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Building sustainability in the Eastern Himalaya: linking evidence to action

Sandeep Tambe[5] · Gopal S. Rawat[1] · Nima Tashi Bhutia[2] · Pem Norbu Sherpa[2] · Subash Dhakal[2] · Sarika Pradhan[2] · Himanshu Kulkarni[3] · M. L. Arrawatia[4]

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Abstract

Operating at the science, policy, practice interface (SPPI) is often contentious, as knowledge creators and end-users seldom engage, preferring to operate in their own worlds. The application of science to solve sustainability challenges has not received the desired attention, especially in developing countries. How to strengthen the credibility, relevance and legitimacy of research so as to enhance the chances of uptake in decision making? How to generate knowledge differently, so that it is more likely to bring about change and benefit society? The purpose of this research is to examine these questions in the context of three sustainability case studies that were able to transcend the knowledge action barrier. These case studies are from the global biodiversity hot spot of Eastern Himalaya, India, and cover the themes of sustainability of pastoral systems, promoting sustainable livelihoods for the poor and co-designing a Himalayan spring revival initiative. The findings are structured to highlight how the demand for science arose, findings of the research and how the knowledge generated was translated into action. The results show that firstly relevance of science increases manifold when aligned to prominent policy decisions and real-world problems. Secondly, trans-disciplinary studies that synthesize social, economic and ecological aspects have a greater chance of influencing policy makers. Thirdly, mediation by science stewards holds lot of promise in connecting the worlds of academicians and policy makers. The study provides practical guidance on bridging the SPPI and contributes to the growing body of the literature on sustainability science.

Keywords Sustainability science · Science stewards · Co-production · Synthesis · Boundary work

1 Introduction

Climate change, biodiversity loss, declining water resources, natural disasters, mass tourism, hydropower development, unplanned urbanization, youth unemployment and declining agricultural productivity are some of the formidable sustainability challenges facing the

✉ Sandeep Tambe
jointsecy@gmail.com

Extended author information available on the last page of the article

Himalayan region (Singh 2006; Shrestha et al. 2012; Sikkim HDR 2014). Rittel and Webber (1973) coined the term "wicked problems" to describe such challenges which cannot be solved using traditional linear, analytical approaches and contrasted them to "tame problems." In wicked problems, stakeholders do not agree, there is no clear measure of success, they are often multi-disciplinary and the construct is socially complex. Sustainability is the classic "wicked" problem, characterized by poorly defined requirements, unclear boundaries and contested causes, that no single agency or discipline is able to address (Brown et al. 2015). Tackling wicked problems involves bridging the divide between the biophysical and the social sciences, as several dimensions, such as ecological, social, economic, technological and political, need to be weighed before decisions can be made (Australian Public Service Commission 2007).

Portraying traditional research as narrow, disciplinary and theory-driven activity, Kates et al. (2001) introduced a science of sustainability in order to change how science could be conducted and applied to transform the world toward a sustainable future. This new branch of science—"sustainability science"—aims to bridge the gap between knowledge and action following trans-disciplinary and transformative approaches. Policy makers while facing complex sustainability challenges often lack useful information needed for good decision making. The decision-making context of policy makers involves inputs on policies, programs, guidelines, regulations and the like. The process of facilitating the uptake of scientific research findings into policy making is complex as the differences between researchers and policy makers in their cultures, time frames, reward structures and motivations create obstacles to good communication (Strydom et al. 2010; Holmes and Clark 2008). Scholarly literature on the science–policy–practice interface (SPPI) overwhelmingly concludes that there are serious and systemic problems for traditional research products to cross the divide to have influence within the policy and political spheres (Dunn and Laing 2017). Cash et al. (2003) provide a compelling concept for understanding why some science is translated into action whereas other science is not. These authors propose that efforts to connect knowledge to action are effective only if they are sufficiently salient, credible and legitimate (abbreviated as CRELE) with multiple audiences simultaneously. Credibility refers to the scientific acceptability of the technical evidence and arguments. Relevance or salience covers the alignment with the requirements of policy makers and practitioners. Legitimacy is the perception that the knowledge creation is respectful of stakeholders' divergent values and beliefs (Cash et al. 2003). For research to cross the knowledge boundary, it must have all these three elements, without which the research is likely to be ignored by decision makers (Cash et al. 2003; Cook et al. 2013).

2 Objective and research questions

The purpose of the study is to provide insights from operating at the science, policy, practice interface using a case study approach. How to strengthen the CRELE quotient of research studies so as to enhance the chances of uptake in decision making? How to generate knowledge differently, so that it is more likely to bring about change and benefit society? We examine these questions in the context of three sustainability case studies that were able to transcend the knowledge action barrier. This action research was conducted during 2006–2018 in the Sikkim Himalaya, one of the global biodiversity hot spots. These sustainability case studies cover (1) sustainability of yak herding in the Khangchendzonga National Park (KNP), now a world natural and cultural heritage site enlisted by UNESCO,

(2) promoting sustainable livelihoods for the poor under the Mahatma Gandhi National Rural Employment Act (MGNREGA), the world's largest public works program and (3) co-designing revival of Himalayan springs for enhancing rural water security. While analyzing these case studies, we focus on three research questions—how the demand for science arose, what were the scientific findings and how the knowledge generated translated into action. In these three case studies, the authors functioned as creators of knowledge and also as science stewards mediating the framing of research questions, conducting the research study in partnership with stakeholders and attempting the subsequent uptake of science into policy. Thus, this study provides a unique insider's view of the science–policy–practice interface, on what worked and what did not and why.

3 Methods

3.1 Study area

The study was conducted in the Eastern Himalayan state of Sikkim located in the remote, northeastern region of India abutting between Nepal and Bhutan. The young fold mountains are characterized by a weak geology, comprising sedimentary and low-grade metamorphic rocks which are prone to landslides. There is severe shortage of land for the development of physical infrastructure, and only 11% of the total land is available for farming (FSI 2017). About three-fourths of the state's population reside in rural areas, with over 60% directly or indirectly dependent on agriculture and allied sectors where earnings are typically low and uncertain (Sikkim HDR 2014). For the most part, it is difficult to come across vast tracts of flat land, and precipitous slopes make agriculture, transportation and communication difficult (Sikkim HDR 2014). The Khangchendzonga National Park (KNP) located in Sikkim, India, was established in 1977 and has an extent of 1784 sq. km. KNP represents one of the 36 global biodiversity hot spots of the world (Myers et al. 2000; Mittermeier et al. 2004, 2011). The park is renowned for its high altitude landscape, housing 9 peaks that rise above 7000 m, 73 glacial lakes and 150 glaciers (Tambe and Rawat 2009). Maity and Maiti (2007) reported 1580 species of vascular plants, while Sathyakumar et al. (2011) confirmed the occurrence of 42 mammals.

3.2 Sustainability case studies

We used mixed methods with explanatory sequential approaches (Creswell 2014). Quantitative data were collected followed by focus group discussions and key informant interviews to explain the quantitative findings. The case studies are structured to highlight how the demand for science arose, what were the research results and how the findings were translated into action. The authors functioned as science stewards bridging the universe of academicians and policy makers and provide an in-depth analysis and a unique insider's view of the science, policy, practice interface.

3.2.1 Sustainability of yak herding in KNP

Over the years, different approaches have been used to assess the sustainability of pastoralism in the Himalayas ranging from carrying capacity, coexistence with wildlife, health of livestock, health of the pastures and others (Mishra et al. 2001; Bagchi et al. 2004). We used multi-disciplinary, mixed approaches using a combination of vegetation sampling, village consultations, herder interviews and remote sensing to assess the sustainability of yak herding in the KNP. Information pertaining to livestock ownership, livestock population trends, migration routes and grazing intensities in various pastures was collected through village consultations and herder interviews. The summer pastures in the alpine meadows have a long history of grazing by sheep and recently by yak, their crossbreeds (locally called *urang*) and pack animals, while the temperate oak and sub-alpine fir forests are used only by the yaks and *urang* as winter pastures. Here, we laid 60 quadrates (10 m × 10 m), 21 in relatively undisturbed, 39 in disturbed in 16 sampling sites about 4 km apart. For the tree species, we recorded density and girth at breast height and cover for the ground-layer plant species. The remote-sensing component involved assessment of the change in Normalized Differential Vegetation Index (NDVI) following Lillesand and Kiefer (2000). This was done with the help of two Landsat images acquired 23 years apart in the winter of 1977 and 2000 (NASA Landsat Program 1977, 2000).

3.2.2 Promoting sustainable livelihoods for the poor under MGNREGA

India's rural employment act (MGNREGA), the world's largest public works programme, is designed to guarantee wage employment as a statutory right. When launched in 2005, it was expected to transform rural labor markets and create durable assets (Verma and Shah 2018). However, large-scale implementation challenges were reported in terms of under-staffing, weak capacity, lack of awareness toward entitlements and elite capture resulting in weak planning, leakages and corruption (Aakella and Kidambi 2007; Tambe et al. 2016). Consequently, it was viewed by many as a drain on the public exchequer, as wages were paid but durable assets were not created (Bhagwati and Panagariya 2012; Shah 2009). This action research analyzes the mid-course policy correction taken up under the MGNREGA programme in Sikkim state to expand the creation of household livelihood assets (HLA) in the lands of the poor. Can this safety net be restructured to double up as a ladder of opportunity for the poor without altering its entitlement-based framework? The policy changes, operational guidelines, administrative orders and progress reports were accessed from the substate teams and the web portal of the programme (RMDD 2016; MoRD 2016). The asset mix approved by the *gram sabha* (village council), extent of HLAs created, and the expenditure incurred before and after this policy were analyzed using time-series data.

3.2.3 Co-designing revival of Himalayan springs

Springs ensure water security in the mid-hills of the Himalayas and are the lifeline of the rural communities. Though a valuable natural resource, the science of springs is not well understood. Studies in the western Himalayas indicated that spring flow is a function of rainfall pattern and the recharge area characteristics (Negi and Joshi 1996; Negi et al. 2001). The problem at hand was the rapid decline in the lean period discharge of these springs, and in this action research, we partnered with technical agencies and NGOs to explore whether these dying Himalayan springs can be revived. Firstly, we identified the recharge area of the spring by hydrogeological mapping and delineating the aquifer. Then in the dry season, artificial groundwater recharge works were carried out on sloping lands comprising rows of staggered contour trenches and percolation pits. These recharge works were mostly land based, and drainage line works were avoided as they run the risk of damage from torrential stream flows during the monsoon downpours. The dry season

(March–May) spring discharge was identified as the impact indicator and monitored every year.

3.3 Data analysis

Data analysis was carried out by aggregating the data of the sampled sites using pivot table function in Microsoft Excel spreadsheet. The data were analyzed to discern the patterns, and summary tables generated. We used livestock units (LU) with 1 LU = 1.1 yak and 0.8 *urang* following Singh and Sundriyal (2005). Livestock impact unit (LIU) was calculated by multiplying the total LU with the duration of stay of the livestock in days per unit hectare. The remote-sensing analysis was carried out in ERDAS IMAGINE version 9.3 and ArcGIS 10.4 digital image processing software.

4 Findings

4.1 Sustainability of yak herding in KNP

4.1.1 Demand for science

In 1998, the government of Sikkim took a policy decision to ban livestock grazing in the reserve forests of South and West districts of the state, in plantation areas and water sources (Lachungpa et al. 2003). This ban was opposed by the herders, and in a response to a plea filed by them, the Sikkim high court reaffirmed the grazing ban as it was as per the provisions of the existing Forest Acts vide its judgment dated May 14, 1999. After several rounds of awareness, persuasion and negotiation, the cattle herders accepted the compensation package of the forest department and voluntarily removed their cattle from the forests (Tambe et al. 2005). However, the number of yaks in the alpine forests reduced only marginally. The ex-cattle herders argued stating, "*Yaks cause more damage to the environment because they stay within the forests throughout the year as compared to cattle. Moreover, the yak herders are wealthy and own buildings in towns, if they are not evicted then we will also return to the forests with our cattle*." On the other hand, during the herder's interaction workshop held in Sikkim in 2004, the yak herder's counter contention was, "*Our yaks do not come down below the tree line and hence cannot impact the forests, infact our yaks manure the alpine meadows and no wonder the alpine plants flower in greatest abundance around our yak-sheds. If you want to forcibly remove us, then the forest department should buy our yaks and provide livelihood support to us.*" The alpine zone being treeless has been traditionally given less importance, now faced with insufficient information about this landscape; the forest department was in an unenviable position. To address this conservation challenge, a research study was taken up by the forest department to better inform the policy makers on the sustainability of the pastoral practices. The main objective of this multi-disciplinary study was to assess the ecological impacts, economic benefits and equity in benefit sharing of the yaks and *urang*.

4.1.2 Findings of the study

Historically, the pastoral systems in the KNP evolved in close consonance with the patterns in climate and fodder availability. The agro-pastoral communities, viz., the *gurung* and *mangers*, practiced long-distance transhumance to access the rich fodder resources of the alpine meadows during summer and during winter returned back to the villages with their flocks. This harmony between the subsistence needs of humans and nature's bounty existed for several centuries. From the mid-twentieth century, trans-border yak herders from the upper reaches of eastern Nepal started migrating and settled in the fringe villages of KNP in West Sikkim district. In 1975, Sikkim merged with India and this created a spurt of economic opportunities and rapid development in this remote border state. The herders in order to meet the growing demand for dairy products expanded the herd size of the yaks and *urangs*. In summer, they accessed the moist alpine meadows till the winter snowfall forced them to descend down to the Yambong valley and Barsey sanctuary located to the south of KNP.

The study found that over the six decades (1950–2007), sheep have been increasingly replaced by yaks and *urangs* in KNP. They are grazed in the multi-layered temperate and sub-alpine forests during winter. These evergreen oak and silver fir forests have a dense middle story of dwarf bamboo and Rhododendron with a moss dominated ground cover. *Yushania maling* and *Thamnocalamus spathiflorus* are the main bamboo species that grow up to 7 m with a 7 to 10-cm girth and are densely packed with an average of 325 stems per 10-m square plot. The livestock impact units (LIU) of the yaks and their crossbreeds in these forests during winter increased more than 8 times (from 2 to 17 LU days/ha) between 1975 and 2004. The herders open up *kharkas* or forest openings around their yak sheds (*goths*), where the top canopy is lopped, and the middle story is cleared to increase the ground fodder availability (Fig. 1). Vegetation sampling in these forest openings showed that the number of trees had reduced from 3.7 ± 2.2 to 0.6 ± 1.6 in a 10-m square plot with the maximum difference noticeable in the bamboo thicket middle story whose stem density reduced from 324 ± 139 to 0.7 ± 2. In these openings heavily used by livestock, *Agrostis pilosula, Arundinella nepalensis, Poa annua,* a few sedges such as *Carex* species, mosses and several unpalatable opportunistic herbs such as *Rumex nepalensis, Potentilla nepalensis* and *Persicaria* spp.

Fig. 1 Biodiversity-rich sub-alpine forests were converted into pastures by the yak and *urang* (yak hybrid) herders to enhance fodder availability during winter

dominate the ground cover. The herders also plant an exotic fodder grass, *Pennisetum clandestinum*, in these openings. Consequently, the availability of ground fodder in these openings increased significantly from 1.8 to 76%. Change detection study in the 1977–2000 time series indicates that 25% of these forests, having an extent of 4800 ha, show more than 15% reduction in Normalized Difference Vegetation Index (NDVI) values.

In terms of economic benefits and equity, we found that only 28 (0.3%) of the total 9482 households living adjacent to KNP benefitted from yak herding. They maintained a large herd size of 25–70 animals and earned USD 1650–4000 annually, which was 2.6–6 times the per capita income of the state. During winter, heavy snow forces the yaks and their crossbreeds to the multi-layered temperate and sub-alpine forests which have been extensively manipulated by the yak herders to increase the fodder availability. In terms of economics and equity in benefit sharing, we found that only a few families earned high incomes by maintaining large herds of yaks and *urangs*.

4.1.3 Pathway from knowledge to action

The *salience* or relevance of the study was enhanced as it was taken up to address a conflict situation being faced by the forest department and the government of Sikkim. The research questions were formed in alignment with the needs of policy makers. Also, there was a strong connect between scientists, policy makers and practitioners on the study design and data collection. The *credibility* of the study was enhanced by associating with the Wildlife Institute of India (WII), a premier research institute of the environment ministry of the federal government. Perceived as an inhouse study, the *legitimacy* of the study was strong as it was taken up in close coordination with the forest department, local community and NGOs.

When the study findings were presented to the forest department, they agreed with the findings but were hesitant to act. The yak herders were influential and networked with politicians, and hence, the forest department though having full ownership of the study was wary of the political will. The legal position in this case was clear, as per the provisions of the Wildlife Protection Act, 1972—grazing is prohibited in a National Park. The study was then presented to the chief minister of Sikkim, and after assessing the ecological impacts, he ascertained the number of households who would be impacted if a ban was imposed on the yak and yak crossbreed herding. Once satisfied that only 28 households were involved, he directed the secretary of the forest department to evict all the yaks and yak crossbreeds from KNP. Assessing socioeconomic dimensions of ecological issues is important, as policy makers synthesize multiple streams of knowledge for decision making. Also, even for stringent state and federal laws to be effectively implemented, political will and support of the local community is needed. During enforcement, the local community and NGOs fully supported the forest department. Consequently, within a short period, the number of yaks and their crossbreed reduced from 1250 to around 520. Impact of this transformative change is now visible with expanding blue sheep populations, increased snow leopard sightings and natural regeneration of temperate and sub-alpine forests (Sathyakumar et al. 2011). The scientific documentation and the conservation outcomes of this study contributed in KNP getting inscribed in 2016 as India's first mixed site on UNESCO world heritage list for fulfilling the nomination criteria under both natural and cultural heritage.

4.2 Promoting sustainable livelihoods for the poor

4.2.1 Demand for science

The government of Sikkim launched the "Mission Poverty Free Sikkim" in 2010 to address the issue of stagnating poverty, and the Rural Management and Development Department, Government of Sikkim (RMDD), was made the nodal agency. The general perception of urban Sikkim and RMDD officials toward rural Sikkim then was, "*the rural folks have become dependent on government doles and are hence leaving their fields barren*." In India, safety net programs are often derided as "freebies," "handouts" or "doles" and looked upon as a burden on the public exchequer (Drèze 2017).

In order to meet the objectives of the poverty free mission, it was crucial to objectively understand who are the poor, why they are poor and what are the pathways out of poverty? An inhouse study was taken up by RMDD to prepare Village Development Action Plans (VDAP) for all the *gram panchayats* (villages) of the state to ascertain the extent and determinants of poverty in rural areas VDAP (2011). The objective of the VDAP was to evolve a need-based planning mechanism from a demand-based one, and prioritize inclusive growth with a focus on the poorest of the poor. This research study has its genesis in the policy announcement of "Mission Poverty Free Sikkim." The study design and process were documented in the VDAP operational guidelines prepared after a few pilots. The criteria for Participatory Wealth Ranking (PWR) of the households were standardized based on these pilots and this absolute measure of poverty used for all the 163 gram panchayats. Joint teams comprising of RMDD functionaries and local villagers were formed and trained on participatory methods and tools.

4.2.2 Findings of the study

Landlessness, near landlessness, repeated failure of the main cash crop and multiple vulnerabilities (e.g., woman or old-aged-headed households, disability, disease) were found to be the main drivers of poverty. Many of the poor families suffered from a combination of the above factors. The main sources of non-farm income were limited to wage employment programs, agricultural labor and the construction sector. The profile of the poor household was prepared for the first time. The study found that the poor were mostly landless or near landless (< 0.5 acre land holding), lived in semi-permanent (*katcha*) houses with labor work being their main source of income. Modern and diversified farming practices such as floriculture, vegetable farming, dairy, poultry and jobs in the transportation and construction sectors had helped the households escape poverty. Better education had helped the youth secure jobs. The non-poor households fell back into poverty mostly due to disease (tuberculosis and life-style diseases) and alcoholism, as a result of the accompanying high health-care expenditure.

The study also found that the government-aided safety net programs, namely food transfer, wage employment, housing grant, free primary education, assistance for the disabled and old, were working well and prevented the poor households from falling deeper into poverty. These programs had resulted in a universal assured minimum standard of living in the rural areas. The largest poverty alleviation programme operating in the state was the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA). It is the largest public works programme in the world and invests funds to the tune of USD 7 billion

(1 USD = INR 65) every year in the rural areas of the country, providing employment to 57 million households. In Sikkim, this programme was investing sizably in the creation of public assets such as rural footpaths for intra-village connectivity, torrent training, drainage works and school playgrounds. However, there was a need for course correction as higher investments were needed in the livelihoods sector to lift the poor households out of poverty.

4.2.3 Pathway from knowledge to action

For the VDAP study, the *salience* or relevance was enhanced as it was taken up to address the pressing issue of persistent rural poverty. The co-design of the research study with the local- and district-level officials and the *gram panchayats* (elected representatives at village level) ensured subsequent ownership from them. The *credibility* of the study was enhanced by enlisting technical support from Professor Bernard Dafflon, University of Fribourg, Switzerland, a renowned expert in the field of fiscal decentralization. The study proposed restructuring MGNREGA to focus investment on household livelihood assets (HLA) instead of public assets. Initially, the MGNREGA investment restructuring proposed a 100% shift from public works to HLAs. However, the *gram panchayats* objected, preferring public works, as the infrastructure projects benefitted a larger section of society, thereby enabling them to showcase their achievements and increasing their chances of winning the next elections. Focusing development interventions only for the poor was not perceived as politically expedient by them. Consequently, to accommodate the viewpoint of the *gram panchayats* and strengthen the *legitimacy* of the study, the minimum investment on HLAs was kept at 50% as a workable solution acceptable to all stakeholders. Also, the initiative was aligned with the Mission Poverty Free Sikkim—a high-priority initiative of the chief minister to garner the support of all stakeholders. These changes helped in strengthening the *legitimacy* of the policy of shifting the investment focus of MGNREGA to livelihood assets for the poor.

The planning process of MGNREGA was made diagnostic, poor households were identified using participatory approaches, and SWOT analysis (strengths, weaknesses, opportunities and threats) of poor households was carried out to target livelihood investments in their lands. It took 4 years of continuous effort for transition to the livelihood approach. The investment on HLAs to create livelihood assets in the lands of the poor grew from 10% in 2012–2013 to 52% in 2015–2016. Animal husbandry which is the main livelihood for the landless and near-landless households was prioritized in a big way for the first time. Works related to horticulture plantations (large cardamom and mandarin orange), fodder development, land terracing, water storage tanks were also scaled up (Fig. 2). Transformative change is now visible as not only the poor farmers got wages, but this public investment to restore the productivity of their small farms is enabling them to return to full time farming.

An independent impact evaluation of MGNREGA covering all the four districts of Sikkim (TISS 2017) found that the creation of these HLAs had contributed toward securing a more robust rural economy, which has attempted to move toward self-employment by lowering economic dependence on government programmes. The greatest multiplier effect is seen in the case of large cardamom plantations, followed closely by assets such as orange plantations and cowsheds. Alternatively, there is only limited evidence of income multiplier visible in the case of plantations such as broom grass and guava plantations. However, the effects of these livelihood assets are not only limited to income multiplier, but extended

Fig. 2 Household livelihood assets (HLAs) like this 10,000-L reinforced concrete water storage tank built with an investment of about USD 1400 has enabled homestead farming

to expenditure multiplier as well. Additional income from MGNREGA has been able to increase purchasing power in terms of daily consumption expenditures, health and education expenditures for most social groups.

This mid-course correction in the planning process and alignment with state policy helped prioritize public investment for creating household livelihood assets (HLAs) in the lands of the poor. This initiative was recognized by the Ministry of Rural Development, Government of India, and bagged the National Award for Excellence in Sustainable Livelihoods in 2014 and 2017.

4.3 Co-designing revival of Himalayan springs

4.3.1 Demand for science

This research study has its genesis in an environmental challenge faced not by the policy makers, but by the local community. In a workshop held in Gangtok, Sikkim, in 2008 on world water day, the women farmers from the mid-hills highlighted the issue of drying up of perennial springs during the lean season resulting in untold hardships. These springs are known as *dhara, mool, kuan, simsaar* in the central and eastern and *chashma* and *naula* in the western Himalayas (Fig. 3). They are considered sacred and are protected as *devithans* (the abode of Gods). Gravity-flow water supply system tap water from these springs and streams to provide piped water at the household level. Drying up of these springs results in drudgery to women who need to then manually carry water from springs below their village. Earlier responses focused on planting wild banana (*Musa* sp.) and *dhokrey phul* (*Datura stramonium*) around the water source and erecting a loose-stone masonry wall around the water source. The questions for science were: What is the source of spring water, is the spring discharge linked to the rainfall pattern and can the dying springs be revived? These questions were posed to several academic institutions, namely WWF-India, People's Science Institute (PSI), G. B. Pant National Institute of Himalayan Environment and Sustainable Development (GBPNIHESD), Advanced Center for Water Resources Development and Management (ACWADAM) and German Technical Cooperation Agency (GiZ). These institutions helped in designing the pilots, training the field

Fig. 3 Springs are the only source of water in the mid-hills of the Himalayas and are drying up due to climate change, land-use change, poor watershed management, reduced infiltration and deforestation

staff in geohydrology and in designing the training manuals with an objective to develop a standard methodology for spring revival.

4.3.2 Findings of the study

The results from these pilots showed that the springs are fed by groundwater and are recharged by rainwater infiltration. The spring discharge generally showed an annual periodic rhythm suggesting a strong response to rainfall. The springshed development approach to revive springs using rainwater harvesting and geohydrology techniques showed encouraging results. The three springs in west Sikkim which were taken up under springshed development in 2011 showed a significant increase of 28–31% in the lean period discharge over the next 5 years. This study showed that revival of springs was possible by taking up artificial groundwater recharge works in the recharge area (springshed) of the aquifer (Tambe et al. 2012). The main challenges faced in springshed development were identifying recharge areas accurately, developing local capacity, incentivizing rainwater harvesting in farmers' fields and sourcing public financing. Science of spring revival is still evolving, and practice is ahead of science. Lack of instrumentation to measure the spring discharge and lack of automated rain gauges were the constraints faced in long-term scientific monitoring. Evaluation was found to be complex due to co-variates such as rainfall, tremors and lack of adequate baselines and controls and inadequate understanding of the structure and characteristics of the aquifers.

4.3.3 Pathway from knowledge to action

Based on the experiments, an eight-step action plan was designed for reviving Himalayan springs. With funding support from MGNREGA, a spring revival initiative (locally *dhara vikas*) was launched. The scientific aspects of this initiative were communicated using a spring revival handbook prepared in comic book style and helped to simplify the science of spring revival. This handbook worked as a boundary object bridging the world of scientists, policy makers and practitioners. Experience sharing with the Himalayan states and countries was also carried out. These interventions created awareness across the Himalayas regarding the problem of dying springs and the need to prioritize their revival. The standardization of the protocol for spring revival based on the learning from the pilots helped other states and countries to get a head start. The *salience* or relevance of the spring revival study was enhanced as it was taken up to address the pressing issue of dying springs in the mid-hills of Sikkim. The *credibility* suffered due to complexities arising due to co-variates such as rainfall and tremors, not having adequate baseline, limited understanding of the spring aquifers and not being able to take up long-term monitoring for a larger set of springs at landscape level. The spring discharge was measured manually which limited the robustness of the experiment. Instrumentation of the springs and automated measurement of rainfall at the field sites would have resulted in a richer dataset and provided useful learning (Rai 2018). The program found feedback from the water users easier to record than the biophysical indicators. The study gained *legitimacy* as it was taken up in close coordination with the district- and village-level officials, *gram panchayats* and the water users.

The bulk of the narrative on climate change in the Himalayas has revolved around glaciers and their retreat, which has implications for future downstream water supplies (Barnett et al. 2005; IPCC 2007). From a mountain perspective, ironically, the water from these rivers is not readily accessible to the densely populated villages and towns in the mid-hills (900–2000 m). These fast flowing rivers cut deep gorges and flow several hundred meters below, while the glaciers are far above this critical ecozone. This study contributed in shifting the focus on the mountain communities by turning the spotlight on the issue of dying springs which are the only source of accessible water in the mid-hills of the Himalayas. Several studies are now reporting the worrying trend of dying springs from other parts of the Himalayas (Chaudhary and Bawa 2011; Chapagain et al. 2017; Poudel and Duex 2017; Kumar and Sen 2018). This Himalayan spring revival initiative has been appreciated and recognized as a success story by UNDP (2012, 2015), SAARC (2013) and NITI Aayog (2018)—the policy think tank of government of India. Over the last few years, teams from several Indian Himalayan states and the Himalayan countries of Nepal and Bhutan have visited Sikkim to learn about the protocol of spring revival, and have got a head start on this climate change adaptation initiative.

5 Discussion

The learning from these case studies provides useful inputs on how to strengthen the CRELE of knowledge production to bridge the SPPI. The credibility of science was strengthened by linking the study with national research institutes, reputed civil society organizations and international experts. The salience or relevance of science was enhanced by first ascertaining the research gaps identified by policy makers and then co-designing the study to bridge these gaps. Inter-disciplinary approach was adopted as policy makers synthesize multiple streams of knowledge for decision making. The demand for science in these case studies was triggered in three scenarios—firstly to guide a new government policy, secondly when a policy or government mission faced implementation hurdles and thirdly as a direct demand from the practitioners. We found that linking science to high-profile policy announcements catapults it into the policy arena and its relevance increases many folds. The entry of science into the universe of policy makers is easier in the wake of new policy announcements. Academicians while designing a study are guided by their research interests or funding priorities and often do not want to cede autonomy in their research design. Legitimacy of science was strengthened by adopting a collaborative approach, as it helped in building acceptability of all stakeholders. Science pursued in a linear manner, with stakeholders meeting in the beginning and then toward the end, has limited acceptability to catalyze change. One of the real-world approaches bridging this science, policy, practice divide is the co-production of actionable science. In co-production, managers, policy makers, scientists and other stakeholders first identify specific decisions to be informed by science, and then jointly define the scope and context of the problem, research questions, methods, make scientific inferences and develop strategies for the appropriate use of science (Beier et al. 2017). Once policy approval has been obtained, implementation of the study depends on a shared understanding of the findings by all the stakeholders. The illustrated spring revival handbook functioned as a boundary object and helped to simplify and translate science for a non-scientific audience, thereby reinforcing the legitimacy of the study. This communication, translation and mediation functioned as bridge to connect scientists, policy makers and practitioners on one plane (Star and Griesemer 1989; Clark et al. 2016).

These case studies benefited from having mid-level policy makers who were exposed to the universe of scientists. These inhouse science stewards involved in the study helped in translating the policy requirements into science questions and then translating the study findings back to the policy makers. Transferring the learning from these case studies to other locations will hence need the support of external science stewards who are trusted by both policy makers and scientists (Boyd and Kramer 2017). They will have to broker the demand for science, frame research questions, interpret the scientific findings to the policy makers and practitioners by creating boundary objects and thereby complete the connect between these two universes. Inhouse studies brokered by science stewards and using co-production approaches have a lot of potential in providing working solutions to wicked problems.

6 Conclusion

Being the fastest growing region in the world, India has the opportunity to demonstrate to the world that it can grow sustainably, lift poor households out of poverty and create jobs while also conserving the natural capital and ecological infrastructure. This approach is all the more relevant in the ecologically sensitive Himalayan region. One of the challenges that India face in mainstreaming sustainability in its development trajectory is the inadequate alignment in the science, policy, practice interface (SPPI). Drawing on the experience gained in the Eastern Himalaya, we propose a three-pronged strategy to bridge the SPPI. Firstly, policy makers need to identify sustainability challenges and demand scientific inputs while scientists need to prioritize engagement with real-world problems to enhance the relevance of science. Secondly, academia needs to intensively engage with policy makers and synthesize the social, economic and ecological dimensions to have a greater chance of impacting policy. Thirdly, making this happen will need facilitation by science stewards to innovatively bridge the universe of scientists and policy makers. Future sustainability research can benefit from the co-production approach, and as more studies transcend the pathway of knowledge to action, we will collectively be able to deliver sustainability solutions that work for both nature and people.

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Affiliations

Sandeep Tambe[5] · Gopal S. Rawat[1] · Nima Tashi Bhutia[2] · Pem Norbu Sherpa[2] · Subash Dhakal[2] · Sarika Pradhan[2] · Himanshu Kulkarni[3] · M. L. Arrawatia[4]

Gopal S. Rawat
rawatg@wii.gov.in

Nima Tashi Bhutia
ntbhutia@gmail.com

Pem Norbu Sherpa
ffkaluk@gmail.com

Subash Dhakal
pkysub@gmail.com

Sarika Pradhan
saree18@gmail.com

Himanshu Kulkarni
acwadam@gmail.com

1 Wildlife Institute of India, Chandrabani, Dehradun, Uttarakhand 248001, India

2 Rural Management and Development Department, Government of Sikkim, Gram Vikas Bhawan, Gangtok, Sikkim 737101, India

[3] Advanced Centre for Water Resources Development and Management, Plot 4, Lenyadri Society, Pashan, Pune 411021, India

[4] Jaipur, India

[5] Indian Institute of Forest Management, Nehru Nagar, Bhopal, Madhya Pradesh 462003, India