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Landslide Hazard Assessment, Spatial Distribution and Land Use Change in Ilam Municipality, Nepal

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ABSTRACT

This study examines the distribution of landslides, slope characteristics, and changes in land uses and land cover (LULC) in Ilam Municipality, Wards 8 and 9, Nepal, between 1997 and 2024. Ilam is extremely vulnerable to landslides due to its steep slopes, delicate geology, and heavy monsoon rains, which endanger livelihoods, infrastructure, and agriculture. The study tracks LULC changes and examines landslide patterns related to topographic features using Google Earth images and GIS. Positive conservation tendencies are shown by the results, which show a dramatic drop in agricultural land (64.05% to 40.20%) and an increase in forest cover (27.27% to 43.92%). However, there are urbanization issues (0% to 9.89%) in unstable areas. Topographic influence is shown by the fact that 56.70% of landslides occur on slopes between 18° and 27°, according to a slope study. Slope instability is also a result of human activity and road networks. According to the study, landslide risks are increased by uncontrolled urban growth and infrastructure development on steep terrain, even though forest expansion may assist in stabilizing slopes. To reduce the risk of landslides in the area, sustainable building methods, slope control, and efficient land-use planning are crucial.

Landslide Hazard Assessment, Spatial Distribution and Land Use Change in Ilam Municipality, Nepal

The far-eastern part of Nepal is home to Ilam, renowned for its diverse ecosystems, tea gardens, and stunning vistas. However, it is extremely vulnerable to landslides due to its hilly, steep terrain and immature geological structure. Ilam, located near the Himalayan tectonic plate boundary, frequently experiences landslides exacerbated by excessive rainfall, deforestation, and haphazard construction. One of the most frequent and damaging natural hazards in the area, these landslides pose serious risks to infrastructure, property, and human life (MoHA, 2021).

In Ilam, landslides frequently happen on precarious slopes or in places where landslides have happened before. During periods of heavy rainfall, especially during the monsoon season, many of these slopes become active again. In Nepal, landslides affect thousands of families and claim hundreds of lives every year; Ilam is not an exception to this pattern (NPC, 2020). The district's steep slopes, delicate geology, and human activities like road building, agricultural growth, and urbanization all contribute to its increased susceptibility.

Geological, geomorphological, hydrological, climatic, and vegetative elements all play a role in the occurrence of landslides (Khanal & Upreti, 1996). Deforestation and uncontrolled infrastructure expansion are two examples of human actions that frequently speed up these processes, causing new landslides to form or dormant ones to reactivate. Significant socioeconomic and environmental losses are caused by landslides in Ilam, which impact homes, farms, forests, and vital infrastructure like roads, irrigation systems, and electrical networks (MoALDc, 2023).

The study Landslide Hazard Mapping in Panchase Mountain of Central Nepal employed GIS and the Statistical Index Method to assess the landslide dangers in the districts of Kaski, Parbat, and Syangja. The model's 82.8% accuracy rate in this study makes it a reliable tool for disaster risk management and land-use planning in the area (Budha, P. B., et al., 2020).

An essential tool for comprehending and lessening the effects of landslides is hazard mapping. It entails forecasting the likelihood of harmful events in a particular location, identifying vulnerable areas, and facilitating well-informed decision-making (Pradhan, 2003). Areas are divided into low, medium, and high hazard zones on a landslide hazard map. Whereas medium-hazard zones indicate a moderate chance of landslides, low-hazard zones are rather stable. High-hazard areas are extremely likely to fail and need to be addressed right away since they exhibit obvious indications of instability (Ghimire, 1993).

Hazard mapping in the Ilam context can use contemporary methods, mostly remote sensing and GIS, to examine elements like soil type, slope angle, rainfall thresholds, and earthquake susceptibility. These types of maps can help with risk reduction, disaster preparedness, and the development of mitigation plans by highlighting high-risk areas. The main objectives of this article are to develop a zonation map of landslide hazards for Ilam so that preventive measures can be put in place to reduce the possibility of harm to people, property, and ecosystems. Communities in Ilam can become safer and more resilient by minimizing the negative impact of landslides through accurate forecasting and hazard zonation.

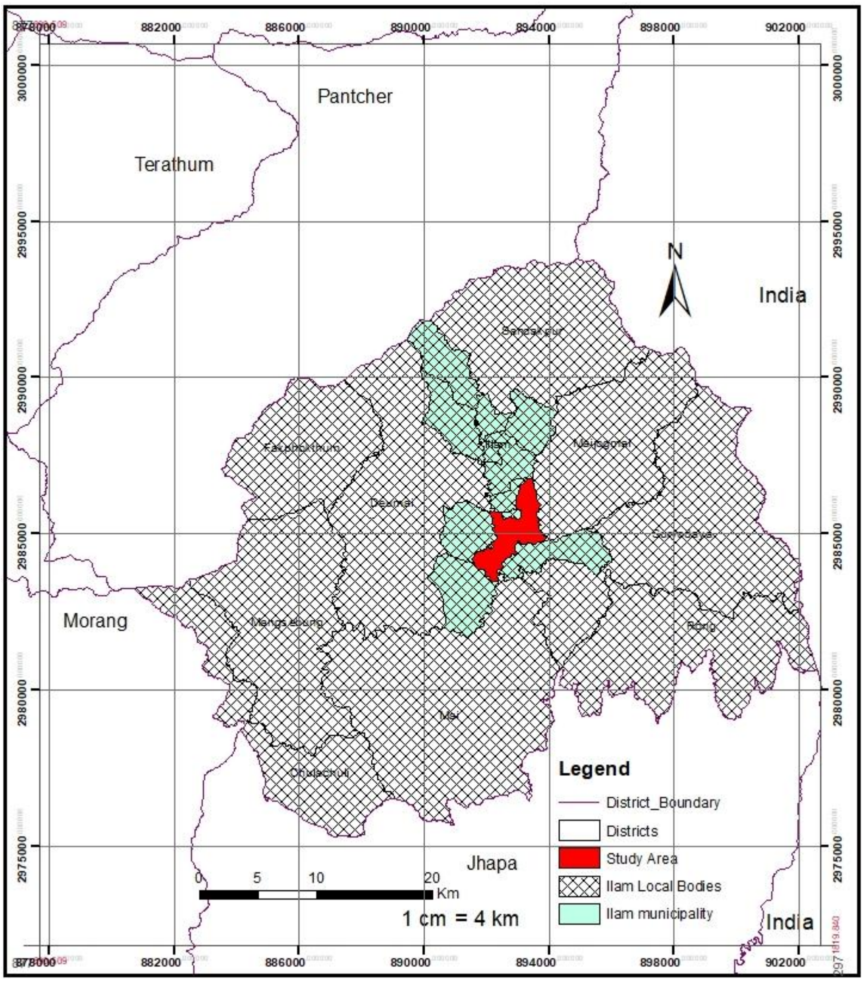
Methods and materials

The study area

This study used a mixed-methods approach to investigate the distribution and contributing variables of landslides in Wards No. 8 and 9 of Ilam Municipality, combining rigorous secondary data analysis with limited field-based observation. With their steep slopes, delicate lithology, and significant land-use changes, these wards, which cover an area of about 2,105 hectares, are sensitive to both geology and geomorphology (Khanal & Upreti, 1996; Ghimire, 1993). Based on their history of frequent landslides, anthropogenic disturbances like as rural road construction, and deforestation, all of which are consistent with findings from national-level assessments, these wards were chosen (MoHA, 2021) (Figure 1).

Figure 1.

The Study Area



This study mostly used secondary data because it was not easy to perform thorough fieldwork. Terrain features and areas susceptible to landslides were identified using geological maps from the Department of Mines and Geology, topographic maps from the Survey Department, and spatial imagery viewed using Google Earth and ERDAS Imagine 2014. To track past landslide scars, road expansion, and vegetation changes, high-resolution, time-series satellite pictures from Google Earth Pro (2010–2023) were used. In order to desensitize to image distortion brought on by seasonal fluctuations, shadowing, and cloud cover, manual digitization techniques were utilized to extract only pertinent elements, while the "historical imagery" feature enabled temporal analysis. Slope maps, landslide inventory maps, and digital elevation models (DEMs) were created using these enhanced images in ArcGIS 10.4 (Pradhan, 2003; Rai et al., 2020).

ArcGIS tools were used to create spatial data layers that evaluated land use, slope, aspect, elevation, and distance from highways and rivers, all of which are widely recognized landslide triggers in the Nepal Himalaya (Gautam & Poudel, 2017; Shrestha, Acharya, & Shrestha, 2023). While SPSS and Microsoft Excel were utilized for quantitative data analysis, ERDAS Imagine was utilized for raster processing and classification. In order to find common patterns, descriptive statistics, including frequency distributions, averages, and percentages, were produced. Meanwhile, GIS mapping showed the spatial correlations between environmental factors and landslide occurrences.

Through an examination of grey literature, policy documents, and field reports, mostly the Annual Agricultural Report (MoALD, 2023) and the 15th National Plan (NPC, 2020), which both emphasize the significance of integrated watershed management in disaster-prone hill regions, qualitative data on land-use patterns, community perceptions, and mitigation strategies were partially acquired. This integrated approach guarantees a thorough, geographically based comprehension of landslide hazards in the socio-environmental setting of Ilam Municipality.

Consultation with local people

Location of the landslide was determined based on a reconnaissance survey within the study area. Additionally, the landslides were identified in the Google Earth satellite image before being exported as KML files. During the area survey, the Google Earth engine with the landslide inventory was partially confirmed. A digital version of the certified landslide inventory map is created.

Landslide inventory map

There were 26 landslides in the research area in 2014, and more than 106 were identified in 2024 by fieldwork and the use of the available latest Google Earth imagery. The distribution of landslides was uneven throughout the whole study area. The map divides the dispersed landslides into areas such as those along the road network, along the banks of rivers, and in other locations.

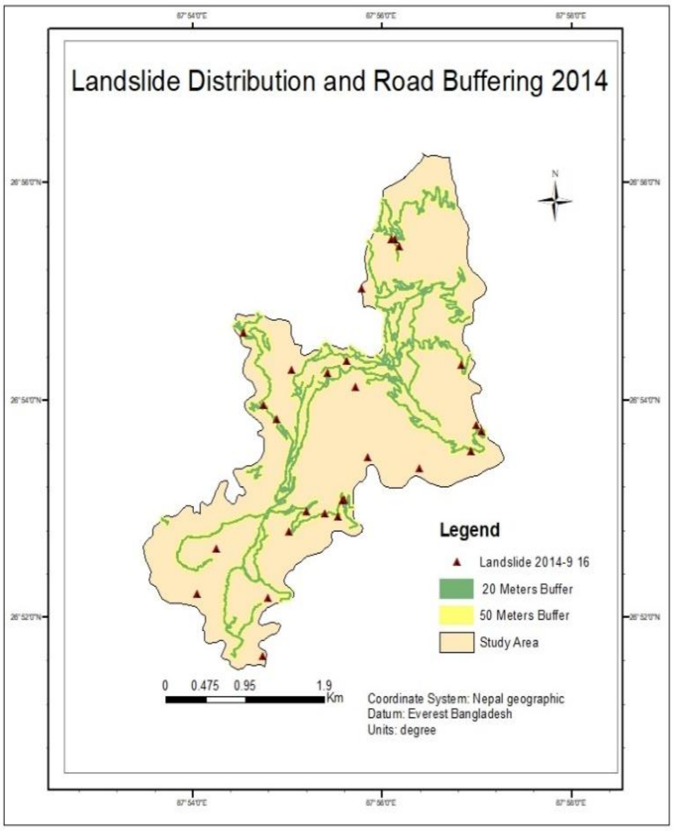
Results and discussion

Major Landslide distribution 2014 and road network mapping.

As demonstrated by the landslide incidents that occurred within designated road buffer zones in 2014, the distribution of landslides within the Ilam Municipality study area was strongly impacted by the area's closeness to highways and riverbank sites. Two important buffer zones were used in the study the improve the visibility (figure 2):

Figure 2.

Landslide distribution 2014 and road network



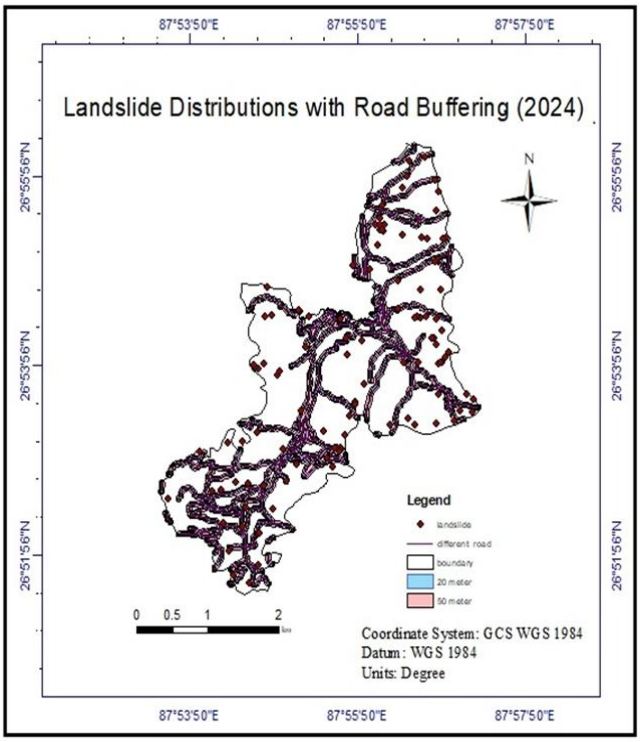
To evaluate the distribution of landslides, place them 50 and 20 meters away from roadways. Five landslides were reported in the 50-meter buffer zone, whereas 13 landslides in the 20-meter buffer zone were found in the same year (2014), indicating a significantly higher frequency. This suggests that landslides are more likely to occur in places that are closer to roadways, especially those that are within 20 meters. This is because human activities like excavation and road construction might cause the nearby slopes to become unstable. In all, 26 landslides were found in the study area in 2014, with a noticeable concentration close to roadways. This shows how important infrastructure development is in reducing the risk of landslides. To lessen the effects of landslides and safeguard infrastructure and human life in Ilam Municipality, these findings highlight the necessity of focused risk reduction efforts, particularly in areas near main and branch roadways.

Major Landslide distribution 2024 and road network mapping.

The landslide events inside the designated road buffer zones in 2024 demonstrated that the distribution of landslides within the study area of Ilam Municipality remained correlated with road proximity (Figure 3):

Figure 3.

Landslide distribution 2024 road network



Eight landslides were reported in the 50-meter buffer zone, compared to a somewhat lower number of nine in the 20-meter buffer zone. Even though there were 106 landslides in 2024 compared to the previous year, these results indicate that landslides are still more common in regions near roadways. According to the distribution pattern, landslide occurrences are still largely caused by road construction and disturbances, but other factors like increased rainfall, shifting land use and land cover, and perhaps even the cumulative effects of previous disturbances may also contribute to these areas' continued vulnerability. Understanding the region's landslide risk is crucial due to the concentration of landslides close to road infrastructure, especially within 20 meters of roads. This emphasizes the significance of integrating road-related hazard mitigation strategies into future planning and disaster management initiatives.

Slope and landslide

The main element influencing the terrain's stability is its natural slopes. The slope angle and slope aspect are components of the slope condition. The interaction of the slope angle with material characteristics, including permeability, friction angle, and material cohesiveness, generally determines the slope's stability. The range of the slope is as follows: <9˚, 9˚ -18˚, 18˚-27˚, 27˚-35˚, and >35˚ (Figure 4).

Figure 4.

Slope map of the Study Area

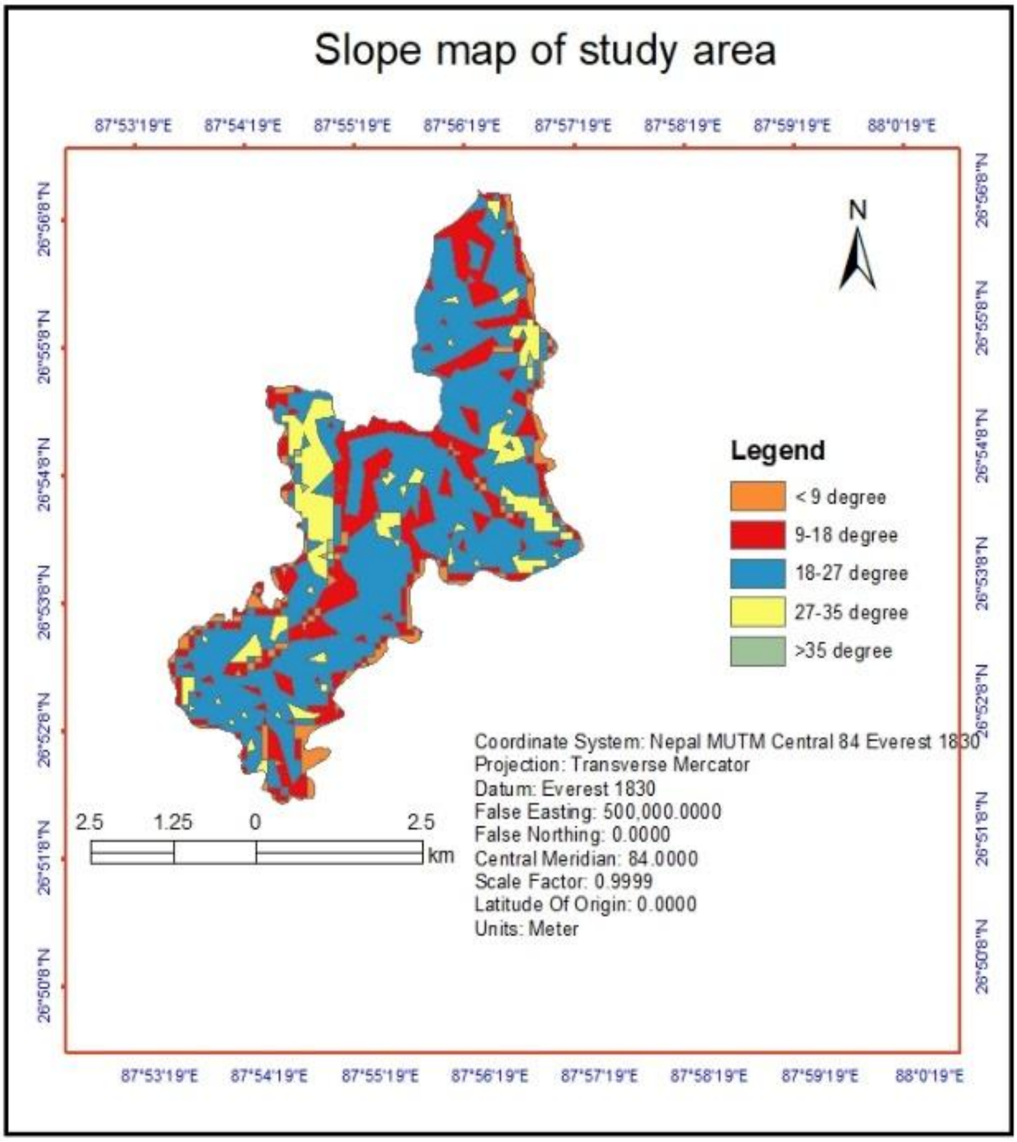


Table 1.

Slope map data of ilam municipality wards 8&9.

Slope of the study area			
SN	**Slope (degree)**	**Area (Ha)**	**Percent (%)**
1	<9	131.20	6.21
2	9 - 18	522.76	24.73
3	18 - 27	1198.31	56.70
4	27 - 35	255.44	12.09
5	> 35	5.76	0.27
	Total	2113.48	100

Source: Derived from slope maps of Ilam municipality

Slope steepness and landslide frequency are two major factors which strongly correlated, according to the slope-wise distribution of landslides in the Ilam Municipality study region. The region is divided into five different slope categories based on Figure 4 and Table 1, which sheds light on how the steepness of the terrain affects the likelihood of landslides.

Although they make up 56.70% of the area, steep slopes (18°–27°) account for the majority of landslide incidents due to their vulnerability to instability. The bulk of landslides are anticipated to occur in these places. Although to a lesser degree, moderate slopes (9°–18°) and extremely steep slopes (27°–35°) also increase the risk of landslides; the risk decreases as the slope's area coverage gets more extreme.

According to this slope-wise analysis, the study area's most susceptible landslide slopes are steep and moderate, particularly in the 18°–27° range, where both natural and man-made causes probably play a role in the most common landslide occurrences.

Landslides, land-use, and land-cover

The stability of the soil slope is also significantly influenced by land usage. While the cultivated land influences the stability of the soil slope owing to saturation of the covered soil, the forest-covered land regularly regulates continuous water flow and infiltration. Withinhe study area.

Figure 5.

Land use and Landover 1997

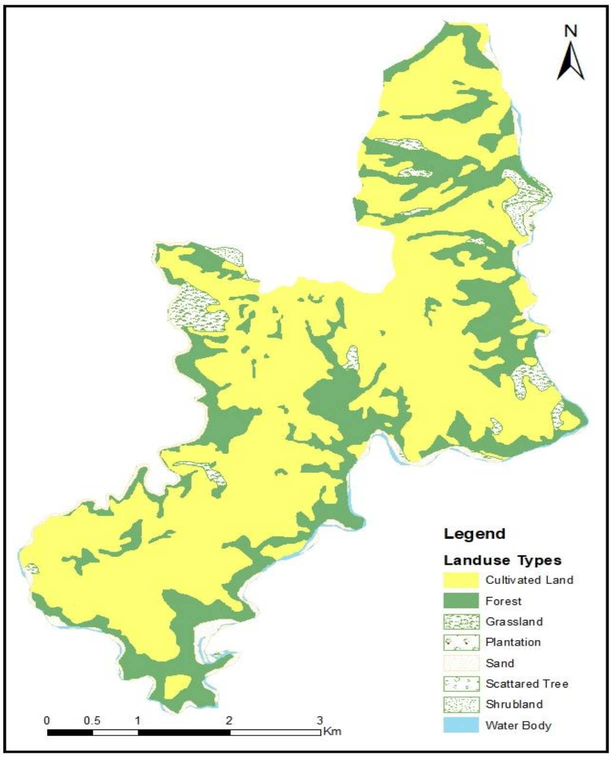


Table 2.

Landuse and Landcover Calculated data

Landuse 1997			
S N	**Landuse types**	**Area (Ha)**	**Percent (%)**
1	Cultivated Land	1353.71	64.05
2	Forest	576.27	27.27
3	Grassland	74.53	3.53
4	Plantation	0.66	0.03
5	Sand	68.15	3.22
6	Scattered Tree	0.14	0.01
7	Shrubland	17.42	0.82
8	Water Body	22.60	1.07
	Total	2113.48	100.00

Source: Derived from land use/land cover maps 1997

Land Use in 1997

Cultivated Land: With 64.05% of the total area under cultivation, agriculture was the most common land use type. Forest: Made up 27.27% of the land, contributing to a very moderate amount of forest cover. Grassland: Grassland accounted for about 3.53% of the totaland area. Other Categories: The remaining area was composed of small patches of sand (3.22%), shrubland (0.82%), water bodies (1.07%), and occasional trees (0.01%).

Figure 6.

Landuse and Landcover 2024

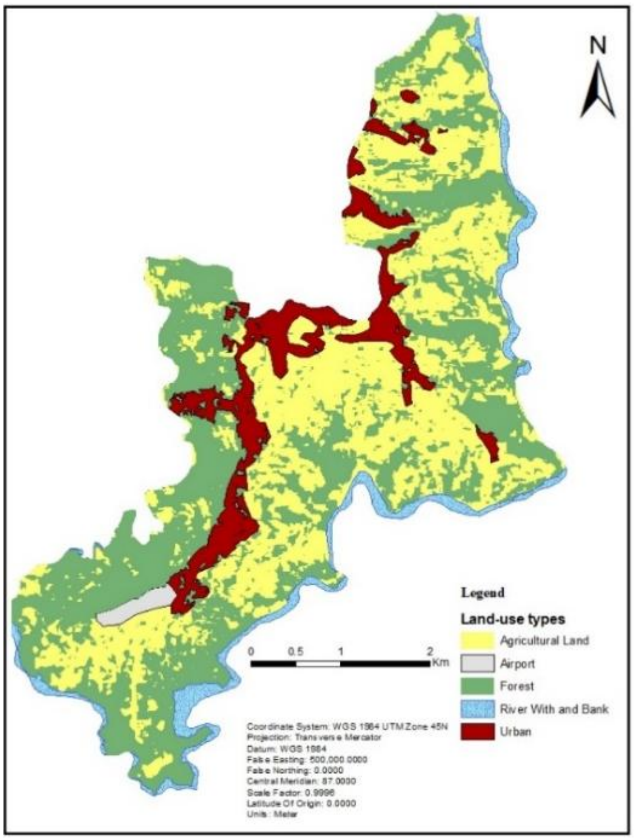


Table 3.

Land Use and Land Cover data 2024

Landuse 2024			
S N	**Types**	**Area (Ha)**	**Percent (%)**
1	Agricultural Land	846.20	40.20
2	Airport	17.18	0.82
3	Forest	924.55	43.92
4	River With Bank	109.20	5.19
5	Urban	208.12	9.89
	Total	2105.24	100.00

Source: Derived from land use/land cover maps 2024

The percentage of land used for agriculture fell to 40.2%, indicating a sharp decline in agricultural activity that was probably brought on by a move to other land uses. The percentage of area covered by forests increased to 43.92%, indicating either reforestation or decreased deforestation. Urban Areas: grew to 9.89%, indicating the region's growing urban population. River with Bank: Possibly as a result of encroachment along riverbanks or modifications in river management, this percentage rose to 5.19%.

Land Use Transition Between 1997 and 2024:

The 27-year period from 1997 to 2024 has seen substantial changes in the land cover and land use in the study area. Landslides and environmental stability are significantly impacted by these transitions:

Table 4.

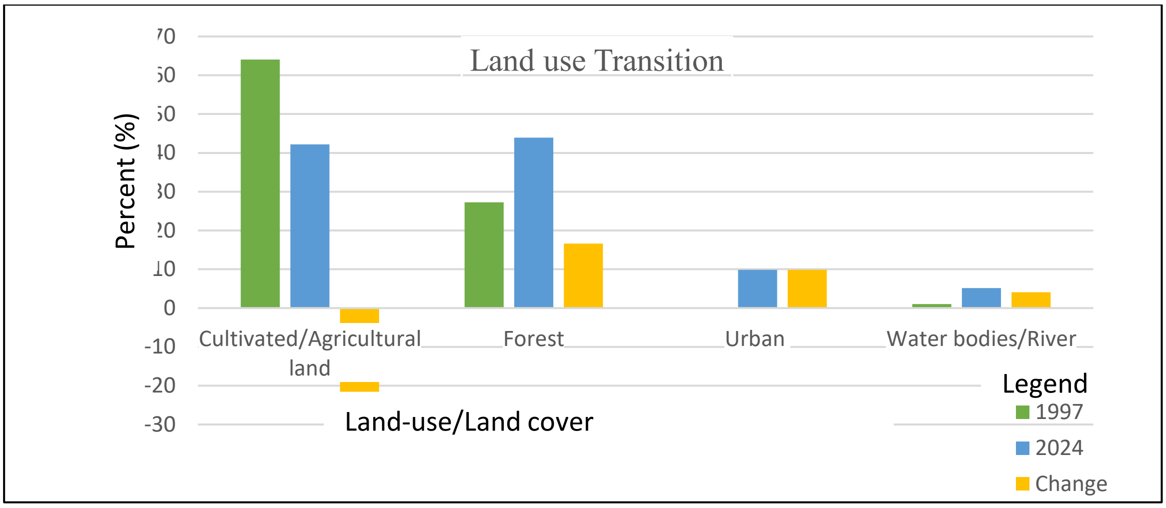
Land Use Transition Between 1997 and 2024

Land-use type	1997 (%)	2024 (%)	change (%)
Cultivated/Agricultural land	64.05	42.20	-23.85
Forest	27.27	43.92	+16.65
Urban (was not listed in 1997)	-	9.89	+9.89
Water bodies/River	1.07	5.19	+4.12

Source: Derived from land use/land cover maps 1996 and 2024

Figure 7.

Land Use Transition Between 1997 and 2024



- Agricultural Land: A significant change in land use patterns is indicated by the dramatic drop in the percentage of agricultural land, which went from 64.05% in 1997 to 40.20% in 2024. Particularly on marginal or slope-prone terrains, this change may be ascribed to natural reforestation, growing urbanization, or even farmland abandonment. Sloped landscapes may experience less anthropogenic pressure as a result of the decline, but landslides and erosion may become more likely on abandoned areas that lack forest cover.

- Forest Cover: The percentage of forestry increased from 27.27% to 43.92%, which can be attributed to either reforestation initiatives, natural regeneration, or a decline in deforestation. This shift has positive ecological effects because forest cover improves slope stability by reducing the likelihood of landslides by reinforcing soil through root systems, absorbing rainfall, and encouraging slow infiltration.

- Urban Areas: From nearly non-existent in 1997 to 9.89% in 2024, urban land cover rose dramatically, indicating both significant population expansion and infrastructure development. Urbanization promotes socioeconomic development, but it also makes people more susceptible to landslides, particularly when communities grow on steep, unstable slopes without proper engineering controls or land-use planning.

- River and Bank Areas: This category increased from 1.07% to 5.19%, which is probably due to either greater mapping accuracy, encroachment into floodplains, or changes in riverbank delineation. The way land management techniques are applied in riparian zones may have an impact on these changes in terms of riverbank erosion and landslide vulnerability.

Landslide Distribution and Land Use Change

In the research region, there is a complicated and varied relationship between landslide risk and land use change:

Forest Expansion and its benefits: When previously disturbed or degraded ground is replaced by forest growth, the increased forest cover is likely to have a major positive impact on lowering the risk of landslides. On the other hand, the growth of cities and urban areas is a danger, particularly on or next to steep slopes, may increase the likelihood of slope failure because of increased surface runoff, infrastructure undercutting, and vegetation loss. The role that agricultural land decrease plays is unclear; it can have a variety of effects. Less irrigation and tilling could, on the one hand, lessen human-caused landslide causes. Conversely, degraded farmland that does not have adequate vegetative succession may continue to be exposed, making it susceptible to erosion and mass wasting.

The land use transformation observed between 1997 and 2024 is marked by a decline in agricultural land, a rise in forest cover, and significant urban expansion is closely tied to the changing dynamics of landslide distribution and hazard potential in the region. Sustainable land-use planning, slope-sensitive urban development, and forest conservation must be prioritized to reduce landslide risks and enhance environmental resilience.

Conclusion

According to the study, there is a significant relationship between the distribution of roads, slope features, landslide occurrences, and changes in land use in Ilam Municipality throughout time. There were 26 landslides reported in 2014, 13 of which were within 20 meters of a road and 5 within 50 meters, suggesting that the proximity of a road affects the likelihood of landslides.

Roads continue to affect the distribution of landslides, as seen by the 106 landslides that occurred by 2024, 9 of which were within 20 meters and 8 of which were within 50 50-meter buffer. The bulk of landslides, according to slope research, happened on 18°–27° slopes (56.70% of the region), which are the most dangerous because of their steep topography and unstable ground. Changes in land use and land cover (LULC) also show a similar pattern, with forest cover rising from 27.27% to 43.92% and agricultural land declining from 64.05% in 1997 to 40.20% in 2024. In developed regions, the probability of landslides increased as urbanization increased dramatically from 0% to 9.89%. According to the study, road construction and unplanned urban growth continue to be major causes of landslides, even though forest expansion may assist in stabilizing slopes.

Reducing landslide threats and guaranteeing safer infrastructure in Ilam Municipality requires rigorous urban development rules, sustainable land-use planning, and slope stabilization techniques.

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