



## Urban Land Suitability Analysis Using Landslide Data for Urban Growth Assessment in the Himalayan Region: A Case of Solan District, Himachal Pradesh

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### Abstract

Unregulated urban growth in hilly areas poses serious environmental concerns, as physiography plays a crucial role in development within fragile terrain. Key terrain factors such as slope, aspect, elevation, land use and land cover, distance from roads, drainage density, and geomorphology are vital for identifying suitable land for urban development. This study assesses land suitability for urban development in the Solan district, Himachal Pradesh, using a geospatial framework. The Analytical Hierarchy Process, expert opinions, and existing literature are used to assign factor weights in ArcGIS software. Final weights are derived through a pairwise comparison matrix to generate the land suitability map. The map classifies land into highly suitable (5.77%), moderately suitable (36.14%), marginally suitable (53.33%), less suitable (4.72%), and least suitable (0.02%). Suitability outputs are overlaid with a landslide inventory to evaluate development patterns relative to terrain characteristics. The highest landslide density occurs in the marginally suitable zone (49.5/100 km<sup>2</sup>), indicating high terrain instability. A high coefficient of determination ( $R^2 = 0.993$ ) from nonlinear polynomial analysis shows strong coherence between suitability classes and landslide distribution. The research suggests incorporating hazard and risk analysis in urban development and offers a land-management decision-support system to delineate priority, conditional, restricted and no-development areas in vulnerable Himalaya. The results can help planners control urban growth, minimise landslide-related land-use disputes and encourage hazard-sensitive land use.

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## 1. Introduction

Land suitability analysis helps identify the most appropriate areas that meet the conditions for urban development. It simplifies the process by saving time used in manual data collection, record searching, and extensive field surveys [1]. Identifying sites for future development is difficult due to rapid developmental pressure and strict environmental criteria [2]. Therefore, land suitability research is an essential tool for urban growth analysis [3]. By demarcating less suitable or unsuitable sites, this analysis provides a comprehensive representation of the best suitable locations for placing an infrastructural facility [4]. Finding potential locations for urban growth in mountainous terrain is one of the most critical tasks for planners and planning authorities [5]. Thus, land suitability analysis has emerged as a crucial tool for identifying suitable sites for urban growth, especially in hilly areas [6]. Compared to traditional methods, Multi-criteria Evaluation using GIS tools yields better results and is more accurate [7]. Suitability analysis, in land management, does not only apply to land development, but can also help regulate, prioritise and protect land based on environmental conditions, infrastructure requirements and risk of disasters. This is particularly relevant for mountainous areas where inappropriate development can exacerbate landslide activity, deplete natural resources and enhance vulnerability to disasters. As such, incorporating terrain and landslide information into land-use management is crucial for sustainable and safe land development.

**Table 1.** Nine-point weighting scale for pairwise comparison [10]

Saaty scale	Suitability class
1	Equal importance
3	Moderate importance
5	Strong importance
7	Extreme importance
9	Extreme importance
1/3	Moderate importance (Column over Row)
1/5	Strong importance (Column over Row)
1/7	Extreme importance (Column over Row)
1/9	Extreme importance (Column over Row)

Previous studies indicate that land suitability evaluations for urban growth become more precise when the weighted overlay method is applied to multiple thematic layers [8]. The theoretical foundation of pairwise comparison methods was introduced by Fechner (1860) and Thurstone (1927), later formalised through Saaty's Analytic Hierarchy Process (AHP) in 1980 [9]. The AHP employs an eigenvalue-based pairwise comparison approach and uses a numerical scale from 1 to 9 to represent relative priorities (Table 1) [10]. AHP is developed for multi-criteria decision-making (MCDM) and is able to incorporate both qualitative and quantitative evaluations. The final weights are computed using the conventional pairwise comparison methods, but these methods can be inaccurate and have constraints in human cognition that may result in suboptimal choices [11,12]. AHP can be used to overcome these deficiencies, as it systematically compares all alternatives at the beginning, providing a more logical, scientific and reliable framework than traditional approaches [10]. In the last 25 years, AHP has been used in various fields with complex problems being divided into hierarchical subproblems, assessed by reciprocal matrices using linguistic variables [13].

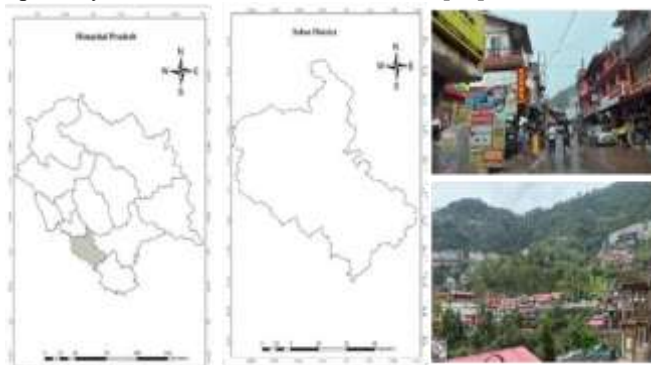
Although it is effective, land suitability analysis is not yet widely used in the planning studies in hilly areas where most of the research is undertaken mostly to assess the hazard. Suitability studies are typically conducted at a site-specific level and there is little likelihood that these will incorporate the effects of land-use/land-cover change and the terrain at district level. This gap requires a comprehensive land suitability framework, informed by the concept of landslides. A comprehensive landslide informed land suitability framework is required in this gap. In this context, the present study proposes use of the AHP technique in order to assess urban growth in Solan District considering the terrain and hazard factors in more appropriate and sustainable planning.

## 2. Materials and Methods

### 2.1. Experimental Study Area

The land suitability analysis is carried out in Solan District of outer Himalayan belt region of Himachal Pradesh, India. The district covers an area of 1936 km<sup>2</sup> and extends between 30°44'53"–31°22'01" N and 76°36'10"–77°15'14" E (Figure 1). The topographic variation from valleys to mountain regions in the northern part of the Himalayas is very noticeable [14]. The elevations range between about 300 m and 2250 m above mean sea level with the highest peak Krol Tibba standing at 2253 m. The geomorphology of the district comprises isolated ridges, narrow valleys and steep slopes, having significant impact on human activities and natural processes in the district [15]. Solan's population growth rate is one of the fastest in the city with an estimated population of 580 320 and the density of almost 300 persons per km<sup>2</sup> which is higher than the State Average (202 persons per km<sup>2</sup>). (2011 Census). The population has grown at 15.9% between 2001 and 2011, which has created a surge in infrastructure needs, and, conversely, fragile terrain has provided challenges for safe development.

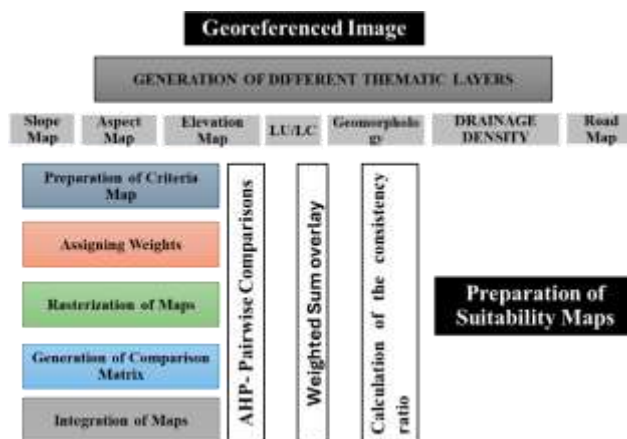
The climate is sub-tropical to sub-temperate, and the temperature and precipitation are highly variable across the region of elevation in Solan [16]. The monsoon period (from June to September) is the rainy season with abundant rainfall which is beneficial for agriculture but also contributes to landslides [17]. Steep topography and weathered lithology in both Satluj and Yamuna basins contribute to erosion due to seasonal streams [18]. Solan is an administrative centre [19] that has been rapidly urbanized due to industries, tourism, horticulture and agriculture activities [20], which has led to a rise in landslide susceptibility and related hazards in the area [21].



**Figure 1.** Location map of Solan District and site visit images in June 2025 (Source: Author)

## 2.2. Data collection

In Solan District, multiple thematic layers were developed from the topographic maps (53A, 53B, 53E and 53F) and high resolution geospatial data (Table 2) to generate the land suitability map for urban development. The Digital Elevation Model (DEM) used was 30 m resolution to create the slope, aspect, and elevation layers by means of ArcGIS spatial analysis tools [22]. Land Use/Land Cover (LULC) data for 2024 were classified from Landsat 8 imagery [23] and grouped into five BIS-defined classes: agricultural, open forest, built-up, barren, and dense forest [24]. Land availability Supervised classification was applied to assess land availability. Geomorphological data from the Geological Survey of India at 1:50 000 scale were used to evaluate terrain characteristics [25]. Buffer analysis and vector data were used to determine the road proximity [26,27]. DEM based flow analysis is used to derive drainage density [28,29]. Prior to the application of the AHP method (using weights from expert input and literature), all layers were rasterised and standardised (Figure 2). The analysis was carried out by 20 experts from related fields [30]. The final suitability map is a combination of topographic and environmental condition for promoting sustainable urban development [31].



**Figure 2.** Study methodology flow-chart

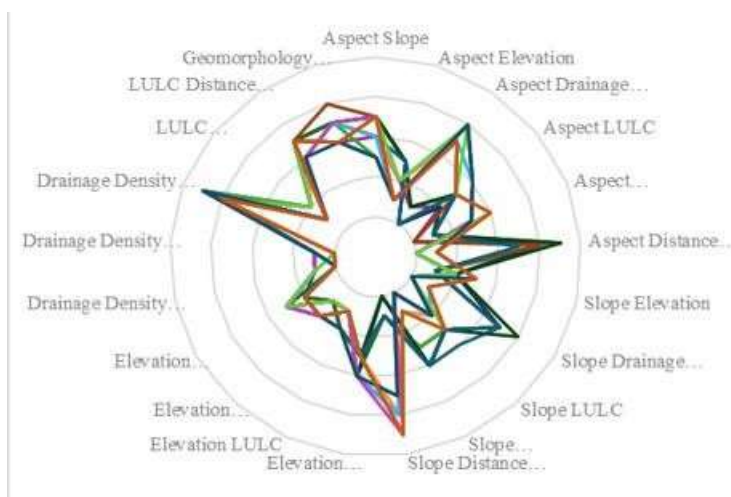
**Table 2.** Thematic layer data collection (Source: Author)

Thematic layer	Resolution/scale	Data source
Slope	30 m	SRTM DEM (USGS Earth Explorer)
Aspect	30 m	SRTM DEM (USGS Earth Explorer)
Elevation	30 m	SRTM DEM (USGS Earth Explorer)
LULC (2024)	30 m	USGS Earth Explorer (Landsat 8)
Geomorphology	1:50000	Geological Survey of India (GSI)
Distance from roads	Vector buffer analysis	OpenStreet Map
Drainage density	Derived from 1:50000 vector	SRTM DEM (USGS Earth Explorer)

The landslide inventory used in this study was prepared by bringing together information from the Geological Survey of India's BHUKOSH portal. These points were then supplemented by field visits and the site coordinates of each landslide were recorded on Google Maps [32]. The mapped locations have been validated with the landslide records on the HPSDMA portal and recent news reports, to ensure that the information is current and accurate. This contributed to a more comprehensive and accurate inventory in the study.

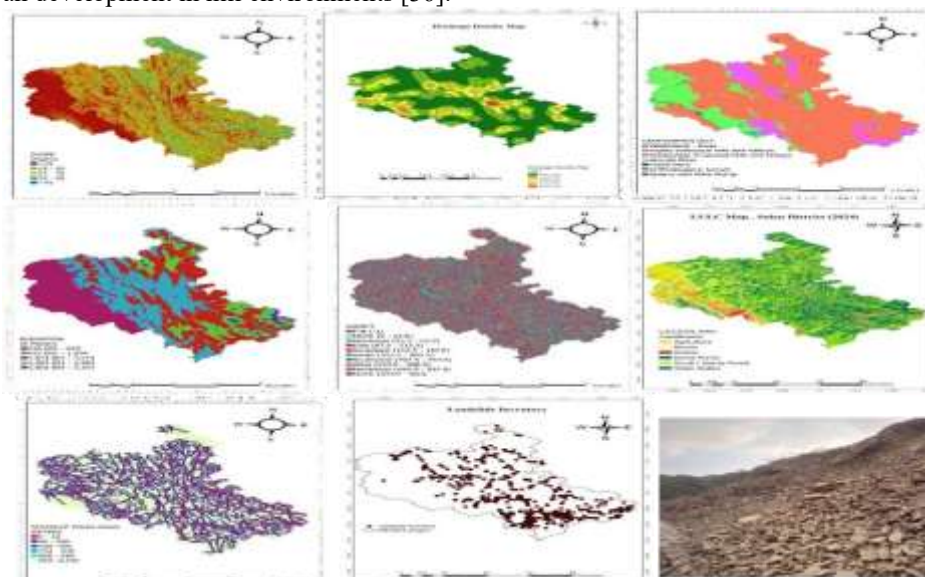
### 2.3. Expert Opinion of Thematic Layers

For this study, seven parameters were selected based on expert opinion and a literature review. Slope, Road Proximity, Land Use/Cover, Drainage Density, Elevation, Geomorphology, and Aspects are the main factors utilised in spatial analysis (Figure 3 and 4).



**Figure 3.** Expert survey results for land suitability criteria (Source: Author)

The expert survey identified key criteria for land suitability analysis in hilly regions. Slope was consistently ranked as the most influential factor affecting terrain stability [33]. LULC, geomorphology, and road distance were considered more important than aspect, elevation, and drainage density [34,35]. Experts emphasised that relying solely on these parameters may overlook critical environmental challenges and recommended incorporating hazard information such as landslide and flood exposure. Additional factors including lithology, soil properties, and vegetation were suggested to enhance suitability assessment. Overall, integrating terrain, accessibility, and hazard data is essential for safe and sustainable urban development in hill environments [36].



**Figure 4.** Thematic layers for study and landslide inventory at Solan district. (Source: Author)

(a) slope, (b) drainage density, geomorphology, elevation, aspect, LULC, distance from road and landslide inventory with field data

### 2.4. Ranking of Criteria

The scores for each criterion were assigned using a nine-point weighting scale based on expert surveys and an extensive literature review. These scores were utilized in the preparation of the criterion maps in the study. A matrix of pairwise comparisons was developed to assess the relative importance of each factor (Tables 3, 4, and 5). The ratio

matrix was normalized and the final criterion weights were determined by Analytical Hierarchy Process (AHP) pairwise comparison method with the inclusion of Consistency Index (CI) and Consistency Ratio (CR) [37]. The matrix was filled in using the Saaty scale from 1 (equal) to 9 (extreme importance) for the direct relationships and the inverse relationships were assigned the reciprocal values (Table 3). To normalise all the elements, they were all divided by the sum of the elements in each column, giving the normalised elements in Table 4. To obtain weights, the elements in each row were averaged and presented as percentages in Table 5.

The literature reviewed was strongly relevant to the development of the AHP model and the weighting scheme. The structure of pairwise comparisons and the 1–9 scale were set by Saaty (2008). Studies emphasised the dominant role of slope and land-use/land-cover (LULC) in development suitability. Bunruamkaew and Murayama (2011) showed that road accessibility, geomorphology are important in heterogeneous terrain [38] and Yalew et al. (2016) proved that the influence of slope and LULC is greater than aspect and elevation in assessing suitability [39].

The final weights showed strong agreement between expert judgment and published studies, identifying slope, LULC, and road distance as key drivers of urban suitability in Himalayan environments, validating the model's applicability to Solan District (Table 6).

### 3. Results and Discussion

#### 3.1. Consistency Ratio

For verifying the consistency of the final comparisons assessment consistency ratio is calculated. The consistency vector and weighted sum vector determination are discussed below (Note: Lambda ( $\lambda$ ) is the average consistency vector.)  $\lambda$  should be equal or greater than the number of criteria under consideration. The value calculated above satisfies this condition.

Consistency index (CI):

$$CI = (\lambda - n) / (n-1) = 0.1 \quad (1)$$

Consistency ratio (CR):

$$CR = CI/RI = 0.076 \text{ (Table 7)} \quad (2)$$

The paired comparisons demonstrated a respectable level of consistency, as indicated by the consistency ratio CR (=0.076) < 0.10. In the present study, the consistency ratio for the seven identified parameters used in the land suitability analysis for urban expansion in Solan district is 0.076. Therefore, by meeting the specified requirements, the figures obtained show that the weight produced is acceptable. Since raster format is simpler than vector data format, all criteria layers were transferred to it for analysis. The seven criterion maps were converted to raster format to determine a score for each pixel. After combining and superimposing all of the criteria maps, the final site suitability map was made using the following formula [40]:

$$\text{Site Suitability} = \sum [\text{factor map } (C_n) \times \text{weight } (W_n)] \quad (3)$$

where  $C_n$  is the standardised raster cell,  $W_n$  – the weight derived from AHP pair wise comparisons (ESRI, 2000).

#### 3.2. Land Suitability Map

A systematic land suitability assessment for urban development was performed using GIS and the Analytical Hierarchy Process (AHP). Thematic layers were rasterised and weighted at the pixel level to generate a suitability map. Weighted overlay analysis classified the area into five ordinal suitability classes ranging from least to highly suitable.

**Table 1.** Pairwise comparison as per expert survey and literature study (Source: Author)

Criteria	Slope	Aspect	Elevation	LULC	Geomorphology	Road distance	Drainage density
Slope	1	6.1	4.6	2.45	4.5	2.65	8.3
Aspect	0.16	1	0.3	0.14	0.19	0.18	2.65
Elevation	0.22	3.33	1	0.18	0.31	0.29	4.6
LULC	0.41	7.14	5.56	1	2.7	2.85	8.7
Geomorphology	0.22	5.26	3.23	0.37	1	0.31	6.7
Road distance	0.38	5.56	3.45	0.35	3.23	1	6.75
Drainage density	0.12	0.38	0.22	0.11	0.15	0.15	1

**Table 4.** Normalised pairwise comparison matrix (Source: Author)

Criteria	Slope	Aspect	Elevation	LULC	Geomorphology	Road distance	Drainage density
Slope	0.398	0.212	0.251	0.533	0.372	0.357	0.214
Aspect	0.064	0.035	0.016	0.03	0.016	0.024	0.068
Elevation	0.088	0.116	0.054	0.039	0.026	0.039	0.119
LULC	0.163	0.248	0.303	0.217	0.224	0.384	0.225
Geomorphology	0.088	0.183	0.176	0.08	0.083	0.042	0.173

Road distance	0.151	0.193	0.188	0.076	0.267	0.135	0.174
Drainage density	0.048	0.013	0.012	0.024	0.012	0.02	0.026

**Table 2.** Weighted sum overlay for computation of criterion weights (Source: Author)

Criteria	Final weight
Slope	0.334
Aspect	0.036
Elevation	0.069
LULC	0.252
Geomorphology	0.118
Road distance	0.169
Drainage density	0.022

**Table 6.** Final weight difference from literature and expert opinion (Source: Author)

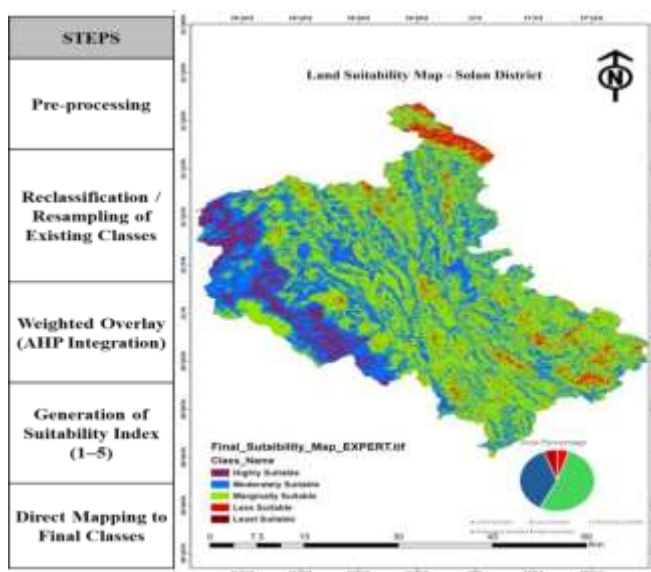
Criteria	Expert final weight	Literature-based Final Weight	Difference (Literature - Expert)	Percent
Slope	0.334	0.3625	0.0285	8.53%
Aspect	0.036	0.0368	0.0008	2.22%
Elevation	0.069	0.0683	-0.0007	-1.01%
LULC	0.252	0.2431	-0.0089	-3.53%
Geomorphology	0.118	0.1129	-0.0051	-4.32%
Road distance	0.169	0.1555	-0.0135	-7.99%
Drainage density	0.022	0.0209	-0.0011	-5.00%

**Table 7.** Weightage of major causative factors (Source: Author)

RANDOMNESS INDEX (R.I)							
Number of criteria	1	2	3	4	5	6	7
R.I.	0.0	0.0	0.58	0.9	1.12	1.24	1.32

**Table 8.** Land suitability classification with percentage area (Source: Author)

Class name	Percent
Least suitable	0.02%
Less suitable	4.72%
Marginally suitable	53.33%
Moderately suitable	36.14%
Highly suitable	5.77%



**Figure 5 (a).** Final site suitability map (Source: Author)

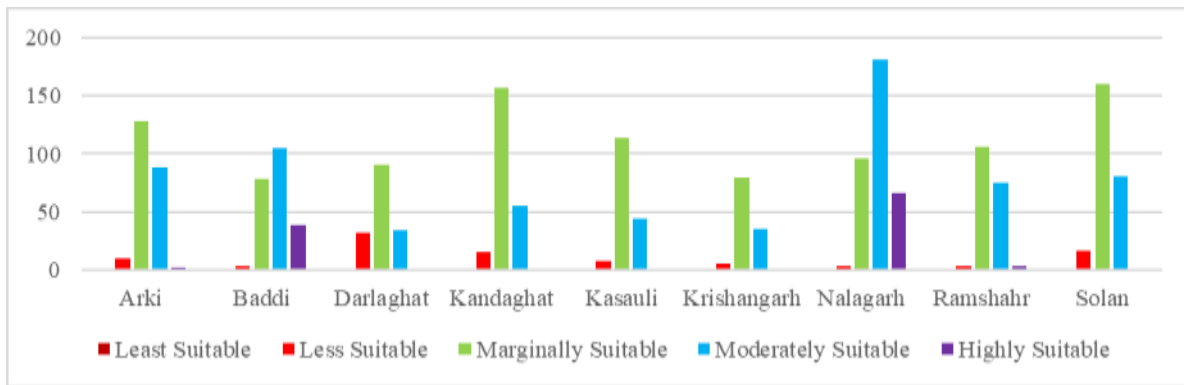


Figure 5 (b). Graph showing sub-district-wise land suitability analysis (Source: Author)

Development across the region is feasible but requires adaptive strategies to address topographic and infrastructural constraints. The analysis reveals that the majority of the area of Solan district is under marginally suitable (53.33%) and moderately suitable (36.14%) category and only 5.7% of the area is very highly suitable due to favorable slope conditions. Map (Figure 5 a and b) shows that less suitable areas (4.72%) and least suitable areas (0.02%) are mostly located in northern and north-eastern parts of the district. Overall, almost 90% of the district's area is moderately to severely constrained for urban development, highlighting the need for informed spatial planning in the areas of limited highly suitable land. The suitability classes may be used as a guideline for land-use planning land-management-wise. Highly suitable zones can be considered as preferred areas for future development, while moderately suitable areas need to be developed with drainage and slope control improvement and infrastructure feasibility studies. Moderately suitable areas need to be tightly controlled and technically verified via geotechnical investigation. Intensive development should be avoided in least and less suitable areas which should be zoned for conservation or low impact development or hazard buffers. The sub-district analysis suggests that the potential for future development is comparatively better in Nalagarh and Baddi areas, while the rest of the area demands strategies of planning in the knowledge of topography.

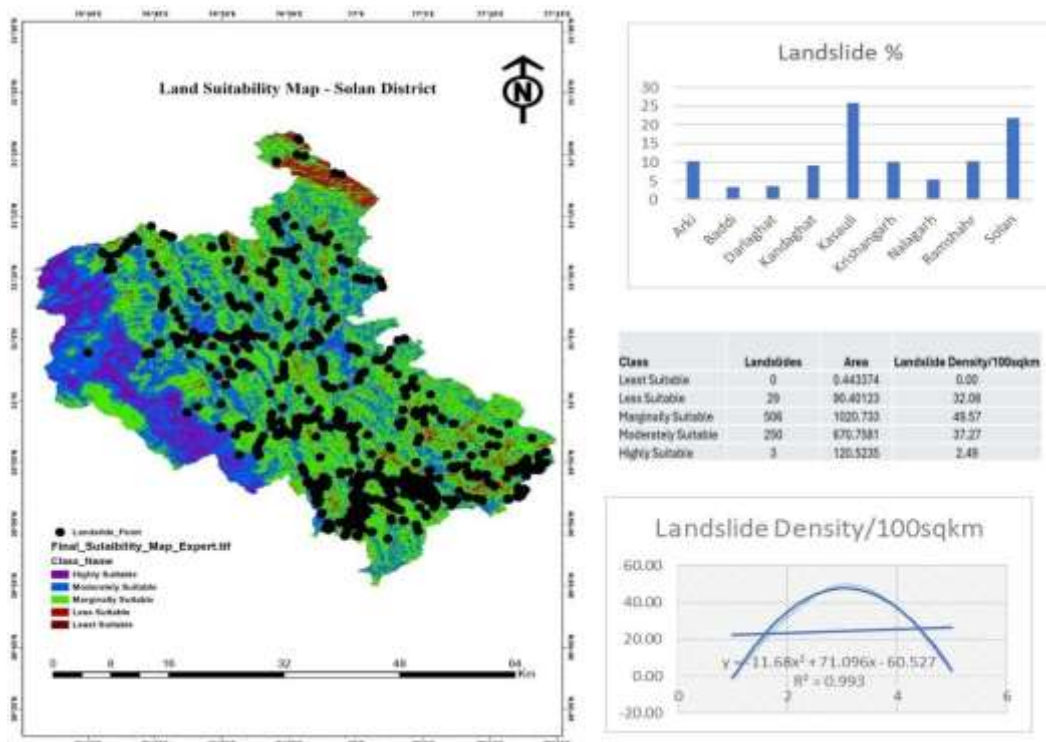


Figure 6: Landslide inventory exposure with respect to land suitability analysis and landslide density/100sqkm.

Source: Author

A landslide inventory was then placed over the land suitability map (Figure 6) to determine hazard exposure, with a strong spatial correlation between land suitability classes and landslides. The landslide frequency is the highest in the marginally suitable areas (64.21%) which represent 53.33% of the district, indicating high landslide hazard exposure (Figure 6). Moderately suitable areas cover 36.14% of the area and 31.75% of landslides, which require mitigation measures like better drainage and geotechnical monitoring [41]. Highly suitable areas account for 5.77% of the area and 0.38% of landslides, which are the safest areas for developing infrastructure. There are 3.68% landslides in less

suitable areas and least suitable (0.02%) areas, which are unsuitable because of hard terrain. There is coherence between suitability and landslide occurrence, as confirmed by a strong non-linear relationship ( $R^2 = 0.993$ ). It is evident that analysis at the Tehsil level reveals maximum landslides in Kasauli, moderate landslide instability in Arki, Kandaghat, Krishangarh and Ramshehr and relatively stable landslide conditions in Baddi and Darlaghat, thus emphasizing the need for proper incorporation of the landslide hazard data into land-use planning.

The map in Figure 7 is supported by: (a) tehsil-wise landslide percentage, (b) landslide density/100 km<sup>2</sup> for each classification, and (c) a non-linear relationship graph between suitability classification and landslide inventory (GSI, HPSDMA and field survey). The physical impact of landslide-related instability is further illustrated by the damaged houses in the Shanti village area of Solan District (Figure 8).

#### 4. Conclusion

The study emphasises the need for sustainable urban growth assessment in rapidly urbanizing and environmentally fragile hilly regions. Using the Analytical Hierarchy Process (AHP) within an ArcGIS environment, a land suitability analysis was conducted for Solan District by integrating seven thematic layers through a multi-criteria decision-making approach based on expert judgment and literature review. Standardised raster datasets were analysed using weighted overlay techniques to generate a land suitability map. Marginally suitable (53.33%) and moderately suitable (36.14%) zones recorded maximum landslides mostly in the Central and eastern part of the district. Although these areas seem to be suitable based on their moderate slopes and the fact that they are close to settlements, there seems to be a mismatch with regard to their exposure to landslides. Only 6.1% of the area is in highly suitable zones and has a low number of landslides, which allows for planned development. High instability (terrain is steep) is indicated in least and less suitable zones. The suitability map produced can be used as a preliminary land-management tool to assist in making planning, zoning, and development permission decisions as well as location decisions for infrastructure. Local governments should give preference to highly suitable sites, allow development with conditions in moderately suitable sites, and not allow development in highly susceptible marginal, less suitable and least suitable areas. This approach of suitability mapping and landslide information can help improve land allocation and promote sustainable urban land use in the Himalayan districts. The study concludes that integrating land suitability analysis with hazard inventories is essential for safe and sustainable urban planning in Himalayan regions.

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#### References

- [1] I. Canco, D. Kruja, and T. Iancu, "AHP, a Reliable Method for Quality Decision Making: a Case Study in Business," *Sustainability*, vol. 13, no. 24, p. 13932, 2021.
- [2] S. Punyal and P. Nair, "Assessing the Urban Form of Hill Settlements, New Shimla, India Using 3D GIS Tools," in *Resilient and Responsible Smart Cities*, Cham, 2022, pp. 149–168.
- [3] C. Vasudevan, S. Mahamad, P. Ravikumar, and B. Vasudevan, "An Analysis of Site Suitability Analysis for Urban Development in Dindigul District, Tamilnadu – a Geomatic Approach," 2017.
- [4] C. Santosh, C. Krishnaiah, and P. G. Deshbhandari, "Site Suitability Analysis for Urban Development Using GIS Based Multicriteria Evaluation Technique: a Case Study in Chikodi Taluk, Belagavi District, Karnataka, India," in *IOP Conf. Ser.: Earth Environ Sci*, vol. 169, no. 1, p. 012017, 2018.
- [5] M. Sharma and V. Kumar, "Site Suitability Analysis for Future Urban Development Using Analytic Hierarchy Process (AHP) Model: a Case Study in Hisar City, Haryana (India)," 2025.
- [6] M. Kumar and V. R. Shaikh, "Site Suitability Analysis for Urban Development Using GIS Based Multicriteria Evaluation Technique: a Case Study of Mussoorie Municipal Area, Dehradun District, Uttarakhand, India," *J Indian Soc Remote Sens*, vol. 41, no. 2, pp. 417–424, 2013.
- [7] M. Kumar and V. Shaikh, "Site Suitability Analysis for Urban Development Using GIS Based Multicriteria Evaluation Technique: a Case Study of Mussoorie Municipal Area, Dehradun District, Uttarakhand, India," *J Indian Soc Remote Sens*, vol. 41, 2013.
- [8] S. Dinda, N. D. Chatterjee, and S. Ghosh, "An Integrated Simulation Approach to the Assessment of Urban Growth Pattern and Loss in Urban Green Space in Kolkata, India: a GIS Based Analysis," *Ecol Indicators*, vol. 121, p. 107178, 2021.
- [9] R. W. Saaty, "The Analytic Hierarchy Process—What It Is and How It Is Used," *Math Modelling*, vol. 9, no. 3–5, pp. 161–176, 1987.
- [10] T. L. Saaty, "Decision Making with the Analytic Hierarchy Process," *Int J Services Sci*, vol. 1, no. 1, pp. 83–98, 2008.
- [11] S. Jafari and N. Zaredar, "Land Suitability Analysis Using Multi Attribute Decision Making Approach," *Int J Environ Sci Develop*, vol. 1, no. 5, p. 441, 2010.
- [12] E. Kinoshita, "Why We Need AHP/ANP Instead of Utility Theory in Today's Complex World – AHP from the

- Perspective of Bounded Rationality,” in Proceedings of the 8th Int. Symp. Analytic Hierarchy Process, 2005, pp. 1–9.
- [13] C. Luan, R. Liu, and S. Peng, “Land Use Suitability Assessment for Urban Development Using a GIS Based Soft Computing Approach: a Case Study of Ili Valley, China,” *Ecol Indicators*, vol. 123, p. 107333, 2021.
- [14] H. Sayal, A. R. Bharose, and M. Tripathi, “Physical and Chemical Properties of Soil of Different Villages of District Solan, Himachal Pradesh, India,” *J Plant Soil Sci*, vol. 36, no. 8, p. 121057, 2024.
- [15] HPSDMA, “Disaster Profile of Solan District.”
- [16] S. K. Sehgal, “Impact of Climate and Environmental Changes on Rainfall Distribution in Himachal Pradesh,” *Int Educ Res J*, vol. 9, no. 7, 2023.
- [17] A. Kumar and O. Singh, “Unveiling Precipitation and Its Concentration over Himachal Pradesh, India,” *Environ Sci Pollut Res*, pp. 1–20, 2025.
- [18] S. Chauhan, S. Chauhan, and S. K. Bhardwaj, “Inventorization of Water Resources in Solan Block of Himachal Pradesh, India,” pp. 456–465, 2017.
- [19] Government of Himachal Pradesh, “District Solan.”
- [20] Sangeeta and S. K. Singh, “Influence of Anthropogenic Activities on Landslide Susceptibility: a Case Study in Solan District, Himachal Pradesh, India,” *J Mountain Sci*, vol. 20, no. 2, pp. 429–447, 2023.
- [21] T. Mehta, S. Ghoshal, Y. Mahajan, M. Sharma, and K. Neha, “Analysis of Patterns of Urban Sprawl and Surface Urban Heat Island in Solan Town of Himachal Pradesh Using Remote Sensing and GIS,” in *IOP Conf. Ser.: Earth Environ Sci*, vol. 1110, no. 1, p. 012084, 2023.
- [22] C. Prakasam, R. Aravinth, V. S. Kanwar, and B. Nagarajan, “Landslide Hazard Mapping Using Geo Environmental Parameters – a Case Study on Shimla Tehsil, Himachal Pradesh,” in *Applications of Geomatics in Civil Engineering*, Singapore, 2019, pp. 123–139.
- [23] Z. Deng, X. Zhu, Q. He, and L. Tang, “Land Use/Land Cover Classification Using Time Series Landsat 8 Images in a Heavily Urbanized Area,” *Adv Space Res*, vol. 63, no. 7, pp. 2144–2154, 2019.
- [24] Indian Standards, *Preparation of Landslide Risk Assessment Maps in Mountainous Terrains — Guidelines*. BIS, 2020.
- [25] D. G. Tarboton, “A New Method for the Determination of Flow Directions and Upslope Areas in Grid Digital Elevation Models,” *Water Resour Res*, vol. 33, no. 2, pp. 309–319, 1997.
- [26] X. Lu and Q. Weng, “Deep Learning Based Road Extraction from Remote Sensing Imagery: Progress, Problems, and Perspectives,” *ISPRS J Photogramm Remote Sens*, vol. 228, pp. 122–140, 2025.
- [27] M. Alamgir, M. J. Campbell, S. Sloan et al., “Economic, Socio Political and Environmental Risks of Road Development in the Tropics,” *Curr Biol*, vol. 27, no. 20, pp. R1130–R1140, 2017.
- [28] S. K. Jenson and J. D. Domingue, “Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis,” *Photogramm Eng Remote Sens*, 1988.
- [29] N. Dragicevic, B. Karleusa, and N. Ozanic, “Different Approaches to Estimation of Drainage Density and Their Effect on the Erosion Potential Method,” *Water*, vol. 11, no. 3, p. 593, 2019.
- [30] A. S. Chandel, K. A. Dedecha, and D. Bekele, “GIS and Remote Sensing Based Site Suitability Analysis for a New Abattoir: a Case Study in Adola Woyu Town, Ethiopia,” *Urban, Planning Transp Res*, vol. 12, no. 1, p. 2300815, 2024.
- [31] N. Suthar, D. Das, and J. Mallik, “Land Use Suitability Assessment for Urban Development Using Multi Criteria Decision Making Analysis in the Himalayan Districts of Shimla, Nainital, and Darjeeling, India,” *Discover Environ*, vol. 2, no. 1, p. 90, 2024.
- [32] P. B. Thapa, S. Lamichhane, K. P. Joshi et al., “Landslide Susceptibility Assessment in Nepal’s Chure Region: a Geospatial Analysis,” *Land*, vol. 12, no. 12, p. 2186, 2023.
- [33] F. K. Tetteh, S. J. Abbey, C. A. Booth, and P. D. Nukah, “Current Understanding and Uncertainties Associated with Climate Change and the Impact on Slope Stability: a Systematic Literature Review,” *Nat Hazards Res*, 2025.
- [34] S. Shah, S. S. Sharma, and D. P. Sharma, “Land Use Change Detection in Solan Forest Division, Himachal Pradesh, India,” 2015.
- [35] S. K. Jain, A. Goswami, and A. K. Saraf, “Role of Elevation and Aspect in Snow Distribution in Western Himalaya,” *Water Resour Manage*, vol. 23, no. 1, pp. 71–83, 2009.
- [36] I. Sonker, J. N. Tripathi, and A. K. Singh, “Landslide Susceptibility Zonation Using Geospatial Technique and Analytical Hierarchy Process in Sikkim Himalaya,” *Quat Sci Adv*, vol. 4, p. 100039, 2021.
- [37] M. Topuz and M. Deniz, “Application of GIS and AHP for Land Use Suitability Analysis: Case of Demirci District (Turkey),” *Humanit Soc Sci Commun*, vol. 10, no. 1, pp. 1–15, 2023.
- [38] K. Bunruamkaew and Y. Murayam, “Site Suitability Evaluation for Ecotourism Using GIS and AHP: a Case Study of Surat Thani Province, Thailand,” *Procedia – Soc Behav Sci*, vol. 21, pp. 269–278, 2011.
- [39] S. G. Yalaw, A. Van Griensven, M. L. Mul, and P. Van Der Zaag, “Land Suitability Analysis for Agriculture in the Abbay Basin Using Remote Sensing, GIS and AHP Techniques,” *Model Earth Syst Environ*, vol. 2, no. 2, p. 101, 2016.
- [40] J. R. Eastman, W. Jin, A. K. Kyem, and J. Toledano, “Raster Procedures for Multi Criteria/Multiobjective Decisions,” *Photogramm. Eng Sens*, no. 5, pp. 539–547, 1995.
- [41] M. Kaspar and D. Scott Kieffer, “Geologic, Geomorphologic, and Climatic Preparatory Conditions for the Evolution of the Dangkhari Landslide, Himachal Pradesh, India,” *J Geol Soc India*, vol. 98, no. 7, pp. 903–910, 2022.