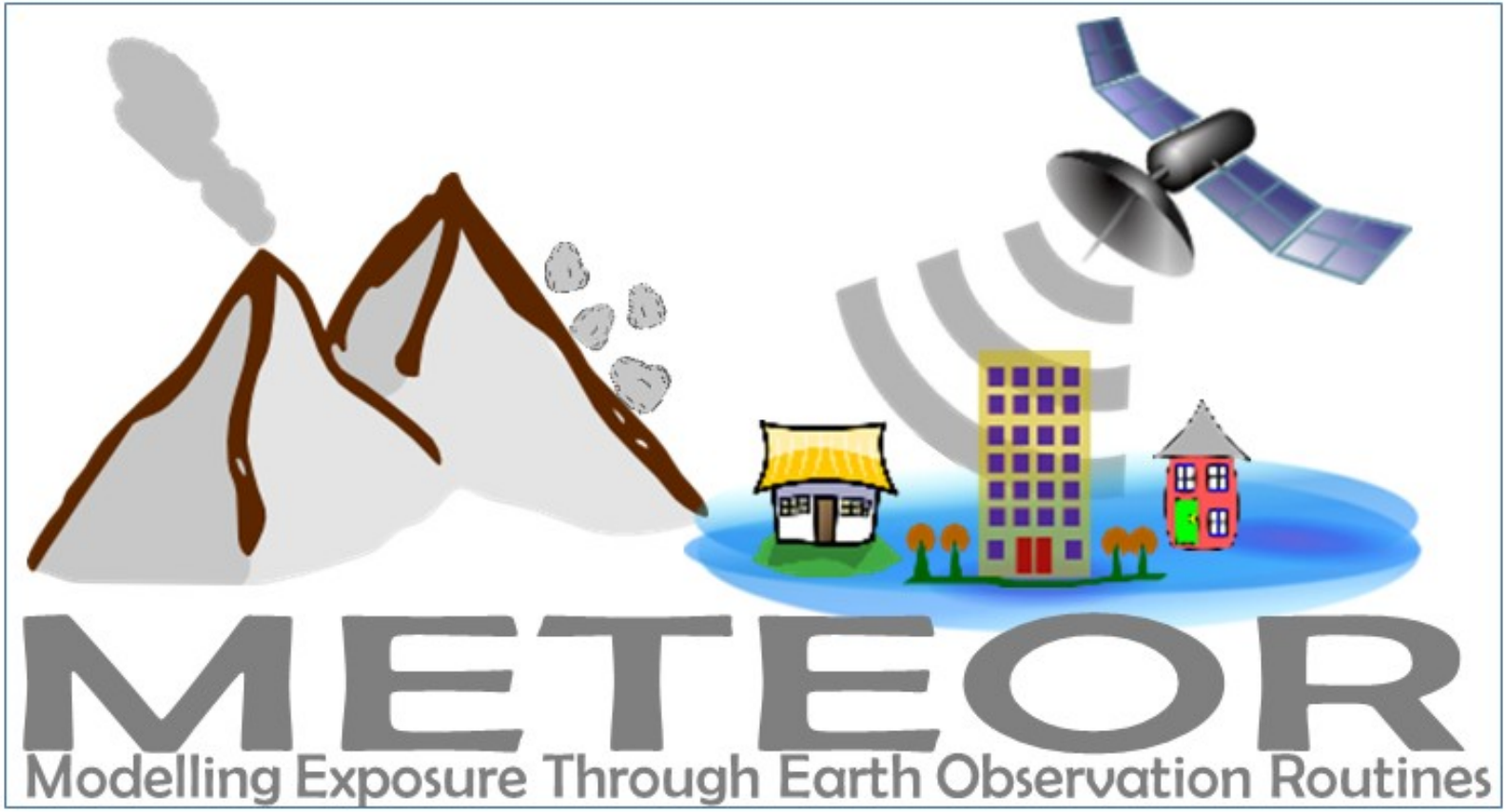
METEOR
Modelling Exposure Through Earth Observation Routines

INTRODUCTION TO LANDSLIDES

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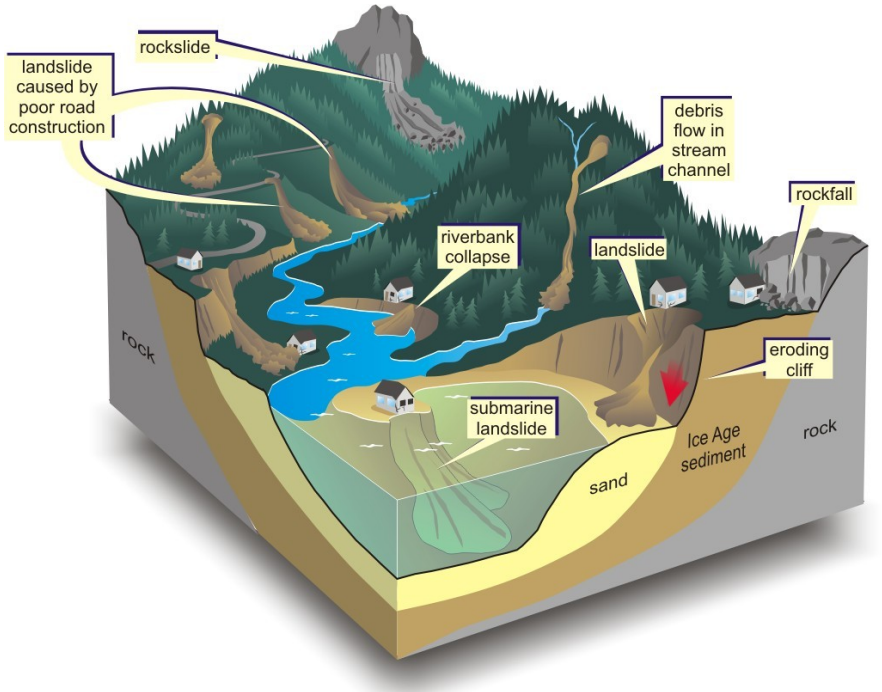
Introduction to Landslides

- What is a landslide?
- How is a landslide classified?
- Example landslides.
- What causes a landslide?
- Landslide inventories.
- Landslide susceptibility mapping.

What is a landslide?



Landslides are a type of "mass wasting" Characterised by down-slope movement of soil and rock under the direct influence of gravity.

“The movement of a mass of rock, debris or earth down a slope”. Cruden (1991)

http://web.mala.bc.ca/geoscape/

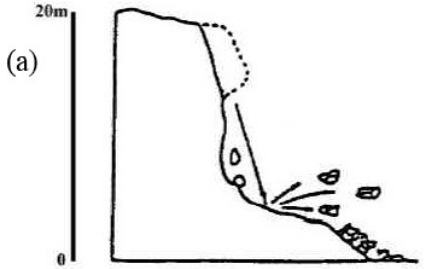
Landslide Classification

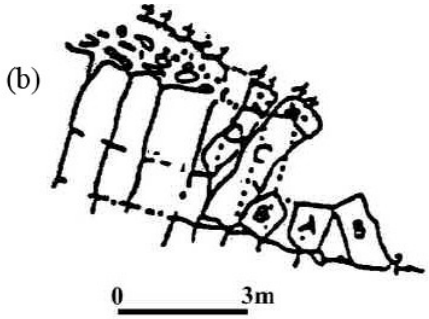
Landslides have been classified on the basis of:

- Type of movement
- Rate of movement (speed or velocity)
- Age/activity of movement
- Commonly used classifications include Hungr (2013), Varnes (1954, 1978), Sharpe (1938) and Cruden and Varnes 1996).

Landslide classification: Type of movement

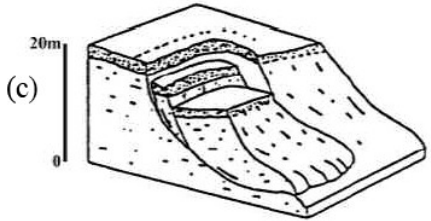
Fall

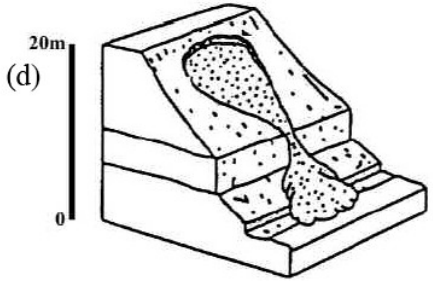




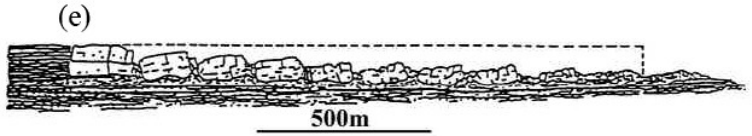
Topple

Slide





Flow



Spread

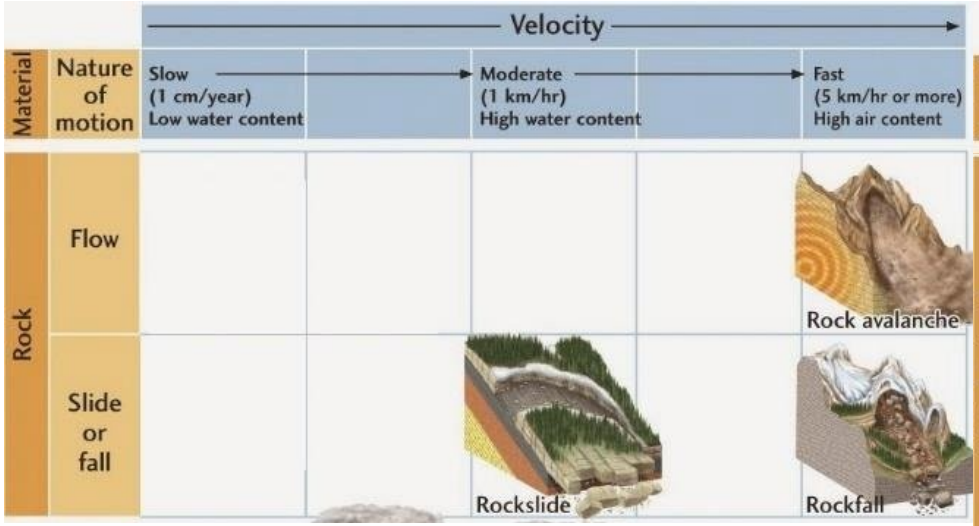
Escario, M. V., George, L.-A., Cheney, R. A. & Yamamura, K. 1997. Landslides: techniques for evaluating hazard. Report of PIARC Technical Committee on Earthworks, Drainage, Subgrade (C12), 12.04B. Paris: PIARC, World Road Association.

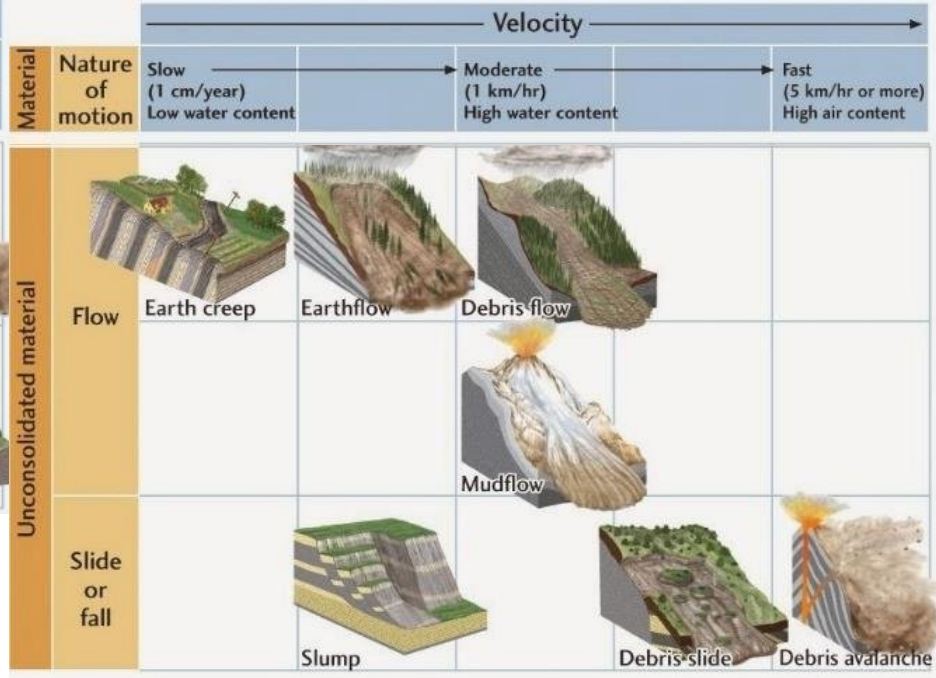
Landslide Classification- material and movement type

Landslide classification (Varnes, 1978) Code: ***RAPID***, SLOW (IN MOST CASES)

	BEDROCK	DEBRIS (<80% sand and finer)	EARTH (>80% sand and finer)
FALLS	***ROCK FALL***	***DEBRIS FALL***	***EARTH FALL***
TOPPLES	***BLOCK TOPPLE*** FLEXURAL TOPPLE	-	***BLOCK TOPPLE***
SLIDES	ROCK SLUMP ***ROCK SLIDE***	***DEBRIS SLIDE***	EARTH SLUMP EARTH SLIDE
SPREADS	ROCK SPREAD	-	***EARTH SPREAD***
FLOWS	ROCK CREEP SLOPE SAGGING	***DEBRIS FLOW*** ***DEBRIS AVALANCHE*** SOIL CREEP SOLIFLUCTION	***WET SAND AND SILT FLOW*** ***RAPID EARTH FLOW*** ***LOESS FLOW*** DRY SAND FLOW EARTH FLOW
COMPLEX	***ROCK AVALANCHE*** EARTH SLUMP-EARTHFLOW		

Landslide Classification: Velocity





http://www.geologyin.com/2015/02/types-of-wasting-slump-rockslide-debris.html

https://meteor-project.org

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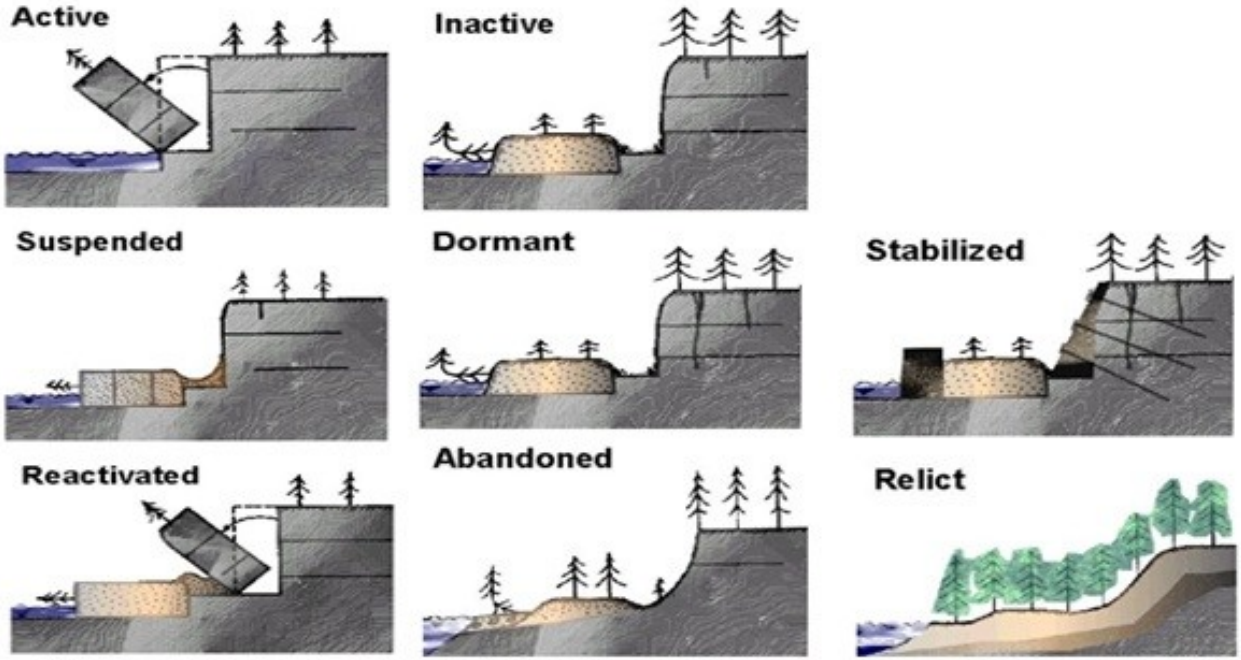
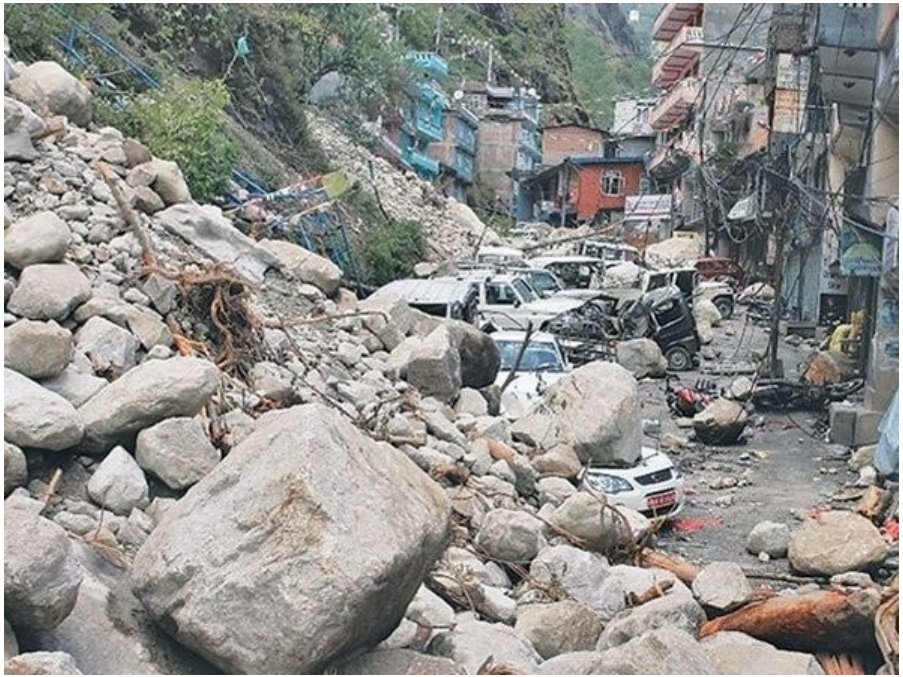
Landslide classification: Activity



www.charim.net

nayapatrikadaily.

Kathmandu Post.



http://www.ekantipur.com/

USGS

https://meteor-project.org

British Geological Survey

ImageCat

NSET

Oxford Policy Management

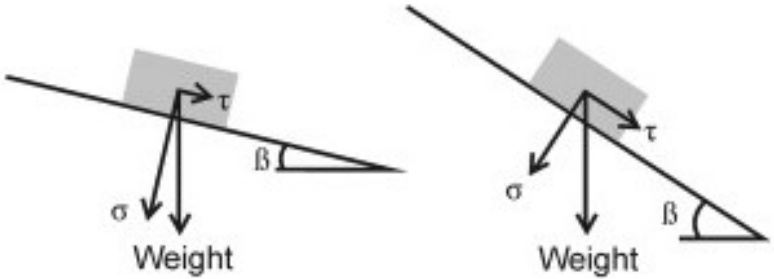
METEOR

Sunkoshi/*Bhote Kosi landslide, Karnali Basin, Western Nepal*

Photo: Landslide

What causes a landslide?

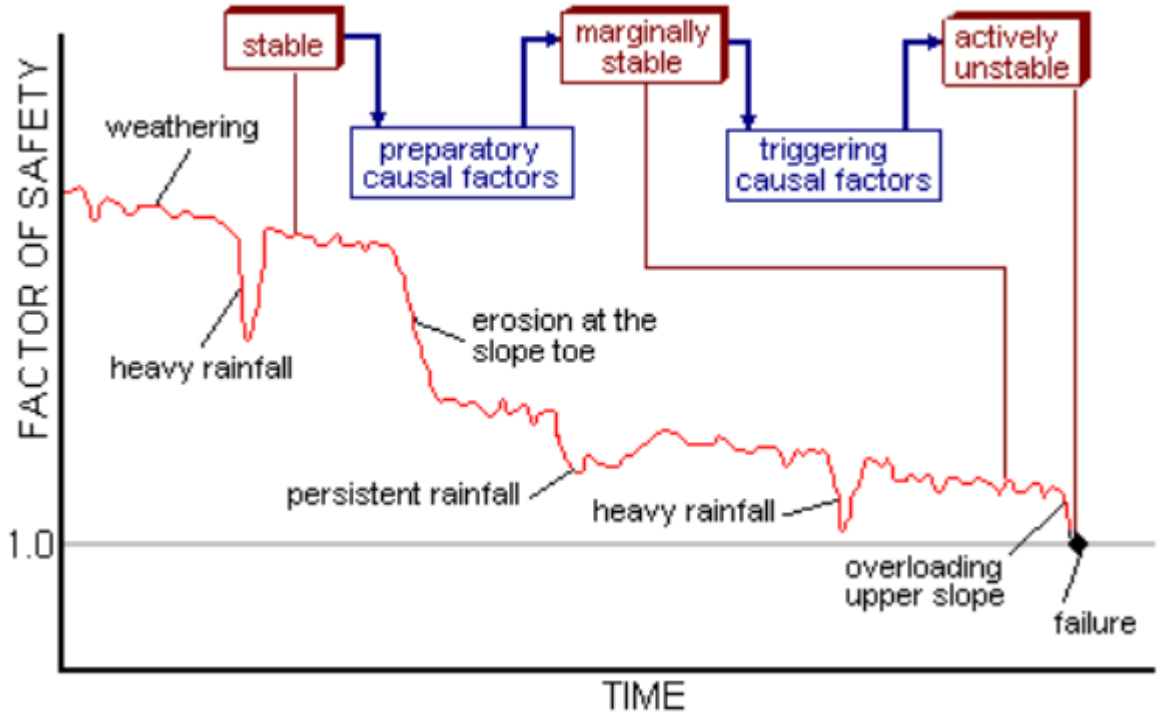
- Slopes are under stress due to gravity- the ultimate cause of all landslides.
- Within a slope there are forces which promote downslope movement and opposing forces which resist movement.
- This block of material is subject to normal stress (σ) which is pushing the block into the hill and shear stress (*t*) pushing the block downhill



McColl, 2015

Landslide Causes

- Preconditioning factors- influence the inherent strength of the slope.
- Preparatory factors- reduce the stability over time but do not cause failure or movement.
- Trigger- factors that change a slope to an actively unstable state (i.e., initiate failure or movement).
- Terzaghi (1950), distinguished between internal changes that induce shear strength reduction, and external causes which give rise to an increase shear stress.
- Often a landslide will have multiple causes- weak geology, steep slopes but one trigger- intense rainfall/seismic activity.



Popescu, 2002

1. GROUND CONDITIONS

- Plastic weak material
- Sensitive material
- Collapsible material
- Weathered material
- Sheared material
- Jointed or fissured material
- Adversely oriented mass discontinuities (including bedding, schistosity, cleavage)
- Adversely oriented structural discontinuities
- Contrast in permeability

2. GEOMORPHOLOGICAL PROCESSES

- Tectonic uplift
- Volcanic uplift
- Glacial rebound
- Fluvial erosion of the slope toe
- Wave erosion of the slope toe
- Glacial erosion of the slope toe
- Erosion of the lateral margins
- Subterranean erosion (solution, piping)
- Deposition loading of the slope or its crest
- Vegetation removal (by erosion, forest fire, drought)

3. PHYSICAL PROCESSES

- Intense, short period rainfall
- Rapid melt of deep snow
- Prolonged high precipitation
- Rapid drawdown (post floods, high tides, breaching of dams
- Earthquake
- Volcanic eruption
- Thawing of permafrost
- Freeze and thaw weathering
- Shrink and swell weathering of expansive soils

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Rainfall Triggered Landslides

Rainfall triggered landslides can be triggered by:

- Storms that produce intense, short duration rainfall events (hours to days)
- Prolonged periods of moderate rainfall (tens of days to months, e.g., monsoon periods).

During storms the rapid infiltration of rainfall and subsequent soil saturation and temporary rise in pore-water pressure can trigger shallow slides.

Intense rains can trigger debris flows in materials with high permeability such as the highly fractured and weathered alternating sedimentary beds of sandstone and mudstone in the sub-Himalayan zone of western Nepal.

Earthquake Triggered landslides

Earthquake induce landslides can occur due to ground shaking, liquification or dilation of sediments.

Strong ground shaking during earthquakes can trigger:

- rock falls or soil/rock slides from steep slopes
- earth spreads or earth slumps are triggered on gentler slopes.

The intensity of earthquake-triggered landslides depends on the magnitude of the earthquake; the higher the magnitude, the greater the landslide intensity it may trigger.

Studies suggest that (a) most landslides are triggered by earthquakes of moderate to high magnitude, and that (b) most of these landslides do not occur beyond a certain distance from the source of the earthquake (magnitude dependent).

Landslide Inventories

A landslide inventory captures the location of landslides in a study area, as point or polygon data.

Inventories can be collected through aerial photograph interpretation satellite image interpretation, direct field mapping, citizen science, social media, news reports.

The techniques employed will be dependent on the scale of the study and its subsequent usage.

There are different types of landslide inventories:

- **Archive inventories-** produced through archives, reports, maps and newspapers.
- **Geomorphological inventories-** historical, event, seasonal or multi-temporal.

Landslide Inventories

Multiple uses for inventory maps were defined by Brabb (1991):

- Documenting the **extent of landslide phenomena** in areas at a range of scales (watershed to National)
- A preliminary **step toward landslide susceptibility, hazard, and risk** assessment
- To investigate the **distribution, types, and patterns of landslides** in relation to morphological and geological characteristics
- To study the **evolution of landscapes** dominated by mass-wasting processes

Landslide Susceptibility Mapping

A quantitative or qualitative assessment of the spatial distribution of landslides which exist or potentially may occur in an area *(Fell et al. 2008*).

- Susceptibility measures the degree to which a terrain can be affected by future slope movements.
- It provides an estimate of “where” landslides are likely to occur.
- Does not provide temporal information on when an event might occur
- The likelihood may be indicated either qualitatively (high, moderate low) or quantitatively (density/km^2).

Landslide Susceptibility Methods

Study area size

Resources

Type of landslide

Qualitative

Heuristic (index-based)

Geomorphological mapping

Quantitative

Deterministic (Process based)

Analysis of inventories

Statistical modelling

Complexity and spatial variability of study area

Objectives of study

Data availabil

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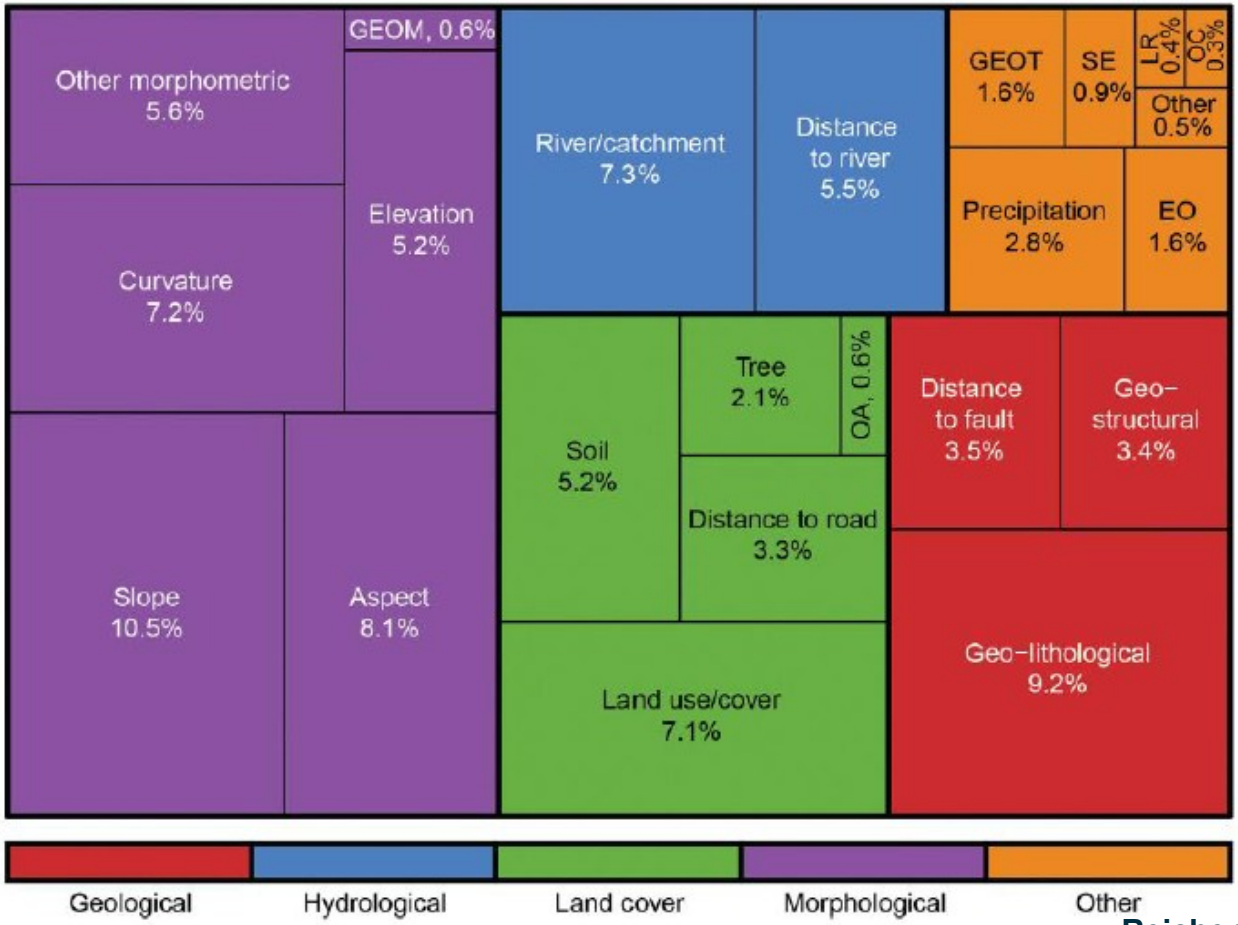

Reichenbach et al, 20

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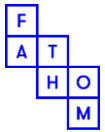

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