INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

Landslide Hazard Assessment & Mitigation

DML – 502 Lecture - 3

Subject Code: DML-502
Course Title: Landslide Hazard Assessment & Mitigation

"To understand the mechanisms, mapping, and hazard assessment techniques of landslides for disaster mitigation"

S. No 1

Definition; overview of Hazard assessment techniques on regional, semi-detailed and detailed scales and their application for planning purposes; **terrain classification and mapping methods, use of RS and GIS.**

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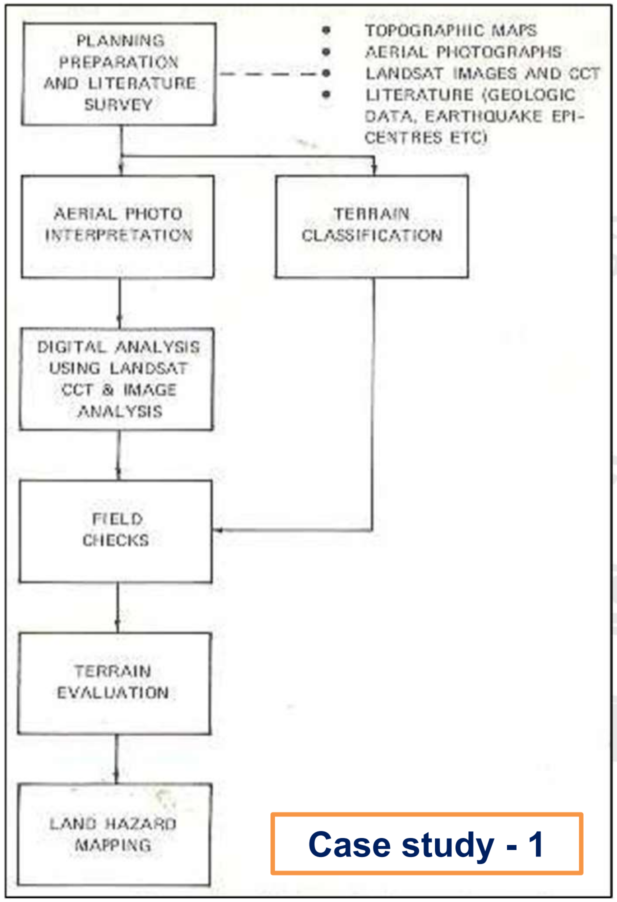
Terrain classification

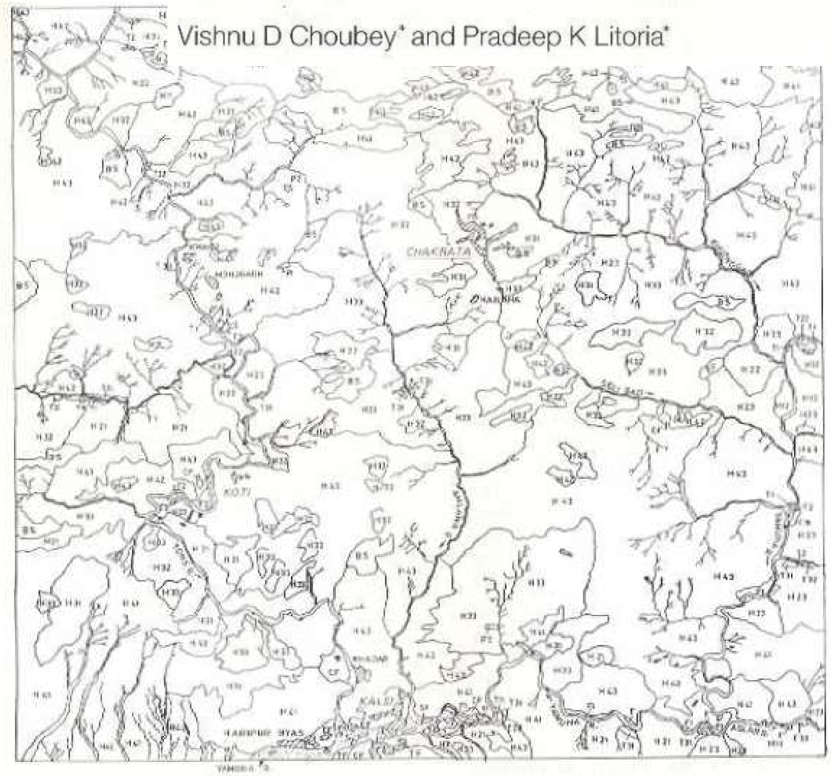
Terrain classification and land hazard mapping in Kalsi-Chakrata area (Garhwal Himalaya), India

Vishnu D Choubey* and Pradeep K Litoria*



Case study - 1

Hazard mapping ITC Journal 1990-91



LEGEND

SYMBOL	PHYSIOGRAPHIC UNIT	LAND USE
H	Hills	
H 1	ESCARPMENT	BARREN LAND
H 2	VERY STEEP SIDE SLOPES	SPARSE FOREST
H 31	STEEP SLOPES	DENSE FOREST
H 32	STEEP SLOPES	SPARSE FOREST
H 43	MODERATELY STEEP SLOPES	TERRACED CULTIVATION
P	Piedmont Plain	
P 1	PIEDMONT PLAIN	DENSE FOREST
P 2	PIEDMONT PLAIN	CULTIVATED LAND
F	Flood Plain	
F 1	FLOOD PLAIN	FORESTED
F 2	FLOOD PLAIN	CULTIVATED

SYMBOL	PHYSIOGRAPHIC UNIT	LAND USE
T	Terrace	
T 1	YOUNGER TERRACE	FORESTED
T 2	MIDDLE TERRACE	CULTIVATED LAND
T 31	OLDER TERRACE	DENSE FOREST
T 32	OLDER TERRACE	CULTIVATED LAND
T 41	UPLIFTED TERRACE	DENSE FOREST
S	Sand Bar	
S 1	SAND BAR	FORESTED
CF	CULTIVATED FIELDS	—
TF	THICK FOREST	—
BS	BARREN SLOPES	—

RIVER BED
LAND SLIDE
RESIDENTIAL AREA

Hazard mapping
ITC Journal 1990-91

Terrain classification

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Vishnu D Choubey* and Pradeep K Litoria*

TABLE 2 The facets of the Kalsi-Chakrata land system

Facet	*Description*	*Slope (o)*	*Number of contours in 1 cm*
1	Ridge	-	-
2	Escarpment/cliff	>60°	>12.5
3	Very steep slope	45-60°	10.5-12.5
4	Steep slope	35-45°	8.8-10.5
5	Moderately steep slope	30-35°	7.2- 8.8
6	Less steep slope	25-30°	5.8- 7.2
7	Moderately gentle slope	20-25°	4.54-5.8
8	Gentle slope	15-20°	3.34-4.54
9	Very gentle slope	10-15°	2.20-3.34
10	Extremely gentle slope	5-10°	1.09-2.20
11	Flat or plain	0- 5°	0-1.09
12	River channels and banks	-	-

TABLE 3 Relationship of land use and physiography in Kalsi-Chakrata area

Physiography	*Land use*
Escarpment/cliff	Usually barren
Very steep slopes Steep slopes	Barren or sparsely/densely forested
Gentle slopes	Forested/cultivated
Piedmont plain	Forested/cultivated
Younger terraces Middle terraces Older terraces Uplifted terraces	Forested/cultivated
Sand bars	Forested/cultivated
Flood plains	Forested/cultivated

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TABLE 1 Main geologic units of the Kalsi-Chakrata area

Geologic unit	*Description*
Subathu	Shales, fossiliferous limestone, quartzites
Blaini, Infrakrol, Krol, Tal	Boulder bed/tillite, slates, limestone, dark shales, impure slaty quartzite, sandstone, red shale, etc
Naghtat	Unfossiliferous sandstones, quartzites, grits, conglomerates with minor beds of clay slates and phyllites
Chandpur	Massive quartzites, highly banded association of quartzite and phyllite
Mandhalis	Compacted quartzite, pyritiferous slates, limestone, highly jointed slates
Deoban limestone	Limestone
Simla slates	Slates with/without nummulitic bands

TABLE 4 Details of lithologic units in different patterns

Pattern	*Lithology*
I	Limestones
II	Slates
III	Compacted quartzites, pyritiferous slates and highly jointed slates
IV	Massive quartzites, banded association of quartzites and phyllites
V	Sandstones, quartzites, grits and phyllites
VI	Tillite/boulder bed, slates, limestones
VII	Shales, sandstones and clay alternations

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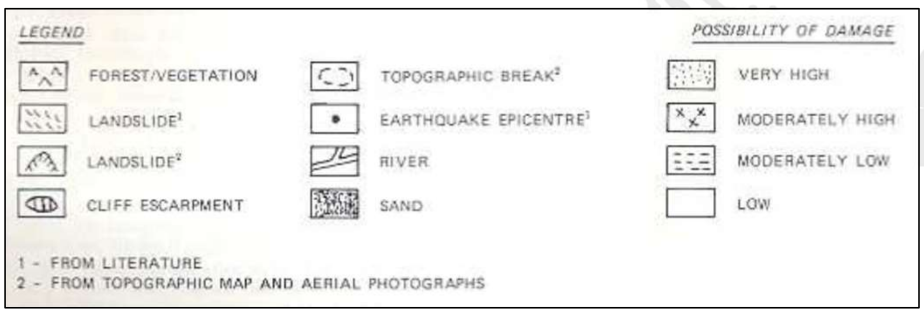

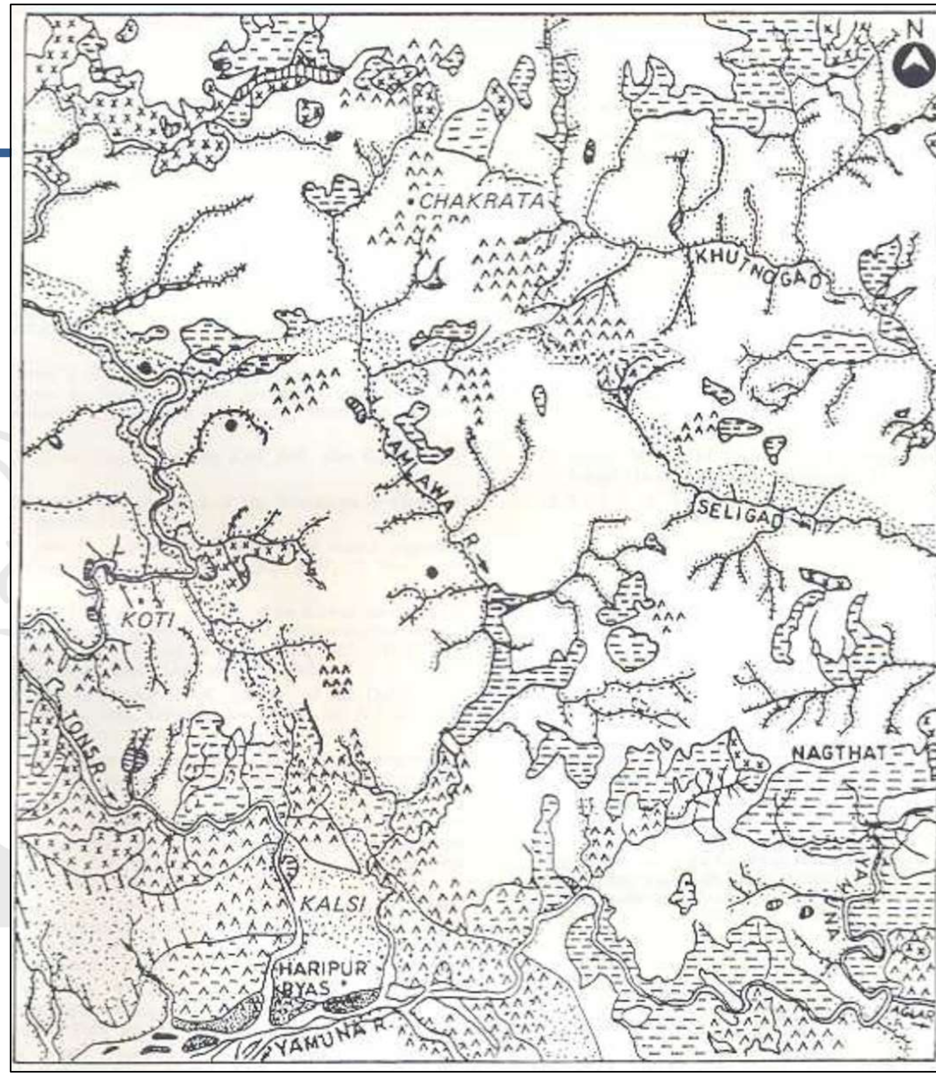

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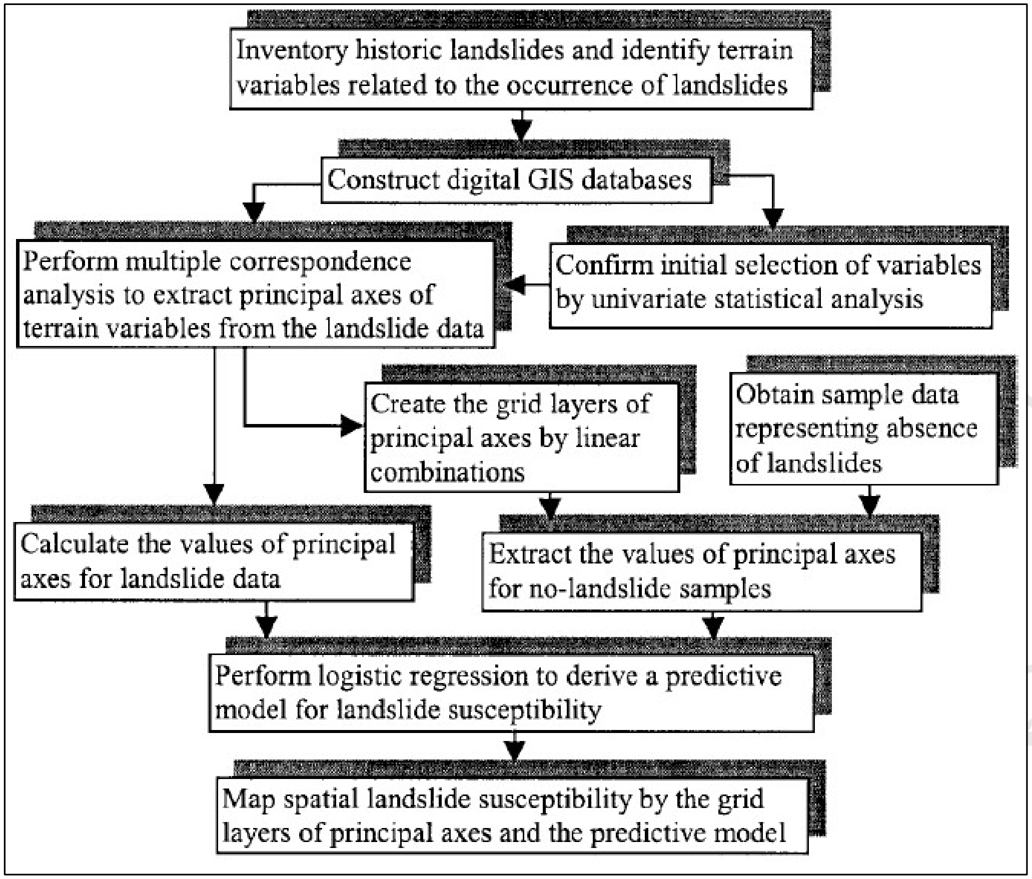
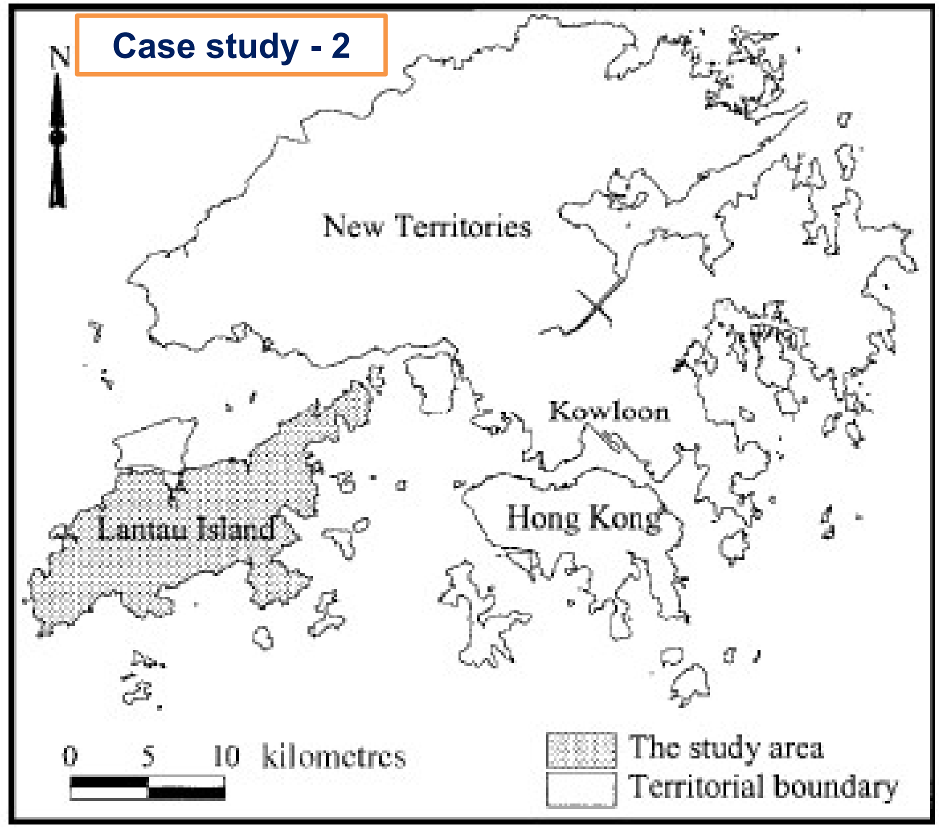
Introduction



Terrain classification and mapping methods



Can. Geotech. J. 38: 911–923 (2001)
 DOI: 10.1139/cgj-38-5-91

Terrain classification

Can. Geotech. J. 38: 911–923 (2001)

Table 1. Terrain variables and categories used for analysis.

Variable	Categories
Lithology	1, superficial deposits (Q); 2, sedimentary rock (SR); 3, metasedimentary rock (MSR); 4, intrusive rock (IR); 5, minor intrusive rock (MIR); 6, ash tuff, tuffite, tuff breccia, and eutaxite (BCT); 7, trachydacite, dacite, and rhyolite lava (TDR); 8, volcaniclastic sedimentary rock (VSR)
Slope gradient (°)	1, 0–15; 2, 15–20; 3, 20–25; 4, 25–30; 5, 30–35; 6, 35–40; 7, ≥40
Slope aspect	1, flat; 2, north; 3, northeast; 4, east; 5, southeast; 6, south; 7, southwest; 8, west; 9, northwest
Elevation (m)	1, 0–100; 2, 100–200; 3, 200–300; 4, 300–400; 5, 400–500; 6, 500–600; 7, >600
Land cover	1, developed land (DL); 2, forested land (FL); 3, shrub – forested land (SFL); 4, densely grassed land (DGL); 5, moderately grassed land (MGL); 6, sparsely grassed land (SGL)
Distance to drainage line (m)	1, <50; 2, 50–100; 3, 100–150; 4, 150–200; 5, 200–250; 6, 250–300; 7, >300

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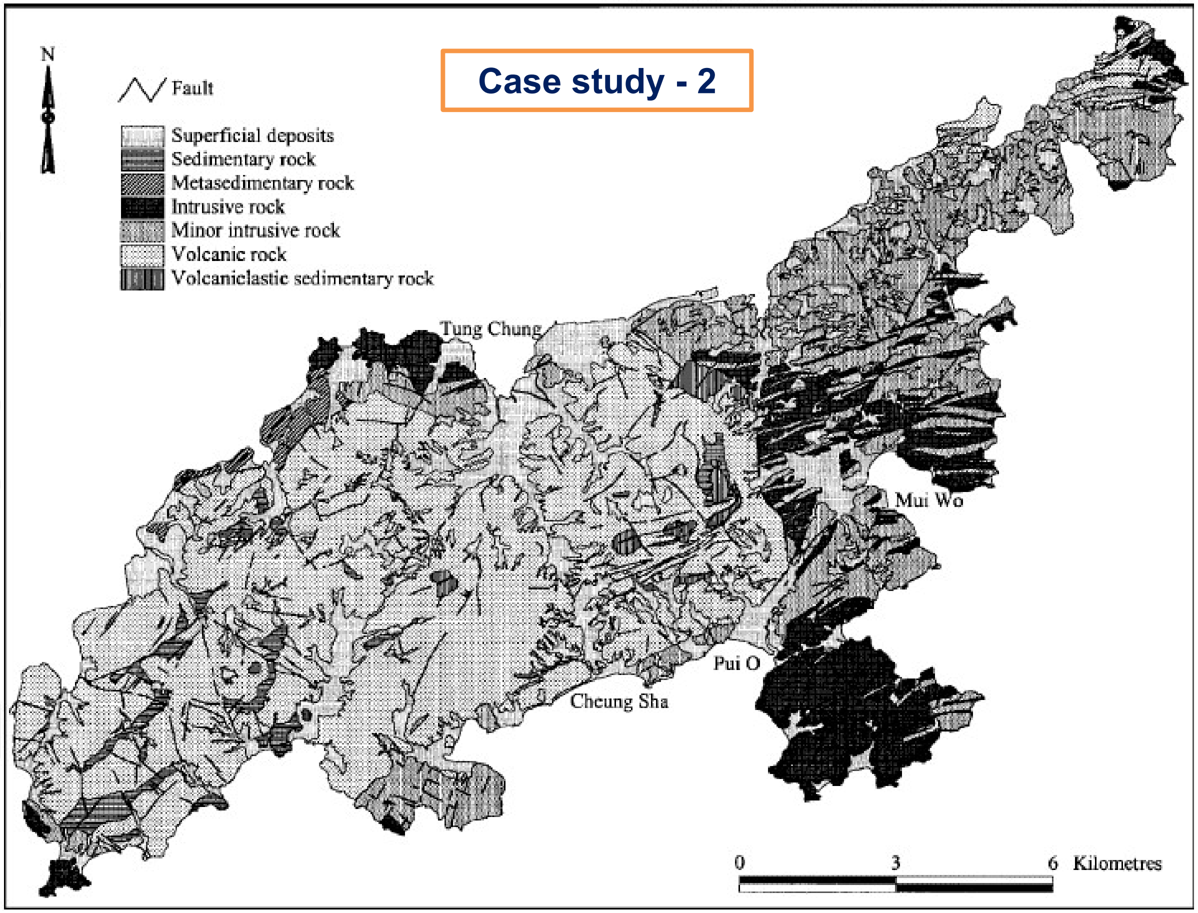
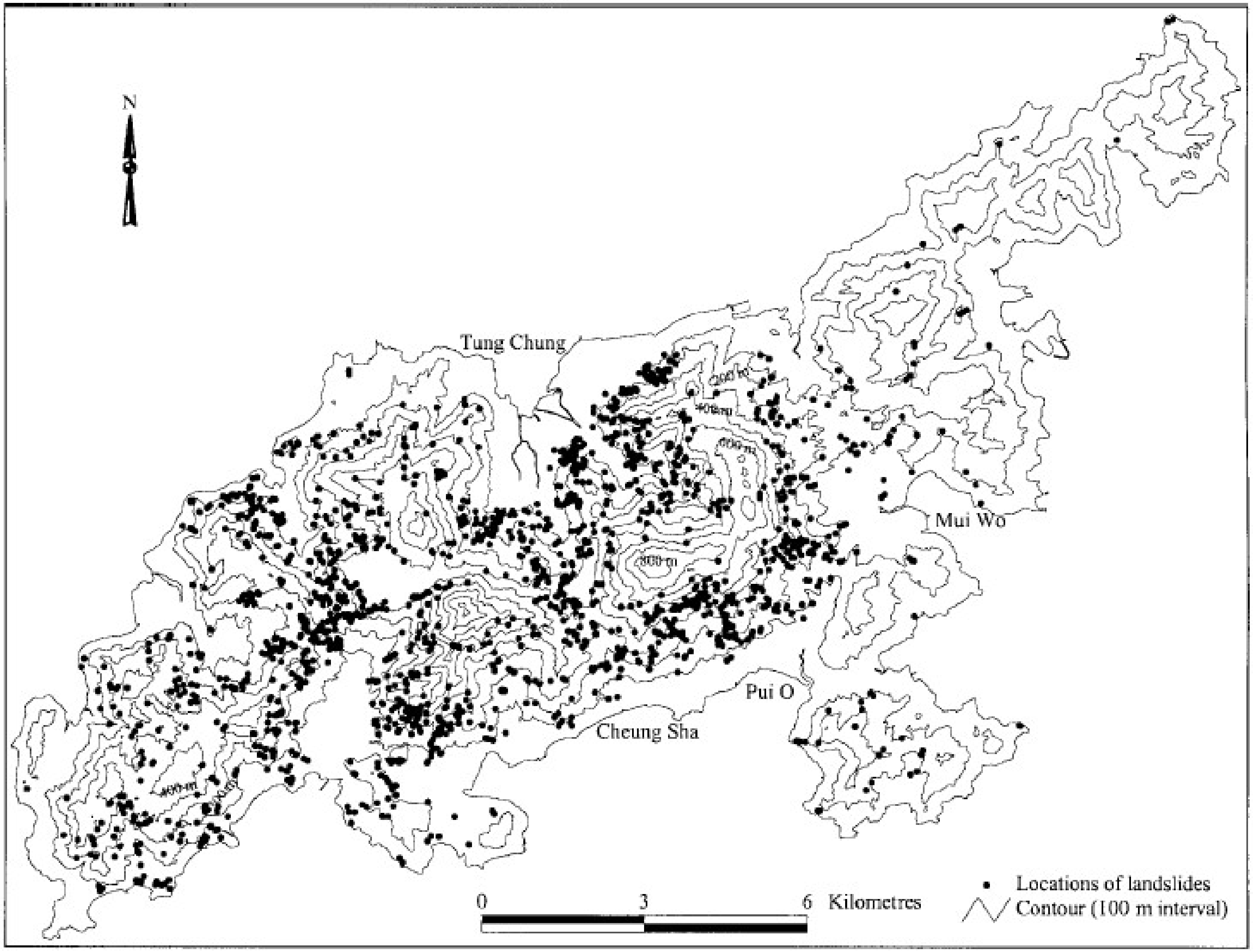


Terrain classification

Case study - 2



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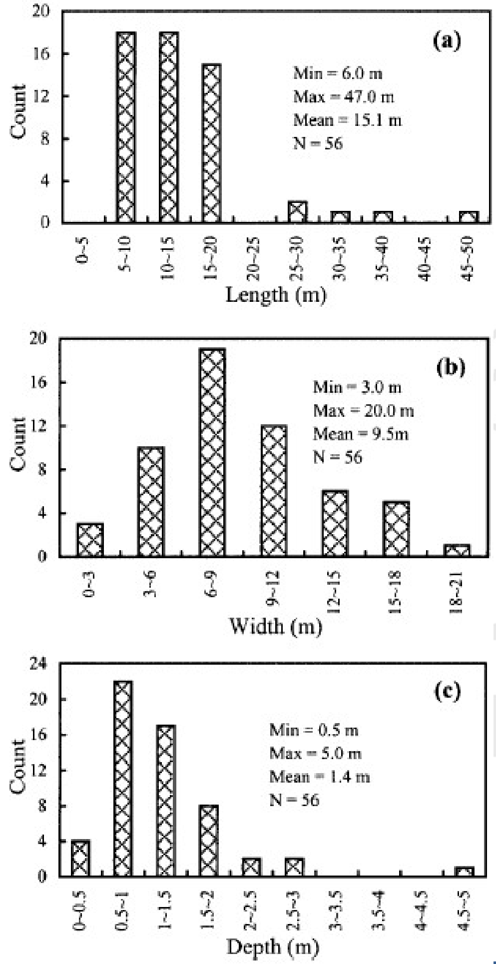

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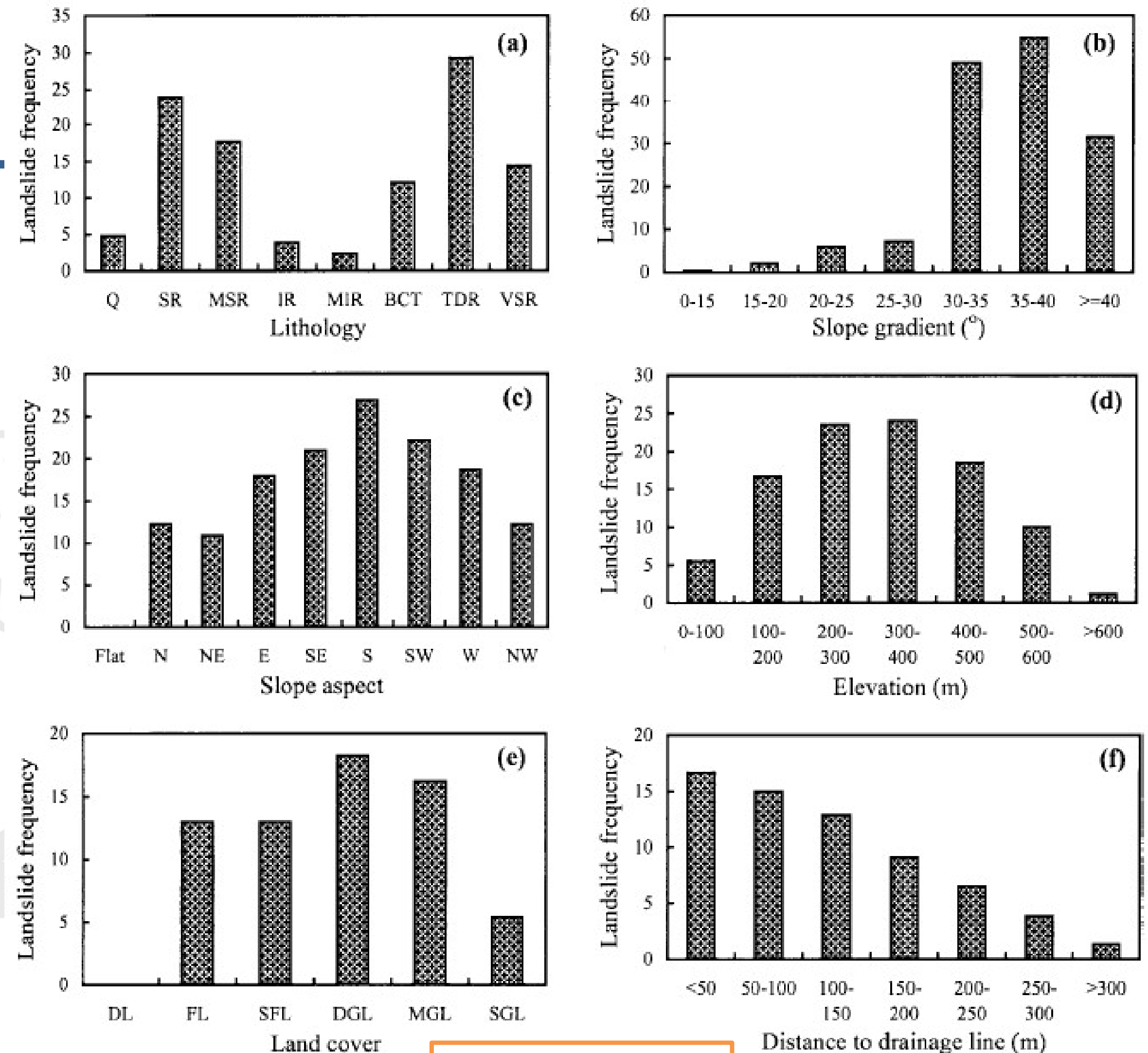
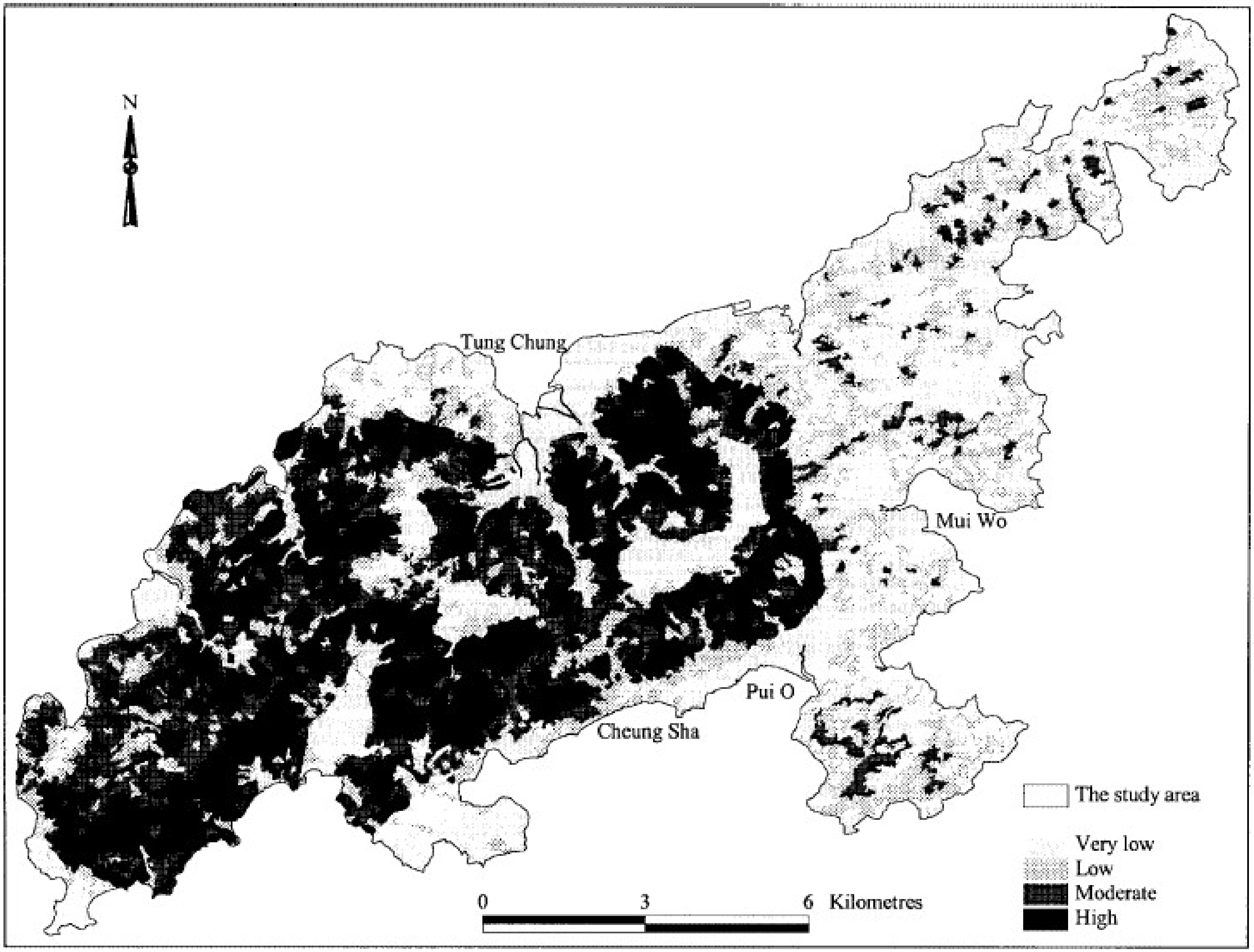


Case study - 2

Terrain classification

Case study - 2



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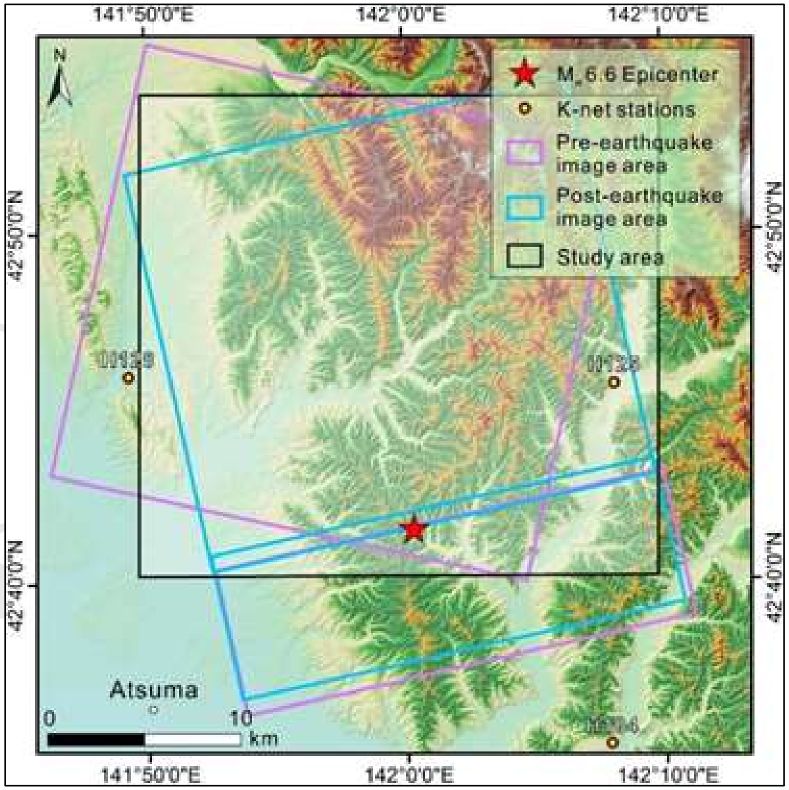
Source, resolution, and metadata information

Factor	Variable	Data source	Original resolution	Resampled resolution
Seismic	Peak ground acceleration (PGA)	Geological survey of Japan	250 m	10 m
	Peak ground velocity (PGV)	Geospatial Authority Institute of Japan (GSI)	Point data	
	Instrumental seismic intensity (INT)			
	Distance to epicenter			
Topographic	Elevation	Geospatial Authority Institute of Japan (GSI)	10 m	10 m
	Slope			
	Curvature			
	Topographic Wetness Index (TWI)			
	Drainage density			
	Distance to river network			
	Topographic Position Index (TPI)			
Tectonic	Distance to geologic faults	Geological survey of Japan		
	Distance to InSAR interpreted (GSI) fault	Geospatial Authority Institute of Japan (GSI)		
Geology	Lithology	Geological survey of Japan	Vector data	10 m
Climate	Hourly rainfall intensity	Japan Meteorological Agency	Point data	10 m
Pre-seismic landslide inventory	Landslide inventory	National Research Institute for Earth Science and Disaster Resilience (NIED)	KML file	

Study area boundary, pre- and post-earthquake coverage map for PlanetScope satellite images, K-net seismic station locations used in the pulse like ground motion analysis.



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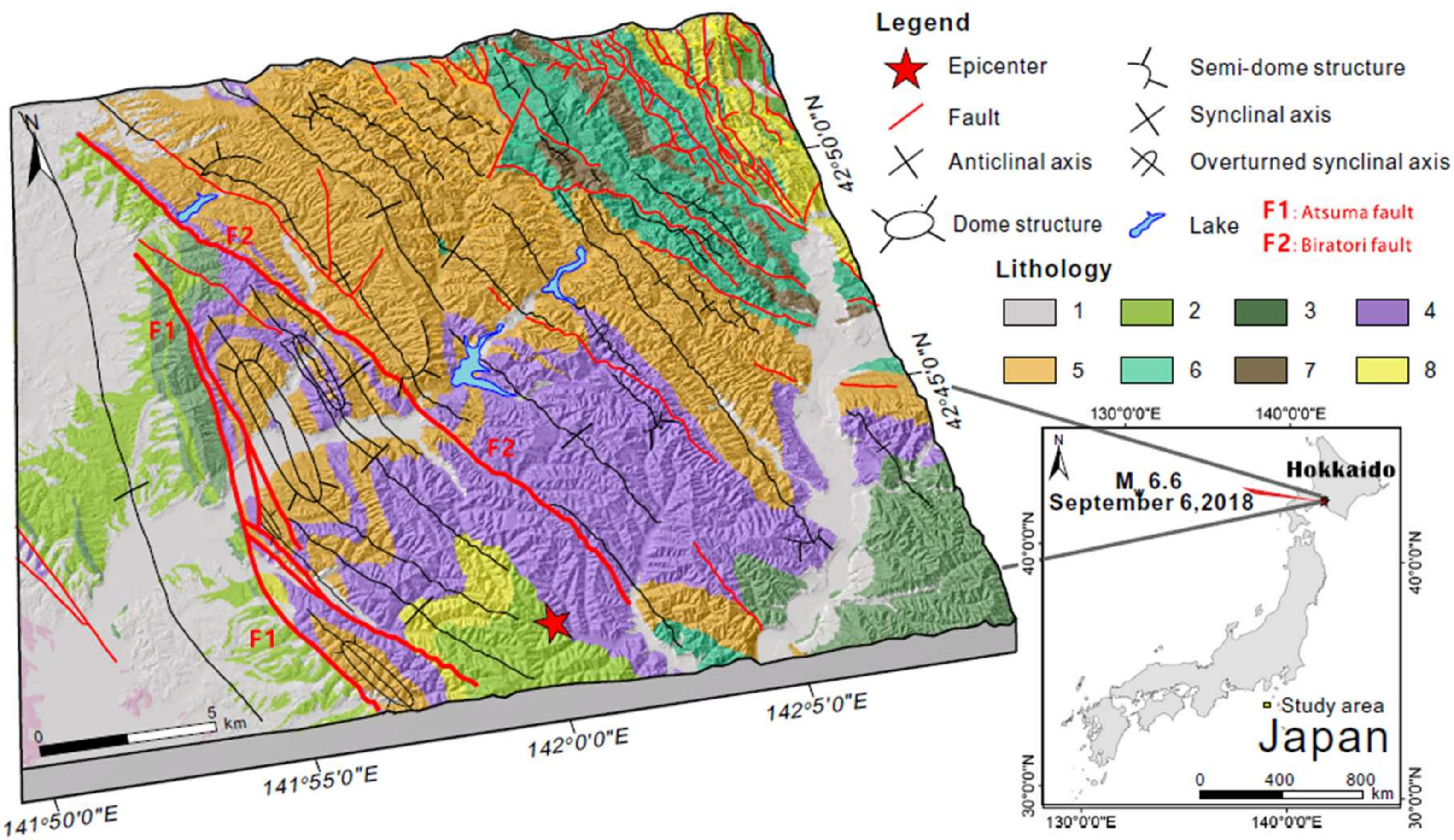

Generalized geological map (1:50,000) of the study area showing faults, structures, and major lithologic units

1. **Conglomerate;**
2. **Altered conglomerate, sandstone and mudstone deposits;**
3. **Mudstone;**
4. **Sand and gravel;**
5. **Shale;**
6. **Sandy siltstone;**
7. **Sandstone, siltstone, and conglomerate deposits;**
8. **Sandstone and siltstone deposits**

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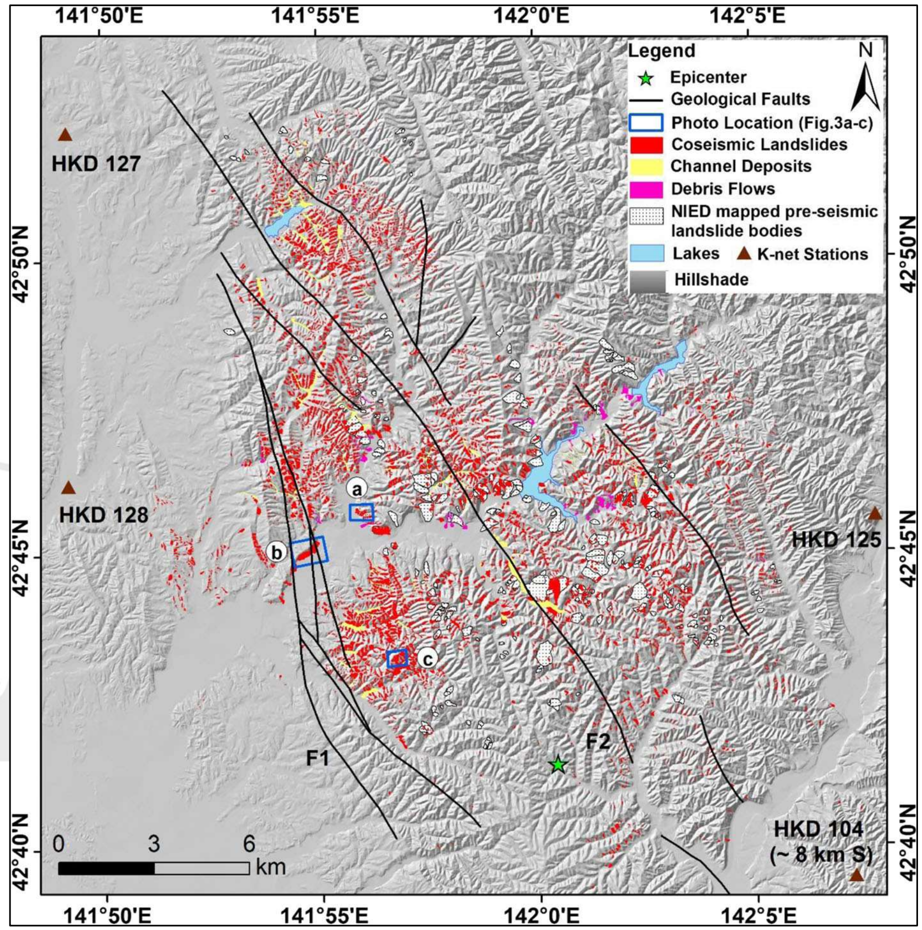
Pre- and coseismic landslides in the study area along with the location of major geological faults, the epicenter of the HEIE and strong motion recording stations considered in this study. Major geological faults were delineated from a 1:50000 geological map.

Table 2 Size distribution and volume estimation for coseismic landslides triggered by the HEIE

Landslide type	Number of landslides	Total area (km^2)	Area (m^2) Min	Max	Avg	^a^Volume (m^3) Vol (i) $\alpha=1.19$ $\gamma=0.19$	Vol (ii) $\alpha=1.31$ $\gamma=0.39$	Vol (iii) $\alpha=1.145$ $\gamma=0.36$
New	7555	22.06	74	54,932	2995	21×10^6	127×10^6	$23–34\times10^6$
Landslides on NIED mapped old landslide bodies	282	1.93	168	85,237	6574	2.3×10^6	15.1×10^6	$2.2–3.5\times10^6$
Total	7837	23.99				23.3×10^6	142.1×10^6	$25.2–37.5\times10^6$

[a] Landslide volume is calculated based on the empirical relationship ($V=\alpha\times A^{\gamma}$) based on three different studies: Vol (i) Imaizumi and Sidle (2007); Vol (ii) Imaizumi et al. (2008); and Vol (iii) Larsen et al. (2010)



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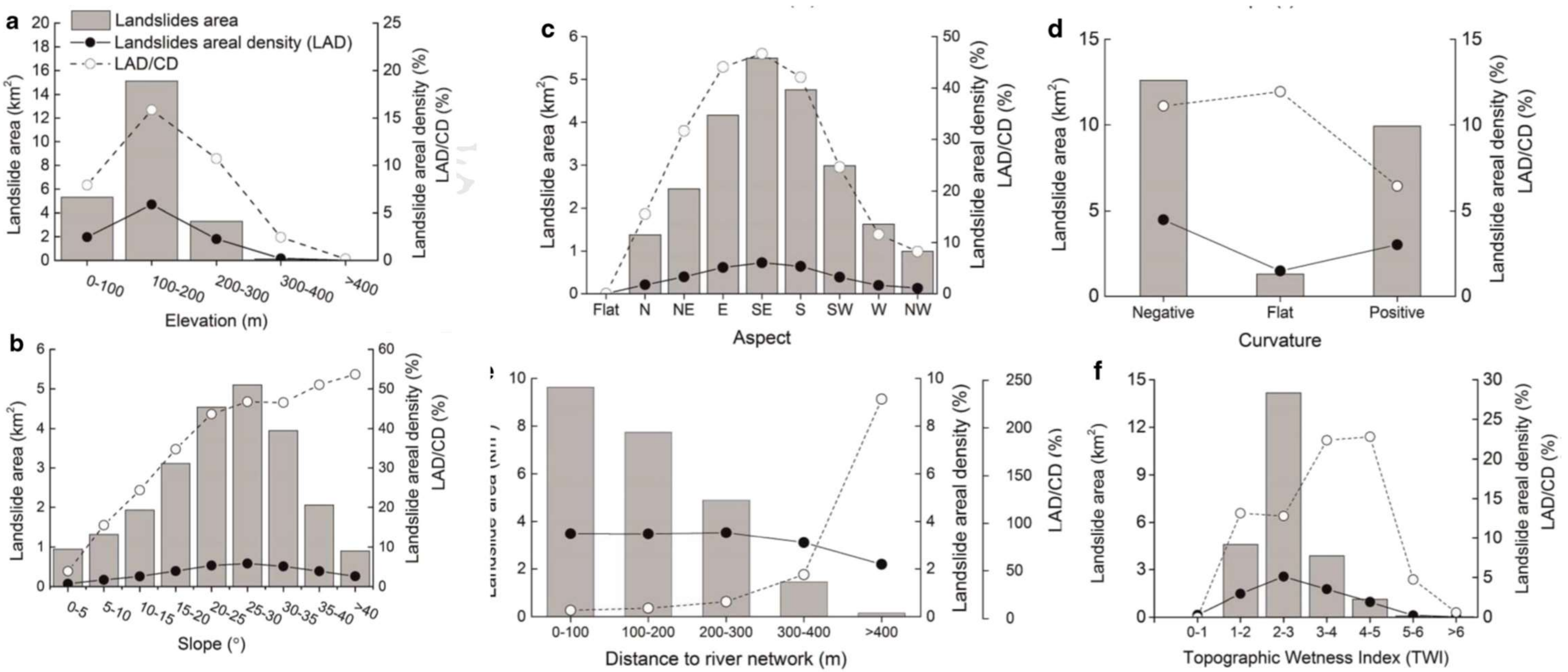

Wang et al., Landslides (2019) https://doi.org/10.1007/s10346-019-01187-7

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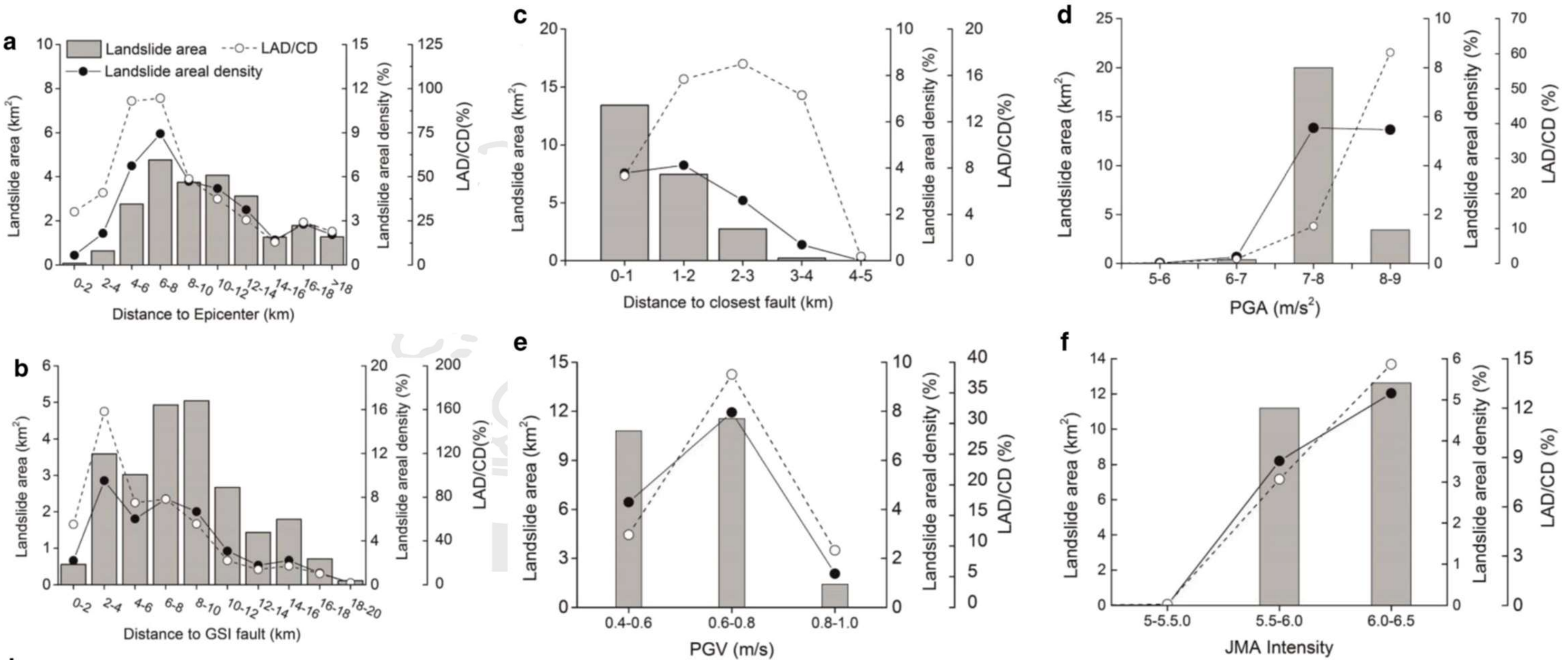

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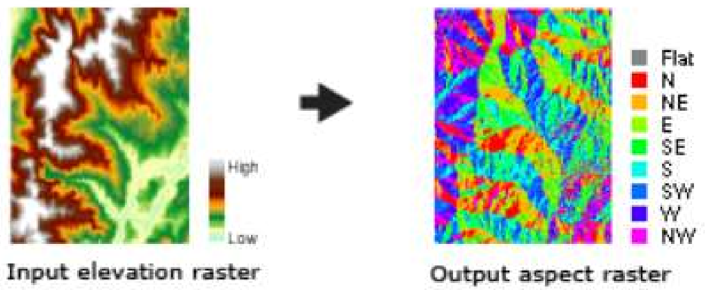
Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbors. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of -1.

Conceptually, the Aspect tool fits a plane to the z-values of a 3 x 3 cell neighborhood around the processing or center cell. The direction the plane faces is the aspect for the processing cell.

The following diagram shows an input elevation dataset and the output aspect raster.



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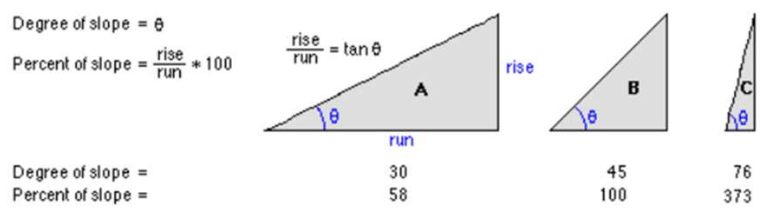
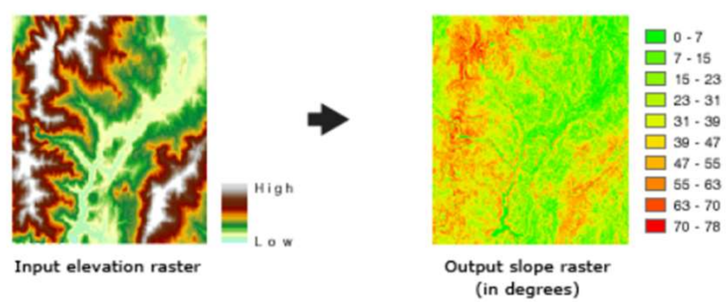
- Slope is the rate of maximum change in z-value from each cell.
- The use of a z-factor is essential for correct slope calculations when the surface z units are expressed in units different from the ground x,y units.
- The range of values in the output depends on the type of measurement units.
  - For degrees, the range of slope values is 0 to 90.
  - For percent rise, the range is 0 to essentially infinity. A flat surface is 0 percent, a 45 degree surface is 100 percent, and as the surface becomes more vertical, the percent rise becomes increasingly larger.

The output slope raster can be calculated in two types of units, degrees or percent (percent rise). The percent rise can be better understood if you consider it as the rise divided by the run, multiplied by 100. Consider triangle *B* below. When the angle is 45 degrees, the rise is equal to the run, and the percent rise is 100 percent. As the slope angle approaches vertical (90 degrees), as in triangle C, the percent rise begins to approach infinity.



Comparing values for slope in degrees versus percent

The Slope tool is most frequently run on an elevation dataset, as the following diagrams show. Steeper slopes are shaded red on the output slope raster.



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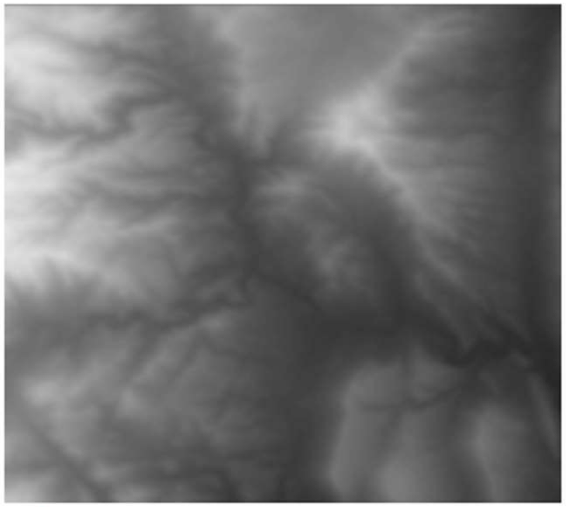
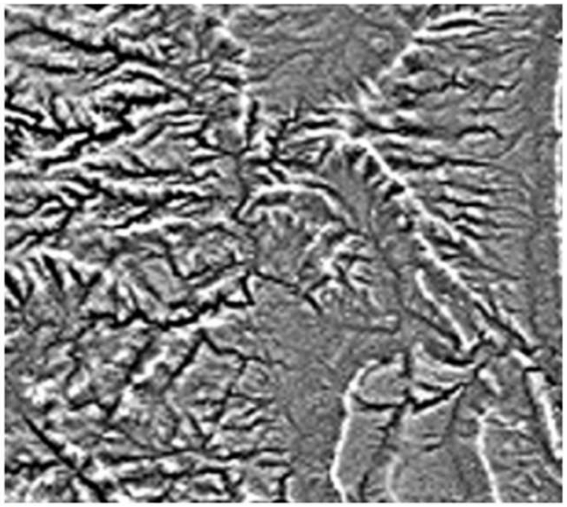
The Curvature function displays the shape or curvature of the slope. A part of a surface can be concave or convex; you can tell that by looking at the curvature value. The curvature is calculated by computing the second derivative of the surface.

The output of the Curvature function can be used to describe the physical characteristics of a drainage basin in an effort to understand erosion and runoff processes. The curvature value can be used to find soil erosion patterns as well as the distribution of water on land. The profile curvature affects the acceleration and deceleration of flow and, therefore, influences erosion and deposition. The planform curvature influences convergence and divergence of flow.



A DEM view of a surface.



The Curvature function surface.

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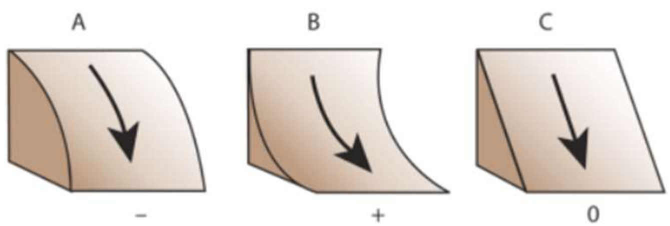
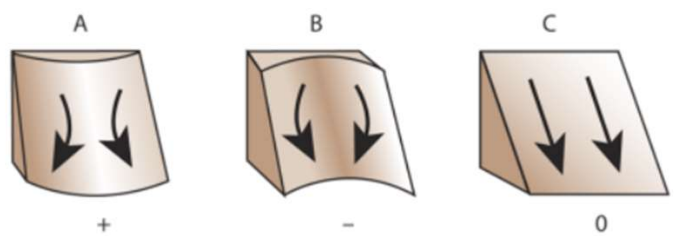
Profile

The Profile curvature is parallel to the slope and indicates the direction of maximum slope. It affects the acceleration and deceleration of flow across the surface. A negative value (A) indicates that the surface is upwardly convex at that cell, and flow will be decelerated. A positive profile (B) indicates that the surface is upwardly concave at that cell, and the flow will be accelerated. A value of zero indicates that the surface is linear (C).



Planform

The Planform curvature (commonly called plan curvature) is perpendicular to the direction of the maximum slope. Planform curvature relates to the convergence and divergence of flow across a surface. A positive value (A) indicates the surface is laterally convex at that cell. A negative plan (B) indicates the surface is laterally concave at that cell. A value of zero indicates the surface is linear (C).



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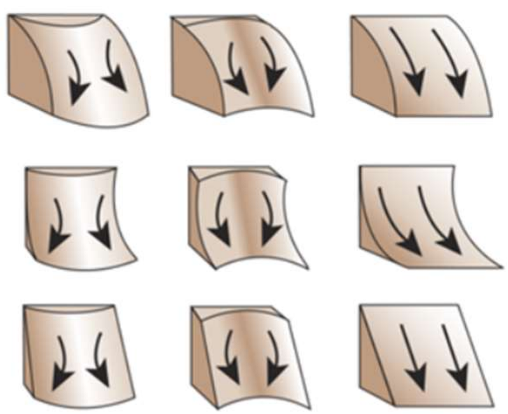
Standard

The Standard curvature combines both the profile and planform curvatures. The profile curvature affects the acceleration and deceleration of flow and, therefore, influences erosion and deposition. The plan curvature influences convergence and divergence of flow. Considering both plan and profile curvature together allows you to understand more accurately the flow across a surface.

In the following diagram, the columns show the planform curves and the rows show the profile curve. The planform columns are positive, negative, and 0—going from left to right. The profiles curves are negative, positive, and 0—going from top to bottom.



Standard curvature generates both profile and planform curvatures.

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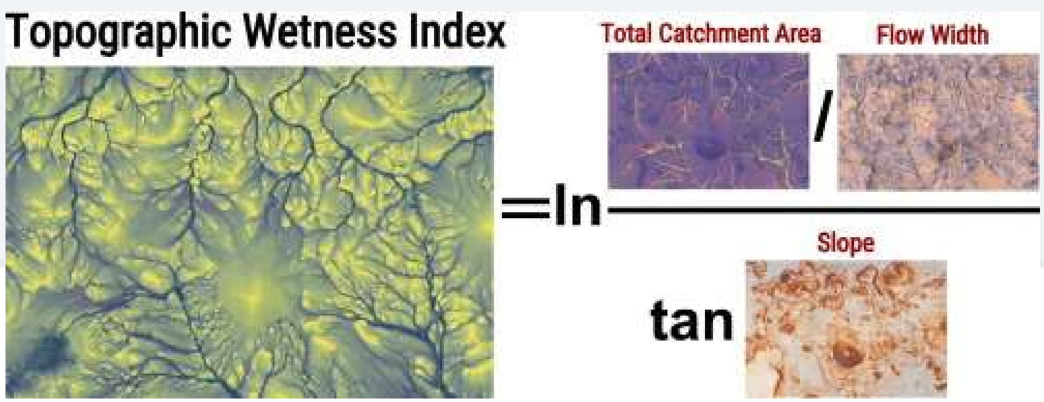
The **topographic wetness index** (**TWI**), also known as the compound topographic index (CTI), is a steady state wetness index. It is commonly used to quantify topographic control on hydrological processes.[1] The index is a function of both the slope and the upstream contributing area per unit width orthogonal to the flow direction. The index was designed for hillslope catenas. Accumulation numbers in flat areas will be very large, so TWI will not be a relevant variable. The index is highly correlated with several soil attributes such as horizon depth, silt percentage, organic matter content, and phosphorus.[2] Methods of computing this index differ primarily in the way the upslope contributing area is calculated.

The Topographic Wetness Index (TWI) is a useful model to estimate where water will accumulate in an area with elevation differences. It is a function of slope and the upstream contributing area:

$$TWI = \ln \frac{a}{\tan b}$$

Where:

a = uplope contributing area (m2)
b = slope in radians.



Science of The Total Environment Volume 757, 25 February 2021, 143785

Wang et al., Landslides (2019) https://doi.org/10.1007/s10346-019-01187-7

Thank you very much for your kind attention and time!

Question time