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Spring Revival in the Mid-Hills of the Himalaya: A Socioeconomic Assessment Using Benefit–Cost Analysis

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Natural springs are the main water source for more than 100 million people living in the Hindu Kush Himalaya. In Nepal, 10 million people in the mid-hills and mountains depend on them. These sources are under stress due to factors such as climate change, infrastructural development, and socioeconomic changes. To combat this trend, spring revival activities have been carried out across the Hindu Kush Himalaya in the last few years. Considering 2 study sites in Nepal, this work attempts the first benefit–cost analysis for spring revival in rural settings. First, using literature and community consultations, a cause–effect map was drafted. Second, the benefits and costs were estimated quantitatively using 4 scenarios: 2 based on the study sites and 2 on more generic situations. Positive (>1) benefit–cost ratios were found in 3 scenarios, showing that spring revival has potential but local conditions (households served, presence of other water sources, usage) are important factors to be considered.

Keywords: *cost–benefit analysis; Nepal; spring revival; water; Hindu Kush Himalaya (HKH); environmental economics; resilience.*

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Introduction

The hydrological system within the Himalayas is facing considerable strain for a variety of reasons. On the one hand, population increase, increased reliability of water supply (Chen et al 2023), and lifestyle and economic changes (Bharti et al 2020; Faulon and Sacareau 2020) are augmenting water demand. On the other, scarce governance capacity (Ojha et al 2020), urbanization and development (Wester et al 2019; Daniel et al 2021), and climate change are contributing to a decline in annual precipitation, glacier volume (Shea et al 2015), runoff (Nie et al 2021), and an increase in extreme weather events, such as floods and glacial lake outburst floods (Akhtar et al 2008; Shrestha and Aryal 2011; Nie et al 2021). Until recently, the main focus of studies on mountain water availability was on glaciers and snowpacks, mostly from a climate and hydrological perspective (Maurya et al 2011; Bajracharya et al 2015; Kumar 2020). Nonglacial contributions, such as groundwater, have been ignored (Andermann et al 2012; Bookhagen 2012; Verma and Jamwal 2022), but research has shown their significant role in water basins (Williams et al 2016; Wilson et al 2016; Wood et al 2020; Yao et al 2021).

The case of Nepal well represents all these challenges. The country is one of the richest in terms of water but ranked among the lowest in terms of drinking water supply (Thakur et al 2017; Gurung, Adhikari, Chauhan, Thakuri, Nakarmi, Ghale, et al 2019; Komatsu et al 2020; Joseph and Shrestha 2022). Mid-hill areas, home to 43% of the national population, are of particular interest (Wester et al 2019) because of their unique characteristics. Indeed, unlike higher-elevation areas that depend on glacier-fed water sources to meet their water needs, these regions primarily rely on groundwater, predominantly sourced from water springs (Agarwal et al 2012; Tambe et al 2012; NITI Aayog 2018).

In recent years, several studies have focused on different aspects of water springs, such as defining conceptual models for mountain water aquifers (Tambe et al 2020), spring hydrological classification (Daniel et al 2021), methods of investigation (Herschy 1993; Smakhtin 2001; Tarafdar 2013; Chinnasamy and Prathapar 2016), understanding discharge trends (Agarwal et al 2012; Chapagain et al 2019; Gurung, Adhikari, Chauhan, Thakuri, Nakarmi, Ghale, et al 2019; Pandit et al 2019; Adhikari et al 2021; Dhakal 2021), causes of spring degradation (Poudel and Duex 2017; Poudel 2020), water quality assessment (Tiwari 2000; Gurung, Adhikari, Chauhan, Thakuri, Nakarmi, Rijal, et al 2019; Bhat and Pandit 2020; Khadka and Rijal 2020; Thapa, Pant, et al 2020), and spring distribution modeling (Al-Manmi and Saleh 2019; Ghimire et al 2019).

Efforts have been made to understand the state of these springs, with estimates suggesting that more than half of the 3 million perennial springs in the Indian Himalayas (NITI

TABLE 1 Summary of study site characteristics at the 2 revived springs in Namobuddha municipality.

Characteristic	Bhagwate Pakhako Kuwa	Patalko Dhara
Location	27°34′08″N; 85°37′47″W	27°34′17″N; 85°37′28″W
Spring type	Depression	Depression
Elevation (masl)	1235	1415
Ethnicity of main users	Lama	Dalit
Recharge area type	Community forest	Private fields and community forest
Ecosystem area	2 hectares (upstream and downstream)	1 hectare (up and downstream)
Water flow increase	from 0 to 0.74 lpm	from 2.84 to 3.37 lpm
Users as primary source	1 household	21 households
Users as secondary source	24 households	14 households
Fetched water	Used for irrigation or as emergency source	Currently piped to tank
Intervention	5 ponds, 16 trenches, 4 check dams, 8 palisades	9 trenches, 1 pond

Aayog 2018) have either dried up or become seasonal (Valdiya and Bartarya 1991; Tiwari 2000; Kumar and Sen 2018; Thapa et al 2023). The trend of declining spring discharge is also observed in the Nepali mid-hill region, where over 30% of monitored springs show a decrease in discharge (Chapagain et al 2019). Different factors contribute to this decline in both water quantity and quality. These include higher temperatures (Pandey et al 2017), changing precipitation patterns (Agarwal et al 2012; Macchi et al 2015), land use and soil erosion (Rautela 2015; Pandey et al 2017), changes in forest types (Ghimire et al 2014; Naudiyal and Schmerbeck 2017), infrastructure (Huber and Joshi 2015; Mukherji et al 2018), and sporadic events, such as earthquakes (Lamichhane et al 2020).

Alongside the hydrological and environmental perspectives, researching water management is crucial from a social science perspective. It is closely connected to key aspects of social inequalities related to caste, gender, and power dynamics, often overlooked in water security initiatives (Leder et al 2017; Shrestha and Clement 2019). In the context of rural domestic water management, women bear significant responsibilities, but they often lack equal representation in decision-making processes (Wali et al 2020). This disparity is rooted in factors such as male-dominated representation on decision boards and deeply ingrained historical and societal norms (Raut 2023). The biophysical perspective has thus evolved, first, by incorporating management considerations and subsequently by integrating socioeconomic dimensions. Currently, approaches such as sociohydrology (Sivapalan et al 2014; Blair and Buytaert 2016; Nüsser 2017; Herrera-Franco et al 2021) conceptualize human–water systems as interconnected entities, recognizing the interactions between society and nature as essential for accurately modeling water systems (Di Baldassarre et al 2015; Gober and Wheater 2015; Troy et al 2015).

Revival projects are being implemented across the Hindu Kush Himalaya (HKH) with varying levels of community involvement. Institutions such as ICIMOD (Shrestha et al 2018) and Aayog–International Water Management Institute (IWMI) (Rathod et al 2021) have provided practical guidelines, yet significant gaps persist. These include the need for better documentation of spring revival projects, deeper understanding of spring mechanisms, and more robust assessments of the effectiveness and benefit–cost ratios of techniques, as well as improved integration of physical sciences with governance and social dimensions (Kumar et al 2023). This study addresses these gaps by offering, to the authors' knowledge, the first known benefit–cost analysis (BCA) of spring revival activities in the mid-hills to inform regulatory efforts.

Methods

Study sites

The 2 study sites consist of the water springs Bhagwate Pakhako Kuwa (BHA; 27°34′08″N; 85°37′47″W) and Patalko Dhara (PAT; 27°34′17″N; 85°37′28″W) and their surroundings. Both are located in Namobuddha municipality (Table 1; Figure 1), 40 km from the capital (GGGI 2018). Despite being situated in a water-rich district, the municipality has recently faced water depletion (Khatri et al 2021). The examined project, a collaboration between ICIMOD and Agricultural Policy, Research and Extension Development (CEAPRED), focused on marginalized groups and aimed to address the drying of springs through the initiation of revival activities (Dhakal 2021; Khadka et al 2021). The project was part of ICIMOD's broader Resilient Mountain Solutions pilot initiative, which emphasizes gender-inclusive, socially resilient solutions (Pokhrel et al 2019). The project employed a "water tower" approach (Tambe et al 2020), which considers the mountain aquifer as the primary unit of planning, rather than individual springsheds. This emphasis is justified by the aquifers' key role in linking precipitation and spring discharge within the mountain water system. The process followed ICIMOD's protocol (Shrestha et al 2018) which outlines 6 steps for spring mapping and revival: mapping, data monitoring setup, understanding governance systems, hydrogeological mapping, spring management protocol, and measuring

FIGURE 1 Overview of the study sites. (A) Location of Fulbari water tower in relation to Kathmandu. (B) Fulbari water tower and location of the 2 study sites within it. (C) Patalko Dhara spring and its surroundings. (D) Bhagwate Pakhako Kuwa spring and its surroundings.

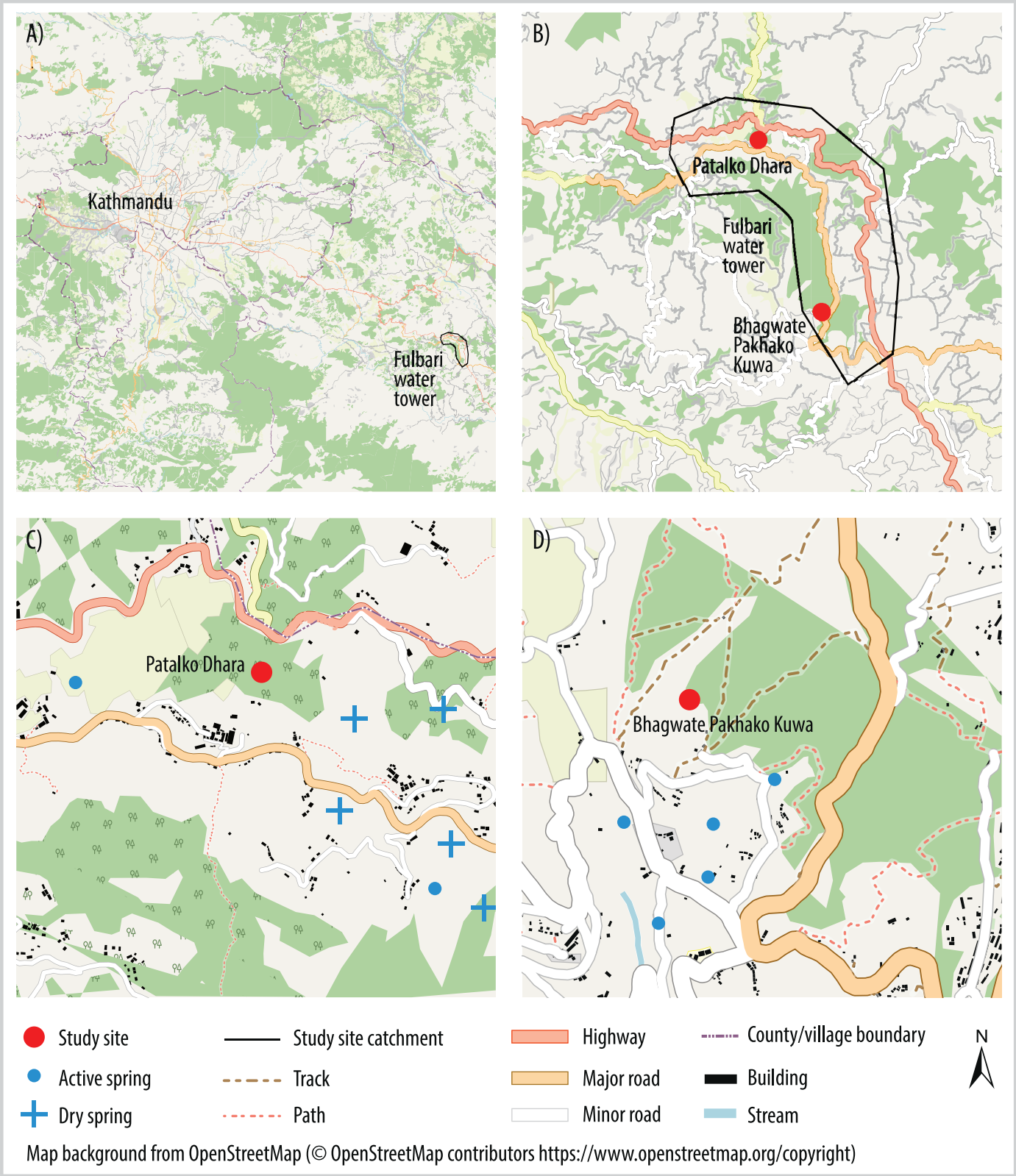
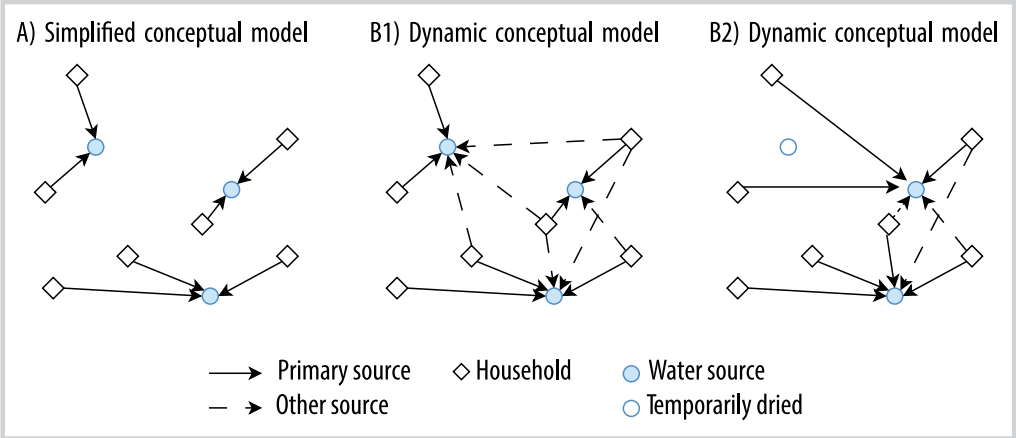


FIGURE 2 Diagram showing 2 different ways of conceptualizing water resources and households in a village. A simplified one where each household is supported by one source (A) and another model (B1, B2) where households can have multiple sources with a primary or secondary role that may change across the seasons. In a benefit–cost analysis (BCA), the 2 models would lead to different weighting for each water source and likely to different results. Arrows point to the water source used by a household.



impact. The project identified 50 springs (28 active, 22 dry) in the Fulbari water tower (Pokhrel et al 2019; Khadka et al 2021), 2 of which were selected for revival.

The Bhagwate Pakhako Kuwa spring is located at 1235 masl, with 1 household (HH) using it as its primary water source and 24 HHs as a secondary/alternative source. The recharge area of the spring lies within the community forest. Downhill from the spring, there is a plains area with several dug wells. The spring was drying mainly due to the rapid increase in the number of dug wells and consequent overextraction. Research shows that it dried up in 2019, possibly due to lowering of the water table (Pokhrel et al 2019). For the revival activities, 5 ponds, 16 trenches, 4 check dams, and 8 palisades were constructed.

The Patalko Dhara spring is located at 1412 masl in Damaidada village, with 21 HHs using it as their primary water source and 14 HHs as a secondary one. The recharge area is partially within community forest and partially within private fields. The spring has been experiencing a decline due to factors such as variability in rainfall intensity and duration, the impact of the 2015 earthquake, and the abandonment of traditional ponds. For the revival activities, 9 trenches were dug and a pond was constructed to enhance groundwater recharge. In 2022 the community further improved their water supply system by installing a pump to transfer water to a water tank. This upgrade allowed for the gravity-driven distribution of water to 21 HHs directly.

The application of the BCA method in this study, though limited to 2 sites, is representative of the spring system in the mid-hill region of the Himalaya. The mid-hills, characterized by longitudinal parallel zones, share regional similarities, particularly in their geology, which influences the spring system (Dhital 2015). The cases studied focus on depression-type springs, the most common type in the mid-hills. Both formal and informal systems exist for managing these spring sources throughout the region. The spring–HH dependency structure illustrated in Figure 2 is also typical of other parts of the mid-hills.

Along with these study sites (scenarios PAT and BHA), 2 more generic scenarios were included in the analysis. The aim was to estimate the potential costs and benefits (1) where ecosystem benefits are fully developed (GEB, for "generic, ecosystem benefits") and (2) where supply needs of the surrounding households are fully provided for (GWS, for "generic, water supply").

Qualitative mapping

Before the BCA economic valuation, qualitative mapping was done to identify the effects of spring revival activities for later quantification. To do so, a literature review was performed from May to July 2023 using Scopus and Semantic Scholar. Key themes were explored with search strings like "water security AND (Himalaya OR Nepal)" (38 relevant documents), "climate change AND Himalaya" (17 documents), and "(spring OR springshed) AND (Himalaya OR Nepal OR HKH OR Hindu Kush OR revival)" (38 documents). Expert opinions (4) were also gathered from within ICIMOD in September 2023 using semistructured interviews focusing on specific themes according to the experts' background.

Furthermore, in September 2023, focus group discussions (FGDs) were held with local communities residing near the springs. Participants were primarily selected from water user groups (WUGs). WUGs are typically structured to reflect the demographic diversity of the municipality, ensuring balanced representation in terms of gender, age, and other social characteristics. In this case, the groups included 2 males and 6 females at Patalko Dhara, and 5 males and 3 females at Bhagwate Pakhako Kuwa, spanning various age groups and including minority populations.

Given the time constraints of the study and the communities' familiarity with this method, FGDs were chosen for their effectiveness in capturing diverse perspectives and fostering equal participation of those most impacted by spring revival activities (Sim 1998; Krueger and Casey 2015; Sangaramoorthy and Kroeger 2020).

Benefit–cost analysis of spring revival

After the qualitative mapping, an economic valuation through BCA was performed (Hanley and Barbier 2009; OECD 2015; Harris and Roach 2017; Boardman et al 2018; Abelson 2020). BCA is a methodology that compares the total costs of implementing an activity (in this case the revival of a

spring), against the expected benefits quantified in the same currency. The aim is to determine whether the benefits outweigh the costs. Although this method has been widely used for policy advice, its application to environmental remediation is more recent (Brauman et al 2007; Atkinson and Mourato 2008; Mendelsohn and Olmstead 2009; Ratnaweera et al 2021). In Nepal, BCAs have been carried out to estimate the willingness to pay for conservation activities (Lamsal et al 2015), environmental costs (Pakhtigian and Jeuland 2019), ecosystem services (Kc et al 2013; Thapa, Wang, et al 2020), households' commitment to contributing to river restoration (Khatiwada et al 2023), and, in Sikkim, soil and water conservation (Mishra and Rai 2014). In this study, the BCA adopts the national standing (Abelson 2020), aligning with Boardman (2018) and national guidelines (Abelson 2020). The chosen perspective affects whether a factor is seen as a cost or benefit.

Results

Cause–effect mapping

The qualitative mapping data and findings were organized into benefits and costs, with each category associated with a numerical equation to facilitate quantitative estimation. The costs were sourced from project data and categorized as follows: material costs (C_{mat}), skilled labor for project management (C_{lab}), skilled labor for mapping and design of infiltrations (C_{lab_wt}), site supervision and unskilled labor for manual work (C_{unlab}), operation and maintenance (O&M) costs for things such as pumps, operator salaries, and repairs (C_{om}), as well as financial and opportunity costs linked to loan interest and other possible investments (C_{fin}).

The identified benefits included ecosystem benefits (B_{ecos}), increased household crop productivity due to greater water availability (B_{prod}), time-saving benefits (B_{time}) from reduced water fetching, and health benefits (B_{health}), particularly from reduced gastrointestinal disease. Additional benefits, such as cultural benefits (B_{cult}) linked to the spring, benefits from land price increase (B_{land}) due to proximity of revived water source, and increased social capital (B_{soc}) were only identified but not quantified. The parameters and equations used for the quantification are provided in Tables 2 and 3.

All results and data, unless stated otherwise, are expressed in NPR 100,000 (LNPR) equal to EUR 707, USD 750, or CNY 5477 as per October 2023. Most parameters were defined using statistical distributions such as uniform (U(min, max)) and normal (N(mean, SD)). Risks and uncertainty were addressed using a Monte Carlo simulation with R package MC2D (Pouillot and Delignette-Muller 2010). Global sensitivity analysis was carried out using the Multisensi package in R (Bidot et al 2018).

A key finding from the mapping phase highlights the complexity of local water supply sources. HHs often rely on multiple sources, including nearby springs, distant piped water, and wells. Although HHs may have a preferred primary source, their choice often shifts due to factors such as seasonal changes, temporary scarcity, and ongoing initiatives that modify the system. Consequently, the impact of each spring varies depending on its role within the broader local water supply system (Figure 2).

The effects of spring revival activities were synthesized and presented in terms of cause and effect (Figure 3). The 2 main activities related to the revival of springs—mapping with capacity building and construction of infiltration structures—yield various outputs. While some short-term effects, such as time savings, health benefits, ecosystem services (ES), employment increase, and productivity, were used in the BCA analysis, others, such as land price and increased social capital, were noted but excluded from the quantification. Regarding land price, while some literature on Nepal exists (Joshi et al 2017), it was not possible to retrieve enough updated information on the study sites to include the effect in the BCA. Social capital increase, on a short time range, was considered not to be significant from a quantification point of view. Long-term effects, such as improvements in employment, children's health, and nutritional development, were acknowledged but omitted due to the difficulty of establishing a direct causal relationship with spring revival.

Specific case studies illustrate the varied impacts of these revival activities. The Patalko Dhara spring serves as the sole water source for 7 HHs and the primary source for 14 others. The revival led to additional infrastructure improvements, including a cement path, fencing, and a water pump, supported by a nongovernmental organization, that now deliver water directly to households via a gravity-fed pipeline. These enhancements resulted in benefits from reduced expenses for water trucking, increased livestock, and higher crop production. However, benefits from ES were minimal, as the surrounding area is little used for productive activities.

In contrast, the Bhagwate Pakhako Kuwa case presents a different scenario. Here, the spring is located near multiple water sources (3 springs, 20 hand wells, and 1 borehole) that diminish its direct impact on the local community, relegating it to the status of an emergency water source. The spring water is primarily used as an additional source for irrigation of nearby fields and as a drinking source during agricultural work in the vicinity. Regarding ecosystem benefits, the community has observed increased vegetation in the recharge area and is considering planting *timmur* (*Zanthoxylum armatum*) and *tite pati* (*Artemisia vulgaris*) (Equation 1 in Table 3) due to their potential income generation.

BCA results

Skilled labor for mapping and design of infiltration was the main cost in 3 scenarios (GEB, GWS, BHA), while cost of operations was the highest for PAT. Total costs were in the range of LNPR 12–16 for 3 scenarios (GEB, GWS, BHA), whereas they were higher in PAT (LNPR 31) due to the O&M costs of the pump (Table 4). Over a 10-year period, benefits were the lowest for BHA (LNPR 6.28), due to the limited use of the spring, but were higher in the 2 generic scenarios (LNPR 32.25 for GEB and LNPR 44.09 for GWS), and the highest for PAT (LNPR 52.72) because of the recently established piped water supply to 21 HHs. Therefore, the benefit–cost ratio (BCR) was below 1 for BHA (0.24) and highest for GEB (4.03) and GWS (3.49). The internal rate of return (IRR)—a parameter commonly used to identify the profitability of an investment by determining

TABLE 2 Summary of parameters used in the BCA. Uniform distribution parameters are written as *U*(min, max), and normal distributions are written as *N*(mean, standard deviation). (Table continued on next page.)

Parameter	Description	Bhagwate (BHA)	Patal (PAT)	General environmental benefit (GEB)	General water supply (GWS)
C_{mat}	Construction material (stone, wood), land and tools used for the physical construction of revival measures (LNPR per spring)	*N*(1.2, 0.3)	*N*(0.8, 0.3)	*N*(1.2, 0.3)	*N*(1.2, 0.3)
C_{lab}	Skilled labor for setting up data monitoring and project management (LNPR per spring)	*U*(1.5, 2.5)			
C_{unlab}	Includes labor used for the construction and for site supervision. This is likely to be sourced locally (LNPR per spring)	*U*(0.8, 1.3)			
C_{om}	Includes costs to cover maintenance of infiltration measures as well as costs for energy consumption and labor in the case of pump installation (LNPR per spring)	*U*(0.1, 0.2)	*U*(1.4, 1.8)	*U*(0.1, 0.2)	*U*(1.4, 1.8)
C_{fin}	Includes cost of capital, assumed at 8% (LNPR per year)	*U*(0.16, 0.26)			
C_{lab_wt}	Includes fees paid to experts and technician for the water tower mapping, hydrogeological survey, measuring impact and detailed revival measures	*U*(8, 10)	*U*(8, 10)	*U*(2, 10)	*U*(2, 10)
R_{ew}	Rate of improvement caused by the additional water flow on the ecosystem assumption based on expert opinion (LNPR per project)	*U*(0.15, 0.30)			
V_{ecos}	Value of the ecosystem services in LNPR/hectare based on Pant (2009) and Taye et al (2021)	*U*(0.6, 1.4)			
A_{ecos}	Area of affected ecosystem as the sum of the recharge area and the downstream area until a road or stream is met	*U*(1, 3.5)			
W_{saved}	Water saved from purchasing due to flow increase, liters per year		*U*(9000, 15000)		*U*(9000, 15000)
W_{cost}	Price per liter in NPR		*U*(0.7, 1.2)		*U*(0.7, 1.2)
HH	Number of households using the spring	*U*(1, 5)	*U*(11, 21)	*U*(5, 30)	*U*(5, 30)
F_{usage}	Fraction of HH saving water, this is to account for the fact not all houses will be saving water	0.66			
W_{prod}	Water productivity at HH level related to crop production, based on Dhakal (2020) with production of NPR 6000/year and in this case only for 6 months, therefore LNPR 0.03	Not used, see Equations 2 and 3 in Table 3	*U*(0.02, 0.04)	Not used, see Equations 2 and 3 in Table 3	*U*(0.02, 0.04)
Q_{rev}	Increased water flow due to revival activity, liters per day.	*U*(800, 1900)	Not used, see Equations 2 and 3 in Table 3	*U*(500, 2000)	Not used, see Equations 2 and 3 in Table 3

TABLE 2 Continued. (First part of Table 2 on previous page.)

Parameter	Description	Bhagwate (BHA)	Patal (PAT)	General environmental benefit (GEB)	General water supply (GWS)
$V_{w.prod}$	Water productivity, NPR/1000 L	$U(5.6, 12)$		$U(5.6, 12)$	
T_{save}	Time saved from a single trip to the spring in hours. Based on community consultation.	$U(0, 0.1)$	$U(0.1, 0.5)$	$U(0.1, 1)$	$U(0.1, 1)$
VOT	Value of time, based on a value of 50–80% (Whittington and Cook 2019) of daily unskilled labor salary (NPR 1000/day). Estimate also considers the 133 NPR/hour given to water pump operator in PAT (NPR 7000/month)	$U(62, 100)$			
$R_{t.prod}$	Fraction of time reallocated to productive activities considering weekly productive hours as 23–28 (Yokying et al 2023; Picchioni 2020)	$U(0.15, 0.5)$			
$R_{loc.l}$	Ratio of labor procured locally	Not used in this BCA, see equation 6 in Table 3			
$R_{loc.m}$	Ratio of material purchased locally	Not used in this BCA, see equation 6 in Table 3			
DW	Disability weight for gastroenteritis as 0.18 DALY (IHME 2020) × 2 events per year (Shlim et al 1999) lasting 4 days	1.44 days			
$R_{ill.red}$	Reduction of illness due to increased water, based on Howard et al (2020)	20%			
GDP_{pppy}	Gross domestic product per person per day based on US$1336 per year (data.world.bank.org)	NPR 485			
COI	Cost of illness that would include medicine and travel to a doctor	NPR 1000			

Note: DALY, disability-adjusted life years.

the discount rate that would lead to a Net Present Value of 0—was negative for BHA and in the range of 144% and 405% for the other scenarios (Figure 4). A comparison across scenarios is detailed in Figure 5. Linear regression on the 2 generic scenarios (GEB, GWS) showed that BCR and IRR can be predicted ($R^2 = 0.85$) with HH and T_{save} for GEB, and with HH, T_{save}, and $R_{t.prod}$ for GWS (Table 3).

Discussion and recommendations

This study aligns with previous research in identifying direct-use benefits from natural resources (Tenge2005; Mishra and Rai 2014), employment opportunities (Kihila et al 2014), and ecosystem benefits (Thapa, Pant, et al 2020; Taye et al 2021). However, it also emphasizes indirect benefits related to human systems, such as enhancing social capital through knowledge acquisition, reducing community tensions, and appreciating land values—factors often overlooked in BCAs (Kc et al 2013; Mishra and Rai 2014; Acharya and Dhungel 2021; Mcharo and Maghenda 2021). While these benefits were identified, they were not quantified, underscoring the need for further research on community participation (Bhandari et al 2005; Longworth 2022), water management conflict (Upreti et al 1999; Upreti 2001; Devkota2018), impact on land prices (Joshi et al 2017; Nepal et al 2017), and cultural benefits (Roebeling et al 2016).

Cost quantification revealed that hydrogeological mapping activities (C_{lab_wt}) were the most impactful, except in scenarios where water supply fees were applied (C_{om} in PAT). This suggests that using an aquifer-based approach for revival can provide economies of scale benefits since mapping costs would be spread across different springs.

Time-saving benefits were particularly significant. However, their quantification is highly dependent on how the saved time is reallocated (Yokying et al 2023) and the difficulty in isolating the factors influencing this decision (Cooke 1998; Koolwal and Walle 2016). Consequently, these estimates should be interpreted with caution and further research is recommended, especially since the value of time (VOT) in rural areas is likely to change in the coming years.

ES and productive benefits were 2 other relevant categories. Although ES were primarily focused on water

TABLE 3 Summary of equations used in the BCA.

Equation no.	Symbol	Equation	Description
1	B_{ecos}	$B_{ecos} = R_{ew} \times V_{ecos} \times A_{ecos}$	Ecosystem benefits for GEB and BHA scenario
2	B_{ecos}	$B_{ecos} = W_{saved} \times W_{cost} \times HH \times F_{usage}$	Ecosystem benefits for GWS and PAT scenario
3	B_{prod}	$B_{prod} = W_{prod} \times HH$	Economic benefits from increased productivity due to increase in water use for PAT and GWS
4	B_{prod}	$B_{prod} = Q_{rev} \times 365 \times V_{w.prod}$	Economic benefits from increased productivity due to increase in water use for GEB and BHA
5	B_{time}	$B_{time} = T_{save} \times 4 \times VOT \times HH \times 365 \times R_{t.prod}$	Economic benefits from time saving assuming 4 trips per day
6	B_{impl}	$B_{impl} = (C_{lab} + C_{unlab}) \times R_{loc.l} + C_{mat} \times R_{loc.m}$	Benefits from activity implementation. Giving the standing of this BCA this item would be in the costs as well as the benefits and therefore was not accounted for. Different BCA standing would bring different results.
7	B_{health}	$HH \times 4 \times DW \times R_{ill.red} \times (GDP_{pppy}/365 + COI)$	Health benefit for population (HH × 4 people)
8	PV	$PV(X_t) = X_t\,[(1+i)^{-t}]$	Present value, where t stands for time (10 years in this case) and i is the discount rate. The discount rate was modeled as U(6%, 12%) considering previous studies with 6% (Mishra and Rai 2014) and 12% (Kc et al 2013).
9	NPV	$NPV = \sum B_t(1+i)^{-t} - \sum C_t(1+i)^{-t}$	Net present value, where B_t is the total benefit, C_t the total costs, i the interest rate, and t the time period in years.
10	BCR	$BCR = \frac{B_t}{C_t}$	Benefit–cost ratio, where a value above 1 is considered positive, as it indicates that benefits outweigh costs, whereas a value below 1 is considered negative.
11	IRR	$0 = NPV = \sum_{t=1}^{T} \frac{C_t}{(1 \times IRR)^t} - C_0$	Internal rate of return, where C_t is the net cash flow during period t, and C_0 is the total initial investment cost.
12	BCR_{GEB}	$BCR_{GEB} = -1.5 + 0.2HH + 3.7T_{save}$	Linear regression for BCR in the GEB scenario, R^2 of 0.85 and sensitivity index of $T_{save} = 0.29$ and HH= 0.39.
13	IRR_{GEB}	$IRR_{GEB} = -0.35 + 0.18HH + 0.52T_{save}$	Linear regression for IRR in the GEB scenario, R^2 of 0.85 and sensitivity index of $T_{save} = 0.29$ and HH= 0.39.
14	BCR_{GWS}	$BCR_{GWS} = -3.93 + 0.2HH + 3.5T_{save} + 10R_{t.prod}$	Linear regression for BCR in the GWS scenario, $R^2 =$ 0.85 and GSI as HH = 0.57, $T_{save} = 0.2$, $R_{t.prod} = 0.08$
15	IRR_{GWS}	$IRR_{GWS} = -0.6 + 0.026HH + 0.42T_{save} + 1.2R_{t.prod}$	Linear regression for IRR in the GWS scenario, $R^2 =$ 0.85 and GSI as HH = 0.57, $T_{save} = 0.2$, $R_{t.prod} = 0.08$

Note: GSI, Generalized Sensitivity Indices (Bidot et al 2018).

provision, they may have been underestimated, as prior research indicates a broader range of potential benefits (Taye et al 2021). Productive benefits could not be fully assessed due to the lack of relevant agricultural activities linked to the springs. These factors resulted in BCR outcomes in the 4 scenarios with ratios (mean 2.35, min 0.24, max 4.05) consistent with published studies on watershed management in India by Joshi et al (2008) that reported BCR with mean of 2.00, minimum of 0.80, and maximum of 7.30. The higher BCR in the generic scenarios suggests that springs have greater potential if their full capacity is developed. This could be achieved by focusing on springs that serve more HHs, increasing water productivity through crop cultivation, reducing O&M costs via semiautomatic controls, and reducing mapping costs through citizen science.

Data limitations prevented disaggregation by gender, age, or sociocultural groups. However, existing studies show that women disproportionately bear the burden of water fetching (Shrestha and Clement 2019; Wali et al 2020; Raut 2023), which affects their time (Yokying et al 2023) and energy (Picchioni et al 2020). This exacerbates women's dual roles in productive

FIGURE 3 Cascade diagram, based on literature and community consultation, showing activities, results, and outcomes of spring revival and what benefits it may generate.

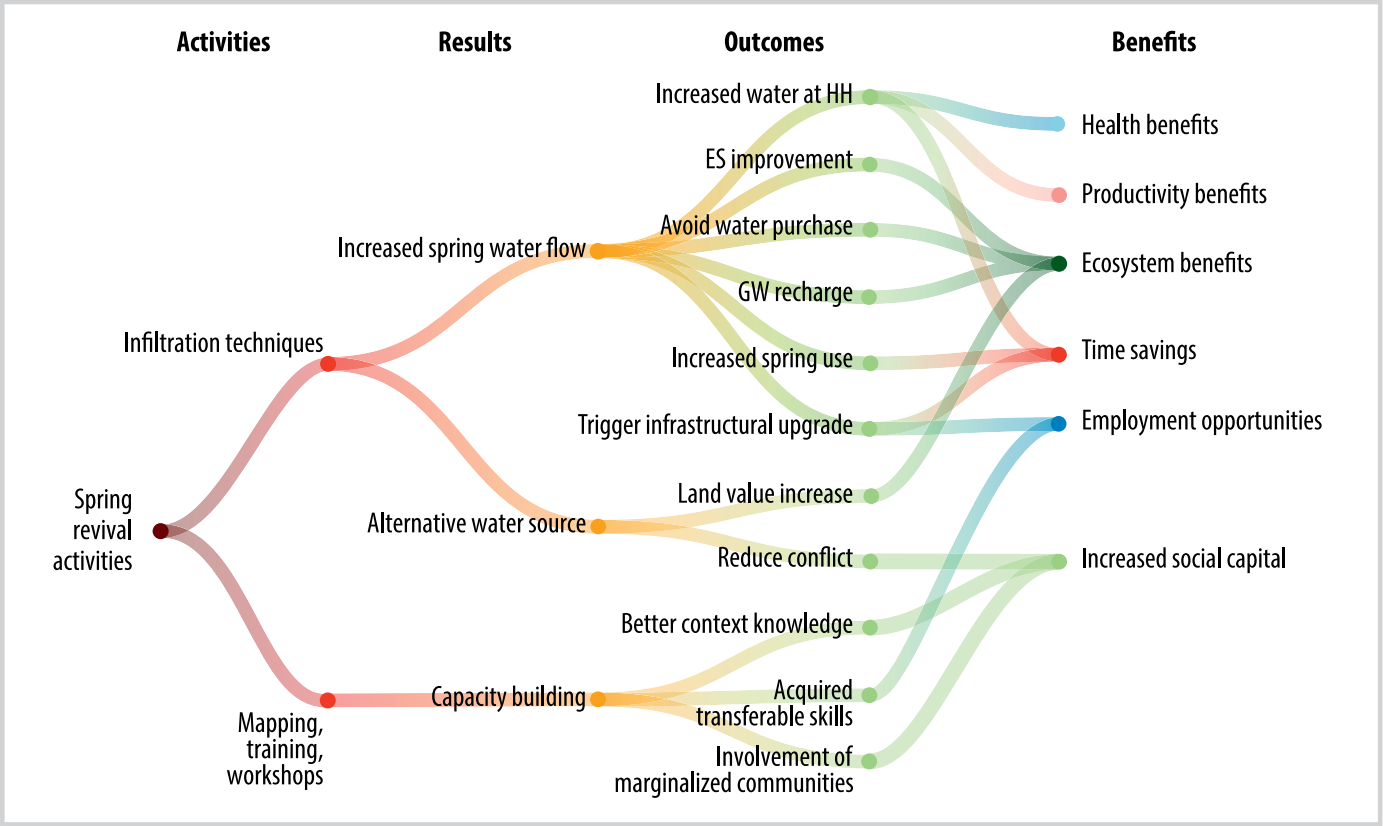


TABLE 4 Summary of BCA results for the 4 scenarios (all values in NPR 100,000): Bhagwate Pakhako Kuwa (BHA), Patalko Dhara (PAT), a generic scenario with fully developed ecosystem benefits (GEB), and a generic scenario with avoided water purchasing (GWS).

Parameter	GEB	BHA	PAT	GWS
C_{mat}	1.14	1.15	1.15	1.15
C_{unlab}	1.06	1.05	1.04	1.05
C_{om}	1.52	1.51	16.03	1.50
C_{lab}	2.00	1.99	1.98	2.02
C_{fin}	2.10	2.12	2.11	2.09
C_{lab_wt}	4.24	8.96	8.98	4.26
Total costs	**12.07**	**16.78**	**31.29**	**12.07**
B_{ecos}	4.92	3.07	13.30	13.06
B_{prod}	0.57	0.43	5.05	5.20
B_{time}	23.66	0.40	31.29	22.66
B_{health}	0.89	0.17	0.89	0.97
IRR	**0.22**	**–0.24**	**0.18**	**0.36**
Total benefits	**32.25**	**6.28**	**52.72**	**44.09**
NPV	**8.53**	**–4.52**	**9.05**	**13.62**
BCR	**4.05**	**0.24**	**1.62**	**3.49**

Note: See Table 2 for a detailed explanation of the parameters.

and reproductive work. Although research on children's involvement in water fetching is limited (Whittington and Cook 2019), evidence suggests that reducing this burden can improve school attendance and health outcomes for children (Nankhuni and Findeis 2004; Koolwal and Walle 2016; Nauges and Strand 2017). These findings suggest that spring revival activities are likely to benefit more vulnerable groups and contribute to reducing gender disparities.

Last, the BCA has some limitations related to its temporal scope. The 10-year time frame may be insufficient given the rapid socioeconomic changes happening in Nepal. Furthermore, the hierarchical and dynamic nature of water source systems was not fully captured, which could benefit from incorporating methods such as system mapping, network analysis (Hevey 2018), and longitudinal data collection to calibrate a dynamic model.

Conclusion

The research employed a mixed-method approach to comprehensively examine the qualitative and quantitative ramifications of spring revival activities in the mid-hill region of Nepal. This mixed methodology proved beneficial in capturing the diverse and complex ramification of revival activities.

The BCA analysis, run on 4 different scenarios over a 10-year timeframe, showed a positive net present value (NPV) and BCR in 3 scenarios (PAT, GEB, GWS) and negative results for 1 scenario (BHA). Overall, costs were mainly influenced by mapping activities, while benefits stem from

FIGURE 4 Histogram showing benefit–cost ratio (BCR) in the 4 scenarios (top row) and internal rate of return (IRR) (bottom row). Red line in BCR histograms at BCR = 1 and IRR histograms at IRR = 0.3 as a reference value.

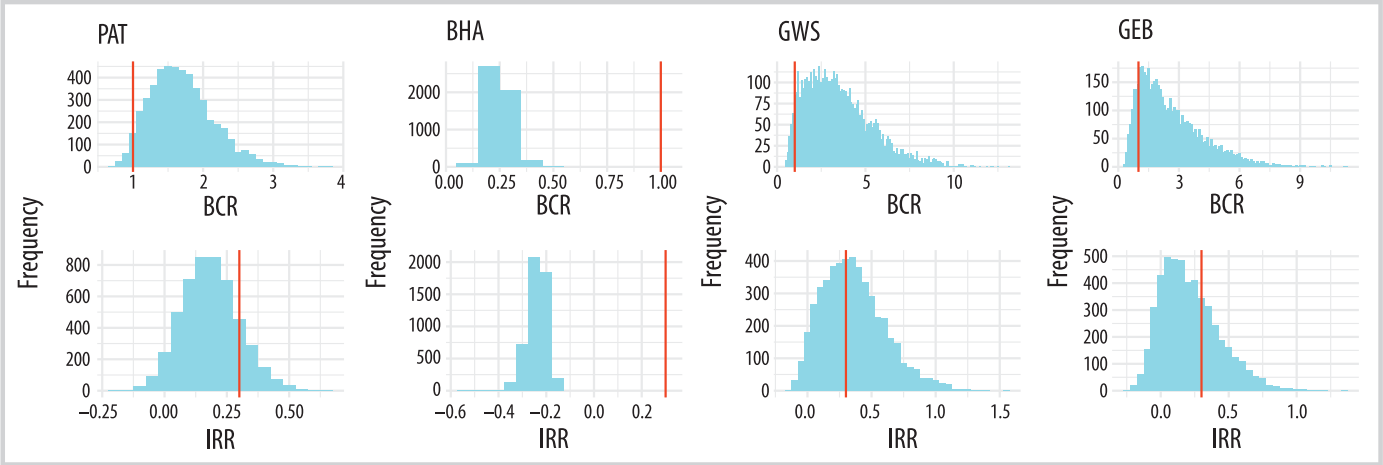
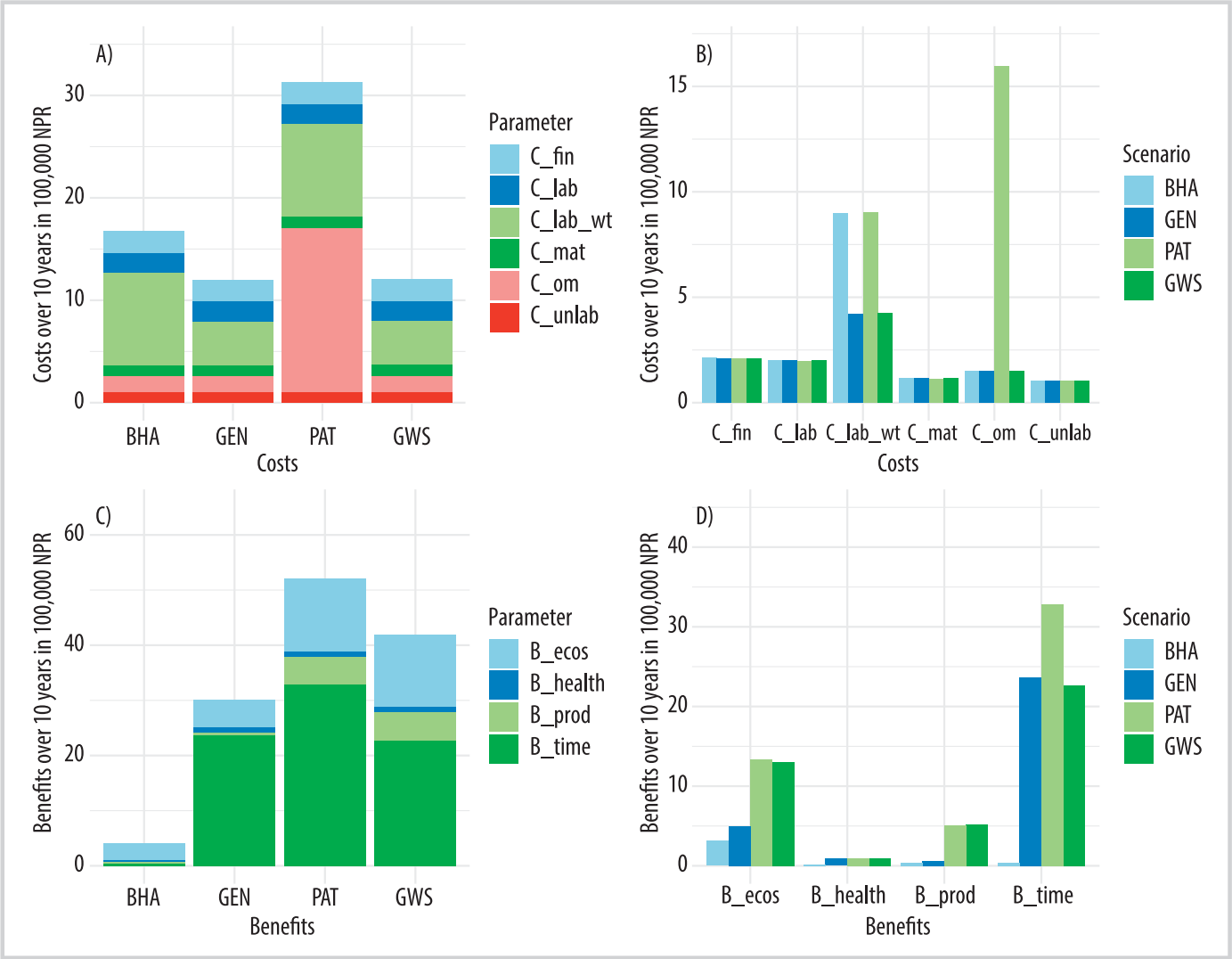


FIGURE 5 Comparison between (A) cost types across the 4 scenarios and (B) contributions of each cost type over a 10-year period for each scenario, and between (C) benefit types across the 4 scenarios and (D) contributions of each benefit type over a 10-year period for each scenario. Values are in 100,000 NPR. See Table 2 for a detailed explanation of the parameters.



time-saving and ecosystem improvements. A linear regression on BCR and IRR results showed that for the 2 generic scenarios, 3 parameters (household number, time saved, and share of time allocated to productive activities) could accurately predict final estimates.

From a sustainability perspective, revival activities impact surrounding communities and the environment in multiple ways, generally with benefits outweighing costs. These activities address the 3 pillars of sustainability (environment, economy, people) and can therefore be considered an effective solution for developing sustainable communities.

Policy recommendations

This study indicates that spring revival activities can yield a positive BCR, despite the fact that some benefits, such as acquired skills, increased social capital, and conflict reduction, cannot be easily monetized. Policymakers should consider this limitation when relying on BCA.

Furthermore, spring revival activities were found to be catalysts for other infrastructural improvements. This indicates that such activities need to be thought of and implemented in synergy with other upgrades happening in the community.

While the suggestion to adopt a springshed (Dahal et al 2021) or an aquifer-based approach is valid, it may find challenges at governance level when the intervention area spans across different wards and municipalities. Policies should account for this aspect and support coordination across actors.

Raising capital for O&M costs is a crucial policy intervention (Rathod et al 2021), as municipalities often fail to allocate adequate budgets for this purpose (Dahal et al 2021; Thapa et al 2023). Although many benefits of spring revival activities are not marketable, this study indicates a willingness to pay for water supply services, particularly in the PAT scenario. The findings demonstrate long-term economic and social benefits of spring revival activities, justifying investments in fund allocation and potentially attracting private investments by offering a clear economic rationale. Policymakers should prioritize securing funds for O&M costs and leverage community willingness to pay to sustain water services. Additionally, policymakers should justify and support investments in these activities.

As demonstrated, this study enhances our understanding of the impact of spring revival in mid-hill rural settings, showing that revival activities are likely to have high BCR if all potential benefits for the surrounding community are fully realized. Therefore, it is recommended that longitudinal monitoring mechanisms be established within the project's beneficiary communities to gain deeper insights into the evolving impacts of spring rejuvenation over time.

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DISCLAIMER

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