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Landslide hazard and risk zonation of Thankot – Chalnakhel area, central Nepal

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ABSTRACT

The rocks in the Thankot–Chalnakhel area constitute the Chandragiri Range bordering the Kathmandu valley. The Phulchauki Group of rocks comprise its steep and rugged south slope, whereas the gentle north slope is covered by fluvio-lacustrine deposits of the Kathmandu basin with some recent alluvial fans. During the field study, 94 landslides (covering about 0.24 sq km) were mapped. Most of them were triggered by intense rainfall within the last two years. Landslides are generally found on steep colluvial slope (25°–35°) and dry cultivated land. Based on a computer-based geographical information system, a landslide hazard map, a vulnerability map, and a risk map were prepared. The landslide hazard map shows 20% of the area under high hazard zone, 41% under moderate hazard zone, and 39% under low hazard zone. The risk map generated by combining the hazard map and vulnerability map shows 19% of the area under high and very high risk zones, 33% under moderate risk zone, and 48% under low and very low risk zones.

INTRODUCTION

The Thankot–Chalnakhel area (Fig. 1) lies in central Nepal and occupies parts of the Kathmandu and Makawanpur districts (27°37' 30" to 27°41'55" N latitude and 85°11'45" to 85°18'00" Elongitude) with a total area of 57.6 sq km. The Chandragiri Range passes through the study area and consists of many high (up to 2561 m) peaks. The Balkhu Khola, Bosan Khola, and their tributaries drain the north face of the range.

Landslides are the most common natural hazard in Nepal, where more than 80% of the total area is mountainous. Steep slopes, prevalent fragile rocks, and concentrated precipitation have made the country highly susceptible to erosion and landslides. A systematic study of landslides including hazard mapping and risk assessment on a larger scale has not been undertaken yet in Nepal (Upreti and Dhital 1996). Landslide hazard maps are useful for planning and implementing developmental schemes in mountainous areas like those of Nepal. In this context, landslide hazard and risk zonation mapping based on landslide distribution, geology, and geomorphic analysis was undertaken in the Thankot–Chalnakhel area using the computer-based geographic information system (GIS).

GEOLOGY AND LAND USE

The northern half of the Thankot–Chalnakhel area lies in the fluvio-lacustrine sediments of the Kathmandu basin and the other half is made up of basement rocks (Fig. 2). The basement rocks are divided into the following four formations, from older to younger respectively: the Tistung Formation, Sopyang Formation, Chandragiri Limestone, and Chitlang Formation. The Tistung Formation consists of metasandstone, slate, and phyllite. The Sopyang Formation comprises calcareous metasandstone and slate. The Chandragiri Limestone contains siliceous and argillaceous blocky limestone, and the Chitlang Formation is made up of slate with a few bands of quartzite (Table 1).

The Mahabharat Synclinorium, Kirtipur Anticline, and Chandragiri Fault are the major geological structures in the study area. The axial trace of the Mahabharat Synclinorium

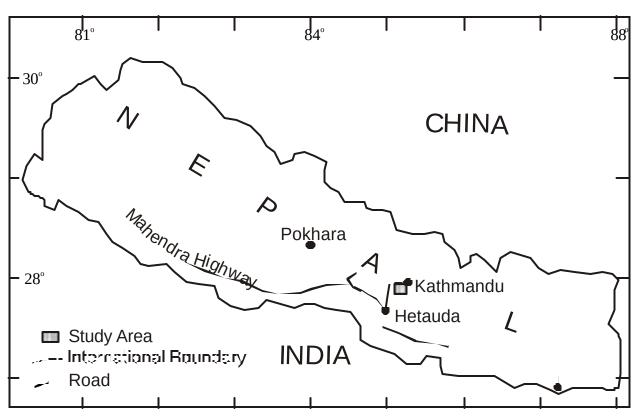

Fig. 1: Location map of the study area

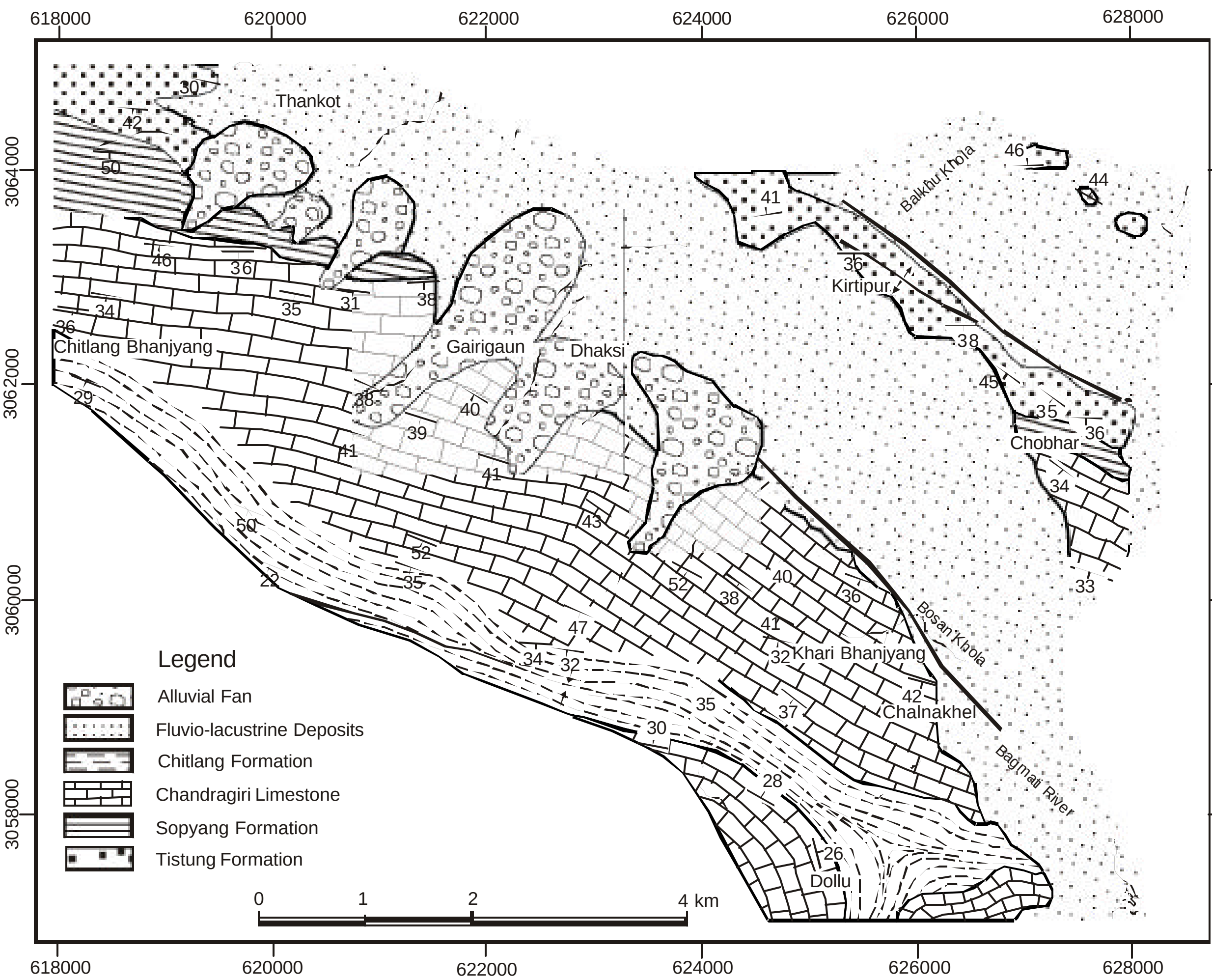

Fig. 2: Geological map of the Thankot–Chalnakhel area, southwest Kathmandu

Table 1: Stratigraphic subdivisions of the Kathmandu Complex (Stöcklin and Bhattarai 1977, Stöcklin 1980)

Rock unit	Group	Formation	Thickness (m)	Main Lithology	Age
Kathmandu Complex	PHULCHAUKI GROUP	Godavari Limestone	300	Limestone, dolomite	Devonian
		Chitlang Formation	1000	Slate	Silurian
		Chandragiri Limestone	2000	Limestone	Ordovician
		Sopyang Formation	200	Slate, calc-phyllite	Cambrian
		Tistung Formation	3000	Metasandstone, slate, phyllite	

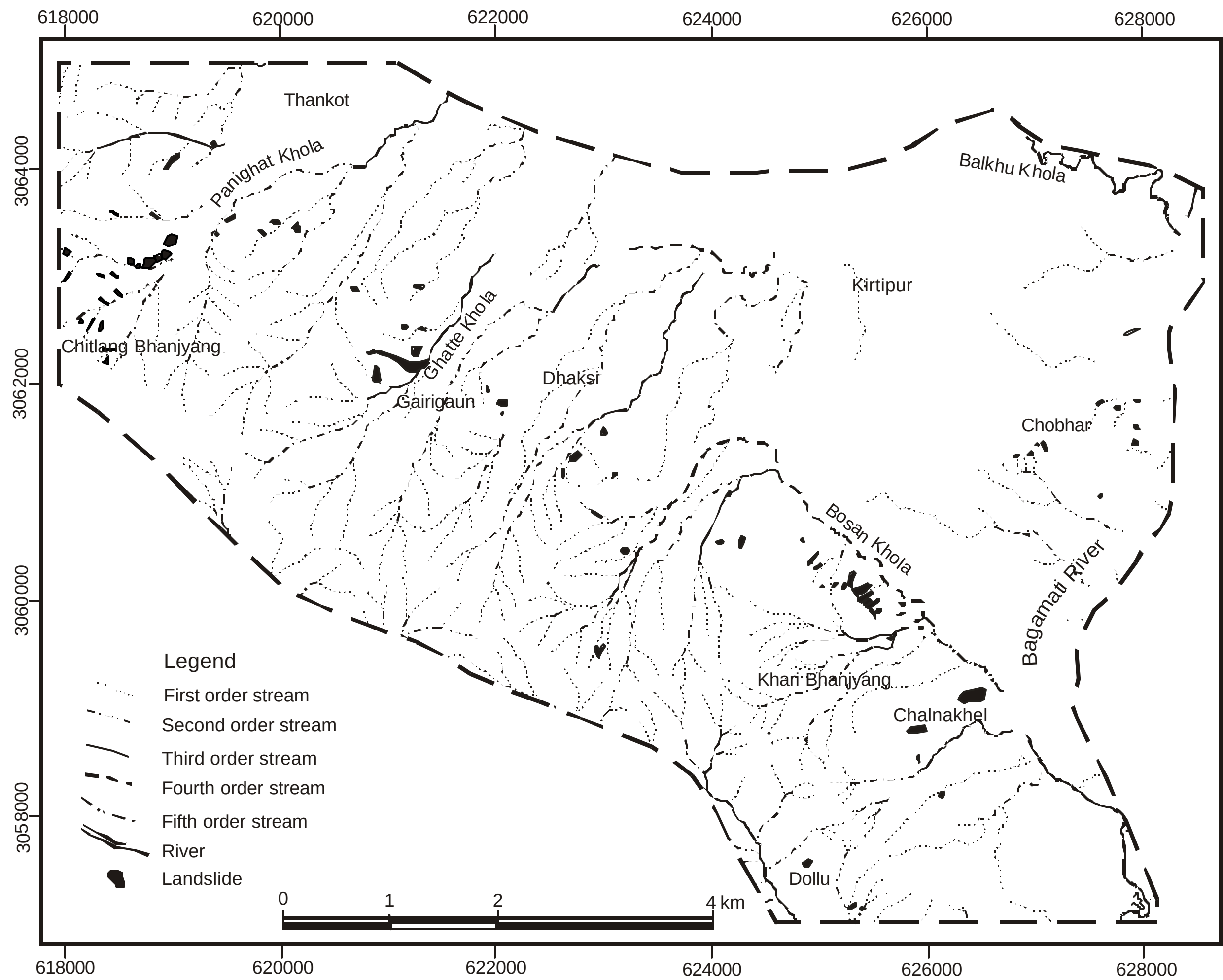

Fig. 3: Landslide distribution map of the Thankot–Chalnakhel area, southwest Kathmandu

trends WNW–ESE and passes through the Chandragiri Range. The axial trace of the Kirtipur Anticline also trends WNW–ESE and passes through Kirtipur and Chobhar. The Chandragiri Fault passes through the Bosan Khola (Fig. 2).

The northern flatlands of lower altitude are used for wet cultivation, whereas the southern slopes (up to 25^{o}) are used for dry cultivation. The ridge and steeper slopes are covered by dense mixed forest.

LANDSLIDES

During the desk and field study, 94 old and active landslides were mapped, and several other small slides were also identified (Fig. 3). The slides cover an area of about 0.24 sq km, which is about 0.4% of the total study area. Among them, active or recently occurred and old landslides occupy about 85% and 15% of the total landslide area, respectively. The highest landslide density is observed in the slope class of 25°–35°. The landslide density increases with increasing slope angle up to 35° and then it decreases (Fig. 4). Some previous studies also have shown a similar trend. Deoja et al. (1991) stated that the landslide density is highest on the slope interval of 25°–35°. Joshi et al. (2000) showed an increasing relationship of landslide density with slope angle up to 35°, which remained constant in the interval of 35°–45°, and then it decreased. Similarly, this study also supports an earlier observation (Dikshit 1994) that the hills with 30° to 45° slopes are the most vulnerable to failure in Nepal.

Landslide density is higher in the limestone terrain owing to its highly jointed nature and the presence of argillaceous partings. The dry cultivated land and bush land include about 13% and 8% of the study area, respectively. They comprise respectively about 36% and 30% of the total landslide area. The landslide density in the bush land and dry cultivated land is 0.0118 and 0.0109, respectively (Table 2). Hence, these areas are highly vulnerable to sliding.

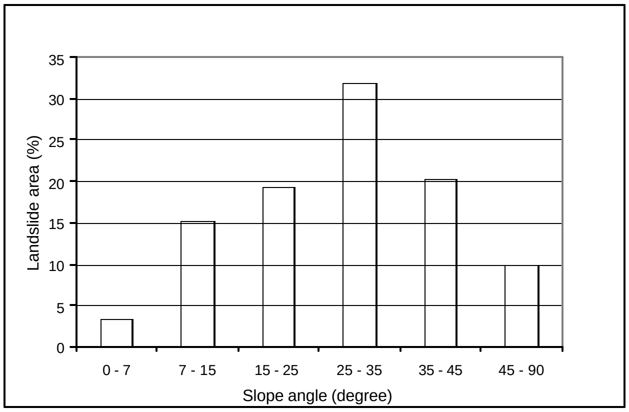

Fig. 4: Relationship between slope and landslide occurrence in the Thankot–Chalnakhel area

HAZARD AND RISK MAPPING

The term 'hazard' is closely related to the term 'risk'. According to Varnes (1984), hazard means the probability of occurrence within a specified period of time and within a given area, of a potential damaging phenomenon. A landslide hazard map should display both the location of actual and potential slope failures, and provide information on the probability of their future occurrence (Varnes 1984). Dhital (2000) classified the landslide hazard maps into the three categories: map of a region, map of a corridor, and map of a site.

The term 'vulnerability' means the degree or loss to a given element or a set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude (Varnes 1984).

Risk can be defined as the expected degree of loss due to a particular natural phenomenon. Risk can be expressed as the product of natural hazard (H) and vulnerability (V) (Varnes 1984).

The data for landslide hazard mapping were collected from the field and secondary sources. ArcView 3.2, a GIS software, was used to prepare various spatial layers. A digital terrain model was obtained from the 1:25000 scale topographic maps (DoS 1994). Detailed field studies were carried out for several times between September 2002 and December 2003 in order to prepare a geological map, landslide distribution map, land use map, and soil types and depth map as well as to verify, edit, and update the collected information. These data were entered into Autodesk Map 5 and were analysed using ArcView 3.2 to obtain hazard, vulnerability, and risk maps.

Landslide hazard map

The landslide hazard map (Fig. 5) was prepared using the GIS-based bivariate statistical technique with quantitatively defined weight values. There are a number of methods for obtaining weight values, and the Landslide Index Method was used in this study. A weight value for a parameter class is defined as the natural logarithm of the landslide density in the class divided by the landslide density in the entire map. It is expressed as

$$Wi = \ln\left[\frac{Dense\ class}{Dense\ map}\right] = \ln\left[\frac{Npix(Si)\big/Npix(Ni)}{\sum Npix(Si)\big/\sum Npix(Ni)}\right]$$

where

Wi= weight given to a certain parameter class,

Dense class= landslide density within the parameter class,

Dense map= landslide density within the entire map,

Npix (Si) = number of pixels containing landslide in a certain parameter class, and

Npix (Ni) = total number of pixels in a certain parameter class.

The landslide hazard map was based on map crossing of a landslide map with the following parameter maps: slope gradient, slope aspect, elevation, slope shape, geology, land use, soil type, average annual rainfall, distance from a road, distance from a stream, distance from a geological structure, and distance from a major ridge line. At first, the parameter maps were crossed by landslide map using the map calculator tool in ArcView 3.2. Then, the weight values were added in the attribute table of all the parameter maps. The natural logarithm was used to give a negative weight when the landslide density was lower than the normal and a positive weight when it was higher. The combined landslide hazard map was reclassified into low, moderate, and high hazard zones.

The landslide hazard map (Fig. 5) was prepared by considering only active and recent landslides. The map was then correlated with the old landslides in the study area. The result showed that about 76% of active landslides and 88% of old landslides lie in the high hazard zone, which covers about 19% of the total study area. Similarly, about 41% and 39% of the territory lies in the moderate and low hazard zones, respectively. Most part of the northern face of the Chandragiri Range and the area around the Dollu village appear highly hazardous (Fig. 5). About 49% of the total dry cultivated land and about 7% of the total forestland lie in the high hazard zone.

Vulnerability map

The vulnerability map was prepared using the following GIS layers:

- Distance from a house,
- Cultivated land, and
- Population density.

Table 2: Landslide density and weight values for different classes of hazard rating parameter maps

Category	Landslide density within the parameter class *(Dense class)*	Landslide density within the entire map *(Dense map)*	Weight values
Slope angle (°)			
Gentle (0 - 7)	0.0005	0.0035	-1.9459
Moderately sloping (7 -15)	0.0035	0.0035	0
Moderately steep (15 -25)	0.0063	0.0035	0.5878
Steep (25 -35)	0.0070	0.0035	0.6931
Highly steep (35-45)	0.0059	0.0035	0.5222
Strongly steep (45-90)	0.0053	0.0035	0.4149
Slope shape			
Concave	0.0058	0.0036	0.4769
Convex	0.0055	0.0036	0.4238
Straight	0.0025	0.0036	-0.3646
Elevation range (m)			
Less than 1350	0.0022	0.0035	-0.4467
1350 - 1500	0.0023	0.0035	-0.4361
1500 - 1650	0.0097	0.0035	1.0273
1650 - 1800	0.0063	0.0035	0.5957
1800 - 1950	0.0014	0.0035	-0.9271
1950 - 2100	0.0049	0.0035	0.3446
2100 - 2250	0.0014	0.0035	-0.8784
2250 - 2400	0.00004	0.0035	-4.3539
More than 2400	0.0002	0.0035	-3.0729
Slope aspect (Direction with respect to north)			
Flat	0.0009	0.0035	-1.3581
0 - 45	0.0035	0.0035	0
45 - 90	0.0061	0.0035	0.5555
90 - 135	0.0063	0.0035	0.5878
135 - 180	0.0048	0.0035	0.3159
180 - 225	0.0023	0.0035	-0.4199
225 - 270	0.0028	0.0035	-0.2231
270 - 315	0.0003	0.0035	-2.4567
315 - 360	0.0022	0.0035	-0.4643
Land use /Land cover			
Forest	0.0118	0.0035	1.2153
Bush land	0.0091	0.0035	0.9555
Grassland	0.0021	0.0035	-0.5108
Dry cultivated land	0.0109	0.0035	1.1360
Wet cultivated land	0.0005	0.0035	-1.9459
Nursery and park	0.0003	0.0035	-2.4567
Hurticulture	0.0011	0.0035	-1.1575
Geology			
Alluvial Fan	0.0029	0.0035	-0.1881
Fluvio-Lacustrine Deposits	0.0011	0.0035	-1.1575
Chitlang Formation	0.0007	0.0035	-1.6094
Chandragiri Limestone	0.0079	0.0035	0.8141
Sopyang Formation	0.0070	0.0035	0.6931
Tistung Formation	0.0014	0.0035	-0.9163
Rock or soil type			
Soil (depth <1m)	0.0022	0.0035	-0.4643
Soil (depth 1-3m)	0.0056	0.0035	0.4700
Soil (depth 3-6m)	0.0099	0.0035	1.0398
Soil (depth >6m)	0.0175	0.0035	1.6094
Rock	0.0039	0.0035	0.1082

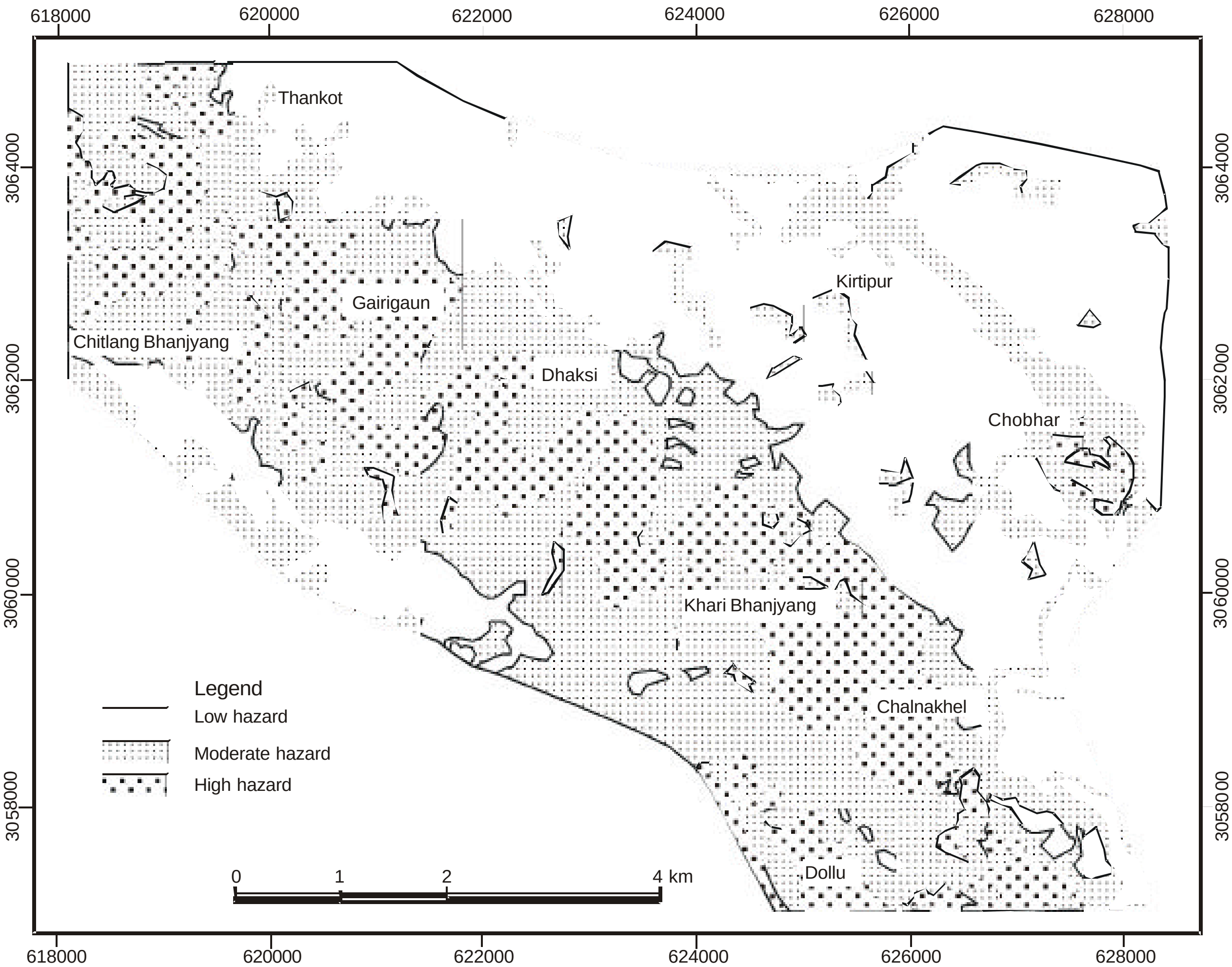

Fig. 5: Landslide hazard map of the Thankot–Chalnakhel area, southwest Kathmandu

The distance from a house was obtained by buffering each house with three distance intervals (i.e. <50, 50–100, and >100 m). The map of cultivated land was extracted from the land use and land cover map. Similarly, the population density of the study area was obtained as follows:

$$Pop.\ density = \frac{No.\ of\ houses\ in\ the\ region \times average\ household size}{area\ of\ the\ region}$$

The average household size of the study area is 6.4 (CBS 2004). Based on these data, the vulnerability map was reclassified into high, medium, and low categories.

Risk map

Owing to the absence of information on cost of infrastructures and landslide recurrence interval, the risk map (Fig. 6) was prepared by combining the landslide hazard map with the vulnerability map. The risk map was categorised into five classes, namely very low, low, moderate, high, and very high, which reflects a relative risk in terms of expected loss or damage of life and property due to the occurrence of landslide of a given magnitude.

The map shows that about 19% of the total area is under the very high and high risk zones in terms of expected loss or damage of property. Similarly, about 33% of the total area lies in the moderate risk zone, while about 47% of the area falls under the low and very low risk zones. The very low risk zone comprises mostly the ridge tops of the Chandragiri Range. The gently sloping urban area in the northern part and the steeply sloping area in the southern part are under the low and moderate risk zones, respectively. Parts of densely populated areas, like Chalnakhel, Kharibhanjyang, Dhaksi, Gairigaun, and Chobhar, lie in the high landslide risk zone (Fig. 6).

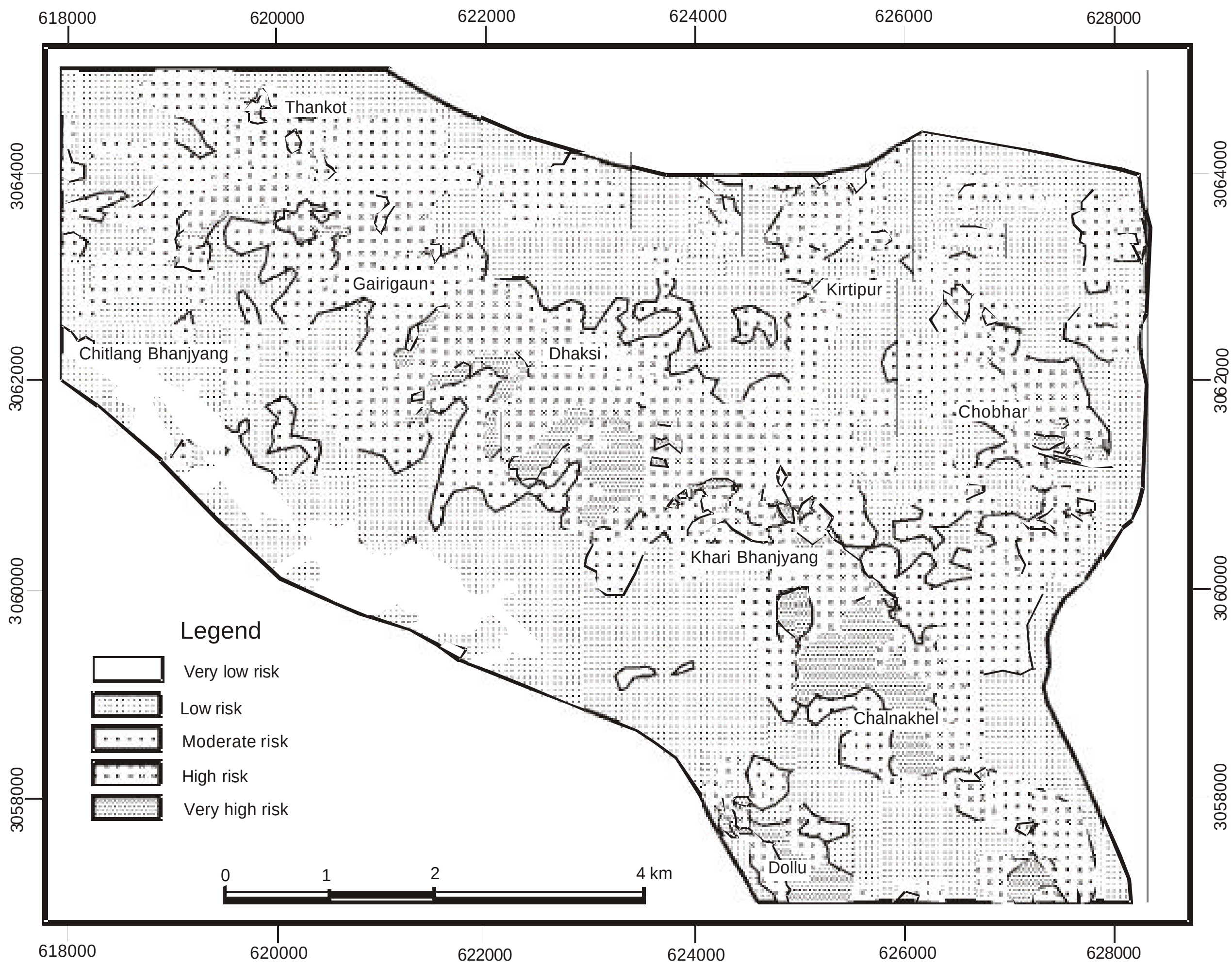

Fig. 6: Risk zonation map of the Thankot–Chalnakhel area, southwest Kathmandu

CONCLUSIONS

In Thankot–Chalnakhel area, landslides widely vary in dimension and are concentrated mainly on the north face of the Chandragiri Range. Most of them were triggered by high-intensity rainfall, and the others were caused by road cutting and indiscriminate stone quarrying. These landslides are shallow to moderately deep. The landslide density is high on 25°–35° slopes, in the bush land and dry cultivated land. Similarly, it is also high in the limestone terrain because of its highly jointed nature and the presence of argillaceous partings. About 11% of the total agricultural land falls under the high hazard zone. Some residential areas, like Chalnakhel, Kharibhanjyang, Dhaksi, and Gairigaun, lie in the high hazard zone. About 19% of the total area is under the very high and high risk zones in terms of expected loss or damage of property. Similarly, about 33% of the total area lies in the moderate risk zone, and about 48% under the low and very low risk zones.

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