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Social Innovation Perspective of Community-Based Climate Change Adaptation: A Framework-Based Study of Ladakh, India

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Abstract: Indigenous knowledge of local environments is crucial for developing innovative and contextual climate change adaptation strategies. Although the significance of community-led efforts based on this knowledge has been well acknowledged, they have not been effectively incorporated into mainstream development processes. The mountainous region of Ladakh presents a novel case of water storage in the form of ice reservoirs as an adaptive strategy against intensified water scarcity. This study aims to assess community-based innovations in climate change adaptation strategies and find solutions for their effective integration. This study theorizes a framework for Social Innovation in Climate Change Adaptation (SICCA) for a structured analysis of the situation in Ladakh. This research was conducted through interviews, surveys, Geographic Information System-based mapping, and field observations to analyze the use of ice reservoirs as a solution to water scarcity issues. The results demonstrate the wide recognition of these techniques' effectiveness and the role of the community in the planning, execution, and operation of the initiatives. The findings highlight the challenges in their scaling up and diffusion. The research emphasizes the need to recognize and value community-based adaptation strategies to address the challenges posed by climate change. It offers recommendations for integrating them into the mainstream development process, and the framework serves as a significant outcome to guide policymakers and civil society actors for practical implementation.

Keywords: community-based innovations; Ladakh; planned adaptations; traditional practices; water management; water scarcity

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Citation: Kumar, T.; Saizen, I. Social Innovation Perspective of Community-Based Climate Change Adaptation: A Framework-Based Study of Ladakh, India. *Water* **2023**, *15*, 1424. https://doi.org/10.3390/w15071424

Academic Editor: Adriana Bruggeman

Received: 27 February 2023
Revised: 3 April 2023
Accepted: 4 April 2023
Published: 6 April 2023

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1. Introduction

The Socio-ecological systems worldwide are undergoing destructive and noticeable changes under the influence of human action induced by climate change [1]. Owing to climate change, there has been widespread degradation of ecosystem resilience, function, and structure, as well as changes in seasonal timing and natural adaptive capacity [2]. Climate change-induced changes in precipitation patterns and warming weather conditions have raised several issues related to the quantity and quality of water resources, negatively impacting human health, agriculture, and ecosystems. Ensuring safe and secure water availability to people worldwide while promoting its sustainable use is a fundamental concern today [3]. Adapting water resource management planning to the changing environments has become extremely important in this regard [4]. According to the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), approximately four billion people worldwide live under extreme water scarcity for at least one month per year [5]. Therefore, holistic and inclusive adaptation efforts and mitigation actions are necessary to address the challenges posed by climate change.

The communities that are already disadvantaged and marginalized are at greater risk of being affected by climate change [6]. Mountainous communities are especially recognized to be among the most vulnerable to climate change [7]. A higher degree of vulnerability arises from their remoteness, altitude, slope, inaccessibility, fragmented nature of settlements, lack of resources, and fragility [8,9]. Weather conditions, hydrology, vegetation, ecological conditions, and socioeconomic settings vary rapidly with elevation in mountainous regions. Cultural and social values have also changed over short distances. It is essential to recognize the complexities of the interaction between the environment and society in this context [10]. These communities living in mountainous regions experience unusual weather patterns, including disproportionate warming, extended and relatively warmer winters, and irregularities in rainfall and snowfall. These changes greatly affect the livelihoods and well-being of communities living in these areas [7].

Community-based adaptation is an effective way to address the challenges posed by climate change [11]. These bottom-up approaches empower people and enhance communities' adaptive capacity to effectively tackle the impacts of climate change [12,13]. The keys to the success of these initiatives are innovation and active participation at the local level [14]. Both components rely heavily on the knowledge, resources, and social ties of the local communities. Additionally, traditional knowledge can provide valuable insights into the local environment and ways to manage it sustainably. The integration of knowledge and technology into climate action can lead to more effective adaptation strategies [15,16]. IPCC's fourth assessment report acknowledges the importance of traditional knowledge and experience in building adaptive capacity and resilience. The creation and application of traditional knowledge involves active interactions with the environment and strong social ties within the community [17]. This knowledge is acquired by the local population through interactive experiences and observations of their natural environments. Throughout history, indigenous communities around the world have adapted their livelihoods to variations in climate and have thus shown great potential in fighting its adverse impacts. Site-specific traditional knowledge and coping strategies can contribute significantly to identifying and providing sustainable solutions to threats posed by climate change [18].

Ladakh is a high-mountainous, cold desert region in India. It is part of the Hindu Kush-Himalayan region and lies between the Himalayas and the Karakoram mountain ranges. A wide range of studies have focused on the physical changes in the cryosphere of the region and their impact on the Upper Indus Basin, of which Ladakh is a part. However, few studies have focused on the high mountain communities of the region, where humans live very close (within 30 km) to cryosphere elements such as glaciers, permafrost, and snow [19]. Water is a scarce resource in the region, and settlements are dependent on meltwater from snow deposits and glaciers flowing down the valley from the higher reaches. Even though the people of the region are habituated to surviving in water-scarce situations based on their traditional knowledge and practices, recent changes in weather patterns have developed concerns [20,21]. In response to these changes, various techniques of preserving water in the form of ice have been introduced in Ladakh and are viewed as innovative and effective adaptation measures [22]. Although these strategies are underpinned by a strong social system, there exists a research gap on the social dimension of these initiatives which is addressed in this study.

Ladakh presents a unique case of community-based initiatives for climate adaptation rooted in traditional knowledge, community ties, and socio-natural relationships. This study presents a comprehensive overview of the water challenges faced by the region and various community-led adaptation strategies to address these challenges. This study aims to explore the potential of community-based approaches for developing innovative strategies to adapt to the impacts of climate change and theorizes a framework for integrating these strategies into mainstream policy structure. This framework is applied to the case of ice reservoirs in Ladakh with the objectives of (i) understanding the socio-natural context concerning water in the region, (ii) identifying the impact of climate change on water availability, (iii) identifying and reviewing the innovative adaptation strategies employed in the region, and (iv) inferring the shortcomings of adaptation efforts and proposing steps for their successful integration into mainstream planning processes.

2. Framework for Social Innovation in Climate Change Adaptation

Recently, the social dimension of change and development has been gaining increasing recognition, with a focus on innovations that contribute to societal well-being and sustainability [23]. In complex socio-ecological systems, they play a significant role in creating new pathways for sustainability [24]. Innovation also plays a crucial role in adapting to climate change. Social Innovation is a key emerging concept in this regard. It is a process in which local communities enhance their capacity to act against challenges and social needs by establishing social and cultural capital [25]. Although it has gained significant interest among researchers in the social sciences and humanities, its definition and relevance have been highly contested [26–28]. The term has been used widely in various contexts with multiple discourses, such as societal transformations, social entrepreneurship, governance and capacity-building models, and new product and service development, among others [29]. One of the most popular narratives revolves around the idea of contextual and novel citizen initiatives that empower society and create new cooperative movements. This study builds on the notion of social innovation and its relationship with community-led development. This idea is frequently used by researchers and policymakers for a shift in the developmental agency from public to private responsibility and from the government to non-government and community actors [26].

Innovation refers to the development of a new idea, method, or device that caters to existing or new requirements. Its general understanding of innovation is mainly focused on technical and economic innovation, with a focus on innovations in materials and products, methods of production, and marketing and organizational processes. However, social innovation refers to a form of innovation that responds to a social need and is created by actors with the goal of social well-being [30]. Social innovation may refer to a collective process in which members of certain groups and communities invent and establish new social practices by acquiring the required intellectual, rational, and organizational skills [31]. One key dimension of social innovation satisfies the needs of society that are not met by the market or state, as they fail to perceive its importance [32]. They provide solutions to societal issues that have otherwise been neglected in mainstream governance and political structures. It is created by individuals or groups with the primary motivation to improve people's lives [33,34]. Andrew and Klein [33] further argued that civil societies make a significant contribution to this process, as they identify the needs of society, raise awareness, and innovate to meet social needs.

In terms of outcomes, social innovation can address the direct and practical needs of the society and can also contribute to intangible outcomes by creating new forms of collaboration and social actions empowering the society [26,35]. Social innovations not only make physical or material contributions to the social good but also help generate social capital by creating new social relations and the capacity to engage in collective and collaborative action [25,29,36,37]. In summary, social innovation can be understood based on the following key characteristics:

i. Socially motivated: It should be conducted with the motivation of the well-being of society
ii. Innovative and Creative: It should present a novel solution.
iii. Collaborative and Inclusive: It should mobilize the actors for collective action.
iv. Capacity building: It should enhance society's capacity to act through participation and empowerment.

Recent research on climate change has emphasized the roles of collective efforts, community resilience, and community-based adaptation to climate variability [38]. By utilizing knowledge, skills, and resources within local communities, social innovation can strengthen communities' abilities to cope with the impacts of climate change. Based on the aforementioned theoretical narrative, this study proposes a framework for social innovation in climate change adaptation (Figure 1). This framework aims to provide a structured approach for identifying and implementing new ideas, approaches, and solutions to address the social and environmental challenges of climate change. The major components of this framework are discussed below.

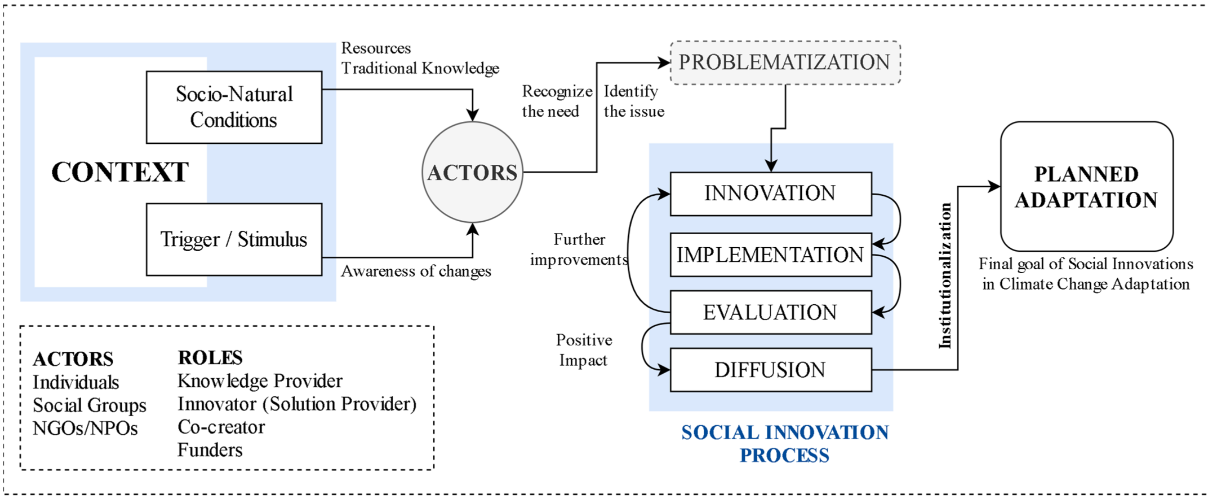

Figure 1. Framework for Social Innovation in Climate Change Adaptation.

Context is an important aspect to consider when examining social innovation. While all forms of social innovation have social well-being at their core, socioeconomic and cultural contexts play a major role in stimulating ideas and providing novelty to the solutions. Many researchers argue that social innovations are socially, culturally, and territorially embedded [36,39–41]. These contexts also determine the acceptance of innovation. Abundant human and social capital, along with the presence of place-based social networks, a common sense of place, and identity, are some of the key contextual factors that form a favorable setting for innovation for social causes [26]. Place-based knowledge of socio-natural interactions and an awareness of ecological functions are also critical for facilitating innovations dealing with changes in environmental conditions. Apart from these, one significant factor leading to social innovation is a trigger or stimulus. These are events of increased intensity or critical junctures in the socio-natural conditions that motivate individuals or groups to seek innovative solutions. Climate change and its associated events act as triggers for social innovation at the global level [42]. Understanding the context in which social innovation occurs is important for evaluating its potential impact and developing effective strategies to support its development and implementation. Further, the understanding of the socio-natural conditions and triggers helps the actors in the 'problematization' process in which they recognize the societal needs and identify the issue to be addressed through innovation.

The second component is the social innovation process. Researchers have attempted to define the social innovation process in various contexts [25,27,30,43–45]. Building on these studies, we propose four steps in the social innovation process: (1) innovation, (2) implementation, (3) evaluation, and (4) diffusion. In the first step, actors identify problems and develop new ideas or solutions. In the second step, the idea is applied in a pilot project. This concept is evaluated to test the impact of innovation. This evaluation is subjective based on the perceptions of the actors involved. This idea may be continued through these processes in a feedback loop of development and refinement. Once an innovation is deemed successful, it undergoes replication and scaling up in the fourth step. The success of this idea attracts an increasing number of actors to adapt and innovate further in various contexts. The entire process of innovation, when applied to climate change adaptation, can be seen as a process that is termed by the IPCC [2] as "autonomous adaptation". Autonomous adaptation occurs when people sense changes in weather patterns and make efforts to adapt. Autonomous adaptations are based on indigenous and local knowledge and reflect the experiences of local people, their awareness, and their perceptions of the risks posed by climate change [2]. Similar to social innovation, autonomous adaptation is considered an initiative by private actors instead of the government [46]. When these adaptation efforts go through institutionalization, they become formalized and are known as "planned adaptation", that is, conscious efforts by the government or public agencies to adapt to climate change [2]. The final goal of this process is to transform social innovation-based adaptation efforts into planned adaptation. Social innovation becomes successful when its positive impacts are recognized and integrated into the mainstream development structure through institutionalization [30].

Incorporating this framework for social innovation in climate change adaptation, hereafter referred to as the SICCA framework, can help analyze and evaluate community-based climate change strategies and guide the process of finding contextual solutions from the community by encouraging innovation and co-creation. The SICCA framework can also be used to identify issues in the process and provide solutions for successful integration into existing development planning processes.

3. Materials and Methods

3.1. Study Area

Located in the northernmost part of India (Figure 2), Ladakh is characterized by its high mountain ranges, reaching up to an altitude of 7750 m. The region has a cold and arid climate, with temperatures dropping as low as −45 degrees in winter. Being located on the leeward side of the Himalayas, it receives very little precipitation (less than 150 mm annually), and due to western disturbances, the majority of this precipitation is in the form of winter snowfall [47–49]. The landscape is barren, with limited vegetation, which is cultivated by villagers, and patches of greenery near glacial streams and rivers [50]. Seventy-seven percent of the population lives in rural areas [51] and relies on subsistence farming and livestock rearing for their livelihood. Local farmers' adaptation to harsh, high-altitude, and cold climates forms the basis of human settlements in the region [52].

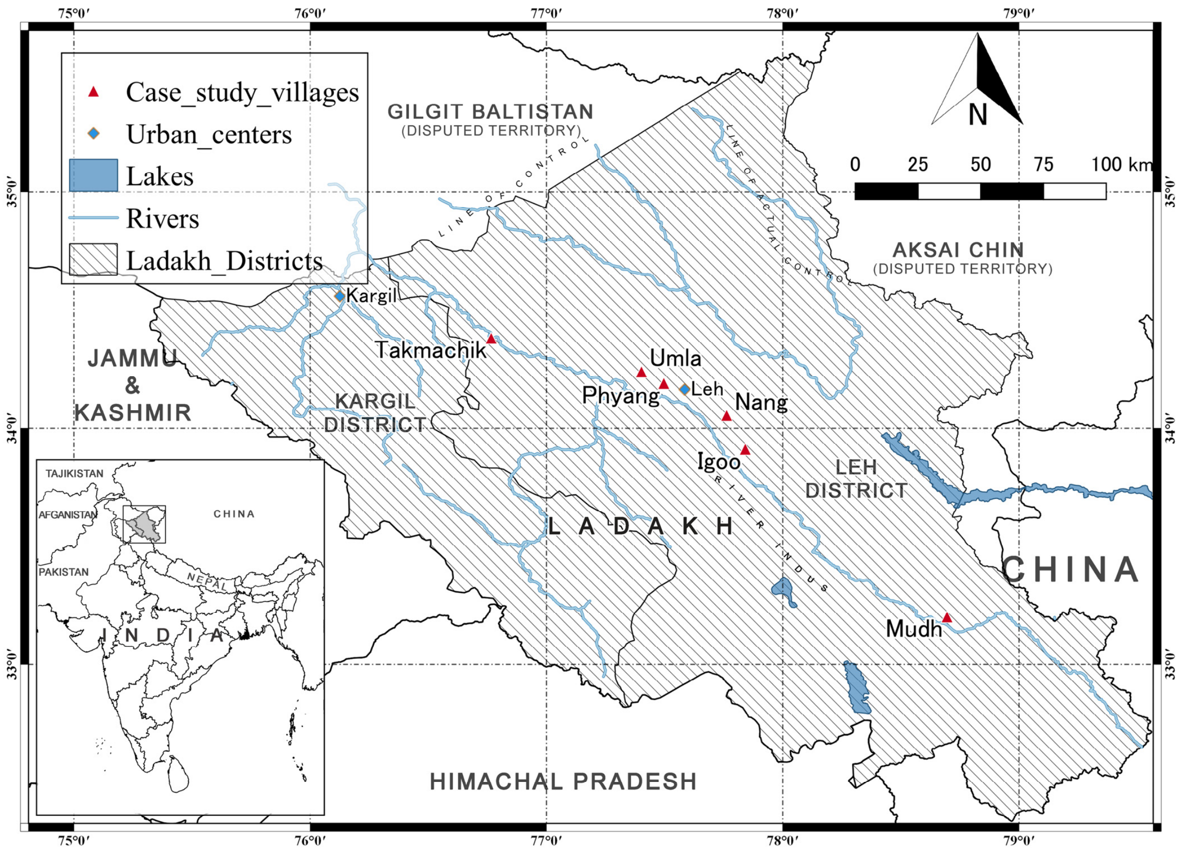

Figure 2. Location map of Ladakh with the case study villages.

Recently, the availability of meltwater has been delayed annually, causing water scarcity during the sowing season. This delay poses a major threat to agricultural practices in this region. As a solution to this seasonal water scarcity and a strategy for long-term climate change adaptation, communities in the region have developed innovative solutions for creating ice reservoirs [53]. Famously referred to as "artificial glaciers," their reservoirs are constructed at lower altitudes compared to natural glaciers to provide meltwater earlier and thus increase the time span of the growing season for the farmers [54]. Communities now use multiple techniques to store water in the form of ice as an adaptation measure. These practices are mostly led by local non-governmental organizations (NGOs) and draw heavily on the traditional knowledge of the community and social ties and networks in rural areas for their success.

3.2. Methods

This study uses a mixed-method approach to analyze the case of Ladakh, incorporating various methods and techniques for collecting and analyzing data while the framework guides the process from start to finish. The research is primarily qualitative and is based on ethnographic research conducted in the region over multiple field studies. The use of the SICCA framework ensures a systematic and thorough examination of the problem and allows for the identification of key factors and relationships.

To understand the context in which ice reservoirs were developed as an adaptation strategy, we first investigated the dynamics of water availability in the region. To gain insight into the socio-natural conditions, the traditional water management practices of the region were studied. Furthermore, the changing weather patterns and their impact on traditional livelihoods in the region were studied to understand the triggers or stimuli that encouraged the innovation of ice reservoirs.

The first author made several visits to the region (in 2014, 2015, 2017, 2019, 2021, and 2022) to gain insights into diverse contextual developmental issues and local socioeconomic practices. Dedicated fieldwork was conducted in October–November 2021 and June–July 2022 to collect information about traditional irrigation management and livelihood practices under the influence of recent socioeconomic changes as well as changes in weather patterns.

The general characteristics of changing weather patterns and their effects on the region were established based on existing literature. The literature included articles focusing on changes in the cryosphere, changing weather patterns, irrigation water management practices in the region, water scarcity, and adaptation techniques. Starting with long-term changes in weather resulting in glacier depletion and warming of the region, irregularities in precipitation and temperature patterns were understood through literature studies. These were then confirmed through the perceptions of the people in the region through questionnaire surveys and interviews.

To clarify the contextual issues in rural areas, especially focusing on agriculture and irrigation management, semi-structured expert interviews were conducted. These interviews were structured to obtain a broad range of information, as well as the experts' exclusive knowledge and understanding of the region. Keeping this in mind, experts were carefully selected, including local actors from the villages and regional stakeholders. A total of 21 interviews were conducted with government officials, Non-governmental Organization (NGO) staff, water conservation activists, community leaders, sub-leaders, and other intellectuals. These interviews provided a crucial understanding of past and existing socioeconomic and cultural practices, recent changes experienced in the region, mitigation and adaptation efforts, and future prospects focusing on development in the rural areas of the region. The interviews were followed by open-ended discussions. With consent from the interviewees, audio recordings and written transcripts were created for the study wherever possible.

Interactions and interviews with the NGO staff provided detailed insights into the water situation in the region and the various efforts undertaken to improve and adapt to water scarcity. Five NGOs involved in development activities in the region were contacted, and interviews were conducted with the heads and other staff members. Four of these NGOs worked to improve water availability in the villages by creating ice reservoirs and played a key role in adaptation efforts. Detailed discussions were conducted on past experiences and the processes followed in planning and executing projects related to water in villages. Information in terms of reports on past projects, photographic documentation, and presentations was collected from the NGOs.

To understand the exclusive dependency of villages on meltwater flowing down glacial streams and their non-reliance on rivers, six villages were selected. The selection criteria were proximity to the Indus River and a history of using adaptation strategies to improve water availability in the village. These villages are widespread in the region. Table 1 provides basic information on the settlements. The table is arranged as villages from upstream to downstream and east to west, as shown in Figure 2.

Table 1. Basic information of study villages.

Village Name	Distance from Leh (km)	No. of Households	Cropped Area (Sq. km.)	Settlement			River Indus at the Village
				Area (Sq. km.)	Min. ele (m)	Max. ele (m)	Elevation (m) (above Mean Sea Level)
Takmachik	110	95	0.5	1.29	2920	3000	2890
Umla	26	21	0.12	2.9	3790	3950	3100
Phyang	18	352	2.13	5.5	3297	4054	3197
Nang	28	74	0.53	1.26	3543	3846	3272
Igoo	45	238	1.51	6.77	3448	4070	3354
Mudh	188	127	0.47	0.77	4175	4293	4139

Semi-structured surveys were conducted in these villages. The questionnaire covered a range of topics to understand the villagers' perspectives on changes in weather patterns, socioeconomic changes, agricultural and irrigation practices, and community engagement. The questionnaire surveys were followed by open-ended interviews and informal discussions focusing on water availability and efforts made for improvements in this regard. The first author stayed with families in three of the study villages (Takmachik, Phyang, and Mudh) during the field research period, participated in agriculture-related activities, and attended four village-level meetings (three in Phyang and one in Mudh).

Field observations were made by taking multiple walks across the village along irrigation canals under the villagers' guidance. The ice reservoirs are located at higher elevations from villages. Hikes were undertaken in each village to check the status of these artificial reservoirs during the summer months (June–July, 2022). A GPS device was used to mark important landmarks and irrigation infrastructures in the villages. Subsequently, a GIS-based mapping of the irrigation system and watershed was performed using QGIS 3.4.15. The "Glacier Area Mapping for Discharge from the Asian Mountains" (GAMDAM) inventory of glaciers by Akiko Sakai [55] for the region was used to map and quantify the glacier area and numbers in the region and also for the watershed of each study village. Furthermore, all the results from these steps were structured based on the SICCA framework, and a case study-based narrative of the changes experienced in rural areas under the influence of changing weather patterns and decreasing water availability, along with the community-based innovative adaptation efforts in the Ladakh region, were developed.

4. Results and Discussion

4.1. Context: Spatiotemporal Variation of Water Availability and Its Traditional Management

Context provides the resources, knowledge, and social capital needed for the creation, implementation, and adoption of innovation. In the case of Ladakh, the region's long experience in dealing with water-scarce environments is a key contextual contributor to the creation of ice reservoirs. The two major parts of this include (i) the spatiotemporal variation in the availability of water and (ii) traditional water management systems.

Spatiotemporal variation in the availability of water: Ladakh is part of the Upper Indus Basin and has river systems such as the Indus, Zanskar, and Shyok. Figure 3 shows a hydrological map of Ladakh. The number of glaciers within the current administrative boundaries of Ladakh is 7715. With a total area of 7375 sq. km., approximately 12.5 percent of the region is covered by glaciers. Furthermore, the lake area in the region is approximately 460 sq. km. The region has a huge reserve of water resources but faces water scarcity. This phenomenon is understood in detail based on the spatiotemporal variations in water availability.

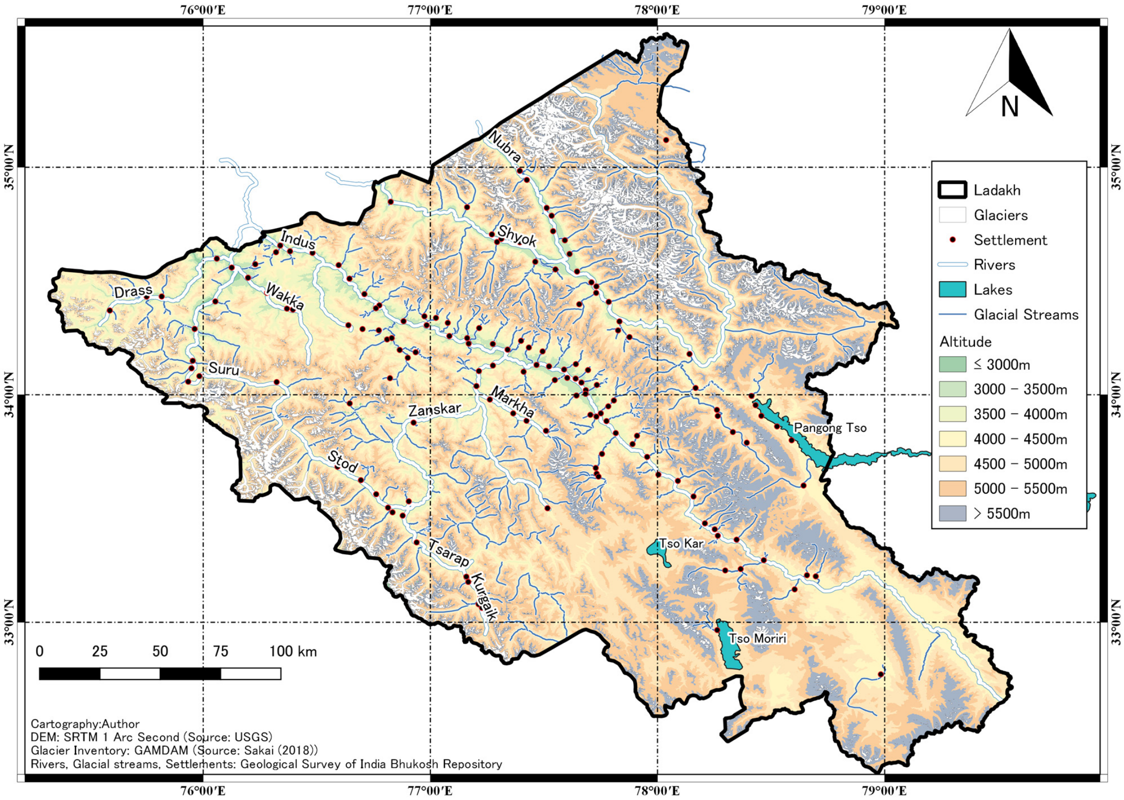

Figure 3. Hydrological map of Ladakh.

To understand the spatial variation in water availability, it is crucial to examine the settlement patterns in the region. Despite the presence of numerous river systems, as depicted in Figure 3, settlements do not depend on them. This is due to the topography. Surrounded by high mountains, rivers are usually at their lowest elevations in valleys. It is challenging to lift water to higher elevations by using traditional methods. Therefore, most settlements in Ladakh depend on the glacial streams flowing down the valley. Consequently, they are located higher in the valleys of glacial streams and use the meltwater flowing in these streams via gravity-fed irrigation systems. Only a few villages are located on the banks of the river where the valley is flat. Such flat valleys are rare in the region, and because of regular flooding in such areas, settlements close to the rivers in such flat valleys are also rare [56]. In addition, in many cases, being close to a river means that the settlements are shadowed by high mountains. This results in fewer daylight hours. Being located higher in the valley and distributed over the mountain slope ensures better daylight availability. This is why most settlements are spread along the slope of the valley. This pattern was observed in the six case study villages. Table 1 shows the minimum and maximum elevations of the settlement as well as the elevation of the Indus River near the settlement (measured at the intersection of the glacial stream and the river). Depending on the topography, villages are located at varying elevations above rivers. Takmachik is the closest to the river in terms of altitude difference, whereas Umla is the farthest. It is also interesting to note the altitude spread (the difference between the maximum and minimum altitudes in the settlement) of the villages on their valley slope. Takmachik has the smallest spread of 80 m, while the altitude spread of Phyang is 757 m. It is difficult to lift water from the Indus River because of this elevation difference. Consequently, settlements in Ladakh are located along glacial streams or at the intersections of glacial streams and rivers. This pattern is observed for most settlements in the hydrological map (Figure 3).

The amount of water flowing down glacial streams mainly depends on the watershed area. The watershed boundaries of these glacial streams are marked by high mountain ridges forming steep valleys. This, along with the slope gradient and slope aspect of the valley, affects the amount of snowfall received and retained in the valley. These factors provide distinct characteristics to each of the micro valleys carved by glacial streams in terms of water availability. The water availability also varies with the presence of glaciers in the watershed. Typically, each of these valleys supports a single settlement that spreads on the slope along the glacial stream. In some cases, depending on the amount of water, valleys/streams support two or three settlements. Table 2 shows the watershed area of each village, altitude details, and the presence of glaciers in the watershed. In summary, the amount of water available to a village depends on the village watershed area, the presence of glaciers in the watershed, and the amount of snowfall received in the watershed.

Table 2. Watershed and Glaciers in study villages.

Village Name	Watershed				Altitude of Natural Glacier
	Area (Sq. km.)	Min. ele. (m)	Max. ele. (m)	Range	
Takmachik	29	2901	5349	2448	Not Available
Umla	33.7	3524	5451	1927	Not Available
Phyang	98	3178	5733	2555	5500
Nang	58.2	3456	5648	2192	Not Available
Igoo	114.5	3435	5956	2521	5600
Mudh	56.7	4182	6049	1867	5870

The availability of water in settlements varies throughout the year. During the winter months, from October to April, the flow in the glacial stream decreases significantly due to very little melting that occurs under subzero temperature conditions. The amount of meltwater in the streams starts to increase in April as the temperature rises. Most glaciers are located above 5500 m altitude and start melting much later, in May and June. During the summer months of June and July, the streams are flooded with water. As the temperature starts decreasing in August, the flow in the streams starts to decrease. The general meltwater flow trends in the villages of Ladakh are shown in Figure 4.

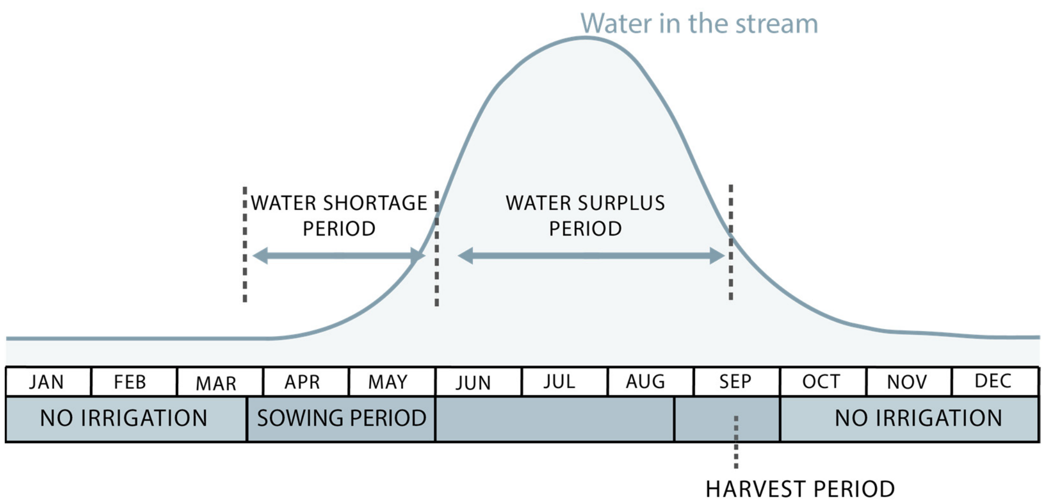

Figure 4. Seasonal variation in the availability of meltwater in glacial streams (conceptual graph. Adapted from [57].

Scarcity is felt when there is a high demand for water, and the supply is low. In Ladakh, owing to the climatic conditions, the agricultural season is short, ranging from mid-April to August. At the beginning of the agricultural season, there is high demand for irrigation water; however, the supply is low because of slow melting. This period in the spring (April–May) is considered critical in terms of water requirements. The amount of water available during this period dictates the amount of land that can be cultivated. Although the water availability improves during the summer months, it cannot be utilized to cultivate more land because of the short agricultural season.

Given the challenges presented by the natural environment, the people of the region have devised traditional irrigation water management practices. These practices are based on indigenous knowledge and have resulted from a long struggle to manage scarce water resources. This gravity-fed water management system is characterized by a complex network of canals, channels, and small reservoirs that are used to divert, store, and distribute water to agricultural fields (Figure 5). The management of water in these networks of physical irrigation infrastructure is related to social and institutional structures. The management of irrigation water follows traditionally established norms for distribution and management based on historically established water rights. These rules are documented as a formal record known as *riwaz-e-abpashi* (irrigation customs), stored at the *Tehsil* office (revenue department), and managed by a *Patwari* (revenue officer). This document contains records of the irrigation channels, the fields (plot numbers) watered by each channel, and the rules for water distribution for each village. It also maintains a record of all the disputes and their resolutions. Typically, water distribution is implemented on a rotational basis and is referred to as *Chures* (turn for watering the field). Households form groups to assist each other during their turns. Historically established rules, rights, and social obligations foster a sense of community and cooperation, shaping villagers' relationships with both their environment and each other.

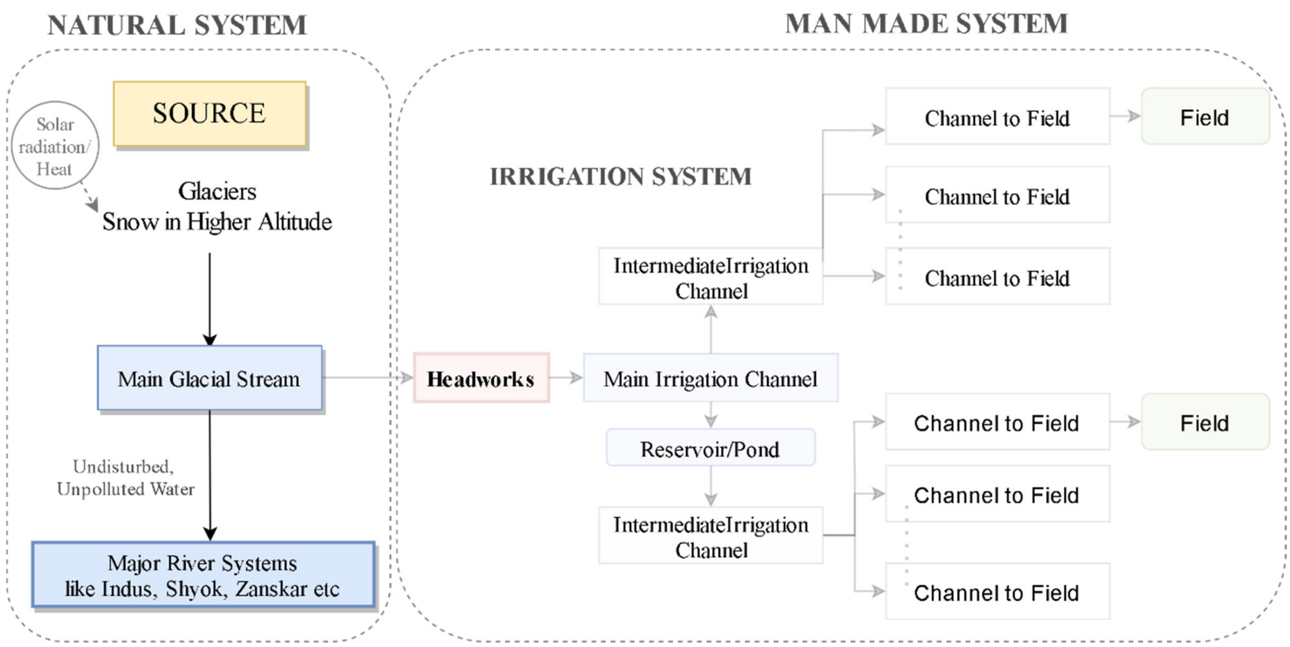

Figure 5. Traditional irrigation in the villages of Ladakh.

To summarize, despite the abundance of water resources in the region, in rivers and lakes and also in the forms of glaciers and permafrost, many settlements experience water scarcity as it is not accessible during the time of need. Villagers in the region, through their long experience dealing with this scarcity, have devised traditional irrigation infrastructure, as well as corresponding rules, rights, and systems of distribution. The current water management structure represents the region's long history of interaction with the environment and shows sustainable practices within the capacity of the environment and society.

4.2. Trigger: Climate Change and Its Impact on Water Availability in the Region

Recently, there has been increased pressure on traditional socio-ecological systems owing to the intensification of water scarcity. The region is experiencing changes in weather patterns with increasing temperature trends, reduction and irregularity in winter snowfall, and glacier recession [58–60]. Moreover, the region is also observing an increase in water demand owing to an increasing population, changes in lifestyles, and a large floating population of tourists during the summer months (the agricultural season). This added pressure due to changing weather patterns and socioeconomic conditions has a significant impact on villagers who practice subsistence farming.

The impact of this intensified water scarcity has resulted in:

- Reduction in cropped areas: Villagers are compelled to leave parts of their fields uncultivated because of the lack of water during the planting period.
- Conflict in villages due to water scarcity: Owing to increasing scarcity, some villages have modified their traditional water distribution methods. Villages such as Mudh rely on a lottery system for the rotational distribution of water to the fields. For some farmers, the interval between cycles is too wide, resulting in crop damage. Such situations often lead to internal conflict in villages.
- Migration to urban centers and other places for off-farm jobs: For subsistence farmers with small landholdings, it is difficult to survive in such conditions. Most migrate to search for off-farm jobs in the army or to serve the growing tourism industry in the region.
- Food insecurity: The region is already heavily dependent on other parts of India for food. Demand has seen a manifold increase recently, owing to the increasing population and inflow of tourists. In this situation, decreasing local production has resulted in a surge in dependency on other regions.

These factors cause significant socioeconomic transformations in the region, leading to the migration of the population from a traditional land-based economy in the villages to non-agricultural jobs in Leh town and other parts of India. Overcoming the water crisis is a challenge in retaining people in rural areas.

4.3. Social Innovation

Through co-evolution, the people of Ladakh have adapted their livelihood practices to accommodate water scarcity. However, recent reductions and irregularities in water availability have called for a major shift in adaptation efforts. The main challenge is to increase water availability to farmers at the beginning of the growing season (April to May). To meet this challenge, locals have developed multiple adaptation techniques.

4.3.1. Problematization

Water scarcity in Ladakh occurs because people are dependent on the real-time flow of glacial streams. During spring, the flow is less due to low melting, and this flow determines the amount of land that can be cultivated. However, during the summer months, there is surplus meltwater from glaciers, which flows down the stream to the river. As succinctly interpreted by an eminent engineer and innovator in the region, Mr. Sonam Wangchuk, “if this water can be stored in some form in the villages, then it can be utilized during the period of deficit. This can be made possible with technology and innovations” (personal communication, 6 July 2022). The inspiration for storing water in the form of ice during the winter months and utilizing it during the deficit spring months comes from a few existing traditional practices. During the winter months, owing to extremely cold weather conditions, there is hardly any water usage in the villages. The water flow in the stream during this period is very low and is allowed to flow down into the rivers. Water demand during this period is low because no agricultural activities are executed. Using various innovative techniques (Section 4.3.2), villagers can store water in the form of ice. These ice storage facilities are located at an altitude lower than that of natural glaciers; thus, they start melting earlier than natural glaciers and provide water at the beginning of the sowing period.

4.3.2. Innovation

Among the multiple techniques of storing water as an adaptation technique against water scarcity in Ladakh, few methods are traditionally employed. These innovations occurred in different parts of Ladakh and are modified to suit varying needs.

Stream blocking: In this age-old practice, villagers put dry plants into the stream to create a temporary blockage. In winter, when the stream flow is slow, and temperatures drop below the freezing point, ice forms on the surface of these dry plants and gradually increases in size. A large amount of ice is formed at these points throughout the winter months and melts earlier in spring to provide water. These practices are now extinct with the advent of other techniques.

Snow fencing walls: In this method, villagers construct dry-stone walls at higher altitudes within a watershed. These stone walls are constructed perpendicular to the prevailing wind direction at that location. During winters, these walls collect snow because deposition occurs on their leeward side. The walls are created by gathering stones from the site and arranging them to form a dry rubble masonry. This is considered an effective way to store water for use in spring. A few years ago, snow fencing walls were constructed by the Public Works Department slightly below *Wari-la* pass, and the villagers considered them effective. In 2013, the Leh Nutrition Project (LNP) started working on reviving this technique near a mountain pass (*Wari-la*) to improve water availability in three villages (*Sakti, Chemry,* and *Karu*). They termed these walls "a snow-barrier band".

Artificial glaciers: In the 1990s, engineer Chewang Norphel first innovated "artificial glaciers" that is similar to the traditional stream-blocking method. Water flow in the glacial stream is blocked using gabion walls. During the winter months, the flow in glacial streams is slow, and these gabion walls cause the water to further lose momentum and freeze, resulting in ice formation. The villagers' knowledge of the terrain in their watershed plays a key role in determining the location of such artificial glaciers. The site should have a consistent water supply even during the winter months and limited exposure to direct sunlight; otherwise, any ice formed during the night will melt during the day. When it is difficult to locate a suitable location on a glacial stream, water is diverted to an appropriate location for the formation of an artificial glacier. Figure 6a shows an artificial glacier from Umla village that still contained ice in June 2022. Figure 6b shows the artificial glacier in Igoo Village during winter.

Ice stupa: In 2013, local engineer and innovator Sonam Wangchuk developed another method for creating ice storage. In this method, water is collected from a high-altitude point on a glacial stream through a gravity-fed pipe. The bottom end of the pipe is attached to a sprinkler on top of a vertical pole. As water is sprinkled at subzero temperatures, it freezes to form a conical volume of ice. Owing to its conical geometry, a smaller surface area is exposed to the sun; thus, melting is reduced. These structures can be located anywhere. The Himalayan Institute of Alternatives Ladakh (HIAL) is creating ice stupas in multiple villages in Ladakh with the help of the village community. Figure 6c shows an ice stupa from Igoo village holding ice until July 2022.

Ice fall glacier: This method involves directing water through a gravity-fed pipe and releasing it onto a cliff; water is allowed to pour down the cliff face. As the water cascades down the cliff face, it freezes due to cold conditions, and ice is formed. Layer-by-layer ice is added, and the structure takes the form of a frozen waterfall. Figure 6d shows the icefall glacier created in Takmachik village in 2019.

Table 3 shows the altitude of natural glaciers and ice reservoirs in the study villages, along with the various techniques used in each village. The implementation of different technique is based on the topography of the village watershed, community involvement, and collaboration with NGOs. These Ice reservoirs are particularly beneficial for villages without natural glaciers.

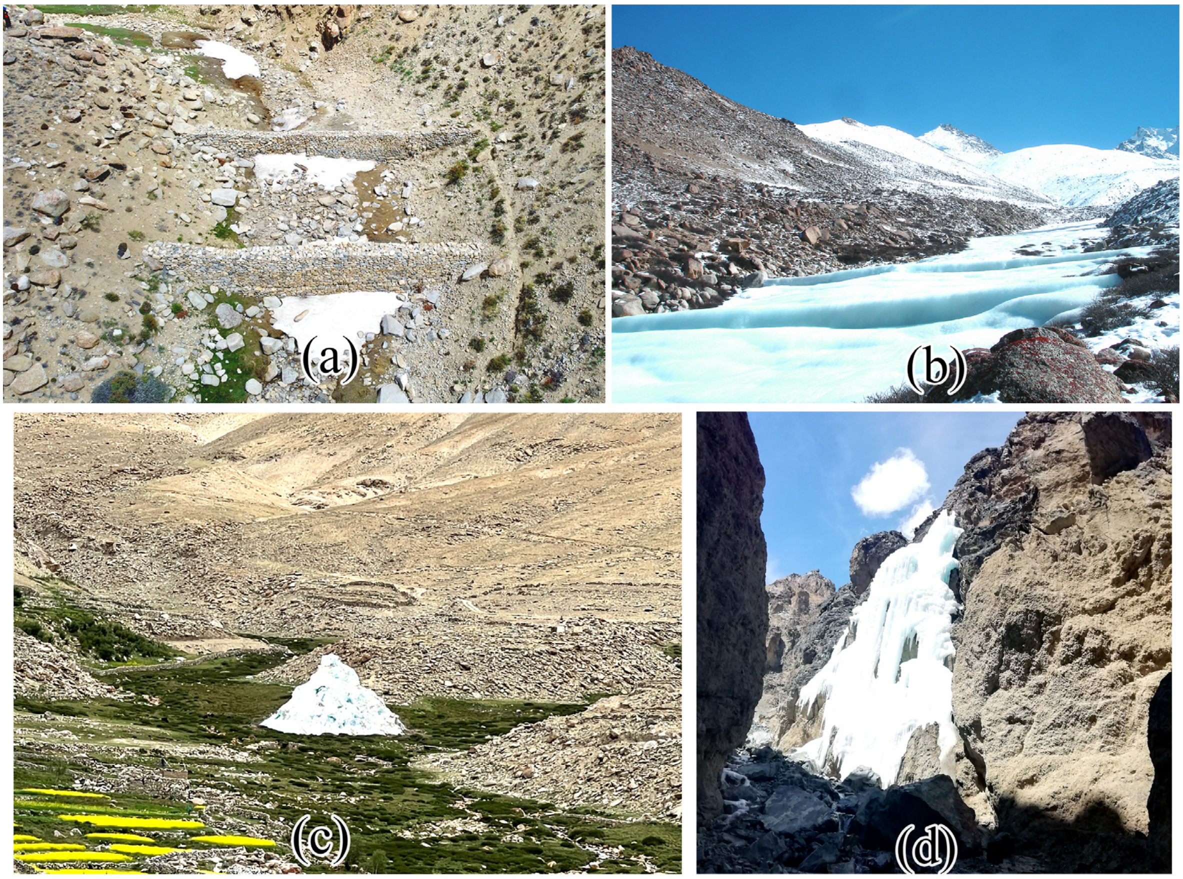

Figure 6. Various Ice reservoir techniques from the study villages-(**a**) Artificial glacier from Umla village, (**b**) Artificial glacier from Igoo village during winter, (**c**) Ice stupa from Igoo village, (**d**) Ice fall glacier from Takmachik village (Source: (**a**,**b**): Authors; (**c**): NGO staff, LNP; (**d**): NGO staff LEHO).

Table 3. Natural glaciers and Ice reservoirs in the study villages.

Village Name	Settlement		Altitude of Ice Reservoirs (m)		Altitude of Natural Glacier	Ice Reservoir Techniques Used *		
	Min. ele (m)	Max. ele (m)	Lowest	Highest		AG	IS	IF
Takmachik	2920	3000	3980	...	Not Available	✓	✓	✓
Umla	3790	3950	4330	4350	Not Available	✓	×	×
Phyang	3297	4054	4135	4150	5500	✓	✓	×
Nang	3543	3846	3870	4600	Not Available	✓	✓	✓
Igoo	3448	4070	4250	4580	5600	✓	✓	×
Mudh	4175	4293	4335	...	5870	✓	×	×

Notes: * AG—Artificial glacier, IS—Ice stupa, IF—Ice fall.

4.3.3. Implementation

For the implementation of the adaptation methods outlined above, it is crucial to involve a range of actors, including innovators, technical specialists, community leaders, funding sources, and especially villagers and farmers, to successfully carry out the implementation of the adaptation methods outlined above. This collaborative effort involves the planning, building, and management of structures. The implementation process was led by four key NGOs: LNP, the Ladakh Environment and Health Organization (LEHO), the Tata Trust (Himmotthan Society), and HIAL. While the first three organizations are involved in the creation of artificial glaciers and icefall glaciers, HIAL focuses its efforts on ice stupa projects. These organizations play a crucial role in bringing together various actors and facilitating processes. They continuously monitor and learn from each project to advance technological innovation. They secured funding from sponsors and motivated and guided the villagers throughout the project. The implementation process for artificial glaciers involves the following steps.

Need and feasibility assessment in water-scarce villages.

A suitable location for the artificial glacier is determined after meeting key persons in the village.

The NGO staff meet with technical experts and finalize the details.

A proposal for the artificial glacier is framed, and sponsors are approached for funding.

After the funding is generated, a meeting is called with the entire village; a few key members from the village are selected to form the "Artificial Glacier Management Committee (AGMC)".

Villagers form groups and take turns executing construction work under the supervision of AGMC and the NGO staff.

The implementation process emphasizes the engagement of the community from the inception to the operation of the projects. In 2022, the LNP built artificial glaciers in the remote village of Mudh village, where 88 households were divided into four groups and took turns in construction, with each household sending one member to participate in the week-long effort. Figure 7a,b shows villagers' meetings at the construction site of artificial glaciers and villagers excavating the foundation. Figure 7c shows a map of Mudh prepared by the villagers, along with the LNP staff, for locating the artificial glacier to benefit the entire village. In Nang Village, all villagers participated in the construction of artificial glaciers in the higher reaches of the village watershed. In Igoo village, one member of each household participated in the construction of an artificial glacier. As the artificial glacier was located far from the village and at higher altitudes, the villagers took turns camping at the site for the entire construction period.

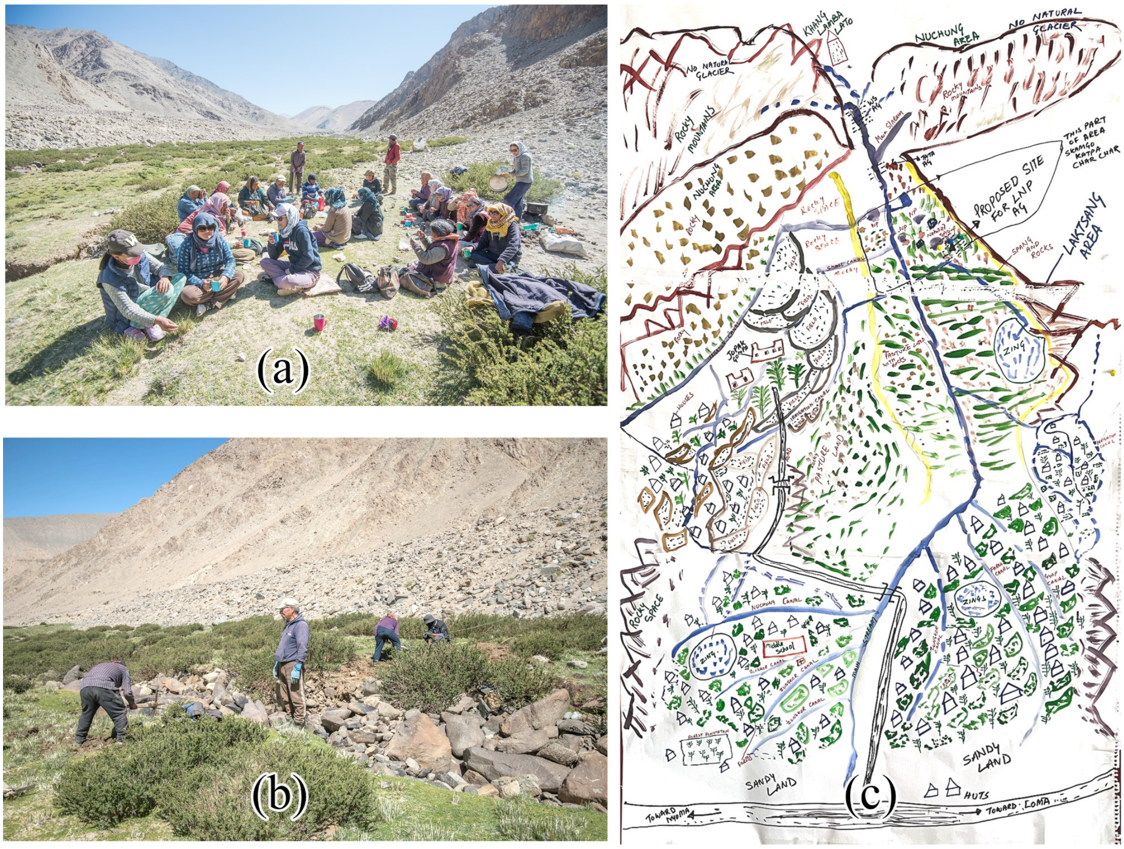

Figure 7. Implementation of Artificial glacier project in Mudh Village by LNP (Source: Authors). (**a**) Villagers meeting at the site of Artificial glacier before beginning of its construction, (**b**) Villagers excavating foundation Artificial glacier, (**c**) A map of Mudh village prepared by the villagers with support from LNP NGO staff to locate the Artificial glacier.

Ice stupas follow a slightly different process of motivating community participation. These initiatives are led by the "Ice Stupa Project" team of the HIAL. The implementation process is as follows:

Every year, before winter, they float competition among villages for ice stupa construction.

Villages (village youth associations, in many cases) register to participate in the competition.

HIAL organizes technical capacity-building workshops.

The HIAL team arranges to fund the Ice Stupas. (Sometimes villagers contribute a portion of the cost.)

Ice stupas are constructed in the respective villages, and on March 22 every year (World Water Day), the village with the highest ice stupa and maximum ice stored (by volume) receives a cash reward.

The ice stupa team monitors each participating village and learns from the process to upgrade next year.

4.3.4. Evaluation and Diffusion

Ice reservoirs have been in operation in Ladakh for almost three decades. More than 20 villages have these ice reservoirs, and some villages have multiple reservoirs spread along the glacial stream above the village. Since its inception in 2017 in Phyang village, an increasing number of villages have participated in Ice Stupa every year (2018—10, 2019—14, 2020—14, 2021—18). Despite being widely acknowledged for their success in meeting the goal of supplying additional water during periods of shortage, it is important to evaluate their potential in terms of their efficiency in retaining and distributing water; ease of construction, operation, and maintenance; and their impact on the environment and society. According to the NGO staff of the Tata Trust's Himmotthan Society, many initial artificial glaciers failed because of a lack of ownership by the villagers. In Takmachik village, the structure was damaged by heavy flow during the summer months, as the villagers did not divert water (personal communication, 9 June 2022). The project staff of the LNP share that artificial glaciers enable villages to receive water one month earlier than normal. Consequently, villagers can plant a greater variety of crops and earn more income (Personal Communication, 21 June 2022). The Ice Stupa project has been successful in rehabilitating Kulum village, which was abandoned due to a lack of water [61]. The head of Umla village gave credit to artificial glaciers constructed by LEHO in 2013 for improving water availability in the village. In terms of social integration, staff from all four NGOs emphasized the role of community engagement from the beginning of the planning process and throughout the success of the artificial glacier and ice stupa projects. Through community engagement, a sense of ownership of the project was imparted among the villagers, ensuring that the project was integrated into the existing water management structure of the village. To summarize, ice reservoirs have contributed to the adaptation to water scarcity as follows:

- Extending the growing season by providing water at least one month earlier than normal.
- Providing an opportunity to make extra income by growing a wider variety of crops and vegetables.
- Successfully motivating the people to continue engaging in agricultural activities.
- Enhancing social capital by fostering collaboration in project execution.

Communities in Ladakh have been using innovative methods to store water in the form of ice in response to the changing climatic conditions. Through these innovative and contextual adaptation efforts, they demonstrate resourcefulness and self-sufficiency in managing their changing water situation. Currently, NGOs are leading and executing ice reservoir projects with the help of village communities. Every year, more villages opt for these methods of improving water availability based on the experiences of other villages. The ice stupa technique has gained international fame and is now being implemented in many countries, including Bhutan, Nepal, Mongolia, Switzerland, and Chile (HIAL staff, personal communication, 8 July 2022). Although some of these projects have been funded by various government-affiliated schemes, they lack formal recognition and support. In the past, many artificial glacial projects were conducted under government watershed development schemes. However, these efforts are not currently prioritized in government development plans. The lack of formal recognition and institutionalization of these projects is a major constraint in scaling up efforts.

5. Policy Implications for Planned Adaptation

Water resource management for climate change adaptation in mountainous settlements presents several challenges that are continuously evolving, with many interdependencies, and exist in complex systems. The Government of India's National Mission for Sustaining the Himalayan Ecosystem includes the objectives of exploring the linking of traditional and formal knowledge systems through a strategic mechanism of formalization for mutual benefit and value for the sustainability of the Himalayan ecosystem and identifying the most desirable adaptation policies to improve regional sustainability. This mission is part of India's National Action Plan on Climate Change [62]. Thus, the institutionalization of these adaptation efforts in Ladakh, such as ice reservoirs, will contribute to achieving these objectives. Through this case analysis of Ladakh under the SICCA framework, it was found that social innovation efforts can be scaled up with proper enabling conditions, such as regulatory, institutional, and resource support. Currently, there are no formal structures to integrate social innovations for climate change adaptation into government policymaking. Government planning and policymaking processes are typically top-down, whereas social innovation practices are based on bottom-up and co-creation approaches. For planned adaption through the institutionalization of these practices, the government must play multiple roles in the form of enablers, knowledge providers, and facilitators. The SICCA framework provides an action-oriented model for the policymakers and civil society actors through which such practices can be identified and become a part of the formal planning process.

Developing clearly defined plans to promote social innovation and creating specific environmental regulations based on local contexts are required. Identifying social innovation practices within the scope of diffusion is an important step in this process. The IPCC [2] states that the enabling conditions for the adaptation of human systems should essentially incorporate the sharing of indigenous knowledge. Accordingly, a common knowledge-sharing platform can be developed to promote a contextual understanding of issues and possible solutions and the ongoing initiatives in various villages. The roles of the various stakeholders in these projects must be defined. The development of such plans can positively impact the willingness of many stakeholders, such as NGOs and communities in villages where these practices are still not engaged in the process. Additionally, the government can play a crucial role by encouraging the further development of new practices through the creation of an enabling environment through funding and regulatory support for start-ups and other innovations.

Institutionalizing collaborations with academic organizations and other knowledge partners is required. This will help (i) encourage further research on ice reservoirs, (ii) develop the capacity of policymakers to incorporate social innovation processes in policymaking, and (iii) develop the technical capacity of communities and NGOs to successfully integrate indigenous knowledge with emerging technologies. These collaborations will also help monitor and evaluate the impact of social innovations to provide inputs for the planning cycle.

Additionally, government agencies can partner with local communities, NGOs, and private players to maximize the impact of ice reservoirs. These partnerships combine different areas of expertise to increase community participation. Developing this type of shared ownership is essential for collective action and for sustainable practices in the long run. Preserving the traditional values of cooperation, sharing, and building upon traditional knowledge and innovation can make adaptation efforts more effective and provide long-term benefits to local communities. By implementing these policy recommendations, the government can encourage social innovations in climate change adaptation rooted in the regional context and integrate them into government schemes in such a manner that they are effective, sustainable, and equitable. As the framework suggests, the success of social innovations lies in their wider acceptance and institutionalization. Through this process, community-based adaptation initiatives can transform into planned adaptations and have a greater impact and potential for further development.

6. Conclusions

Human-nature interactions in indigenous communities have been perfected over centuries to create a symbiotic and sustainable way of life. Indigenous community members have a deep understanding of their local ecosystems and are sensitive to subtle variations in weather patterns. Traditional ecological knowledge equips them with the skills to innovate contextual adaptation strategies while maintaining sustainable consumption patterns and land use. While this knowledge and practices are recognized as significant assets for adapting to climate change, they are often overlooked in mainstream adaptation efforts and are not effectively incorporated into policies and research [63,64].

Bresciani et al. [65] highlighted the need for research on social innovation scaling strategies and supportive ecosystems that can facilitate growth. This study contributes in this regard by proposing a framework for encouraging and integrating social innovations into climate change adaptation. Incorporating the SICCA framework ensures that adaptation strategies respond to the needs of local communities. Involving local communities in design and implementation can ensure that these strategies are appropriate to local conditions and are more likely to be adopted and sustained over time. The framework has practical implications as it can provide a structured overview of social innovation efforts and can be utilized to assess and strategize the integration of community-led initiatives into mainstream development planning processes. IPCC [2] has highlighted that remote communities demonstrate the ability to respond on their own against the impacts of climate change by exhibiting their resourcefulness and capabilities. The Ladakh ice reservoirs represent a novel case of social innovation in remote mountainous regions to adapt to intensified water scarcity due to climate change. Building the literature on this article contributes to the understanding of community-based innovative practices in mountainous settlement contexts, and the insights could be of interest to development practitioners in similar regions. The results from this study imply that transformative climate change adaptation can be based on existing practices, particularly in communities with a long history of coping with extreme climatic conditions.

Further studies can build upon the findings of this research by applying the framework to other sectors, such as agriculture, as it is interrelated with water resource management. This will aid in translating local knowledge and practices into actionable strategies to adapt to climate change. Social innovation can manifest in different forms and in various contexts. Therefore, case studies on social innovation in other sectors and regions will lead to further refinement of the proposed SICCA framework.

Author Contributions: Conceptualization, T.K. and I.S.; methodology, T.K.; investigation, T.K.; resources, I.S.; data curation, T.K.; writing—original draft preparation, T.K.; writing—review and editing, I.S. and T.K.; visualization, T.K.; supervision, I.S.; funding acquisition, I.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Japan Society for the Promotion of Science: KAKENHI 20H04401 and KAKENHI 21KK0014.

Data Availability Statement: All survey data, GIS maps, generated or used during the study are available from the corresponding author by request.

Acknowledgments: Authors would like to thank the organizations for their support during the field survey: LeDEG; LNP; LEHO; HIAL; Tata Trust—Himmotthan.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. IPCC. IPCC, 2014: Summary for Policymakers. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Agrawala, S., Alexeyevich Bashmakov, I., Blanco, G., Broome, J., Bruckner, T., Brunner, S., Bustamante, M., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014.
2. IPCC. *Climate Change 2022: Impacts, Adaptation and Vulnerability. Working Group II contribution to the Sixth Assessment Report of the Intergovernamental Panel on Climate Change*; IPCC: Cambridge, UK; New York, NY, USA, 2022; ISBN 9781009325844.
3. UNEP. *Water Quality for Ecosystem and Human Health*, 2nd ed.; UNEP-Global Environment Monitoring Systems: Ontario, Canada, 2008; ISBN 0203888081.
4. Wang, X.J.; Zhang, J.Y.; Shahid, S.; Guan, E.H.; Wu, Y.X.; Gao, J.; He, R.M. Adaptation to climate change impacts on water demand. *Mitig. Adapt. Strateg. Glob. Chang.* **2016**, *21*, 81–99. [CrossRef]
5. Caretta, M.A.; Mukherji, A.; Arfanuzzaman, M.; Betts, R.A.; Gelfan, A.; Hirabayashi, Y.; Lissner, T.K.; Liu, J.; Gunn, E.L.; Morgan, R.; et al. 2022: Water. In *Climate Change 2022: Impacts, Adaptation and Vulnerability*; IPCC: Cambridge, UK; New York, NY, USA, 2022; pp. 551–712.
6. Tompkins, E.L.; Adger, W.N. Does Adaptive Management of Natural Resources Enhance Resilience to Climate Change? *Ecol. Soc.* 2004, 9. Available online: https://www.jstor.org/stable/26267677 (accessed on 23 December 2022).
7. Brodnig, G.; Prasad, V. A View from the Top: Vulnerability in Mountain Systems. *Soc. Dev. Notes; No. 128. World Bank, Washington, DC*. 2010. Available online: https://openknowledge.worldbank.org/handle/10986/11085 (accessed on 15 January 2023).
8. Jodha, N.S. Adaptation strategies against growing environmental and social vulnerabilities in mountain areas. *Himal. J. Sci.* **2007**, *3*, 33–42. [CrossRef]
9. Hofer, T. Introduction: The International Year of Mountains Challenge and Opportunity for Mountain Research. In *Global Change and Mountain Regions*; Springer: Berlin/Heidelberg, Germany, 2005; pp. 1–8.
10. Sharma, E.; Molden, D.; Rahman, A.; Khatiwada, Y.R.; Zhang, L.; Singh, S.P.; Yao, T.; Wester, P. *Introduction to the Hindu Kush Himalaya Assessment*; Springer International Publishing: Cham, Switzerland, 2019; ISBN 9783319922881.
11. Pisor, A.C.; Basurto, X.; Douglass, K.G.; Mach, K.J.; Ready, E.; Tylianakis, J.M.; Hazel, A.; Kline, M.A.; Kramer, K.L.; Lansing, J.S.; et al. Effective climate change adaptation means supporting community autonomy. *Nat. Clim. Chang.* **2022**, *12*, 213–215. [CrossRef]
12. Kirkby, P.; Williams, C.; Huq, S. Community-based adaptation (CBA): Adding conceptual clarity to the approach, and establishing its principles and challenges. *Clim. Dev.* **2018**, *10*, 577–589. [CrossRef]
13. Singh, C.; Iyer, S.; New, M.G.; Few, R.; Kuchimanchi, B.; Segnon, A.C.; Morchain, D. Interrogating 'effectiveness' in climate change adaptation: 11 guiding principles for adaptation research and practice. *Clim. Dev.* **2022**, *14*, 650–664. [CrossRef]
14. Shammin, M.R.; Haque, A.K.E.; Faisal, I.M. A Framework for Climate Resilient Community-Based Adaptation. In *Climate Change and Community Resilience*; Springer: Singapore, 2022; pp. 11–30, ISBN 9789811606809.
15. Hiwasaki, L.; Luna, E.; Syamsidik; Shaw, R. Process for integrating local and indigenous knowledge with science for hydro-meteorological disaster risk reduction and climate change adaptation in coastal and small island communities. *Int. J. Disaster Risk Reduct.* **2014**, *10*, 15–27. [CrossRef]
16. Audefroy, J.F.; Sánchez, B.N.C. Integrating local knowledge for climate change adaptation in Yucatán, Mexico. *Int. J. Sustain. Built Environ.* **2017**, *6*, 228–237. [CrossRef]
17. IPCC. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; IPCC: Cambridge, UK, 2007. Available online: https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf (accessed on 5 January 2023).
18. Krishna, V. Indegenous Communities and Climate Change Policy: An Inclusive Approach. In *The Economic, Social and Political Elements of Climate Change*; Leal Filho, W., Ed.; Springer: Berlin/Heidelberg, Germany, 2011; pp. 27–49. ISBN 9783642147753.
19. Mukherji, A.; Sinisalo, A.; Nüsser, M.; Garrard, R.; Eriksson, M. Contributions of the cryosphere to mountain communities in the Hindu Kush Himalaya: A review. *Reg. Environ. Chang.* **2019**, *19*, 1311–1326. [CrossRef]
20. Behera, B.; Vaswan, R.T. Understanding the Relationship between Global and Local Commons: A Study of Household Perceptions of Climate Change in Leh, India. In Proceedings of the Governing Shared Resources: Connecting Local Experience to Global Challenges, Cheltenham, UK, 14–18 July 2008.
21. Sharma, A. Giving water its place: Artificial glaciers and the politics of place in a high-altitude Himalayan village. *Water Altern.* **2019**, *12*, 993–1016.
22. Nüsser, M.; Dame, J.; Kraus, B.; Baghel, R.; Schmidt, S. Socio-hydrology of "artificial glaciers" in Ladakh, India: Assessing adaptive strategies in a changing cryosphere. *Reg. Environ. Chang.* **2019**, *19*, 1327–1337. [CrossRef]
23. Dawson, P.; Daniel, L. Understanding social innovation: A provisional framework. *Int. J. Technol. Manag.* **2010**, *51*, 9–21. [CrossRef]
24. Olsson, P.; Galaz, V. Social-Ecological Innovation and Transformation. In *Social Innovation*; Palgrave Macmillan UK: London, UK, 2012; pp. 223–247.
25. Vercher, N.; Barlagne, C.; Hewitt, R.; Nijnik, M.; Esparcia, J. Whose Narrative is it Anyway? Narratives of Social Innovation in Rural Areas—A Comparative Analysis of Community-Led Initiatives in Scotland and Spain. *Sociol. Rural.* **2021**, *61*, 163–189. [CrossRef]

26. Bock, B.B. Rural Marginalisation and the Role of Social Innovation; A Turn Towards Nexogenous Development and Rural Reconnection. *Sociol. Rural.* **2016**, *56*, 552–573. [CrossRef]
27. Cajaiba-Santana, G. Social innovation: Moving the field forward. A conceptual framework. *Technol. Forecast. Soc. Chang.* **2014**, *82*, 42–51. [CrossRef]
28. Pol, E.; Ville, S. Social innovation: Buzz word or enduring term? *J. Socio. Econ.* **2009**, *38*, 878–885. [CrossRef]
29. The Young Foundation. Social Innovation Overview: A Deliverable of the Project: 'The Theoretical, Empirical and Policy Foundations for Building Social Innovation in Europe' (TEPSIE). 2012. Available online: https://www.youngfoundation.org/our-work/publications/tepsie-social-innovation-overview-parts-i-ii-iii-iv-and-bibliography/ (accessed on 4 January 2023).
30. Normand, M. *Innovation in Community Governance, Volume 2: Literature Review*; University of Ottawa: Ottawa, ON, Canada, 2012; Volume 2.
31. Schwarz, M. *Social Innovation: Concepts, Research Fields and International Trends*; TU-Dortmund: Dortmund, Germany, 2010.
32. Moulaert, F.; Martinelli, F.; Swyngedouw, E.; González, S. Towards alternative model(s) of local innovation. *Urban Stud.* **2005**, *42*, 1969–1990. [CrossRef]
33. Andrew, C.; Klein, J.-L. *Social Innovation What Is It and Why Is It Important to Understand It Better*; Ontario Ministry of Research and Innovation: Toronto, ON, Canada, 2010; Volume ET1003, ISBN 9782896053186.
34. Mulgan, G.; Sanders, B.; Tucker, S.; Rushanara, A. *Social Innovation: What It Is, Why It Matters and How It Can Be Accelerated*; The Young Foundation: London, UK, 2007.
35. BEPA. *Empowering People, Driving Change: Social Innovation in the European Union*; Bureau of European Policy Advisers: Brussel, Belgium, 2010.
36. Bock, B.B. Social innovation and sustainability; how to disentangle the buzzword and its application in the field of agriculture and rural development. *Stud. Agric. Econ.* **2012**, *114*, 57–63. [CrossRef]
37. Chen, H.C.; Knierim, A.; Bock, B.B. The emergence of social innovation in rural revitalisation practices: A comparative case study from Taiwan. *J. Rural Stud.* **2022**, *90*, 134–146. [CrossRef]
38. Rodima-Taylor, D. Social innovation and climate adaptation: Local collective action in diversifying Tanzania. *Appl. Geogr.* **2012**, *33*, 128–134. [CrossRef]
39. Kerlin, J.A. Considering Context: Social Innovation in Comparative Perspective. In *Social Innovation: Blurring Boundaries to Reconfigure Markets*; Nichollas, A., Murdock, A., Eds.; Palgrave Macmillan UK: London, UK, 2012; pp. 66–88.
40. Copus, A.; Perjo, L.; Berlina, A.; Jungsberg, L.; Randall, L.; Sigurjónsdóttir, H. *Social Innovation in Local Development: Lessons from the Nordic Countries and Scotland*; Nordregio: Stockholm, Sweden, 2017.
41. Fløysand, A.; Jakobsen, S.E. The complexity of innovation: A relational turn. *Prog. Hum. Geogr.* **2011**, *35*, 328–344. [CrossRef]
42. Scott Cato, M.; Hillier, J. How Could We Study Climate-Related Social Innovation? *Applying Deleuzean Philosophy to the Transition Towns. Environ. Politics* **2011**, *19*, 869–887. [CrossRef]
43. Neumeier, S. Why do Social Innovations in Rural Development Matter and Should They be Considered More Seriously in Rural Development Research?—Proposal for a Stronger Focus on Social Innovations in Rural Development Research. *Sociol. Ruralis* **2012**, *52*, 48–69. [CrossRef]
44. Mulgan, G. The Process of Social Innovation. *Innov. Technol. Gov. Glob.* **2006**, *1*, 145–162. [CrossRef]
45. van Wijk, J.; Zietsma, C.; Dorado, S.; de Bakker, F.G.A.; Martí, I. Social Innovation: Integrating Micro, Meso, and Macro Level Insights From Institutional Theory. *Bus. Soc.* **2019**, *58*, 887–918. [CrossRef]
46. Malik, A.; Qin, X.; Smith, S.C. Autonomous Adaptation to Climate Change: A Literature Review. *IIEP Work. Pap.* **2010**, *27*, 1–25.
47. Kulkarni, A.V.; Shirsat, T.S.; Kulkarni, A.; Negi, H.S.; Bahuguna, I.M.; Thamban, M. State of Himalayan cryosphere and implications for water security. *Water Secur.* **2021**, *14*, 100101. [CrossRef]
48. Soheb, M.; Ramanathan, A.; Bhardwaj, A.; Coleman, M.; Rea, B.R.; Spagnolo, M.; Singh, S.; Sam, L. Multitemporal glacier inventory revealing four decades of glacier changes in the Ladakh region. *Earth Syst. Sci. Data* **2022**, *14*, 4171–4185. [CrossRef]
49. Tandup, C. Natural Environment of Cold Desert Region Zanskar. *Int. J. Sci. Res. Publ.* **2014**, *4*, 1–18.
50. Juyal, N. Ladakh: The High-Altitude Indian Cold Desert. In *Landscapes and Landforms of India*; Kale, V.S., Ed.; Springer: Dordrecht, The Netherlands, 2014; pp. 115–124.
51. Directorate of Census Operations, "District census handbook-Leh (Ladakh)," Srinagar, India. 2011. Available online: https://censusindia.gov.in/nada/index.php/catalog/499 (accessed on 5 October 2021).
52. Angchok, D.; Singh, P. Traditional irrigation and water distribution system in Ladakh. *Indian J. Tradit. Knowl.* **2006**, *5*, 397–402.
53. Chostak, S. Local adaptation strategies to climate change: Learning from Ladakh. *ILI Law Rev.* **2016**.
54. Nüsser, M.; Baghel, R. Local Knowledge and Global Concerns: Artificial Glaciers as a Focus of Environmental Knowledge and Development Interventions. *Ethn. Cult. Dimens. Knowl.* **2016**, *8*, 191–209. [CrossRef]
55. Sakai, A. Gamdam glacier inventory for High Mountain Asia. *Suppl. to Sakai A Br. Commun. Updat. GAMDAM Glacier Invent. over High Mt. Asia. Cryosphere* **2018**, *13*, 2043–2049. [CrossRef]
56. Labbal, V. Traditional oases of Ladakh: A case study of equity in water management. In *Sharing Water: Irrigation and Water Management in the Hindukush-Karakoram-Himalaya*; Kreutzmann, H., Ed.; Oxford University Press: Oxford, UK, 2000; pp. 163–183, ISBN 0195791592.
57. Kreutzmann, H. From water towers of mankind to livelihood strategies of mountain dwellers: Approaches and perspectives for high mountain research. *Erdkunde* **1998**, *52*, 185–200. [CrossRef]

58. Shaheen, F.A.; Wani, M.H.; Wani, S.A.; Norphel, C. Climate Change Impact in Cold Arid Desert of North–Western Himalaya: Community Based Adaptations and Mitigations. In *Environmental Science and Engineering*; Springer: Berlin/Heidelberg, Germany, 2013; pp. 239–256, ISBN 9783642361432.
59. Chevuturi, A.; Dimri, A.P.; Thayyen, R.J. Climate change over Leh (Ladakh), India. *Theor. Appl. Climatol.* **2018**, *131*, 531–545. [CrossRef]
60. Yangchan, J.; Raghuvanshi, M.S.; Kumar, A.; Arya, C.K. Climate Change-Induced Impact on Water Resource of Ladakh Cold Arid Region. *Int. J. Curr. Microbiol. Appl. Sci.* **2019**, *8*, 1996–2009. [CrossRef]
61. Ministry of Tribal Affairs; SECMOL. Eco-Rehabilitation of Tribal Villages through Innovative Design in Water Management Using Ice-stupa, Promoting Farm-Stay Tourism and Passive Solar Heating System. New Delhi. 2021. Available online: https://tribal.nic.in/downloads/IceStupa/IcestupaReport.pdf (accessed on 24 January 2023).
62. DST. National Mission for Sustaining the Himalayan Eco-System. New Delhi. 2010. Available online: https://dst.gov.in/sites/default/files/NMSHE_Mission_document.pdf (accessed on 28 January 2023).
63. Petzold, J.; Andrews, N.; Ford, J.D.; Hedemann, C.; Postigo, J.C. Indigenous knowledge on climate change adaptation: A global evidence map of academic literature. *Environ. Res. Lett.* **2020**, *15*, 113007. [CrossRef]
64. Muchaku, S.; Magaiza, G.; Hamandawana, H. Translating Indigenous Knowledge into Actionable Climate-Change Adaption Strategies: A Case Study of Maluti-a-Phofung Local Municipality, Free State Province, South Africa. *Sustainability* **2023**, *15*, 1558. [CrossRef]
65. Bresciani, S.; Rizzo, F.; Deserti, A. Toward a Comprehensive Framework of Social Innovation for Climate Neutrality: A Systematic Literature Review from Business/Production, Public Policy, Environmental Sciences, Energy, Sustainability and Related Fields. *Sustainability* **2022**, *14*, 13793. [CrossRef]

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