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Comparative Evaluation of Various Statistical Models and Its Accuracy for Landslide Risk Mapping: A Case Study on Part of Himalayan Region, India

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and B. Nagarajan*

Abstract

Among other natural hazards, Landslides are the most prominent and frequently occurring natural disaster in the state of Himachal Pradesh with higher socio-economical losses. About 0.42 million sq.kms of area are prone to landslide activities in our country that is excluding the snow covered areas. The current research focuses on estimating the landslide risk zones of the Shimla Tehsil, Himachal Pradesh using various statistical models. Landslide contributing factors as such Landuse Landcover, Elevation, Slope, Lithology, Soil, Geology and Geomorphology has been used to assess the Landslide risk factors. Data obtained from LANDSAT 8 OLI sensors, SRTM DEM, Soil and Land Use Survey of India and SOI Toposheets have been used as sources. Weighted Overlay, Fuzzy logic and Analytical Hierarchical Process models will be used to categorize the Vulnerability and risk Zones of the study area. The causative factors were analyzed and processed in GIS environment. These values will be then being integrated using various studied models to produce individual landslide vulnerability and risk zones. The results reveal that most of the study area falls under Very Low risk category with a total coverage of 67.34%. Low and Moderate area covers about 23% and 9.13% of the study area. Higher risk areas only account for about 0.46%. Higher percent of the study area is mostly covered by settlements. National highways, Metal roads, Slopes and Denser settlements are located along the Moderate and low risk areas. The results retrieved from the WOM model reveals a total of 55% of the area comes under very low category. Low and Moderate category covers about 31.4% and 10.6% of the study area. High and Very High category cover a total of 1.9% together.

Keywords: weighted overlay, fuzzy logic, risk mapping, Shimla tehsil, landslide inventory

1. Introduction

“Landslides are simply defined as down slope movement of rock, debris and/ or earth under the influence of gravity. This sudden movement of material causes extensive damage to life, economy and environment” [1, 2]. Landslide occurrence in mountainous regions can be due to both natural and Man-made causes such as Roadway and Settlement construction etc. (**Figure 1**). These causes include cloud-burst, thunderstorm, construction for various activities etc. [3]. The most sensitive areas are the Himalayan belt, Western and Eastern Ghats. Among other ecosystems Mountain ecosystem is one of the most fragile ecosystem in the world, when these ecosystems are disturbed either due to natural process or Anthropogenic process or the combined effect of both results in Geohazard and environmental problems such as landslides, soil erosion, reservoir siltation and land degradation [4–7]. Among other various problems that affect hill ecosystem, landslides have observed as fast spreading epidemic due to its multivariate morphodynamic process and also due to improper interaction of human being on nature, especially terrain ecosystem [8–10]. Not only In India but countries located along the borders of Himalayan region experience frequent landslide occurrences. These areas include the North Western and North Eastern Himalayas and the Western & Eastern Ghats [3]. Statistics on world landslides and its impacts is given in **Table 1**.

Landslides of Various types, Pose severe hazards in the Himalayan mountains. Some of the worst disasters in the world have been caused by landslides [11–14]. Every year the damage cause by caused landslide amounts 1 billion\$ says a us study and an average of 200 deaths in a year which is 30% of the such losses around the world [15, 16]. Map derived from the world bank data [17] indicates that most of the landslide hotspots are located the along the mountainous region and active tectonics region (**Figure 2**) [18].

Surya Prakash [19] has compiled a list of landslides that have socio- economic impacts in India (**Table 2**). In his research he reported that the Western and North Western Himalayas account for about 51% high prone landslides.

Over the years’ various scientist and researchers have addressed the landslide problems using various qualitative, Quantitative, Statistical and Numerical

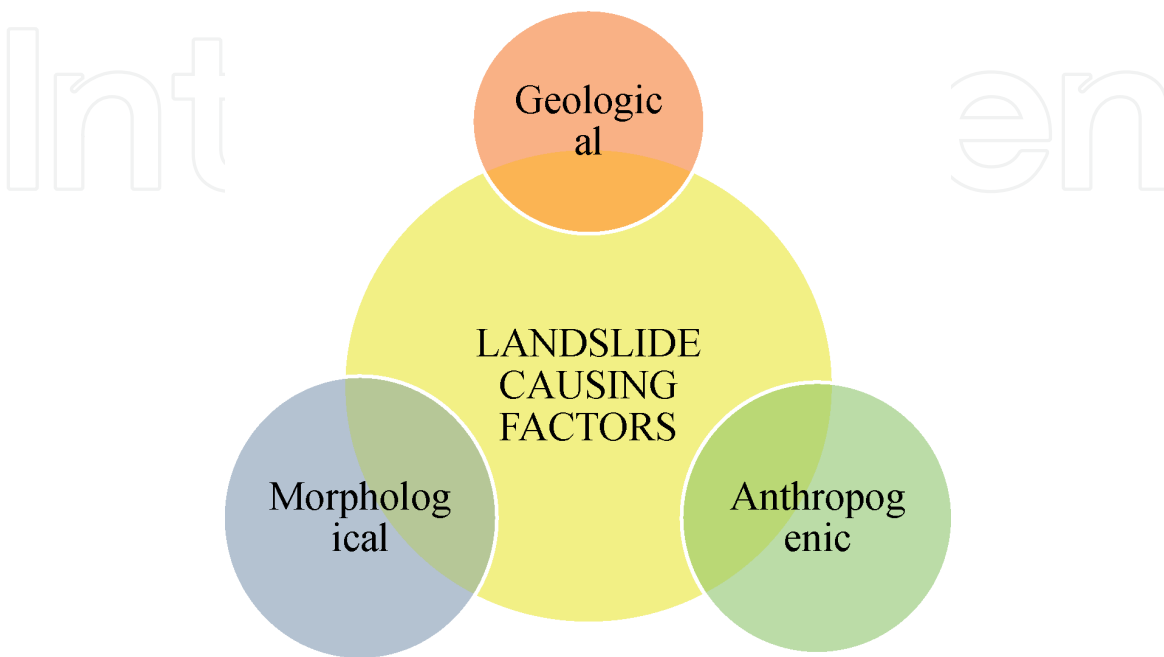


Figure 1.
Landslide causative factors.

Continents	Events	Killed	Injured	Homeless	Affected	Total affected
Africa	23	745	56	7936	13,748	21,740
Avg. Per event		32	2	345	568	945
America	145	20,684	4809	1,86,752	44,85,037	46,76,598
Avg. Per event		143	33	1288	30,931	32,252
Asia	255	18,299	3776	38,25,311	16,47,683	54,76,770
Avg. Per event		72	15	15,001	6462	21,478
Europe	72	16,758	523	8625	39,376	48,524
Avg. Per event		23	7	120	547	674
Oceania	16	542	52	18,000	2963	21,015
Avg. Per event		34	3	1125	185	1313

Table 1.
World statistics on landslides (1900–2010).

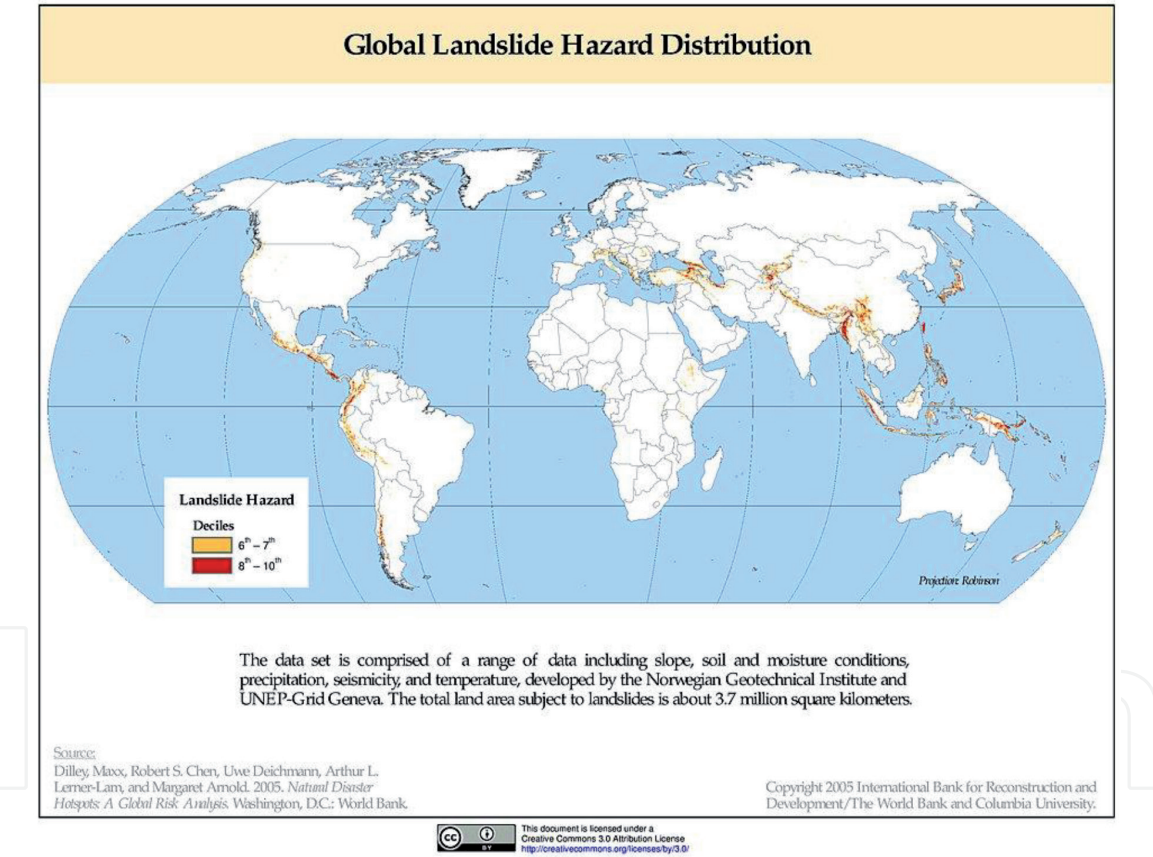


Figure 2.
Global landslide hotspots (2017), source (World Bank).

methods. Every methodology used has its own merits and demerits. The type of landslide involved depends upon varying condition such as slope, geology, geomorphology, nature of landslide, type of causative factor etc [16, 20, 21]. Based on the literature it can be concluded that no methodology is global for landslide studies. The accuracy of estimating landslide risk zones varies for each method [22–28]. It is imperative reliable methodology should be used for the analysis of regional scale landslide risk mapping. Addressing the nature and causative factor of individual landslide is as important as preparing landslide risk maps. Most of the literature address the mapping risk zones or slope stability analysis, it is imperative that all

Sl.no	Year	No. of socio economically significant events	Persons killed	No. of fatal events
1	2018–2019	1	0	0
2	2007–2017	893 (Nasa Catalog)	6614	893
3	2011	26	74	19
4	2010	85	368	53
5	2009	47	270	46
6	2008	36	220	30
7	2007	54	409	39
8	1800–2007	123	2630	61

Table 2.
Socio-economic significant landslides (1800–2011).

these problems should be addressed together. The current research is focused on analyzing the accuracy of weighted Overlay model and Fuzzy logic model to estimate the landslide risk mapping along the Rampur tehsil, Himachal Pradesh, India.

2. Study area

The study area extends from “76°58’19” to 77°19’21” longitude and 30°59’3” to 31°14’10” h latitude” with a total area of 368 Sq.km hectares (**Figure 3**). According to 2011 census the Shimla has a total of 576 villages. The total population of Shimla as of 2011 census is 1,71,640 people among which 1,69,578 reside in “Shimla Municipal Corporation” and the rest in Shimla Rural and Jutogh cantonment board.

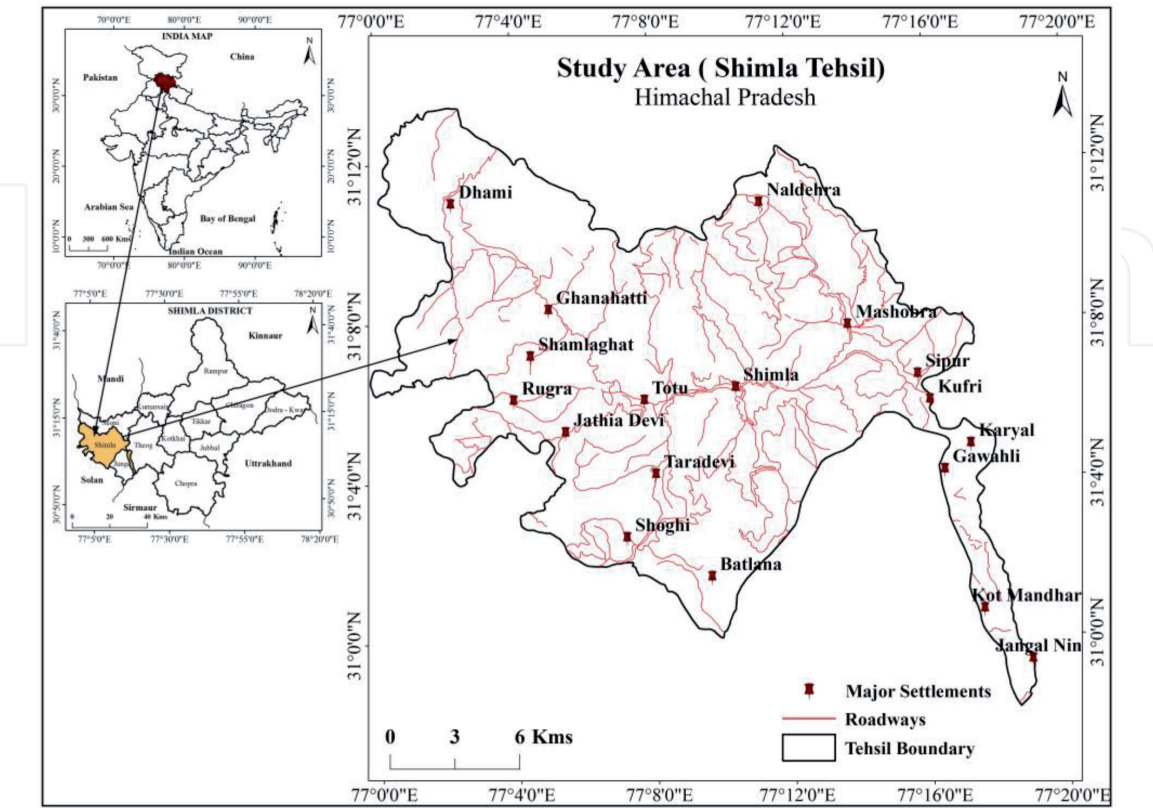


Figure 3.
Study area.

Sutlej, Giri and Pabbar are the three major rivers that drain through Shimla. The economic activities are majorly dependent upon agriculture, horticulture and tourist activities in these areas. Cereals, Off season vegetables and stone fruits are most suitable to grow in the high altitude areas. Most of the Agriculture is rainfall dependant. The soil varies from Sandy loam to Loamy skeletal in the valley and mountain regions. Geologically. Lithology was interpreted from the maps retrieved form the Soil and Landuse survey of India (SLUSI). Major rock types present in these area are Granite, Phyllite, Dolomite, Limestone and Shale. Geomorphologically the area is mostly Undifferentiated hill side and mountain side slope. An average of 999.4 mm of rainfall is recorded where most of the rainfall is received during monsoon period. “The temperature can go as low as 0°C during winter times and as much as 40°C during summer times”.

3. Dataset and research method

The base map of the study area was digitized from Survey of India Toposheets. One cloud free satellite data LANDSAT 8OLI (26/01/2020) was downloaded from the earth explorer website. Soil data covering the study area was received from “Soil and Landuse Survey of India (SLUSI)”. In addition, a 30 mts ASTERGDEM data was downloaded from USGS website for topographical analysis. Rainfall data has been acquired from Indian Meteorological Department, Shimla. The types of data used is given in (Table 3).

Weighted Overlay and Fuzzy logic models are the two type statistical methods used in the research. In the recent years many researchers and scientist have used the methodology to derive landslide risk mapping with higher accuracies [29–36]. “Barrile Vincenzo et.al, 2016 used Fuzzy logic method for mapping landslide susceptibilities. The province of Reggio Calabria, Italy chosen as study area. Parameters such as Elevation Slope, Lithology, Rainfall and Landuse were assigned values and processed in GIS environment. The output subdivides into five categories ranging from Very low to Very high. The results indicate that 22%, 36% and 20% of the area comes under Very high, High and Moderate risk zones”. “Leonardi Geovani et.al, 2016 used a Fuzzy approach to analyze landslide susceptibility for Reggio Province, Calabria, Italy. Rainfall, Elevation, Slope, Landuse and Lithology were used as landslide influencing parameters. The output signifies that 22% and 36% of the area

Sl. No	Data	Source	Date	Resolution
1	Toposheets	SOI	1987	1:50,000
2	Rainfall	IMD	2000–2017	—
3	Soil	“Soil and land use survey of India”	—	1:50,000
4	Geology	“Soil and land use survey of India”		1:50,000
5	Geomorphology	“Soil and land use survey of India”		1:50,000
6	LULC	Landsat 8 OLI USGS	26/01/2020	30 mts
7	ASTERGDEM	USGS	2009	30 mts
8	Landslide Inventory	Google Earth	2017	0.4 mts

Table 3.
Data used.

comes under high and very high risk areas. The results were validated with accuracy of 80% with the data”. The fuzzy logic method uses a value of 0 to 1 to evaluate the relation between landslide occurrences with it respective causative factors. Then the causative factors are analyzed and integrated in the GIS environment to create landslide risk maps and landslide inventory data collected from the field is used to establish the degree of association with each causative factors. “Weighted Overlay Model (WOM)” uses numerical based rating method to classify the parameters ranging from very low to very high based on its degree of importance for landslide initiation and each sub factor is classified into sub categories at a scale of 1 to 5 where 1 indicating the very low risk and 5 indicates very high risk.

4. Result and discussion

4.1 Landuse and landcover

Landuse and Landcover is one of the important causative factor for landslide risk and initiation. Urbanization along hilly areas and unstable constructions lead to slope instability causing slope failure. The LULC has interpreted from LANDSAT OLI imagery for the year 2020. Supervised classification method has been use to map Land cover of the study area. Shimla Tehsil has been classified into four classes namely Forest, Agriculture, Slopes and Settlement (**Table 4**). The classification was based NRSC Level I classification system of Landuse.

Among the various land covers forest is comprised of 63.4% of the total area. Agriculture and barren land together makes 26.7% of the study area. Settlement account for only about 9.7% of the study area (**Figure 4**). The occurrences of mass movements of landslides are minimal along forest due to its soil binding capacity. Tree root bind the soil to the ground avoiding soil erosion due to torrential and monsoon rainfall. In places such as slopes and settlements soils are exposed without vegetation cover and hence prone to a large No. of landslides during monsoon season in the stud area.

4.2 Soil

Soil plays an active role a landslide control factor especially in rugged terrains such as Himalayas. In the study area the soil class area differentiated into coarse loamy, fine loamy and loamy skeletal (**Table 5**). Fine loamy soils in these areas make up about 95.6% of the study area. The rest of the soils coarse loamy and loamy skeletal makes up about 4.2% of the area. Fine soil loamy soil has as clay content of between 18 to 35% and the reminder covered by sand and silt (**Figure 5**). Fine loamy

Sl. no	Class	Area (hectares)	Percent (%)	Weighted overlay model	Fuzzy logic
1	Agriculture	5225.31	14.19%	2	0.3
2	Forest	23,354.53	63.42%	1	0.1
3	Build-up	3605.37	9.79%	4	0.7
4	Slope	4639.24	12.60%	5	0.8
	Total	36,824	100.00%		

Table 4.
LULC with WOM and fuzzy overlay values.

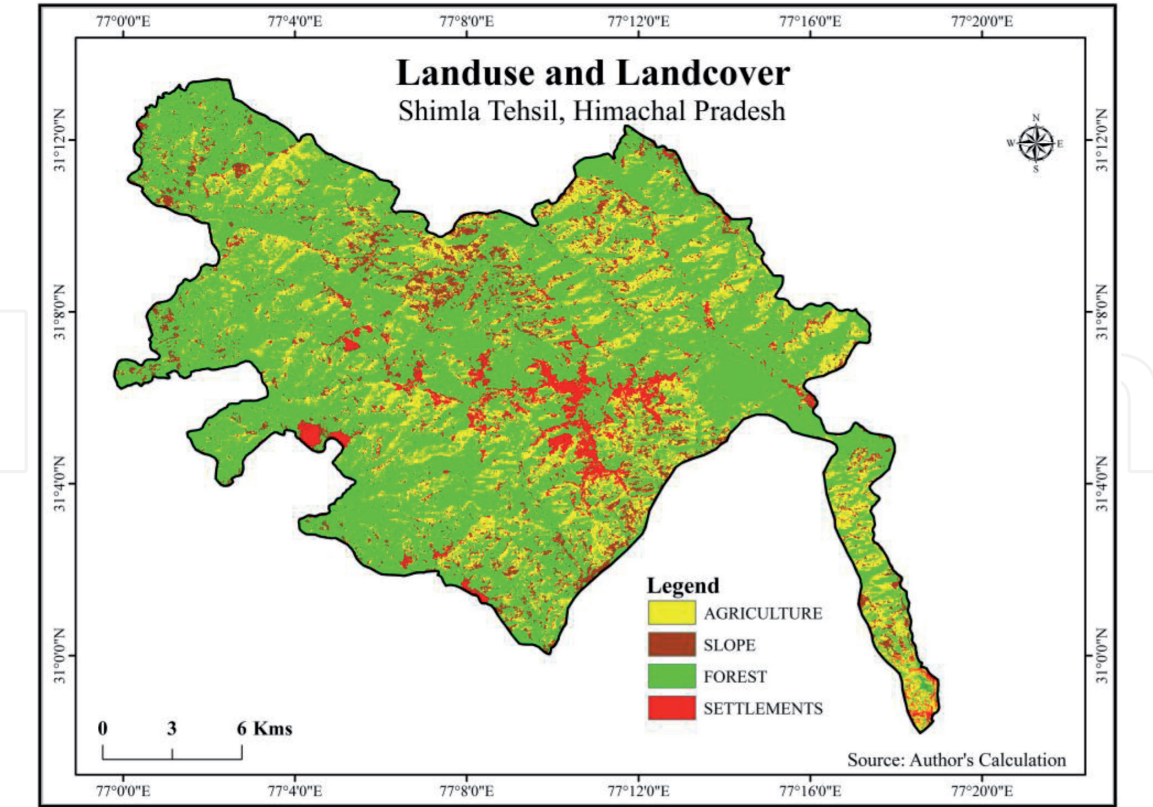


Figure 4.
Landuse and Landcover.

Sl. no	Soil class	Area (sq.km)	Percent coverage (%)	Weighted overlay model	Fuzzy logic
1	Coarse Loamy	6	1.63%	4	0.6
2	Fine Loamy	352	95.65%	3	0.4
3	Habitation	5	1.36%	4	0.8
4	Loamy Skeletal	5	1.36%	3	0.5
		368	100.00%		

Table 5.
Soil with WOM and fuzzy overlay values.

soils are moderately prone to landslides due to their high clay content. These types of soils are prone to mass movements when the water stress in the soil particle exceeds the effective stress of the soil. Coarse loamy and loamy skeletal soil have less clay content between 10 to 18% which are considerably more prone to landslides than fine loamy soil. These soil particles without any vegetation cover are more susceptible to mass movements when the deformation rate in the ground is high.

4.3 Geomorphology

The geomorphology has been differentiated into Habitation, Undifferentiated Hillside and Mountainside slopes (**Table 6**). Undifferentiated mountainside slopes cover about 97.83% and the hillside slopes and habitation covers only minor quantities about 0.5% and 1.6% in the study area (**Figure 6**). Geomorphologically Shimla Tehsil is moderately prone to landslides while the settlement areas are highly prone to mass movement.

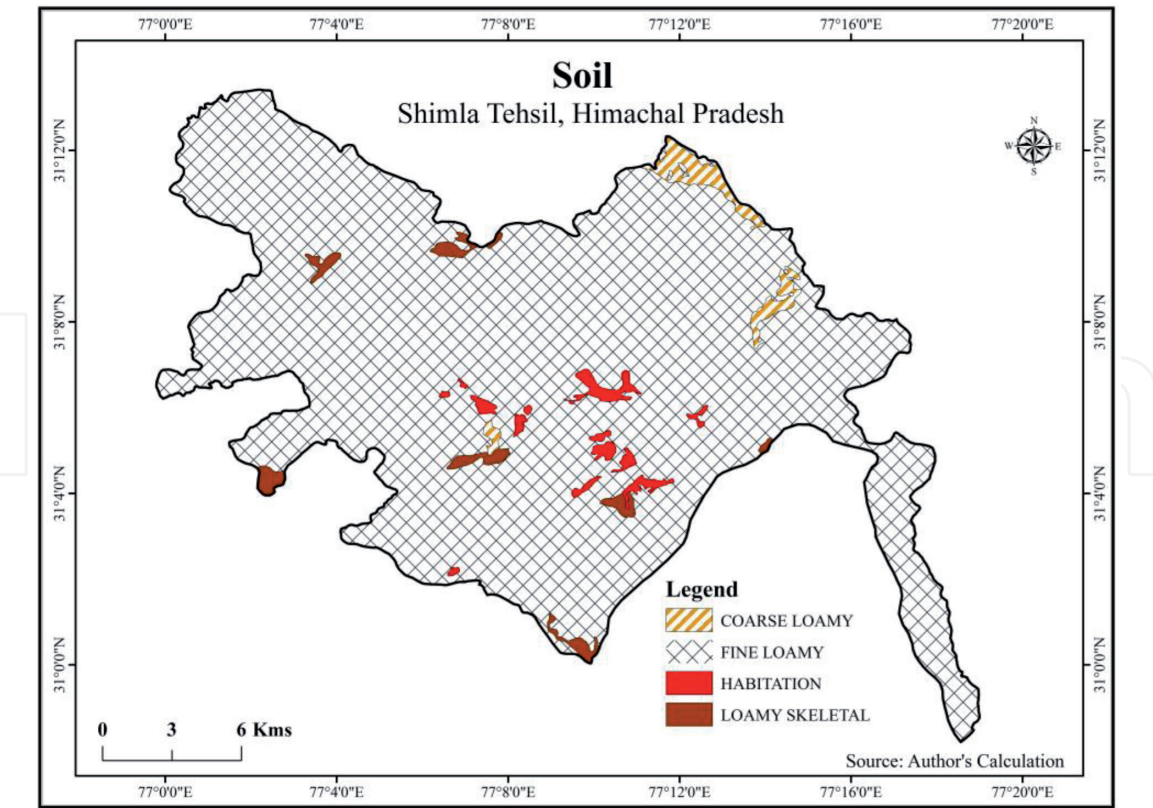


Figure 5.
Soil.

Sl.no	Soil class	Area (sq.km)	Percent coverage (%)	Weighted overlay model	Fuzzy logic
1	Habitation	6	1.63%	4	0.8
2	Undifferentiated Hill Side Slope	2	0.54%	3	0.5
3	Undifferentiated Mountain Side Slope	360	97.83%	3	0.5
		368	100.00%		

Table 6.
Geomorphology with WOM and fuzzy overlay values.

4.4 Geology

Geology plays a key role in groundwater recharge as the types rocks present in an area could hugely affect the amount of water entering into the groundwater table. The study area is covered three major classes namely Schist, Slate and Habitation (**Figure 7**) in which mainly dominated by two types of rock formation namely Slate and Schist that comprises 95.9% and 2.1% (**Table 7**) of the study area. These rocks vary from Moderate to strong in nature in the GSI index. Waters can percolate through the cracks within the rocks or even between them. Fractures and joints formed along the rock surface act as perfect carriers for Rainwater into the ground-water table. Habitation accounts for only 1.90% and these areas mostly comprised of settlements they are placed in the high risk factor for mass movements initiation.

4.5 DEM

Elevation is a secondary factor often used in landslide risk mapping. The risk mapping in DEM model depends upon the no of landslides occurring within a particular

elevation height. In the current study area most of the landslide occurs between 1400 to 2100 mts (**Table 8**) above the mean sea level compared to other elevation heights. Hence these particular elevations are assigned higher risk values (**Figure 8**).

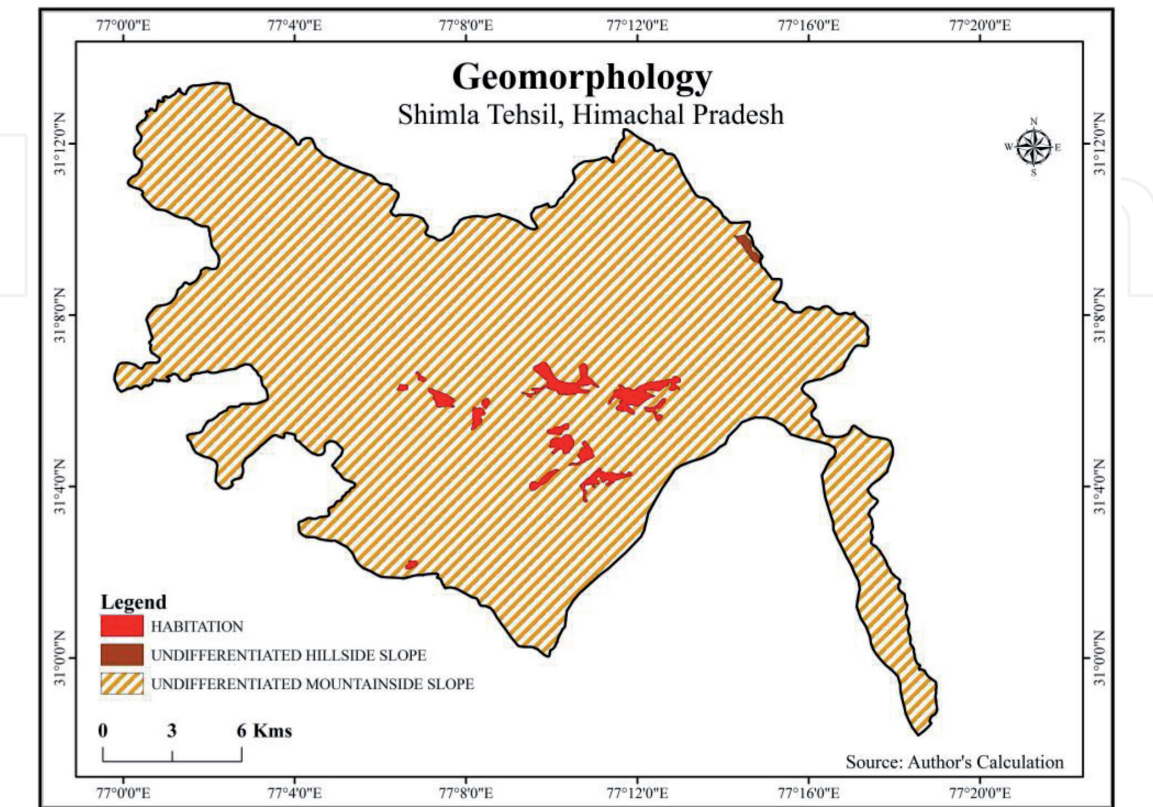


Figure 6.
Geomorphology.

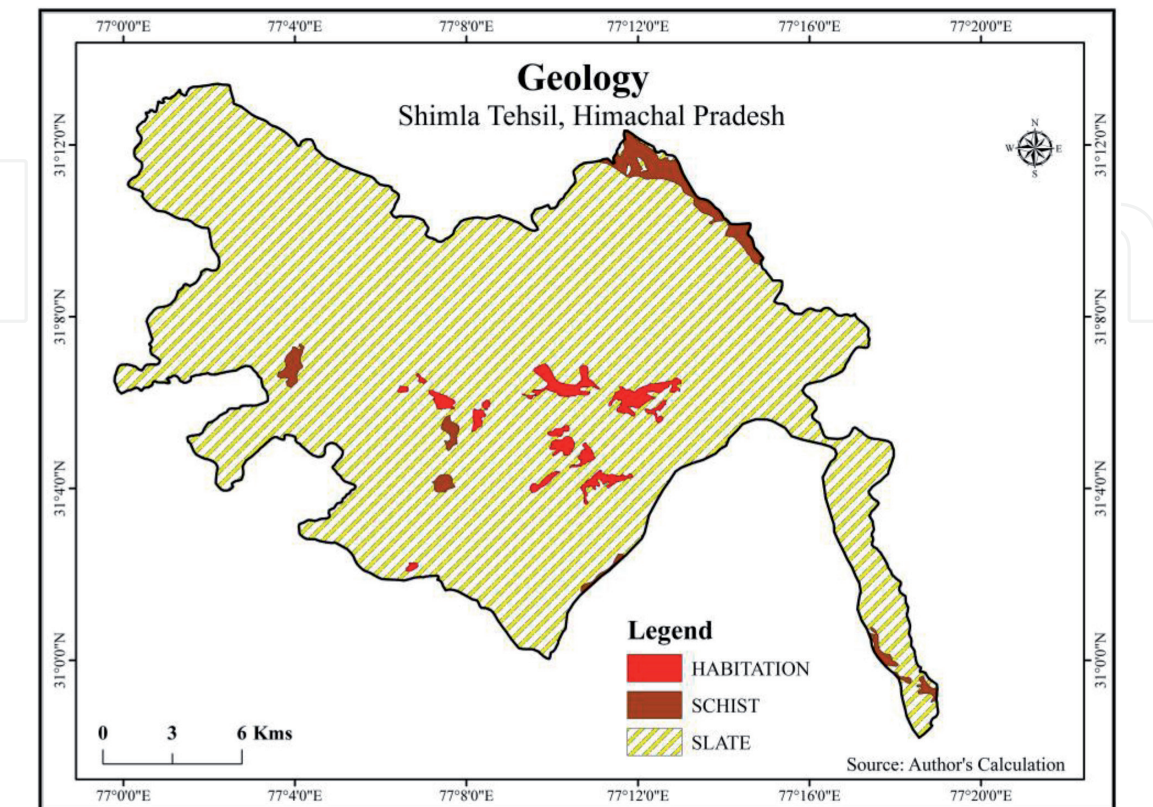


Figure 7.
Geology.

Sl. no	Soil class	Area (sq.km)	Percent coverage (%)	Weighted overlay model	Fuzzy logic
1	Habitation	7	1.90%	4	0.8
2	Schist	8	2.17%	3	0.6
3	Slate	353	95.92%	3	0.4
		368	100.00%		

Table 7.
Geology with WOM and fuzzy overlay values.

Sl. no	Elevation (mts)	Weighted overlay model	Fuzzy logic
1	820 to 1300	1	0.3
2	1301 to 1600	3	0.6
3	1601 to 1800	4	0.8
4	1801 to 2100	4	0.7
5	2101 to 2200	2	0.3

Table 8.
DEM with WOM and fuzzy overlay values.

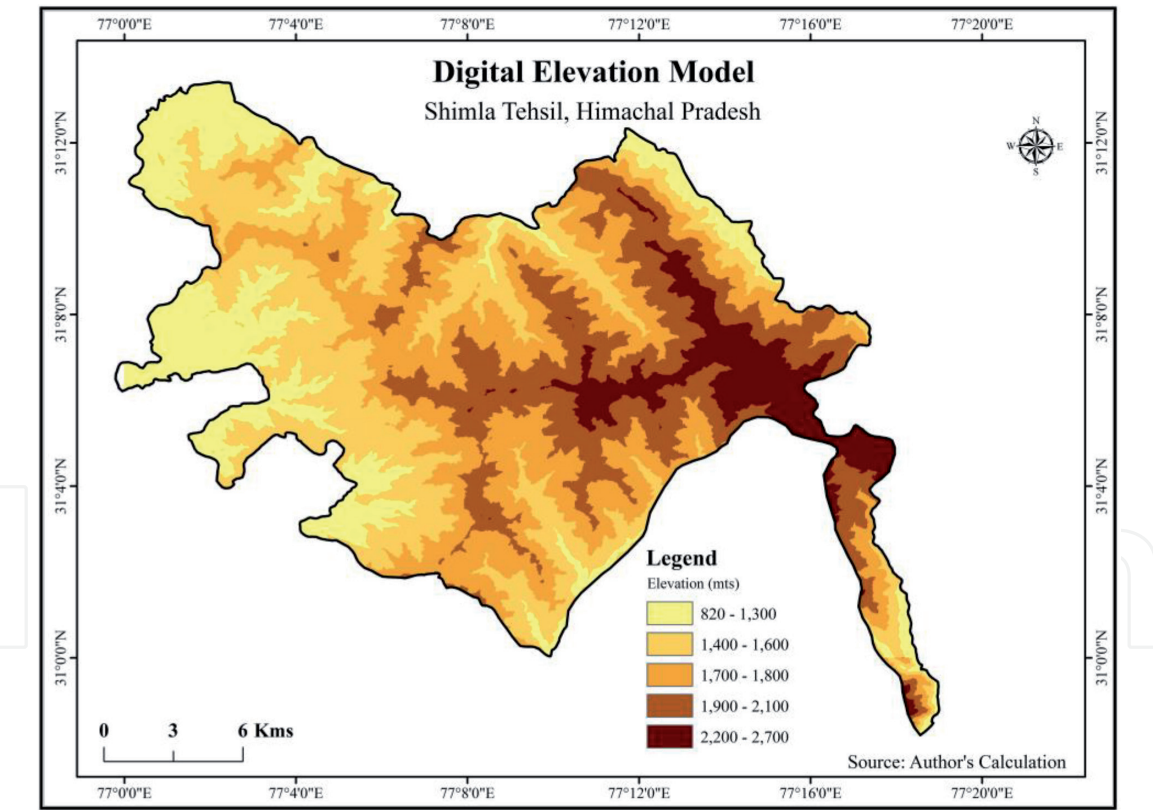


Figure 8.
Digital elevation model.

4.6 Slope

Slope aspect plays a crucial in highly dissected mountainous regions for land-slide movements. The steeper the angle of the slopes the higher the possibility of the mass movements. In the research SRTM DEM data has been used for deriving slope parameters (**Figure 9**). The slopes has been classified into five ranging from very gentle to very steep (**Table 9**) in nature.

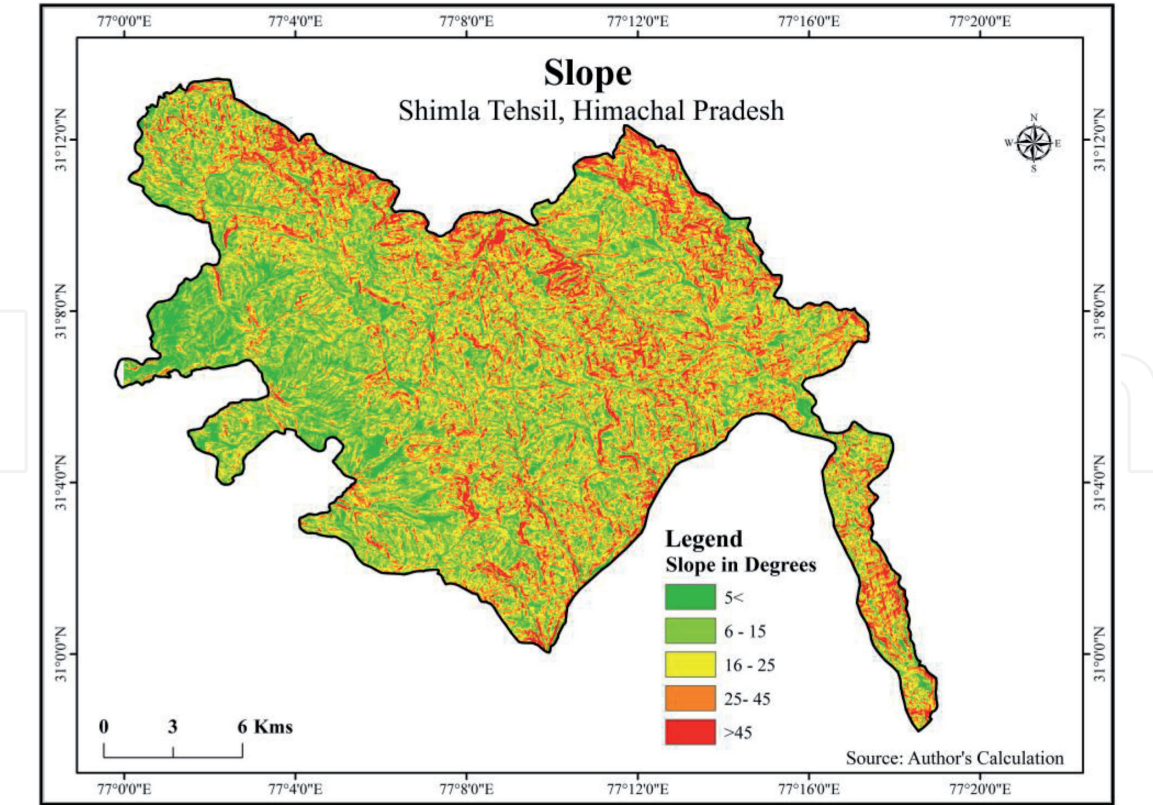


Figure 9.
Slope.

Sl. no	Slope (degrees)	Angle	Weighted overlay model	Fuzzy logic
1	< 5	Very gentle	1	0.1
2	6 to 15	Moderately gentle	2	0.3
3	16 to 25	Moderately steep	3	0.5
4	26 to 45	Very steep	4	0.8
5	45	Extremely steep	5	0.9

Table 9.
Slope with WOM and fuzzy overlay values.

4.7 Landslide risk mapping

4.7.1 Fuzzy logic model

For the current study two statistical models were employed “Fuzzy logic and Weighted Overlay model (WOM)” for landslide risk mapping. Factor including LULC, Geology, Geomorphology, Soil, slope (**Table 10**) were used as factoring parameters for risk mapping. Each causative factors were assigned a value of 0 to 1 based on it degree of association between causative factors. The factors are then processed in the GIS environment to derive fuzzy logic based landslide risk mapping.

Based on the results it can be concluded that most of the study area falls under very low risk with a total coverage of 67.34%. Low and Moderate area covers about 23% and 9.13% of the study area. Higher risk areas only account for about 0.46%. Higher percent of the study area is mostly covered by settlements. National highways, Metal roads, Slopes and Denser settlements are located along the Moderate and low risk areas (**Figure 10**).

Sl. no	Landslide risk class	Area (sq.km)	Percent coverage (%)
1	Very low	247.8	67.34%
2	Low	84.9	23.07%
3	Moderate	33.6	9.13%
4	High	1.7	0.46%
		368	100.00%

Table 10.
Fuzzy logic landslide risk categories.

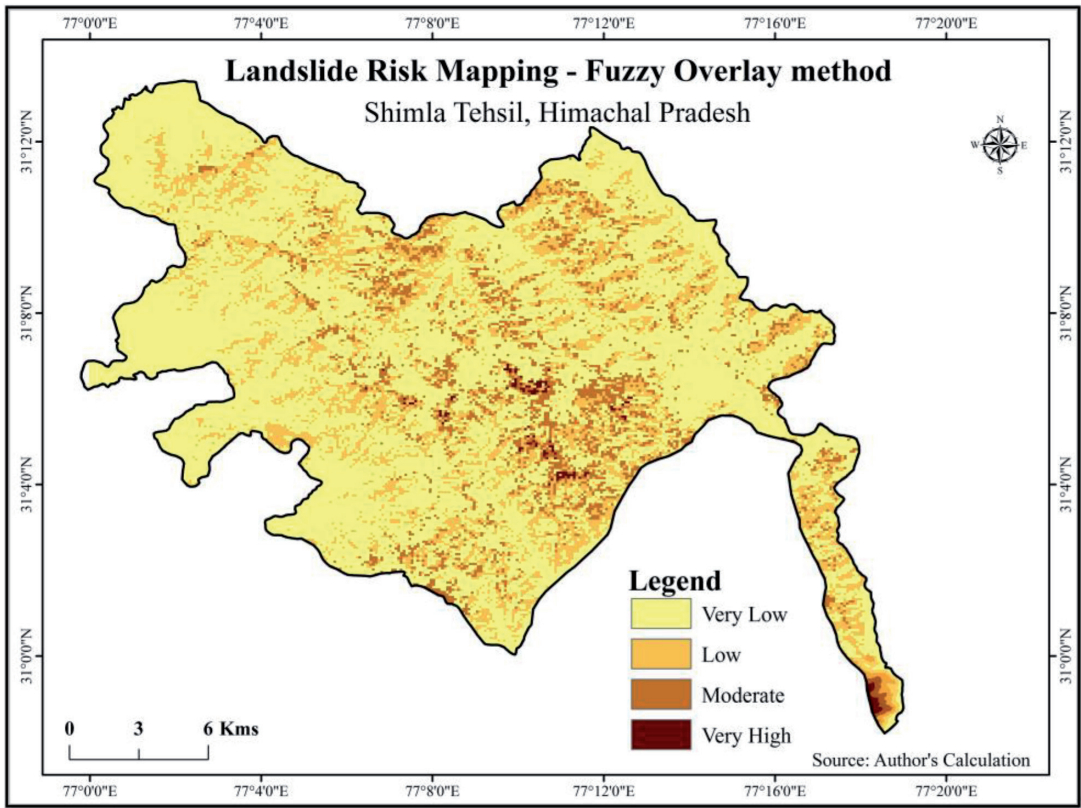


Figure 10.
Fuzzy logic based landslide risk assessment.

4.7.2 Weighted overlay model

Weighted Overlay Model (WOM) was used as a second statistical method for Landslide Risk mapping. Weighted overlay model uses the ranking method to classify each causative factors based on its degree of importance for landslide initiation and each sub factor is classified into sub categories at a scale of 1 to 5 where 1 indicating the very low risk and 5 indicates very high risk. Six causative factors namely LULC, Geology, Geomorphology, Soil (Table 11) etc. was used. The factors are then processed in the GIS environment to derive fuzzy logic based landslide risk mapping (Figure 11).

The results retrieved from the WOM model reveals 55% of the Tehsil comes under very low category. Low and Moderate category covers about 31.4% and 10.6% of the study area. High and Very High category cover a total of 1.9% together. Most of the low category indicators are located along the Forest and Agricultural areas that include plantations. Slope and settlements covers a major part of Moderate to Very High vulnerable areas.

Sl. no	Landslide risk class	Area (sq.km)	Percent coverage (%)
1	Very low	205.726	55.90%
2	Low	115.829	31.47%
3	Moderate	39.028	10.61%
4	High	6.547	1.78%
5	Very high	0.876	0.24%
		368	100.00%

Table 11.
Weighted overlay based landslide risk categories.

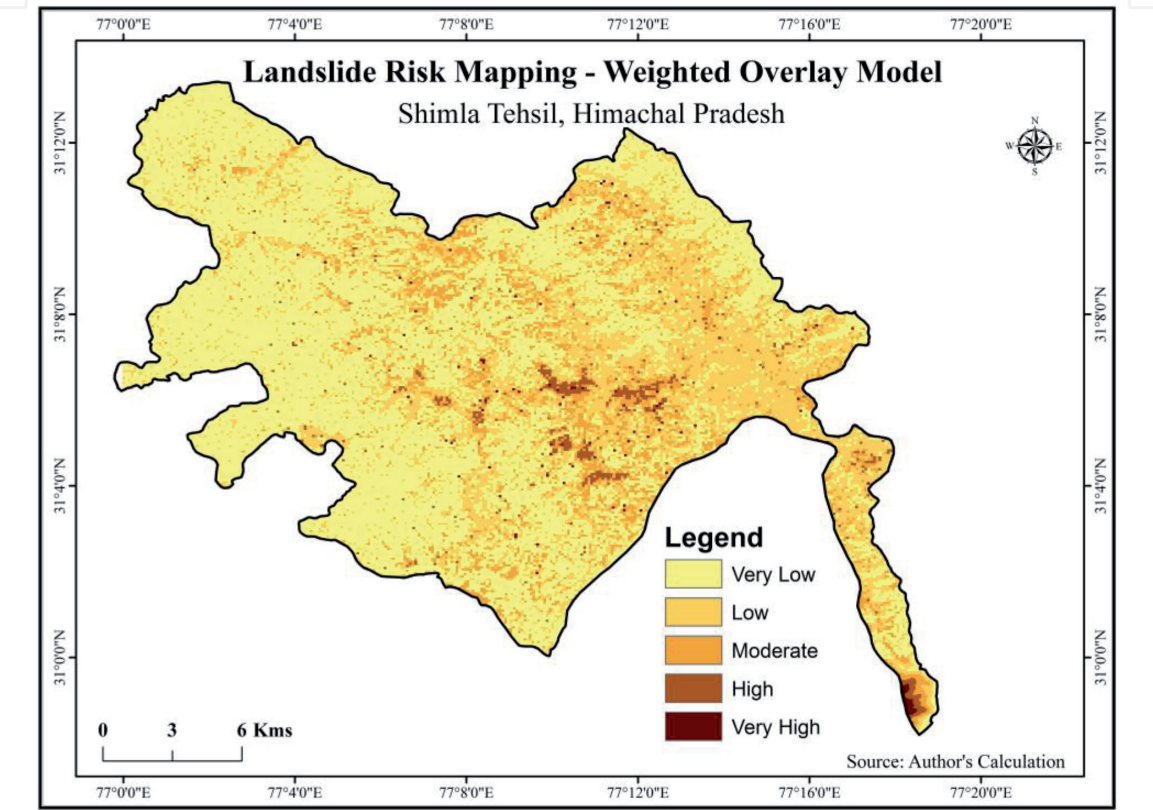


Figure 11.
Weighted overlay model based landslide risk assessment.

5. Conclusion

The research reveals the landslide risk mapping of the study area through Weighted Overlay and Fuzzy logic models. Fuzzy model classified a total of 9.1% and 0.4% of the area under moderate and high risk categories whereas Weighted Overlay model classified a total of 10% and 2% area under moderate and high to very high risk categories. Both the statistical model covers Forest and Agricultural areas under Very Low to Low Risk factor. Areas located along barren lands, Settlements and Roadways are classified under moderate to Very High risk areas for mass movements.

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