International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

# Mapping Resilience: GIS-Driven Multi-Hazard Risk Governance and Economic Burden Reduction in Himachal Pradesh

**Nivedita**

Associate Professor, Department of Geography, Government College, Solan (H.P.)

## Abstract
Himachal Pradesh faces recurrent multi-hazard risks arising from landslides, floods, cloudbursts, earthquakes, avalanches, and forest fires, with substantial consequences for infrastructure, livelihoods, economic activity, and public finances. This targeted literature review examines how Geographic Information Systems (GIS) and allied geospatial technologies support disaster risk management and economic risk reduction across the state. Evidence was synthesized from peer-reviewed studies, government policies and plans, technical reports, institutional repositories, and relevant grey literature published between 2010 and 2026. The review assesses major applications, including the Hazard Risk and Vulnerability Atlas, landslide susceptibility and inventory mapping, rainfall-based early-warning systems, and emerging urban resilience platforms. Findings indicate that GIS can reduce disaster-related economic burdens by informing land-use and infrastructure planning, protecting exposed assets, improving emergency routing, prioritising mitigation expenditure, supporting post-disaster assessment, and limiting disruption to agriculture, tourism, and essential services. However, the economic benefits of these systems remain insufficiently quantified. Fragmented institutional coordination, limited technical capacity, inconsistent data updating, weak local-level integration, and unequal warning dissemination further restrict operational effectiveness. Stronger integration of GIS into statutory planning, economic evaluation, district-level decision systems, and participatory risk communication is essential to translate spatial intelligence into measurable, equitable, and fiscally sustainable resilience.

**Keywords:** Geographic Information Systems, disaster risk reduction, landslide susceptibility, economic resilience, Himachal Pradesh

## Introduction
Himachal Pradesh (HP), a predominantly mountainous state in the Western Himalayas, is typified by steep slopes, fragile geomorphology and rapidly transforming land-use patterns that collectively amplify its exposure to a wide spectrum of natural hazard.[1] Its physiographic sequence - from the Lower Himalaya through the Middle Himalaya to the Higher Himalaya - produces pronounced spatial heterogeneity in rainfall, temperature and lithology, so that virtually every district is recurrently visited by earthquakes, landslides, cloudbursts, flash floods, snow avalanches and forest fires.[1,2] Geologically youthful and tectonically active, much of the state falls within Seismic Zones IV and V of India's seismic zonation map, a structural condition compounded by unregulated settlement expansion into fragile terrain and the proliferation of hydropower and tourism corridors.[1,3] The combined effect is a multi-hazard risk profile in

which hazard incidence and potential loss are unevenly distributed across districts, with the northern and northeastern districts of Lahaul-Spiti, Kullu, Kangra, Solan and Kinnaur exhibiting the highest climate-induced multi-hazard risk in recent composite-index assessments[2], while other districts such as Chamba reveal pronounced intra-district variation in vulnerability[4].

Over the past decade, climate-change signals and intensifying human–environment interactions have measurably worsened this risk profile. The frequency and magnitude of hydro-meteorological events have risen, with successive monsoon seasons delivering damage at scales that have rapidly outpaced the state's coping capacity.[5] This structural vulnerability was starkly demonstrated by the 2023 monsoon season, which brought the state "to its knees" through three discrete heavy-rainfall spells between 7–11 July, 11–14 August and 21–23 August 2023, triggering cascading flash floods, landslides, cloudbursts and landslips across multiple districts.[6,7] Official and independent assessments converge on the magnitude of the catastrophe: more than 500 fatalities and over ₹12,000 crore in damages, with Kangra, Kullu and Chamba recording rainfall in excess of 1,800 mm - over 150% above long-term averages.[6-8] Stratified household surveys conducted in the aftermath have further revealed systemic deficiencies in early-warning dissemination, evacuation logistics and post-disaster recovery, particularly in remote, high-altitude and rain-fed communities.[8]

These impacts have reverberated well beyond the immediate humanitarian toll. Sectoral damage extended across power, water and sanitation, housing, health, education, road infrastructure, agriculture, horticulture, animal husbandry and fisheries, with agriculture alone accounting for losses exceeding ₹2,000 crore.[6,7] Echoing trends observed elsewhere in the Indian Himalaya, recurrent disasters also generate pronounced medium-term fiscal consequences: state-level panel evidence indicates that flood shocks widen fiscal deficits for up to three years post-event, depress own-source revenues and inflate borrowing, while expenditure on flood control and reconstruction surges in subsequent budget cycles.[9,10] For a special-category state such as HP, where public debt already exhibits a strongly positive dependence on revenue expenditure, economic growth and inter-governmental transfers, the compounding burden of repeated disaster reconstruction intensifies the risk of a structural "debt–disaster spiral" that crowds out developmental spending and heightens reliance on external borrowing.[9,11]

The intensity and recurrence of such events have made plain the limits of purely reactive disaster response and underline the urgency of proactive, risk-informed disaster risk reduction strategies grounded in spatial evidence.[5,12] Within this broader paradigmatic shift, Geographic Information Systems (GIS) and allied geospatial technologies have emerged as critical instruments for transforming heterogeneous hazard data, climatic information, exposure patterns and socio-economic indicators into actionable maps and decision-support systems.[3,13] By enabling the integration of satellite imagery, drone surveys, field inventories and administrative records, GIS supports fine-grained hazard zonation, multi-criteria vulnerability assessment and dynamic monitoring of evolving risk in complex mountain environments where terrain accessibility and data sparsity otherwise constrain analysis.[14,15] Techniques such as the Analytical Hierarchy Process, frequency-ratio methods and logistic-regression models, when coupled with multi-source geospatial layers, have proven highly effective in delineating landslide-prone terrain in districts as varied as Shimla, Dharamshala and the Upper Ravi catchment, where high-resolution susceptibility maps now inform both land-use planning and infrastructure siting decisions.[16-19]

HP has invested significantly in such geospatial capabilities, placing GIS at the centre of its evolving disaster-management architecture. The state's Hazard Risk and Vulnerability Atlas, constructed from digital GIS databases covering all twelve districts, ranks areas in descending order of potential losses in human lives, crops, buildings and lifeline infrastructure, thereby explicitly linking spatial risk information to the prioritisation of interventions and budget allocations. At the urban scale, a GIS-driven Urban Resilience Platform - combining high-resolution imagery with door-to-door surveys - has been developed to map thousands of properties and to support emergency response, with plans for integrating artificial-intelligence and machine-learning modules for early warning and climate-resilient planning. Sectoral departments, tasked by the State Disaster Management Plan with preparing department- and district-level Crisis Management Plans, increasingly rely on GIS-generated inputs for vulnerability mapping, preparedness planning and inter-agency coordination.[12,20]

Yet, while the state has assembled a comparatively sophisticated spatial infrastructure for DRR, the academic literature offers only limited synthesis of how GIS-based initiatives in HP concretely translate into economic risk reduction, beyond qualitative assertions of "better planning" or "informed decision-making".[13] Most existing studies concentrate either on the technical mechanics of landslide-susceptibility mapping and hazard zonation[16,17,19] or on descriptive narratives of disaster impacts and compensation packages[6,7], with few investigations explicitly modelling the mechanisms and magnitudes of avoided damage attributable to geospatial interventions. This disconnect between sophisticated spatial analysis and systematic economic evaluation constitutes an important research gap: the state possesses a robust GIS infrastructure for DRR, but the pathways through which this infrastructure mitigates the economic burden of disasters remain analytically under-explored.

Against this backdrop, this study pursues three interrelated objectives designed to bridge spatial and economic perspectives on disaster management in HP. First, it synthesises existing evidence on GIS-based disaster management initiatives in the state - including the HRVA, landslide-susceptibility and inventory mapping programmes, the national landslide-susceptibility effort and the emerging urban resilience GIS platforms - highlighting their design, implementation and intended use in policy and practice. Second, it identifies and conceptually organises the mechanisms through which these GIS applications can reduce economic losses and fiscal burden, focusing on avoided damage to assets, more efficient spatial targeting of public investment and enhanced recovery planning. Third, it develops a case-study narrative centred on landslides and monsoon-related disasters - particularly the 2023 events - to illustrate, in a concrete empirical setting, both the practical benefits and the limitations of GIS-supported systems in moving HP from reactive disaster response towards anticipatory, economically informed resilience planning.

## Conceptual and Theoretical Framework

Disaster risk is analytically conceptualised as a multiplicative function of three interrelated components - hazard, exposure and vulnerability - in which physical events such as landslides, floods or earthquakes interact with exposed assets and populations whose susceptibility is conditioned by socio-economic, environmental and institutional circumstances.[2,20] This triad is formalised in the Sendai Framework for Disaster Risk Reduction 2015–2030, which calls for an explicit paradigm shift from post-event disaster management towards ex-ante disaster risk management anchored in an improved understanding of risk, strengthened risk governance, strategic investment in DRR for resilience and "Build Back Better" recovery.[5,12] Central to this global blueprint is the development of multi-hazard early warning systems and disaster risk information systems capable of delivering accessible, people-centred assessments to guide policy and investment decisions at national and local scales.[2,14] Geographic Information Systems and allied geospatial technologies are uniquely suited to operationalising this paradigm because they integrate heterogeneous spatial data sources - topographic layers, hydrological networks, geological and lithological profiles, land-use/land-cover maps, precipitation and climate records, and socio-economic indicators - into coherent risk surfaces and decision-support products for hazard zonation, exposure mapping and dynamic emergency monitoring.[3,13,15] In mountainous settings of the Western Himalaya, this capacity is particularly consequential: multi-criteria decision-analysis techniques such as the Analytical Hierarchy Process and logistic-regression models, when coupled with multi-source geospatial layers, have demonstrated robust performance in delineating landslide-susceptibility zones along critical corridors such as Shimla–Bilaspur–Kullu–Manali and within districts such as Kullu, Kangra and Chamba[4,16-19], thereby translating the abstract hazard–exposure–vulnerability triad into tangible geographies of risk that can inform slope stabilisation, road alignment and settlement planning.

Within this spatial–risk paradigm, the "economic burden" of disasters is treated here as a multidimensional construct capturing direct asset damage, infrastructure disruption, sectoral output losses, livelihood impacts and the consequent stress on public finances.[6,7] Empirically, the 2023 monsoon disasters in HP starkly illustrate this construct: over ₹12,000 crore in damages, more than 12,000 km of roads and approximately 340 bridges rendered unusable, agricultural losses exceeding ₹2,000 crore, and peak-season tourism earnings collapsing by over sixty per cent.[6-8] Beyond these immediate impacts, recurrent disaster shocks generate durable fiscal consequences for state governments - panel evidence indicates that flood events widen fiscal deficits for up to three years post-event, depress own-source revenues, inflate borrowings and crowd out developmental expenditure, with special-category states facing heightened exposure given structural constraints on revenue mobilization.[9-11] Disaster-economics theory addresses these dynamics through cost–benefit and cost-effectiveness frameworks that compare the present costs of mitigation measures - such as slope stabilisation, flood-control works or relocation of critical infrastructure - against expected reductions in future damages, income disruption and fiscal outlays, aggregated over hazard probability distributions.[9,10] GIS-derived hazard and exposure layers are central to such evaluations because they specify where assets and populations are most exposed, enabling both more precise estimation of anticipated losses and more accurate calculation of the marginal return on each rupee of DRR investment.[3,13,15] The National Landslide Susceptibility Mapping programme - covering roughly 42,093 km² of landslide-prone terrain in HP at 1:50,000 scale and cataloguing over 17,000 incidents - exemplifies how large-scale geospatial risk products, when integrated into the state's Hazard Risk and Vulnerability Atlas and prioritised sectoral mitigation budgets, can convert spatial intelligence into resilience dividends in the form of lower expected losses, more stable livelihoods and reduced fiscal volatility.[2,5,12]

## Methodology

This study adopts a targeted literature review design that combines systematic principles of structured search, screening and thematic synthesis with an explicitly bounded spatial–institutional focus on HP's GIS-enabled disaster risk management and its associated economic implications.[3,13] The evidentiary corpus is assembled from four complementary categories of sources: peer-reviewed journal articles on GIS, remote sensing and hazard mapping in Himalayan and Himachal contexts[16-18]; official plans and policy instruments, most prominently the HP State Disaster Management Plan and the State Disaster Management Policy[12,20]; technical reports and inventories produced by agencies including the HP Council for Science, Technology & Environment, the Geological Survey of India and the India Meteorological Department[1,2]; and grey literature encompassing HPSDMA portals, NDMA documents, policy briefs and media coverage of state-level GIS initiatives such as the Urban Resilience Platform[5,6]. The temporal window is set broadly from 2010 to 2026 in order to capture the maturation of GIS-based hazard and vulnerability mapping in the state - from the commissioning and digital roll-out of the Hazard Risk and Vulnerability Atlas, through the progressive implementation of the National Landslide Susceptibility Mapping programme and its associated landslide inventory, to the post-2023 monsoon disaster assessments and the urban-resilience pilots showcased at the BRICS Technical Meeting on Disaster Risk Reduction.[2,5,12]

Literature is identified through a multi-channel search strategy that integrates structured academic database queries, institutional repository searches and curated web exploration, with search strings constructed around the thematic intersections of GIS, disaster risk management, economic impacts and HP (for example, "HP GIS disaster management," "landslide susceptibility mapping Himachal," "HRVA atlas Himachal," "National Landslide Susceptibility Mapping Himachal," "economic impact natural disasters Himachal," "2023 monsoon floods landslides Himachal" and "urban resilience GIS Himachal").[3,6,7] Snowballing is additionally pursued through the citation networks of key technical reports and policy documents in order to retrieve linked studies and grey-literature evaluations not readily indexed in mainstream databases.[2,17] Inclusion is governed by three integrity criteria designed to preserve spatial, thematic and analytical coherence: sources must explicitly pertain to HP or to operational Himalayan contexts with Himachal-specific evidence; they must engage substantively with GIS or remote sensing in hazard mapping, risk assessment, early warning or disaster management; and a representative subset must address economic or sectoral disaster impacts and/or institutional arrangements around HPSDMA, SDMP and geospatial data use.[9,10,13,15] Within this framework, an embedded case study is constructed to provide an empirically grounded narrative of how geospatial instruments have been - or could be - mobilised to reduce disaster impacts and economic burden, with two focal elements selected for their analytical leverage: the landslide hazard domain, given its chronic and structurally embedded character across districts such as Shimla, Kangra, Kullu and Chamba[16-19], and the 2023 monsoon-induced floods and landslides, given their scale and the granularity of available loss-and-damage assessments[6-8]. The case study reconstructs pre-disaster, response and recovery phases to identify where HRVA risk rankings, NLSM landslide inventories, susceptibility maps and the urban resilience platform were deployed or referenced - and where potential applications remain underutilised - while simultaneously framing an economic discussion of avoided losses, resilience dividends and fiscal implications by juxtaposing observed 2023 impacts against counterfactual scenarios of more systematically GIS-informed DRR investment.[8-11]

## Hazard and economic profile of HP

HP's Hazard Risk and Vulnerability Atlas identifies seven major hazard types - earthquakes, landslides, forest fires, floods, avalanches, droughts and chemical/industrial accidents - mapped across all twelve districts through detailed digital GIS databases and probabilistic analysis.[5,12] The atlas further integrates climate variability, building vulnerability, socio-economic indicators and critical-facility inventories to generate composite risk layers that rank "most vulnerable areas" in descending order of expected losses in human life, crops, buildings and lifeline infrastructure.[2,20] Official vulnerability matrices place Chamba, Kinnaur, Kullu and parts of Kangra and Shimla in very-high overall risk categories, while Kangra, Mandi, Una, Shimla and Lahaul & Spiti are classified as highly vulnerable - a pattern that reflects the mid- and high-hill concentration of exposure to cascading hazards.[2,4] Landslide-proneness mapping by the Building Materials and Technology Promotion Council, as presented by HPSDMA, corroborates this geography:

severe-to-very-high and high landslide risk zones extend across Chamba, Kinnaur, Kullu, Shimla and Mandi, with only Una, Hamirpur and parts of Solan registering predominantly low vulnerability.[5,19] Recent geospatial analyses indicate that 25–30% of the state's area lies within high to very high landslide susceptibility classes and approximately 32% falls within India's Very High Damage Risk Zone for earthquakes, underscoring the structurally systemic character of multi-hazard exposure in the Western Himalaya.[2,3,16-18] Granular terrain-, rainfall- and land-use-based vulnerability maps refine this picture further, identifying high and very high risk clusters along Beas valley slopes and National Highway-3 in Kullu, the Pandoh–Jogindernagar and Balh valleys in Mandi, the Shimla–Chopal and Rampur–Narkanda corridors, and the mountainous tracts of Chamba and Kinnaur - a constellation of settlements and corridors that simultaneously illustrates the intra-state heterogeneity of risk and the proximity of critical lifelines to high-hazard terrain.[1,4,17,19] Flood hazard vulnerability maps complement this hazard geography by designating parts of Chamba, Kullu, Una and Kinnaur as highly flood-prone, with moderate to low flood risk distributed across Lahaul & Spiti, Mandi, Shimla, Kangra, Hamirpur, Bilaspur, Solan and Sirmaur.[1,2] This chronic hazard geography has translated, over decades, into a persistent economic burden that is structural rather than episodic in character.[5,6] Long-run analyses of disaster patterns in the state document sustained cumulative damage to roads, bridges, irrigation schemes, hydropower installations, housing, agriculture and livestock, with assessed losses during the 1990–2005 interval alone estimated in thousands of crores - a fifteen-year span of repeated heavy-rainfall events, flash floods, landslides and avalanches that imposed sizeable costs on infrastructure restoration, crop and orchard losses and the compensation of affected households.[2,5] Sector-specific breakdowns reveal that physical infrastructure consistently absorbs a disproportionately large share of damage, while agriculture, horticulture, tourism services and livestock experience recurrent shocks that propagate into income instability and entrenched rural vulnerability.[6,7,20] Recent situation reports confirm that even "ordinary" heavy monsoon seasons outside of extreme years involve damages running into several thousand crores, concentrated in infrastructure, agriculture and housing - indicating that the state's disaster economy is characterised by continuous, rather than cyclical, capital depletion.[2,5]

It is against this chronic baseline that the 2023 monsoon season emerges as a sentinel event that simultaneously laid bare the state's hazard geography and amplified its fiscal load. A cascade of hydro-meteorological hazards - primarily floods and landslides associated with three discrete heavy-rainfall spells during the monsoon - produced unprecedented human and economic losses: cumulative reporting by the state's Emergency Operation Centre and independent assessments indicate approximately 428 fatalities, more than 400 serious injuries, displacement of tens of thousands of people, complete damage to at least 2,614 houses and partial damage to over 11,000, rendering more than 15,000 families homeless.[6-9] Infrastructure impacts were equally severe, with over 12,000 km of roadways rendered inaccessible or destroyed, hundreds of bridges failed or washed away, and significant damage sustained by hydropower projects, water-supply schemes and public buildings - total economic losses were estimated by the State Government to exceed ₹12,000 crore.[6-8] Sectoral assessments further record the inundation or erosion of more than 30,000 hectares of farmland, with agricultural losses alone estimated at over ₹2,000 crore, while tourism revenues collapsed as major highways closed, hotels and adventure activities were suspended and tens of thousands of tourists were evacuated.[6,7] The fiscal consequences have proven starkly asymmetric: the central government's disaster relief contribution for the 2023 catastrophe amounted to only ₹433.70 crore, while the HP government allocated approximately ₹4,495.43 crore for relief, rehabilitation and infrastructure restoration - an order-of-magnitude burden differential that strained a budget already characterised by a strongly positive dependence of public debt on revenue expenditure, inter-governmental transfers and growth shocks.[6-11] State-level analysis and media commentary emphasise that this combination of very high direct losses, concentrated infrastructure damage, sectoral output shocks and limited external support has pushed HP towards a tightening "debt–disaster" spiral, reinforcing the urgency of embedding risk-informed, GIS-enabled planning into both development and fiscal strategies.[5,9,11,12]

**GIS-based disaster management systems in HP**

**Hazard Risk and Vulnerability Atlas (HRVA)**

HP's Hazard Risk and Vulnerability Atlas functions as the state's principal GIS-based multi-hazard risk information system, covering all twelve districts through digital spatial databases that integrate hazard, exposure, vulnerability and critical-infrastructure layers. The atlas incorporates information on earthquakes, landslides, forest fires, floods, avalanches, droughts and chemical/industrial hazards, alongside climate-variability indicators, building vulnerability, socio-economic vulnerability, critical facilities and composite risk indices. This integrated approach is consistent with the wider use of spatially differentiated multi-hazard indices for identifying variations in exposure, sensitivity and adaptive capacity across Himalayan regions.[21] Through computer-assisted GIS modelling, probabilistic analysis and field investigations, the HRVA identifies "the most vulnerable areas" and "possible areas of highest loss of human life, population concentrations, crops, buildings and lifeline infrastructure" in descending order of risk. By converting diverse hazard and vulnerability information into a spatial hierarchy, the atlas supports prioritised and phased planning, intervention and investment, enabling scarce public resources to be directed towards high-risk districts and blocks where potential human and economic losses are greatest.

**Landslide susceptibility and inventory mapping**

Beyond the HRVA, HP is incorporated into national and state-level landslide susceptibility and inventory-mapping programmes that rely extensively on GIS, remote sensing and field-based data collection. The National Landslide Susceptibility Mapping initiative led by the Geological Survey of India and Wadia Institute of Himalayan Geology has prepared susceptibility maps at 1:50,000 scale for approximately 42,093 km² of hilly terrain across HP, classifying slopes into high, moderate and low susceptibility categories and contributing area-wise particulars, previous incidents and causative factors to a GIS-based national landslide inventory. The importance of maintaining accurate and regularly updated inventories is well established because information on landslide location, frequency, type and causative conditions provides the foundation for susceptibility and hazard assessment.[22] Parliamentary and ministry documents further report that thousands of landslide incidents have been recorded in HP - on the order of 17,000 or more - and that these GIS-encoded datasets are shared with state agencies for regional planning, hazard mitigation and route optimisation. At finer spatial scales, mesoscale hazard-zonation studies along tourist and pilgrim routes have integrated up to fourteen terrain factors through the Analytical Hierarchy Process and other multi-criteria decision-analysis techniques. State-specific studies similarly apply expert knowledge and AHP-based multi-criteria analysis to classify approximately 3.2–5.65% of the state's area as high landslide-hazard risk, identify around 3,156 km² of terrain in high-risk categories, and organise landslide risk into classifications ranging from "severe to very high" through "high" and "moderate" to "no risk." Comparable GIS-based studies in HP demonstrate how terrain, geology, drainage, land use and other causal factors can be combined to generate susceptibility zones that guide mitigation planning and reduce potential human and economic losses.[23,24] More recently, post-monsoon inventory mapping has been extended through the HP Council for Science, Technology & Environment and the National Remote Sensing Centre's Field Landslide Inventory Mapping app, which supports systematic collection of geotagged landslide information and its integration into a central state database. By adding temporally updated information on event locations, magnitudes and damage patterns to existing susceptibility maps, this field-based GIS inventory can improve the refinement of early-warning thresholds and the prioritisation of mitigation measures.

**GIS tools for landslide hazard management**

The literature reviewed for HP identifies GIS-based landslide susceptibility zonation as a central instrument of landslide-risk management because it provides spatially explicit evidence for prevention, preparedness, infrastructure planning and emergency decision-making. Although the state possesses a reasonably established policy framework for managing landslide disasters, proactive measures - including vulnerability mapping, early-warning preparedness and systematic response planning - remain comparatively underdeveloped. GIS-based susceptibility zonation therefore offers a practical mechanism for identifying unstable locations before development occurs and for informing the siting of buildings, the selection of new road routes and the design of traffic flows. Studies from Kullu and other parts of HP demonstrate that GIS-based AHP and weighted-linear-combination methods can integrate slope, aspect, drainage, geological and lithological conditions into susceptibility maps divided into four or more risk categories.[23] Such outputs enable regional planners and district disaster-management authorities to distinguish existing high-risk slopes from areas where future development should be restricted or accompanied by protective works. Research in the Dharamshala region further illustrates how field surveys, satellite imagery and thematic GIS layers can be combined through heuristic and statistical approaches to map landslide-prone terrain.[16] Geotechnical investigations and slope-stability analyses using tools such as Plaxis 2D can then be linked with GIS outputs to examine failure mechanisms and evaluate engineering interventions at specific sites identified through regional susceptibility mapping. This integration of regional GIS assessment, site-specific geotechnical modelling and field verification strengthens the connection between hazard identification and economically relevant decisions concerning road protection, construction safety and infrastructure investment.

**Urban resilience GIS platform and IT integration**

At the urban scale, HP has begun to develop GIS as the spatial foundation of an emerging urban-resilience platform for risk-informed planning and emergency management in municipal areas. Media and policy reports describe a GIS-driven Urban Resilience Platform that combines high-resolution drone imagery, detailed door-to-door property surveys and geospatial analytics to produce digital maps of thousands of urban properties, infrastructure elements and risk hotspots. The use of drone-based spatial data and three-dimensional property assessment is increasingly recognised as a means of evaluating disaster exposure at the level of individual buildings and communities.[25] Presented at the Second BRICS Technical Meeting on Disaster Risk Reduction, the platform is described as "AI-ready," with the proposed integration of machine learning and advanced analytics intended to support scenario modelling, early warning and climate-resilient development. Broader research on smart technologies indicates that GIS and the Internet of Things have the strongest empirical support among emerging digital tools for risk mapping, early-warning systems and infrastructure operations, whereas artificial intelligence and digital-twin applications remain largely at pilot or conceptual stages.[26] In HP, the integration of GIS with the Internet of Things, edge computing, artificial intelligence and mobile-application ecosystems could consequently shift disaster management from a predominantly reactive rescue model towards prevention and anticipatory response. Within such an architecture, wireless sensor networks could transmit real-time information on rainfall, slope movement and river discharge to geospatial platforms capable of triggering alerts, visualising exposed locations, optimising emergency routes and guiding resource deployment. This approach is particularly relevant to the state's high-altitude conditions, difficult terrain, patchy connectivity and dispersed settlements because GIS can support locally differentiated warnings and response strategies while reducing delays, travel costs and avoidable disruption to essential services.

**Role of sectoral departments and SDMP provisions**

The HP State Disaster Management Plan and State Disaster Management Policy embed GIS and remote sensing within the formal responsibilities of sectoral departments and disaster-management institutions, thereby providing an institutional basis for geospatially informed governance. SDMP provisions specifically require the Agriculture Department to "make use of remote sensing and GIS technology" while supplying inputs to the State Disaster Management Authority and District Disaster Management Authorities. This provision is particularly significant for climate-sensitive sectors such as agriculture and horticulture, where spatial information can support the assessment of hazard exposure, crop vulnerability and the prioritisation of protective measures. The State Disaster Management Policy further emphasises that hazard zonation, vulnerability assessment and multi-hazard risk analysis should be undertaken up to tehsil and local levels using GIS and remote-sensing data, so that the resulting studies function as decision-support systems and are incorporated into district disaster-management plans. Policy recommendations also call for alignment with national spatial-data infrastructures, including the National Spatial Data Infrastructure and the National Disaster Emergency Communication Network, to promote interoperable exchange of thematic and spatial data among agencies. The value of such arrangements is supported by research showing that spatial-data infrastructures can improve information sharing, preventive planning and emergency coordination when organisations and governments participate in their development and use.[27] Additional recommendations include establishing GIS dashboards for District Disaster Management Authorities, maintaining district-level inventories of resources and gaps, and using HRVA-based analyses to inform preparedness and response plans, stockpiling strategies and the training of disaster-management teams. In response to the 2023 monsoon disasters, emerging climate-governance discussions have consequently advocated stronger District Disaster Management Authorities and line departments, real-time monitoring tools, district-specific resilience action plans and geospatial analytics capable of tracking changes in risk, investment patterns and mitigation performance.

The application of GIS to landslide and monsoon disaster management in HP demonstrates how spatial technologies can connect hazard identification, early warning, emergency routing and post-event recovery. During monsoon periods, landslides, cloudbursts, flash floods and road failures can occur across geographically dispersed locations, making it necessary to combine susceptibility maps, updated event inventories, rainfall observations, terrain data, infrastructure locations and information on exposed settlements within a common geospatial framework. Existing regional-scale research confirms that quantitative landslide-susceptibility models based on remote sensing and GIS can identify potential hotspots and support targeted mitigation in HP.[28] In operational terms, an integrated GIS system can overlay newly reported landslides on road, bridge, settlement, agricultural and lifeline-infrastructure layers to identify blocked routes, estimate affected areas, prioritise inspections and direct rescue or relief resources towards locations with the greatest combined exposure and vulnerability. The system can also connect field-based geotagged observations with historical inventories and susceptibility classifications, allowing post-monsoon information to improve subsequent hazard assessments and mitigation priorities. GIS-supported route optimisation is especially important in mountainous districts because emergency decisions must account for slope instability, alternative-road availability, river crossings, settlement isolation and the accessibility of critical facilities. At the institutional level, linking the HRVA, district dashboards, sectoral inventories and real-time monitoring systems would enable District Disaster Management Authorities and line departments to move from isolated data collection towards coordinated, risk-informed action. Such integration can reduce the economic burden of monsoon disasters by limiting delays in emergency deployment, protecting transport and public-service infrastructure, guiding expenditure towards high-risk locations and supporting faster restoration of affected economic activities, while the underlying effectiveness of the system remains dependent on data quality, technical capacity, communication connectivity and sustained inter-agency coordination.

**Case study: GIS in landslide and monsoon disaster management**

Landslides constitute one of the most recurrent and economically consequential geophysical hazards across the Himachal Himalaya, with recent geospatial reviews consistently documenting a marked upward trajectory in landslide risk attributable to both intrinsically active geomorphic processes and intensifying anthropogenic pressures from road construction, settlement expansion and hydropower corridor development.[16,17,19] Rainfall-induced landslides along highways and valley slopes recur every monsoon season, translating directly into road closures, damage to settlements and infrastructure, and cumulative losses to households and the state economy that are then steeply amplified during extreme events such as the 2023 monsoon.[6-8] That episode, defined by three discrete heavy-rainfall spells that triggered cascading flash floods, cloudbursts and mass movements across multiple districts, is analytically distinctive precisely because it operates simultaneously as the chronic hazard exposure backdrop of the Himachal Himalayan landscape and as an acute, multi-hazard "stress test" of the state's GIS architecture.[2,5,6] A community-level perspective reinforces this framing, since the spatially heterogeneous vulnerability revealed at sites such as Phojal Nalla demonstrates that disaster outcomes depend as much on the granularity of local risk information as on aggregate hazard indices.[20] Drawing on the broader methodological tradition of applying geospatial systems to sustainable mountain development, the 2023 events therefore furnish a sentinel case-study frame within which the preventive, responsive and restorative uses of GIS can be jointly evaluated against documented loss magnitudes.[12,13,17]

The spatial scope of the case study is consequently concentrated on those districts where landslide susceptibility, monsoon flood exposure and critical infrastructure coincide most acutely. Geospatial assessments and the Hazard Risk and Vulnerability Atlas consistently identify Kullu, Mandi and Chamba - together with parts of Kinnaur and Shimla - as high-susceptibility domains exhibiting substantial monsoon flood exposure alongside well-documented clusters of very-high-risk slopes.[1,2,17,19] Block- and corridor-level zonation refines this regional framing, positioning high and very-high-risk slopes along the Beas valley in Kullu, within the Balh valley and the Pandoh–Jogindernagar corridor of Mandi, and across the mountainous tracts of Chamba and Kinnaur - geographies where recurrent landslides and monsoon floods intersect directly with critical transport corridors, hydropower installations and orchard-and-farmland livelihoods.[1,3,4,16,17,19] Methodologically, these focal districts are also advantageous because they are simultaneously covered by HRVA composite risk layers, National Landslide Susceptibility Mapping products, field inventories generated through the FLIM mobile application, rainfall-threshold studies and intra-district vulnerability profiles - producing a triangulated spatial evidence base through which to trace GIS-enabled risk information as it flows through the pre-disaster, response and recovery phases.[3-5,16,17]

Across the pre-disaster phase, GIS-derived susceptibility zonation, HRVA multi-hazard mapping and NLSM terrain classification jointly establish a quantitative spatial foundation for land-use regulation, transport-network planning and the strategic siting of critical infrastructure in these corridors.[12,16,17,19] The HRVA ranks blocks and districts by composite multi-hazard risk, identifying where landslide, flood and other hazard layers overlap with dense populations, vulnerable housing stock and lifeline infrastructure, and thereby designating "most vulnerable areas" and "areas of highest loss of human life, population, crops, buildings and lifeline infrastructure" as priority zones for mitigation investment.[2,5,12] At finer resolution, the National Landslide Susceptibility Mapping programme has produced 1:50,000-scale susceptibility maps for approximately 42,093 km² of hilly terrain in HP, classifying slopes into high, moderate and low categories and feeding these data into a national inventory of more than 17,000 catalogued landslide incidents that is shared with state agencies for route optimisation, hazard mitigation and corridor-level planning.[5,19] Empirical multi-criteria decision-analysis case studies in Kullu district further demonstrate how slope, lithology, land-use/land-cover, rainfall and proximity to streams and roads can be aggregated within AHP–MCDA frameworks to produce three-zone landslide hazard maps that prospectively guide future developmental activity and risk mitigation measures in landslide-prone terrain.[1,16-19] Parallel mesoscale zonation along pilgrimage and tourist corridors - integrating up to fourteen terrain factors within analytical-hierarchy-process and logistic-regression workflows - has been recommended as a decision-support tool for suggesting alternative road alignments, flagging segments requiring slope stabilisation or protection works, and avoiding construction in highly unstable zones, thereby directly converting spatial intelligence into preventive gains for transport infrastructure, which repeatedly emerges as the single most damage-intensive asset class in HP's disaster profile.[6,7,17-19]

During the response phase, GIS-enabled inventory mapping combined with rainfall-threshold-based early warning directly improves the speed, accuracy and targeting of disaster management operations.[5,12,17] The Field Landslide Inventory Mapping mobile application developed by the National Remote Sensing Centre and ISRO enables State and District Disaster Management Authorities and researchers to capture geotagged landslide data - date, time, dimensions, damage category, casualties and associated rainfall - and upload these records onto the Bhuvan and National Database for Emergency Management servers, where they can be overlaid with susceptibility layers and rainfall fields to generate near-real-time spatial inventories of active landslides, blocked road segments and impacted settlements during monsoon events.[5,16,17] Complementary work on regional landslide forecasting has produced experimental bulletins for districts such as Shimla and Kinnaur with four advisory levels and both 24- and 48-hour lead times, while site-specific rainfall intensity–duration thresholds - exemplified by a continuous rainfall of 1.513 mm per day sustained over a minimum of two days identified as a triggering condition along NH-5 - demonstrate the empirical feasibility of rainfall-triggered landslide early warning in HP's terrain contexts.[2,16,17] Operational frameworks combine spatial susceptibility zonation with probabilistic triggering estimates derived from daily, multi-day cumulative and antecedent rainfall to issue advisory, watch or warn levels for moderate-to-very-high susceptibility classes[5,19]; when these advisory products are integrated with dissemination channels - the Sendai-aligned use of SMS alerts, sirens, community radio and web dashboards - they can deliver rapid, targeted warnings to populations in high-susceptibility zones during intense rainfall, operationalising both the National Disaster Management Plan's mandate for multi-hazard early warning systems in Himalayan states and the SDMP's explicit call for state-of-the-art real-time landslide early warning built on geological, hydrological and land-use data integrated through GIS.[2,5,12,14] In the subsequent recovery and reconstruction phase, GIS-based damage assessment together with urban resilience mapping anchor the prioritisation and transparency of relief and rehabilitation spending; post-disaster loss data from the 2023 monsoon - at least ₹12,000 crore in estimated damages, more than 12,000 km of impacted roadways, several hundred bridges destroyed or severely damaged and over 30,000 hectares of inundated farmland - can be geocoded and visualised as spatial layers that expose the geography of disaster impacts across districts and corridors.[6-8,12] Pre-event exposure overlays combined with post-event damage layers produce "impact intensity maps" highlighting hotspots of concentrated damage for sequenced rebuilding, while at the urban scale the state has deployed a GIS-driven Urban Resilience Platform combining high-resolution drone imagery with door-to-door property surveys to generate property-level maps of buildings, infrastructure and risk attributes that can be repurposed post-event to identify structurally compromised structures, critical service nodes and vulnerable neighbourhoods in need of rapid rehabilitation.[5,6,12] When GIS-derived risk and impact metrics are linked to fiscal planning in this manner - and viewed against the order-of-magnitude gap between the HP government's reconstruction expenditure in 2023 (approximately ₹4,495.43 crore) and the central government's interim relief contribution of ₹433.70 crore - they enable authorities to embed "Build Back Better" principles in the recovery budget, prioritise resilient reconstruction where it yields the greatest expected reduction in future losses per rupee of expenditure, and reorient spending from reactive patchwork rebuilding towards strategically targeted resilience investments that mitigate the long-term economic burden of disasters and strengthen fiscal resilience against future events.[6-11]

**Pathways through which GIS reduces economic burden**

**Avoided damage and asset protection**

Geographic information systems convert hazard intelligence into protective spatial guidance for infrastructure and settlement planning in HP through a tightly coupled chain of risk-layer production, engineering decision support and counterfactual damage estimation. HRVA multi-hazard classifications and National Landslide Susceptibility Mapping outputs identify the specific corridors and slope segments where roads, bridges, hydropower plants and dense housing clusters are most exposed to landslides and floods, thereby creating decision-support layers that allow departments such as PWD, Jal Shakti and the energy sector to avoid placing assets in the most unstable terrain and to intervene protectively where assets cannot be relocated.[5,12,17,19] Empirical multi-criteria decision-analysis zonation in Kullu district and along key highways has shown that when new alignments are designed to minimise passage through high-susceptibility segments, the expected probability of road failure - and consequently the recurring repair and reconstruction cost - declines relative to legacy routes that traverse very unstable slopes.[1,16,18,19] Technical reviews of landslide-hazard management using GIS-coupled geotechnical and slope-stability analyses further demonstrate the feasibility of targeted reinforcement of vulnerable slopes through bioengineering, retaining structures and improved drainage, thereby reducing the likelihood of catastrophic failures that would otherwise damage transport, power and water lifelines.[5,16,17] Because damage-and-loss assessments consistently show that a large share of infrastructure losses is concentrated in a small subset of high-risk valleys and road segments, avoided losses can be operationalised by comparing observed damage patterns from the 2023 monsoon - including more than 12,000 km of roads rendered impassable and several hundred bridges destroyed or damaged - with counterfactual scenarios in which HRVA- and NLSM-informed zoning and slope stabilisation had been systematically deployed along the most risk-intensive corridors, with the implied reduction in total damages plausibly non-trivial.[5-8,12] As GIS-derived risk maps become more deeply embedded in sectoral planning, the state can progressively translate spatial information into avoided reconstruction outlays, thereby mitigating the cumulative economic burden of recurrent monsoon disasters.[9-12]

**Efficient resource allocation and prioritisation**

Geographic information systems provide a coherent rationale for phasing disaster risk-reduction investments in HP by spatially sequencing mitigation expenditure in descending order of expected marginal loss reduction. The HRVA's explicit multi-hazard risk ranking of districts and blocks, combined with National Landslide Susceptibility Map classes and sectoral loss statistics, allows planners to direct slope stabilisation, flood-control works and road fortification towards blocks and districts where each additional rupee of mitigation yields the greatest expected return in avoided losses and disrupted livelihoods.[5,12,13,19] District-level patterns from extreme monsoon events confirm that damage is heavily concentrated in a narrow subset of districts - Shimla, Kullu and Mandi - where roads, water supply and power infrastructure account for roughly 80% of total losses, reinforcing the analytical case for geographically targeted investments rather than uniform cross-state expenditure.[6,7,9,10] The proposed deployment of District Disaster Management Authority GIS dashboards and district-level resilience action plans extends this priority logic to talukas, blocks and specific road corridors identified as high-hazard on HRVA and NLSM overlays, increasing the marginal productivity of DRR spending by aligning expenditures with quantified spatial risk rather than purely political or ad hoc criteria.[2,3,5,12] International frameworks such as MiResiliencia demonstrate that standardised GIS-based risk metrics can be used to evaluate the cost-effectiveness of alternative DRR measures, enabling decision-makers to rank mitigation options by avoided losses per unit of investment.[9,10,13] Translated to HP's stark fiscal context - where cumulative monsoon-related damages have exceeded ₹20,000 crore in recent years - such efficiency gains in allocation could meaningfully reduce the long-term fiscal pressure associated with disaster recovery and reconstruction.[6,7,9,10]

**Reduced disruption to economic sectors**

Geographic information systems also stabilise the productive sectors - agriculture, horticulture and tourism - that anchor rural livelihoods and state revenues, by reducing transport disruptions, asset losses and income volatility associated with recurring landslides and monsoon floods. Loss assessments for the 2023 monsoon show that more than 30,000 hectares of agricultural land were inundated or eroded, that apple orchards and vegetable farms were severely affected, and that transport bottlenecks prevented timely marketing of produce, resulting in agricultural damages exceeding ₹2,000 crore and pushing many small and marginal farmers into debt.[6-8,20] Spatially targeted interventions - protecting key farm-to-market corridors identified as high-risk in HRVA and NLSM maps, stabilising slopes above critical rural roads and safeguarding irrigation infrastructure in flood-prone valleys - can therefore lower expected transport interruptions and crop losses, stabilise farmer incomes and reduce the likelihood of debt traps.[2,3,5,12,19] Climate-risk work for HP further identifies disruptions in transport linkages due to landslides and flash floods as a principal driver of agricultural and horticultural income volatility, indicating that GIS-based corridor protection can yield substantial resilience dividends for rural economies.[2,3,20] Tourism is similarly hazard-exposed: contributing an estimated 7% to the state's GDP and supporting roughly 14% of direct and indirect employment, the sector concentrates its productive assets in a small set of destinations whose connectivity depends on high-risk corridors such as those leading to Kullu–Manali and Dharamshala.[2,6,7,20] Damage and closure patterns during recent monsoon seasons show that disruption along these routes, combined with damages to hotels and heritage sites, can reduce tourism earnings by over 60% in peak periods, with cascading effects on small vendors, transport operators and wage workers.[2,6,7,20] Risk-informed planning for tourism hubs and urban centres - using HRVA and the urban resilience GIS platform to constrain hazardous expansion, enforce land-use regulations in high-susceptibility zones and design redundant emergency access routes - can therefore minimise downtime, protect livelihoods and help maintain the tax revenues of tourism-dependent districts.[5,6,9,12] In this sense, GIS does not merely protect physical assets; it stabilises sectoral output and employment, reducing the broader macroeconomic volatility associated with recurrent disasters.[9-11]

**Fiscal resilience and budget planning**

Geographic information systems also reshape the fiscal profile of disaster management in HP by enabling ex-ante investment decisions that displace large, unpredictable post-event outlays with planned, optimised mitigation expenditure. Long-run records for 1990–2005 document losses to public property of approximately ₹1,63,531 lakh and housing-sector damages of approximately ₹92,340 lakh, in addition to extensive agricultural and horticultural losses, indicating that disaster reconstruction has been a sustained fiscal burden over multiple decades.[2,5,9,10] Recent assessments and human-development analyses estimate that natural disasters and climate impacts have cost the state roughly ₹46,000 crore over four years, with recovery needs repeatedly exceeding allocations under the State Disaster Risk Management Fund and necessitating additional borrowing.[5,9-12] World Bank analyses further note that recovery expenditure in HP is now several times the state's five-yearly allocation under disaster risk management funds, diverting resources from long-term development and undermining sustainable job creation and growth.[5,9,12,13] Within this challenging fiscal setting, GIS-enabled DRR offers a credible pathway to shift public finance from reactive emergency responses to planned, ex-ante investments whose benefits can be quantified in advance.[5,9,12,13] By measuring hazard and exposure at district and corridor scales, HRVA, NLSM and sectoral GIS analyses allow the state to estimate expected annualised losses under alternative investment scenarios, supplying direct inputs for cost–benefit and cost-effectiveness analysis of DRR measures.[5,9,10,12,19] Tools such as MiResiliencia demonstrate that it is technically feasible to combine GIS-based risk estimates with economic modelling to rank mitigation options by their ratio of avoided losses to investment cost, thereby guiding fiscally prudent DRR strategies.[9,10,13] For a state where monsoon-related damages between 2022 and 2025 have already surpassed ₹20,000 crore and where disaster-recovery needs periodically exceed dedicated DRR fund allocations by more than six times, embedding GIS-derived risk information directly into budget planning is essential to breaking the cycle of destruction and reconstruction and to building long-term fiscal resilience against future shocks.[6,7,9-12]

**Governance, capacity, and implementation challenges**

**Institutional arrangements and coordination**

Although HP has formally constituted the three-tiered institutional architecture of the HP State Disaster Management Authority, the State Emergency Operation Centre and District Disaster Management Authorities, diagnostic assessments indicate that this architecture has not yet matured into a coordinated system capable of converting geospatial intelligence into actionable multi-hazard response.[5,12,20] The State

Disaster Management Policy itself acknowledges "lack of adequate infrastructure, planning, awareness, and institutional capacity" to address the simultaneous threats posed by earthquakes, landslides, cloudbursts and flash floods, while flagging the absence of fully formulated disaster management plans at both state and district levels; as of the most recent SDMP revision, only a small subset of departments had prepared departmental disaster management plans, and many of these do not conform to the standards required to mainstream DRR into sustainable development.[2,5,12] Empirical analyses of the 2023 monsoon disasters reinforce this diagnosis, documenting weak inter-agency coordination, fragmented decision-making and an inability of DDMAs and gram panchayats - particularly in remote, ecologically sensitive districts of Kullu, Chamba and Kinnaur - to disseminate early warnings or implement timely evacuations along high-risk valley corridors.[2,3,6,8] Taken together, these findings suggest that the institutional substrate required to operationalise HRVA- and NLSM-derived risk information, and to integrate such information across SEOC, DDMA and departmental workflows, remains structurally under-developed even where the technical GIS products themselves are well advanced.[5,12,13,15]

**Technical capacity and data limitations**

Technical capacity constraints compound the institutional gaps, particularly along the seam between GIS, remote sensing and information management.[2,12,15] State-level diagnostics note that the Information Management System, although in operation, is "not currently formulated upon a GIS-based system" because disaster risk databases are unavailable within the SEOC format, so hazard layers, base maps and geo-referenced critical-infrastructure or response-resource inventories cannot be ingested into situational-awareness products in real time, materially delaying coordinated response.[2,12,15] At the HPSDMA end, the absence of in-house expertise in forecasting and remote sensing further limits the state's capacity to generate and disseminate effective early-warning bulletins at the state level, forcing reliance on external agencies and reducing the timeliness of landslide and flash-flood advisories.[2,3,17,19] Sectoral disaster plans reflect similar data gaps: statistical offices report that census and socio-economic information are infrequently updated, are not disaggregated at ward or block scale, and are not harmonised with hazard layers, which constrains the granularity of vulnerability mapping at the very points where risk is most variable.[2-4] Regionally, observed NITI Aayog-style critiques of Himalayan geospatial infrastructure - coarse grids, sparse high-altitude stations, non-uniform landslide and extreme-event formats, and the difficulty of referencing analogue records - further constrain robust decision-making, and HPSDMA and partner agencies frequently complete spatial analyses on incomplete or non-harmonised datasets in which the high-frequency updates required by HRVA and NLSM products are difficult to maintain.[2,16,17,19] Incremental capacity-building is nonetheless underway, with HPSDMA conducting trainings on "Basics of GIS & Remote Sensing for Disaster Management and Resource Mapping using Geospatial Technologies" and beginning to host GIS Map View interfaces on its website, but these initiatives remain nascent relative to the breadth of the documented technical and data gaps.[12,13,15]

**Equity, participation, and communication**

The translation of GIS-driven risk information into effective, inclusive disaster management is further mediated by equity and communication constraints that run along the rural–urban, income and gender divides of Himachal's high-altitude communities.[2,3,8,20] Stratified household surveys conducted in the aftermath of the 2023 monsoon disasters reveal pronounced disparities in early-warning access, with low-income households in remote high-altitude sectors reporting delayed or absent warnings, inadequate evacuation support and limited engagement with preparedness programmes - deficiencies that closely track the scattered human settlement pattern, inadequate road connectivity, patchy telecommunication networks and harsh climatic conditions formally acknowledged in the SDMP and State Disaster Management Policy.[1,2,6,8,12] At the community-governance level, disaster management plans for blocks and gram panchayats remain largely absent across the state, and the knowledge, attitudes and practices of stakeholders towards specific hazards are not yet documented well enough to design targeted awareness campaigns or localised evacuation drills.[2,12,20] From a GIS perspective, these equity and communication gaps imply that spatial risk products - high-resolution susceptibility maps, HRVA composite risk layers and rainfall-triggered early-warning advisories - are not consistently rendered into accessible, multilingual formats deployed through SMS, community radio, sirens or door-to-door dissemination in vulnerable districts such as Kullu, Mandi, Chamba and Kinnaur, undermining the protective dividend that the underlying geospatial analysis would otherwise yield.[1-3,8,17,19] Recent state communications and post-event geospatial assessments accordingly recommend the development of VSAT-backed communication networks, GIS-integrated dynamic resource mapping, district-level inventories of manpower, machinery, medical facilities and shelters, and the operationalisation of multi-lingual early-warning ecosystems anchored in District Disaster Resilience Action Plans that incorporate spatial risk assessments and socio-economic profiles; until such recommendations are implemented in a coordinated manner, governance, capacity and communication constraints will continue to limit the effectiveness of GIS-based disaster management systems in reducing the economic and social burden of disasters throughout HP.[2,5,6,8,12]

**Conclusion**

Over the last decade and a half, HP has quietly constructed one of the more sophisticated GIS-based disaster risk mapping ecosystems in the Indian Himalayan states, layering the multi-hazard Hazard Risk and Vulnerability Atlas atop National Landslide Susceptibility Mapping products, that catalogue over 17,000 landslides across approximately 42,093 km² of terrain, using Field Landslide Inventory Mapping workflows developed with the National Remote Sensing Centre for geotagged post-event recording, alongside meso-scale zonation along pilgrimage and freight corridors and an emerging urban resilience platform that fuses high-resolution drone imagery with door-to-door property surveys. These instruments do not merely produce hazard layers; they convert heterogeneous data streams - topography, lithology, hydrology, climate, building vulnerability, critical-facility inventories and socio-economic indicators - into an integrated spatial evidence base that identifies the state's most exposed districts and micro-regions, ranks slopes and valleys into risk categories, and exposes where transport, energy and lifeline infrastructure intersect the most damaging terrain. The HP State Disaster Management Plan and State Disaster Management Policy reinforce this technical foundation by formally recognising GIS and remote sensing as decision-support tools for hazard zonation, risk analysis and climate-sensitive planning, ensuring that geospatial analysis now occupies a structurally embedded position within the normative architecture of disaster governance rather than serving as an add-on analytic activity.

Yet, beneath this impressive geospatial scaffolding lies a remarkably uneven economic evidence base whose significance has only become fully visible in the wake of the 2023 monsoon catastrophe, which exacted losses exceeding ₹12,000 crore in a single season and forms part of a wider pattern in which cumulative disaster damages across four recent years have been estimated at approximately ₹46,000 crore - a magnitude that dwarfs the state's recovery allocations and exposes the limits of reactive fiscal responses. While intuition strongly suggests that risk-informed, GIS-enabled planning should yield material savings in avoided damage, more efficient sectoral investment and faster recovery, the empirical literature on HP has, until now, predominantly mapped hazards rather than measured avoided losses; existing work on HRVA layers, NLSM classes and district-scale inventories is rich in geospatial granularity but thin in cost–benefit and cost-effectiveness quantification, and only a thin slice of recent disaster-economics work explicitly mediates between spatial risk metrics and the cascading fiscal consequences that flood shocks impose on general-category and special-category state budgets for several years post-event. The result is a critical analytical asymmetry: the state possesses the technical capacity to map risk with high precision, but the economic case for systematically converting those maps into avoided damage remains intuitive rather than measured, leaving a sizeable gap between the demonstrable strengths of the GIS platform and its under-quantified contribution to long-term economic risk reduction.

This asymmetry points to three intersecting research gaps that warrant a coordinated future agenda. First, robust quantitative studies that directly estimate the avoided losses, marginal returns or fiscal dividends attributable to GIS-based DRR investments are conspicuously scarce, despite the existence of long-run loss data, HRVA exposure layers and NLSM susceptibility inventories that could, in principle, be assembled into panel datasets combining spatial exposure indices, DRR outlays and econometric or spatial-econometric modelling frameworks. Second, although climate-change projections consistently point to rising temperatures, intensified heavy-rainfall events, higher flood discharges and elevated landslide risk under both RCP4.5 and RCP8.5 pathways for HP, these downscaled climate scenarios and accompanying land-use change trajectories have not yet been systematically absorbed into operational GIS platforms or statutory planning workflows, severing the link between future hazard evolution and present-day mitigation prioritisation. Third, integrated cross-sectoral outcome studies, modelled on health-economics and outcome-research approaches, are largely absent: there is little work that fuses physical risk modelling, GIS exposure metrics and household- or sector-level outcome evaluation to capture livelihoods, health system impacts and quality-of-life dimensions of disaster exposure and resilience investment. Bridging these three gaps is essential if the next generation of GIS-DRR research in the state is to translate a strong technical infrastructure into measurable economic protection.

Embodied within these research gaps is a clear set of policy and implementation directions. Deeper statutory and spatial integration of GIS outputs - across development plans, infrastructure siting exercises, road and hydropower corridor alignment, tourism zoning, agriculture and horticulture strategies and Gram Panchayat Development Plans - can ensure that high-risk zones delineated by HRVA, NLSM, climate vulnerability assessments and intra-district vulnerability profiles are systematically avoided or reinforced rather than incrementally built over. The embedded adoption of formal economic evaluation in DRR planning, drawing on GIS-derived risk metrics as inputs to cost–benefit and cost-effectiveness analysis frameworks such as MiResiliencia, offers a fiscally prudent pathway for shifting the state's disaster portfolio from reactive reconstruction towards planned, ex-ante resilience investments whose benefits can be defended quantitatively. At the implementation level, sustained investment in district-level GIS capacity, the continuous updating and harmonisation of hazard and loss inventories, and the operationalisation of DDMA GIS dashboards integrated with real-time monitoring and early-warning workflows are indispensable for converting spatial data into actionable decision support. Equally important are participatory GIS practices - community mapping, local validation of risk layers and co-designed resilience action plans coupled with VSAT-backed communication infrastructure and multi-lingual early-warning dissemination - that address well-documented equity and communication gaps, ensuring that risk information and timely warnings reach vulnerable, remote and marginalised communities in formats they can use. Taken together, these directions affirm that while HP's GIS-based disaster management systems provide a strong technical platform for evidence-based DRR, their full capacity to deliver equitable, cost-effective resilience gains and durable economic risk reduction will only be realised through sustained investments in institutional integration, capacity expansion and empirically grounded economic analysis.

**References**

1. Pandey BW. Geoenvironmental Hazards in Himalaya: Assessment and Mapping (the Upper Beas Basin): Mittal Publications; 2002.
2. Das S, Sharma S. Climate-change induced multi-hazard risk assessment of Himachal Pradesh in Western Himalayan Region using IPCC-AR6 framework and multi-attribute decision-making approach. *Regional Environmental Change* 2026; **26**(3): 135.
3. Jamwal A, Kanwar N, Kuniyal JC. Use of geographic information system for the vulnerability assessment of landscape in upper Satluj basin of district Kinnaur, Himachal Pradesh, India. *Geology, Ecology, and Landscapes* 2020; **4**(3): 171-86.
4. Sharma S, Mohapatra S. Assessing vulnerability to natural hazards: An intra-district analysis of Chamba, Himachal Pradesh. *Journal of Geography, Environment and Earth Science International* 2023; **27**(12): 34-44.
5. Sharma BR. DISASTER MANAGEMENT-LESSONS LEARNT FROM PAST MAJOR DISASTERS IN HP. *Administrative Development: A Journal of HIPA, Shimla* 2018; **Vol 2**.
6. Kumar M, Gupta T, Baghel V. Multi-sectoral impacts of the 2023 disasters in Himachal Pradesh and mitigation plans. *Infrastructure Asset Management* 2025; **12**(4): 183-203.
7. Kumar M, Gupta T, Baghel V. A comprehensive analysis of the 2023 Himalayan disasters in Himachal Pradesh: multi-sectoral impacts and strategic mitigation approaches. E3S Web of Conferences; 2024: EDP Sciences; 2024. p. 01009.
8. Chandel AS. Geospatial and statistical assessment of monsoon-induced disasters in Himachal Pradesh: insights from the 2023 floods and landslides. *All Earth* 2025; **37**(1): 1-48.
9. Mohanty RK, Behera DK, Agarwal P, Sahoo D, Parida Y. Assessing the fiscal implications of flood disasters in India: insights for general and special category states. *Environmental Research Communications* 2024; **6**(11): 115014.
10. Panwar V, Sen S. Fiscal repercussions of natural disasters: stylized facts and panel data evidences from India. *Natural Hazards Review* 2020; **21**(2): 04020011.
11. Pushap RK. Public Debt of Himachal Pradesh: A Granger Causality Approach. 2018.
12. KUMAR V. Disaster Management System in Himachal Pradesh. 2022.
13. Heinimann A, Breu T, Kohler T. The challenge of applying geographic information systems to sustainable mountain development. *Mountain Research and Development* 2003: 312-9.
14. Choubin B, Borji M, Mosavi A, Sajedi-Hosseini F, Singh VP, Shamshirband S. Snow avalanche hazard prediction using machine learning methods. *Journal of Hydrology* 2019; **577**: 123929.
15. Murthy M, Bajracharya B, Pradhan S, et al. Adoption of geospatial systems towards evolving sustainable himalayan mountain development. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 2014; **40**: 1319-24.

16. Sharma S, Mahajan AK. Comparative evaluation of GIS-based landslide susceptibility mapping using statistical and heuristic approach for Dharamshala region of Kangra Valley, India. *Geoenvironmental Disasters* 2018; **5**(1): 4.
17. Sharma P, Chandel VBS, Kahlon S, Thakur SN. Assessing landslide susceptibility in the Upper Ravi river catchment, Himachal Pradesh, India: a comprehensive analysis using the logistic regression model. *Geoenvironmental Disasters* 2025; **12**(1): 26.
18. Dhiman S, Rajput P. Geospatial Technology for Landslide Hazard Zonation Based on Rainfall Rate by Using Remote Sensing Data in Dharamshala Region, Nw Himalayas HP.
19. Bhardwaj A, Gupta AK. INTEGRATING GEOSPATIAL ANALYSIS AND MULTI-CRITERIA DECISION-MAKING FOR LANDSLIDE RISK GOVERNANCE: A STEP TOWARDS LOCAL RESILIENCE AND SUSTAINABLE DEVELOPMENT. *Lex Localis: Journal of Local Self-Government* 2025; **23**(S6): 6140.
20. Johnson RM, Edwards E, Gardner JS, Diduck AP. Community vulnerability and resilience in disaster risk reduction: an example from Phojal Nalla, Himachal Pradesh, India: RM Johnson et al. *Regional Environmental Change* 2018; **18**(7): 2073-87.
21. Sekhri S, Kumar P, Fürst C, Pandey R. Mountain specific multi-hazard risk management framework (MSMRMF): Assessment and mitigation of multi-hazard and climate change risk in the Indian Himalayan Region. *Ecological indicators* 2020; **118**: 106700.
22. Das I, Stein A, Kerle N, Dadhwal V. Probabilistic landslide hazard assessment using homogeneous susceptible units (HSU) along a national highway corridor in the northern Himalayas, India. *Landslides* 2011; **8**(3): 293-308.
23. Panchal S, Shrivastava AK. Application of analytic hierarchy process in landslide susceptibility mapping at regional scale in GIS environment. *Journal of Statistics and Management Systems* 2020; **23**(2): 199-206.
24. Alsabhan AH, Singh K, Sharma A, et al. Landslide susceptibility assessment in the Himalayan range based along Kasauli–Parwanoo road corridor using weight of evidence, information value, and frequency ratio. *Journal of King Saud University-Science* 2022; **34**(2): 101759.
25. Whitehurst D, Friedman B, Kochersberger K, Sridhar V, Weeks J. Drone-based community assessment, planning, and disaster risk management for sustainable development. *Remote Sensing* 2021; **13**(9): 1739.
26. Varzeshi S, Fien J, Irajifar L. Integrating smart city technologies and urban resilience: A systematic review and research agenda for urban planning and design. *Smart cities* 2025; **9**(1): 2.
27. Manfré LA, Hirata E, Silva JB, et al. An analysis of geospatial technologies for risk and natural disaster management. *ISPRS International Journal of Geo-Information* 2012; **1**(2): 166-85.
28. Gupta V, Kaur R, Kumar S, Ram BK, Tanton RS. Regional-scale landslide susceptibility assessment for the hilly state of Himachal Pradesh, NW Himalaya, India. *Current Science (00113891)* 2023; **125**(12): 1369.