Spring Revival through Sustainable Land Management (SLM) in the Himalayan Foothills: Uttarakhand, North India

Springs are the blue "life-points" in the mountains and lowlands. Women and children collect spring water from a 1,000 year-old water harvesting structure, the *Naula*. Bhurmuni Village, Gorang Valley, Uttarakhand (Photo HP Liniger).

Key Messages :

- Of the estimated 3 million springs in the Indian Himalayan Region (IHR), roughly 60% have dried up or become seasonal.
- Land use changes related to the overexploitation of natural broad-leaved forests and encroachment of pine forests has been identified to be the core reason for depleting spring flows. Climate change is further exacerbating the situation.
- Springshed protection through community forest management (*Van Panchayat*) and conservation of broadleaf forests can stabilize and rejuvenate spring flows to communities.
- Additional spring recharge interventions through water harvesting, infiltration ponds and trenches are labour demanding, but can contribute to support the restoration of vegetation cover and recharging of ground / spring water.
- There is an urgent need to further identify, assess and disseminate effective springshed management approaches and technologies.

Introduction

The "Water Towers of Asia" are characteristic of the sacred, water-rich Hindu Kush Himalayan (HKH) region, which directly support a population of over 240 million people. Between 60-80% of the population is estimated to depend on springs as a source of water for drinking, domestic purposes, sanitation and general livelihoods[2]. However, of the estimated 3 million springs in the Indian Himalayan Region (IHR), roughly 60% have dried up or become seasonal in the past two decades[2]. The phenomena of drying up springs may also have serious consequences not only for mountain communities, but also for downstream populations who depend on spring contributions to river flows. Land use change intensified by climate extremes have been identified to be the main cause for the drying up of springs. However, there are promising sustainable land management (SLM) solutions that can rejuvenate mountain springs in rural communities of the Himalayas.

Spring into Action

The neglect of springs in the larger context of rivers, watersheds and aquifers has led to large gaps in practice and policy in developing any strategic national response to spring water management. The Indian Government recently reacted to this growing crisis by forming a joint Union Ministry, Jal Shakti (Water Power), which is a collaborative effort of the central and state governments to accelerate progress on water conservation activities in the most water stressed districts of India. Jal Shakti has promised to disseminate a comprehensive plan for spring rejuvenation across the country. This includes the mapping of springs and springsheds, establishing a data monitoring system, as well as developing springshed management and governance protocols through consultative processes with stakeholders and land users[5].

There have been collaborative efforts from various institutions, NGOs and researchers to work jointly with land-users on spring restoration (e.g. ICIMOD's Eight-step Methodology for Spring Revival 2017, Working Group Niti Aayog's 2018 Report — Inventory and Revival of Springs in the Himalayas for Water Security). Hydrogeological mapping, identifying springs and establishing structural technologies (recharge trenches, ponds, check walls, and check dams) requires sufficient technical expertise, intense manual labor and maintenance. Such structures alone have not been proven sufficient for long-term spring recharge, hence experts recommend the combined restoration through afforestation and forest fire protection[6.] However, the physical and ecological aspects of spring hydrology are still poorly understood and insufficiently documented, as are the social, cultural and economic aspects related to changing water demand and use[1]. In response to growing demands, the Indian Government recently initiated a pilot project for spring inventory and rejuvenation in the northern Indian State of Uttarakhand.[7]

Importance of Springs

For thousands of years people in the HKH region have preferably relied on springs to meet their daily needs. Even today, an estimated 260,000 springs provide about 90% of the drinking water to 10.3 million people in Uttarakhand[3].

Figure 1. Local spring water gathers in a Naula, the sacred and traditional water harvesting technology of the Kumaon Region in the Himalayas. Villagers value the protection and care for the Naula, as it represents deities like Lord Vishnu, Ganesh, Sun, Earth, and Moon. Nakina Village, Pithoragarh, 2019 (Photo: HP Liniger)

Springs are the "blue life-points" for the rural communities in the Himalayan region, as they the main source of water for the household, irrigated agriculture and livestock production. Although the area of cultivation has decreased, agriculture and animal production still serves as the main source of income for about 70% of people in the Himalayas[3]. However the majority of the population relies, in one way or another, on the wealth of resources from forests (for fuel, fodder and timber). Forests remain socially and environmentally interlinked with the people in the hilly areas, as well as play an important role in the economic welfare and development of the region. The jungle (Hindi: forest) is attributed by local communities as the foundation for groundwater recharge and spring sanctuaries

Uttarakhand State's Water Crisis – the drying up of Springs

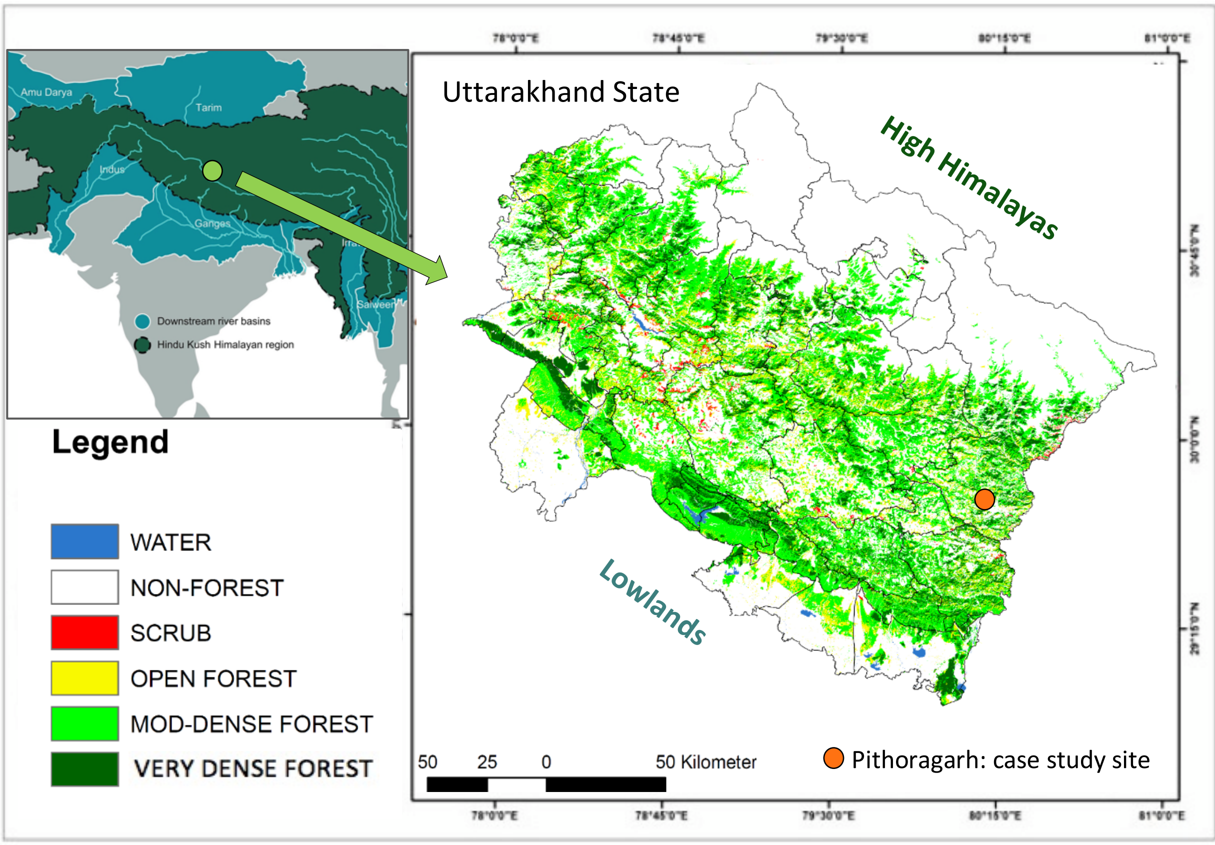


Figure 2. Map of the northern Indian State of Uttarakhand (51,955 km^2) [4]. The recorded forest area is 24,240 km^2, which constitutes 47% of total geographical area covered by the state[5].

Since 2018, Uttarakhand has faced an acute water crisis. Less than 50% of the people in Uttarakhand receive adequate quantities of safe drinking water[3]. The availability of potable water during the dry season in rural areas is reported to drop to 25-30 liters per capita per day[6]. In 2019, it was estimated that over 50% of Uttarakhand's springs have dried up according to investigations with land users[2]. It is widely accepted that climate change, population shifts to urban towns, development and land use changes are diminishing spring flows[7]. However, there is a lack of data and investigations on how land management impacts springs.

Land use impacts on Springs

In collaboration with ICIMOD and G.B. Pant National Institute of Himalayan Environment & Sustainable Development (GBPNIHESD), WOCAT conducted a study to investigate the potential impacts of land management on spring discharges and their implications on upstream (onsite) and downstream (offsite) areas in the Himalayan foothills and lowlands.

Box 1. Case Study Site: Pithoragarh Town and Gorang Valley, Pithoragarh District, Uttarakhand

a) **Pithoragarh town** (Population: 56,044, Elevation: 1,645m, Area: 50km^2). Pithoragarh is one of many hill towns with a "floating population", consisting of tourists that come to visit Uttarakhand for its cultural and spiritual significance, natural beauty and mild climate. This flux of tourists ranges between 0.3 and 0.35 million throughout the state, which increases seasonal demands for water[35] .Despite the potential for development in tourism, Uttarakhand struggles to secure water for its inhabitants especially in the dry season. The Pithoragarh town requires 11-12 MLD (million liters daily), but is currently supplied with only 8 MLD. Increasing settlements in the valley has limited the cultivation area and increased flood risks. (Photo: *Liniger*)

b) **Gorang Valley** (Population: 3,249, Area: 23.23 km^2). The Gorang Valley lies just 4km away from the Pithoragarh town and consists of 17 villages that depend on 53 springs. About 30 years ago, the Pithoragarh town depended on the Gorang Valley to supply their local market, providing agriculture products such as citrus fruits (malta), spices (ginger, garlic, turmeric) and local varieties of rice, millet, and pulses. Today, cultivation has significantly decreased and most villagers make regular trips to the Pithoragarh town to purchase imported foods from the plain regions. (Photo: *Liniger*)

The role of climate change in spring flow regimes

While some estimates suggest that the Himalayan region is warming at rates two to three times faster than the global average[8], an average increase of only 0.35°C (half the global average of 0.7°C) was recorded over the past century in Pithoragarh. In 2016, Pithoragarh observed a record breaking maximum temperature of 23.5°C and minimum temperature of 13.1°C[9] (Figure 3).

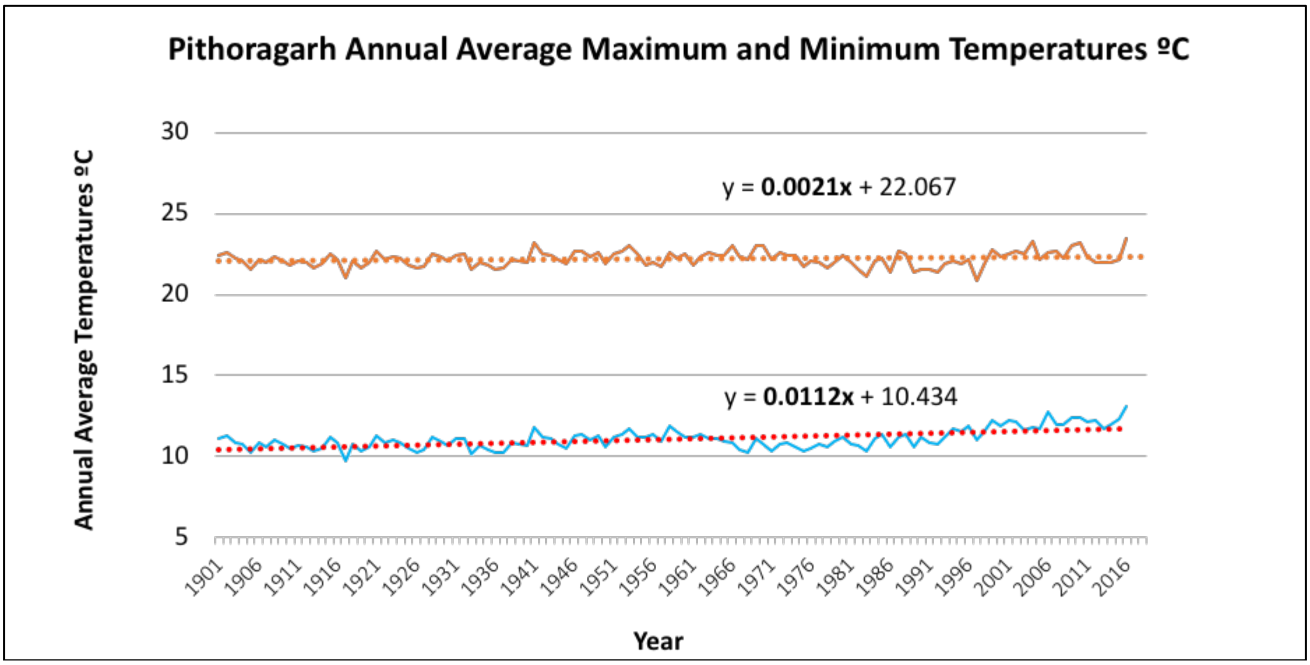


Figure 3. Pithoragarh Average Annual Maximum and Minimum Temperature (1901-2016) provided by Tyagi N, Narayan R, State Climate Change Center, Uttarakhand[9].

Long-term rainfall records indicate that Pithoragarh receives an annual average rainfall of 1692 mm (Figure 4), however precipitation in the study area varies depending on altitude, slope direction and seasonal monsoon patterns.

From 1950 to 2016, average annual rainfall declined by 120 mm, and the lowest precipitation on record occurred between 2001 and 2010[9]. Although a reduction in rainfall would help to explain a decrease in spring flows, the issue of drying springs in the region was recognized before the turn of the century. Therefore, this widespread phenomenon of drying springs must be influenced by factors other than climate change.

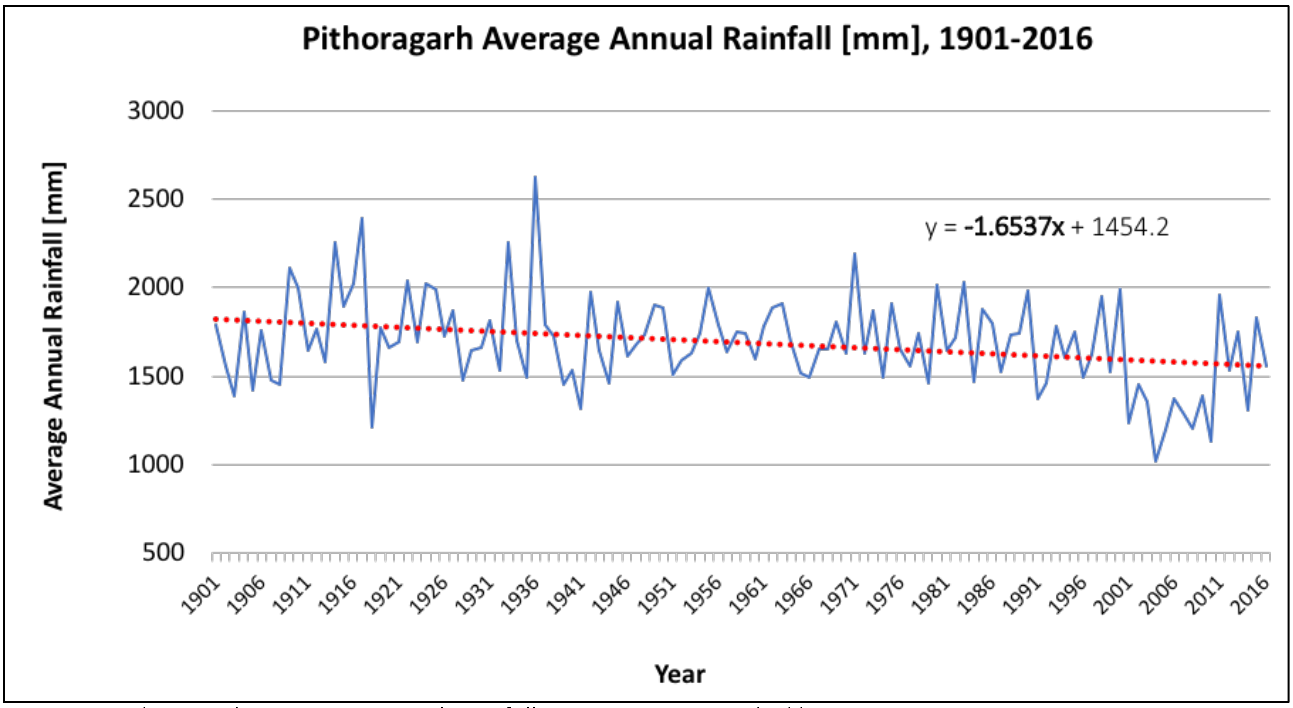


Figure 4. Pithoragarh Average Annual Rainfall (1901-2016) provided by Tyagi N, Narayan R, State Climate Change Center, Uttarakhand[9].

Onsite impacts of Land use change: Forests

LULC (Land Use/Land Cover) changes are known to affect regional circulation patterns, temperature, surface energy fluxes and precipitation patterns— all of which determine moisture availability[20]. The surface temperature over western India is found to be warming by ~0.13 °C/decade due to the combined effect of greenhouse gases and LULC change of which 50% was attributed to LULC change[21] . Current land use changes and historical degradation of Indian Himalayan forests appear to be contributing to this warming phenomenon (Box 1).

Of the 22.6 million hectares officially classified as forest in the Indian Himalayas, about 27% is under open forests with less than 40% canopy density[5]. Relentless collection of firewood, tree leaf fodder, and leaf litter from forest floor by local people for subsistence is claimed as one of the main causes of degradation[10]. Sustainable forest management can sustain long-term provision of these essential resources, however there have been insufficient efforts to encourage the dissemination of SLM practices in rural areas. Many parts of the region are now struggling to meet basic fuel and fodder requirements, and Uttarakhand is experiencing steady decline in broadleaf forests and increase in pine forests partially due to the extensive propagation of monoculture pine plantations during the British rule (Raj).

Chir pine (Pinus roxiburghii) is used for construction, timber, fuel, and resin production. It propagates aggressively and sheds flammable pine needles, which are acidic in nature and decompose slowly, making it difficult for other vegetation to grow. Pine needle cover results in extreme surface temperatures of over 70°C with sun exposure (Box 2). These extreme surface temperatures impose harsh conditions on understorey vegetation and soil health. This results in a decrease in infiltration, increase in runoff, and diminished annual recharge of groundwater stores that feed into springs.

Such conditions create microclimates that favour increasing fire frequencies. In 2018 alone, an estimated 4,500 hectares of classified forest area burned in Uttarakhand[5]. One of the major potential off-site consequences of increased wildfires in Uttarakhand is the generation of smoke containing "black carbon", which is created by the incomplete combustion of any biomatter and fossil fuels. Long distance transport of black carbon and setting over Himalayan glaciers may significantly reduce the snow albedo resulting in trapping of heat and faster melting of glaciers and increasing flood risks.

Box 2: Onsite implications of forest degradation: Chir pine, fire risk and forest protection

Surface Temperature in Pithoragarh Forests. Left to Right: Pine Needles in Degraded Pine Forest: 73.5°C, Grass in Mixed Pine/Oak Forest: 34.9°C, Oak Canopy: 30.3°C, Grass under Oak Canopy: 20.6°C. . Date: July 27, 2019. Time: 13:30. High soil surface temperatures (73.5°C) bake the topsoil and make it impossible for vegetation to establish in degraded pine forests. Due to a lifeless, crusted topsoil, water infiltration is impeded and groundwater stores cannot be replenished, further drying the springs. Location: Gorang Valley, Pithoragarh. (Photos: H.P. Liniger) Location: Gorang Valley, Pithoragarh.

Box 2 continued…

A Chir Pine Forest is regularly affected by fire. This degraded pine forest burns near rural villages, leaving no understory. About a 40–50% decline in biomass and 80% decline in net primary productivity has been estimated in chronically disturbed forests[10] Gorang Valley, Pithoragarh June 2019. (Photos: HP Liniger, J. Bandy).

Offsite impacts of Land use change: Disaster risk

Figure 5. Kedarnath flood of Uttarakhand killed thousands of people in June 2013. Overflow and collapse of the moraine-dammed Chorabari lake caused massive losses in the valley below, which remains seismically and ecologically fragile. Kedarnath Valley, 2019. (Photo: Joshi K, GBPNIHESD Research Fellow)

Uttarakhand is particularly vulnerable to floods and landslides, thus extreme weather events and glacial melt impose a high risk of disaster for the state. Toe-erosion by the high discharge of streams swollen rivers creates instability in river banks and slopes, increasing susceptibility to massive land sliding and debris flows[9]. Landslide frequency has increased with development, and is mainly concentrated along the river valleys, road sides and steep slopes where landscape vulnerability is high (Figure 6). In June 2013, Uttarakhand became devastated by severe rainfall and flash floods, which killed nearly 6,000 people, 9,200 livestock animals, and damaged some of the country's most important pilgrimage centers, natural habitat, settlements and hydropower infrastructure[14]. This resulted in an estimated direct loss of USD 4.25 million (INR 255 million)[14] to the state. Susceptibility to glacial lake outbursts, pre-monsoon floods and landslides is expected to increase in intensity and frequency outside the core monsoon months (i.e. July-August)[2], therefore disaster prevention is paramount in these vulnerable regions.

Figure 6. Landslide in Dharchula 2019, Pithoragarh District, Uttarakhand. (Photo: K. Joshi, GBPNIHESD Research Fellow)

Climate models by Immerzeel, et al. 2010 suggest that spring and river discharges in the Hindu Kush Himalayas are predicted to decrease sharply from 2046 to 2065 after a period of increased flows due to accelerated glacial melt[19]. A decrease in mean upstream water supply from the upper Indus (−8.4%), the Ganges (−17.6%), Brahmaputra (−19.6%), and Yangtze rivers (−5.2%) is anticipated to have considerable effects on food security, as these basins provide water to more than 1.4 billion people (over 20% of the global population)[19]. When considering upstream water availability, net irrigation requirements, crop yields, caloric value of crops, and required human energy consumption, it is estimated that the food security of 63 million people (4.5% of the total dependent population) will be threatened as a result of reduced water availability[19].

Figure 7. Mahakali River in Dharchula (2019) marks Nepal's western border with India. The region is especially vulnerable to water-related disasters – erosion, landslides, flash floods and polluted water. (Photo: K Joshi, GBPNIHESD Research Fellow)

In Uttarakhand there has been no dissemination in a methodology or protocol that includes hydrogeology, watershed protection and flood mitigation in development, therefore no concept of protecting upstream recharge areas and fragile buffer zones near developing and growing urban areas. Rapid urbanization has affected Uttarakhand in unprecedented ways, as urban built-up area increased by fivefold between 1993 to 2013[13]. Such development has increased paved areas, decreased water bodies, reduced groundwater recharge and capacity of urban drainage channels. When taking into account the consequences of impacted spring, stream, and river flows on seasonal water availability and food insecurity, there is a widespread demand to undertake nature-based, local level measures for springshed treatment, protection and rejuvenation of recharge zones.

Assessing the different land management options for spring rejuvenation

Sustainable community forest management combined with springshed protection has proven to be the most effective approach for improving the spring flows, maintaining forest resources and preventing further land degradation. In the rural village of Nakina, the community Forest Council (Van Panchayat) is reviving their local springs through a protective forest-springshed approach with GBPNIHESD, the Uttarakhand Forest Department (funding from the Japan International Cooperation Agency), and local NGOs (Himalayan Sewa Samiti, Tata Trusts) that includes: 1. regulated forest resource extraction, 2. natural assisted regeneration with planting of broadleaved species (Figure 8), 3. maintaining an oak and fodder nursery, 4. protective demarcation of the forest perimeter with a stone wall that deters trespassers, overgrazing, and shields the forest with a firebreak (including regular clearing of pine needles surrounding the wall), and lastly, 5. point interventions (recharge ponds, trenches, check dams) within the Vaishnavi and Bhind springshed, mapped using the WOCAT Watershed Tool (Figure 9,10).

Figure 8. Nakina's enriched broadleaf forest through natural assisted regeneration, regulated resource extraction and community protection.

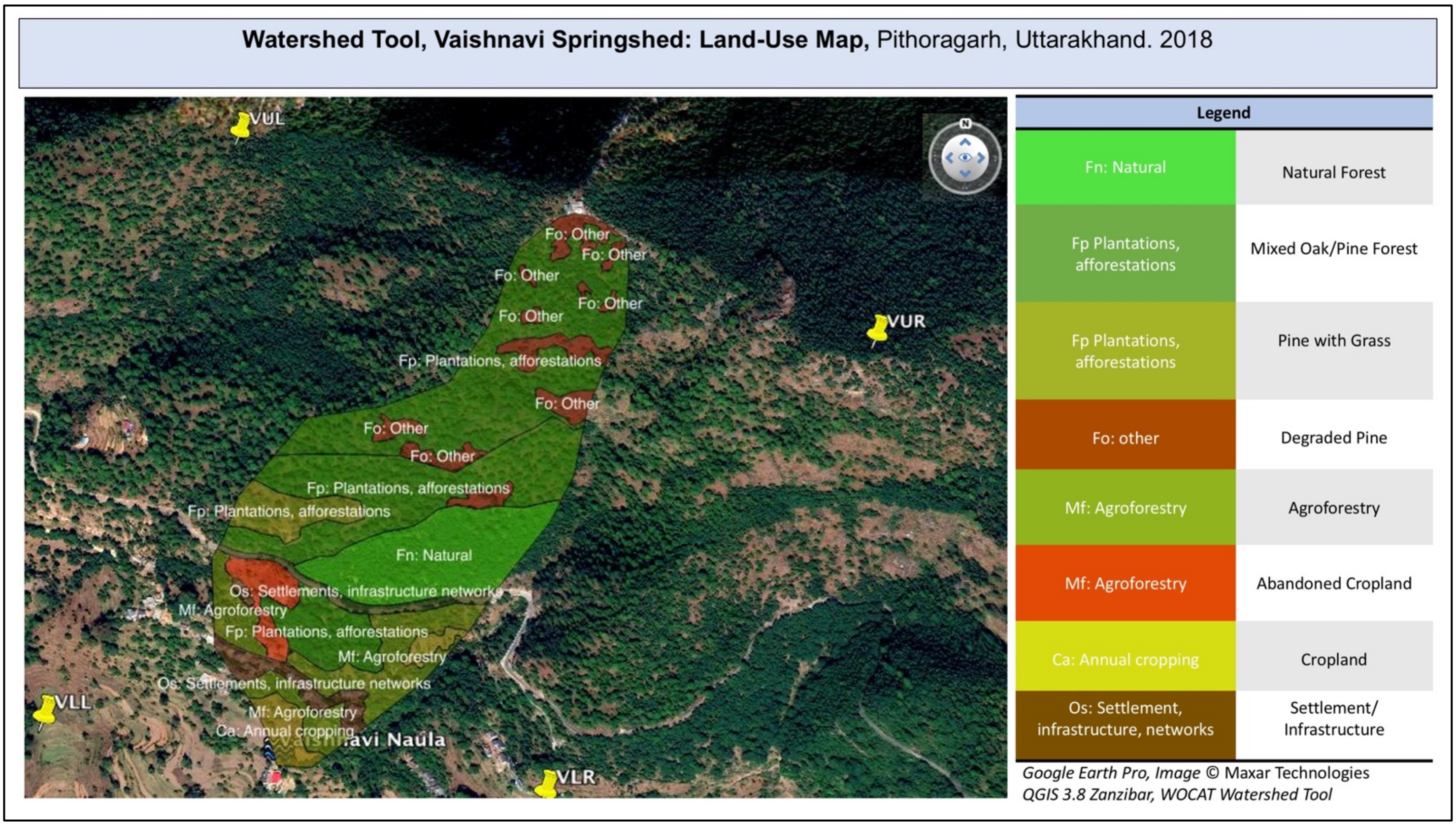


Figure 9. Vaishnavi Springshed: WOCAT Watershed tool application and mapping of the different land uses within the catchment area of 15 hectares (J. Bandy).

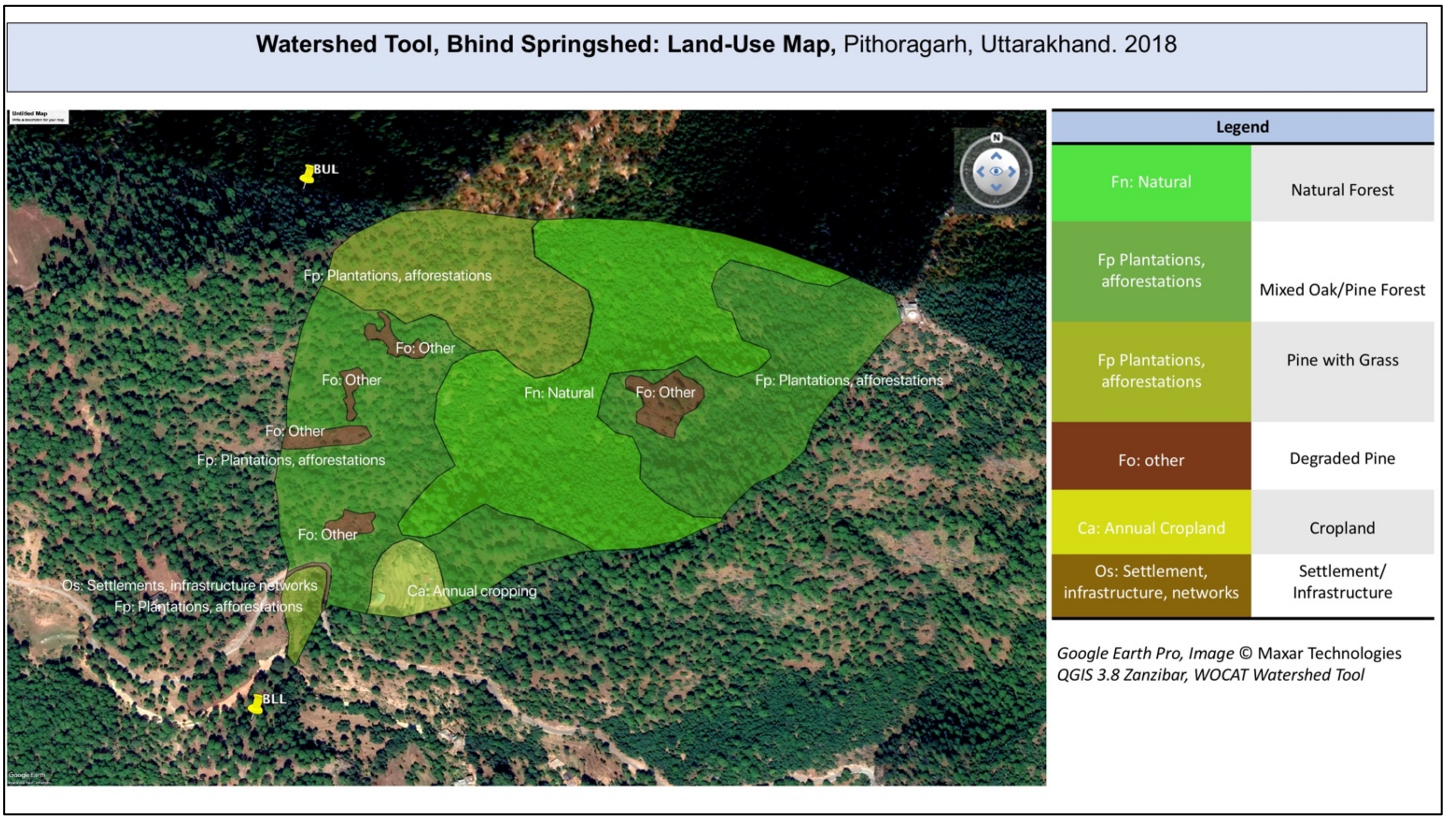


Figure 10. Bhind Springshed: WOCAT Watershed tool application and mapping of the different land uses within the catchment area of 17 hectares. (J. Bandy)

Figure 11. Vaishnavi Naula lies below Nakina's settlement, surrounded by cropland next to the village temple. The Naula is reported to be 1,500 years old and has remained a key source of drinking water. Spring discharge has reduced in the dry season over the last 30 years, but increased in the last two years because of improved forest management and springshed protecction. (Photo: HP Liniger)

Figure 12. Bhind Naula lies 400m from Nakina's settlement and supplies most of the water for the villagers. Over the last 40 years spring discharge has significantly decreased due to a pine encroachment in the springshed. However, villagers reported that there has been an increase in water availability in the last 2 years due to sustainable forest management. (Photo: HP Liniger)

Water Harvesting with Point Interventions

Point interventions can be made more effective by mapping springsheds and understanding potential recharge contributions under different land-use/cover types. Using local knowledge and a topographic assessment of their community forest, the Nakina Van Panchayat collectively decided to create a large pond in the lower catchment area of the Vaishnavi Spring (Naula). The area of the recharge pond is located near the oak nursery, contained in an old-growth broadleaf forest that has gentle slopes and easy access for maintenance if sedimentation or excessive pond-filling occurs. (Figure 13). The upper catchment of the springshed is dominated by steep slopes and some bare forest patches, which generates high runoff into the lower catchment. The recharge pond, situated in the natural forest area below, acts as a point of interception and captures runoff that flows from above.

The pond has a water storage capacity of 40 cubic meters, and—based on observation of villagers—it fills up about 5 times during the monsoon season. Assuming that all the water infiltrated from the pond flows into the Vaishnavi spring, a potential recharge contribution of 200 cubic meter per monsoon season could provide an average spring flow of 0.38 litres per minute for 365 days. Although hydrogeological aspects (rock types, fractures, joints) largely dictate the productive flow of groundwater, one can conceptualize the impacts point interventions can offer given their dimensions and strategic placement. Integrating this information with springshed mapping (and hydrogeological mapping, when feasible) can support management and intervention decisions for spring recharge. Estimations of recharge potentials can then be confirmed by long-term spring discharge monitoring and comparing local daily rainfall measurements.

Figure 13. Sarpanch, (main head of forest council), Sir Jagdamba Prasad Joshi stands in the recharge pond. A recharge pond serves as a water harvesting system collecting runoff water from a nearby pine forest and serves as a point of infiltration and groundwater recharge for the Vaishnavi spring. Given a total estimated water storage capacity of 200 m^3, the pond has the potential to give 0.38 Litres/ha/minute for 365 days. (Photo: HP Liniger)

Figure 14. Infiltration trenches established in the recharge zones of a springshed have the potential produce about 0.01 litres per minute per hectare, assuming 957 mm rainfall (30 trenches, 1 meter distance apart, dimensions: 2.5m x 0.25 m x 0.35 m). Cost of labor and maintenance is intensive, as many structures are required to make any substantial contribution to the groundwater recharge. (Photo J Bandy)

Nakina Village: Costs and Benefits

Villagers estimated a 30% increase in spring discharge during the dry season and reported a reduction in time spent collecting water, fodder and fuelwood[11]. Out of the total 44 households in Nakina, an estimated time saved was 1.5-3 hours per household per day, and improved water provisioning saved each household an estimated $30.9 –

$318 USD per year (7-21% of annual income)[12]. The total costs were estimated at $3,500 USD per springshed (15 hectares), and returns were apparent 3 years after implementation was initiated[11,15].

Inputs and Costs for Springshed Restoration					
Treated Area	Number of Trenches	Number of Recharge Ponds	Storage Capacity (m^3)	No. of Tree Saplings	No. of Grass Saplings
3 ha	100	4	180	2000	4000
Estimated Time for Spring Recharge	Labour and Consultation Cost	Equipment Cost	Plant Material and Inputs Cost	Maintenance and Monitoring	Total Costs per Springshed
+2 years	1200 USD	700 USD	900 USD	700 USD	3,500 USD

Figure 15. Inputs and Costs for Springshed Restoration. Costs were estimated using WOCAT Questionnaires[12] and People's Science Institute, Dehradun, Spring Development Case Studies[13]. Plant species may include the following tree (T) and grass (G) species: (T) Banj Oak (Quercus leucotrichophora), Falyaat (Quercus glauca), Khasru (Q. semecarpifolia) Koeraal (Bauhinia verigata), Bhimal (Grewia optiva), Padam Paaya (Prunus cerasoides), Haradh (Terminalia chebula), Reetha (Sapindus Mukorossi), Utees (Alnus napalensis), Ainyar (Lyonia ovalifolia), Khadik (Celtis australis), Rhododendron (R. campanulatum, R. arboreum) Timla (Ficus Roxburghii), Thelka (Ficus nemoralis), Chanchara (Ficus clavata); (G): Khor (Chrysopogon gryllus) (Khor) and (Pennisetum purpureum) Ringal Hill Bamboo (S. falcata), Italian ryegrass (Lolium multiflorum).

Water Balance: Runoff and Spring flows

Three negative offsite impacts of principal concern for up- and downstream land management are increased surface runoff, flood disaster risk, and the loss of groundwater recharge that feeds springs. Because 85% of annual rainfall occurs during the monsoon, (June-September) [10], high and intensive rainfall events are concentrated within a short period of time. Rainwater must effectively infiltrate into the soil and recharge groundwater levels.

To understand the affects of land management on surface water, a water balance was calculated for different land use types in Nakina Village (Figure 16).

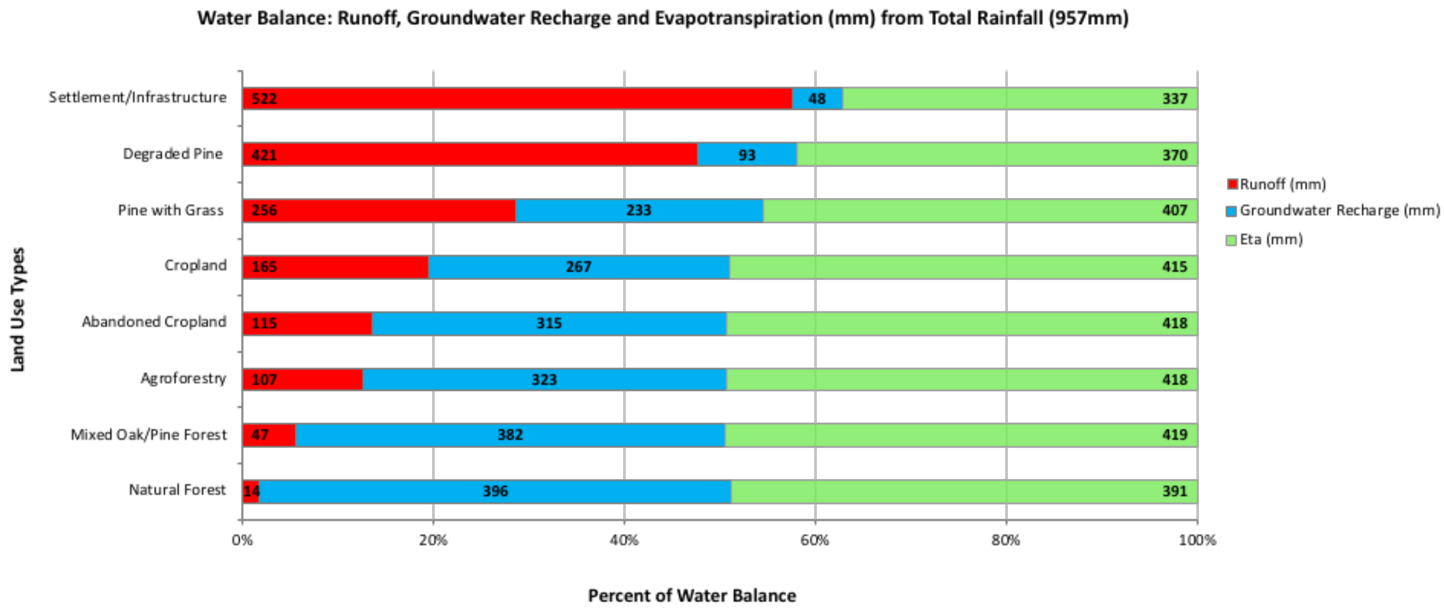
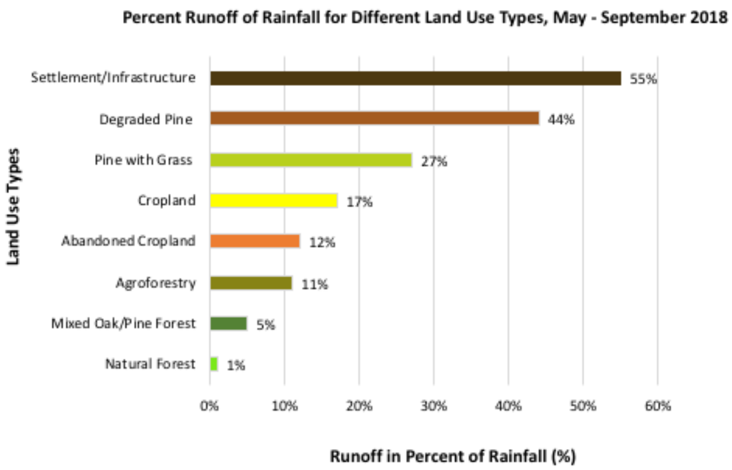


Figure 16. Water Balance: Rainwater divided into runoff, groundwater recharge and evapotranspiration in mm for different land use types. The calculation assumes a total rainfall of 957 mm (between May and September 2018) using daily local rainfall records. (Source: Bandy and Liniger 2020)

The resulting water balance and percent runoff of rainfall for each land use type (Figure 16a) reveals that the majority of the rainfall is lost to runoff from Settlement/infrastructure (55%) and Degraded pine forests (44%). Although Settlement/Infrastructure gives the highest runoff, the total coverage of built-up area is much less than the area of pine forest, and springsheds are usually situated in upper forest zones above human settlements.

Runoff in a Degraded Pine Forest (44% of the monsoon rainfall) is much higher than that of the best forest-case scenario, i.e. conserved Natural Forest (1%) and Mixed Oak/Pine Forest (5%). Compared to Degraded Pine Forest, other land use types, namely Cropland, Abandoned Cropland and Agroforestry are much more efficient in reducing runoff, (between 256-324 mm), thus saving one quarter to one third of the monsoon rainfall for groundwater recharge.

a)



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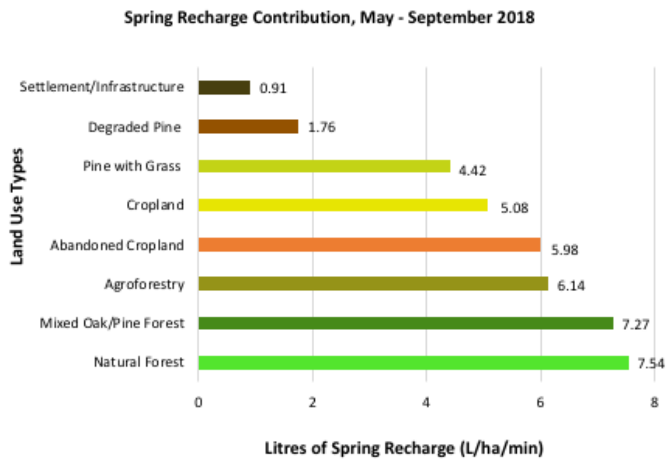


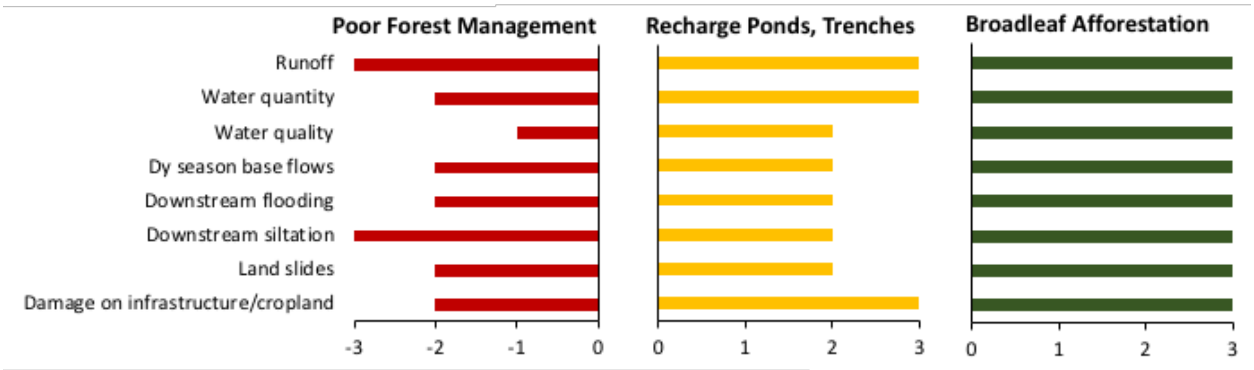
Figure 16a) Percent runoff of rainfall for different land use types. The calculation assumed total of 957 mm from daily local rainfall records (between May and September 2018). **Figure 16b)** Spring Recharge Contribution (Liters/ha/minute) are compared for different land use types. The calculation assumed a total of 957 mm from daily local rainfall records (between May and September 2018). Each land use type assumes an annual average rate of discharge, given 957 mm of rain.

For spring recharge under different land use types, Figure 16b demonstrates that, assuming under one hectare and 957 mm of rainfall, Natural Forest and afforested Mixed Oak/Pine Forest can provide an annual average spring flow of at least 7 litres per minute, while Degraded Pine Forest gives only 1.76 litres per minute.

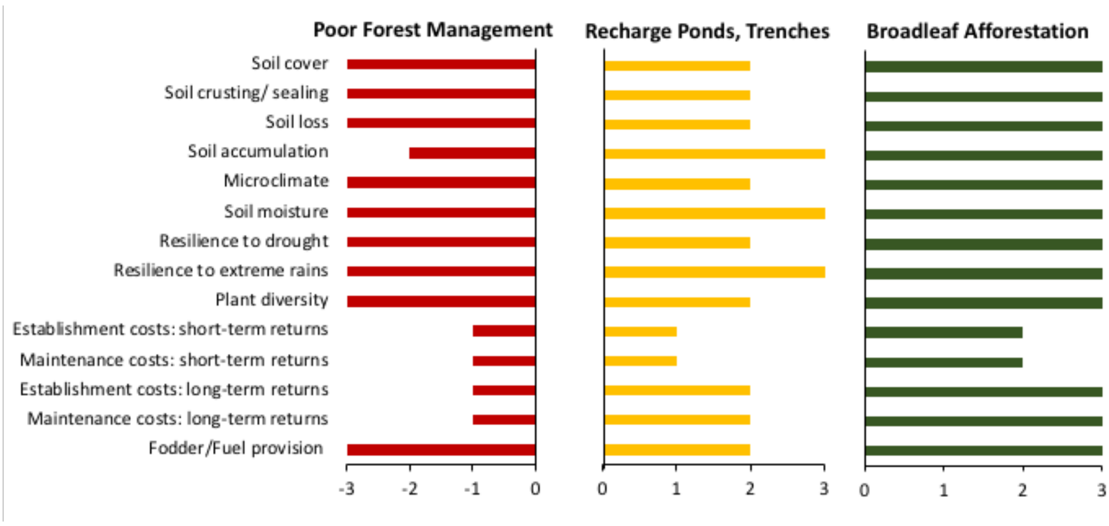
Although these estimations assume total productive groundwater flow into a spring, the water balance approach illustrates how the problem of diminishing spring flows is rooted in land use changes within Uttarakhand's forests. The vast degradation of natural broad-leaved oak forests and their replacement with degrading pine forests are threating natural resources and spring water provision for rural communities.

However, not only Natural Forest but also well managed Cropland and Agroforestry have a relatively high spring water recharge, reaching two-thirds to 80% of Natural Forest. Under sustainably managed systems, Cropland and Agroforestry will not only reduce runoff and help recharge springs, but also increase productivity (food, fuel and fodder) and prevent the spread of pine forests. Abandoned Cropland also enhances spring water recharge due to increasing perennial vegetation cover on the terraces. Using WOCAT Questionnaires[11] with land users and local stakeholders, the on- and offsite impacts of land management and practices were evaluated and summarized for Nakina Village (Box 3,4).

Box 3. Evaluating On and Offsite Impacts of SLM Technologies



a) **Onsite impacts of land use practices**: Poor forest management, recharge ponds and trenches, and broadleaf afforestation. Poor forest management is without community forest resource regulation, broadleaf afforestation, soil/water conservation efforts, or fire prevention. (-3 = very negative impact, 0 = negligible impact, 3 = very positive impact).



b) **Offsite impacts of land use practices**: Poor forest management, recharge ponds and trenches, and broadleaf afforestation. Poor forest management is without community forest resource regulation, broadleaf tree planning, soil/water conservation efforts, or fire prevention (-3 = very negative impact, 0 = negligible impact, 3 = very positive impact).

Box 4. Summary of Spring Recharge Potential and SLM Impacts

Spring Recharge Potential in Degraded Pine Forest. Contribution to spring discharge is 1.76 litres per hectare/minute from 1 hectare of degraded pine forests (exposed to reoccurring forest fires) over 365 days using 2018 daily rainfall (957 mm from May to September) in Pithoragarh, Uttarakhand. (Photo: HP Liniger).

Spring Recharge Potential in Natural Broadleaf Forest Contribution to spring discharge is 7.5 litres per hectare/minute from 1 ha of natural broadleaf forest over 365 days using 2018 daily rainfall (957 mm from May to September) in Pithoragarh, Uttarakhand. (Photo: HP Liniger).

Nakina *Van Panchayat* member collects enough fodder for her livestock. Forest health improves and land degradation decreases with community forest management. SLM interventions involve: establishing a protective fire wall, firebreak, enriching the forest with broadleaf trees, fodder grasses, as well as constructing check dams, recharge ponds and trenches within springsheds. (Photo: J. Bandy)

Springshed management increases spring flows in the dry season. Improved water provisioning reduces drudgery of water collectors (mainly women and children), saving each household up to 20% of their annual income. Commitment to overall resource management is enhanced, as springs preserve the cultural bond between people and nature. (Photo: HP Liniger).

On- and Offsite Impacts: Migration, Agriculture, Development

The future of Uttarakhand's hill population will depend largely on how socioeconomic "push" and "pull" factors transform migration patterns, market demands and agriculture development. Migration from rural villages to urban hill-towns has become one of the most significant issues in Uttarakhand About 18% of the rural population has migrated to the urban-towns in recent decades. Between 2001 and 2015, roughly 26,000 rural houses were abandoned, and the cultivated agriculture land declined by

8%[12]. Increasing land fragmentation has been detrimental to crop production and discouraged cultivation altogether. The average landholding size is 0.68 hectares (national average: 1.16 hectare per farmer) and most farmers occupy several patches of land scattered across steep landscapes[9]. Today, farmers tend to cultivate only on lands close to their households and other areas are left as fallow land. Large areas of unattended land and less cultivation has increased human wildlife conflict. Forest degradation and water scarcity is pushing animals (monkeys, wild boar, leopard) closer to rural settlements and abandoned cropland reverts to wildlife habitat[9].

Many farmers are unable to make a profit or sustain themselves through agriculture, therefore they purchase staple foods from the town markets. The hill-markets offer a variety of cheap produce imported from the lowlands that rest on Himalayan foothills, known as the Terai region of the Indo-Gangetic Plain. The Indo-Gangetic Plain is also facing water scarcity, groundwater contamination and climate-induced production constraints[5,10]. The region is considered a global climate change hot spot because it has experienced higher than average climate change signals, and it intersects with large numbers of vulnerable and poor people[11]. As the dependency on plain agriculture imports in the mountain regions increases, pressure on natural resources will threaten food security for both upstream (hill) and downstream (plain) populations[11].

Despite environmental pressures and market constraints, Uttarakhand still has rich potential to expand horticulture, organic dairy production and local mountain products, namely for temperate fruits, nuts, vegetables and spices (e.g. apple, pear, peach, apricot, walnut, potato, turmeric, ginger) as well as ornamental flower production[28]. There are also several traditional varieties of drought tolerant, highly-adapted crops that can be promoted for cultivation, including rice, millet (Koni), flaxseed, legumes (horse gram, cowpea) barley, pulses and oil-seeds (mustard, sesame). Because the cultivation area of Uttarakhand is is 90% rainfed[5], variations in temperature and precipitation highly impact crop selection and yield. Therefore, adaptive agriculture– which incorporates local innovation, indigenous knowledge and traditional crop varieties– needs appraisal and support from the state to make cultivation productive and profitable.

Furthermore, parts of Uttarakhand's forests are home to 40.1 % of medicinal and aromatic plants (MAPS) in Indian Himalayan region, of which 28 are recognized as globally significant medicinal plants[29]. Presently there 132 of 701 identified species of medicinal, herbal and aromatic plants (MAPS) that are considered as substantial for the socioeconomic development of the state[29,30]. Besides recognizing Uttarakhand's forests as spring water sanctuaries, these rich ecosystems should be revered as storehouses of biodiversity sustained by springs, which offer invaluable genetic resources and have the potential to initiate a new wave of organic mountain agriculture. Developing special markets and local mountain products will simultaneously support the growing population[9].

Key Conclusions

Acknowledge the impacts of land use and land use change

In Uttarakhand, the major causes of the drying-up of springs are forest degradation, land use and climate change. Over-exploitation of forest resources and encroachment of pine forests are provoking intense and frequent forest fires and leave the soil impermeable, inhibiting groundwater recharge and disrupting spring flow regimes. The impacts of these changes affects downstream areas, increasing risks of floods during the monsoon, followed by sedimentation and disruption of river flows during the dry season. The paradigm of "too much" (floods) followed by "too little" (drought) is apparent, and mitigation through land management is critical.

Develop an integrated methodology for spring monitoring and revival across the Himalayas

There is a need to establish collaborative initiatives (with land-users, research institutions, NGO's, local government and international agencies) to identify appropriate interventions and support grassroots innovation in local communities for spring recharge. Long-term monitoring of local rainfall, spring discharges and river flows is crucial for understanding seasonal variations, capacity of groundwater storage and validation of recharge efforts. The Uttarakhand case study suggests that community forest management (e.g. afforestation and conservation of broadleaf forests) integrated with springshed protection can maintain or increase spring flow to communities, as well increase fuel and fodder availability in the dry season.

Agriculture-based schemes for water conservation and resource management

There is a need to monitor land use change, identify on- and offsite impacts, and increase efforts to promote SLM practices in the HKH region. Mainstreaming good land management practices will increase the capacity to implement spring revival programs that simultaneously sustain Himalayan livelihoods. For a future in mountain agriculture, the local people require support and engagement with multidisciplinary experts (agriculturalists, land practitioners, hydrogeologists, etc.), governmental agencies, and NGOS in order to collectively envision alternative land management options that secure water resources. Improving market access and encouraging the production of traditional crops, local medicinal and aromatic plants, and other niche mountain products holds great potential for sustainable development and biodiversity preservation. Furthermore, enhancing eco-tourism needs to be explored to create novel opportunities for the next generation in HKH mountain region.

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