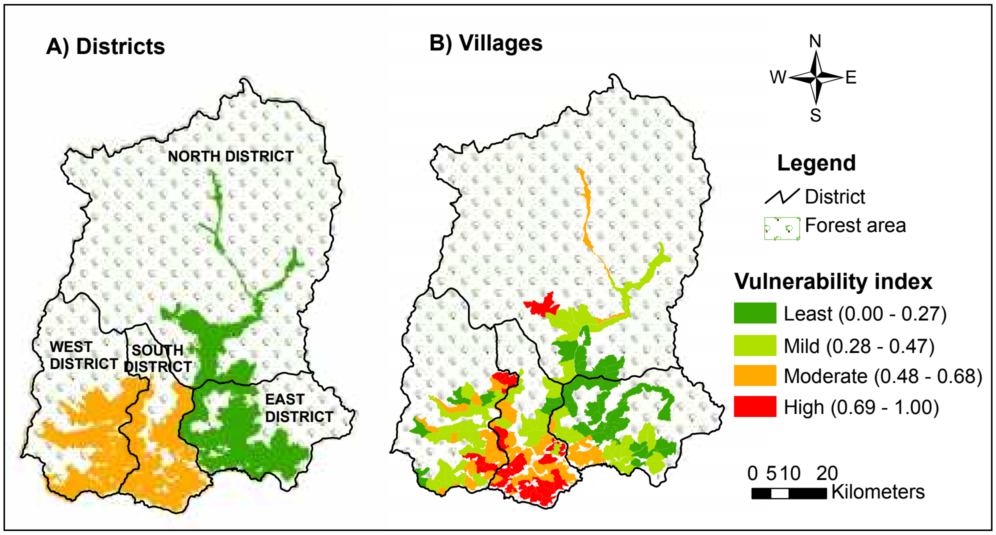


Figure 2: Map of climate related vulnerability of rural communities of Sikkim, India (Tambe *et al.*, 2011)



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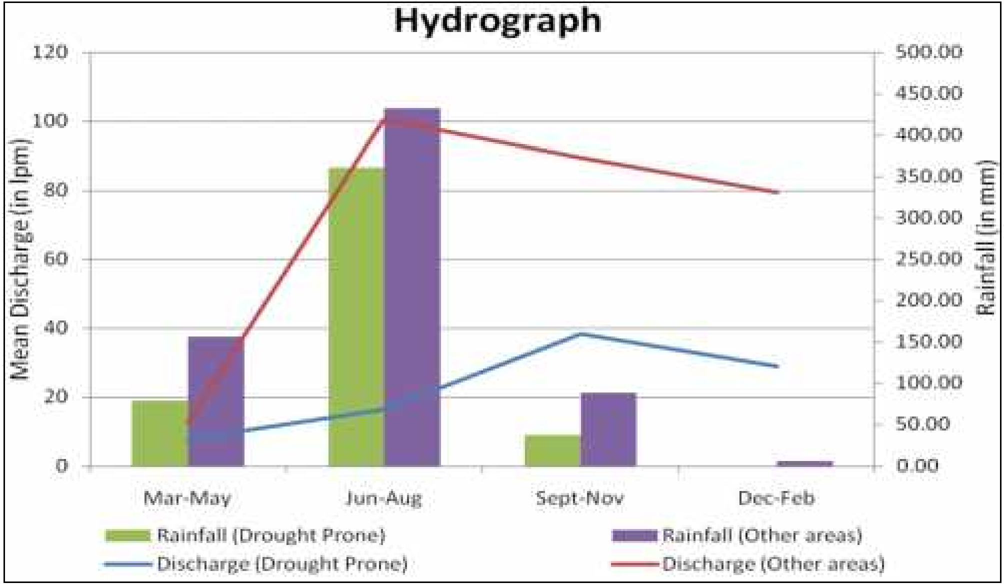

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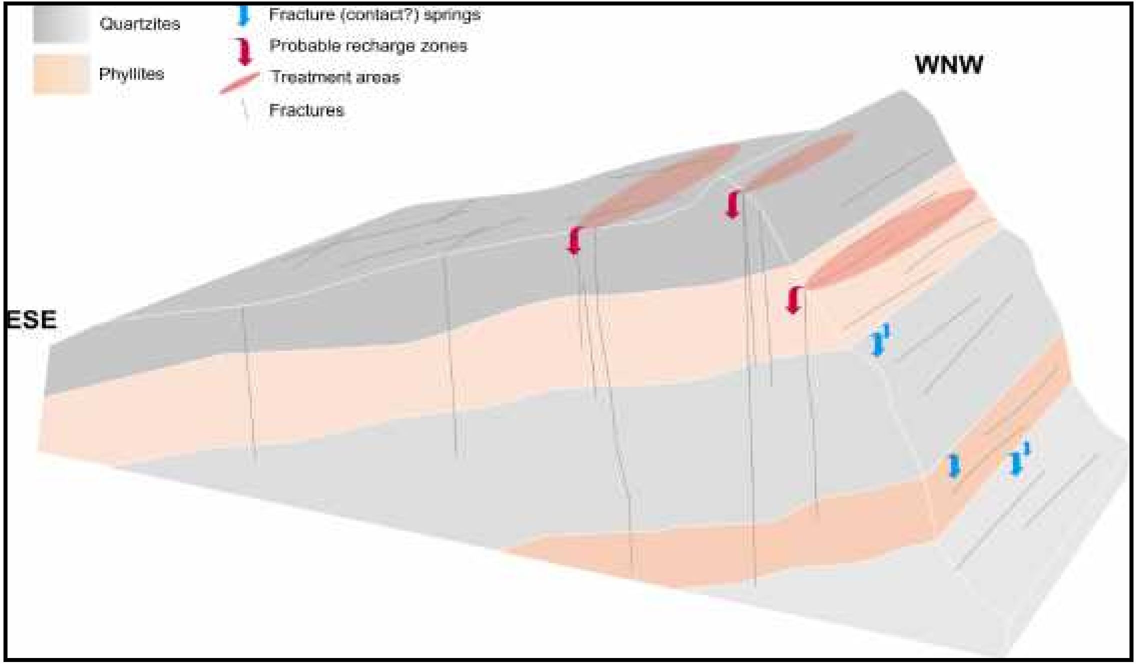


Figure 7: Hydrograph of Aitabarey Dhara, Kaluk block, showing the impact of artificial recharge on spring discharge along with rainfall patterns during 2010-11

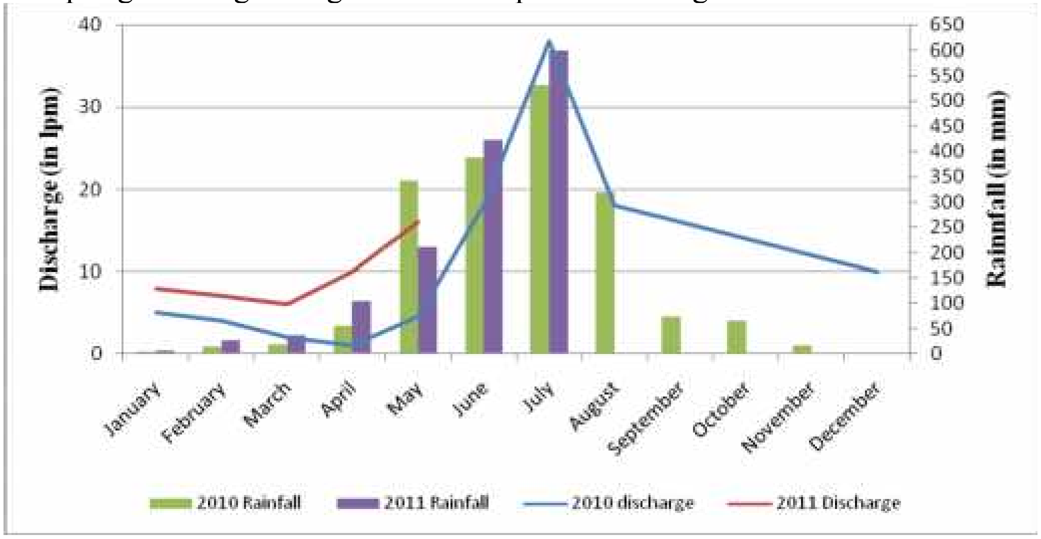


Figure 8: Hydrograph of Malagiri Dhara, Melli block, showing the impact of artificial recharge on spring discharge along with rainfall patterns during 2010-11

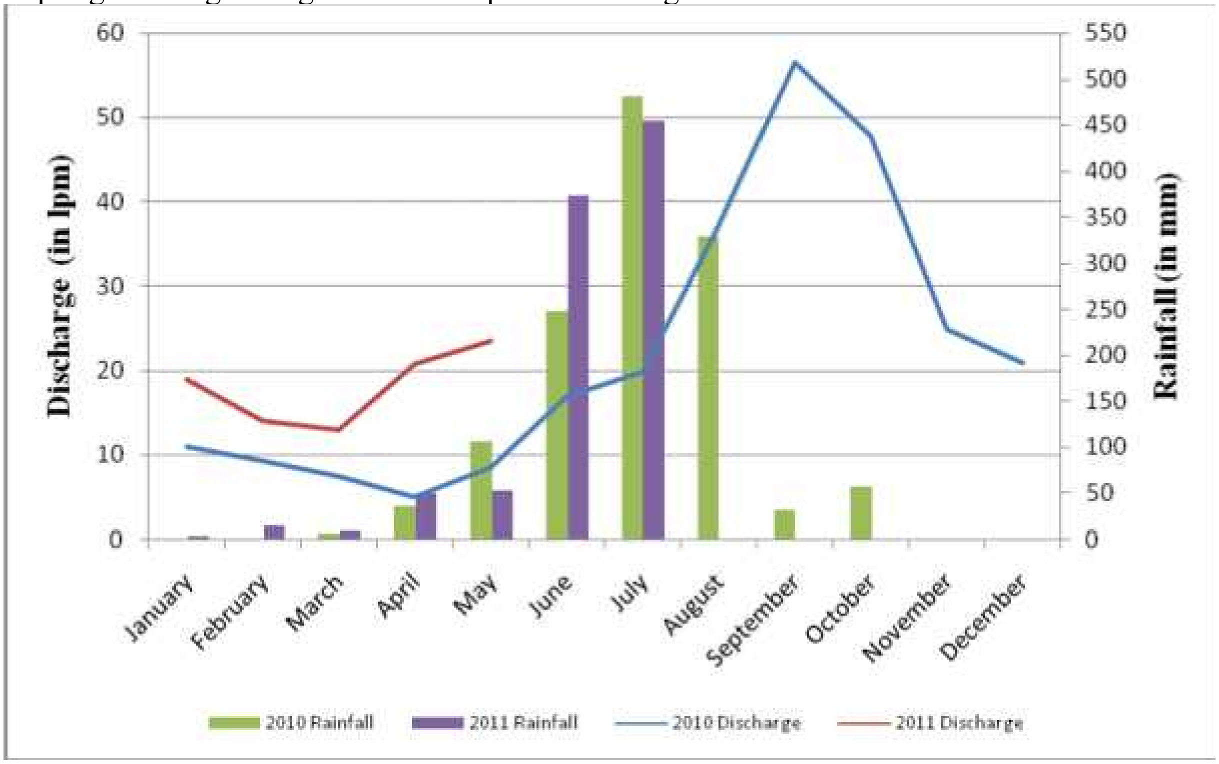


Figure 9: Hydrograph of Dokung Dhara, Kaluk block, showing the impact of artificial recharge on spring discharge along with rainfall patterns during 2010-11

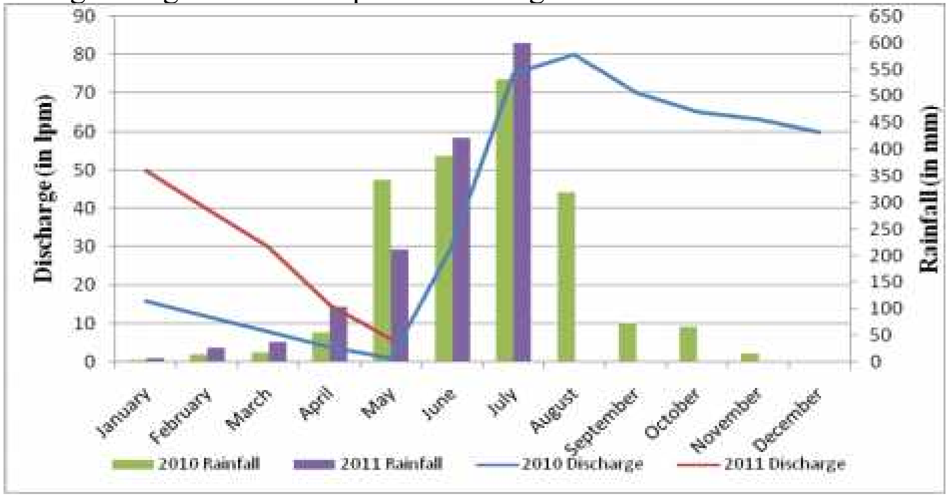


Figure 10: Hydrograph of Nunthaley Dhara, Kaluk block, showing the impact of artificial recharge on spring discharge along with rainfall patterns during 2010-11

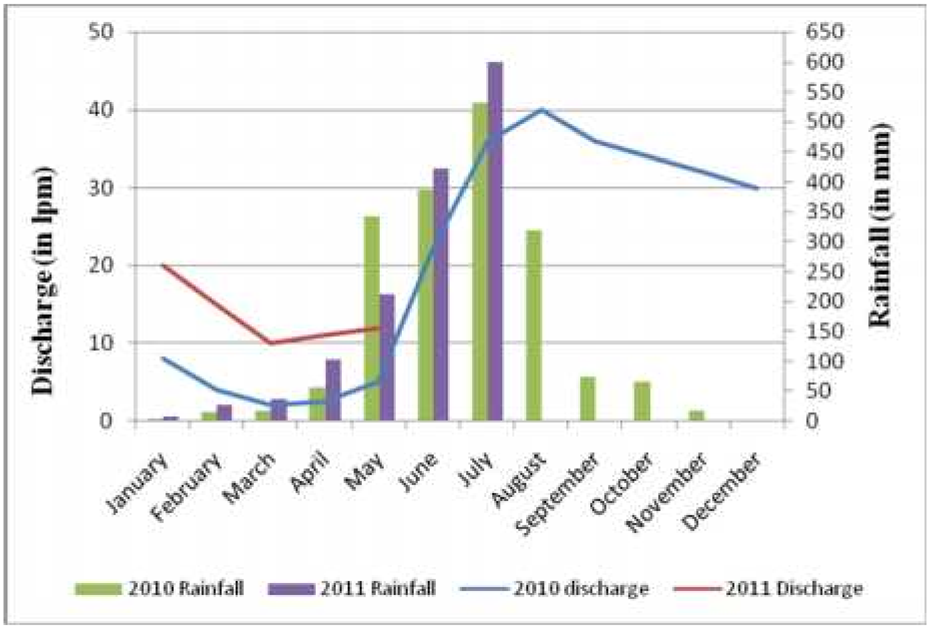
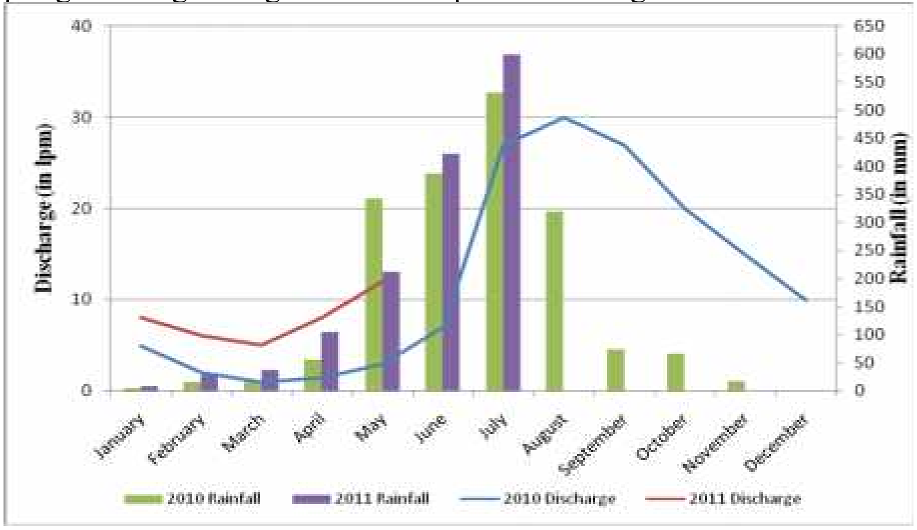


Figure 11: Hydrograph of Kharkharey Dhara, Kaluk block, showing the impact of artificial recharge on spring discharge along with rainfall patterns during 2010-11



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