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.

Figure 28: Computer aided soil slope hazard map of Charnawati area, Lamosangu-Jiri Road, Central Nepal (Deoja et al. 1991)

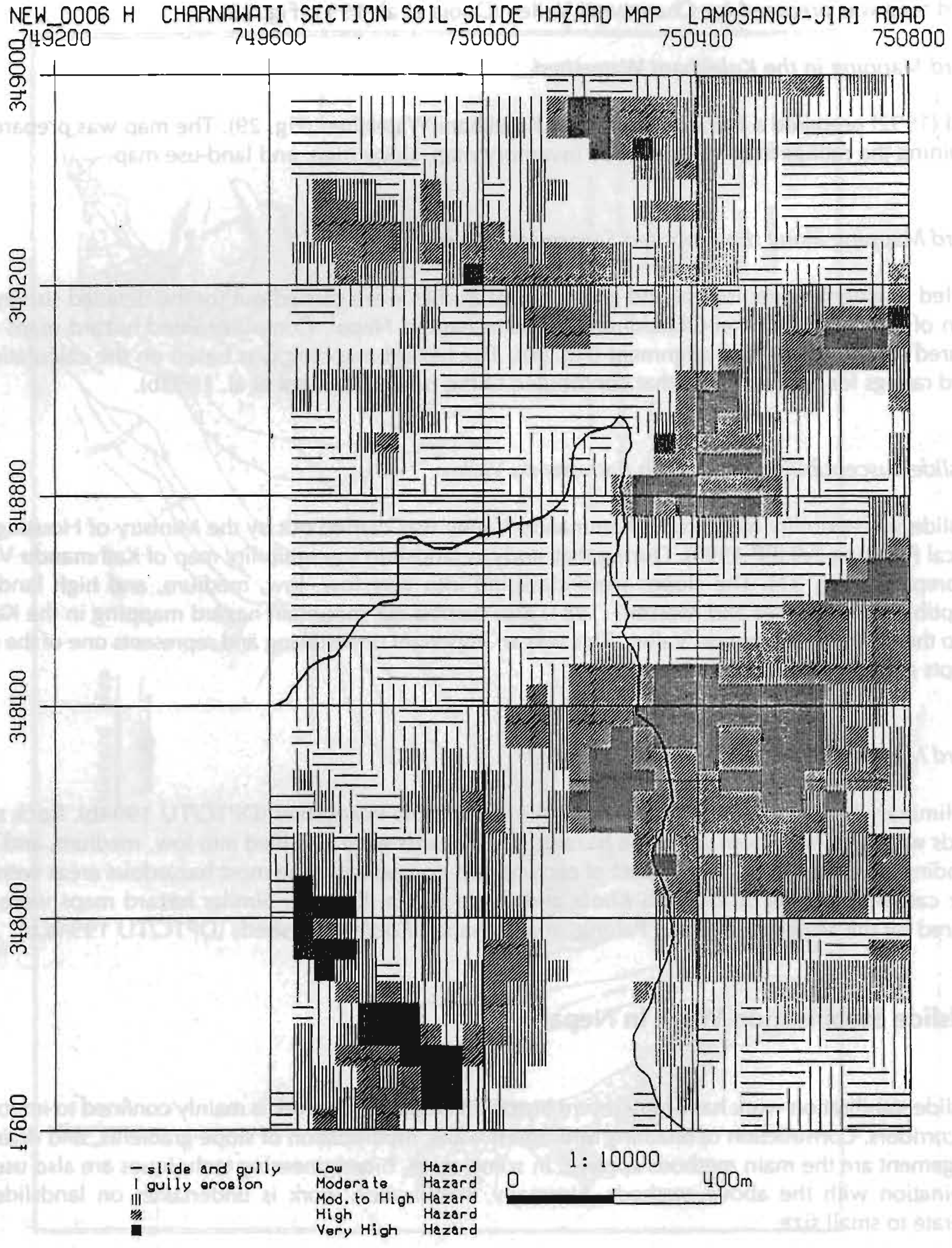


Figure 29: Hazard map of the Kulekhani Watershed (Nepal 1992, redrawn)

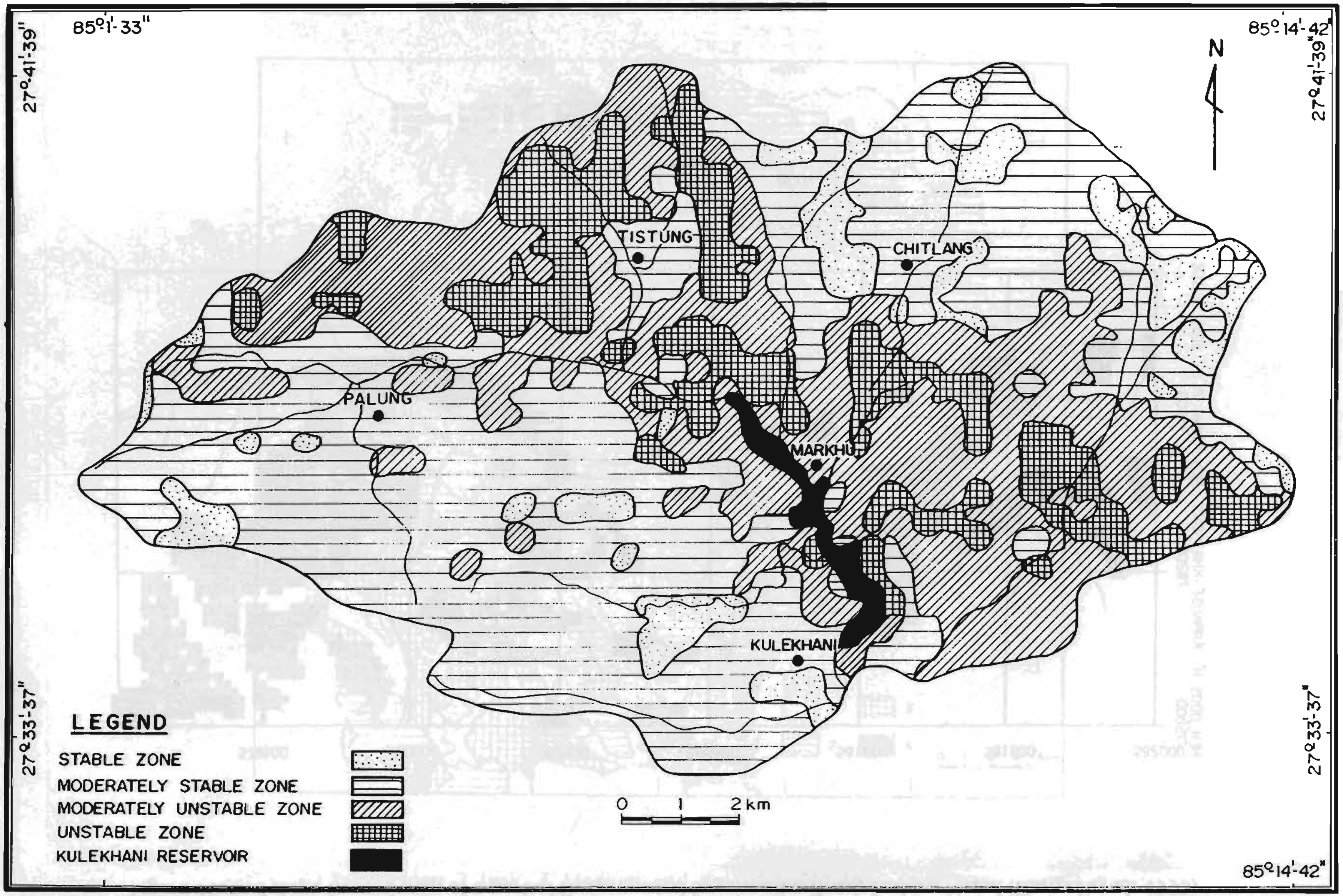


Figure 30: Soil slope hazard map of a part of the proposed Sagarmatha Road, Eastern Nepal (Dangol et al. 1993)

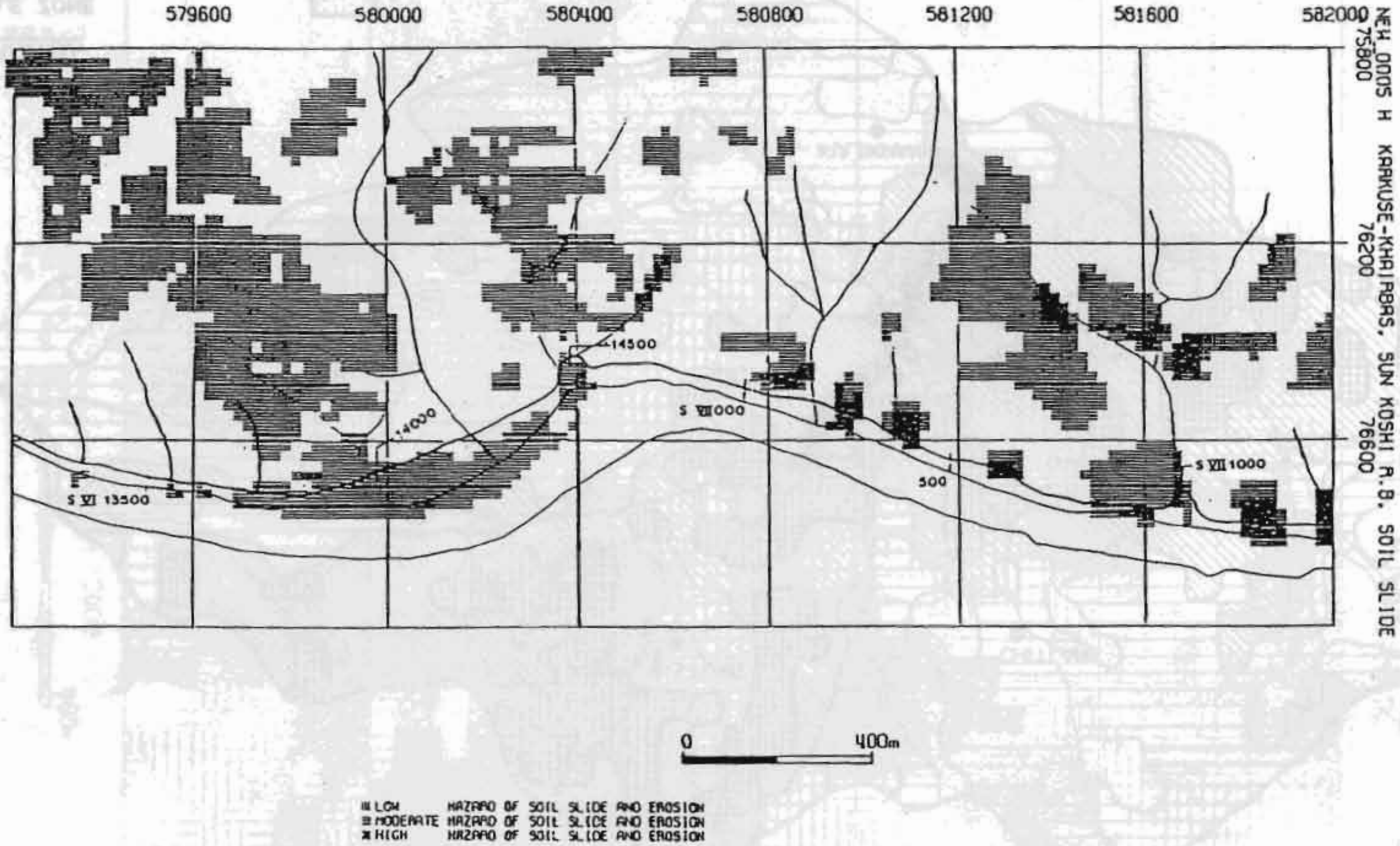
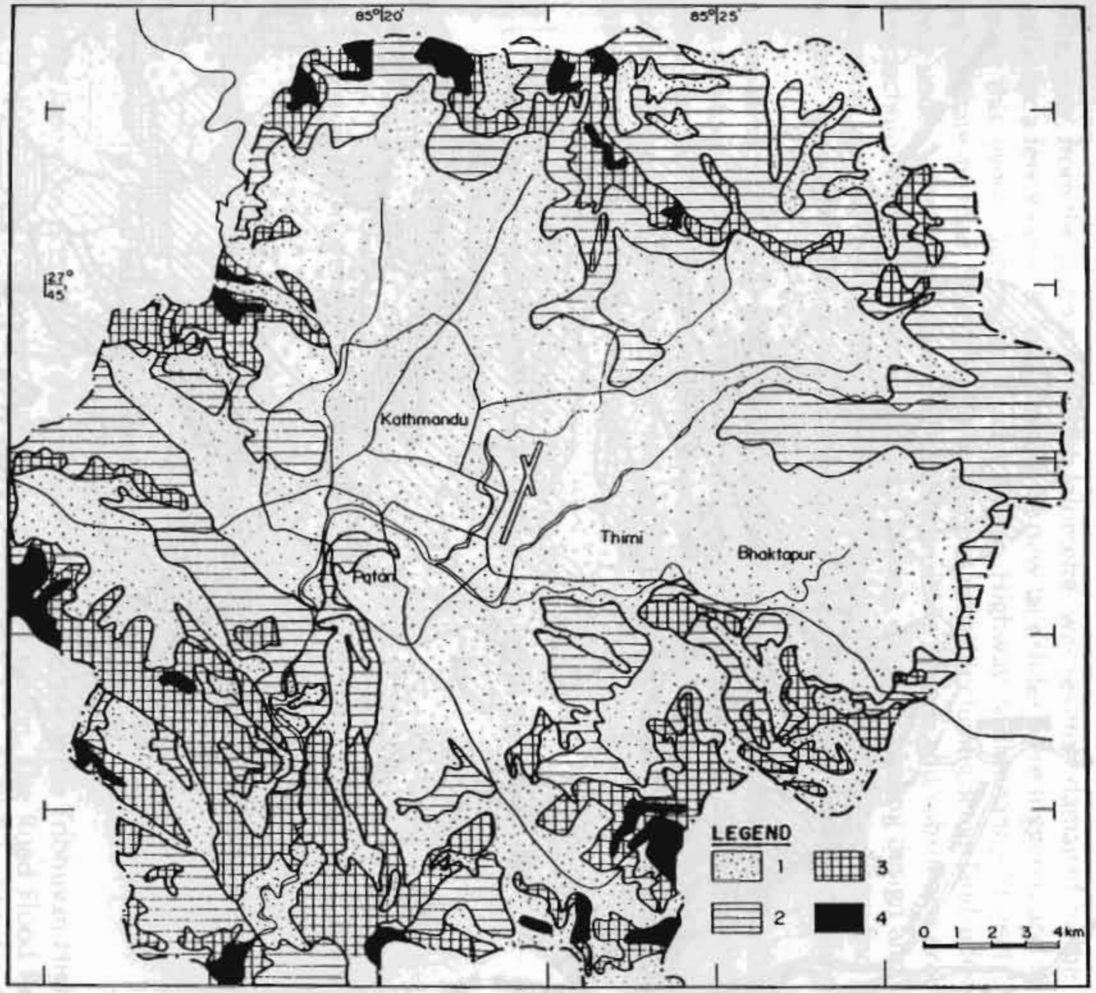
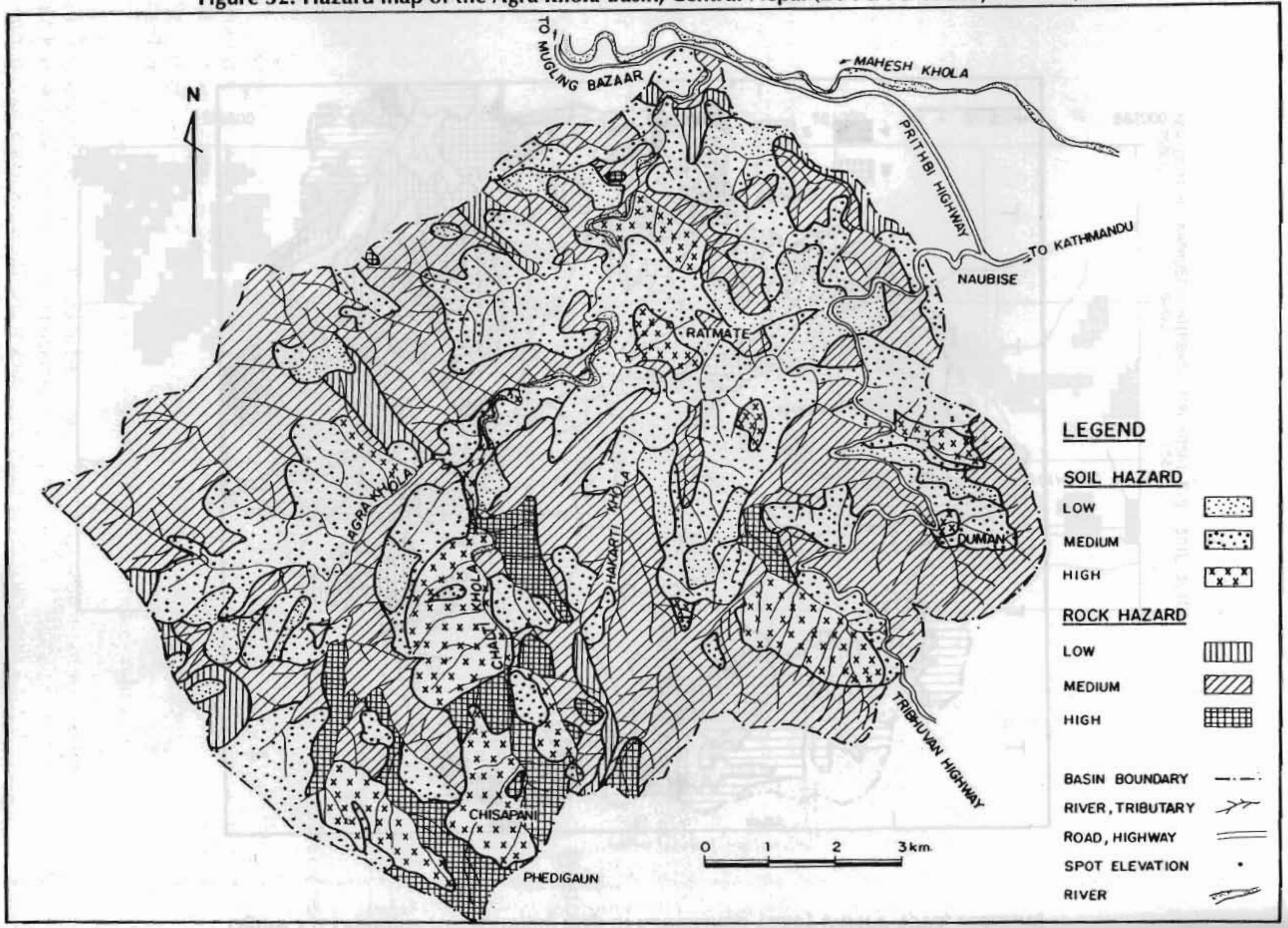


Figure 31: Landslide susceptibility map of Kathmandu Valley (MHPP 1993, redrawn)



1. Very low; 2. Low, 3. Medium, and 4. High landslide susceptibility

Figure 32: Hazard map of the Agra *Khola* Basin, Central Nepal (DPTC/TU 1994b, redrawn)



Slope Stabilisation in Charnawati Valley

The first major effort at landslide stabilisation and gully erosion control in Nepal, using modern technology (such as anchoring, surface and subsurface drainage management, bioengineering, and use of large concrete tetrapods), was carried out in the Charnawati Valley of Dolkha District along the Lamusanghu-Jiri road (Plate 9). The 1987 cloudburst damaged nearly three kilometres of the road lying in a thick zone of colluvium and debris deposit, by triggering a number of landslides and gully erosion. Landslide stabilisation work and gully erosion control were completed at a cost of about Rs 190 million (approximately 38 million US$) (Deoja 1993). Local consultants and contractors gained valuable experience and knowledge from this project.

Landslide Stabilisation Work along the Arniko Highway

The Arniko Highway, from the 62nd to the 87th kilometre, was severely damaged by the 1987 flood, disrupting traffic for a few weeks. A large number of new landslides were triggered and old landslides activated during this event. Subsequently, the Arniko Highway Maintenance Project (AHMP) was launched to rehabilitate the road. Several highly hazardous zones (including active landslides, gullies, and areas with river undercutting) were stabilised by constructing surface and subsurface drains, applying bioengineering techniques, and anchoring and rock bolting. The engineering design and construction work for stabilisation were carried out after extensive geological, engineering geology, and geotechnical studies of the sites. A typical landslide stabilisation work along the road is described below.

The landslide between km 72+300 and 72+500 is about 100m high. The toe of the landslide is on the river bed. It is a rotational debris slide. The slide material is mainly composed of fine-grained colluvial and eluvial deposits. The landslide is affected by the perched groundwater, weak bedrock, steep road cut slope, surface runoff into the landslide, and toe undercutting by the Sunkoshi River. To stabilise the landslides, the following measures were taken.

- Construction of lined catch drains above the landslide
- Construction of a network of tributary drains (French drains) in the landslide
- Horizontal drains for draining subsurface water
- Extensive use of bioengineering

There has been noticeable movement in the landslide zone after the first monsoon, and it seems to be under control (Plate 6).

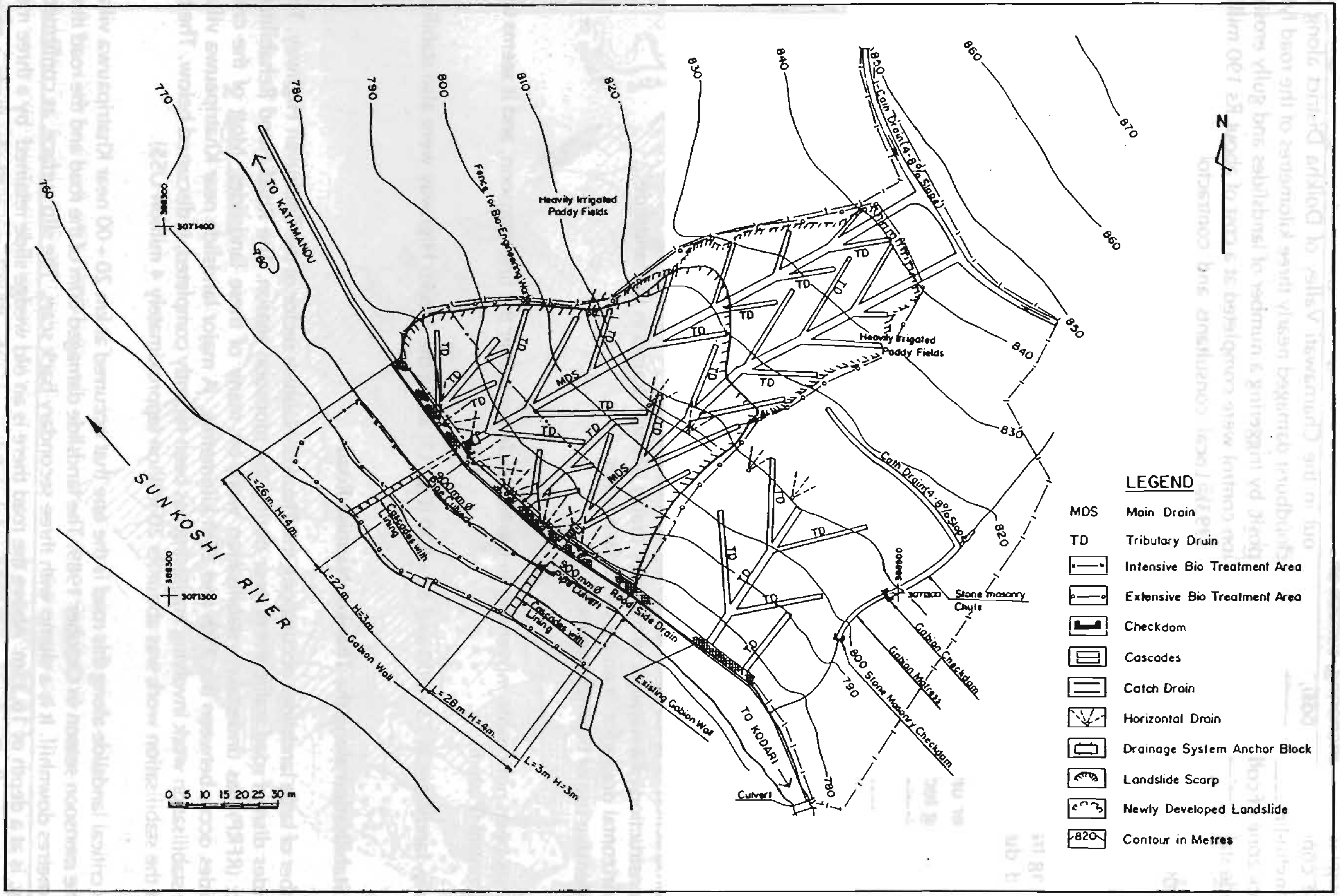
Similarly, landslides at 73+300 and 82+800 (Fig. 33) along the Arniko Highway were also stabilised.

Slope Stabilisation along the Thankot-Naubise Road

A number of large landslides occur along the Thankot-Naubise sector of the Tribhuvan Highway. These landslides disrupt road traffic every year during the monsoon season. The Road Flood Rehabilitation Project (RFRP) has undertaken stabilisation work on many of these landslides. Most of the critical landslides occur between the 11th and 26th kilometres. A major landslide near Khatripauwa village, where stabilisation work involving anchoring has been recently completed, is discussed below. The total cost of the stabilisation work was about Rs 20 million (approximately 4 million US$).

A very critical landslide along this road is the one that occurred at km 20+00 near Khatripauwa village, after the monsoon season in October 1989. The landslide damaged 80m of the road and the road moved three metres downhill. It is a slump with three secondary back scars. The slip surface, as confirmed by drilling, is at a depth of 16.35m. Above the road there is an old wedge slide retained by a three metre-high masonry wall. On the opposite side of the slide across the Khatripauwa *Khola*, there is another shallow rockslide initiated by rock quarrying in the past (DOR 1990).

Figure 33: Detailed design for the landslide stabilisation work between km 82+800, the Arniko Highway (DOR 1990, redrawn)



The landslide is in the Sopyang Formation of the Phulchowki Group of the Kathmandu Complex (Stöcklin 1980). It is composed of moderately to highly weathered phyllite and metasandstone with foliation dipping into the slope. The depth of the weathered zone is 8-12m, as indicated by the seismic refraction survey. Several prominent joint sets are found and their orientations have made the slope favourable for wedge and plane failures (DOR 1990).

The stabilisation work was completed recently and the first monsoon had no adverse effect on the stability of the area. The landslide was stabilised by constructing a composite toe wall, French drains, horizontal drains, diversion catch drains, and rock anchors (Plate 10). The anchors are 20-30m deep and each is designed to take a load of 25 tons.

Landslide Monitoring and Warning System

There are very few examples of landslide monitoring in Nepal. The landslides on the slopes of the Kulekhani Reservoir near the intake were monitored by the NEA before the stabilisation work (1989). A few large slope areas along the left bank of the Charnawati River (Valley in the original) are being monitored after its stabilisation. The Water Induced Disaster Prevention Technical Centre has selected a few landslides for monitoring along the Kathmandu-Trishuli Road from the 19th to the 48th kilometres (km19 and km48), at Kharani Tar (Nuwakot), near the Sunkoshi Hydropower Station, and near the large landslide at Butwal (Amao and Sunuwar 1993).

Engineering geology mapping of the landslide at the 19th kilometre along the Kathmandu - Trishuli Road was carried out before monitoring. A borehole of 32m was drilled and two rows of moving piles, a rain gauge station, two extensometers, and a tiltmeter were installed for monitoring (Amao and Sunuwar 1993).

So far, no attempt has been made to develop a warning system for landslide disasters in Nepal.

Landslide-dam Outburst Floods

Landslide dams are formed by the blockage of rivers and streams by the materials produced from landslides on either banks. The dams may remain for several minutes, days, months, or years. When they fail, they cause catastrophic floods in downstream areas. In the Himalayas, the narrow and steep river valleys and their fragile slopes contribute to frequent landslide damming.

Nepal, with its many large rivers and numerous smaller streams, suffers from landslide-dam outbursts and consequent floods. However, no systematic studies on such events have been made in Nepal so far and there is no proper emergency planning. Damming of large rivers in the deep gorges of the Higher Himalayas seems to be a common phenomenon in Nepal's geological history (Hanisch 1995). The landslide dam formed in the Budhi Gandaki River in 1968 created a 60m deep lake within 29 hours; it then breached, the resulting flood causing great damage downstream (Sharma 1981). Similarly, the Trishuli River was also dammed in the past, causing similar damage. The Tinau River in western Nepal was dammed many times in the recent past, causing great damage to Butwal *Bazaar*, lying downstream at the foot of the Siwaliks. In the past, the Nepalese army's help was taken to breach these dams (e.g., during the Trishuli River damming) by using explosives.

Public Awareness

In spite of frequent landslide disasters in Nepal, the people are still not very aware of their causes and mitigative measures. Such awareness could save many lives and much property. Villages situated on old flood plains of rivers and streams and in the areas susceptible to landsliding and debris flows have suffered from disasters. Prevention of gully erosion in the initial stage by using local materials and low cost techniques (such as *sabo* dams) may help avoid serious landslides and gully-erosion problems in the future. Local people are very unaware about such matters and there are hardly any public awareness programmes. Recently, the Water Induced Disaster Prevention Technical Centre (DPTC) has started conducting roving seminars in different districts and village centres to make the authorities and local representatives aware of water-induced disasters, including landslide problems.

Technical Consulting Services

In recent years, quite a number of technical consulting services have been actively engaged in the field of landslide studies, stabilisation, and landslide hazard mapping. The number of qualified and experienced persons/professionals in engineering geology, applied geophysics, geotechnical engineering, civil engineering, bioengineering, etc, available for landslide studies and management in the country, is rather limited.

Institutions Concerned with Landslide Research, Monitoring, Warning, Management and Training

Public Agencies

Department of Mines and Geology

The Department of Mines and Geology of His Majesty's Government of Nepal was established in 1941. It is responsible for the geological mapping of the country, mineral exploration work, mining, petroleum exploration, and study and mitigation of natural hazards such as landslides, debris flows, soil erosion, and earthquakes. There are over 40 geologists working in the Department. It has a separate engineering geology section responsible for the study of landslides and related phenomena and supported by a well-equipped geotechnical laboratory. There is also a well-equipped seismological centre. The Department started systematic landslide inventory survey and slope stability mapping in 1986 to get an overview of those areas of Nepal most affected by landslides as a basis for future infrastructural planning. New landslide inventory sheets were introduced based on the IAEG recommendations, after having been adapted to the special conditions of the Himalayan range. A database on the landslides of Nepal has been maintained. The German Technical Assistance Programme in the Department aims to investigate and monitor selected landslides, create a landslide inventory in the Lesser Himalayas by using remote sensing and Geographical Information Systems' (GIS) technology, and prepare the engineering and environmental geological maps of Kathmandu Valley. The Department is also carrying out a detailed study and monitoring of a landslide in Chalnakhel in the southern part of the Kathmandu Valley.

The Department of Mines and Geology, with its geologists, engineering geologists, geotechnical engineers, mining engineers, and a well-established geotechnical laboratory and infrastructure, has a very wide scope for advanced studies on landslides and soil erosion, as well as hazard and risk mapping, in Nepal.

Department of Roads

The Department of Roads is actively engaged in the study, monitoring, and mitigation of landslide hazards along road corridors. The Road Flood Rehabilitation Project (RFRP), the First and Second Road Improvement Projects, and the Arniko Highway Maintenance Project (AHMP) are some of the important projects run by the Department, and they have completed a considerable amount of work on landslide stabilisation, particularly along the Arniko Highway and the Kathmandu-Mugling section of the Prithvi Highway. The Department has a Maintenance and Rehabilitation Control Unit (MRCU) which has introduced a slope monitoring programme with the help of a database created for the Naubise-Mugling section of the Prithvi Highway.

The rapid expansion of roads during the last four decades has had an adverse impact on the physical environment of Nepal. The initiation of a large number of landslides and increase in soil erosion, which