

"A STUDY OF LOCAL COPING AND ADAPTIVE STRATEGIES TO CURRENT IMPACT OF CLIMATE CHANGE IN LEH DISTRICT OF LADAKH"

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ABSTRACT

The study highlights the livelihoods of rural communities in the study region, highlighting key socio-economic and environmental adaptations. Using a mixed-methods approach, we analyze various aspects of daily life, including healthcare accessibility, agricultural diversification, non-farm employment, water resource management, housing trends, government employment, and literacy patterns. Our findings reveal significant disparities in healthcare access, with remote villages facing limited medical services, often relying on traditional healers. The study also documents a shift in agricultural practices, as households increasingly cultivate exotic vegetables and mushrooms to adapt to changing climatic conditions. Additionally, economic diversification is evident, with many households supplementing agricultural income through non-farm activities, particularly in villages closer to district headquarters. Water availability remains a critical challenge, with seasonal variations affecting household access. Infrastructure initiatives like the Jal Jivan Mission Scheme have improved water accessibility, but disparities persist. Housing trends indicate a transition toward concrete roofs to mitigate water leakage, although traditional homes remain prevalent due to their climate adaptability. Government employment, especially in the armed forces, plays a crucial role in household financial stability, while literacy trends demonstrate a divide between villages with better educational access and remote areas with limited schooling opportunities. Overall, the study underscores the resilience and adaptability of these communities in navigating climate change and socio-economic transformations. These insights provide valuable guidance for policymakers and development agencies in formulating targeted interventions to enhance rural livelihoods and sustainability.

KEYWORDS: *Livelihood; Adaptation; Climate Change Resilience; Rural Communities; Sustainable Development; Socioeconomic Dynamics.*

INTRODUCTION

Climate change has emerged as a critical global challenge, manifesting through rising temperatures, shifting precipitation patterns, and an increasing frequency of extreme weather events (Masson-Delmotte et al., 2021; Fawzy et al., 2020; Parmesan et al., 2022). These changes have particularly profound effects on vulnerable and remote regions (Kagan & Dodge, 2023). One such region is Leh, located in the Union Territory of Ladakh, India. Known for its high-altitude desert landscape and rugged terrain, Leh faces unique climatic challenges that threaten its ecosystems, livelihoods, and overall well-being (Chevuturi et al., 2018).

Agriculture, the primary livelihood source for Leh's rural communities, is particularly vulnerable to climate change. The melting of glaciers, unpredictable rainfall, and growing water scarcity directly impact farming practices, endangering food security (Tuladhar et al., 2023; Malik et al., 2023). Additionally, extreme weather events such as flash floods and cloudbursts have become more frequent, posing risks to both life and property (Bhat et al., 2023; Bhattacharjee et al., 2023; Singh et al., 2022). Given these challenges, understanding how local communities adapt and cope with climatic changes is crucial.

Adaptation involves proactive strategies that reduce vulnerability and enhance resilience, including infrastructure improvements, agricultural diversification, and efficient water management (Altieri & Nicholls, 2017; Lal et al., 2011; Anderson et al., 2012). Coping strategies, on the other hand, are immediate responses to climate shocks, such as emergency relief efforts and temporary livelihood adjustments (Berman et al., 2015; Mengistu et al., 2011). This study explores the adaptation and coping mechanisms employed by rural communities in Leh, with the aim of informing policymakers, researchers, and practitioners involved in climate resilience efforts.

Study Area Descriptions

The study area, Leh district, is situated in the Trans-Himalayan region of Ladakh, characterized by its cold, arid, and fragile ecosystem. Bounded by the Karakoram range in the north and the Greater Himalayas in the south, it sits at an average altitude of 3,514 meters and extends from 34°10'12" N to 77°34'48" E (Haq et al., 2021). Leh shares borders with China and Himachal Pradesh to the east and Jammu & Kashmir and Pakistan to the west. The region relies on glacial meltwater from Kang Yangtse, Siachen, and smaller glaciers to sustain its streams and the Indus River. Traditional livelihoods include subsistence farming, livestock rearing, and agro-pastoralism, though tourism has become a key economic driver since 1974. As of the 2011 census, Leh district has a population of approximately 274,281. Leh's climate is marked by extreme conditions, with annual rainfall of only 50-70 mm due to the rain shadow effect (Kumar et al., 2017). High altitude and low humidity intensify solar radiation, shaping its delicate ecosystem. Temperatures fluctuate between 35°C in summer and -45°C in winter. Politically, Ladakh is divided into Leh and Kargil districts, with Leh covering 45,110 square kilometers, making it one of India's largest districts. It is subdivided into regions such as Nubra, Changthang, and Sham, encompassing 113 villages. Climate change has significantly impacted the region over the past two decades, posing challenges for its ecosystem and traditional livelihoods. As Leh navigates modernization, understanding these changes is crucial for sustainable development in fragile mountain environments.

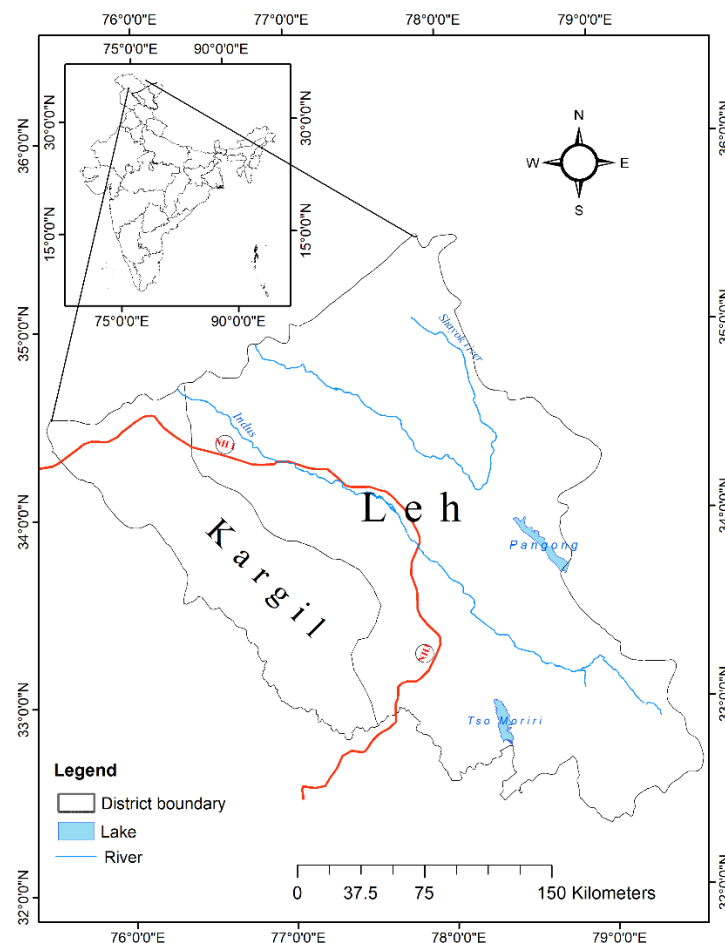


Fig. 1 Study area in Leh in Ladakh

Database and Methodology

To investigate the adaptation and coping strategies of Leh's rural farmers, a mixed-methods approach was employed. The study was informed by a review of existing literature, exploratory field visits, and structured surveys conducted among local farming households. Survey data served as the primary source for identifying key adaptation strategies and assessing their effectiveness. Farmers were asked about their perceptions of climate change, observed environmental shifts, and the measures they have adopted to mitigate its impacts. The study identified a range of locally developed adaptation strategies, including the use of artificial glaciers, shifts to climate-resilient crops, and participation in non-agricultural income-generating activities (Tripathi & Mishra, 2017; Aguiar et al., 2018; Aryal et al., 2020). By analyzing these responses, the study aims to provide insights into the factors influencing adaptation choices and resilience-building efforts in Leh. The findings contribute to a broader understanding of how high-altitude communities navigate climate challenges and offer recommendations for sustainable adaptation planning.

Results and Discussions

In our research, we have identified a set of significant adaptation measures reported by rural households in the study area. These measures encompass the following aspects: household

access to healthcare facilities, utilization of artificial glaciers, seeking assistance from social networks such as neighbors and relatives, the use of chemical fertilizers to enhance crop production, the adoption of new crop varieties, engagement in non-farm activities to augment income sources, awareness of climate change among household heads, ownership of at least one vehicle, access to electricity, availability of mobile network communication, access to in-home water supply, the presence of concrete roofs in households, the employment of household members in government positions, and the literacy of household members.

Our analysis primarily focuses on enhancing household livelihood resilience in the face of climate change, which encompasses all the major adaptation measures mentioned above. These measures are instrumental in bolstering the households' ability to withstand the adverse impacts of climate change, such as water scarcity, flash floods, and heavy rainfall. It is evident that these adaptations are of paramount importance and have the potential to significantly enhance the well-being of rural households. Throughout our survey, it became apparent that these adaptive capacities are held by the rural households we studied. Figure 5.1 shows the frequency with which the different options were employed by the rural households.

Table 1 Respondents response to distinct adaptive measures to vulnerability.

Adaptive capacities	Percentage of affirmative response	Percentage of negative response
Household members literate	79.4	20.6
Household member with government job	15.9	84.1
Concrete roof	22.3	77.7
Household having source of water at home	54.3	45.7
Household having mobile communication	69.2	30.8
Household having electricity	97.2	2.8
Household with vehicle	74.9	25.1
Household head having climate knowledge	67.5	32.5
Household members engaging in non-farm activities	48.0	52
Household planting new crops	68.2	31.2
Household using chemical fertilizer	38.7	61.3
Household seeks help from social networks	100	0
Household taking advantage of artificial glaciers	52.4	47.6
Household accessibility to Hospital	85.8	14.2

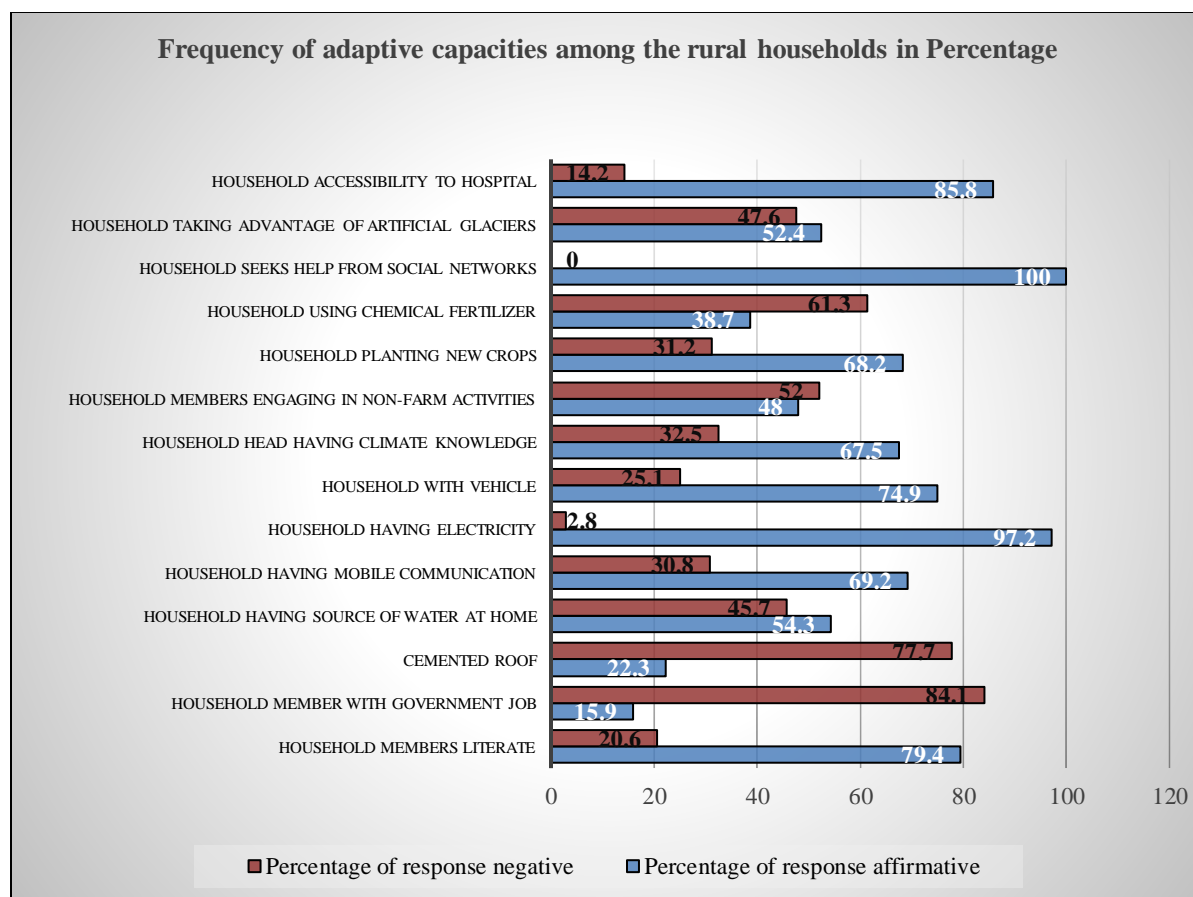


Fig.2 Graph showing frequency of adaptive capacities employed by the households in the region.

Household Accessibility to Hospital

In the course of our survey, a significant observation came to light concerning healthcare accessibility in the surveyed villages. While each village was equipped with a primary health center, it was evident that several villages, including Chushul, Hunderdok, Gya, Hemya, Liktshe, and Kaya, were situated more than 50 kilometers away from the nearest hospital. Conversely, villages like Shey, Nang, Shang, Stakmo, Umla, and Chilling were relatively closer to the hospital, with distances of less than 50 kilometers. The data analysis unveiled that approximately 85.8% of the respondents reported having access to the hospital, whereas 14.2% expressed their lack of access to hospital facilities. Notably, respondents residing in villages distant from the hospital mentioned their reliance on traditional healers within their localities for medical advice. Furthermore, they indicated that when conventional medicine failed to yield positive results, they sought out traditional Ayurvedic remedies from these healers. It is worth noting that respondents from both remote and proximate villages to the hospital acknowledged that for advanced medical emergencies, doctors often recommended seeking treatment at esteemed institutions such as PGIMER Hospital in Chandigarh or AIIMS in Delhi. However, some respondents raised concerns about the financial constraints associated with the expenses incurred for travel, medical treatment, and accommodation in these major cities. This highlighted a significant barrier to accessing specialized healthcare services for a portion of the population (Singh et al., 2022).

Household Taking Advantage of Artificial Glacier

Our extensive fieldwork in the study area has brought to light the prevalent reliance on snow and glacier meltwater for agricultural purposes in the majority of the villages. Specifically, Chushul, Hemya, Liktsé, Gya, Shang, Egoo, Nang, Stakmo, Chilling, Kaya, Umla, and Hunderdok predominantly rely on these crucial water sources, with the notable exception of Shey, which sources its water from the Indus River. Notably, the presence of artificial glaciers was a common sight in most of the villages dependent on snow and glacier meltwater. Upon close examination, it became evident that these communities grappled with water shortages, leading to the strategic construction of artificial glaciers in the lower valleys at higher elevations.



Fig.3 Image of an artificial glacier in the study region.

Our data revealed that 52.4% of respondents made use of artificial glaciers, while 47.6% reported not benefiting from them due to either unsuccessful implementation or their absence of such initiatives in the village. For instance, a respondent from Stakmo village reported that although an artificial glacier was constructed in the village, it proved unsuccessful, resulting in continued water shortages during peak seasons. The artificial glacier, a pioneering human-made technology, was first conceptualized and implemented by Chewang Norphel in 1987 as a proactive response to the pressing issue of water scarcity within these communities (Norphel & Tashi, 2015). The inception of artificial glacier techniques dates back to their experimental deployment at Phuktsephu in 1987, marking a pioneering milestone. Their remarkable success in augmenting water resources precipitated the dissemination of this technology to numerous other villages. Presently, this innovative approach finds application across various districts, testifying to its widespread adoption.

The construction of an artificial glacier comprises a sequence of integral components, each serving a crucial role in the overall effectiveness of the technology:

Data Collection: Initial stages involve the comprehensive collection of data regarding the persistence of water during the winter months, allowing for informed site selection.

Site Selection: The selection of sites is underpinned by a multifaceted criteria framework. Factors such as the site's orientation (favoring north-facing mountain locations to minimize direct sunlight exposure), topography featuring gentle slopes, lower altitudes (typically around 13,000–14,000 feet) to expedite early melting, and proximity to villages to reduce water transit losses collectively inform the strategic site choice.

Diversion Channel Construction: The construction of the diversion channel across hill slopes plays a pivotal role in channeling water towards the glacier formation site.

Snow Barrier Bund: Dry stone masonry snow barriers are meticulously erected along the lower edge of the diversion channel at the glacier formation site. The number and dimensions of these bunds are contingent upon the slope characteristics.

Water Release and Ice Formation: The next critical phase entails the controlled release of water at the glacier site through designated outlets, allowing for a gradual freezing process. This operation is executed over a period spanning from May to October, commencing when temperatures reach the freezing point at 0°C. The resultant stabilized ice mass persists until March when the natural melting process commences.

During periods characterized by overcast weather conditions or protracted snowmelt durations, the water reservoir can be judiciously employed for irrigation purposes, further accentuating the technology's multifaceted utility. It's notable that artificial glaciers exhibit an earlier onset of melting when compared to their natural counterparts, primarily due to their lower altitudinal placement. This complementarity with natural glaciers plays a pivotal role in ensuring a continuous and reliable water supply for the local community (Norphel&Tashi, 2015).

Help from Social Networks

Our comprehensive observations within the study area have unveiled a pervasive sense of companionship and neighbor bonds among the households. The respondents consistently attested to a deeply ingrained practice of mutual assistance within their communities. This spirit of cooperation extends to virtually every major aspect of household life, encompassing agricultural activities, the construction of homes, and the elaborate arrangements of marriage ceremonies. In particular, our investigations shed light on the significant role played by these interconnected social networks in times of adversity. Respondents who had experienced the distressing consequences of flash floods in both 2010 and 2015 emphasized that they were not alone in facing these challenges. Rather, they received invaluable support from their immediate neighbors, extended family members, and even external organizations. The data we gathered underscores the extent of this communal reliance, as nearly 100% of the respondents reported seeking assistance from their neighbors, relatives, and various organizations during emergency situations. It is evident that these social networks are not merely a cultural tradition but also serve as vital safety nets in times of crisis, playing a pivotal role in the livelihood and resilience of the entire community (Kumar et al., 2023).

Introduction of New Crops

Observations from the study area reveal significant variations in vegetation across different villages, particularly between the eastern and western parts of the region. Chushul village, located in the easternmost part, exhibited sparse vegetation, whereas villages such as Hemya, Likkse, Shang, Egoo, Nang, Stakmo, Gya, Shey, Chilling, Umla, Kaya, and Hunderdok displayed more abundant greenery. Furthermore, differences were noted in household vegetable cultivation.

In the western part of the region, where vegetation is more abundant, respondents reported growing a diverse range of vegetables. Traditionally, crops such as turnips, radish, potatoes, carrots, and onions were cultivated. However, recent findings indicate a shift toward exotic vegetables, including broccoli, cauliflower, zucchini, and capsicum.

An interesting development was the cultivation of subtropical fruits such as watermelon and muskmelon in Shey village, as well as a rising trend in mushroom cultivation, with households receiving training for effective production. Survey data revealed that 68.2% of respondents actively diversified their crops and vegetables in response to the region's challenging climatic conditions. Conversely, 31.2% of households did not opt for diversification due to harsh climatic constraints, underscoring the complexity of agricultural adaptation in the region. The shift toward new crops and techniques reflects the resilience of farming communities in adapting to climate change, ultimately increasing household adaptive capacities.

Non-Farm Activities

The study indicates a growing trend among households diversifying their income sources through non-farm activities. Many respondents emphasized a shift from traditional agriculture to multiple income streams. A 75-year-old participant reflected on how life today has become much faster-more paced compared to previous generations. Spatial variations in non-farm activity participation were evident. Villages closer to the district headquarters reported higher engagement in occupations such as shopkeeping and tourism. Survey data revealed that 48% of respondents were involved in non-farm activities, while 52% were not. Additionally, education levels played a key role in occupational diversification—household members with higher education were more likely to engage in alternative livelihoods, leading to improved economic well-being. This shift underscores the evolving nature of rural economies, where non-farm activities contribute significantly to household income.

Household Access to Water at Home

Water availability is crucial for subsistence farming in the study region, where communities depend on snow and glacier-fed water sources. Water scarcity was particularly evident in villages such as Nang, Stakmo, and Umla during peak crop cultivation periods. A seasonal shift in water sources was observed—during summer, households relied on pipeline water for drinking, but in winter, freezing temperatures rendered these pipelines unusable, forcing residents to rely on nearby streams. Additionally, ground excavation activities under the Jal Jivan Mission Scheme (JJMS) were noted, reflecting efforts to improve water access. Survey data showed that 54.3% of households had access to water within their homes, while 45.7% still relied on nearby streams. Pipelines and hand pumps played a crucial role in providing drinking water, demonstrating the adaptive capacity of these communities in managing seasonal water challenges.

Houses with Concrete Roofs

A significant shift in housing construction has been observed, with many villages transitioning to concrete-roof houses. Traditional houses with earth-rammed roofs were reported to be ineffective in preventing water leakage during rainfall, prompting households to adopt modern construction methods, particularly in villages experiencing higher rainfall levels.

However, variations were noted—remote villages like Chushul and Hunderdok still predominantly feature traditional houses, while villages closer to district headquarters exhibit a greater inclination toward concrete roofs due to easier access to construction resources.

Data analysis revealed that 22.3% of surveyed households had concrete roofs, while 77.7% continued to reside in traditional homes. Despite issues like water leakage, traditional houses remain popular due to their climate-adaptive features. Built with dry mud bricks and wooden log roofing, these structures help regulate indoor temperatures, keeping interiors warm in winter and cool in summer.

Household Members with Government Jobs

Differences in living standards were evident between households with government-employed members and those without. Respondents widely perceived that families with government jobs enjoyed higher financial stability. A notable trend emerged in the prevalence of government employment within the armed forces, particularly in remote areas. In Chushul and Hunderdok, many household members have migrated to Leh town for private-sector jobs, particularly in tourism. A generational shift was also observed—while older generations remained engaged in agriculture and livestock farming, younger individuals showed a preference for employment in the armed forces or other non-farm sectors. Survey data indicated that 15.9% of respondents had household members in government jobs, while 84.1% did not. These findings highlight the evolving employment patterns and economic disparities within the region.

5.3.14 Literacy of Household Members

A notable disparity in literacy rates was observed among villages in the study area. Villages closer to the district headquarters, such as Shey, Stakmo, Nang, and Shang, exhibited higher literacy levels due to better access to educational facilities. In contrast, remote villages like Chushul and Hunderdok had lower literacy rates. Respondents from Chushul highlighted the absence of a local school, forcing children to travel to Puga for education. Historically, older generations in this village had limited access to schooling, contributing to higher illiteracy rates. The nomadic lifestyle further hindered educational development in these communities. Survey data showed that 79.4% of household members were literate, while 20.6% remained illiterate. Most illiterate individuals belonged to older generations, indicating a need for targeted educational initiatives to bridge this gap. Despite challenges, the presence of primary schools in most villages represents progress toward improving literacy levels in the region.

CONCLUSIONS

Our study provides a comprehensive understanding of the evolving livelihoods within these villages, emphasizing how communities adapt to climate change and socioeconomic challenges. Healthcare accessibility remains a significant concern, with disparities in medical services. While many villages have primary health centers, remote villages such as Chushul, Hunderdok, and Kaya are over 50 kilometers away from the nearest hospital. Approximately 85.8% of respondents have hospital access, while 14.2% face medical service challenges, often relying on traditional healers. Innovative water conservation methods, such as artificial glaciers, have emerged as adaptive strategies. First pioneered in 1987, these structures provide essential water sources, though some villages, such as Stakmo, have encountered implementation challenges. Social networks play a critical role in these communities, fostering cooperation in agriculture, construction, and daily life. Nearly all respondents seek support from neighbors and

organizations during hardships, highlighting the importance of communal resilience. The shift from traditional to chemical fertilizers has increased crop yields but raised concerns about long-term soil health. Crop diversification is becoming a common adaptation strategy, with 68.2% of households actively diversifying crops to counter changing climatic conditions. A growing number of households are engaging in non-farm activities, with proximity to Leh headquarters playing a key role. Education levels strongly influence employment choices, with better-educated individuals more likely to pursue diversified occupations. Infrastructure improvements, such as concrete roofing, have gained traction in response to water leakage issues, though traditional homes remain prevalent due to their climate-adaptive design. Government employment continues to influence household living standards, with the armed forces providing a crucial source of stable income. Finally, literacy disparities highlight the need for targeted educational initiatives, especially in remote villages. While 79.4% of household members are literate, remote areas still face educational accessibility challenges. In conclusion, these observations highlight the resilience and adaptability of these communities as they navigate environmental and socioeconomic changes. These insights offer valuable guidance for developing strategies to enhance livelihoods and improve adaptive capacities in these remarkable villages.

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