GEOGRAPHIC INFORMATION SYSTEM BASED HILL-SLOPE INSTABILITY ANALYSIS FOR LAND-USE PLANNING PERSPECTIVE: THE CASE OF UPPER MADI WATERSHED KASKI, NEPAL

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INTRODUCTION

'Slope' is one of the most concerned term in the high mountainous terrain, particularly like Himalayas, which is the highest, youngest and geologically most unrest mountain system of the world. Fragile hill-slope are widely extended over the terrain. Slope and slope processes are important considerations in land use planning both from the viewpoint of the environmental constraints they pose and the environmental impact related to their alteration. Inclination, erosion, and failure are three major problems of slope concerned with land-use planning of a specific region (Marsh; 1978). 'Slope Instability' is the condition which gives rise to gravity-dominated down-slope movements of ground-forming materials without the primary assistance of a fluid-transporting media. Such displacements have been variously germed 'mass movements', 'slope movements' or 'mass wasting' and display considerable variety owing to the great range of ground-forming materials and agents responsible for movement. (Marsh; 1978, Walker et.al.; 1987, Jones; 1993). All slopes are under stress owing to the force of gravity. "Should the forces acting on a slope exceed the strength of the materials forming the slope, then the slope will fail and movement occur" (Jones; 1993:1987). The balance of forces can be affected by the various way of changes above the threshold limit either from the internal or from the external as well as natural or accelerated.

Following the approach to environmental analysis of land use and site planning suggested by (Marsh; 1978), the indicators of slope instability of Madi Watershed have been categorized into two groups of forces, i.e. the shear strength and the shear stress. According to the nature of terrain properties the weightage of share stress and share strength for each parameter has been assigned. Adopting this approach, four classes of stability level of the slope i.e. stable, potentially unstable, unstable and highly unstable have been delineated for the land use planning perspective in a rural activities based condition of Upper Madi Watershed of Kaski District of Nepal (Appendix Fig. 1).

METHODOLOGICAL PROCEDURES AND ANALYSIS CRITERIA

The slope is analyzed from the topographical base map scale 1:50,000 with the vertical contour separation in 100 feet (30.48m). The valley-slope and crest-slope were demarcated with the help of the direction of contour crenulation in the topographic base map. After getting three separate grouping of mapping unit, the gradient is measured by the help of transparent graph Overlay on the contour map. In a single mapping unit the total number of contour crossing is a 500 meter grid square were taken as basis of delineation according to the method suggested by (Marsh; 1978:53).

Two sets of forces operate in all inclined materials which are shear stress and shear strength. *Shear Strees* tends to produce movement or failure, and *Shear Strength* tend to resist movement or failure. Whether a slope is stable or unstable depends on the balance of these forces. The point of balance between these forces is the critical threshold, which, of course, varies greatly in different earth materials.

Analysis of these two sets of forces through the selection of the major surface variables can provide a certain basis for the critical threshold limits.

Following the method suggested by (Marsh; 1978) the criteria for the slope instability measurement of the Madi Watershed have been established as follows (Table: 1).

Table 1: Selected surface variables and the trend of contribution to the force

Parameters	**Shear Strength**	
	High	Low
Measured properties	Value of the Properties	Value of the Properties
i. Drainage Density	Low	High
ii. First-order Stream Frequency,	Low	High
iii Relative Relief	Low	High
iv. Slope Gradient	Low	High
Mapped properties:		Sparse
i. Vegetation Coverage	Dense	High
ii. Geological Faults and Lineaments	Low	High
iii. Existing Landslide	Less Extensive	Erodible
iv. Soil testure and water seepage level	Not Erodible	
Parameters	Shear Stress	
	Low	High
1. Removal of Lateral and underlying Materials:	Value of the Properties	Value of the properties
i. Stream side-cutting	Low	High
ii. Cultivated terraces	Low	High
2. Slope loading:		
i. Paddy field	Low	High
ii. Water supply	Low	High
3. Existing landslide	Low	High

RATING WEIGHTAGE

To find out the different level of stability of the hill-slope the rating weightage were assigned according to the nature of the properties providing the shear stress and shear strength. The scores were assigned in an ascending order according to the forces involving to increase the shearing stress and decreasing the shearing strength in the hill slope respectively following the basis adopted by Joyce and Evan (1976 cited, Walker et. al.; 1987:20). Score 1 is given for the minimum level.

Drainage Density

Class (length/ km²)	Score
<2.5	1
2.5-3.5	2
3.5-4.5	3
>4.5	4

First-order Steam Frequency

Class (number of Stream/km²)	Score
<3	1
3-6	2
6-9	3
>9	4

Relative relief

Class (height/km²)	Score
<304.8 m (<1000 ft)	1
304.4-457.2 m (1000-1500 ft)	2
457.2-609.6 m (1500-2000 ft)	3
>609.6m (>2000 ft)	4

Slope

Class	Percent	Score
Valley Boottom Slope	0-5	1
	5-15	2
	15-30	2
Mid Slope	30-45	3
	45-60	4
	60 and above	5
Crest Slope	0-5	1
	5-15	2
	15-30	3

Soil texture and depth

Categories	Score
i. Very deep sandy soil	1
ii. Deep loamy skeletal soil	2
iii. Medium loamy skeletal soil	3
iv. Shallow and stoney skeletal soil	4

Land--use/land cover

Type	Score
Dense Forest (forest having >40 percent Crown Density)	1
Sparse Forest (forest having 10 to 40 percent crown density)	2
Bushes (having <10 percent crown density)	3
Open field (meadow and waste land)	4
Cultivated Land	4

Geological Structure

	Categories	Score
1.	Main Central Thrust (MCT)	
i.	500 meter from the Line	1
ii.	1000 meter from the Line	2
iii.	1500 meter from the Line	3
iv.	<1500 meter from the line	4
2.	Fault Displacement:	
i..	250 meter from the Line	1
ii.	500 meter from the Line	2
iii.	750 meter from the Line	3
iv.	>750 meter from the Line	4
3.	Joints/Lineaments	
i.	50 meter from the Line	1
ii.	100 meter from the Line	2
iii.	150 meter from the line	3
iv.	150 meter from the line	4

Existing hazard

Class	Score
1. Landslide zone (200 meter buffer from the edge of slide)	4
2. Deposited site (100 meter buffer from the edge)	4

Map analysis

Slope stability analysis was organized through the step by step procedures to eliminate the PC Hard Disk Space facilitated in the ARC/INFO software (Fig. 2).

Step 1. Different measurable parameters were derived from the base map and run the overlay processes. At the first step four different measured properties namely drainage density, first-order stream frequency, relative relief and slope were considered as the important physical attributes on the terrain. Following linear combination procedure in overlaying these properties provided the maximum score at 34 and the minimum score at 8. The sum of the score of all polygons were divided into four classes as low, medium high and very high respectively on the basis of equal distribution. In this stage the final coverage was produced by the dissolving all previous class identification values and produced the new score coverage according to the range.

Step 2. The outcome of the first step was taken as one single output of the different physical parameters so the other mapping coverage were overlaid over that coverage. From the mapping coverage existing land-use/land cover, geological structure soil texture, slope and seasonal range of water seepage level and exiting hazard were taken into consideration. The scores from the land-use/land cover, soil and geological feature were added with the output of the first step coverage. The geological parameters were separated by buffering of the specified distance. Existing landslide hazard areas were delineated by the buffering with specified distance and the final score of all parameters were added. Finally, the sum of the scores is divided by four to get the equal distribution of the chances. The score in ascending order were arranged for the stable to highly unstable respectively.

NATURAL FACTORS RESPONSIBLE TO HILL-SLOPE INSTABILITY

Hill-slope gradient, drainage density, first-order stream frequency, relative relief, geological fault, lineaments and displacements, seismicity and climatic conditions have been taken under the natural factors responsible for hill-slope instability due to changing on shear strength. Stream side-cutting and existing landslide are another set of natural factors increase the shear stress over the hill-slope materials.

All these factors interact over time, for the most part making slopes increasingly susceptible to failure without actually inducing movement, but sometimes sufficiently affecting the balance to initiate movement. Thus, it is difficult to separate the individual role for slope instability. Gradient, relative relief, drainage network, geological lineaments and seismicity each can play a significant role over time. But the spatial distribution pattern can provide a satisfactory line of assumption of susceptibility. In the Madi Watershed about more than half of the total area falls under the inclination of 60 percent and above. In spite of this, breaking point of valley and hill-side slope and mid-slope and crest slope have more than 100 percent slope and under cliff. All these areas have very delicate 'angel of repose' of hill-relative relief of the area indicates that some of the areas have as high as 800 meter height interval within a one kilometer square grid cell. The length of slope and vertical exaggeration of steepness also provide more susceptibility of hill-slope instability in the basin.

The lithological character of the surface and sub-surface materials provides further information. Extensive area of the region have mica, gneiss, schist and phyllite dominated lithological character. The rocks are highly weathered. The dip-strike angle over the major area have more than 30 degrees. The steep structural bedding plane with highly weathered subsurface are highly prone to failure. The structural joints, displacements and density of lineaments also provide high possibility of instability. Although the areal extension of the study area is small and faults displacement and lineament density can not derive, it provides a lot of logical evidences of slope instability. MCT is the major zone of displacement in this region. This is the major contact zone of Indian continental block in south and Tibetan continental block in north. Because of colloidal zone of two huge and thick continental masses this zone is very sensitive to endogenetic activities along the whole Himalayan territory. (Bhandary; 1987).

The multiple correlation matrix between buffer zone of different geological discontinuities i.e. MCT, fault displacement, and lineaments, and existing landslide distribution followed a positive trend. The regression analysis of these two parameters indicates the X coefficient 0.022 with 0.0134 R square (Fig. 3). This trend indicates that, along with other factors geological faults are playing a considerable role in the hill-slope instability although statistically it is weak.

Because of paucity of long term and detail map of seismicity of Himalayan Region it was not possible to correlate the epicenter and slope instability. In spite of this, many micro seismic tremors were recorded within the basin area (Fig. 4), which have also played significant role in the slope instability.

Climatic variables manly result in internal changes where they stimulate surface erosion. The significance of climate manly relates to the role of water within the ground, i.e, weathering, removal of fines, elevated pore water pressure, but over the

ground it design the drainage courses. Both drainage density and first-order stream frequency are closely determined by the over flow on the ground. The texture and under cutting in the hill-slope depend upon the climatic parameters. Therefore, climatic condition can influence the slope stability directly or indirectly.

In Madi Watershed about 70 to 75 percent of the total annual rainfall (nearly 4,000 mm) occurred within the four month, June to September, of summer monsoon. The amount of rainfall is not evenly distributed within this period also. Both seasonal variation and annual variability posses a significant role in the distribution. Thus, the materials of whole watershed have great chance to vary on pore water weight, under cutting of stream channel and expansion of gullies and rills. All these processes make the hill-slope more unstable.

ACCELERATED FACTORS RESPONSIBLE TO HILL-SLOPE INSTABILITY

Human activities are also extremely important in determining the slope instability of the watershed. Land-use change and land management practices can strongly affect slope stability. Deforestation, terracing, and farming practices are the major rural activities over the steep hill-slope. Directly or indirectly these activities are associated with the slope instability in the hill-slope.

DEFORESTATION

Although the watershed has more than 40 percent area under forest with 40-70 percent crown density, it has some serious problems in deforestation near the settlement location. Settlement units of this areas have large number of housing units. There are four settlements with more than 300 household units, and 11 settlements have more than 100 household units, units out of 38 total settlements units in the basin. Because of the large number of household concentration in a single settlement unit the pressure on nearby forest land is greater due to competition in collection of materials from the common land. The collection of fodder, timber and firewood as well as free grazing inside the forest are the major causes of deforestation in the watershed. Because of the high stress on the forest the thick forest is depleted and has been converted to the scrub and bushes near the settlement areas. Near the Siklesh and Khilang village the bushes were also completely depleted and the area is converted to meadow due to over pressure of both human and animal of the village. The areas nearby these villages are highly prone to failure.

Deforestation or degraded forest provides the direct effect on slope instability. It increases the intensity of physical as well as chemical weathering. Decay of tree roots reduces the cohesiveness of the hill-slope materials. It also helps in increasing pore water pressure. Surface temperature fluctuation can be increased due to the removing of shadow over the ground. Changing temperature ultimately reduce the cohesion of materials beneath the surface. In addition, it undergoes chemical processes such as oxidation and decomposition. Similarly, the decay of roots usually leaves many root rapidly to the storms and eventually resulted the instability on the hill-slope.

TERRACING

It is widely considered that hill-slope terraces are good measures of soil erosion. But this logic seems not to be universally appropriate. The top soil erosion in bench level terraces seems to be lesser than the slopping areas, but the terracing in steep hill-slope as high as 60 percent and above gradient seems to be unbearable for cut and filled load. The edge of the terraces get more load than the back edge (corner). The shear strength of the edge gradually reduced due to the heavy load on cut and filled materials. During rainy season the materials of cut and filled get more wet due to their looseness or compactlesspess. Most of the new terraces are not stabilized, so, the chance of failure is very high in the recently constructed terraces. In the Madi Watershed marginalization of agricultural system pushing the farmers to construct new terraces towards the toe of the old terraces which are highly susceptible to failure. Therefore, most of those terraces slump down after heavy monsoon downpour.

FARMING PRACTICES

Different cropping system, their land preparation and water requirement condition reduce the shear strength of the hill-slope. In the Madi Watershed paddy cultivation terraces are distributed even above 60 percent hill-slope gradient. Levelled bench terraces are required for the paddy cultivation as well as they need certain level of water retention within the terrace. Bench terraces are itself weak in shear strength when the water Load adding in the terraces it affect the stability. The retaining water percolate down the rock strata and it assist the weathering. In the feldspar dominated rock structure the weathering processes in paddy field seems very faster than upland cropping area. The saturated weathered rock multiplied the load of regolith, which can not adjust the slope and start to fail down.

In the Madi Watershed many existing landslides are started from the paddy terraces. The big 'Nang Nung' slide in Taprang, landslide in Khilang and Yangjakot all are the greatest in volume and prominent examples of slope failure in the region are started from the paddy field.

In spite of paddy terraces, 'khoriya' system also very sensitive to slope failure. This is done after the slash-and-burning processes. Due to loosing forest, these areas are more pron to failure. Although the 'khoriya' system is not extensive at present, it is reported by the local people that many former landslide in the bushes and forest were started from this land-use.

DISTRIBUTION OF AREA UNDER DIFFERENT STABILITY CLASSES

The area under Madi Watershed has been evaluated on the basis of above discussed various parameters. The expansion of land is not evenly distributed (Appendix Fig. 5). The table shows that only 48.08 ha or 0.13 percent of the total area under study falls under the stable class. This area is confined in the river valley terraces. Highly unstable class has 2.89 percent of the total area. Except these two extremes nearly 97 percent of the total area is confined in potentially unstable and unstable classes. The potentially unstable class is confined in most of the forest covered area, where human pressure is less and slope is moderately steep to steep. Due to less human pressure and good forest cover the chance of 'slope failure' seems to be less with compare to unstable and highly unstable classes. This class comprises 66.5 percent of the total area of the basin.

Unstable class basically confined in bare land, steep slope, human occupance area and along the geological faults and lineaments. The proportion of unstable land is 30.4 percent of the total.

Table 2: Distribution of area under different slope condition

(Area in hectare)

Stability Class	Area	Percent
Stable	48.08	0.13
Potentially Unstable	24541.70	66.53
Unstable	11225.77	30.43
Highly Unstable	1066.25	2.86
Total	36882.69	100

Source: Analyzed from the different parameters.

From the general pattern of the distribution of area under different stability classes it is revealed that the watershed is not safe from the slope failure. It needs certain level of management in overall areas. Because the proportion of stable area is very small on the one hand and on the other hand the location of those area are along the river courses, which have possibilities of heavy sedimentation from the side hills.

The proportion of the stability classes according to the land-use categories provides the better scenario of the hill-slope condition (Table 3). All the portion of the stable land is confined under the forest coverage, and very high proportion of highly unstable area is under treeless wasteland. Cultivated land also has considerable amount of very high unstable land. The Maximum area of the potentially unstable land falls on both dense and sparse forest coverage. In terms of potentially unstable land Khet terraces have larger extension than Bari terraces. The share of both potentially unstable and unstable slope is high in *Khet* terraces in comparison to Bari terraces.

Table 3: Distribution of Land-use/Land cover by stability of slope

(Area in hectare)*

Land-use/Land cover		Stable	Potentially Unstable	Unstable	Highly Unstable	Total
Forest	Dense forest	42.58 (0.11)	13598.98 (36.87)	17.05.96 (4.62)	5.06 (0.01)	15353.4 (41.62)
	Sparse forest	5.50 (0.02)	4895.16 (13.27)	1207.41 (3.27)	2.08 (0.005)	6110.2 (16.56)
	Bushes	-	2942.28 (9.97)	2142.01 (5..8)	52.02 (0.14)	5137.3 (13.92)
Waste Land, cliff and river courses		-	1093.66 (2.96)	3462.26 (9.38)	505.85 (1.37)	5061.8 (13.92)
Open Land		-	69.47 (0.18)	65.02 (0.17)	5.21 (0.01)	139.7 (0.37)
Cultivated Land	Khet terrace	-	1278.86 (3.46)	1680.30 (4.55)	276.28 (0.74)	3235.4 (8.77)
	Bari terrace	-	663.29 (1.79)	962.81 (2.61)	218.75 (0.59)	1844.9 (5.00)
Total		48.08 (0.13)	24541.7 (66.53)	11225.77 (30.43)	1066.25 (2.86)	36882.7 (100.00)

Source: Land-use/land cover map and slope stability map.
*Figures in parenthesis indicate the percentage of the total.

Table 4: Distribution of area by slope class and stability

(Area in hectare)*

Slope Class (in percent)		Stable	Potentially Unstable	Unstable	Highly Unstable	Total
Valley Bottom	0-5	17.61 (36.63)	387.09 (1.58)	214.35 (1.91)	71.30 (6.68)	690.35 (1.87)
	5-15	17.77 (36.96)	340.97 (1.39)	343.79 (3.60)	160.86 (15.08)	862.54 (2.34)
	15-30	0.06 (0.12)	913.97 (3.73)	611.23 (5.44)	35.47 (33.3)	1560.73 (4.23)
Mid-slope	30-45	0.17 (0.35)	1901.59 (7.75)	1564.08 (13.98)	259.70 (24.35)	3725.54 (10.10)
	45-60	1.92 (3.99)	5472.42 (22.30)	2029.09 (18.08)	285.37 (26.76)	7788.80 (21.12)
	>60	8.89 (18.49)	13587.78 (55.37)	5945.42 (52.96)	237.68 (22.28)	19779.8 (53.63)
Crest Slope	0-5	0.29 (0.60)	433.56 (1.77)	112.57 (1.00)	3.32 (0.31)	549.74 (1.49)
	5-15	1.31 (2.85)	618.98 (2.52)	116.18 (1.03)	0.08 (0.01)	736.60 (2.00)
	15-30	-	886.20 (3.45)	288.96 (2.56)	12.82 (1.20)	1187.98 (3.12)
Total		48.08 (100)	24541.70 (100)	11225.67 (100)	1066.60 (100)	36882.2 (100)

Source: Slope Class Map and Slope Stability Map.
*Figure in parenthesis are in percent.

Table 4 shows that the distribution of unstable slope is increasing with increasing slope gradient. But the very unstable area is highly concentrated on the slope class of 45 to 60 percent. All the slope class above 30 percent have larger proportion of very high unstable area. This is due to the high fragility shown by the combination of all hill-slope parameters.

CONCLUSION

Both valley slope and crest slope have less proportion of unstable area. From this discussion it should be concluded that 30 to 60 percent mid-slope are more fragile and prone to slope failure. Main reason behind this is that those hill-slope classes are extensively distributed in the watershed and which are very close to the human settlement areas. Thus, the accessible slope is under the intensive terracing and the remaining inaccessible land also under the use of livestock and severe affect of the human activities. Therefore, the area has high chance of failure, although the slope is gentle in comparison to above 60 percent. Above 60 percent slope class forest coverage is rather good due to less impact of human and livestock due to inaccessibility, which provide the safety for slope failure. Specially, agricultural terraces have less share of unstable and highly unstable slope condition in comparison to bushes and open land. This is true that agricultural lands are properly managed by the farmers. The open land and bushes are left as common land, where no management activities are effectively running, and the pressure is high. Thus, those land-use coverage have high chances of slope failure.

APPENDIX

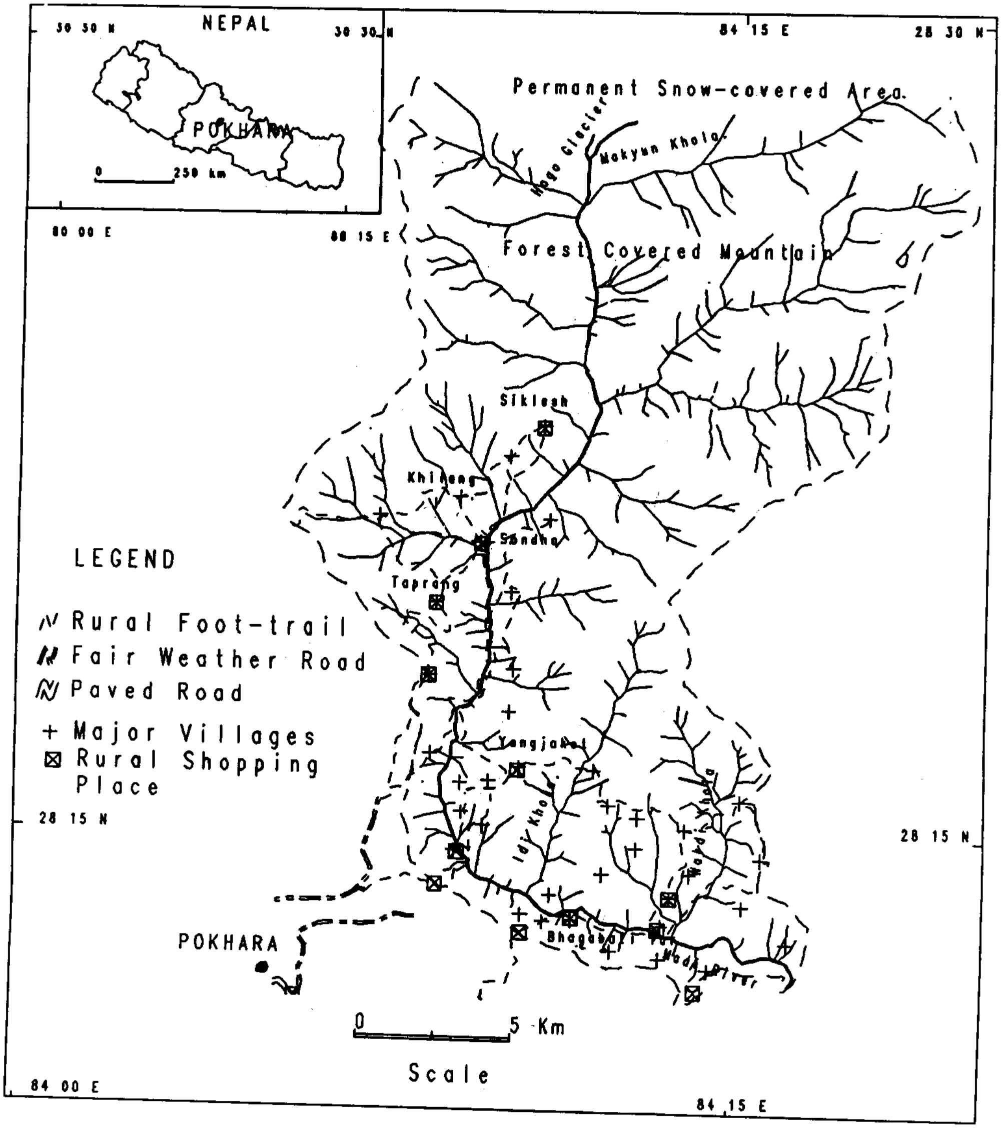


Fig. 1: Location of study area, upper Madi watershed, Nepal

Fig. 2: GIS asssisted model for slope stability assessment

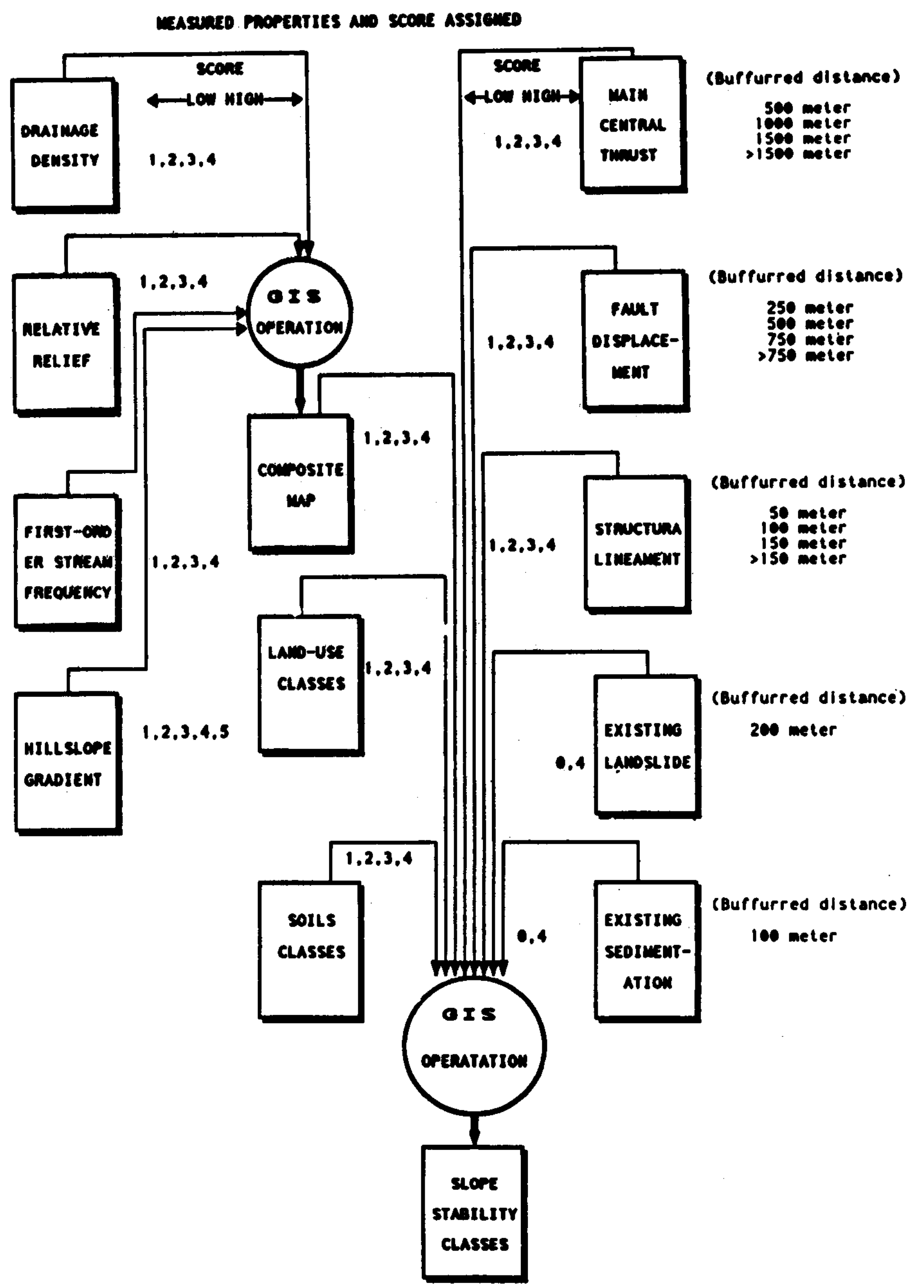
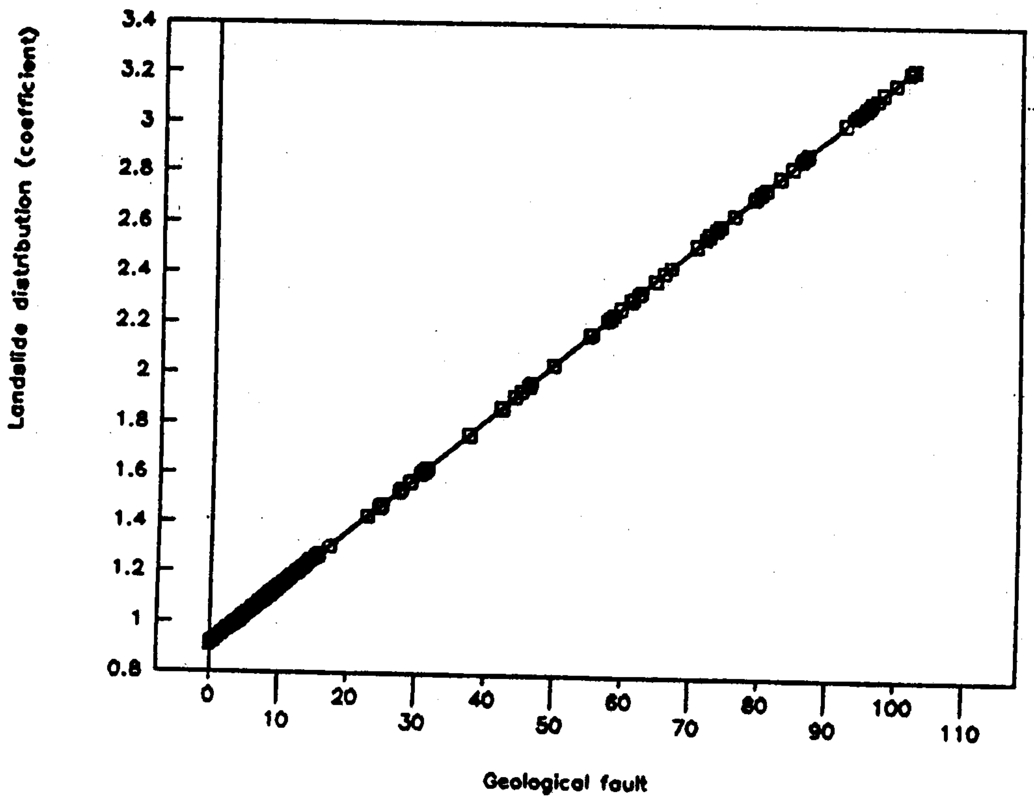


Fig. 3: Best-fit regression line



Regression Output:

Constant	0.9111
Std Err of Y Est	4.9103
R Squared	0.0134
No. of Observations	402
Degrees of Freedom	400

X Coefficient(s)	0.022
Std Err of Coef	0.009

Independent Variable : Geological fault zone
Dependent Variable: Landslide Area

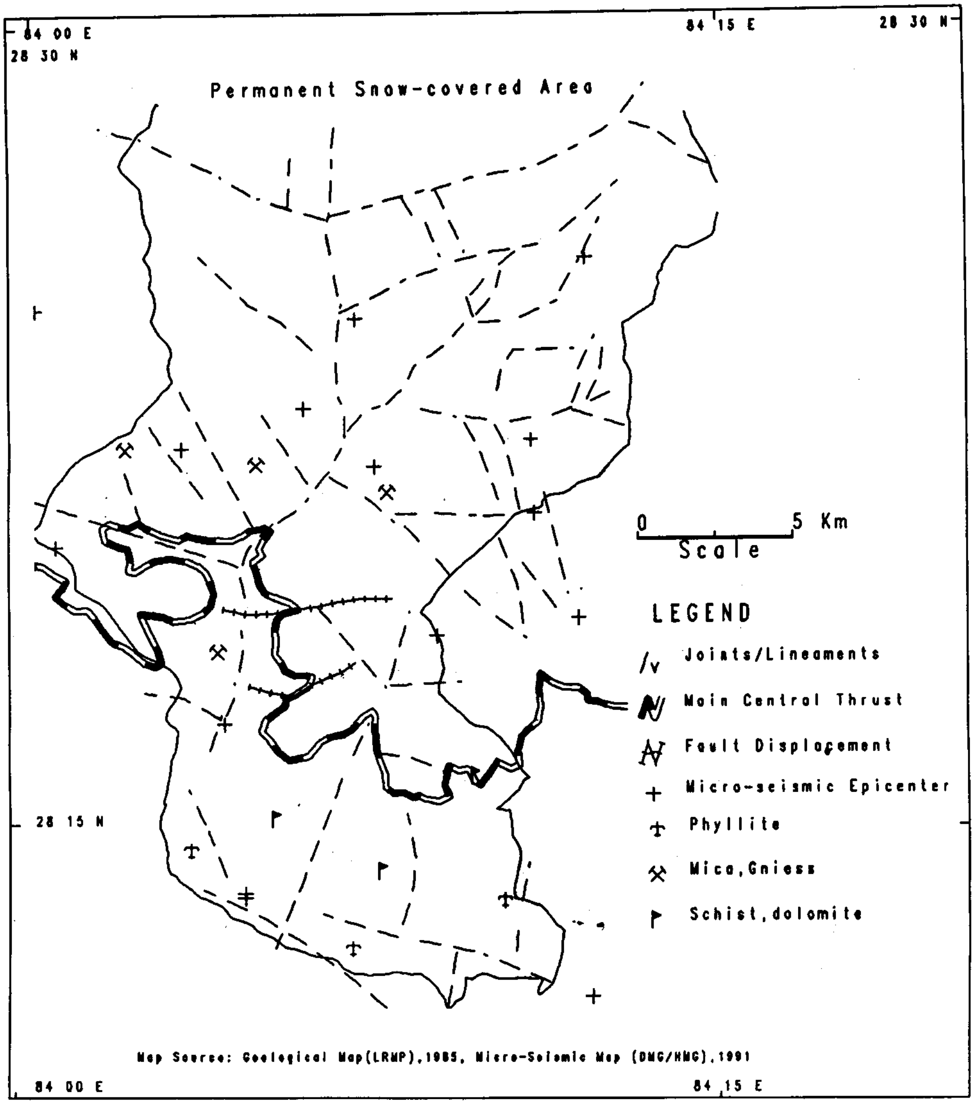


Fig. 4: Geological structure, lineaments and seismisity, Madi watershed, Nepal

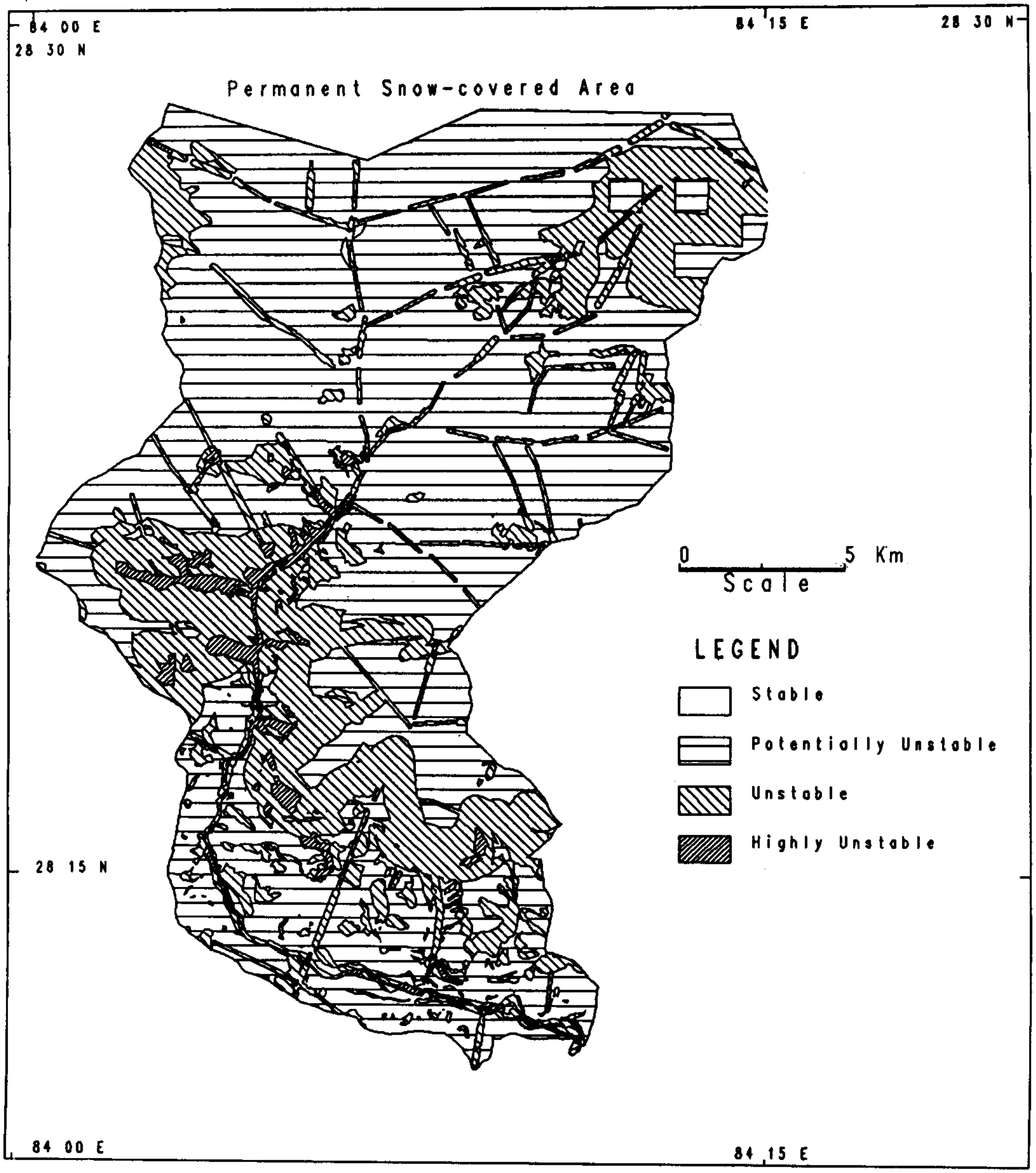


Fig. 5: **Slope stability zonation Madi watershed, Nepal**

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