CHAPTER 8
LANDSLIDE HAZARD ZONATION

8.1 Definition

Rapid movements of sliding rocks, separated from the underlying stationary part of the slope by a definite plane of separation, are designated as Landslides in the stricter sense. Sliding phenomenon also include slow, long term deformations of slopes, which usually occur not along one distinct sliding surface, but within a thick zone consisting from a system of partial sliding planes. These deformations possess the character of a viscous movement and are termed as “creep” As long as landslides occur in remote, unpopulated regions, they are treated as just another denudation process sculpting the landscape, but when occur in populated regions, they become subjects of serious study.

Because of the great damage they cause to forest growths, farmland, communications, constructions and buildings, they may be a serious economic problem.

*Factors producing slide movements:* To recognize the reasons for the susceptibility of an area to sliding, and the factors
which trigger the movement of the rock mass, is of extreme importance, because only precise and correct diagnosis can serve as a basis for effective remedial measures. The variety of landslides reflects the diversity of factors, which are responsible for their origin.

They are briefly characterized as:

- The change of slope gradient
- The excess load of embankments etc
- Shocks and vibrations
- Changes in water content
- Weathering of rocks
- Changes in the vegetation cover of slopes

The last factor is most important in the area under study. The roots of trees maintain the stability by mechanical effects and contribute to the drying of slopes by absorbing part of the ground water. The deforestation of slopes impairs the water regime in the surface layers. Most of the landslides occur due to exhaustive deforestation for the development of urbanization and plantation. In these areas rainwater directly penetrates into the soil and cause landslides.

**8.2 Case of Garhwal**
Garhwal has a complex geomorphology, lithology, structure and stratigraphic succession. The Geology of this region resembles that of Himachal Pradesh in the west and Kumaun in the east. From south to north, Garhwal may be divided into the following geological zones:

1. Shiwalik or outer Himalayas
2. Lower or lesser Himalayas
3. Higher or Main or Central Himalayas

Our study area falls under the second category of lower or lesser Himalayas. The lower or lesser Himalayas extends from the main boundary thrust in the south to the main central thrust in the north. It has a complex lithology and structure. Auden, 1934, gave a detailed account of the geology of the area.

8.3 Classification of Landslides

Based on the mass movement, landslides are divided into four major groups.

- Slow Flowage: Rock Creep and Soil Creep
- Rapid Flowage: Earth movements, Mudflows, Debris Avalanche
- Sliding: Slumps, Rock Slides, Rock falls, and Landslips
8.4 Causes of Landslides

Internal factors: The steeping of the slope, water content of the stratum and mineralogical composition and structural features, which are tending to reduce the shearing strength of the rocks.

External factors: A slight vibration or jerk to the mass would greatly add up against the frictional resistance and the mass would become unstable. The heavy traffic on hill roads is of great contributing factors towards causing the imbalance of the masses.

The landslide investigation and hazard zonation mapping study involves preparation of number of thematic databases such as slope, soil, rainfall, geomorphology, geology, and landuse of the area. As the main purpose of the study is to prepare landslide hazard zonation map and collection of these information being carried out for several decades through the traditional, conventional-ground based surveying and mapping methods, which had taken a lot of time, more man power and cost. But nowadays the emerging satellite based remote-sensing techniques has become more efficient tool for obtaining such information with less cost and time.
8.5 GIS analysis

In order to generate the landslide prone areas map for Huinyal watershed area, a model has been developed in a GIS environment. Data in the form of thematic maps such as slope, soil and landuse were input in to GIS. The detailed method of assigning weights has been discussed below. Finally the landslide prone areas map has been prepared.

*Slope*: Slope is a very important parameter in any landslide hazard zonation mapping. In the study area slope varies from 0 to greater than 55 deg. The entire slope contour map was divided in to six categories (Percentage wise) as 0-5%, 5-10%, 10-20%, 20-40%, 40-60% and >60%. Thus, the slope contour map has got six categories and suitable weights are assigned.

*Soil*: The occurrence of landslide is mainly due to the presence of huge thickness of loose soils when mixed with water, it triggers the landslide. In the study area, based on the soils erodable nature, it is divided in to four categories as follows:

- Very highly erodable
- Highly erodable
• Moderately erodable
• Poorly erodable.

Thus, the Soil map has got four categories and suitable weights are assigned.

Geology

In the Tehri district, the lithology is divided into four different types of formations:

1. Lower Shiwalik
2. Blaini
3. Nagthat
4. Upper Shiwalik

Landuse

Landuse / land cover map of an area under investigation has got direct or indirect influence in triggering the landslides. Different types of landuse /land cover features are identified in the study area are such as forest, agriculture, road, settlement and tree farmland. Suitable weights are assigned. (Figure)

8.6 Landslide Hazard Zonation Mapping
Most hazards occur when natural processes have crossed some kind of threshold and have changed into a catastrophic event. Hazard mapping may be defined as, the identification of those sites where there is likelihood of a hazardous event rather than hazard effected sites. Under the present study, natural hazard zonation is undertaken with reference to probability of an area to be affected by the mass movement processes.

Moreover, hazard is a process and it is very difficult to map a process, that the process which has not yet occurred. But the results of hazardous zones can be mapped or prediction of hazard effects can be indicated.

Using union command, Landslide hazard zonation map was prepared by integrating the effect of various triggering factors. The zonation map divides the study area into six zones of landslide vulnerability viz., very high, high, moderately high, low to moderate, low and very low. Thus, the landslide prone areas having 6 zones were obtained
Slope Stability Model

Slope stability model used in this study area is based on an infinite slope form of the Mohr-Coulomb failure law in which the downslope component of the weight of the soil just at failure, τ, is equal to the strength of resistance caused by cohesion (soil cohesion and/or root strength), C, and by frictional resistance due to the effective normal stress on the failure plane. This phenomenon is represented in the form of equation as:

$$\tau = C + (\sigma - u) \tan \phi \quad \text{......... (1)}$$

where $\sigma$ is the normal stress, $u$ is the pore pressure opposing the normal load and $\tan \phi$ is the angle of internal friction of the soil mass at the failure plane.

The equation (1) is further simplified by setting the value of cohesion to zero and the angle of friction to a high, but acceptable value (i.e. $35^0$). Which compensates for the absence of root strength and brings out the maximum possible instability across the land (Burroughs and Thomas, 1977; Gray and Megahan, 1981; Sidle, 1992).

Under the assumption that the failure plane, water table, and
ground surface are parallel the weight of the soil for a square unit area of soil plane are written in terms of soil depth ‘z’, water level above the failure plane ‘h’, are the soil and water bulk density ‘ρs’ and ‘ρw’, respectively, and gravitational acceleration ‘g’

\[
W = \text{mass of soil per unit surface area} \times \text{gravity}
\]

\[
= (\text{density of soil} \times \text{depth of soil}) \times g
\]

\[
= (\rho_s \times z \cos\theta) \times g
\]

Similarly, downslope component of the weight of the soil

\[
\tau = W \sin \theta
\]

\[
= \rho_s z \cos\theta \times g \sin\theta
\]

\[
= \rho_s g z \cos\theta \sin\theta
\]

Normal Stress on the soil

\[
\sigma = W \cos\theta
\]

\[
= \rho_s g z \cos\theta \times \cos\theta
\]

\[
= \rho_s z \cos^2\theta
\]

Pore pressure opposing the normal component of the weight

\[
u = (\rho_w \times h \cos\theta) \times g \cos\theta
\]

\[
= \rho_w g h \cos^2\theta
\]
By putting $C = 0$ and substituting the values of $\tau$, $\sigma$ and $u$ from above, equation (1) can be written as

$$\rho_s g z \cos \theta \sin \theta = (\rho_s g z \cos^2 \theta - \rho_w g h \cos^2 \theta) \tan \phi$$

........... (2)

where $z$ is soil depth, $h$ is water level above the failure plane, $\rho_s$ and $\rho_w$ are the soil and water bulk density respectively, and $g$ is gravitational acceleration.

Rearranging equation (2), and solving for $h/z$ (portion of the soil column that is saturated at instability), we get

$$\frac{h}{z} = \frac{\rho_s}{\rho_w} \left(1 - \frac{\tan \theta}{\tan \phi}\right)$$

........... (3)

From equation (3) it can be concluded that $h/z$ could vary from zero (when the slope is as steep as the friction angle) to $\rho_s/\rho_w$ when the slope is flat ($\tan \theta = 0$). On the basis of the assumption made earlier that the failure plane, water table, and ground surface are parallel, $h/z$ can only be less than or equal to 1 (Montgomery et al., 1998).

Therefore, four fields emerge out of equation 3.

1. Unconditionally Stable
Since, Any area having \( \frac{h}{z} > 1 \) is unconditionally stable i.e. no storm can cause it to fail. Such environments can support saturated overland flow without failing (Heimsath, 1997).

\[
\Rightarrow \frac{\rho_s}{\rho_w} \left( 1 - \frac{\tan \theta}{\tan \phi} \right) > 1
\]

\[
\Rightarrow \tan \theta < \tan \phi \left( 1 - \frac{\rho_w}{\rho_s} \right)
\]

2. Unconditionally Unstable

Any slope equal to or greater than the friction angle i.e. \( \tan \theta \geq \tan \phi \) will cause the right hand side of equation (3) to go to zero. Hence the site is unstable even if the site is dry (\( h/z = 0 \)). This is called as “unconditionally unstable” and it is found that it commonly corresponds to sites of bedrock outcrop.

3. Stable State

Stable State corresponds to the condition in which \( h/z \) is greater than or equal to that needed to cause instability

i.e. \( \frac{h}{z} \geq \frac{\rho_s}{\rho_w} \left( 1 - \frac{\tan \theta}{\tan \phi} \right) \)

4. Unstable State
Unstable State corresponding to the case in which \( \frac{h}{z} \) is less than that needed to cause instability

\[
\frac{h}{z} < \frac{\rho_s}{\rho_w} \left( 1 - \frac{\tan \theta}{\tan \phi} \right)
\]

To model the hydrologic controls on \( \frac{h}{z} \), a steady state shallow subsurface flow based on the work by O'Loughlin (1986) and which has similarities to TOPOG (Beven and Kirkby, 1979) has been used.