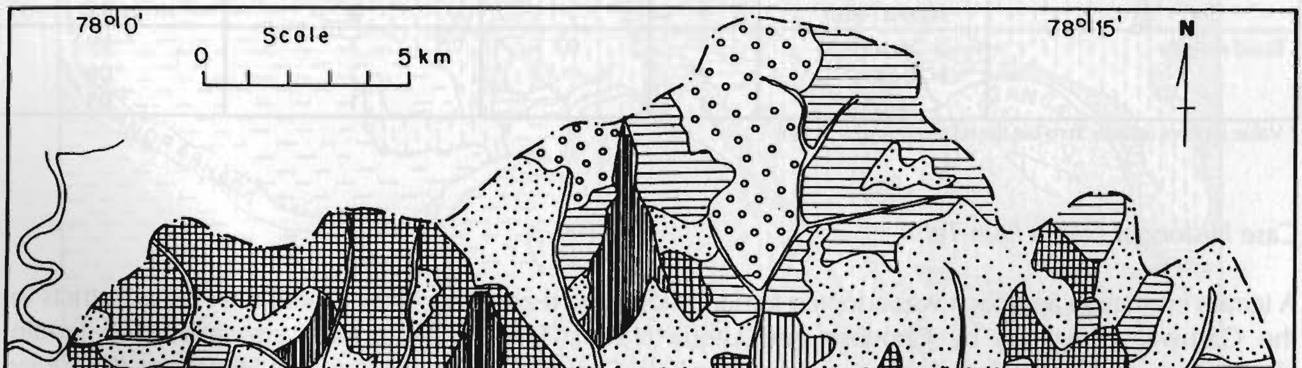
Landslide Hazard Zonation

A landslide hazard zonation map (LHZM) depicts the division of a land surface into zones of varying stability, based on the estimated significance of the causative factors in inducing instability (Anbalagan et al. 1993). The LHZ maps are useful for planning and implementing development schemes on mountainous terrain. They help planners to take into account the existing instabilities while implementing development schemes in the mountains. Several workers have carried out landslide hazard zonation mapping using their own different methodologies. Case histories of some of these are described here from the Aglar Catchment, Dehra Dun-Tehri, the Doon Valley, and the Sutlej Valley.

Case History of Aglar Catchment

Based on geological attributes, landslide hazard mapping was carried out in the Aglar Catchment, a tributary of the Yamuna River in the Garhwal Himalayas, by Pachauri and Pant (1992). Hazard zonation is assessed on the basis of the geological attributes of the catchment, lineament analysis and earthquake history, terrain classification and distribution of landslides, and relation of geological attributes to the landslides. Geological attributes include major structural elements, such as major folds and faults, and the lithology of geological formations. Terrain classification involves subdividing the terrain patterns into homogeneous units called facets, which are based on slope gradient. Landsat imagery and aerial photographs were used to map the distribution of existing landslides. In studying geological parameters in relation to landslides, the attributes used were geotechnical parameters (slope stability and slope kinematics), proximity to major faults, relative relief, relative altitude, lithology, land cover (use), degree of slope, distance from nearest ridge top, and road density. The landslide hazard zonation map was prepared on the basis of a classification system based on ranking (Fig. 8).

Figure 8: Landslide hazard zonation map (ref. above paragraph)



To quantify the zonation, a weighting and rating system was used, as described in Table 1 overleaf.

Table 1: Weighted Landslide Hazard Rating System in the Aglar Catchment (after Pachauri and Pant 1992)

Factor	Class	No.	Weighting	Class rating	Weighted rating
Geological factor	Dip slopes				
	Non-dip	1	11	2	22
	slopes	2		0	00*
Distance from active fault	0-2km	1	10	4	40
	2-4km	2		3	30
	4-6km	3		2	20
	6-8km	4		1	10
	> 8km	5		0	0*
Slope angle	> 40°	1	09	4	36
	30-40°	2		3	27
	20-30°	3		2	18
	10-20°	4		1	09
	< 10°	5		0	0*
Relative relief	> 800m	1	08	5	40
	600-800m	2		4	32
	400-600m	3		3	24
	200-400m	4		2	16
	0-200m	5		1	8
Geological formation	Main rock				
Nagthat Krol Blaini	quartzite	1	07	4	28
Chandpur Land cover	limestone	2		3	21
	boulder slate	3		2	14
	phyllite	4		1	7
	Sparse vegetation	1	06	3	18
	Cultivated land	2		2	12
	Forested land	3		1	06
Distance from ridge top	0-900m	1	06	3	15
	900-1800m	2		2	10
	1800-2700m	3		1	05
Road density	> 2km/km²	1	03	3	09
	1-2km/km²	2		2	06
	< 1km/km²	3		1	03

* Value is never actually zero but the relatively lowest in rank.

Case History of Dehra Dun-Tehri

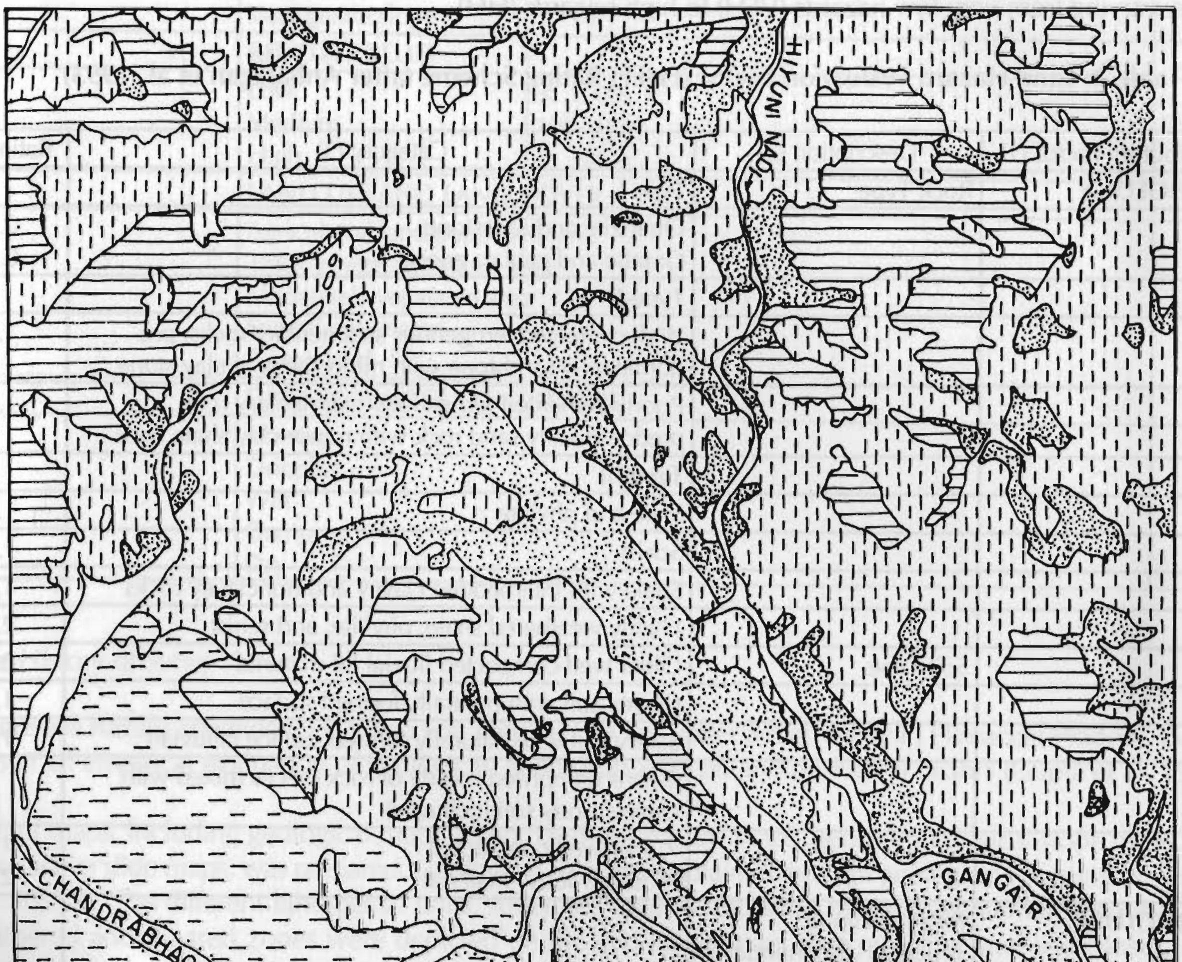
A terrain evaluation approach was adopted for landslide hazard zonation of the Dehra Dun-Tehri districts in the Garhwal Himalayas by Choubey and Litoria (1990). These authors have also attempted terrain classification and landslide hazard mapping in the Kalsi-Chakrata area in the Garhwal Himalayas (Choubey and Litoria 1990).

The terrain classification map (TCM) was prepared by using a topographic map on a scale of 1:50,000, showing various facet (slope) categories together with landslides, escarpments/cliffs, and ridges. The geological features of the area, showing lithological units and structural features, are superimposed on the TCM. Land-use mapping was carried out on the basis of aerial photographs and toposheets on a scale of 1:50,000. The various physiographic units, such as escarpments, slopes, river terraces, and land-use classes, such as forest, cultivated land, and barren area, are depicted on the physiographic land-use map (PLM). Various existing landslides and landslide-prone zones are also demarcated on the PLM. The landslide hazard zonation map of the Rishikesh-Shivpuri area was constructed by combining the TCM and PLM (Fig. 9). On this map, four landslide hazard-prone areas are demarcated, according to the degree of severity of the hazards, on the landslide hazard zonation map (LHZM).

Case History of Doon Valley

Landslide hazard zonation (LHZ) mapping of a part of the Doon Valley in the Garhwal Himalayas was carried out by Anbalagan and his co-workers (1993) based on a quantitative approach called the landslide hazard evaluation factor (LHEF).

Figure 9: Landslide Hazard Zonation map of Rishikesh-Shivpuri area in the Garhwal Himalayas (Choubey and Litoria 1990)



Landslide hazard mapping of the Maldeota-Sahastardhara area of Doon Valley involved, in the first stage of preparation, a series of maps on slope, facet, lithology, structural features, slope morphometry, relative relief, land use, land cover, and hydrology. The maximum LHEF ratings for different categories are determined in these maps on the basis of their estimated significance in causing instability. The rating value was given on the basis of the land hazard evaluation factor described in Table 2. The LHZ map shows four categories of hazards, varying from very low hazards (VLH) to high hazards (HH).

Table 2: Land Hazard Evaluation Factor (LHEF) Rating Scheme (after Anbalagan et al. 1993)

Contributory Factor (1)	Description (2)		Category (3)	Rating (4)
A. LITHOLOGY	Rock Type		**Type-I**	
			Quartzite and limestone Granite and gabbro gneiss	0.2 0.3
			Type-II	
			Well-cemented terrigenous sedimentary rocks, predominantly sandstone with minor beds of clay stone	1.0
			Poorly-cemented terrigenous sedimentary rock, predominantly sand rock with minor clay shale beds	1.3
			Type-III	
			Slate and phyllite	1.2
			Schist	1.3
			Shale with interbedded clayey and nonclayey rocks	1.8
			Highly weathered shale, phyllite, and schist	2.0
	Soil Type		Older well-compacted fluvial fill material	0.8
			Clayey soil with naturally formed surface	1.0
			Sandy soil with naturally formed surface (alluvial)	1.4
			Debris comprised mostly of rock pieces mixed with clayey/sandy soil (colluvial)	
			-Older well compacted -Younger loose material	1.2 2.0
B. STRUCTURE	Relationship of structural discontinuity with slope			
	i) Relationship of parallelism between the slope and the discontinuity* Planar (s-s) Wedge (i-s)	I II III IV V	> 30° 21° -30° 11° - 20° 6° - 10° < 5°	0.20 0.25 0.30 0.40 0.50
	ii) Relationship of dip of discontinuity* and inclination of slope Planar (B_j-B_s) Wedge (B_i-B_s)	I II III IV V	10° 0° - 10° 0° 0° -(-10°) (-10°)	0.3 0.5 0.7 0.8 1.0
	iii) Dip of discontinuity* Planar-B_j Wedge-B_i	I II III IV V	<15° 16° - 25° 26° - 35° 36° - 45° 45°	0.20 0.25 0.30 0.40 0.50
	Depth of Soil cover		5m 6-10m 11-15 16-20m 20m	0.64 0.85 1.30 2.0 1.20

	SLOPE MORPHOMETRY		
	Escarpment/cliff Steep slope Moderately steep slope Gentle slope Very gentle slope	> 45° 36°-45° 26°-35° 16°-15° < 15°	2.0 1.7 1.2 0.8 0.5
	RELATIVE RELIEF		
	Low Medium High	< 100m 101-300m > 300m	0.3 0.6 1.0
	LAND USE AND LAND COVER		
	Agricultural land/populated land Thickly-vegetated forest area Moderately-vegetated area Sparsely-vegetated Barren land		0.65 0.80 1.2 1.5 2.0
	GROUNDWATER CONDITIONS		
	Flowing Dripping Wet Damp Dry		1.0 0.8 0.5 0.2 0.0

Case History of Sutlej Valley

A landslide hazard zonation (LHZ) map was prepared for the upper Sutlej Valley in Himachal Pradesh, on the basis of an empirical evaluation of geological, geomorphological, and biological factors (Gupta et al. 1993).

A set of maps, including geological maps, major land-use pattern maps, geomorphological slope maps, and major active slide maps, was prepared. Geological data were obtained through geological mapping on a scale of 1:50,000. The different lithological units, structural features, old slide material, quaternary deposits, and weathered and sheared zones were depicted on the geological map. Five principal land-use classes, from extreme barren land to dense protected forest, were incorporated in the land-use map. The major active landslides were studied and classified according to their type and rate of movement (Fig. 10). The area was divided into various smaller homogeneous units called facets, which are based on the direction of the slopes. A facet represents a part of the area having more or less similar slope characteristics and slope aspects. A facet map is used as a base map for landslide hazard mapping of the area. A landslide hazard rating (LHR) system has been adopted to prepare the final LHZ map. In this system, numerical values are assigned to each facet, based on the relationship between occurrence of landslides and various factors such as lithology, weathering, relationship of S-planes with one another as well as with slope, hydrological condition of the slope, slope angle, land-use pattern, and anthropogenic activities. The LHR values are given in Table 3. These values are determined on the basis of the weightage of their relationship with landslides.

After assigning the LHR, the Landslide Hazard Index (LHI), indicating the probability of instability of unit facets, has been calculated by multiplying the rating of individual causative factors incorporated in that particular facet. The whole area of the upper Sutlej Valley under investigation has been divided into five different hazard zones characterised by very low, moderately low, high, and very high landslide hazards by drawing isohazard lines with LHI values of 50, 200, 400, and 600.

Methodology for Landslide Hazard Zonation

Under a coordinated programme for the study of landslides, the Department of Science and Technology, Government of India, constituted a group to prepare a standard methodology for landslide hazard zonation. This group has prepared a report (Department of Science and Technology 1994), and the methodology adopted for this report is described here.

Figure 10: Landslide Hazard Zonation map along Sutlej Valley, Kinnaur District, Himachal Pradesh (Gupta et al. 1993)

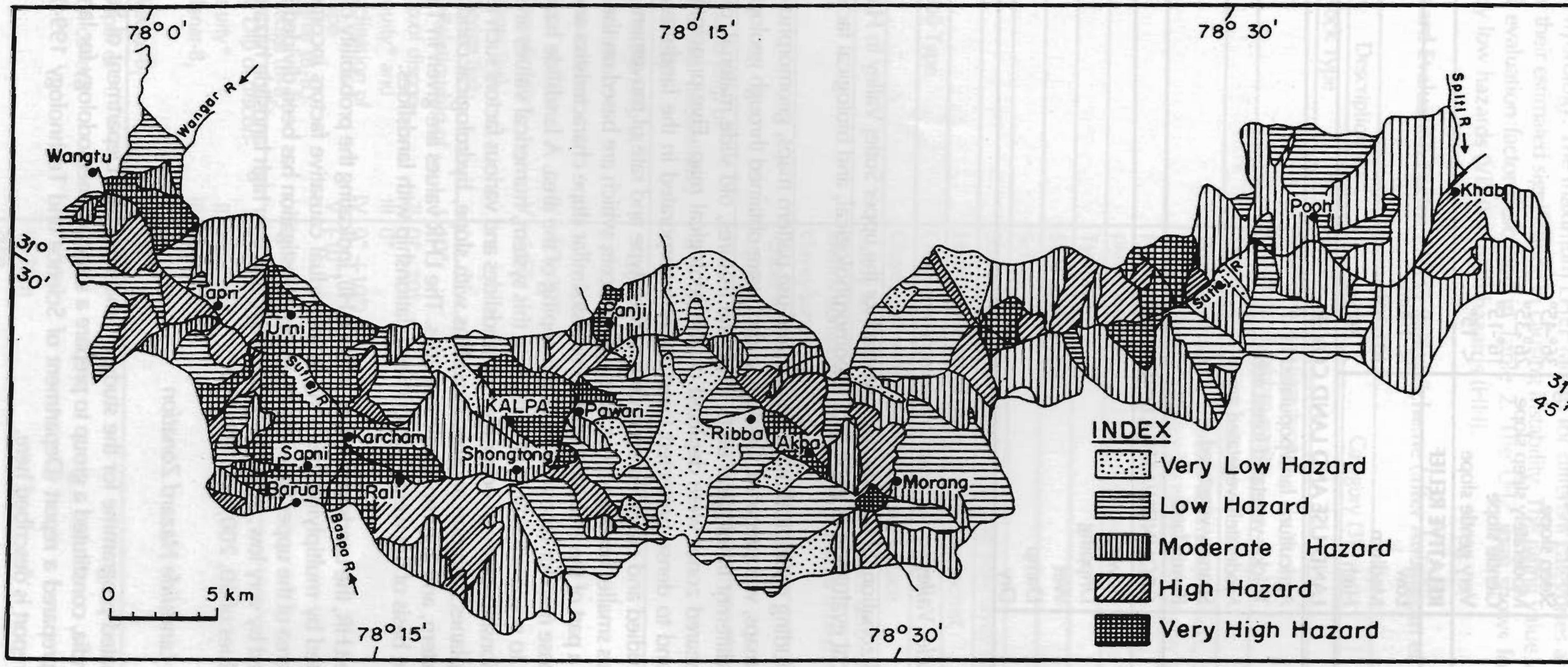


Table 3: Landslide Hazard Rating System in the Upper Sutlej Valley of H.P. (after Gupta et al. 1993)

Factor	Class	Weighted Rating
Lithology	Augen gneiss, porphyritic gneiss, granitic gneiss, hard quartzite, migmatites	1
	sandstone, granite	2
	slate, phyllite, mica schist	3
	slate, phyllite, mica schist interbedded with clay	4
	clay, soil, loose material	5
Weathering	Fresh rock	1
	Slightly weathered; absence of any weathered material (Rock fabric is not altered)	2
	Moderately weathered; presence of leached material along joint planes (Rock fabric is altered on the surface only)	3
	Highly weathered; presence of leached material on the surface (rock fabric is altered up to a depth of a few cm)	4
Relationship of planes with one another as well as with the slope	(a) When the intersection of S planes plunges in the direction of the slope plunge of line of intersection	
	0-20	2
	20-40	3
	40-60	4
	> 60	5
	(b) When the intersection of S planes plunges away from slope plunge of line of intersection	
	> 60	2
	40-60	3
	20-40	4
	> 20	5
Hydrological condition		
	Dry slope	1
	Presence of streams, canals, springs on the lower slope	2
	Toe cutting of lower slope	3
	Presence of streams, canals, springs on the middle slope	4
	Presence of streams, canals, springs on the upper slope	5

Preparation of Thematic Maps

The various factors that contribute to instability are lithology, structure, slope, relative relief, hydrology, land use, and land cover pattern. Different thematic maps can be prepared on a scale of 1:50,000 using aerial photographs, satellite imagery, and field investigation.

Lithological Map

A geological map should show the different lithologies in the area. Lithology is an important factor and includes composition, texture, degree of weathering, and other attributes such as the consolidated or unconsolidated nature of sediments that influence the physical behaviour of rocks. A lithological map should show the geological setting, including the nature and types of rocks present.

Structural Map

Geological structures include major faults, folds, bedding, foliations/schistosity, joints, shear zones, and non-conformity. These structures can be plotted on the lithological map and, in my opinion, there is no need to prepare a separate structural map. The degree of fracturing, shearing, attitude of bedding or jointing in relation to slope, and nearness to active fault zones are also important factors in determining slope stability. Information on structures can be generated through field work, by incorporating already existing information, and also from aerial photographs and satellite imagery.

The seismic status of the region, including past earthquakes, locations of their epicentres, and their intensity zones in the map, can have an added significance for evaluating landslide hazards.

Slope Map

A slope map divides the terrain into small facets of varying slope angles. All facets are to be marked with the slope direction. It is proposed that the slopes be classified into six categories, viz., 15°, 16-25°, 26-35°, 36-45°, 46-60°, and above 60°.

Relative Relief Map

The difference between the highest and the lowest values of contours (altitude) defines the relative relief. A high value for relative relief indicates faster uplift, presence of active faults, and relatively strong competency contrasts of lithologies in the area. Lower reliefs owe their origin to the maturing of the topography and slower uplift. A relief map can be prepared with the help of toposheets. It classifies the terrain into various zones representing the range of relief.

Hydrological Map

First a drainage map of the area is prepared with the help of toposheets. The various basins are demarcated on the drainage map, and the morphometric parameters, particularly the drainage density values of each basin, are determined. Hydro-geological data, such as springs, seepage zones, ponds, and reservoirs, are incorporated in the map. Rainfall data and groundwater levels are also useful additional inputs for the hydrogeological map. The surface indication of groundwater, such as damp, wet, dripping, and flowing conditions, are used for rating purposes.

Land-use and Land-cover Map

The type of land cover and land use affects the stability of the slopes on mountainous terrain. Barren and sparsely-vegetated areas show faster erosion and greater instability than reserve or protected forests. Forests and thick vegetation cover generally reduce the effects of erosion and weathering. A well-spread root system increases the shearing resistance of slope material. Agricultural land may be considered stable due to repeated water charging for cultivation purposes. The rating is given on the basis of intensity of vegetation cover.

A land-use and land-cover map of an area of terrain can be prepared using aerial photographs, satellite imagery, and field investigation. Five categories are classified on the basis of different land-use patterns, e.g., dense forests, moderate forests, sparse vegetation, barren land, agricultural land, and populated areas.

Also, a separate landslide inventory map can be prepared that will depict both the active and old landslides. Since this map can be prepared using aerial photographs, satellite imagery, and field investigation, it is more appropriate that the inventory of landslides is also incorporated in the land-use and land-cover map.

Landslide Hazard Rating (LHR)

An LHR is a numerical scheme based on the major causative factors of slope instability such as geology, slope and relative relief, land use and land cover, and hydrological conditions. The LHR rating for different thematic maps is assigned on the basis of the estimated risks of their causing instability that leads to landslides.

The rating (LHR) number is assigned on a scale of one to 20, on the basis of the evaluation of the nature of features for each thematic parameter (map) as described in Table 4.

Table 4: Assigned Rating of Various Thematic Maps (after DST Report 1993).

Thematic Maps	Features to be studied	Rating (LHR)
Lithology	* Rock types	20
	* Extent of weathering	
	* Soil types	
	* Thickness of soil cover	
Structure	* Major thrust and fault (nearness to a tectonically-active zone)	20
	* Geological discontinuities, including bedding, joints, foliations and fractures, etc and their relationship with slope/aspect	
	* Effect of seismicity	
Slope and Relative Relief	* Slope angle	20
	* Local relief	
Hydrology	* Surface drainage (drainage density)	20
	* Seepage zones	
	* Spring points	
	* Ponds, lakes, water bodies, etc	
	* Toe erosion	
	* Rainfall/cloudburst	
	* Groundwater level	
Land use/Land cover	* Forest cover	20
	* Agricultural land	
	* Barren slope	
	* Human habitation	
Total		100

Data Analysis

There can be two approaches to the analysis of data required for preparing landslide hazard zonation maps. One approach is the superimposition method which obtains the total landslide hazard rating by overlaying all the factor maps one by one. All the thematic maps are successively overlain and every time the total hazard rating value for each facet is added (a facet is a part of the hill slope which has more or less similar slope characteristics, showing consistent slope direction and inclination). Finally, a map showing various facets of different landslide hazard rating values is obtained. Based on this, the categorisation of the area is carried out in terms of instability.

Another approach to obtaining the total landslide hazard value of the area is to divide each thematic map into square grids of four sq.cm. each and mark all the grids with numbers, which should be the same in all maps. For each grid in each map, the LHR of different factors is marked. Finally, the total landslide hazard rating (LHR) of different grids is obtained by adding the LHR values collected from different maps for each grid. The minimum and maximum values of the LHR will give the range, which may be categorised in terms of instability. Wherever it is not feasible to collect data to determine LHR in four sq.cm.grids, it is better to further divide the area into four equal grids.

Investigators may select any of the two above-mentioned approaches to analyse the data needed for preparing final landslide hazard zonation maps. However, the facet concept has an advantage in that it indicates the smallest mapping unit which has a definite boundary.

Landslide Hazard Zonation

To divide the area into different hazard-prone zones, the range of TLHR obtained is categorised into five divisions in terms of instability, namely, very high, high, moderate, low, and very low, for the purpose of preparing landslide hazard zonation maps. Thus, a final landslide hazard zonation map of the terrain is prepared which will broadly show different areas or zones of the hill slopes, based on the nature of their instability. This map will be useful for better land-use planning of any development activity.

The methodology described above is simple and can easily be adopted by the investigators engaged in hazard zonation mapping. The final hazard zonation map should reflect the intensity of hazard potential of the terrain. The investigator may modify the methodology if necessary, depending upon the conditions of the terrain and geo-environmental factors. It is recommended that a landslide hazard rating system be used for preparing pre-feasibility reports of development projects in hilly areas.