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Keywords: Flood exposure, Land use change, Flood vulnerability, Institutional governance, Global South

Posted Date: November 3rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11216205/v1

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Additional Declarations: No competing interests reported.

Development, Governance and the Production of Flood Exposure in a Himalayan Hill Town: The Case of Kullu

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Abstract

Flood risk in Himalayan hill towns is usually assessed as a hazard problem, yet the spatial concentration of exposure reflects decades of land-use decisions. The study examines how flood risk in the Kullu district is increasingly shaped by land-use governance rather than by environmental factors. In this study, we investigate how planning and governance decisions have influenced patterns of flood exposure over time. Using LULC change analysis, vulnerability assessment, return period analysis, and population projections, we show that development has become increasingly concentrated in high-risk zones, particularly along the Beas River corridor, where built-up areas expanded from 1.71% to 4.31% between 1991 and 2021. The analysis further shows that fragmented institutional responsibilities and weak enforcement have allowed development to expand into high-risk zones, widening the gap between risk knowledge and land-use decisions, which has resulted in a gap between policy and practice. Comparative studies from other cities across the globe show a similar pattern. The study proposes an integrated framework combining exposure reduction, nature-based strategies, and institutional coordination to address risk in hilly regions and cities across the global south. The findings contribute to wider discussions on how planning and governance systems can reduce flood risk in hill towns and beyond.

Keywords: Flood exposure, Land use change; Flood vulnerability; Institutional governance; Global South

1. Introduction

Flooding occurs when water overflows onto land that is typically dry, which is often triggered by heavy rainfall, rapid snowmelt or other hydrometeorological events. Depending on the origin, floods can be broadly categorised into three types, i.e., Flash floods (Excessive rainfall in a short period of time), Riverine (when the river overflows & floods the surrounding area), & Costal floods (caused around the coastal areas due to tropical cyclone or Tsunami) (W.H.O 2018). In hilly regions, flash floods and riverine floods frequently co-occur. Steep slopes, heavy rainfall, and narrow valleys often amplify these

flooding events and reduce response time which causes large destruction to life and property. Globally, around 1.8 billion (23% of the world population) are prone to flooding (World Bank, 2020). In India alone, 12% of the population is highly vulnerable to flooding(CEEW, 2020). Since 2020, the state of Himachal Pradesh has witnessed nearly 200 flash floods, causing damage of around 135 million dollars to the state..

Climate change is a global phenomenon that has intensified extreme weather events. A temperature rise beyond 2°C is expected to alter precipitation patterns, accelerate glacier melt, and increase the frequency of such hazards (Bamford et al., 2022).The state government report suggests that these changes will lead to a temperature increase of 1.3 and 1.9 degrees in Himachal by 2050 (TERI 2015). According to a remote sensing-based study conducted, the number of glacial lakes that cause flash flooding in the state has almost doubled from 562 in 2019 to 1,048 in 2023 (Government of Himachal Pradesh, 2023).Despite increasing literature on urban flood risk and climate resilience, most studies focus on coastal cities and riverine floodplains, while hill towns remain significantly underrepresented. Existing studies focus on hazard mapping and often ignore how terrain constraints and socioeconomic vulnerability interact with the urban planning decisions and governance structure in these hill towns. These areas experience different levels of flooding due to slopes, limited developable land and tourism-led uncontrolled development, creating a unique situation that flood risk frameworks are unable to address. To address this gap, the study examines flood vulnerability in the Himalayan hill town of Kullu through an integrated analytical framework. The study uses Geographic Information System (GIS)-based spatial analysis coupled with the Entropy weighting method to assess and map flood vulnerability across the urban landscape. The research also follows a case study approach. The study aims to answer the following research questions:

- How is flood risk is spatially produced through land-use change in hill towns?
- How do governance and land-use decisions drives the production of flood exposure in the study area?
- What shifts in planning and governance are needed to move from reactive approach to risk-reducing approaches?

This study contributes to the existing literature in three ways. At first, we examine flood vulnerability in Kullu as both a spatial and governance challenge. This was done by mapping how risk varies across topography and land use. Then we demonstrate the application of GIS and multi-criteria methods in a data-scarce hilly region, and then we examined how land constraints, urban development, and governance factors influence flood risk in hill towns, providing insights into more resilient hill towns. This aligns with the international frameworks such as the Sendai Framework for Disaster Risk Reduction (2015–2030) and Sustainable Development Goals (SDG 11 and SDG 13), both of which emphasise localised understanding of risk to inform resilient urban planning. Thus, this case provides an empirical basis for risk-sensitive planning in hills (Wolff, 2021). By linking a local case study with global frameworks, the paper connects local evidence to broader discussions on urban flood resilience.

The next section reviews the relevant literature related to floods and urbanisation. Section 3 presents the theoretical framework guiding the study. In Section 4, we describe the study area, including its flood history, climatic context, and patterns of urban growth. In Section 5, we outline the methodology of the study. Section 6 presents the results, including Land-Use/Land-Cover change, physical vulnerability, and population at risk. In Section 7 we discuss the findings in relation to planning and governance. Finally, Section 8 concludes with key insights and directions for future research.

2. Literature Review

2.1 Approach

The literature review for this study involved examination of peer-reviewed journals, academic papers, and government reports on flood risk in the Himalayan hill regions. The study aims to identify key drivers of increasing flood vulnerability in these regions, examine existing approaches to flood risk, and highlight gaps in the literature to guide future research.

2.2 Disaster Risk

Risk is increasingly recognised as a product of the interaction of climate change, population growth and increasing infrastructure as the main causes (IPCC, 2022; World Bank, 2019). In hill towns, the situation is worse as these events are amplified due to limited developable land and steep slopes. Disaster risk is viewed as a function of hazard and vulnerability expressed as *Risk = Hazard × Vulnerability* (Pelling, 2003).However, this definition has changed in recent years where risk is shaped by a broader interaction between hazard, exposure, vulnerability, and the capacity to respond and recover (UNISDR, 2009), shifting focus towards a broader process.

2.3 Flood Risk in Hill Towns

Flood risk in hill towns is influenced by terrain and rainfall conditions. Steep slopes, narrow valleys, and intense rainfall result in rapid runoff, leading to intense flooding within a short time. In plains, the water spreads out easily, but in hills, it is more concentrated and gives less time to respond. The conditions are further affected by urban growth, which is limited to the valley, making these settlements more prone to flooding. This increases the exposure of buildings and infrastructure to flood hazards.

2.4 Gaps in Existing Studies

While reviewing the literature, we identified a major gap: hazard-based approaches have largely focused on mapping flood-prone areas, whereas vulnerability studies have focused on social and economic susceptibilities. These are often studied separately and cannot explain how planning and governance decisions have led to patterns of built-up exposure. The study will focus on physical vulnerability and examine how it is shaped by the interaction between topographic constraints and the planning process in hill towns.

2.5 Geospatial and Multi-Criteria Approaches in Flood Assessment

Geographic Information Systems (GIS) techniquie is widely used in analysing flood vulnerability. It uses variables such as elevation, slope, land use, and proximity to water bodies (Jha, 2012). These parameters helps to identify the risk zone but are largely focused on hydrological parameters. However, in hill towns, flood risk results from the integration of terrain constraints and unregulated development, rather than solely hydrological factors, which are not captured in GIS-based approaches. To address these, multi-criteria decision-making (MCDM) methods have been increasingly used to improve vulnerability assessment. Techniques such as Shannon's Entropy assign weights based on data variability, therefore reducing researcher bias (Malczewski, 2006; Hwang & Yoon, 1981). By integrating GIS with Entropy-based weighting method, this study provides a more robust approach to assessing flood vulnerability in hill towns.

3. Theoretical framework

3.1 Flood vulnerability in Urban systems

Flood risk in urban systems is viewed as hazard–exposure–vulnerability (H–E–V) framework and is widely used in disaster risk research (IPCC, 2014).In this framework, hazard refers to the physical characteristics of flood events, while exposure means the distribution of people and infrastructure within

flood-prone areas. Vulnerability refers to the susceptibility of exposed elements, which are shaped by physical conditions whereas risk emerges from the interaction of these components (IPCC, 2014).
The H-E-V framework functions in complex conditions in the Himalayan hill towns. Hazards in these hill towns are intensified by cloudbursts, steep slopes, and cascading events such as landslides and debris flows (Dimri et al., 2017). Tourism-led development has led to an increase in exposure in hill towns as more development is occurring along narrow valley floors and unstable slopes (Singh et al., 2021), whereas vulnerability is shaped by informal housing near riverbeds (Wisner et al., 2016; Birkmann, 2006)

3.2 Risk Governance

Risk governance scholarship emphasises the role of institutions, decision processes, and actor networks in shaping how people manage and respond to risks (Renn, 2008). It looks beyond hazard characteristics through which risks are produced and managed. In hill towns, governance plays an important role in sustaining vulnerability (Renn, 2008; Wisner et al., 2016). Fragmented institutions and weak enforcement of land-use limits limit the effectiveness of risk reduction. These challenges are more common in Himalayan contexts, where there is overlapping responsibility between different institutions, which creates a coordination gap(Rieux et al., 2016). While this study is focused on spatial vulnerability mapping, risk governance serves as an interpretive lens (see Fig. 1, which presents the conceptual framework for this study). Vulnerability is not only considered as an outcome of terrain and exposure but also governance limitations like gaps in planning and institutional coordination. (Renn O., 2008 ;Wisner et al., 2016).

3.3 Governance and Urban Resilience in Flood Risk Reduction

Integration of planning and governance is important for understanding how flood risk is produced and managed in hill towns. Slope shapes the behaviour of flood hazards, whereas planning decisions influence patterns of exposure and vulnerability. Urban resilience refers to the capacity of urban systems to absorb disturbance and adapt to changing conditions (Meerow et al., 2016); IPCC, 2022 to make the area flood resilient, an integrated approach combining structural, nature-based, and non-structural measures is needed. Structural interventions include drainage improvements, while nature-based solutions focus on restoring floodplains (Raymond et al., 2017) on non-structural measures, such as risk-sensitive land-use planning and early warning systems, which are also important in mitigating floods. To prevent introducing new risks, effective flood risk reduction requires coordination across institutions (Ahern, 2011; Davoudi et al., 2012). The study identifies areas of high vulnerability, which will help determine the priority areas for intervention. This approach will help to link spatial analysis with planning-relevant insights (Fig.1).

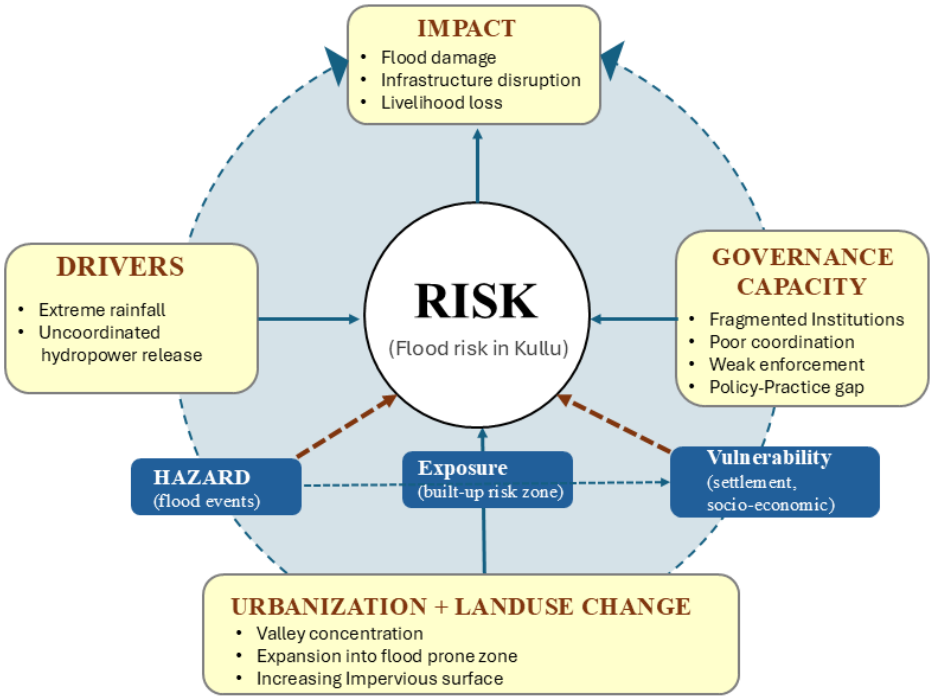


Figure 1: Conceptual framework of flood risk in Kullu
(Source: Author)

4.Study area

4.1 Location and Physical Setting

The study focuses on the Kullu district in the Indian state of Himachal Pradesh which is situated in the Upper Beas watershed (Fig. 2). It lies between latitudes 31°50′14″ and 32°24′51″ N and longitudes 76°56′12″ and 77°23′35″ E, covering approximately 1,417.15 km² (Bisht et al., 2018; Census of India, 2011). Forests cover 35% of the total land area. (Forest Survey of India, 2021). The terrain is characterised by highly variable elevation, ranging from 1,074 m to 6,017 m above sea level. The watershed has twenty smaller basins, and the Beas River is a seventh-order stream (Strahler, 1957); (CWC, 2015).

4.2 Climate

The Kullu Valley has a temperate climate with seasonal changes that are influenced by monsoon and western disturbances (Bookhagen et al., 2010). Around 43% the total annual rainfall is received during the monsoon season (June–September). Average annual precipitation across the valley ranges from approximately 1,200 to 1,400 mm (IMD, 2020). Regional climate projections indicate a mean temperature increase of 1.3°C to 1.9°C in Himachal Pradesh by 2050, which will alter precipitation patterns and increase the intensity of extreme rainfall events (DEST, 2021).

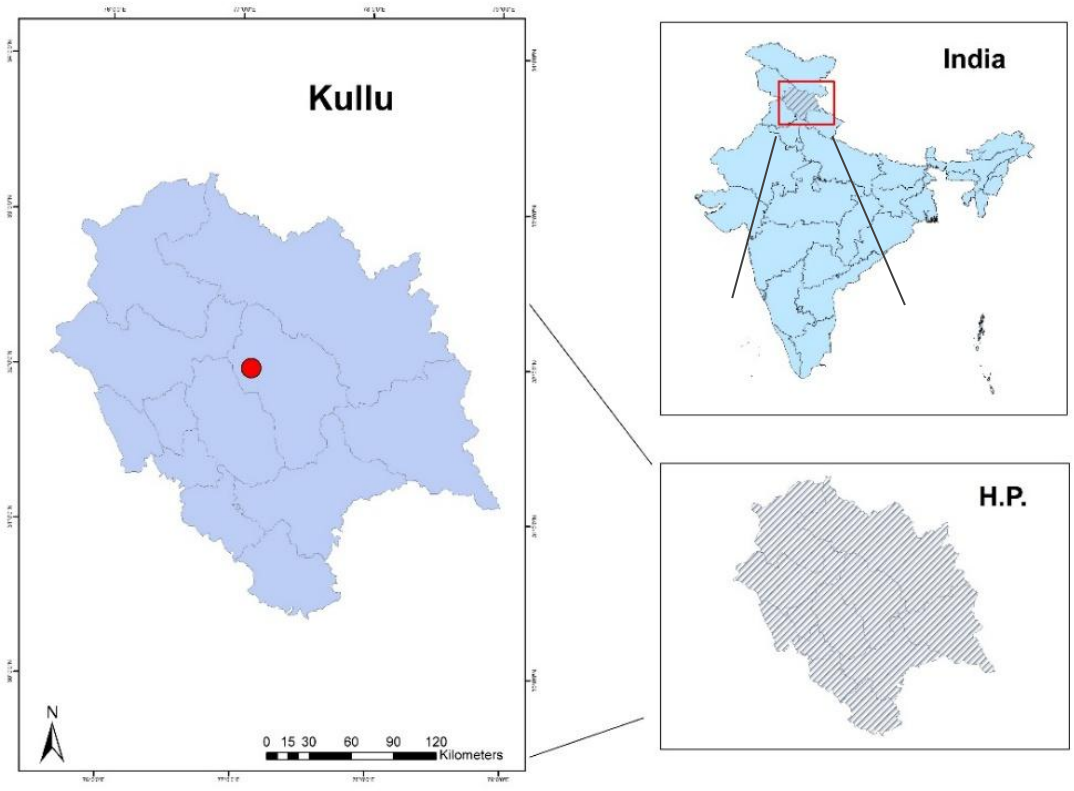


Figure 2 Location of the study area
(Source: Author)

4.3 Flood History

Kullu has a long history of floods, but the flood risk has only been clearly understood in recent years. A recent study found that the valley has witnessed 128 flood events across 59 locations over 175 years (1846–2020), and their frequency has increased in recent decades (Johnson et al., 2025).In Kullu, flooding happens seasonally, with around 87% of events concentrated during the monsoon (June–September)(Nagamani et al., 2024). These events are concentrated along the Beas River and its tributaries, and in recent years their impact has been growing. In the past 3 years, cumulative losses due to flooding have exceeded INR 17,000 crore (TOI, 2025).

4.4 Urban Growth and Demographic Pressure

The population of Kullu has tripled from 1961 to 2011 and is growing with an average annual growth rate of 2.85%, which is more than the state average of 2.25%. The growth in the region is due to natural increase and also due to the immigration of people from the Lahul district, where there are harsh living conditions across the year (Census of India, 2011).Development in the Kullu district has followed a ribbon pattern along the river. While 90% of the rural population is still dependent on agriculture. Tourism has rapidly changed land use, with built-up areas increasing and infrastructure being pushed into floodplains. (Table 1) shows population growth in the district from 1951 to 2031 (projected), highlighting rising pressure on limited, hazard-prone land.

Table 1: Demographic Growth Trends in Kullu District (1951–2031)
(Source: Author, Census of India)

Year	Population

1951	1,45,688
1961	1,52,925
1971	1,92,371
1981	2,38,734
1991	3,02,784
2001	3,81,571
2011	4,37,903
2021	4,96,425
2031	5,64,735

5. Methodology

5.1 Overall Research Design

The study follows an integrated approach to assess flood vulnerability in kullu (Fig.3) by combining spatial, demographic, and hydrological analyses, while interpreting the results through a governance lens.

The research is structured into four components:

i) Analysis of land use and land cover (LULC) to examine urbanisation patterns across the district.

ii) Assessment of flood vulnerability using the Analytic Hierarchy Process (AHP) combined with weighted overlay analysis

iii) Estimation of population at risk by identifying populations located within high-vulnerability zones.

While spatial analysis identifies patterns of hazard exposure and physical vulnerability, the findings are interpreted through the governance process. This allows the study to go beyond hazard mapping by linking vulnerability patterns with planning and governance factors.

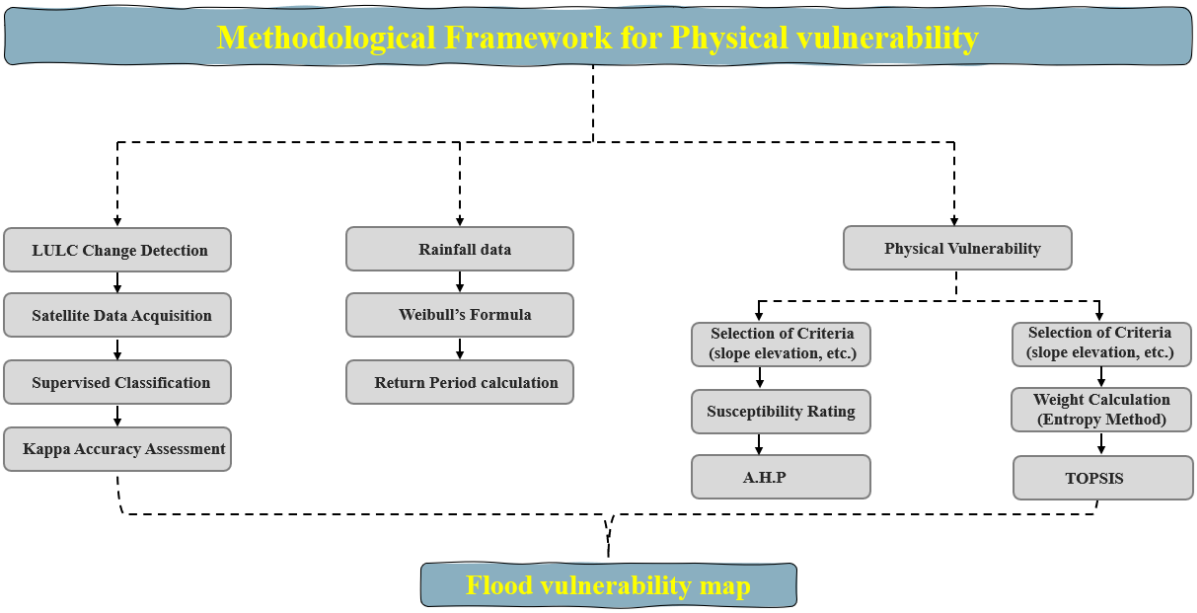


Figure 3 Methodological framework
Source: Author

5.2 LULC Change

Land-use and land-cover change are examined to show how urban growth and land-use change have increased flood exposure in Kullu. Satellite imagery from **Landsat 7 ETM+ (2001)**, **Landsat 7 ETM+ (2011)**, and **Landsat 8 OLI (2021)** is acquired from the United States Geological Survey (USGS). Supervised classification using the Maximum Likelihood Classification [1] algorithm was applied to generate LULC maps for each year, with six classes identified: water bodies, forest, built-up area, barren land, snow/glaciated areas, and agricultural land. Change detection was performed by comparing LULC maps for 1991–2011 and 2011–2021 to quantify change in each decade.
(Seyam et al., 2023)

$$\text{Rate of Change (\%)} = \frac{A_2 - A_1}{A_1} \times 100$$

where A_1 and A_2 are the areas of a given LULC class at the beginning and end of the study period, respectively. To measure the overall accuracy, the Kappa coefficient[2] was used, which was based on data from Google Earth and field observations.

5.3 Flood Vulnerability Mapping: AHP and Entropy Weighted Overlay

5.3.1 Indicator Selection

The indicators of Physical vulnerability are selected based on their relevance to the hazard–exposure–vulnerability framework. Indicators (Table 2) such as elevation, slope, and TWI represent flooding

[1] Maximum Likelihood Classification is a supervised classification technique that assigns each pixel to the class with the highest probability based on its statistical characteristics.
[2] The Kappa coefficient evaluates the accuracy of LULC classification by comparing classified results with reference data and accounting for agreement that may occur by chance.

conditions, proximity measures such as distance to river, and drainage density capture exposure to flood ((Birkmann & University, 2006); (Tehrany et al., 2015).

Table 2 Indicators used in preparing flood maps

S. No.	Indicator	Data Source
1	Elevation (DEM)	SRTM 30 m
2	Slope	Derived from DEM
3	Drainage network (presence)	DEM
4	Distance to river	OSM
5	Topographic Wetness Index	Derived from DEM
6	NDVI	Landsat
7	Precipitation	IMD
8	Proximity to major roads	OSM

5.3.2 AHP Weight Derivation

The Analytic Hierarchy Process[3] (AHP) is used to assign weights to each indicator based on its importance to flood vulnerability. A pairwise comparison matrix is constructed by evaluating each indicator using Saaty's 1–9 scale, where higher values indicate greater importance. From this matrix, normalized weights are calculated.

The Consistency Ratio (CR**)** is calculated to verify the logical consistency of expert judgements

$$CR = \frac{CI}{RI}, CI = \frac{\lambda_{max} - n}{n - 1}$$

Here, λ_max is the principal eigenvalue, and n is the number of indicators. A CR value of ≤ 0.10 indicates acceptable consistency; otherwise, the comparisons are revised (Saaty, 1987).

5.3.3 Entropy Weight Derivation

To reduce bias from AHP weights, Shannon's Entropy method[4] (Shannon, 1948) is used to calculate objective weights (Steps shown in Fig.4). This method determines the relative importance of the attributes and how they are related to the evaluation or final result. Unlike various subjective weighting models, this method's key advantage lies in its ability to minimise human interference in determining indicator weights, thereby enhancing the objectivity of the overall evaluation results(Zhu et al., 2020).

In this method, m indicators and n samples are set in the evaluation, and the measured value of the i^{th} indicator in the j^{th} the sample is recorded as x_{ij}.

[3] The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method that assigns weights to different factors based on pairwise comparisons of their relative importance

[4] The Entropy method is an objective weighting technique that assigns weights to criteria based on their data variability, with greater variation indicating higher importance.

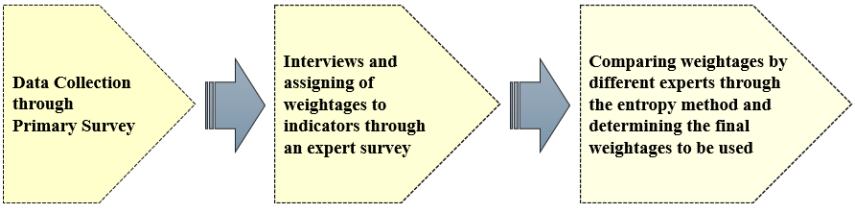


Figure 4: Methodology for Weighted overlay
(Source: Author,Sharma et al., 2025)

Step 1: Calculate Normalised matrix: The first step is the normalisation of measured values. The standardised value of the i^{th} index in the j^{th} The sample is denoted as r_{ij}, and its calculation method is as follows:

$$r_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}}$$

Step 2: Calculate Entropy: Entropy value e_i of the i^{th} index is defined as:

$$e_i = -h \sum_{i=1}^{m} r_{ij} \ln r_{ij}\,, \quad i = 1,2,\dots\dots n$$

h = $\frac{x}{\ln(m)}$, where m is the number of alternatives.

Step 3: Calculate Weightage: The range of entropy value e_i is [0, 1]. The larger the e_i The greater the degree of differentiation of index i, the more information can be derived. Hence, higher weight should be given to the index. Therefore, in the EWM, the calculation method of weight w_j is:

$$w_j = \frac{1-ej}{\sum_{j=1}^{n}(1-ej)}, \quad j = 1,2,\dots\dots n \text{ (Hwang \& Yoon, 1981)}$$

5.4 Identification of vulnerable population

To identify the population exposed to flood risk, the flood vulnerability map is overlaid with the population map, which is generated from (Census of India, 2011).The number of people living in high and very high vulnerability zones is then calculated to estimate the population at risk. This helps identify priority areas where high flood vulnerability overlaps with dense population, and where planning interventions are most required.

5.6 Validation

The flood vulnerability map is validated by comparing high and very high vulnerability zones with flood-affected areas from the 2020 to 2024 Kullu events, using HPSDMA records, reports, and satellite-based flood extents. The overlap helps to assess the accuracy and reliability of the prepared flood map.

6. Results

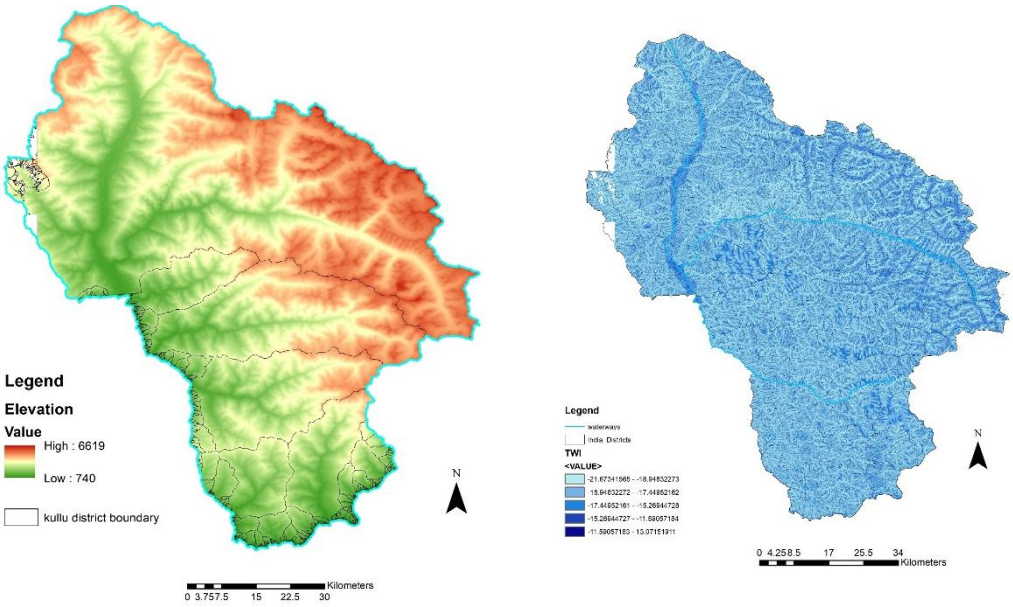
6.1 Spatial Distribution of Physical Indicators

The spatial distribution of physical indicators helps in understanding flood vulnerability in the Kullu district. In (Figure 5) we represent four primary physical conditioning factors: slope, Terrain Wetness

Index (TWI), proximity to river networks, and Land Use/Land Cover (LULC). These factors collectively shape the spatial concentration of high-risk zones.

Slope values in the study area range from about 3.46° to 55.1°, with lower slopes (3.46°–6.27°) predominantly located along the Beas River, while steeper slopes (>17.9°) are situated in the surrounding hills and upper catchment areas. Areas along the lower slope are more prone to flooding, whereas steep slopes allow water to flow quickly, reducing water accumulation and increasing the risk of flash floods and debris flows (Rai, 2023)

The Terrain Wetness Index (TWI) ranges from approximately 2.17 to 3.07. Higher TWI values are mainly concentrated along the Beas River and its tributaries, including the Sainj and Parvati, where water accumulates and remains for longer. In contrast, lower TWI values are observed in higher and steeper slopes, where it drains quickly. This spatial pattern highlights that the concentration of flood-prone areas is along valley and river corridors
Drainage density in the study area ranges from 0 to 90.2, with higher values in hilly regions reflecting dense stream networks. While lower drainage density is observed in flatter valley regions, where there are fewer channels present, leading to water accumulation and increased flood susceptibility. The LULC map shows that built-up areas are mainly concentrated along the valley floor and major transport corridors, particularly along NH-3 (Kullu–Manali) near the river. This spatial pattern indicates a strong overlap between human activity and zones exposed to flooding. Overall, the convergence of low slopes, high TWI values, low drainage density, and concentrated built-up areas along river corridors highlights that the area is most vulnerable to flooding.



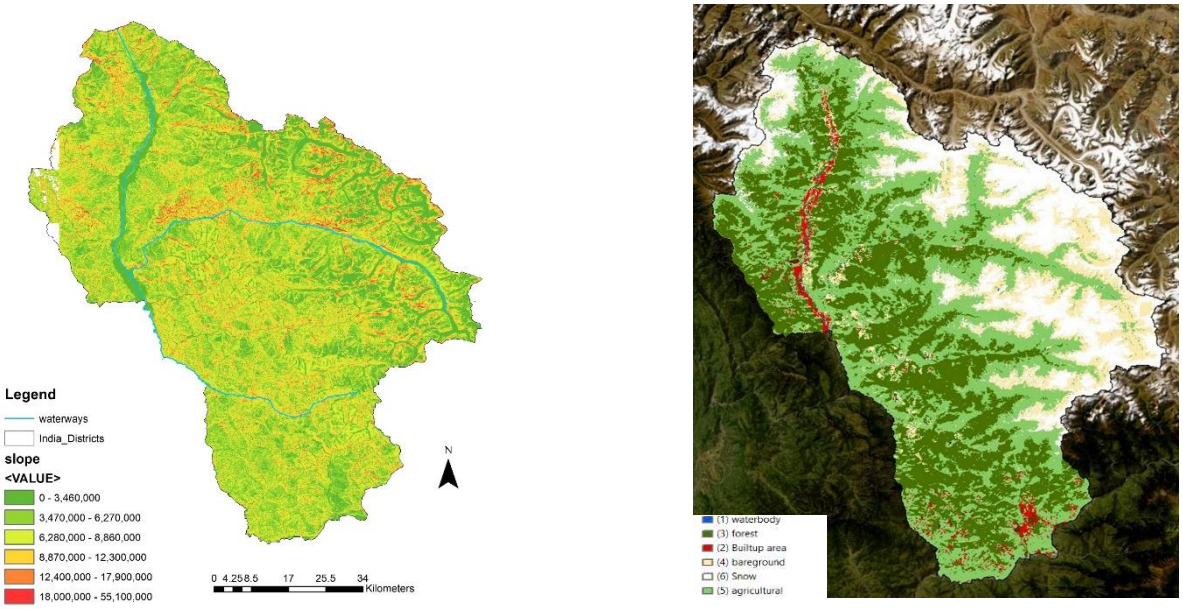


Figure 1 Spatial distribution of key physical indicators of flood vulnerability in Kullu (Source: Author)

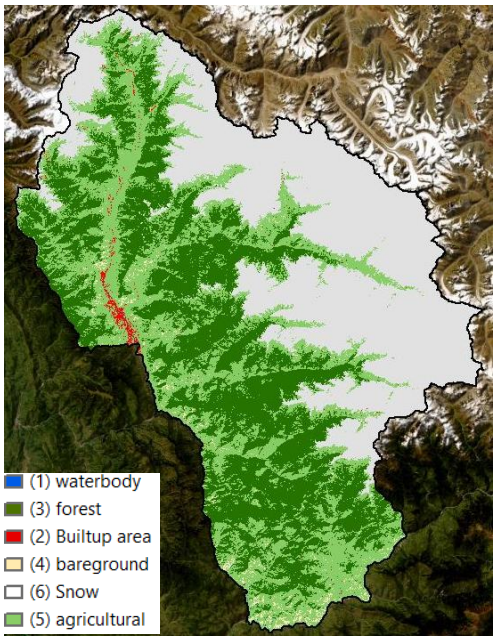
6.2 Land Use/Land Cover Change

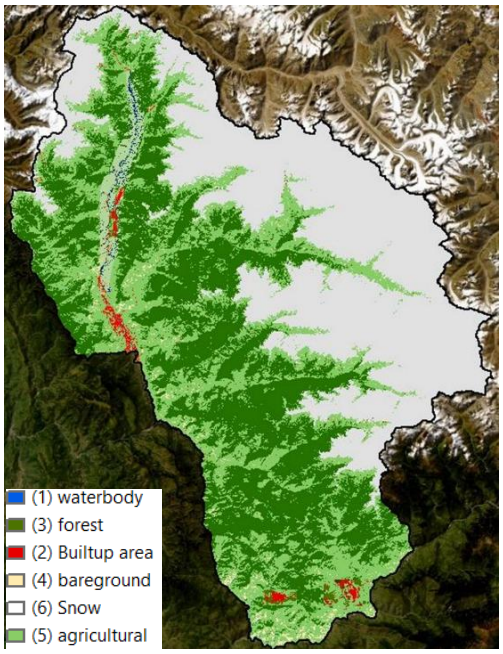
Land use and land cover (LULC) changes between 1991 and 2021 have played a significant role in shaping flood vulnerability in the study area (Zope et al., 2016).LULC change analysis from 1991 to 2021 (Fig. 6) clearly shows that flood risk has increased in the district due to the expansion of built-up areas along the river. The built-up area has increased from 1.71% in 1991 to 4.31% in 2021 (Table 3) and is primarily concentrated along the National Highways due to the limited availability of land, as it is surrounded by mountainous terrain(Apurv et al., 2015). This has led to ribbon development along both the highway corridors and adjacent river channels. Such a pattern of development increases exposure to flooding and vulnerability patterns identified in Section 6.1. Snow and glacier cover declined from 28.6% in 1991 to 18.9% in 2021. This has increased dependence on monsoon rainfall, leading to higher peak flows and a larger risk of flash floods. Glacier retreat also makes slopes more unstable and increases sediment flow, worsening the impact of floods. Bare ground increased from 12.07% in 1991 to 18.45% in 2021, indicating an increase in erosion-prone surfaces due to deforestation and landslides. Forest cover remains largely the same, but the increase in built-up and bare ground indicates fragmentation, especially in lower areas (Chia-An Ku, 2024).Overall, LULC changes show an increase in flood vulnerability due to the growth of built-up areas, decline in snow and glacier cover. Together with terrain and drainage conditions described in Section 6.1, these factors explain the spatial pattern of flood vulnerability analysed in the next section.

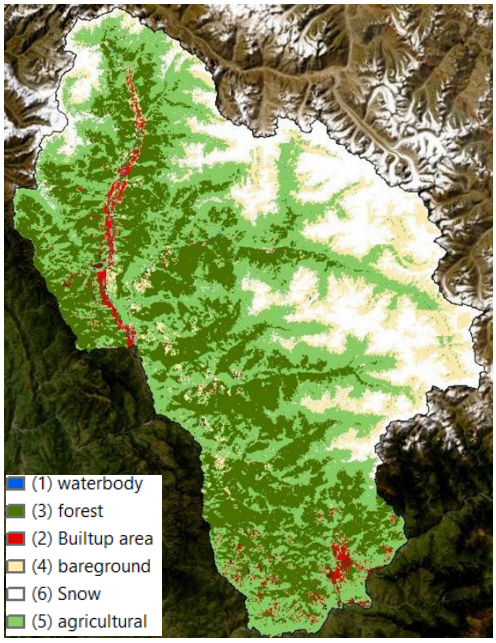
Table 3 Percentage change in LULC from 1991 to 2021

S.NO	LAND USE /LANDCOVER	1991	2001	2011	2021
1.	Snow/Glacier	28.6%	19.8%	20.8%	18.9%

2.	Waterbody	0.1%	0.1%	0.13%	0.13%
3.	Bare ground	12.07%	18.11%	17.1%	18.45%
4.	Agriculture	15.45%	17.57%	16.31%	17.30%
5.	Built-up	1.71%	2.85%	3.02%	4.31%
6.	Forest	41.89%	41.57%	42.67%	41.21%







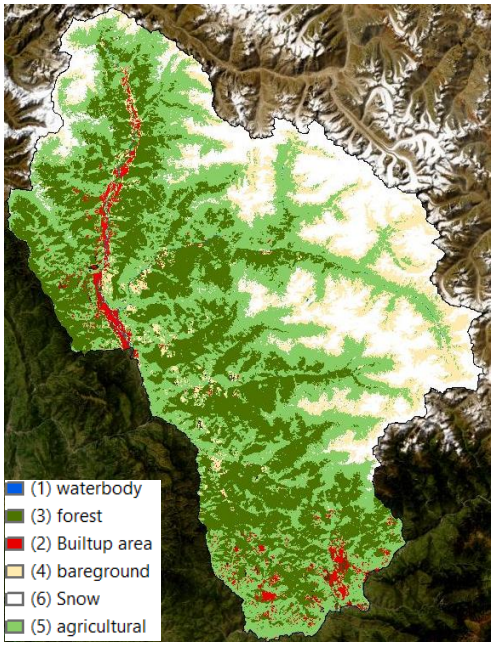


Figure 6 LULC change from 1991 to 2021
Source: Author

6.3 Physical Vulnerability Assessment

In this study, we accessed Physical vulnerability using two techniques. At first, the Analytic Hierarchy Process (AHP) was used to generate flood maps, and then we used Weighted overlay analysis to derive a composite physical vulnerability index.Using these two methods allowed comparison of results and also improved reliability by reducing bias (Mitra et al., 2023;Pathan et al., 2022).

6.3.1 AHP-Based Flood Susceptibility Mapping

The AHP-based analysis was carried out using multiple physical indicators (as shown in Table 2) which are widely used to assess flood risk in hilly areas. Each parameter was reclassified into five susceptibility classes (1–5). A pairwise comparison matrix was used to assign weights to each indicator, and the Consistency Ratio (CR) was found to be below 0.10 (Mitra & Saha, 2022). The AHP-based flood risk map (Fig.7) divides the Upper Beas watershed into five classes: Very Low, Low, Moderate, High, and Very High risk. Moderate risk is the most dominant, covering a large part of the valley. High-risk zones are predominant in the central and western parts, especially along the Beas River and in settlements such as Bhuntar, Kullu, and Raison. Very high-risk areas are mostly located close to river channels, whereas Low- and very low-risk zones are in the eastern and southern areas, which have higher elevations and steeper slopes.

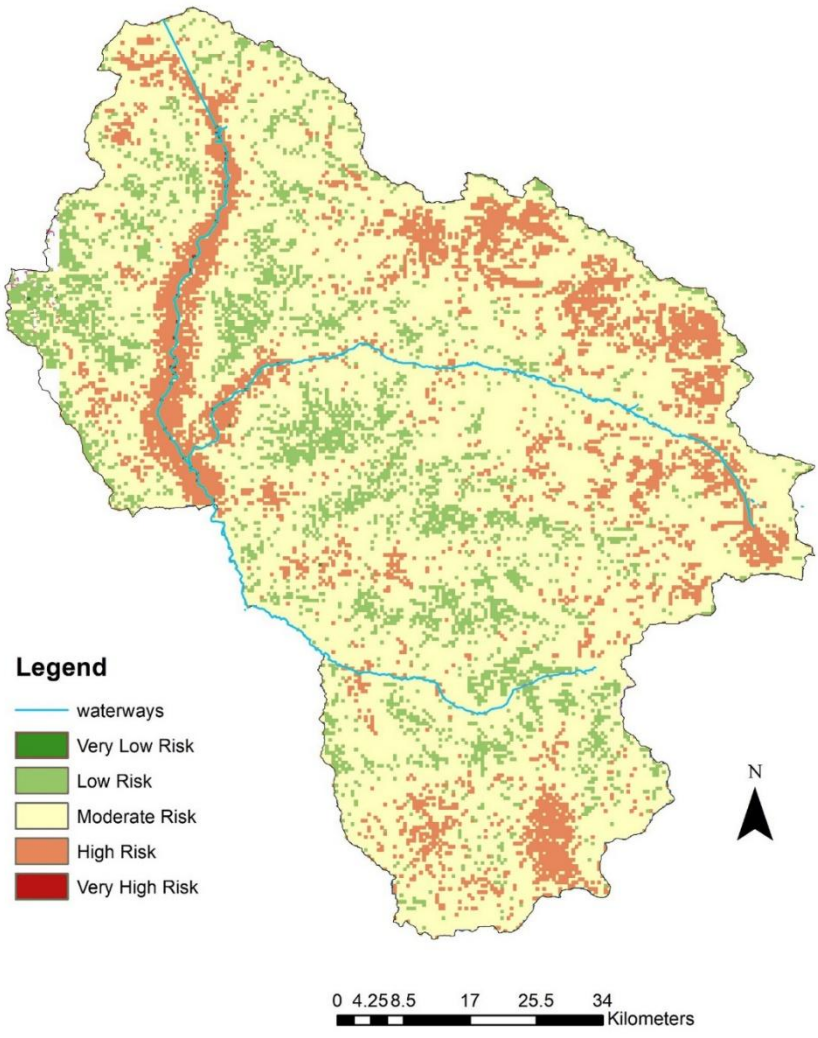


Figure 2 Flood vulnerability map using A.H.P
Source: Author

6.3.2 Weighted overlay analysis

The Weighted overlay analysis uses indicators (as shown in Table 2) that show a continuous Physical Vulnerability Index ranging from 1.2 (Very Low) to 4.6 (Very High) across the district (Fig.8). Unlike AHP, the Weighted overlay result shows a continuous pattern of vulnerability, which allows a better identification of changes and risk hotspots along rivers (Pathan et al., 2022; Yang et al., 2018).The results show a clear west-to-east trend, with higher values (3.5–4.6) along the Beas River and its tributaries. Lower values (1.2–2.0) are found in the northeastern high-altitude areas, where flood risk is lower. A major high-vulnerability hotspot is seen around the Bhuntar–Kullu area, where there is dense built-up development occurring within a narrow valley. Such locations are more exposed to flooding due to the interaction of terrain, drainage, and land use (Bisht et al., 2018)

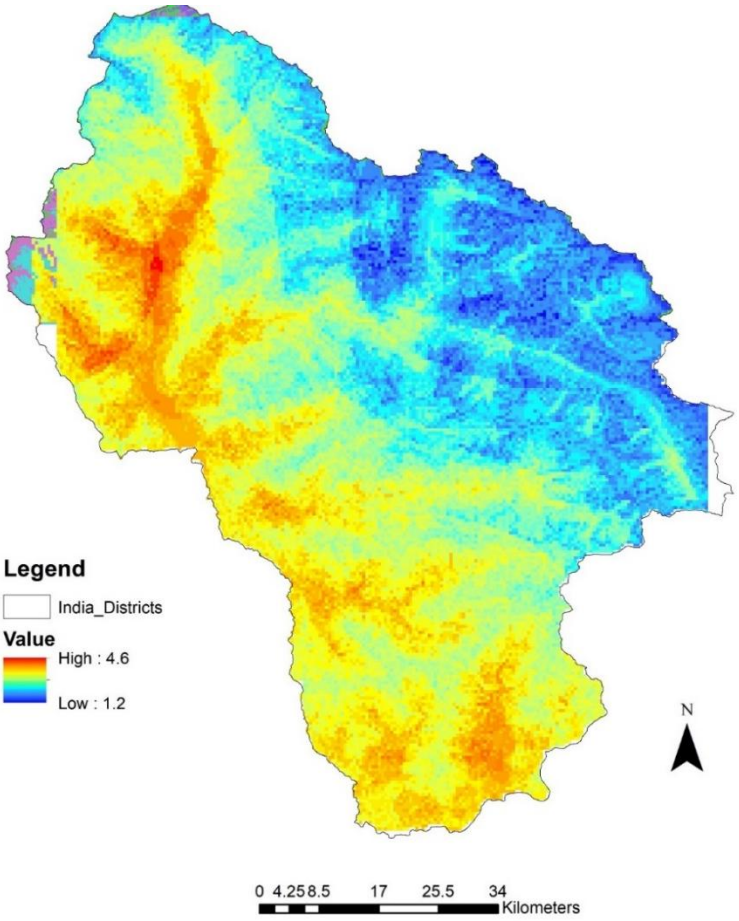


Figure 3 Physical Vulnerability using Weighted overlay analysis
Source: Author

6.4 Validation of Results

The results were validated by overlaying the AHP and weighted overlay results with observed flood locations and historically affected areas in the region. The analysis shows a strong spatial alignment, with recorded flood events concentrated within high-vulnerability zones along the Beas River corridor and around the Bhuntar–Kullu region(Mitra et al., 2023).This overlap confirms that the model is

effective in capturing areas of actual flood impact. Previous studies on the Beas watershed have also shown flood susceptibility in the region, with a large proportion of the area classified as highly vulnerable to flash floods (Bisht et al., 2018)

6.5 Population at risk

Population at risk was calculated by integrating the physical vulnerability map with watershed-level population data using GIS-based spatial analysis (Fig 9.). The vulnerability map was reclassified into five categories (Very Low to Very High), and overlaid with watershed boundaries to assess the distribution of population across different risk zones (Mortensen et al., 2025)

A large population is in moderate-to-high vulnerability zones. Watersheds in the central and western parts show the highest exposure due to the overlap of dense settlements and high-risk areas. The total population at risk is about 1,63,738, with the highest concentration in the Bhuntar–Kullu region(Table 4). . In contrast, eastern and northeastern areas have lower exposure due to their sparse populations. Overall, flood risk is concentrated in valley regions where both vulnerability and population are high, rather than evenly distributed across the watershed.

Table 4 Population at Risk in study area

Watershed	***Area (sq.km)***	***Pop.at risk***
5	75.93498	845
6	35.73324	2,127
7	111.4008	26175
8	149.7908	13,745
17	18.37724	2,758
18	36.98487	3,804
19	111.7114	13,320
20	31.29611	5,752
23	408.8136	95,212
	Total-	1,63,738

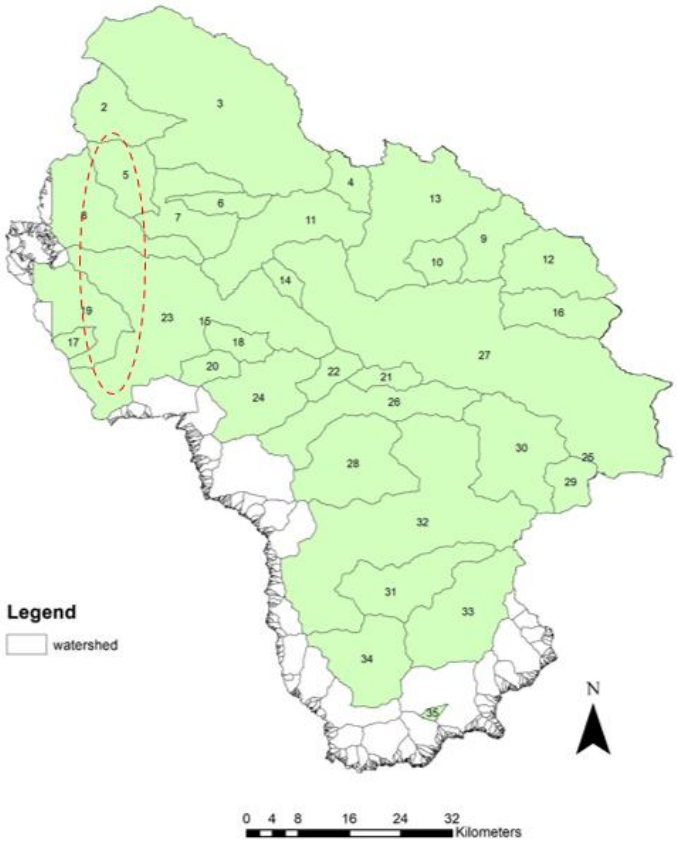


Figure 9 Watershed map of Kullu District
(Source: Author)

7. Discussion

The results of this study reveal spatial patterns of flood vulnerability in Kullu which were shaped by the interaction of terrain characteristics, land-use dynamics, and population concentration. Building on these findings, the discussion interprets flood risk not merely as a function of environmental processes, but as an outcome of development patterns and governance decisions that influence the spatial distribution of risk (Fig.10). The following sections will examine

(i) the role of urbanisation in shaping vulnerability patterns and
(ii) the contribution of governance processes in producing risk over time

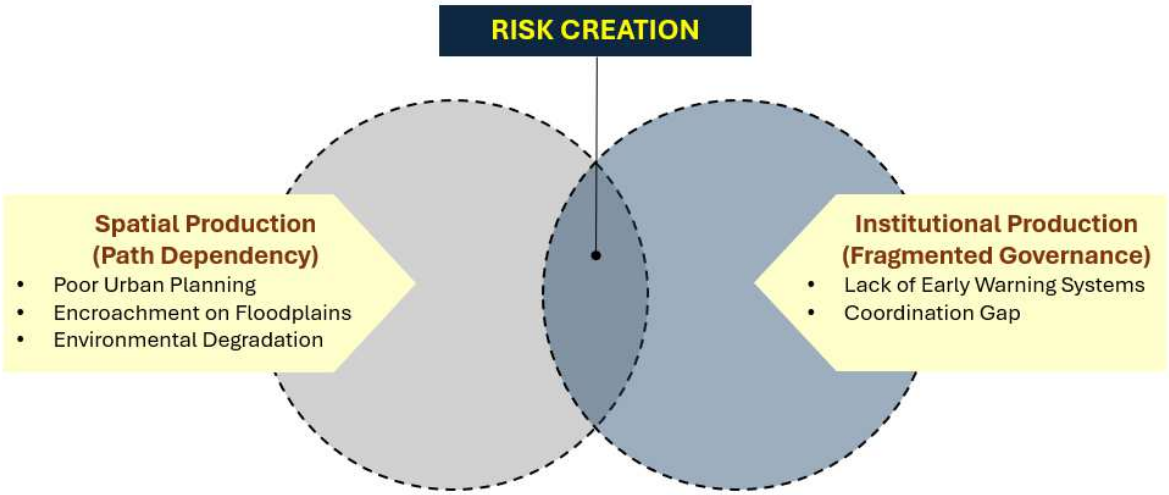


Figure 10 Framework showing how spatial and institutional factors interact to produce flood risk (Source: Author)

7.1 Spatial production of risk

The spatial distribution of physical indicators helps in understanding flood vulnerability in the Kullu district. Figure 5 shows the spatial pattern of slope, Terrain Wetness Index (TWI), proximity to river networks, and Land Use/Land Cover (LULC), which are widely used in GIS-based flood vulnerability assessment (Hernández-Atencia et al., 2026).The results shows that areas along the lower slope are more prone to flooding, whereas steep slopes allow water to flow quickly, reducing water accumulation. This results in increasing risk of flash floods and debris flows (Jain et al., 2025). The spatial pattern indicates a strong overlap between human activity and zones exposed to flooding.Built-up areas are mainly concentrated along the valley floor , particularly along NH-3 and near river channels. This pattern reduces infiltration and increases surface runoff, thereby increasing flooding in that area(Gupta et al., 2024). The concentration of development in low-lying valley areas, therefore, creates an important relationship between land-use change and flood exposure.

Changes in LULC between 1991 and 2021 further demonstrate this process. Built-up t has expanded along the valley, while snow and glacier cover has declined from 28.6% to 18.9% (Table 3).The pattern of growth is not uniform but has followed a selective pattern of concentration along the valley, indicating that urban expansion is driven by economic connectivity rather than environmental suitability. When the landuse map was overlayed with builtup map the results shows that areas are expanding in medium- to high-vulnerability zones, indicating development in flood-prone areas, especially along the Bhuntar–Kullu corridor, where settlements are concentrated along the river. Limited flat land is often identified as a reason for development in valley areas; this explanation alone is insufficient. Tourism, hotels, shops, transport activities, also concentrate in these locations.

Urban Political Ecology helps explain this pattern by showing how environmental risks are shaped by the political economy of land, investment, and infrastructure rather than being distributed only according to physical conditions. In Kullu, the economic benefits of development are concentrated around tourism and commercial activities, while the consequences of flooding are experienced by residents living in exposed areas. Thus, the spatial production of flood risk is connected not only to environmental conditions but also to how land and economic opportunities are organised. However, this

mainly helps explain how these patterns are produced, while path dependency helps explain why they continue over time (Pierson, 2000).

Similar patterns have been observed in other hilly regions. For example, if we look at the case of Kathmandu, changes in land use have led to the conversion of agricultural land into built-up areas, which has resulted in increased surface runoff and has produced unequal exposure to flood risk across socio-economic groups. Similar cases have been observed in South Jakarta and the Philippines, where urban flooding is linked with development in built-up areas near rivers.(van Voorst, 2016) Despite having the highest vulnerability, most of the population is concentrated in the flood zone. This exhibits characteristics of path dependency, in which infrastructure investments and prior development patterns drive further expansion into risk-prone areas (Seto et al., 2012& Güneralp et al., 2015).

In Kullu, early settlements were established in areas accessible to the surrounding areas. Over time, roads, infrastructure, and services were built in the same locations, attracting more development. And economic activities were also concentrated there, planning decisions continue to support this pattern instead of redirecting growth. As a result, development continued to expand into riskier areas. Each phase of development added to the cumulative exposure, making it difficult to shift growth to safer locations. The above evidence clearly indicates that flood risk in Kullu is not increasing due to environmental change but is being shaped by development patterns that prioritise economic activity over ecology. Rainfall acts as a trigger, but how growth is organised. Thus, flood vulnerability in Kullu is not natural but is created through patterns of growth over the period.

7.2 Institutional production of risk

The findings of this study suggest flood risk in Kullu is not an outcome of environmental processes alone, but is largely shaped by governance decisions that regulate urban development. The concentration of population in high-vulnerability zones demonstrates that exposure has been systematically produced over time. This gives us a new insight: flood risk in Kullu is not simply a result of natural hazards, but is largely determined by government decisions. A key mechanism driving this pattern is fragmented governance, in which planning authorities, municipal bodies, and disaster management operate with overlapping responsibilities and limited coordination, creating a disconnect between risk knowledge and spatial decision-making. While these institutions are familiar with the risk through vulnerability maps but these insights are not effectively translated into land use policies which reflects there is a gap between policy and practice (Beer et al., 2019)

While going through the literature, we identified many such gaps. One of the most critical gaps observed is the absence of forecasting infrastructure in the region. Although flood forecasting is formally the responsibility of the Central Water Commission, its implementation depends on state-level coordination, which has not been done in Kullu (Joshi, 2023). This is due to a lack of institutional alignment, where responsibilities are spread across agencies without accountability. Another such example was seen in basin-level coordination, where hydropower projects operate without proper coordination. During high-flow periods, this leads to sudden downstream surges and increases flood risk (Joshi, 2023).These practices highlight how governance structures can amplify the impacts of hazards through uncoordinated decision-making. The same pattern exists in regulation. Land-use planning, disaster management, and environmental rules function separately. The planning department focuses on development and land use control, while disaster management authorities focus primarily on preparedness and response, creating a divide between long-term planning and short-term intervention. District Disaster Management Authorities, despite their role in disaster response, lack the

authority to influence land-use decisions in high-risk areas. As a result, their role is limited to relief and relocation instead of preventing risk in the first place.

This is not a failure of the governance, but how governance operates. Development continues to concentrate in areas that offer greater economic returns, not because of the absence of institutions, but because planning decisions align with economic connectivity and tourism. Population growth in vulnerable areas shows that exposure is created, not accidental. This aligns with Berk's concept of manufactured risk, which highlights how modern institutions generate and manage risk(Beck, 1992).The built-up area has increased from 1.71% to 4.31% within the flood-prone area(Table 3). The problem there is not a lack of awareness, but a lack of coordination among the institutions where risk is known to them; it exists, but they are unable to use that knowledge while making decisions. (Felix et al., 2025).

Comparative studies from other regions show the same pattern. In South Jakarta, flood risk has increased due to rapid urban development and increased paved surfaces, while the government is focused more on economic growth than on long-term resilience (Gaillard et al., 2008).Similarly, in Metro Manila, projected urban expansion is expected to significantly increase population exposure in flood-prone areas due to weak zoning enforcement. If we talk about the Indian context, Darjeeling exhibits the same dimension where there is unregulated development due to tourism, and fragmented institutional capacity has contributed to an increase in exposure (Acharyya et al., 2024).

These cases show that flood risk is not simply produced by high rainfall but is the result of governance systems shaped by economic priorities, fragmented institutions, and weak enforcement. Our case on Kullu adds to this argument by showing how risk is gradually built over the years. The case highlighted that fragmented institutions have limited the integration of risk into planning, and areas are expanding into high-risk zones, increasing exposure. As a result, even a moderate rainfall event can have a severe impact. To address this concern, we need to think about more than just technical solutions. Without integrated, risk-sensitive land-use planning, current approaches will continue to manage risk rather than reduce it.

The findings suggest a need for a fundamental shift in flood risk governance. Ongoing exposure shows that reactive measures are not enough. Effective mitigation must focus on the concentration of development in vulnerable areas. Together, these approaches go beyond managing flood impacts and instead focus on reducing exposure. This will be studied in the next section.

8. Planning implication

In response to the identified governance and spatial gaps, this study proposes a set of interventions which are aimed at reducing exposure and restoring the landscape's natural capacity to regulate floodwaters (De Magalhães et al., 2026).

8.1 River Corridor Restoration and Floodplain Expansion

This proposal adopts a land reclamation strategy based on the "room for the river" approach, which aims to reduce flood risk along the Beas River (Fig. 11). Instead of relying on embankments, this approach reduces flood risk by slowing water before it reaches settlements. This is done by shifting protection away from the river and creating a buffer that can accommodate flooding. (Rijke et al., 2012). This approach is supported by global examples showing that increasing river space can reduce flood peaks. Example from the Waal River in the Netherlands shows that widening river channels and moving embankments can lower flood risk and improve surrounding areas (Stokkom et al., 2005). These strategies slow down the flow of water and reduce its downstream impacts. By allowing more water to

spread sideways. Also, the cost of this is 1/10 that of making embankments. It reduces dependency on infrastructure and addresses the main cause of risk in Kullu. So, this shift in flood management is from controlling water to reducing exposure.

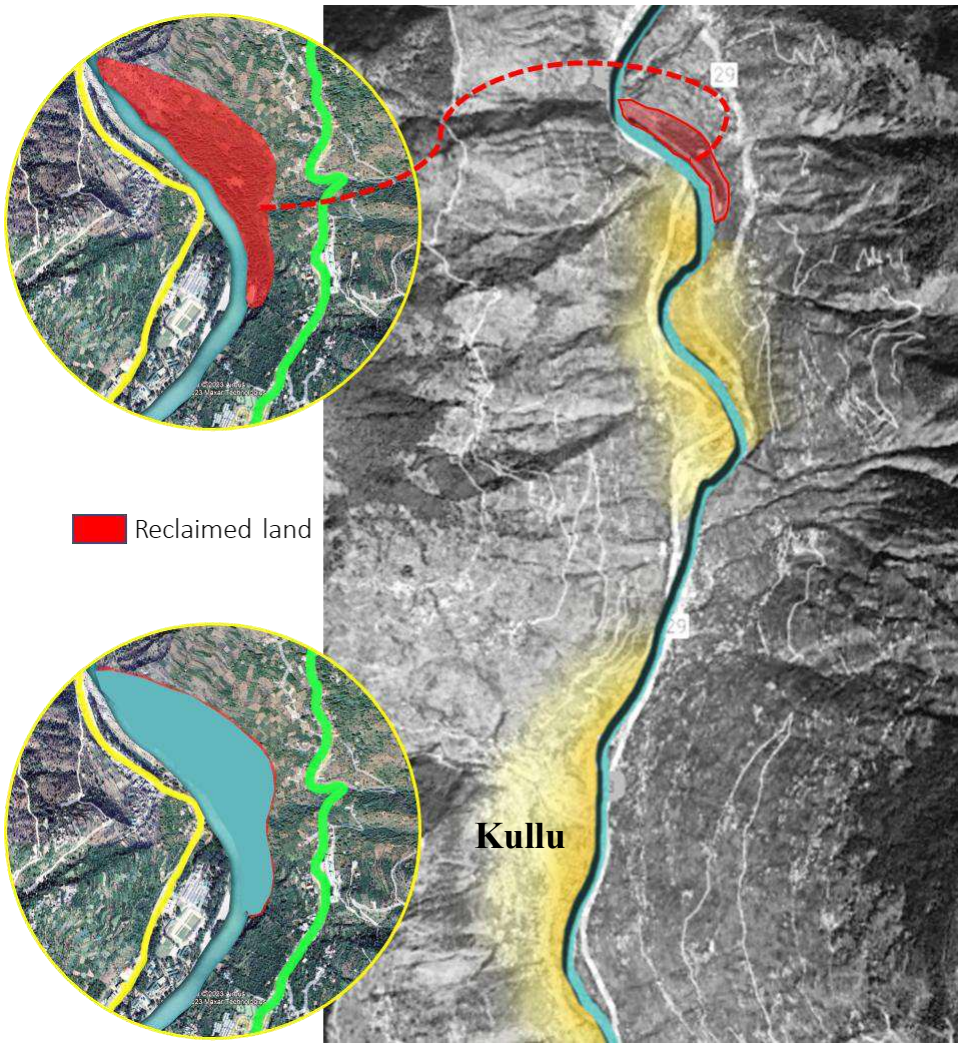


Figure 11 Proposal for River Corridor Restoration and Floodplain Expansion
(Source: Author)

8.2 Relocation of Settlements from High-Risk Flood Zones

Slums are located along the riverbanks in Kullu and Bhuntar. A total of 160 HH live in these high-risk zones along riverbanks in Kullu and Bhuntar and face a significant risk during seasonal flood events (Fig. 12). Relocation will aim to reduce exposure rather than simply displacing residents. Alternative sites are selected on stable land at a safe distance from the river, while remaining close to existing settlements. This helps reduce new social and economic risks, which are common in poorly planned resettlement programmes(Ketankumar et al., 2020).This intervention helps reduce the concentration of vulnerable people in high-risk areas. By relocating households from the most exposed locations, it lowers the risk of life and property and allows these areas to be used as flood-compatible spaces. This shifts the focus from responses to risk reduction. (Sherbinin et al., 2011)

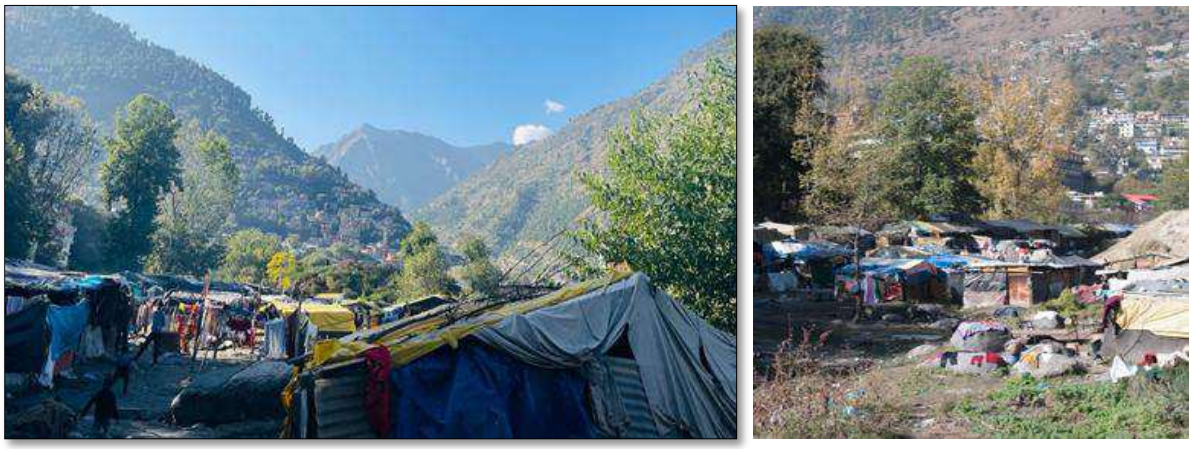


Figure 4 Existing Slums in Kullu
(Source: Author)

8.3. Nature-Based Flood Management through Sponge Landscapes

We propose a network of sponge landscapes as a nature-based strategy to enhance urban flood resilience in Kullu (Fig.13). These spaces are designed as open areas that function as parks in normal conditions and store water during floods, and they use permeable surfaces, vegetation, and storage areas to absorb runoff, hold stormwater, and reduce surface flow. These spaces also help reduce risk by acting as buffers. When there are floods, they store excess water and reduce pressure on built-up areas, and on normal days, they act as regular parks and provide ecological and social benefits. This also aligns with increasing evidence that nature-based solutions can effectively manage floods by improving how the landscape manages water (Ahern, 2011b; Andersson et al., 2017). These parks support the shift from flood management to proactive risk reduction by working with natural processes rather than relying solely on engineered solutions.

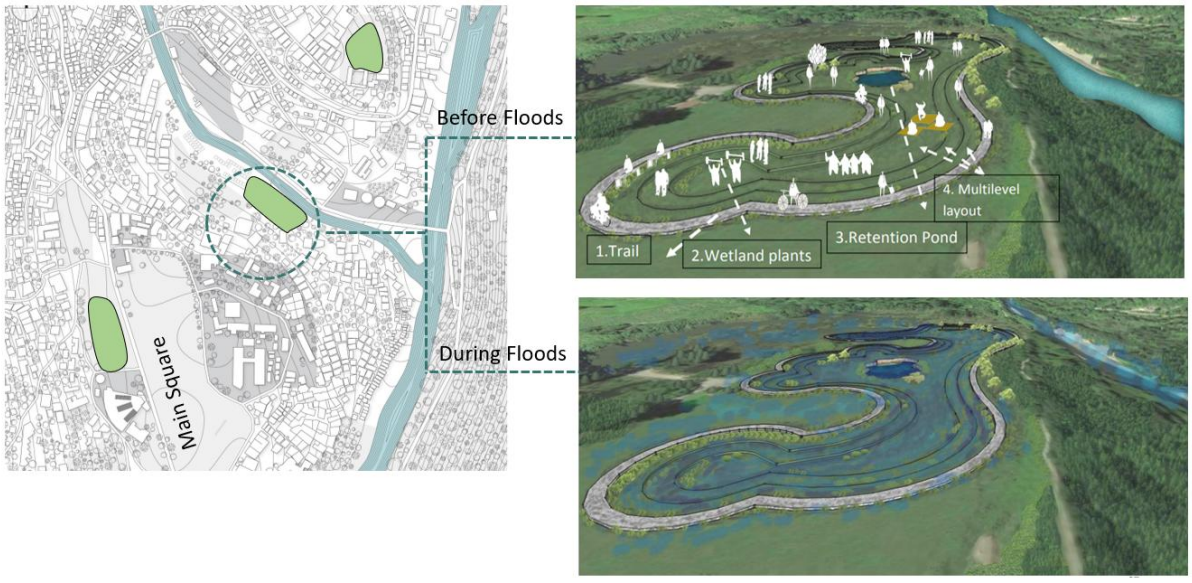


Figure 13 Proposal of sponge parks in Kullu
(Source: Author)

8.4 Institutional Coordination for Risk-Sensitive Planning

In the previous section (section 7), we discussed that flood risk in Kullu is not natural but is created through fragmented governance, which prevents risk information from influencing planning decisions. At the national and state level, each department have their defined roles but their coordination remains weak, particularly in smaller hill towns (Janizadeh et al., 2024). As a result, all the institutions continue to operate in isolation with limited effective risk reduction. So to solve this problem. There is a need to establish a district-level coordination mechanism that brings together all institutions, including planning authorities, disaster management agencies, hydropower operators, and municipal bodies, to review land-use decisions, infrastructure approvals, and risk assessments. This will respond to broader evidence that fragmented decision-making and weak institutional coordination are key drivers of urban risk(Ishiwatari, 2019). Overall, strengthening institutional coordination is essential to translate risk knowledge into land-use decisions, which is the precondition for integrated, risk-sensitive flood governance.

9. Conclusion

In this paper, we understand that flood risk in Kullu isn't just a natural phenomenon but a result the land is planned, developed and governed. We used a combination of spatial analyses, including LULC change, physical vulnerability mapping, population exposure, and return period analysis, to demonstrate how risk has intensified over time through the expansion of built-up areas into flood-prone zones. This population expansion into the floodplain reflects planning and governance failures that have not been able to integrate risk knowledge into land-use decisions. Here, formal institutions continue to operate within a fragmented structure, whereas enforcement gaps allow development in highly vulnerable areas. If these gaps are ignored, flood management will be limited to technical measures while the main cause of exposure will be overlooked. This study, therefore, highlights the need to move beyond a hazard-focused approach and examine flood risk through a governance and planning lens.

We underscore that if these governance processes remain unexamined, existing risks can be easily overlooked, and governance responses may remain limited to rhetoric rather than real action. These findings are relevant in similar contexts of Global South cities facing similar flood risk. This highlights the need to examine the gap between the planning document and practice. Our findings also have broader implications by showing that risk should not be studied in isolation. The Kullu case provides useful insights into how flood risk should be managed in hill towns that are facing recurring disasters and ongoing development pressures. Future research should examine how changing climate narratives, institutional priorities, and social dynamics interact to create new governance challenges. These challenges will determine how development is managed in Himalayan towns as flood risks intensify over the coming decades.

Declaration of Generative Artificial Intelligence (AI)

During the preparation of this work, the authors used the Grammarly application to enhance the clarity and grammar of the writing. The authors reviewed and edited the content as needed and take full responsibility for the article's contents.

Conflict of Interest

The authors declare that they have no known conflict of interest, competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The datasets used in this study are publicly available through the United States Geological Survey (USGS) Landsat program. The data generated and analysed during the study are available from the corresponding author upon reasonable request.

Acknowledgements

No funding was obtained to conduct this study.

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