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Vanishing Springs in Nepalese Mountains

Assessment of Water Sources, Farmers' Perceptions, and Climate Change Adaptation

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The Thulokhola watershed of the Nuwakot district in the midhills region of Nepal can be considered typical of climate change-related stresses in the region. To assess the status of water resources and document farmers' perceptions of and adaptation to climate change impacts in this watershed, we invited community groups to monitor water quality and conducted 6 focus group meetings, 3 participatory rural appraisals, and spring and household surveys in 2011 and 2012. Historical precipitation data from a nearby weather station and discharge data for the Tadi Khola, the nearest major river, were also analyzed. The spring survey results confirmed farmers' perceptions and showed that 73.2% of the springs used as water sources had a decreased flow and 12.2% had dried up over the past 10 or more years, as recognized by local residents. In response to the severe decline of precipitation and the drying up of springs, local communities have implemented some climate change adaptation measures, such as constructing water tanks at water sources, using pipes to transport drinking water, diverting water from other springs, digging deeper wells, and traveling farther to wash clothes and fetch drinking water. To enhance drinking water supplies and ensure the agricultural, ecological, and environmental integrity of the watershed, initiatives such as comprehensive research on springs and groundwater hydrology, a spring rejuvenation program, and community capacity building for water sustainability and climate change adaptation are suggested.

Keywords: *Farmers' perceptions; springs; water quality; climate change; hydrogeology; Nepal.*

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Introduction

Population growth and urbanization are leading to a sharp rise in global demand for freshwater for drinking, sanitation, agriculture, energy production, industry, and environmental protection (FAO 2011; WWAP 2015). But the sustainability of the freshwater supply is seriously threatened because of widespread depletion of groundwater, surface water pollution, and climate change impacts (IPCC 2007; Gleeson et al 2012; WWAP 2012). Because of declining availability of freshwater in many parts of the world, a global water crisis is possible in the near future if appropriate water conservation and adaptation measures are not undertaken.

Springs are the principal source of domestic water supply for rural communities in the Hindu Kush–Himalayan region; when they dry up or decline, the resulting water shortages become a major environmental threat (Negi and Joshi 2002; Merz et al 2003; Vaidya 2015). Tambe et al (2012) reported that over the past decade, there was a perceived decline in dry-period spring discharge of 48% in drought-prone areas and 35% in other areas of the Sikkim Himalaya. This apparently has resulted in a serious water shortage during the dry period. Negi and Joshi (2002) reported that a hill community in the Pauri-Garhwal district of India in the central Himalayan region was surviving on just 45% of its total water needs. Similarly, Agarwal et al (2014) found that a hill community in the Danda watershed of Uttarakhand in India was getting by with just one third of its total domestic water needs. This widespread water scarcity has adversely affected public and ecological health, agricultural production, and livestock populations in the entire Himalayan region (ICIMOD 2015). Solving the problem of water scarcity for rural communities is a critical policy challenge and a daunting task.

Almost 80% of the 13 million hill and mountain people in Nepal rely on springs as their primary source of water (CBS 2012; Tambe et al 2012; Sharma et al 2016). Despite the existence of vast water resources (Chaulagain 2009; WECS 2011), most rural villages and towns, as well as some cities in Nepal, are experiencing serious water shortages (Merz et al 2003). Many rural settlements in Nepal are located on the mountaintops and mountain slopes because of pleasant weather, sufficient sunshine, absence of mosquitoes, and lower incidence of diseases and parasites. In most cases, agricultural terraces are built on hillsides. Although isolated drinking water projects have been implemented across the region, many mountain communities are experiencing increasing hardship in meeting their needs for freshwater because of population growth, land use changes, and the drying up or decline of water sources. Families located near streams and rivers or in valleys are not exempt from drinking water shortages, primarily because of the degradation of surface water quality by sediments, suspended solids, organic substances, and bacteria (Prasai et al 2007; Rai et al 2012).

Numerous factors including population growth, agricultural intensification, land use changes, deforestation, economic development, and climate change impacts are responsible for water shortages (Negi and Joshi 2002; Merz et al 2003; Nellemann and Kaltenborn 2009; Vaidya 2009). In recent years, climate change impacts such as changes in the reliability of stream flow, erratic monsoons, and flooding have been pronounced (Timsina 2011); these, coupled with other anthropogenic causes, have led to serious water shortages (Tambe et al 2012). Climate change has caused degradation of natural resources and ecosystem services, shrinking of water supplies, shorter winters with earlier snowmelt, and an increase in natural hazards (Schild 2007). Other effects include increasing mean maximum temperature and changes in the timing of the monsoons (Hua 2009), as well as rapid shrinkage of glaciers (Chaulagain 2009; Shrestha and Joshi 2009). Adapting to climate change and enhancing water availability have become major issues in the region (Tambe et al 2012; Bharati et al 2014). In response, the Government of Nepal has developed the National Adaptation Program of Action (Ministry of Environment 2010), which has identified climate adaptation needs across 6 cross-cutting sectors: agriculture and food security, water resources and energy, climate-induced disasters, forests and biodiversity, public health, and urban settlements and infrastructure.

Natural disasters such as earthquakes have also severely affected water sources. For example, the 2015 Gorkha Earthquake in Nepal, which killed more than 9000 people, caused more than 5000 springs to dry up (Khanal 2016). The loss of spring water has resulted in many people leaving their ancestral villages or making long treks (sometimes of several hours) to fetch drinking water (Upadhya 2012; Sharma 2014). It is urgent to identify strategies for reversing this trend of water scarcity to prevent a human and natural disaster. This requires transformational scientific inputs from a variety of fields (eg geology, hydrology, sociology, engineering, and design), as well as an original framework for integrating them.

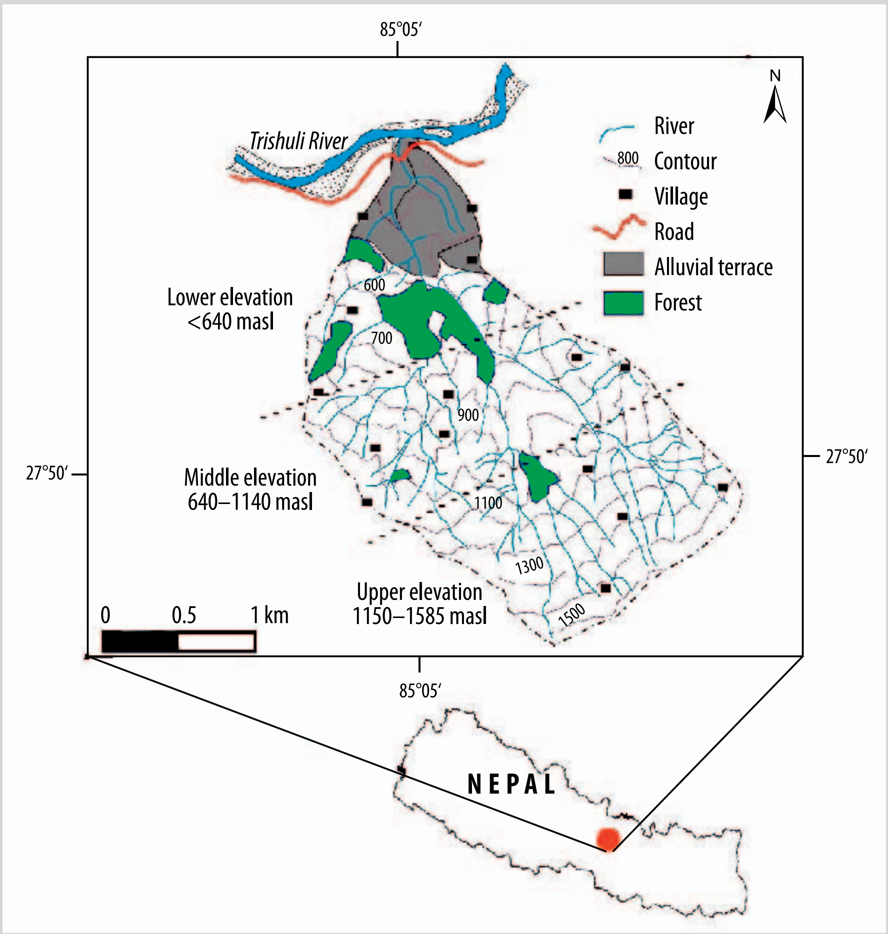
Although field research on the revival of springs in the Himalayan region began at least 14 years ago (Negi and Joshi 2002), the first full-fledged spring revival program was launched by the Government of Sikkim in 2009 (Government of Sikkim 2014). The Consultative Group on International Agricultural Research–Water, Land and Ecosystems Program funded a 2-year project titled "Reviving Springs and Providing Access to Solar Powered Irrigation Pumps Through Community-Based Water Use Planning," which is led by the International Centre for Integrated Mountain Development (ICIMOD) and is active in Nepal and India (ICIMOD 2016).

Addressing the complex issue of water shortages in rural communities requires a comprehensive understanding of biophysical, socioeconomic, and institutional settings, which is only possible by using a combination of diverse qualitative and quantitative research methods. Although there are implementation challenges, using multiple methods allows researchers to collect an array of information on cross-cutting themes in a relatively short time. This approach becomes even more relevant when data are limited and issues are complex.

Researchers have used a range of techniques and approaches to study watershed hydrology, sustainable water management, and climate change adaptation in the Hindu Kush–Himalayan region. Agarwal et al (2012) measured rainfall and spring flow and conducted regression analysis to understand the rainfall dependence of springs in 2 watersheds in the midwestern Himalayan hills of Uttarakhand in India. Bharati et al (2014) used the Soil and Water Assessment Tool to assess the impact of climate change on water availability in the Koshi Basin of Nepal. Tambe et al (2012) conducted an extensive field survey of spring sources, locations, and discharge trends; land tenure; and number of households using each source in the Sikkim Himalaya. Household surveys and farmers' participatory research are other commonly used techniques for investigating socioeconomic conditions and natural resources management (Timilsina-Parajuli et al 2014). Focus group discussions, key informant surveys, and participatory rural appraisals (PRAs) have also been used to assess farmers' perceptions, technology adaptation, resource management, climate change impacts, and community empowerment (Maikhuri et al 2011; Timilsina-Parajuli et al 2014).

This study is a part of a larger project in the Thulokhola watershed of the Nuwakot district, Nepal, active from June 2011 to January 2013, that sought to identify factors responsible for the decline of livestock production and subsequently to build community livestock capacity for climate change adaptation. Water availability is one such factor. The objectives of this study were to assess (1) farmers' perceptions and understanding of the impacts of climate change on water resources, (2)

FIGURE 1 Map of the study area. (Map by Durga D. Poudel, based on Poudel 2015, p 234)



the status of water sources in the watershed, and (3) changes in hydrometeorological trends in the region. Information generated by studies like this one can help planners develop comprehensive strategies for managing water resources such as springs, seeps, groundwater, rainwater, and surface runoff, as well as overall water use and development in the watershed.

Methods

Study area

The Thulokhola watershed (Figure 1) is located in the Nuwakot district of Nepal; it drains northward into the Trishuli River. The elevation of the watershed extends from less than 440 m above sea level (masl) at the Trishuli River to 1585 masl in the surrounding hills. The watershed has a total area of 580 hectares and contains 359 households. It is underlain by foliated metamorphic rocks that created the main Himalayas over the past 50 million years. The Main Central Thrust, a well-known Himalayan fault system, cuts through the area and has pushed higher-grade rocks, mainly gneisses, over lower-grade phyllites and related rocks (Robinson et al 2003; Searle et al 2008). These older metamorphic rocks are overlain by Pleistocene to Holocene alluvium, colluvium, and soil, which are more dominant and thicker along streams and in lower elevations.

Community livestock groups and water-quality monitoring

For the larger project, the Thulokhola watershed was divided into 3 elevation zones: lower (<640 masl), middle (640–1150 masl), and upper (1150–1585 masl). Then, 9 informal community livestock groups (CLGs) were formed across the 3 elevation zones. To identify potential CLG participants, a household list for the watershed was obtained from the Village Development Committee, and CLG participants representing the 3 elevations were selected during a stakeholder participatory meeting in June 2011. They included 27 men and 25 women; 38 of them were farmers. The groups were composed as follows:

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- Lower elevation: 81 households, 15 CLG members (6 men and 9 women);
- Middle elevation: 159 households, 21 CLG members (13 men and 8 women); and
- Upper elevation: 119 households, 16 CLG members (8 men and 8 women).

CLG members were invited to a workshop on 3 July 2011, where they learned about the project and were trained in water-quality monitoring.

For surface water monitoring, different CLGs were assigned different water-quality parameters and were given a portable LaMotte GREEN Water Monitoring Kit (LaMotte, Chestertown, MD, USA). This kit included test tablets and color charts for coliform bacteria, pH, dissolved oxygen, phosphate, and nitrate and a turbidity chart. The CLGs monitored water quality monthly from July 2011 to May 2012.

Focus groups, PRAs, and household survey

To assess farmers' perceptions of climate change impacts and adaptation, focus group meetings attended by the CLG groups and an interdisciplinary research team were conducted on 3 January 2012. The 9 CLGs were divided into 6 representative focus groups, 2 at each elevation. The interdisciplinary team consisted of 8 experts in the fields of soil science, environmental science, animal science, geology, hydrology, veterinary medicine, forestry, agriculture, and agricultural marketing. Questions related to climate change impacts, natural resources, agricultural production, and government services were asked in each group meeting (*Supplemental material,* Table S1: http://dx.doi.org/10.1659/MRDJOURNAL-D-16-00039.S1). Each meeting lasted about 1 hour and was recorded. The research team also collected field observations of climate change impacts and agricultural conditions, which were used in group discussions, problem descriptions, and interpretations of results.

To collect other (non-CLG) farmers' perceptions, a freestyle PRA was conducted in each of the 3 elevation zones on 21–22 May 2012. The PRAs were attended by 83 individuals with the following characteristics:

- *Gender:* 54% women, 46% men;
- *Age:* 22% 18–24 years, 52% 25–44 years, 23% 45–64 years, 3% 65 years or older;
- *Literacy and education:* 18% unable to read and write, 29% just able to write their names, 13% with a primary-level education (grades 1–5), 6% with a lower secondary-level education (grades 6–7), 22% with a middle secondary-level education (grades 8–10), 7% with a higher secondary-level education (grades 11–12), 4% with a bachelor's degree, 1% with a master's degree; and
- *Occupation:* 92% farmers, 8% teachers and students.

Each PRA group listed climate change impacts, ranked them in terms of severity, and then summarized their effects on water supply and agricultural production. Group members were then asked what climate change adaptation measures they had implemented on their farms and any constraints and limitations they had experienced. At the end of the session, the climate change impacts, adaptations, and constraints and limitations were summarized for the group.

In addition to the focus group and PRA discussions, 97 households (38 upper elevation, 28 middle elevation, and 31 lower elevation) were surveyed during 17–22 May 2012 to collect more comprehensive information on climate change impacts and adaptations. Households were selected for the survey from the household list obtained from Village Development Committee using stratified random sampling to ensure that all 3 elevation zones were sufficiently represented. The survey contained questions about livestock composition, fodder and forage, water sources, climate change impacts and awareness, perceptions of climate change, women's empowerment, capacity building, and livestock climate change adaptation. Survey questionnaires were developed, pretested, and administered by trained enumerators. Of the respondents, 57.7% were female and 42.3% were male.

Spring survey and hydrogeology assessment

Surveys of 41 springs in the 3 elevation levels were conducted from 17–22 May 2012. Major tributaries of the Thulokhola watershed were identified, and streams draining into these tributaries were surveyed. Spring surveys were done using topographic maps with direct participation by CLG members. Local people were interviewed with the help of field assistants who were familiar with the area so that relevant springs could be visited and evaluated. The springs were classified according to standard terminology (Fetter 2014), and changes in their flow conditions over the last 10 or more years were established by consulting local residents. Springs were divided into 3 categories:

1. *Fracture or foliation springs* come from metamorphic bedrocks where groundwater flows along fractures and foliation planes.
2. *Depression springs* issue from the younger, overlying colluvium and alluvium and flow into depressions or valleys.
3. *Contact springs* come from the contact between the metamorphic rocks and the overlying colluvium and alluvium.

Historical information on water sources was collected by questioning the nearby villagers, and the flow and geology of the water sources were visually described. Type

TABLE 1 Ranking of perceived climate change impacts by farmers in PRAs.

Rank	Upper elevation	Middle elevation	Lower elevation
1	Drought	Drought, less rain and patchy rains, extreme rain events	Drought
2	Drying up of water sources	Decline in crop productivity	Poor animal health
3	Decline in crop productivity	Poor animal health	Soil degradation
4	Crop damage by wildlife (monkeys, mice, and porcupines)	Drying up of water sources	Decline in crop productivity
5	Lack of fodder and forage	Lack of fodder and forage	Lack of fodder and forage
6	Poor animal health	Decline in livestock reproductive capacity	Drying up of water sources
7	Decline in livestock reproductive capacity	Rising temperature	Decline in livestock reproductive capacity
8	Increased workload for women	Water sources migrating downhill	Increased crop diseases and pests
9	Increased crop diseases and pests	Drying or dying forest trees	
10	Invasive plants	Poor forage and feed quality	
11	Lack of firewood	Disappearance of plant species (eg medicinal plants, orange, papaya, jackfruit, peach, and litchi)	
12	Landslides	Phenological changes in plants (eg off-season bloom in citrus)	
13	Drying out of crops	Dry landslides	

of spring, land use types, slope position, water use, and flow conditions were noted.

The hydrogeology of the Thulokhola watershed was assessed through fieldwork along several transects from lower to higher elevations. The springs were observed and their sources were determined according to the geological units present at each site. These were identified as foliated and fractured Tertiary metamorphic rocks (such as phyllite, schist, and gneiss), alluvium, and colluvium, which consists of unconsolidated fragments of various sizes from sand to gravel.

Data analysis

For household survey data, simple statistics such as mean, standard deviation, frequency, and range were calculated using JMP 8.0 software (SAS, Cary, NC, USA). All recordings from focus group and PRA discussions were transcribed and translated, and the content was analyzed and synthesized considering the impacts, sensitivity, adaptation, and limitations in relation to crop production, forest condition, animal health, animal breeding, water quantity and quality, natural hazards (landslides, flooding, and sediments deposition), soil fertility, women's empowerment, and government services and policies.

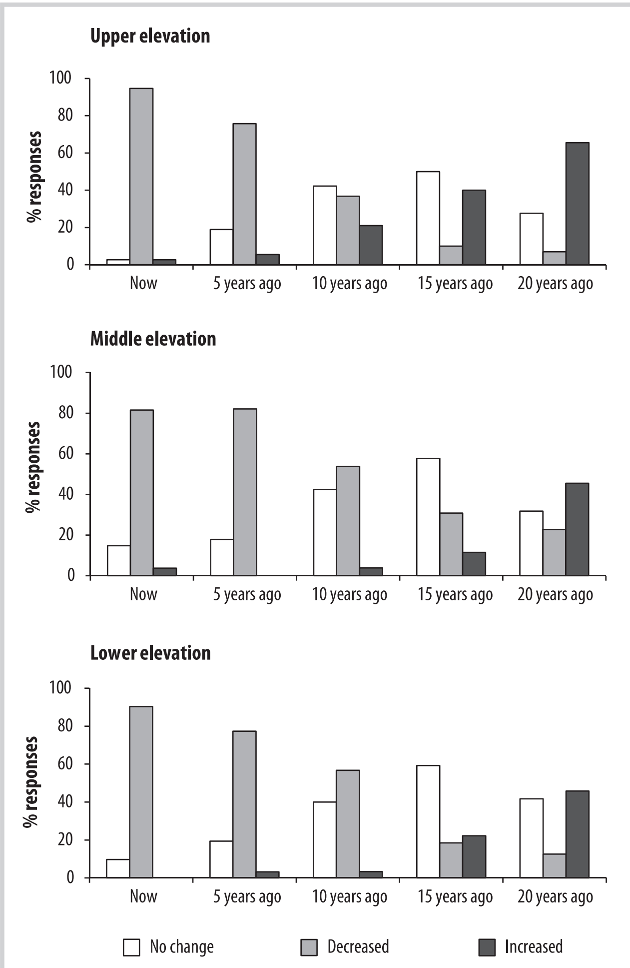
Because the Thulokhola watershed did not have precipitation and discharge data, we obtained historical (1985–2009) precipitation data for the nearby Bidur weather station, and discharge data for the nearby Tadi Khola river at Tadipul Belkot station (27°51′N and 85°8′E, 400 masl), from the Department of Hydrology and Meteorology, Ministry of Population and Environment, Government of Nepal (DHM 2016). We used Excel to calculate, for each year, the total annual precipitation, total monsoon season precipitation (defining the monsoon season as lasting from the 23rd week to the 39th week of the year), and weekly maximum precipitation, as well as the corresponding discharge values. Simple linear regression analyses of the precipitation and discharge data were carried out in JMP 8.0 (SAS, Cary, NC, USA).

Results and discussion

Farmers' perceptions of climate change impacts and adaptation

PRA participants indicated that the 5 greatest climate change impacts among the Thulokhola watershed communities were drought, declining crop productivity, poor animal health, drying up of water sources, and lack of fodder and forage (Table 1). Drought has taken a great

FIGURE 2 Perceived changes in spring flow in the past 20 years in the Thulokhola watershed.



toll on agricultural production in recent years, because farmers have been unable to plant their crops in time, which has resulted in crop failures, poor harvests, and an overall decline in agricultural productivity. Frequent droughts and their adverse effects on agricultural production and livelihoods in the region were also reported by Sharma (2015). PRA participants also mentioned inconsistent rainfall (patchy rains, less rain, or extreme rain events), delayed onset and early ending of the monsoon, and hotter summers and warmer winters as additional recent climate change impacts (Table 1).

The household survey results showed that on average, a household that was using 5 or more water sources 10 years ago has been using fewer than 3 water sources in recent years. Most respondents (94.6% in the upper elevation, 81.5% in the middle elevation, and 90.3% in the lower elevation) reported a severe decline in the flow of their water sources in recent years (Figure 2). The average number of completely dry water sources that a household had been using over the past 20 years for the upper, middle, and the lower elevations was 3.2, 2.5, and 2.3, respectively, suggesting that farmers in the upper elevation are experiencing a greater loss of water sources than farmers in the lower elevation. Many water sources that were once perennial have become seasonal. Drying up and downhill migration of water sources have made less water available for drinking, livestock, and irrigation and have negatively affected households' ability to wash clothes and maintain general cleanliness.

Because of shortages of irrigation water, farmers in the Thulokhola watershed are reducing or abandoning winter rice cultivation, which has resulted in decreased grain production. Lack of irrigation water has also affected vegetable production, which is critical for family health, nutrition, and household income.

Communities have also been exposed to natural hazards such as landslides, soil degradation, and sediment deposition on agricultural lands in recent years. Women's workloads have increased because of increased household chores and more time required to fetch drinking water, forage, and fuelwood and produce vegetable crops. Farming has become more unstable and costly, and because there are fewer chances to earn income from farming, young people are leaving the villages for outside employment, which is resulting in labor constraints on agricultural production.

Deforestation may have contributed to loss of rainfall water storage in the Thulokhola watershed, resulting in the drying up of both springs and surface water sources. During fieldwork, we noticed forest degradation and a lot of bare land in the upper elevations, with limited vegetation along the stream corridors in the watershed. Even the 2 community forests in the watershed were quite degraded, with forest floors lacking brush vegetation and leaf litter because of overgrazing by goats and overuse of leaf litter for bedding. Forest degradation in the region has resulted in water scarcity, declines in agricultural productivity, and community hardships for rural livelihoods such as shortages of timber and non-timber forest products (Bhuchar 2006). Land use changes because of increasing population may be another factor associated with declining water sources.

Local farmers have taken a number of steps to adapt to climate change impacts; these are summarized in Table 2. Among the most important steps are the following: they have made changes to their water supplies, have implemented new agricultural practices and technologies, and have started visiting veterinary clinics for their animal's health. They have also begun planting fodder trees on their farmland.

Because agriculture is the major economic activity in rural Nepal, rural communities are susceptible to climate change impacts (Park and Alam 2015). Therefore, greater implementation of climate change adaptation measures in these communities is necessary. Park and Alam (2015) suggested ecosystem-based climate change adaptation to enhance community resiliencies. In the ecosystem-based

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TABLE 2 Local climate change adaptation measures mentioned by farmers during focus group discussions.

Impacts	Adaptation measures
Drinking water shortages	Installing tanks at water sources, planting trees at water sources, traveling longer distances to fetch water and wash clothes, diverting water from another spring, installing pipes for drinking water, digging deeper wells, reducing the water supply to livestock, taking fewer baths, postponing washing clothes
Irrigation water shortages	Constructing water retention ponds, establishing a schedule to take turns accessing water, delaying rice planting, reducing the area planted to vegetables and corn, giving up winter crops, adjusting cropping sequences
Decline in soil fertility	Applying chemical fertilizers and manures, digging out terrace ridges and walls and filling in terraces, planting crops according to soil types, using unirrigated upland fields in alternate years
Landslides and flooding	Planting trees, erecting stone walls and wire retainers, worshiping the snake god, using sandbags, leveling areas with sediment deposits and bringing them back into cultivation after applying fertilizers and manures
Deforestation and forest degradation	Conserving existing forest and reforesting degraded forest, planting trees along stream banks and on the edges of fields, traveling farther for forest products (fuelwood, fodder, leaf litter, and forage), ceasing to raise livestock or reducing their number because of lack of forage, planting trees on privately owned land, planting fodder trees on terrace ridges and the edges of fields, practicing community forestry
Decline in crop yields	Using hybrid seeds, using chemicals for disease and pest control, using traditional methods for pest and disease control, introducing winter crops, increasing the area under cereals
Poor livestock health because of diseases and parasites	Buying medicine, consulting a private veterinarian, providing good feed to animals, applying traditional treatments, vaccinating goats for PPR *(peste des petits ruminants)*
Delayed pregnancies in cattle, goats, and buffalo	Simply keeping animals for an extended time hoping for pregnancies, administering medicine, using traditional local remedies, selling goats and buffalo for slaughter

approach, which is people centered and emphasizes natural or ecological solutions, local communities use biodiversity and ecosystem services in climate change adaptation. In this context, local communities in the Thulokhola watershed can develop and implement comprehensive strategies for watershed management, soil and water conservation, agroforestry, reforestation, spring rejuvenation, and livestock management.

Springs, hydrogeology, and water quality

Confirming the results of the household survey, the spring survey results showed that 73.2% of the springs used as water sources had an observed decreased flow and 12.2% had dried up over the past 10 years or more (*Supplemental material,* Table S2: http://dx.doi.org/10.1659/MRDJOURNAL-D-16-00039.S1). Other reports also suggest that 15 to 30% of springs have dried up in the last decade in 2 other midhill watersheds in Nepal (ICIMOD 2015). Of the surveyed springs, 78.1% were used for household drinking water and the rest were used for irrigation and other purposes, such as fish ponds. The primary land use types around the springs were forest (53.6%), cropland (34.1%), and brush (12.3%).

Hydrogeologically, there are 2 main types of aquifers or flow systems, a regional and a local system, in the Thulokhola watershed (Figure 3). The regional flow system is present in the foliated Tertiary metamorphic rocks and flows along foliation and fractures. Groundwater moves slowly through the metamorphic rocks, because they have low porosity and permeability, and emerges as foliation or fracture springs. The local flow system is found in the younger sediment and debris of the Pleistocene and Holocene deposits that are superimposed on the older rocks; it tends to have higher porosity and permeability, and hence water flows more rapidly in it and emerges on the surface as depression and contact springs. Groundwater flowing from the contact between the 2 rock bodies comes to the surface as contact springs. Contact springs were the most consistent, dependable, and productive, whereas the foliation or fracture springs had the smallest volume. Depression springs showed the greatest decrease in output over the last 10–20 years.

Beside natural processes, groundwater and springs can be recharged in various ways, including through artificial ponds and tanks, temporary runoff collection areas, injection wells, channeling rainwater into the ponds, flooding of agricultural lands during fallow periods (Shrestha 2009; Vaidya 2009; O'Geen et al 2015), or

FIGURE 3 Idealized model of the hydrogeology of the Thulokhola watershed. (Sketch by Durga D. Poudel)

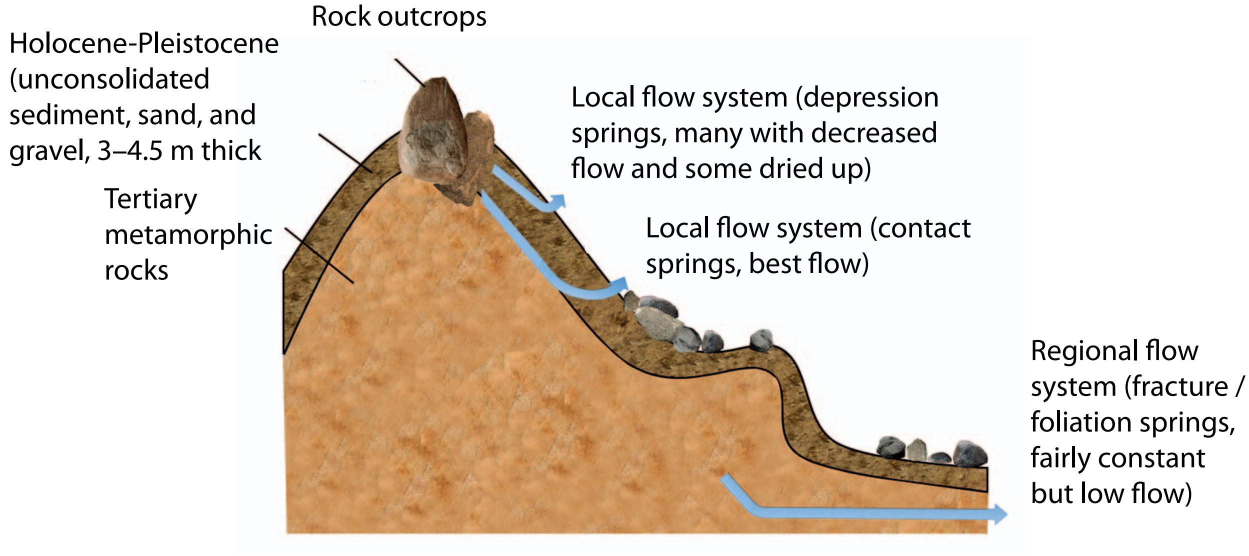

TABLE 3 Water-quality monitoring data for the Thulokhola watershed, July 2011–May 2012.[a), b), c)] (Table continued below.)

Elevation	Dissolved oxygen (n = 44) Excellent (91–110% saturation), good (71–90% saturation), fair (51–70% saturation), poor (≤50% saturation)	Turbidity (n = 22) Excellent (0 JTU), good (>0–40 JTU), fair (>40–100 JTU), poor (>100 JTU)	pH (n = 33) Poor (4, 5, 9, 10, 11), good (6, 8), excellent (7)
Upper	All 11 excellent	NA	All 11 good
Middle	All 22 excellent	8 good and 3 poor	All 11 good
Lower	All 11 excellent	6 good and 5 poor	All 11 good

a) Because of unavailability of thermometers, water temperature was not measured. Water temperature was assumed to be >22°C for the calculation of dissolved oxygen percentage saturation even during winter because of transportation, sample preparation, and handling.
b) Differences in sample sizes were because of differences in the availability of test kits and sampling design.
c) JTU, Jackson turbidity units; NA, not available.

TABLE 3 Continued. (First part of Table 3 above.)

Elevation	Phosphate (n = 44) Excellent (0–1 ppm), good (2 ppm), fair (4 ppm)	Nitrate (n = 44) Fair (5 ppm), poor (20–40 ppm)	Fecal coliform bacteria (n = 97) Negative (good), positive (poor)
Upper	All 11 good	All 11 fair	All 32 positive
Middle	15 good and 7 fair	16 fair and 6 poor	All 32 positive
Lower	7 good and 4 fair	8 fair and 3 poor	All 33 positive

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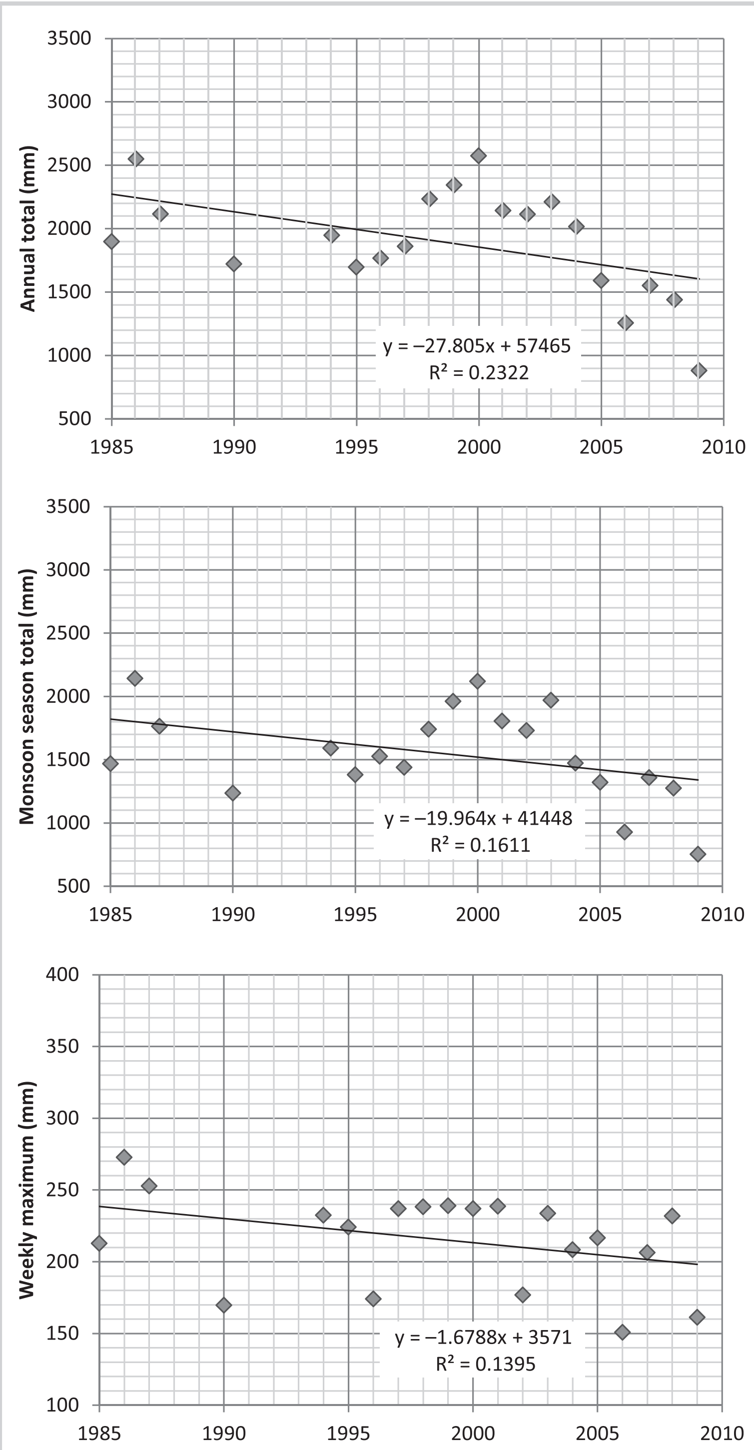
FIGURE 4 Precipitation trends in Nuwakot district, 1985–2010. (DHM 2016)



creating ponds in the recharge zones filled with gravel and stone (Fetter 2014).

The problem of water shortages is aggravated by poor water quality (Table 3). Water samples collected by CLG members showed high rates of fecal coliform contamination and problematic turbidity and nitrate levels. Higher phosphate levels occurred from July through October only in the middle and the lower elevation zones. Turbidity levels were high for July–September in the middle elevation and for July–October and February in the lower elevation. Nitrate levels were high in August–October in the middle and the lower elevations. Dissolved oxygen levels were excellent, and pH levels were acceptable throughout the year.

Baseline information on water quality, captured with a portable LaMotte GREEN Water Monitoring Kit at the outlet of the Thulokhola watershed on 3 July 2011, also showed fecal coliform, poor turbidity and nitrate conditions, and fair phosphate conditions. These results suggest poor surface water quality because of sediments, nutrients, and pathogens in the watershed. The higher fecal coliform, nitrate, and phosphate concentrations may be due to inappropriate manure collection techniques and the use of chemical fertilizers in the watershed. Aryal et al (2012) also reported fecal coliform contamination as a major problem in drinking water in the nearby Mygdi district. Therefore, sufficient attention to non-point-source pollution control, especially during the rainy season and the months with agricultural activities, is necessary to ensure improved surface water quality.

Precipitation and river discharge

Confirming farmers' perceptions of declining annual precipitation, regression results from the precipitation data showed a statistically significant decline in total annual precipitation, total monsoon season precipitation, and weekly maximum precipitation from 1985 to 2009 (Figure 4). A remarkable decline in the monsoon precipitation by as much as 30–40% from the 1960s to the 2000s has also been reported for the upper Sutlej area in western Himalaya (Collins et al 2013). In the Nuwakot district, while the total annual precipitation from 1985 to 2000 fluctuated between 1600 and 2500 mm/y, it decreased from about 2573 mm in 2000 to 882 mm in 2009. Our fieldwork took place during a drought (17–23 May 2012). Analysis of the monthly precipitation data also indicated that the monsoon season is shrinking and the winter months (October–February) are becoming drier, especially since 2006. While rainfall was generally well spread from May through September in the past, most rainfall in recent years occurred in June, July, and August. Changing precipitation patterns across the Himalayan region will affect water resource availability and livelihoods not only for the population in the region but also for people downstream (Miller et al 2012).

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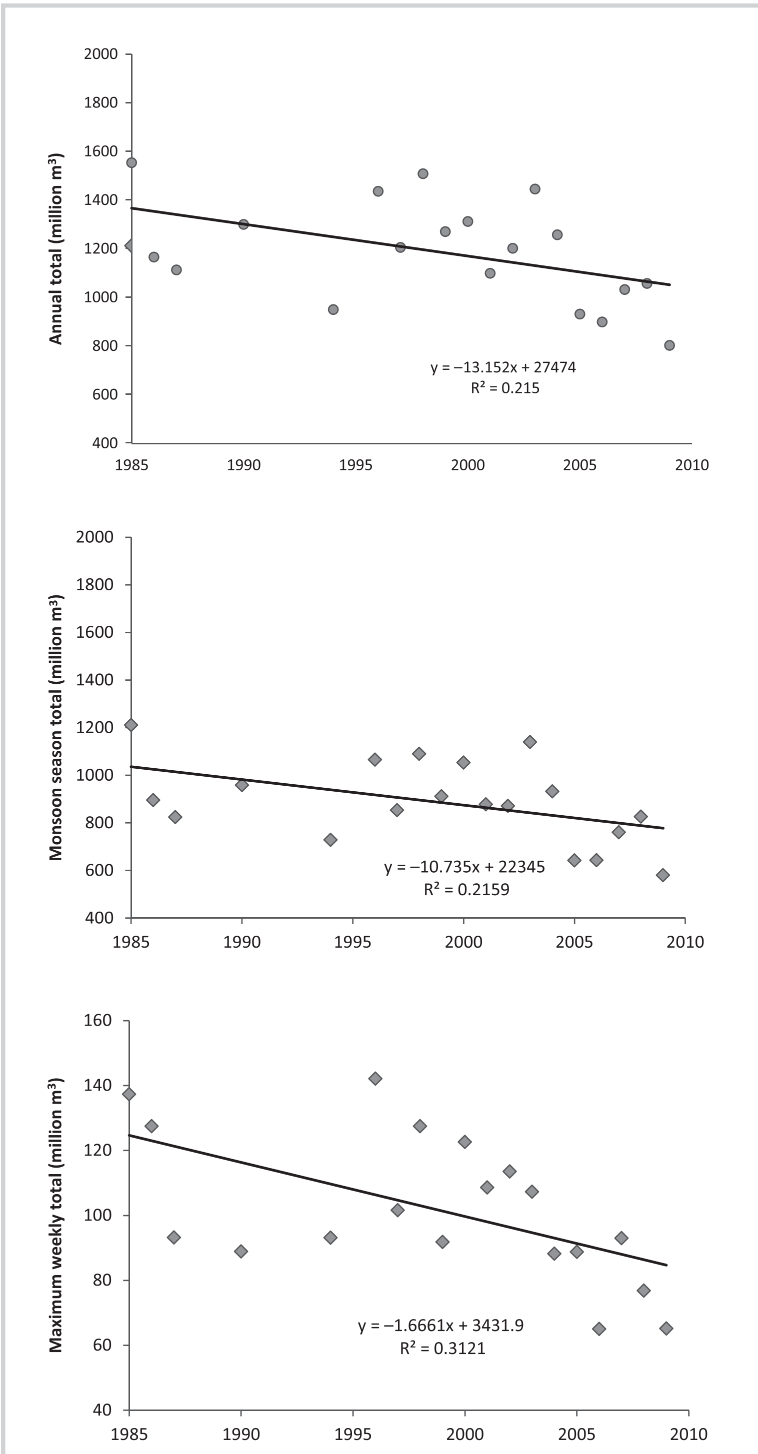
FIGURE 5 Discharge trends for the Tadi Khola, 1985–2010. (DHM 2016)



In line with the declining precipitation trends, the regression results for the total annual, total monsoon, and weekly maximum discharge for the Tadi Khola also showed significant decline from 1985 to 2009 (Figure 5). The Tadi Khola originates in the higher mountains in Nepal and has a catchment area of 653 km^2 (Sharma 1993; Shrestha et al 2010; ESSA Technologies 2014). While monsoon precipitation constitutes the major source of discharge water for the Tadi Khola, it is also fed by groundwater, springs, and snow and glacier melt. Researchers have estimated that the contribution of snow and glacier melt to river discharge is as high as 34% annually and 63% premonsoon (spring months) in the Koshi basin of eastern Nepal (Nepal 2016) and 35% in winter, 18% in summer, and 19% annually in the Langtang basin to the north of the watershed in Nepal (Bhattarai and Regmi 2015).

Although establishing a direct relationship between springs drying up and hydrometeorological conditions in the Thulokhola watershed was not possible because of lack of data, the precipitation and discharge trends presented here provide a general view of regional hydrometeorological conditions. Future research in the watershed would be necessary to refine these relationships.

Conclusion and policy recommendations

Springs are the primary source of water for local communities, livestock, and agricultural and environmental uses in a mountain watershed. Drying up of springs because of changes in hydrometeorological patterns and land uses has become a major concern for communities in the region. As perceived by local communities, precipitation is decreasing significantly, severely affecting the drinking water supply, agricultural production, and ecological health. Impairment of surface water quality because of pathogens, nutrients, and sediments further limits the availability of drinking water for humans and livestock.

To address the challenges of declining water sources in a mountain watershed, we make 3 policy recommendations: (1) conducting comprehensive multidisciplinary research on mountain geohydrology, geochemistry, structural geology, and socioeconomics for better understanding of these complex systems with regard to the impact of climate change and natural hazards on water sources, livelihoods, and local communities; (2) launching watershed-scale spring rejuvenation programs targeting depression and contact springs by involving local communities, government agencies, and other stakeholders based on the knowledge generated from the multidisciplinary research; and (3) building community capacity for water sustainability and climate change adaptation.

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Dedication: We dedicate this research article to Dr. Eldred Griffin Blakewood (13 March 1960–26 May 2014), our esteemed friend and a member of the faculty of the Environmental Science Program in the School of Geosciences at the University of Louisiana in Lafayette. Dr. Blakewood visited the research site in the Thulokhola watershed of the Nuwakot district in Nepal in January 2012. He passed away on 26 May 2014 at the age of 54. Dr. Blakewood had a great passion for the environment, social justice, and brotherhood. He loved the people of Nepal and felt welcomed here.

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Supplemental material

TABLE S1 Focus group discussion questions.
TABLE S2 Characteristics of water sources in the Thulokhola watershed.
All are found at http://dx.doi.org/10.1659/MRD-JOURNAL-D-16-00039.S1 (33KB PDF).