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Impact of Climate Extremes on Socio-economic Characteristics of Peri-urban Mountain Settlements

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Abstract

Rapid urbanisation and a changing climate are transforming the Indian Himalayan Region (IHR), driving profound socio-economic and environmental changes. Himachal Pradesh, located in the western IHR, exemplifies these transformations. As climate change undermines the viability of traditional livelihoods such as agriculture and pastoralism, rural households are increasingly shifting towards secondary and tertiary occupations through livelihood diversification within villages or migration to urban peripheries. This trend is particularly visible in settlements located near major infrastructure, such as highways and hydropower plants, and urban centres where economic opportunities are concentrated.

However, such peri-urbanisation often unfolds in an unregulated and unplanned manner, straining the fragile mountain ecosystems and amplifying vulnerabilities to extreme climate events. Despite this, peri-urban mountain settlements remain largely overlooked in policy and research. Fragmented governance structures and overlapping rural and urban jurisdictions result in administrative neglect, exposing these areas to cascading social, environmental, and economic pressures.

This study investigates the developmental and climate-induced challenges faced by peri-urban settlements in Himachal Pradesh. Drawing on policy reviews, secondary literature, and primary research, it examines the interlinked risks of climate change and unregulated peri-urban growth, their impacts on livelihoods and infrastructure, and the associated gendered vulnerabilities. A review of the Indian policy landscape highlights critical gaps in existing plans, frameworks, and governance approaches for addressing these compounding challenges. Building on field-based and policy best practices, the study proposes context-sensitive recommendations to strengthen adaptation planning and support climate-resilient development across the peri-urban regions of the IHR.

Keywords: Peri-urbanisation, Indian Himalayan Region, Socio-economic challenges, Peri-urban governance, Climate adaptation.

1. Introduction

Climate change has emerged as one of the most wicked problems facing humanity in the 21st Century [1]. Extreme climate events such as floods, cyclones, heatwaves and droughts, which are increasingly frequent and intense, act as threat multipliers [2], surfacing pre-existing vulnerabilities physical as well as social systems. As a result, multifaceted impacts are felt on both the physical and social environment, affecting natural and human systems across scales [3]. While these impacts are observed globally, mountain ecosystems are among the most impacted ecosystems of all.

Occupying 24% of the Earth's surface, mountains are areas of high biological and cultural diversity that provide vital goods and services such as water, food, energy, minerals, medicinal plants, tourism, recreation, aesthetic and spiritual values to people living in and around these mountain regions and in downstream areas [4, 5]. However, mountain regions have increasingly become hotspots of climate-related losses, especially in the last three decades. The frequency of disaster events shows a rising trend in the Hindu Kush Himalaya, the Andes, and mountain regions in Africa. Severe damage and disruptions to people and infrastructure from floods are projected to sharply increase in South Asia, the Tibetan Plateau, and Central Asia. Increasing temperatures will continue to induce changes in mountain regions throughout the 21st Century, with expected negative consequences for the cryosphere, biodiversity, ecosystem services, and human wellbeing [4].

Hindu Kush Himalaya (HKH), also known as the 'Third Pole' or 'the Water Tower of Asia', holds the largest ice reserves outside of the polar regions. These freshwater reserves feed 10 major Asian river systems and support four global biodiversity hotspots [6]. Research suggests that HKH is warming at a higher rate than the rest of the world due to which, the glaciers could lose up to 80% of their current volume by the end of the century, on current emissions trajectories [7]. The occurrence of climatic disasters like floods, cloudbursts, landslides and GLOFs are also expected to increase, with potential devastating impacts on the natural and socio-economic systems, many of which will be beyond the limits of adaptation [8].

The Indian Himalayan Region (IHR)[1], forming a significant part of the larger HKH region, serves as a critical ecological and climatic buffer for the Indian subcontinent, and is home to nearly 50 million people. It is amongst the most environmentally fragile ecosystems in the world. In recent decades, climate change, habitat degradation, and rapid urbanisation have accelerated socio-economic and environmental transformation [9]. Increasing variability in temperature and precipitation has disrupted both the biophysical and socio-economic systems across the region [10; 11]. The IHR is warming at nearly twice the global average, intensifying the frequency and intensity of extreme climate events such as heatwaves, floods, cloudbursts and their cascading impacts [12]. As climatic variables are projected to be increasingly anomalous, the IHR is considered one of the most climate-sensitive geographies in the world [13].

Alongside these climatic shifts, the IHR also observes rapid, and in most cases, unplanned and unregulated urbanisation [14]. With an average decadal urban growth rate of 49%, compared to the Indian national average of 30% [15], the spatial, demographic, and economic characteristics of the IHR are rapidly changing. A changing climate also impacts the productivity of crops and livestock in the region, affecting the profitability of traditional livelihoods in rural mountain areas [16]. This, in turn, has led to reduced rural incomes, spurring migration to urban peripheries, and re-shaping socio-economic structures [17] in both original and destination regions.

[1] The Indian Himalayan Region (IHR) spans over 2,500 kilometres and covers an area of approximately 533,600 square kilometres, comprising 10 Indian states.

Himachal Pradesh, situated in the Western part of the Indian Himalayan Region, is an exemplar of these systemic shifts. In the past decade, the state has experienced increasing climate variability and rising impacts of extreme climate events [18]. As a result, traditional livelihoods in the State, especially the primary source, i.e., agriculture, are being adversely impacted. For instance, the contribution of the agriculture sector to Himachal Pradesh's Gross Domestic Product (GDP) has sharply declined from 35% in FY 1990-91 to a meagre 14% in FY 2023-24 [19]. Alongside a decline in agriculture's GDP, a drop in agricultural workers has been seen from 75.82% to 62.85% between 1971 and 2011 [20]. This trend is observed strongly in rural settlements located either in proximity to growing urban centres such as Shimla, Mandi, and Kullu, or close to critical infrastructure such as hydropower projects and highways, being heavily influenced by the pull factors[2] of such development. This indicates clearly that rural settlements are increasingly choosing to be engaged in secondary and tertiary services in search of stable incomes, showing clear signs of peri-urbanisation[3].

In Himachal Pradesh, steep slopes, fragmented holdings, and scarce tenable land exacerbate environmental risks. Expansion often entails slope cutting, encroachment on fragile zones, and obstruction of water bodies, increasing the likelihood of landslides and floods [21]. This makes unplanned urban expansion and peri-urbanisation particularly challenging and often detrimental to the environmental and developmental stability of the region [22], often getting associated with encroachment into fragile ecological zones [23]. Peri-urban growth in the State thus disregards growing climatic risks in the mountainous region, magnifying the potential impacts of extreme climate events.

Owing to these factors, peri-urban settlements are disproportionately vulnerable than urban centres during extreme climate events [24; 25], creating a vicious cycle in which climatic stressors drive peri-urbanisation, and unchecked growth intensifies climate risks [26].

Governance is further complicated by the duality of peri-urban areas, posing several developmental challenges. First, the scarcity of tenable land[4] intensifies competition between rural and urban land uses, causing significant challenges for decision makers [27]. Second, the overlapping jurisdictions often leave peri-urban areas outside controlled and regulated planning, as urban and rural local bodies either clash or institutional function is hindered due to gaps in planning and management. Existing approaches to governance in the mountains, therefore, often fail to ensure resilient and self-sustaining peri-urban settlements [ORF 2024], leaving them exposed to overlapping climatic and socio-economic challenges that go beyond current resilience frameworks [26]. Addressing these gaps demands developmental policies that explicitly integrate mountain peri-urban contexts within socio-economic and ecological frameworks by adopting an interdisciplinary lens [29].

Recognising peri-urbanisation as a defining trend in mountain development, this paper examines the developmental and climate-induced challenges faced by Himachal Pradesh's peri-urban settlements.

[2] "Pull factors" are conditions or attributes in a destination area that attract migrants. These include better wages, employment conditions, labor recruitment, family unification, and access to improved social opportunities such as healthcare and education [96].

[3] Peri-urbanisation refers to a dynamic process where rural areas in the hinterland of urban centres gradually become more urban [97]. Positioned at the interface of urban and rural domains, these transitional zones are characterised by an interplay of economic, social, and environmental forces. Peri-urban areas, often previously undisturbed by land use changes, offer more affordable housing, land, and services, while still providing access to urban facilities. This attracts migrants, increasing population and driving unregulated development [65].

[4] Tenable land refers to land that can reasonably be occupied, used, farmed, or built upon without undue risk or hardship, while untenable land refers to those that are not viable or safe for sustained human occupation or use, either physically, economically or environmentally.

Combining literature and policy review with field research in four case study areas, it identifies key planning gaps and priority areas of intervention to strengthen resilience.

2. Literature Review

The following sections build on the research argument by drawing insights from recent studies in Himachal Pradesh and the latest available data relevant to the study's context.

2.1. Rise in climatic extremes and associated socio-economic challenges in Himachal Pradesh

In the past five decades, the frequency of extreme climate events in Himachal Pradesh has increased eightfold, including heatwaves, extreme precipitation, floods, cloudbursts, and thunderstorms [18]. These events have led to substantial economic losses and damages in recent years. Between 2001 and 2011, over 400 lives were lost due to floods, with total damages of up to INR 7400 crores (Government of Himachal Pradesh 2020). This trend seems to have solidified in recent years, as in 2023 alone, the devastation due to floods resulted in over 150 deaths and economic losses exceeding INR 10,000 crore, indicating the increasing extent of such losses [31]. The agriculture sector is the hardest hit, as close to 349 thousand tons of agricultural and horticultural crops are lost annually (Government of Himachal Pradesh 2016).

Gradual yet large-scale climatic shifts have also been observed. Between 1989 and 2018, the number of annual rainy days as well as the number of annual snowy days has declined significantly, while dry spells have become more frequent. This pattern has contributed to water scarcity and soil degradation, magnifying the vulnerability of mountain agriculture in Himachal Pradesh [33; 34].

These climatic shifts have also directly exacerbated socio-economic vulnerabilities in the State. Rising temperatures and erratic rainfall patterns have reduced the viability of traditional farming and pastoralism, making it challenging for mountain communities to sustain themselves through traditional livelihoods [35; 17]. Agriculture alone has therefore become insufficient for sustenance under these conditions. Tourism, another major source of livelihood in the state, is also increasingly sensitive to climate change [36]. These livelihood-centric climate-induced disruptions not only reduce household incomes but also lead to food and water insecurity, influencing migration patterns in rural areas. Pressured to find alternative livelihoods, rural community members increasingly look beyond agriculture, shifting to secondary and tertiary sectors within the village, or in the nearest urban centre. Thus, climate change has driven peri-urbanisation in Himachal Pradesh.

2.2. Tracing peri-urbanisation trends and associated developmental challenges in Himachal Pradesh

Although Himachal Pradesh is the least urbanised state in India, with only around 10.3% of its population living in urban areas as of 2023 (Projected estimate by NITI Aayog 2025 [37]), it has observed a steadily rising urban population in recent decades. The state's urban population growth rate has, in fact, surpassed the national average in two out of the last four decades, as shown in Table 1.

Table 1 Comparison of decadal urban population growth rate between Himachal Pradesh and India.

Decade	1971-1981	1981-1991	1991-2001	2001-2011
Himachal Pradesh	34.76	37.8	32.58	15.61%
India	46.14	36.46	31.36	31.8%

Source: 38; 39; 37

This growth in urban population is also accompanied by a corresponding growth in built-up area, characterised both by densification of the urban centre, as well as by urban sprawl[5]. For example, In the Kullu Valley, between 1989 and 2016, the built up area has increased by 90.81% (Fig. 1), followed by orchards: 12.39% and forest cover: 6.26%, whereas area under agriculture has decreased by 56.88%, highlighting a shift from agricultural practice [40]. Kullu has been under environmental stress due to these transformations. Expanding tourism and urbanisation have encroached upon farmlands, forests, and fragile slopes, leading to concerns about soil erosion, loss of water bodies, and increased disaster risk [41].

While urban growth in Himachal Pradesh is evident, most new physical and social infrastructure is developed in city centres. Peri-urban areas often lack such infrastructure and must rely on their neighbouring urban centres, which both increases the burden on city facilities and holds back the independent growth of peri-urban regions [42]. Tourism has also emerged as a key driver of urbanisation and peri-urbanisation in Himachal Pradesh, with built-up areas expanding far more rapidly in tourist hotspots, growing by an average of **427% compared to just 55% in non-tourist areas** between 1990 and 2020 [43]. Peripheral villages near major tourist destinations like Shimla and Kullu frequently develop infrastructure such as hotels and homestays to capture tourism benefits, which gradually leads to their peri-urban character.

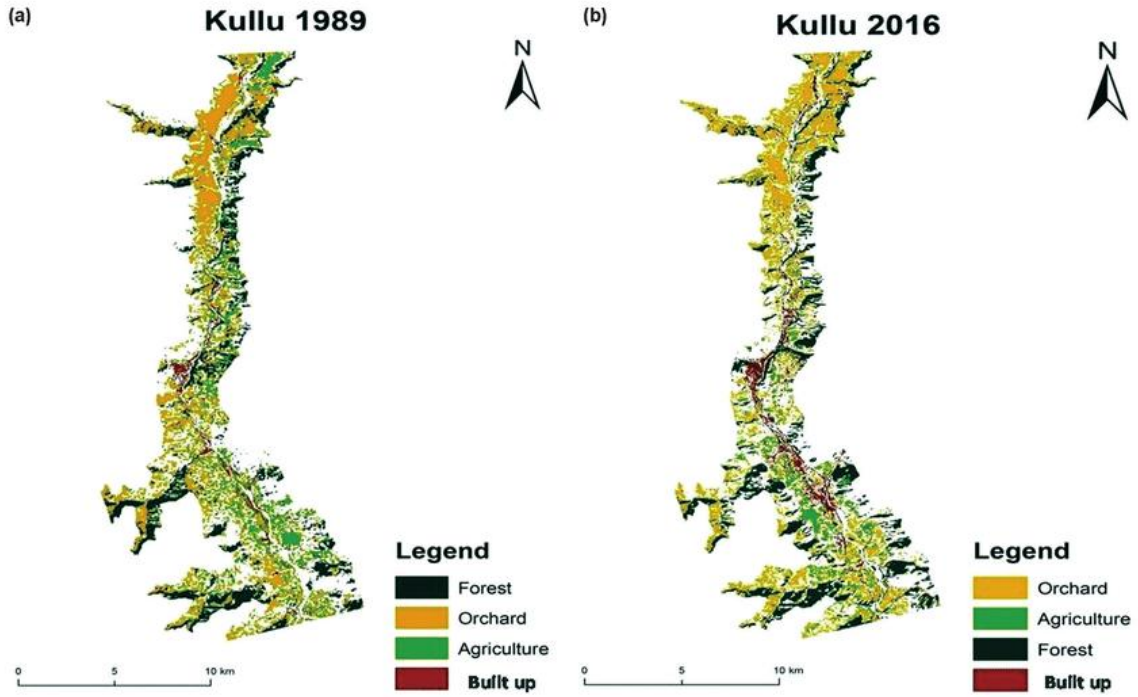


Fig. 1 Land Use and Land Cover Change in Kullu Valley between 1989 and 2016 [40]

[5] Urban sprawl can be defined as expansion of a city beyond administrative boundaries and urban fringes [98].

2.3. Peri-urban mountain settlements face disproportionate socio-economic risks in the context of climate change

Disparities in availability and access to critical infrastructure and employment opportunities, between the peri-urban and urban mountain areas results in an increasing number of people being dependent on the urban centre for education, employment and critical services such as healthcare [42]. In such a scenario, uninterrupted physical connectivity to these critical infrastructure systems via road network and reliable public transport becomes a prerequisite to be able to access these systems. Extreme climate events such as floods and landslides often disrupt this access by causing physical damage to the road network, bringing traffic to a standstill, and as a result, making these critical infrastructure systems unavailable to peri-urban communities at times of need [44].

For example, In July 2025, cloudbursts and flash floods in Mandi, Himachal Pradesh, cut off access for over 400 roads. In one case, students from the College of Horticulture and Forestry in Thunag had to carry two pregnant teachers, using makeshift pallanquins, on foot for 11 km to reach medical help in the nearest urban centre, as roads were blocked and emergency medical services were inaccessible [45]. These socio-economic interdependencies cause peri-urban communities to face disproportionate climate risks, as extreme climate events not only cause damage and loss but adversely impact lives and livelihoods and therefore, quality of life of peri-urban communities.

These disproportionate vulnerabilities are also strongly exacerbated by factors of intersectionality[6] existing within peri-urban communities, such as gender, age, and disability. For instance, while the proximity of peri-urban mountain areas to urban centres induces an increase in aspirational migration [46], this kind of migration is predominantly observed among young males [47], as the socio-economic predisposition of the elderly, women, and children, render them immobile [48]. In many agriculture-dominant rural mountain communities, a resultant "feminisation of agriculture[7]" is observed, which drives their risk instead of empowerment [49]. In Himachal Pradesh, more than half (55%) of the total agricultural workforce is female, yet their contribution lacks recognition and major agricultural decisions continue to be made by male members in the family [50, 51]. Thus, even though the absence of men increases the managerial ability of women, enhancing their involvement in economic and community spaces, they are often not granted decision-making power and control over economic resources [52]. These burdens intensify for women during extreme climate events due to their limited access to social, political and economic resources, which hampers their ability to recover from disaster, and further reduction in adaptive capacities. [53].

Additionally, increasing temperature and frequent flooding, compounded with limited access to healthcare and sanitation, increases the incidence of communicable diseases [54]. Research shows that the geographic range of vector-borne illnesses such as malaria and dengue is expanding to higher altitudes and latitudes that were previously unaffected [55]. Shimla, Himachal Pradesh observed a dengue outbreak for the first time in 2024, a weak signal that can soon turn into a dominant trend in the region [56].

Lastly, an instability in seasonal weather patterns combined with decline in the availability of cultivable land poses a threat to agriculture, further endangering livelihoods and food security [57]. For instance,

[6] Intersectionality can be defined as the interconnected nature of social categorizations such as race, class, and gender as they apply to a given individual or group, regarded as creating overlapping and interdependent systems of discrimination or disadvantage

[7] Feminisation of agriculture is a situation where women must undertake both productive tasks in addition to their traditional caregiving duties, as well as their previous farm roles in absence of male labour [52].

the 2023 floods led to losses of around 83 crore INR to agriculture crops and 75 crore INR to fruit crops [58]. Diminishing natural resources and competing demands for land, whether agricultural, industrial, commercial or residential, thus often results in social conflicts as well as an environmental struggle to strike a balance between preservation and development [59], posing a critical challenge for the development of fragile mountain areas in the State.

2.4. Gaps in institutional mechanisms for the governance of peri-urban mountain settlements

Peri-urban areas, being transitional zones between urban and rural areas, depict both rural and urban characteristics. However, reliable methodologies to delineate peri-urban regions are yet to be developed [26], and defining characteristics of such areas remain subjective to parameters being used as per the context being studied, and could thus be different for plains and hills [60]. This ambiguity blurs administrative jurisdictions, legal rights and overlapping responsibilities of governance actors [61], as these areas sometimes fall under the jurisdiction of multiple scales of governance, often with conflicting interests. In such a scenario, interdepartmental coordination and alignment among both rural and urban local bodies, regional authorities as well as state governments becomes crucial for the development of integrated and risk-informed policies and strategies [59, 62]. However, such efficient interdepartmental and multi-sectoral coordination has been a central challenge, which has historically remained unaddressed, hindering inclusive planning and governance of peri-urban areas [63]. Furthermore, opportunistically exploiting loopholes in the governance structure to navigate the unavailability of developable land, industries such as hospitality, tourism and manufacturing, as well as real estate markets, are seen to encroach on unclaimed land in peri-urban regions [64]. As a result, peri-urban mountain settlements are now characterised by unplanned, demand-driven urban growth, an inequitable distribution of infrastructure and services, environmental degradation and stressed natural resources, all resulting in a heightened vulnerability to a changing climate [65].

Similarly, at the national level, there exist no dedicated or standalone policies, schemes or guidelines exclusively catering to the developmental needs of peri-urban areas. However, some fragmented provisions can be traced.

The 74th Constitutional Amendment Act of 1992, for example, although not specifically designed for peri-urban areas, introduced governance mechanisms that could potentially address their planning needs. The Act introduced District Planning Committees (DPCs) and Metropolitan Planning Committees (MPCs), which are constitutionally mandated to consolidate plans prepared by Panchayats and Municipalities into a comprehensive development plan for the district or metropolitan region [67]. While Zilla Parishads and municipal bodies are responsible for planning and resource allocation in rural and urban areas, respectively, the urban–rural interfaces demand an integrated vision and coordinated investment across both rural and urban jurisdictions, which can be done by the DPCs and MPCs. Yet, despite the formation of DPCs in most states, district development plans for most districts remain unprepared [66].

In the absence of coherent national-level planning, some fragmented and largely uncoordinated efforts are observed. For example, the recent expansion of municipal boundaries of Shimla, the State capital, to include "semi & peri-urban areas" around Jawalamukhi, Dehra, and Jawali [68] is primarily administrative, with no corresponding strategies yet developed for infrastructure upgrades, governance reforms, or disaster preparedness. In contrast, the Development Plan for Shimla 2041 offers a more deliberate vision, extending its scope to include "a well-regulated and planned Shimla and its peri-urban areas." The plan covers an enlarged planning area, encompassing Shimla's municipal limits and notified special areas in peri-urban fringes such as Shoghi, Kufri, and Ghanhatti. As Shimla reaches its carrying capacity, these peripheral areas are expected to absorb future growth and population. However, while

envisioned as counter-magnets to the congested core, their environmental and socio-economic challenges remain largely unaddressed.

Additionally, national and state policies still address peri-urban challenges only implicitly. In theory, peri-urban planning could be addressed through the extension of city development plans or via regional planning mechanisms [67], but such measures are rarely implemented effectively. Rural Panchayats often lack the capacity to manage urban-style growth, while municipal authorities tend to avoid assuming responsibility until areas are formally annexed. This governance gap perpetuates a lack of coordination between urban and rural planning systems in India, further compounded by a shortage of specialised skills in rural, regional, and hill area planning [69].

Given that peri-urban areas are characterised by dynamic interactions between social, economic, and environmental systems, siloed and sectoral approaches have limited effectiveness [70; 71]. There is an urgent need for holistic, adaptive, and place-based strategies that can respond to local realities while also recognising the broader patterns and interdependencies shaping these regions [72]. A systems-based approach offers the potential to transform perceived conflicts between rural and urban priorities into opportunities for synergy, especially when stakeholders work collaboratively towards shared goals [73], in this case, the sustainable and equitable development of peri-urban settlements in Himachal Pradesh.

2.5. Research Gaps

While it is well-established that peri-urban mountain areas exhibit distinct climate-induced vulnerabilities, research on such settlements and their specific developmental challenges remains scarce. Existing studies often approach these issues in silos, focusing either on regional or local scales, thus overlooking critical interdependencies and systemic relationships between peri-urban settlements and the larger city-systems [74]. The IPCC notes equivalent gaps in mountain settlement research, highlighting the existence of a "global research void on climate adaptation within *mountain settlement systems*[8]". Between 1976 and 2023, only 264 articles have been published on mountain settlement systems, indicating it to be a niche research topic [75]. Both these gaps combined, for a developing economy like India, understanding and addressing the challenges of growing mountain peri-urban settlements becomes crucial. When planned for purposefully, these systems can capture the unique complexities of regional development and strengthen the links between settlements to improve overall functioning in social, economic and environmental terms [76].

However, compounding this research gap is a policy vacuum stemming from the administrative ambiguity of peri-urban settlements, where overlapping jurisdictions hinder coordinated governance [64]. For example, the entire state of Himachal Pradesh is organised into revenue estates or *mohals* under the Revenue Department, which often approves development in urban and peri-urban areas without consulting the Town and Country Planning Department, despite legal requirements, resulting in developments that may later be demolished by planning authorities [77]. Further, local communities residing in peri-urban areas often face widening health and infrastructure inequalities, alongside differential social, economic, and environmental challenges [78].

There is also a lack of research on socio-economic variables surrounding peri-urban expansion. Examining these variables is crucial because they determine land-use changes, infrastructure needs, and livelihood shifts; insights that form the base of effective policy interventions [79]. Existing studies majorly assess peri-urban landscapes only in terms of loss of agricultural land and water bodies, rarely

[8] Settlement systems are defined by interactions between a set of local units like villages, towns, or cities [99].

addressing environmental degradation and evolving socio-economic dynamics [80]. Climate change intensifies all of the above transformational changes, yet research remains fragmented, lacks an integrated approach, and fails to address both the immediate and long-term impacts on livelihoods and infrastructure [81]. As these transformations deeply impact the welfare and quality of life in peri-urban areas [82], understanding this becomes necessary to develop grounded and context-specific planning strategies. The study, therefore, seeks to fill these gaps, focusing on peri-urban areas in the State of Himachal Pradesh.

3. Methods

A mixed-method approach, combining qualitative, quantitative and geospatial methods, has been adopted to analyse the relationship between socio-economic and climatic risk drivers in peri-urban settlements of Himachal Pradesh. A keyword-search led literature review has been conducted to synthesise existing research on the topic, identify research gaps, and frame research objectives which guided the methodology.

3.1. Research objectives

Building on the identified gaps, this study aims to examine the intersection of climate change, peri-urbanisation and urban governance in mountain contexts, with focus on Himachal Pradesh. The objectives of this study are:

1. To analyse the climate-induced developmental and socio-economic risks faced by peri-urban mountain settlements in Himachal Pradesh, with particular attention to how changing climatic patterns interact with livelihood transitions, access to services and infrastructure, and settlement growth.
2. To examine the governance, planning, and policy landscape shaping peri-urban development in mountain regions, and identify institutional gaps that limit climate-resilient and inclusive development of peri-urban settlements.
3. To identify intervention areas and strategies for strengthening the resilience of peri-urban mountain settlements, drawing on insights from primary field engagement, and relevant best practices.

3.2. Selection of case study areas

Through literature reviews, information on climate risks, developmental trends and associated climatic impacts were consolidated, which guided the identification of study's geographical context, i.e, four Gram Panchayats (Fig. 2) across three districts in Himachal Pradesh:

1. Gram Panchayat Pandoh, District Mandi
2. Gram Panchayat Bajaura, District Kullu
3. Gram Panchayats Dhamun, District Shimla
4. Gram Panchayat Shoghi, District Shimla

Further, similarities and differences between the case study sites, as identified from the evidence base, were used to establish dominant socio-economic and developmental trends in the region, and further streamline the analytical scope of the study.

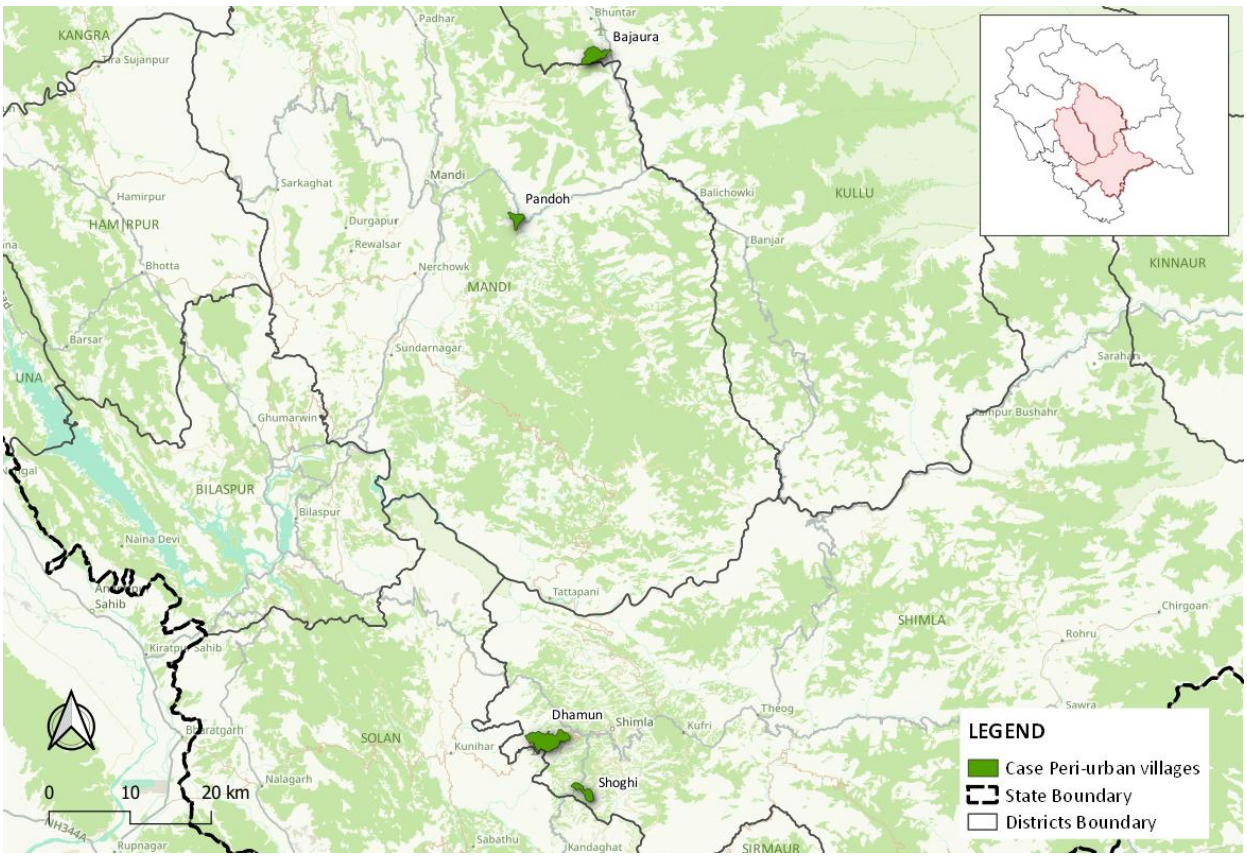


Fig. 2 Case study Gram panchayats - Bajaura, Pandoh, Dhamun and Shoghi in Himachal Pradesh

3.3. Data collection and analysis methods

Leveraging insights from the evidence base, **semi-structured key informant interviews** were conducted with Gram Panchayat representatives such as the Gram Pradhan, Panchayat secretary, and/or ward members to collect hyperlocal data related to the demographic, socio-economic, cultural and developmental trends in each case study area. Questionnaires were developed, integrating principles of STEEPLE Analysis[9], to identify all internal and external variables influencing the peri-urban mountain system in each case study area. Integrating **strategic foresight tools**, such as rich pictures, participatory hazard-mapping and visioning, focus group discussions were conducted to facilitate primary hands-on interaction with local communities in the four case study areas and collect insights on systemic interrelationships between socio-economic and climatic variables.

An average of 20-25 community representatives across three focus groups were consulted in each Gram Panchayat to ensure statistical viability and consistency across the collected responses. Additionally, photographic observational surveys guided by community representatives were conducted at disaster-affected sites to document physical risk factors. Lastly, satellite data from Google Earth were processed in an ArcGIS software to conduct change detection analyses of the peri-urban mountain settlements, to provide insights into their urban growth and land-use change patterns and identify intra-settlement disparities.

[9] STEEPLE is a strategic planning tool that helps identify internal and external factors influencing a system.

4. Results

This section presents findings from the field visits conducted across the four Gram Panchayats exhibiting peri-urban transition across three districts in Himachal Pradesh: Gram Panchayat Pandoh in Mandi, Gram Panchayat Bajaura in Kullu, and Gram Panchayats Dhamun and Shoghi in Shimla. An example case is presented for the respective Gram Panchayat(s) each district, and a comparative narrative is explored as the peri-urban characteristics observed and the nature of associated socio-economic relationships differ across the three districts. Furthermore, synthesing and comparing on-ground insights with the evidence based developed through the literature review, the section comments on whether or not on-ground realities are congruent with research-established notions of peri-urban development in Himachal Pradesh.

4.1. Land-Use Change, Flood Risk, and Socio-Economic Disparities in Pandoh, Mandi

Pandoh is a rapidly growing peri-urban settlement located in close proximity to the Beas River, in Mandi Sadar tehsil of District Mandi. Over the past 50 years, Pandoh and its surrounding regions experienced a series of administrative, infrastructural and environmental changes. First, the Pandoh hydropower project was established in 1977 [83], which increased the strategic importance of the major road connecting Pandoh with Mandi (now reclassified and upgraded as a National Highway - NH3). This resulted in two large-scale socio-economic shifts. Improved connectivity to the district capital of Mandi increased Pandoh's administrative significance and offered opportunities for seasonal or circular migration of Pandoh's youth for education and employment. Concurrently, landowners near the National Highway capitalised on corridor accessibility by establishing roadside marketplaces, a process characteristic of ribbon development along transport arteries [84].

This induced a shift from residential to commercial and mixed-use functions, with shop-house typologies: ground-floor retail with upper-level housing, emerging as common forms. Characterised by these settlement-level reconfigurations under new economic opportunities, the peri-urban character of Pandoh was factored into its demarcation as a Census town in 2011.

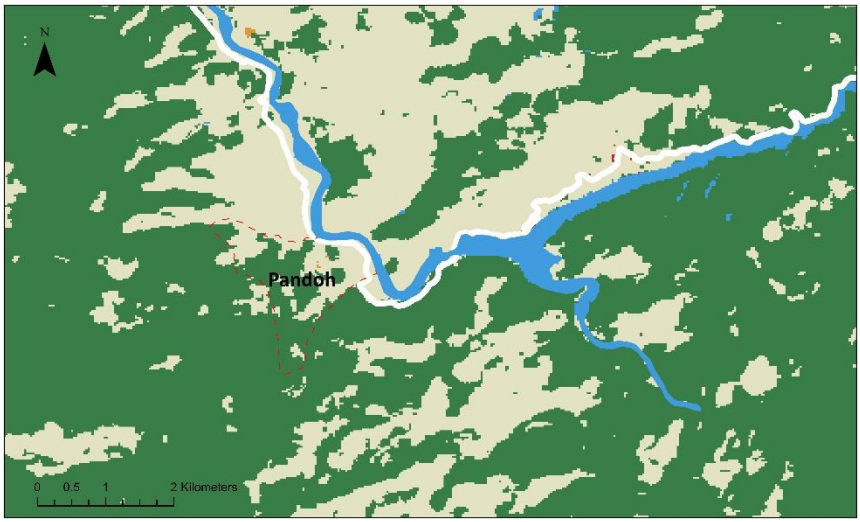


Fig. 3 Market area of Pandoh, captured during Primary survey (2025)

However, rapid land-use conversion (see figure 8) and consequent GHG emissions in Pandoh disregarded the region's ecological sensitivity, its proximity to the Pandoh dam, and the settlement's low-lying riverfront topography. Such transformations, in the absence of enforced riverine zoning, mirrored patterns observed prominently in peri-urban India, resulting in proliferating impervious surfaces, markedly elevated runoff and increased flash-flood risk in Pandoh due to diminished infiltration capacity and disrupted hydrological balance [85]. The same can be correlated with increased flash flood incidences in Pandoh in recent years.

The aftermath revealed cascading effects on social well-being as lives and livelihoods were disrupted through economic as well as non-economic losses. Women and children reported heightened anxiety, children's schooling was interrupted, and reliance on Mandi for critical services (healthcare, education and commerce) was exposed as a key vulnerability. Women in Pandoh expressed that as their children travel to nearby urban centres for schooling, this routine is disrupted during extreme climate events or high precipitation periods. The uncertainty of safety, particularly during monsoon due to the danger of falling rocks or landslides on NH-3, leads many women to fear sending their children to schools, which are located in nearby Mandi town. This constant anxiety not only strains their mental health but also creates intangible losses through interrupted education for children, underscoring the social costs of such extreme events. Further, residents reported that the Pandoh market area being flooded for almost a week, led to increased cases of water-borne and vector-borne diseases in the following weeks, showcasing clear linkages between an extreme climate event and impact on public health. As Pandoh exhibits a mixed plot-level land use character, where household-owned shops are present on the ground floor with residential spaces on the upper floors, businesses and household income were largely affected as businesses had to remain shut for at least a week. The extreme climate event thus led to cascading risks, disrupting livelihoods at the community level. Household-level tangible losses (loss of furniture, household assets, identity documentation) were recorded upto INR 2 Lakh (as reported by loss-holders), beyond repair costs.

Pandoh experienced catastrophic floods in July 2023, intensified by sudden discharge from the Pandoh dam, which washed away the century-old Pandoh Bridge and inundated homes and businesses along the Beas River and the Jayuli channel. Residents reported that the impacts of the flash flood were further exacerbated by misinterpreted early warning, as, despite siren alerts, residents interpreted warnings as routine, highlighting key gaps in graded early warning communication, especially in residential areas in close proximity to hydropower infrastructure.



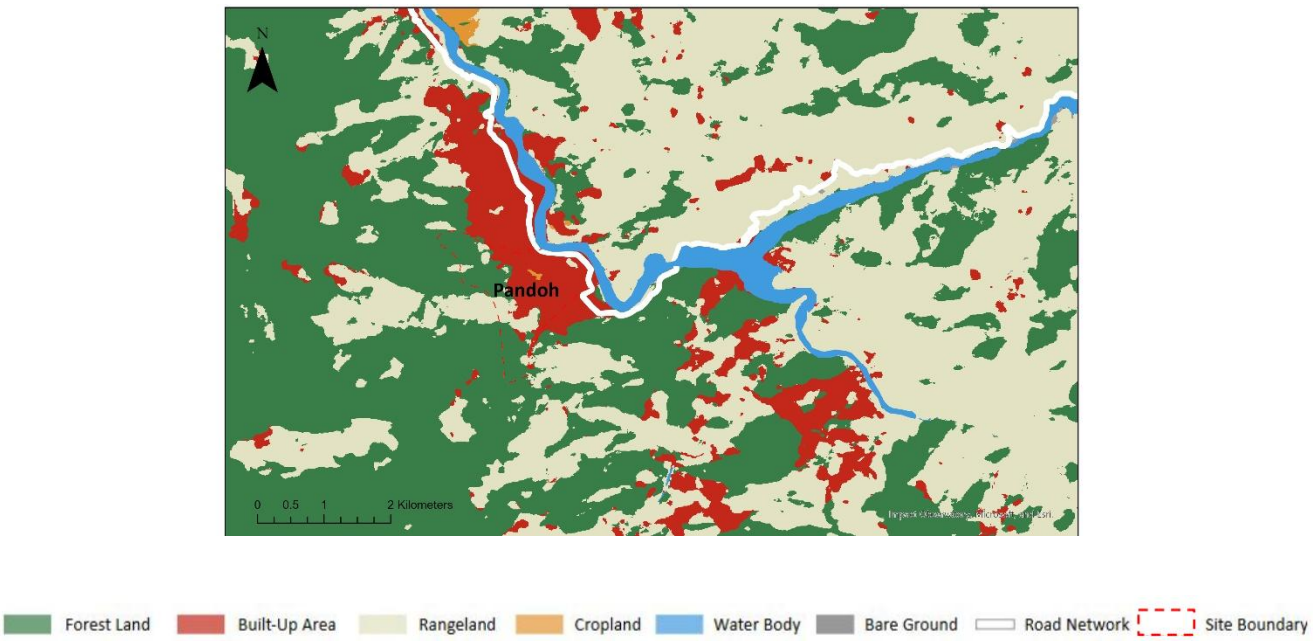


Fig. 4 Land Use and Land Cover Change in Pandoh and surrounding areas (1980 to 2024), mapped in ArcGIS Pro using Landsat 1980 and Sentinel-2 10 m resolution data (2024)

Pandoh exemplifies how unregulated peri-urban land conversion in ecologically sensitive zones magnifies flood risk and deepens socio-economic disparities. Its experience underscores the need for Integrated Flood Management (IFM), combining hazard zoning, graded early warning, ecosystem-based approaches, participatory planning, and institutional coordination.

4.2. Climatic and Socio-Economic Vulnerabilities in Bajaura, Kullu

Bajaura functions as a peri-urban growth node in the Kullu valley, strategically positioned on NH-3 and adjacent to Bhuntar airport, which has enhanced its regional connectivity, market integration, and exposure to external influences. The settlement performs multiple roles: as a centre of research and extension (hosting the Regional Horticultural Research and Training Station), as a service hub (linked to the HIMUDA colony and Bhuntar Sabzi Mandi), and as a cultural landmark through the 9th-century Basheshwar Mahadev Temple. Yet, its location along the Beas river, coupled with unregulated land-use conversion and recurrent flood as well as heat exposure, positions Bajaura as a fragile peri-urban landscape in urgent need of integrated land-use planning, hazard-sensitive zoning, and climate-resilient critical infrastructure.

Historically, Bajaura displayed a dual agrarian character: Lower Bajaura, close to the river, cultivated cereals and vegetables such as wheat, maize, and garlic, while Upper Bajaura, marked by fragmented hill slopes and lower temperatures, was dominated by apple orchards. Over the past decade, however, climatic shifts have altered this balance. Maximum temperatures show an upward trend while minimums decline, widening diurnal ranges [86]. At the same time, Bajaura's position in a frost-prone, rain-shadow zone has intensified water stress [86], especially in the upper slopes. Responding to these pressures, and facilitated by the local horticultural research station and KVK trainings, farmers in Upper Bajaura with traditionally higher income and education levels diversified from apples to persimmons, while in Lower Bajaura, recurrent flooding and an opportunity posed by the proximity to the highway prompted a transition from agriculture to trade and tourism. Additionally, as a part of this transition, Bajaura also observes a stark increase in barren land (+6.9%), owing to increasingly unfavourable climatic conditions

for agricultural activities, a decrease in animal husbandry and an increase of tertiary livelihoods, as reported by local government representatives and farmers. These changes are highlighted by the changing land cover, as highlighted by the Fig. 9.

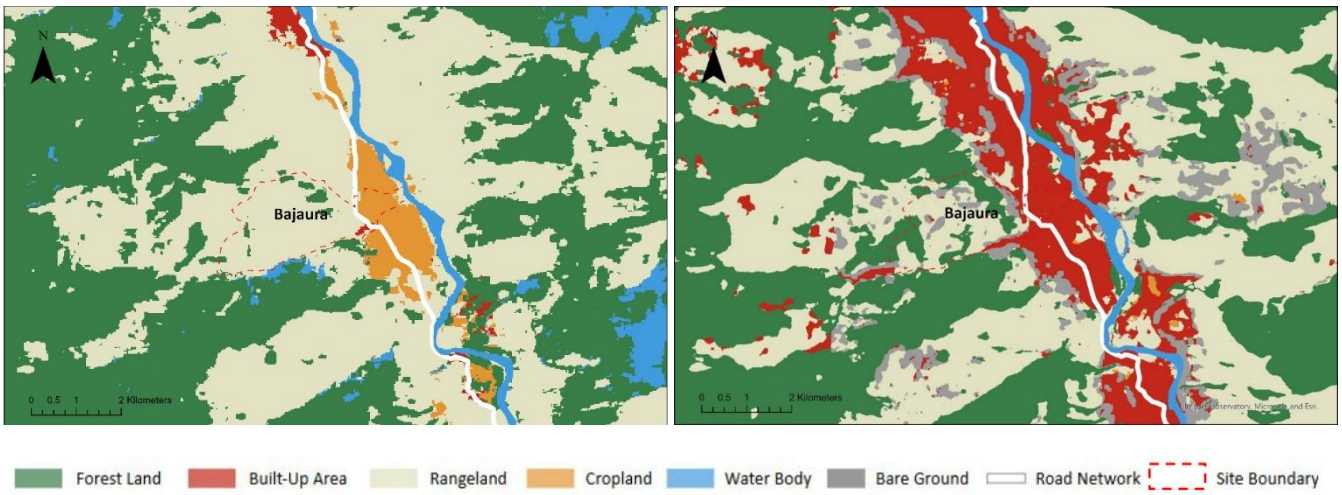


Fig. 5 Land Use and Land Cover Change in Bajaura and surrounding areas (1980 to 2024), mapped in ArcGIS Pro using Landsat 1980 30m and Sentinel-2 10 m resolution data (2024)

An important observation in the Bajaura case is the stark socio-economic and hazard divide between the two areas of the settlement. Members of Gram Panchayat Bajaura report that Lower Bajaura, prone to frequent flooding and associated damages, is home to marginalised groups such as religious minorities, scheduled castes, and scheduled tribes. Upper Bajaura, by contrast, is more is inhabited by higher-income households engaged in horticulture, a sector increasingly exposed to extreme heat. This demonstrates how climate variability impacts different socio-economic groups *disproportionately*, however a changing climate impacts *all* social groups.

On the contrary, adaptive capacity is correlated to social and financial security. While adaptive measures like rainwater harvesting are widely practised in Upper Bajaura, such knowledge and practices are far less accessible in Lower Bajaura, underscoring how socio-economic stratification directly shapes the adaptation potential of the Gram Panchayat overall.

Thus, Bajaura illustrates how socio-economic differentiation interacts with climatic variability to produce divergent peri-urban trajectories: upland communities pursuing adaptive crop diversification, and lowland households reorienting livelihoods toward the urban economy. This layered transformation highlights the need for planning frameworks that integrate ecological sensitivity with the differentiated socio-economic realities of peri-urban settlements.

4.3. Climate-Livelihood Interactions and Planning Challenges in Dhamun and Shoghi, District Shimla

Dhamun and Shoghi, both high-altitude Gram Panchayats located on the peri-urban fringe of Shimla, illustrate how rural settlements are being reshaped under the twin pressures of climatic variability and urban sprawl (see Fig. 10).

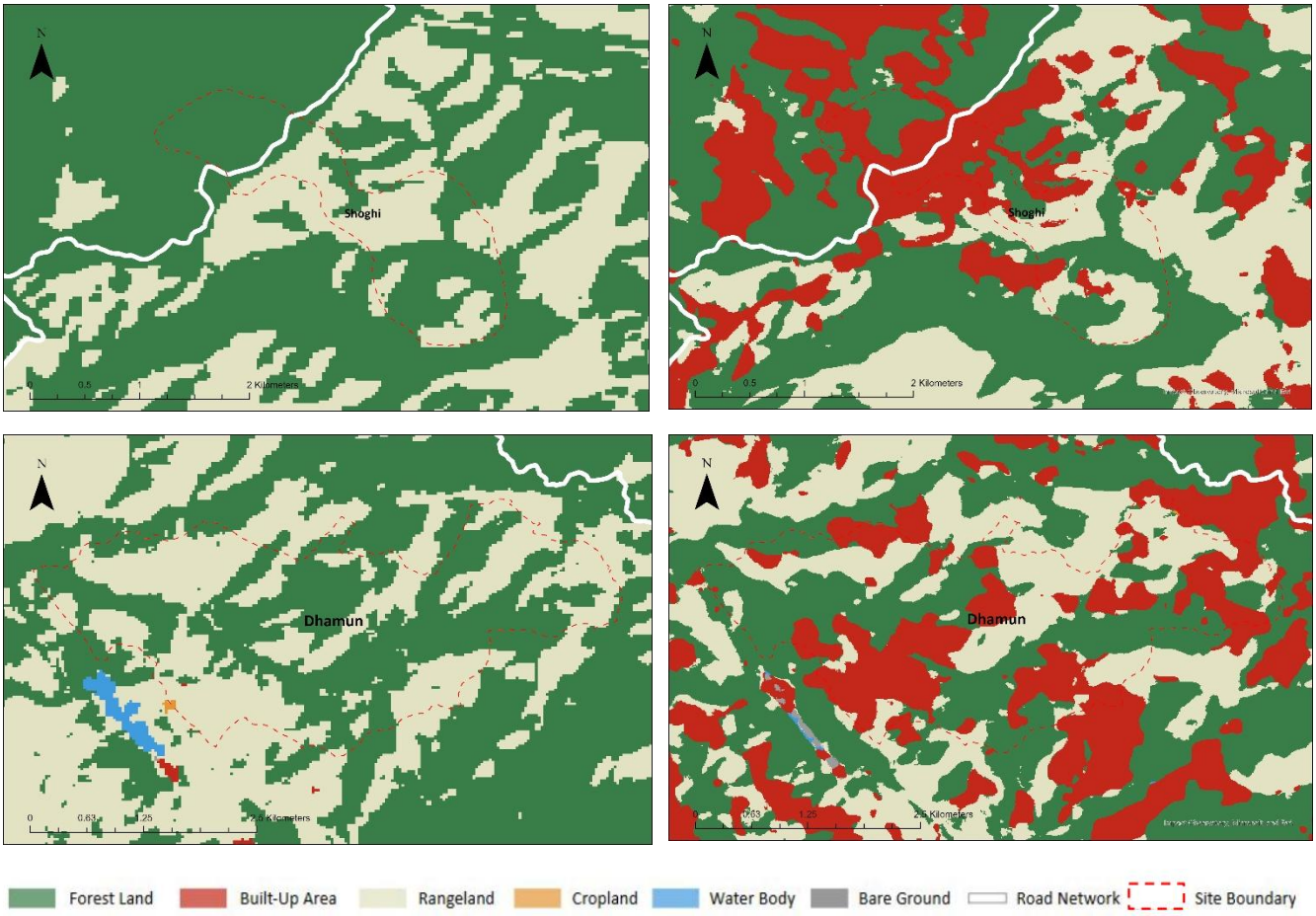


Figure 6. Land Use and Land Cover Change in Shoghi and Dhamun, Gram Panchayts neighbouring the State Capital of Shimla (1980 to 2024), mapped in ArcGIS Pro using Landsat 1980 and Sentinel-2 10 m resolution data (2024)

With Shimla city itself having reached saturation in terms of land availability, adjoining settlements have increasingly absorbed its growth impulses. Yet, in contrast to river-valley peri-urbanisation (as seen in Kullu), these high-altitude settlements reveal a different spatial logic: expansion is scattered and patchy, oriented among nodal roads, but dictated by the steep terrain and fragmented land parcels. This pattern of urban sprawl, with inconsistent built-up areas, defined as **leapfrog development** in the urban periphery of Shimla, demonstrates how peri-urbanisation in the mountains can pose unique challenges for land management and infrastructure provision [87] .Despite these shared dynamics, the two Panchayats differ in how climate and socio-economic shifts interact with local livelihoods and infrastructure. Dhamun exemplifies the compounded climatic vulnerabilities of a peri-urban agrarian settlement, as the primary economic activity in Dhamun revolves around supplying agricultural produce to the markets of Shimla and beyond. However, erratic rainfall, coupled with intensified wildfires, has degraded croplands, triggered human-wildlife conflict in cultivated areas, and accelerated soil erosion in the Gram Panchayat in recent years. Locals report that widespread deforestation associated with road and building construction has destabilised slopes, amplifying landslide risks and often cutting off road connectivity, crucial for transporting produce to urban markets in Shimla and Chandigarh. Additionally, the changing climate has led to an increase in plant viruses, especially in hybrid varieties, which has led to widespread decrease in cultivated land for many crops such as wheat and maize.

Despite these challenges, agriculture remains the primary source of livelihood, and Dhamun observes a gradual but steady shift from subsistence crops to cash crops such as capsicum, cabbage, ginger, and beetroot. Indigenous crops like ***kodra and banjiri***, grown from indigenous seeds and more resistant to a changing climate, continue to provide dietary diversity and act as a resilience buffer against climatic shocks when the produce of staple crops is low or unreliable. However, being economically unviable, they do not reach the urban markets.

Further, declining youth engagement in agriculture foreshadows long-term labour constraints. The proximity of Dhamun to Shimla encourages seasonal as well as circular migration, and a large percentage of the male youth population is reported to be engaged in tertiary activities such as masonry, carpentry, driving, etc. in Shimla city. Similarly, children access educational institutions in Shimla city on a day-to-day basis. This short-term migration is also fuelled by a lack of reliable critical infrastructure within the Gram Panchayat, as facilities such as secondary education and health are still lacking within the settlement. Conversely, infrastructure spillovers from Shimla manifest as negative externalities for peri-urban settlements. The location of a waste-to-energy plant near Dhamun, while addressing Shimla's solid waste management needs, creates locational disadvantages for local residents who face foul odour, mosquito breeding, and heightened health risks: an issue of environmental justice that underscores how urban benefits are often secured at peri-urban costs.

In Shoghi, climate stresses intertwine directly with large-scale infrastructure expansion. The Shoghi-Dhalli project, aims to four-lane a part of the Chandigarh-Shimla Expressway (National Highway 3) to improve connectivity and alleviate traffic congestion in and around Shimla [88]. However, the four-lane highway construction has led to widespread deforestation, heightened slope instability and landslide risks in the Gram Panchayat. The upcoming highway has spurred the development of large resorts in Shoghi, with tourism largely driven by non-residents. This externally fueled growth has been met with apprehension by local inhabitants, who are already grappling with climate-induced agricultural stress. Tourism expansion has further strained water availability, aggravated challenges of unmanaged sewage and solid waste, and created a sense of insecurity among residents due to the influx of outsiders. Simultaneously, rising temperatures have dried up traditional water sources such as dharas and baoris, while erratic electricity supply, limited healthcare access, and fragile road connectivity continue to heighten community vulnerability. While this trajectory aligns with a tourism-led growth model, it has exacerbated existing socio-ecological stresses for residents, underscoring gaps in participatory governance.

When compared, both Dhamun and Shoghi Panchayats exhibit common trends that define peri-urban transformation in mountain regions: a shift from subsistence to cash cropping, modest but significant engagement with tourism, intensifying climatic pressures, and uneven infrastructure provisioning. Both have also seen a phenomenal expansion of road networks over the last five decades, which has simultaneously improved market access and amplified slope instability [89]. Yet, key differences are visible. Dhamun remains more agrarian, with adaptation efforts such as rainwater harvesting and institutional schemes (e.g., MNREGA-supported soil conservation) still rooted in local agriculture, whereas Shoghi is more urban-facing, with livelihoods increasingly tied to tourism and service activities. Consequently, the adaptation potential in Dhamun is anchored in strengthening agricultural resilience and ecosystem restoration, while in Shoghi it lies in integrating slope stabilisation, participatory waste management, and climate-proofing of tourism infrastructure.

Together, these cases highlight how proximity to an urban core like Shimla generates differentiated peri-urban outcomes, shaped not only by socio-economic drivers but also by ecological conditions and infrastructural trajectories. They reinforce the planning imperative for context-sensitive peri-urban

strategies, combining hazard zoning, slope stabilisation, ecosystem restoration, and livelihood diversification, rather than one-size-fits-all interventions across mountain settlements.

5. Discussion

Across Shoghi, Pandoh, Dhamun, and Bajaura Gram Panchayats, LULC transitions from 1980 to 2024 reveal a consistent shift toward built-up expansion, with important implications for disaster and cascading risks. Built-up area has increased sharply across all Panchayats, i.e, ~24% in Shoghi, ~34% in Pandoh, ~42.5% in Dhamun, and ~44% in Bajaura, largely concentrated along road corridors and river-adjacent zones. This expansion corresponds with substantial declines in tree cover (−19% in Shoghi; −25% in Pandoh; −30% in Dhamun) and rangeland (−4.5% in Shoghi; −12% in Pandoh and Dhamun; ~−48% in Bajaura), indicating both land use change from agriculture and allied uses to urban, and consequent fragmentation of traditional livelihood systems.

Table 1 Land Use change across case study areas

Case Study Area/ Gram Panchayat Name	Land Use (%) (1980 vs 2024)					
	Built-up		Rangeland		Trees	
Dhamun, District Shimla	0.5	43.2	38	26	58	28
Shoghi, District Shimla	0.0	24.0	33.6	29.1	66.2	46.9
Pandoh, District Mandi	0.0	37.6	28.2	15.3	68.1	42.3
Bajaura, District Kullu	0.7	44.8	70.9	22.5	28.4	32.7

Source: Author's analysis

These transitions directly alter hazard dynamics in mountainous terrain. Deforestation reduces slope stability and soil cohesion, increasing susceptibility to landslides and slope failures, particularly under extreme rainfall. Simultaneously, the loss of rangeland and vegetative cover reduces infiltration, while expanding impervious surfaces amplify surface runoff, intensifying flash flood risks. This is especially critical in Pandoh and Bajaura, where development intersects with river systems.

Hydrological changes, evidenced by slight increases in bare ground and localised shifts in water extent suggest riverbank destabilisation and altered sediment regimes, which can exacerbate flooding and erosion. Encroachment into drainage channels and floodplains further elevates exposure. The co-location of expanding settlements with hazard-prone zones thus reflects a transition from risk-buffering to risk-amplifying landscapes, where land-use change is compounding multi-hazard vulnerability.

The observed LULC transitions across the case study areas have significant implications for socio-economic risk amplification, particularly through the interaction of **exposure, sensitivity, and adaptive capacity**. The rapid expansion of built-up areas into hazard-prone zones has increased the physical exposure of households, livelihoods, and critical infrastructure to floods and landslides. This is compounded by the erosion of natural buffers such as forests and rangelands, which previously supported ecosystem services including slope stabilisation, water regulation, and livelihood provisioning.

These changes disproportionately affect socially and economically marginalised groups, as seen in Lower Bajaura and flood-prone areas of Pandoh, where vulnerable populations are often concentrated in high-risk locations with limited access to resources, early warning systems, and recovery mechanisms. Simultaneously, the shift away from agriculture toward tourism and tertiary activities introduces income volatility and market dependence, reducing livelihood resilience to climate shocks. Disruptions to connectivity, due to landslides or flooding, further exacerbate these vulnerabilities by restricting access to markets, healthcare, and education, as illustrated by the case examples.

Collectively, these dynamics indicate a transition toward risk accumulation, where land-use change, socio-economic differentiation, and climate hazards interact to produce cascading and uneven impacts, underscoring the urgency for integrated, equity-sensitive peri-urban planning in mountain regions.

5.1. Pathways to Successful Climate Adaptation of Peri-urban Mountain Settlements

The empirical findings from peri-urban mountain settlements in Himachal Pradesh underscore a persistent governance-ecology mismatch as rapid peri-urban expansion outpaces regulatory capacity, driving ecosystem fragmentation, hydrological stress, and socio-ecological inequities [90; 91]. Peri-urban mountain regions operate at the interface of rural livelihoods and urban demand, where ecological functions such as springs, recharge zones, and slope stability, underpin regional resilience, yet are seldom recognised in conventional planning paradigms [90]. The policy and plan analysis conducted here reveals both gaps and opportunities in existing frameworks, offering two recommendations for planning reforms that internalise mountain-specific risks and local knowledge.

5.1.1. Urban and Regional Development Plans, Norms, and Regulations Should Be Revised with Specificity to the Mountain Context

A foundational gap identified is the lack of institutional mechanisms to integrate peri-urban mountain zones into statutory planning bodies such as District and Metropolitan Planning Committees (DPCs/MPCs). These committees have the legal mandate to coordinate urban and regional growth, yet their use is ad-hoc and rarely designed to address peri-urban climatic vulnerabilities [91]. Amending state planning rules to require a peri-urban/mountain annex, with mandatory Gram Panchayat and relevant department consultations and bi-decadal reviews, can prevent disjointed decision-making that degrades fragile ecosystems [91].

The need for a normative overlay tailored to mountain ecologies finds support in peri-urban resilience literature, which highlights how **peri-urban ecosystems act as buffers** against climatic stressors but are systematically undervalued in planning. Therefore, a **state-level Mountain Peri-urban Planning Framework (MPPF)** should overlay existing master plans and building bylaws. The MPPF could: (a) define mountain peri-urban typologies; (b) set thresholds for slope, land use, and groundwater recharge; and (c) make these conditions mandatory for approval of sectoral plans. Embedding such criteria into statutory instruments would operationalise ecosystem thresholds rather than treating them as discretionary.

Stricter **land-use conversion controls** around critical features such as springs, wetlands, and steep slopes are needed to reduce flood and water scarcity risk. Empirical studies in peri-urban contexts note that unregulated conversion of ecosystems accelerates socio-environmental inequalities and hazard exposure [90, 91]. Accordingly, state land-use norms should map and legally protect these features as no-development zones; require environmental impact screening; and link approvals to spring-recharge plans. These reforms align with broader calls to treat peri-urban ecosystems not as residual spaces, but as integral **risk governance assets**.

In mountain peri-urban settlements, **generic flatland building norms have repeatedly failed** due to slope instability and runoff amplification [92]. A mountain schedule in state model building bylaws should specify: reduced floor area ratios and ground coverage on steep slopes; mandatory permeable surfaces; stormwater detention; foundation-design standards suitable for shallow landslide zones; and regulated road gradients and drainage designs. These measures directly address observed hazard amplification mechanisms in peri-urban expansion [92].

Integrated Local Area Plans (LAPs), prepared jointly by municipalities, Gram Panchayats, and district planning units, can overcome jurisdictional fragmentation, which is a recurring barrier identified in both peri-urban governance reviews and resilience compendia [91; 79]. For each peri-urban growth corridor, a time-bound LAP (5 to 10 years) chould cover land use, ecosystem services mapping (springs and recharge zones), water and sanitation services, affordable housing, transport corridors, and socially just relocation plans. Approvals by the DPC should be a **precondition for infrastructure clearances**, ensuring iterative alignment across governance tiers.

Economic incentives can also play a role. Land conversion pressures stem from limited livelihood alternatives and inequitable economic returns on peri-urban land. Introducing **environmental service payments** and **land-use incentives** (e.g., tax reductions or direct payments) for conservation of orchards, wetlands, and recharge areas can align local economic interests with ecosystem protection, while incentives conditioned on conservation covenants enforceable at the Panchayat level can reinforce long-term stewardship.

5.1.2. Local Communities must be capacitated to contribute to the planning process

Participatory planning literature consistently highlights that **place-based knowledge**, especially regarding springs, traditional water harvesting, and grazing routes, is critical for climate adaptation [91, 93]. Gram Panchayats, as custodians of this knowledge, can significantly improve ecological outcomes and local legitimacy of planning processes [91; 79]. Case documentation from Mukteshwar and Shimla emphasises that communities hold diagnostic insights on water and forest regimes often missing in formal datasets [91].

Meaningful participation reduces socio-economic and cultural biases, and improves equity outcomes - two persistent challenges in peri-urban governance [90; 79]. To institutionalise participation, state policy should mandate **formal seats for affected Gram Panchayats** on DPC and LAP approval committees, with published minutes and divergence notes to ensure transparency. Support mechanisms such as training stipends can further strengthen representation.

However, many Panchayats currently lack the data and technical skills to engage effectively, limiting their influence in planning negotiations [79, 93]. Targeted capacity programmes, focusing on ecosystem mapping, land tenure documentation, and participatory planning techniques, should be developed jointly by state agencies and academic institutions. District-level bootcamps with field exercises, such as spring mapping and household vulnerability assessments, can convert latent local knowledge into usable planning inputs.

Beyond capacity building, **Community-Led Ecosystem Management Plans (CEMPs)**, prepared and owned by Gram Panchayats, should be recognised as formal inputs to LAPs. CEMPs would prioritise community-identified ecosystem services that support both rural livelihoods and urban utility. Embedding such community plans within statutory processes gives concrete structure to participatory ideals and aligns local priorities with planning outcomes [93 ,91].

Finally, alignment with national schemes such as the **Shyama Prasad Mukherji Rurban Mission (SPMRM), MNREGA** and **AMRUT 2.0** remains partial. While these schemes emphasise bridging rural-urban divides and recognise peri-urban challenges, they often lack **specific operational mandates** or resources to address mountain peri-urban dynamics. Extending their scope to incorporate peri-urban planning corridors, especially in states like Himachal Pradesh where land is a state subject and planning areas can legally extend beyond municipal limits, represents an opportunity that remains under-utilised [94, 95].

6. Conclusion

With rapid socio-economic and environmental transformation driven by climate change and unplanned urbanisation, Himachal Pradesh's peri-urban areas are emerging as critical systems that can not only help decongest already saturated hill cities, but also support alternative and more resilient livelihood pathways for mountain communities. However, while existing planning mechanisms such as delineation of planning and special areas allow partial recognition of these regions, they fall short of addressing the distinct ecological sensitivities and socio-economic transitions that define these contexts.

Moving forward, there is a clear need to reposition peri-urban areas not as residual spaces, but as strategic zones within the broader mountain development processes. Strengthening institutional coordination, embedding local knowledge into planning processes, and recognising ecological thresholds as central to development decisions can enable these regions to evolve as resilient and self-sustaining systems. With a more integrated approach, peri-urban areas in Himachal Pradesh have the potential to transition from zones of vulnerability to drivers of climate-resilient and inclusive growth in the Indian Himalayan Region.

Declarations

Funding statement

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Data Availability statement

All data generated or analysed during this study are included in this published article and its supplementary information files.

Ethical approval and accordance

This manuscript draws on field engagement undertaken as part of a larger project "Fostering anticipatory action to climatic and socio-economic risks at sub-national scales in the Hindu Kush Himalaya region," managed by the International Centre for Integrated Mountain Development (ICIMOD). The project received ethical approval from ICIMOD's Research Ethics Committee. The research was carried out in accordance with the guidelines and requirements of ICIMOD's Research Ethics Committee and relevant ethical principles for research involving human participants.

This study involved primary engagement with local community members and Gram Panchayat representatives in Himachal Pradesh, India, through semi-structured key informant interviews, focus group discussions, participatory exercises, and field-based observational surveys. Participation was voluntary, and verbal informed consent was obtained from participants before their involvement. The study did not involve any animal subjects, biological materials, or clinical intervention. No personally identifiable information has been disclosed in the manuscript, and community inputs have been reported in an aggregated and anonymised manner.

Consent to participate

Verbal informed consent was obtained from participants involved in the study.

Consent to publish

No personally identifiable participant information, images, videos, or individual case details are included in the manuscript.

Clinical trial number

Clinical trial number: not applicable.

Competing interests

The authors declare no competing interests.

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