Mitigation of Landslide Hazard

Landslide Hazard Mapping

Varnes (1984) has defined natural hazards as the probability of occurrence, within a specific period of time and within a given area, of a potentially damaging phenomenon. Varnes also pointed out that the French word 'risque' could be regarded as equivalent to the English word 'hazard'. 'Hazard' and 'risk' are used interchangeably in most reports on geological processes, but they must be clearly differentiated. Landslide risks signify the expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to a landslide (Brabb 1984).

Hazard evaluation may also be classified as a relative hazard (based on mapping alone or in combination with calculations and used to rate the slide susceptibility), absolute hazard (e.g., factor of safety based on calculations), empirical hazard (based on existing knowledge and often used when it is very difficult to make a relevant calculation), and monitored hazard (connected to internal processes of the slope, such as ongoing movements, or to external factors, such as rainfall or seismic activities) (Hartlen and Viberg 1988). Relative hazard is assessed by assigning (ratings?) to different factors contributing to a hazard.

Different approaches to landslide hazard assessment have been developed. There are three main groups of techniques (Jones 1984).

1. Geotechnical investigations, involving detailed analyses of surface and subsurface conditions and ground materials
2. Direct mapping, involving the analysis of landforms and identification of existing landslides so that areas of past instability can be identified, thereby facilitating extrapolation from areas of recognised past instability to similar situations which may suffer slope failures in the future
3. Indirect mapping, which requires the collection of data on the causes and mechanisms of landsliding, so that slope stability can be assessed through the application of known landslide-inducing parameters.

To these may be added the fourth approach of Land System Mapping, which is intermediate between direct and indirect mapping

Among the several methods available for landslide hazard mapping, the method proposed by Deoja et al. (1991) is summarised below. This method has been applied in several landslide hazard mapping projects in Nepal, especially along road corridors.

This landslide hazard mapping method requires the preparation of maps which deal with engineering geological concerns such as slope and aspect as well as hydrogeological features. The landslide hazard map is finally prepared by superimposing all of the above maps and other relevant data. It can show not only the hazard level (i.e., low, medium, high, and very high) but also the main type of failure, extent, and direction of movement in case of failure.

The **engineering geological** map is prepared in the field and it depicts rock and soil types, bedding/foliation and joint characteristics (stereographic projections), major faults, folds, and other important geomorphic features related to landslides. On the same map active, ancient, and dormant landslides are also shown (Fig. 25).

The **slope map** shows the natural slope angles at appropriate intervals. It is prepared by using existing topographic maps, and appropriate corrections are made in the field.

The **aspect map** divides the natural slope into more or less uniform faces with consistent sloping directions. Various rock and soil structural boundaries can also be shown on it.

The **hydrogeological map** includes all the surface and groundwater conditions relevant to landslides.

Broadly speaking, hazard assessment is mainly based on the study of the state of nature (rock, soil, geomorphology, and so on), danger (old, recent, dormant landslides, etc), and types of landslide trigger (cloudburst, earthquakes, GLOF, landslide-dam failures, etc). For the production of the final hazard map, ratings are given to the state of nature, average annual rainfall, danger, and triggers. The maximum and minimum values of the total ratings will be between 1.0 (highest hazard) and 0.0 (no hazard). In this method, soil slope hazard maps and rock slope hazard maps are prepared separately. The hazards are categorised as low, medium, and high depending upon the total value of ratings.

Computer-assisted landslide hazard mapping has been used increasingly in recent years (Brabb 1984; Wagner et al. 1988 and 1990). Wagner et al. (1988, 1990) developed the computer programme SHIVA, based on studies in Nepal, to make soil and rock hazard maps. The method takes into account the slope angle, lithology, rock structure, soil type, soil depth, hydrology, hydrogeology, and tectonics. The maps are digitised and ratings are given as described above. The programme superimposes different maps and data and produces the hazard maps. Hazard maps of a few areas in Nepal were prepared using this (SHIVA) software.

Landslide Hazard Mapping in Nepal

Landslide susceptibility maps show the areas likely to experience landslides in the future by correlating some of the principal factors that contribute to landsliding (Brabb 1984). Landslide hazard maps, on the other hand, show the probability of occurrence of the danger (e.g., landslide, gully erosion) in that area (Einstein 1988). The following are a few examples of landslide susceptibility and hazard mapping in Nepal

Hazard Mapping in the Ankhu Khola Basin, Central Nepal

Thouret (1981) studied the slope evolution in the Ankhu *Khola* area and prepared a map on a scale of 1:7500 depicting slope attributes, various types of mass movement, structural and erosional landforms, glacial landforms and deposits, and dynamic processes on various landforms. He prepared hazard maps of the lower and upper reaches of the Ankhu *Khola*. He also studied the mechanism of failure of landslides at Jharlang, Khading, Chalis, Hindung Pul, and other places in the basin.

Landslide Hazard Mapping of Roads in Rapti Zone

A detailed study of roads in Rapti Zone in Midwestern Nepal was carried out by DOR/USAID (1986). The alignments studied were the roads from Tulsipur to Salyan, Ghorahi to Pyuthan, and Pyuthan to Libang. During the study, the road alignments were divided into zones with low, medium, high, and very high rock or soil failure and gully erosion hazards. For this purpose, the existing geological, engineering geology, geomorphological, and surface and groundwater conditions were analysed in detail and the slope was divided into more or less uniform zones of similar hazard types and levels (DOR/USAID 1986).

Hazard Mapping along the Baitadi-Darchula Road

The Baitadi-Darchula Road, which is under construction, lies in Far-western Nepal. The alignment was studied in the prefeasibility, feasibility, and detailed stages. During the study, hazard maps were prepared along the road corridor for the feasibility and detailed stages. The hazard maps of the feasibility stages showed the general hazard level along the road alignment, whereas the hazard maps of the detailed stage depicted the hazard type and its level (Dhital et al. 1991). The morphostructural map and the hazard map of part of the road corridor are shown in Figures. 26 and 27 respectively.

Hazard Mapping in the Charnawati Valley

Charnawati Valley is in eastern Nepal (45.8km from Lamosangu). High-intensity rainfall in 1987 caused severe damage to the Lamosangu-Jiri road and triggered several landslides on the surrounding slopes. Several gullies were also reactivated.

Figure 26: Feasibility stage morphostructural map of a part of the Baitadi-Darchula Road alignment (Dhital et al. 1991)

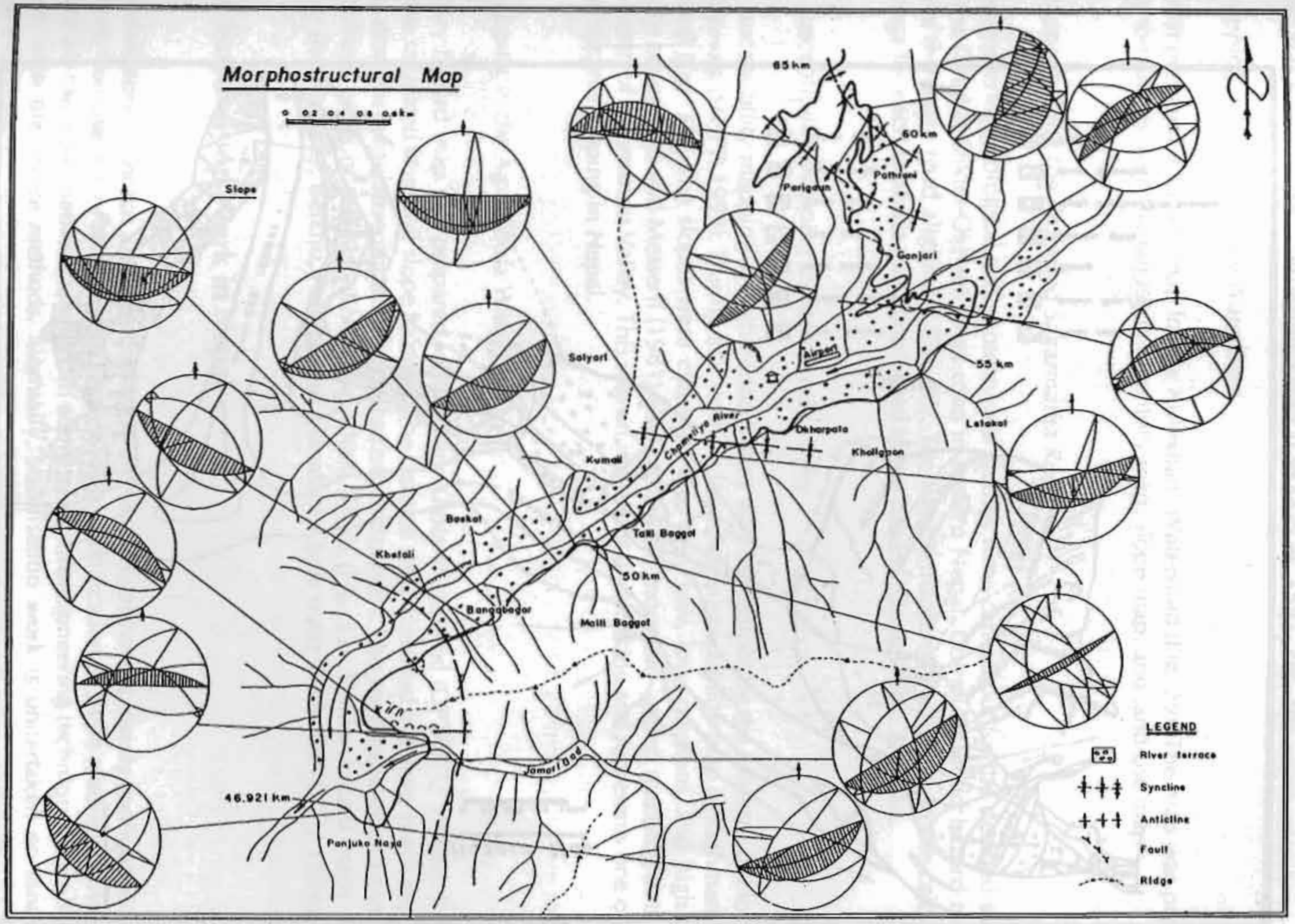
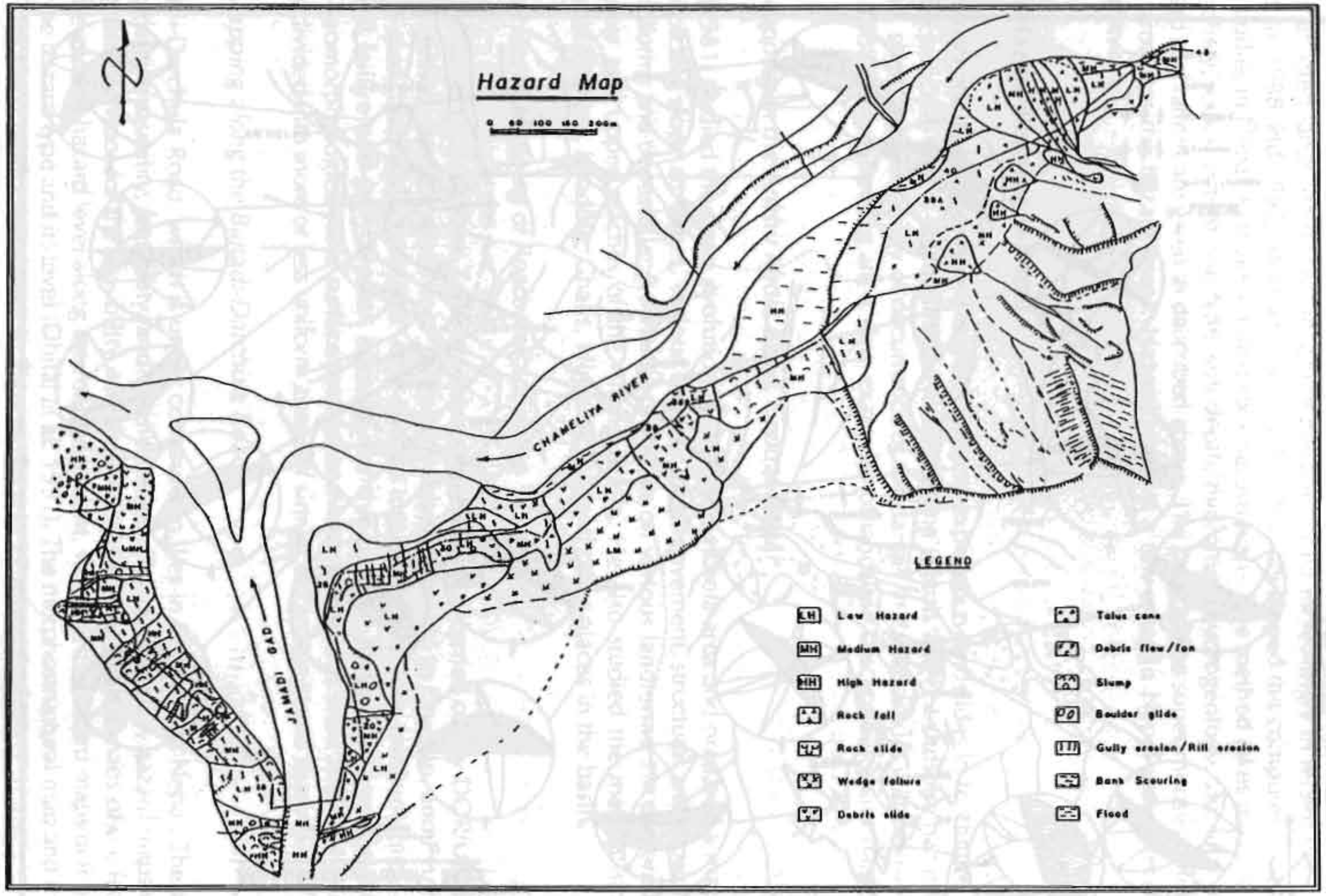


Figure 27: Detailed stage hazard map of a part of the Baitadi-Darchula Road alignment (Dhital et al. 1991)



The Charnawati region is characterised by the presence of thick colluvial and debris flow deposits on the highly weathered gneiss. A flash flood in the Charnawati Stream triggered several slides on its banks and washed away its bridge. Most of the damage was on the left bank of the river. At the same time the Kalimati Gully, a tributary of the Charnawati Stream, also experienced a very high concentration of runoff, resulting in deep gully erosion. More than 17 houses were destroyed overnight and several people were killed. A large slump on the left bank of the road blocked the traffic (Dhital 1994). A computer-aided hazard map was prepared for Charnawati Valley (Deoja et al. 1991, Fig. 28).

Hazard Mapping in the Kulekhani Watershed

Nepal (1992) prepared a hazard map for the Kulekhani Watershed (Fig. 29). The map was prepared by combining the ratings from the landslide inventory map, slope map, and land-use map.

Hazard Mapping along the Proposed Sagarmatha Road

Detailed engineering-geological and geotechnical studies were carried out for the detailed survey and design of the Gaighat-Diktel-Okhaldhunga road in eastern Nepal. Computer-aided hazard maps were prepared for the entire road alignment (Fig. 30). The hazard mapping was based on the calculation of hazard ratings for each attribute that contributed to the hazard (Dangol et al. 1993b).

Landslide Susceptibility Mapping in Kathmandu Valley

Landslide susceptibility mapping in Kathmandu Valley was carried out by the Ministry of Housing and Physical Planning (MHPP 1993). During that study, a landslide susceptibility map of Kathmandu Valley was prepared (Fig. 31). The slopes were classified into very low, low, medium, and high landslide susceptibility zones. Ives and Messerli (1981) also carried out mountain hazard mapping in the Kakani area to the north of Kathmandu Valley. This was an important undertaking and represents one of the early attempts at hazard mapping in Nepal.

Hazard Mapping in the Agra Khola Watershed

A preliminary hazard map was prepared for the Agra *Khola* Watershed (DPTC/TU 1994b). Rock slope hazards were separated from soil slope hazards. The hazards were classified into low, medium, and high depending upon the cumulative impact of each hazard component. The most hazardous areas were the upper catchment areas of the Agra *Khola* and Chalti *Khola* (Fig. 32). Similar hazard maps were also prepared for the Malekhu, Belkhu, Palung, and Manahari *Khola* watersheds (DPTC/TU 1994a,b).

Landslide Stabilisation Work in Nepal

Landslide stabilisation work has a very recent history in Nepal. Such work is mainly confined to important road corridors. Construction of retaining and breast walls, modification of slope gradients, and drainage management are the main methods applied. In some cases, bioengineering techniques are also used in combination with the above methods. Normally, stabilisation work is undertaken on landslides of moderate to small size.

Currently, the Department of Soil Conservation, HMG, is trying to help local people in the hills control and stabilise landslides by using various low-cost methods such as afforestation, checkdams, and use of local materials. Small landslides occurring on agricultural land are, in most cases, managed by the villagers themselves. Some of the important landslide stabilisation works in Nepal are summarised below.