BHARATHIDASAN UNIVERSITY

Tiruchirappalli- 620024
Tamil Nadu, India

Programme : M.Tech., Geological Technology and Geoinformatics

Course Title : Geoinformatics in Disaster Management
Course Code : MTIGT0704

Unit-2: Landslides and Slope Stability

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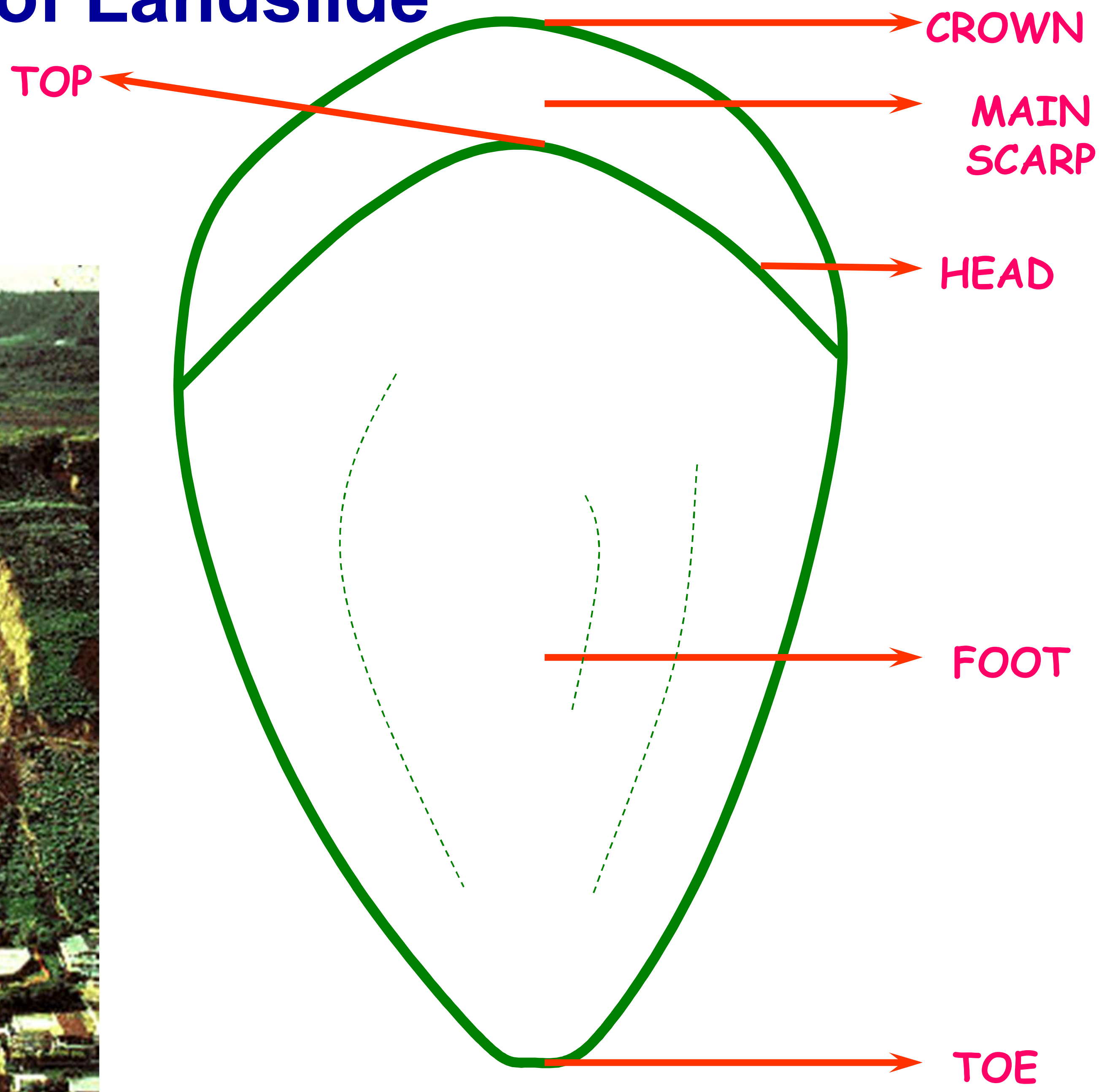
Unit:2. Landslides and Slope Stability: Mass wasting, morphology and classification of Landslides - Causes and triggering factors of landslide: geomorphological, geological, hydrometeorological parameters- Remote Sensing and GIS based Landslide Hazards Zonation Mapping: Integrated Land system Analysis, Information Value, Weight of Evidence, Index Overlay and BIS Methods - Factor of safety - Risk assessment - Mitigation Strategies.

LANDSLIDES

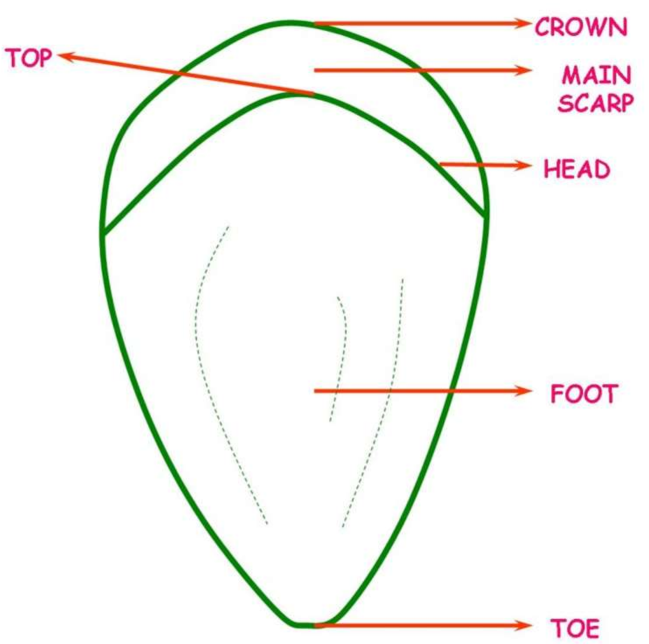
- Landslide is a major geological hazard, which poses serious threat to human population and various other infrastructures like highways, rail routes and civil structures like dams, buildings and other structures
- A Landslide is the downward and outward movement of slope forming materials (Varnes 1953), composed of rock, soil, artificial fills (dumping) or a combination of all these along the surface of separation by falling, sliding, flowing under a fast or slow rate, but under the action of gravitational force and where the triggering factor may be natural or anthropogenic

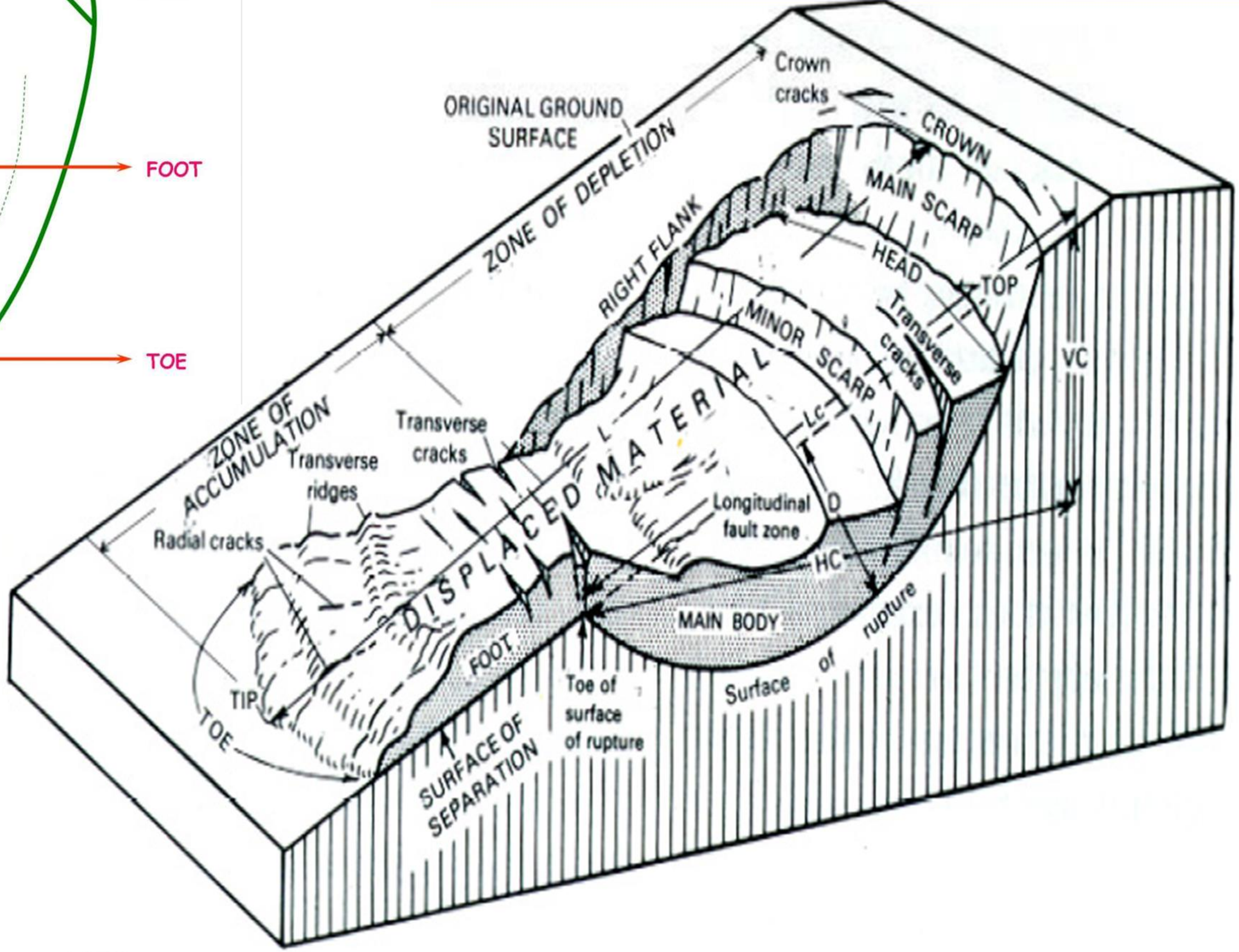
- **The word ‘Landslide’ particularly represents only a type of movements that is slide. However, it is generally used as a term to cover all the types of land movements including falls, creep, spreads, flows and other complex movements.**
- **A correct term to represent all these movements may be ‘mass movement’ or ‘mass wasting’. However, the term ‘landslide’ has been accepted and is being used commonly around the world as a synonym of ‘mass wasting’.**

Morphology of Landslide



Morphology of Landslide

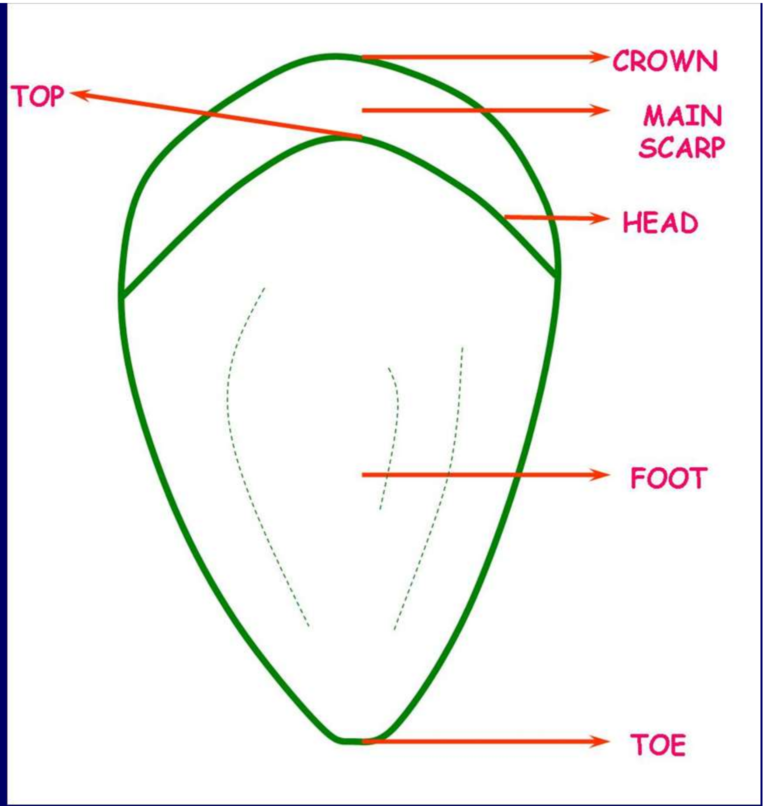


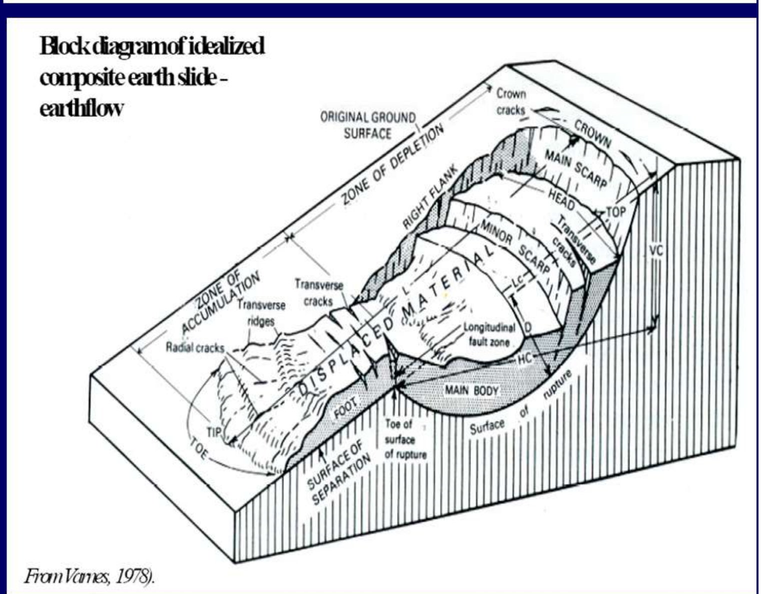


From Varnes, 1978).

Morphology of Landslide

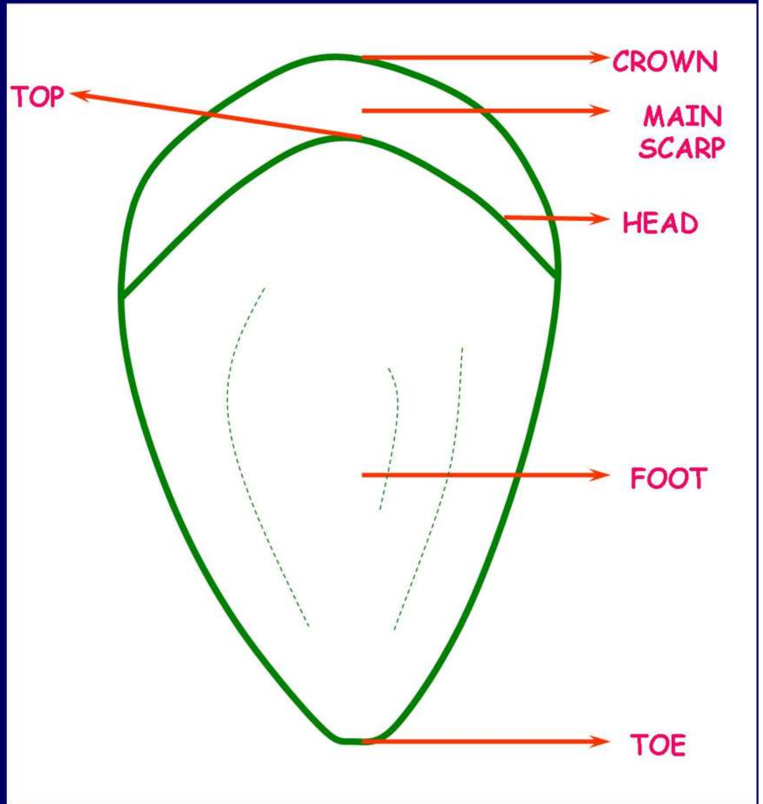
1. **Main Scarp:** It is generally a steep surface on undisturbed ground around. The continuation of scarp face under the disturbed materials is called surface rupture.
2. **Minor Scarp:** It is also a steep surface on disturbed material produced by differential movements within the sliding mass.
3. **Crown:** The highest point seen on main scarp is called crown
4. **Head:** It is the upper portion of slide material which is in contact with main scarp
5. **Top:** The highest point of contact of the slide material with main scarp is called



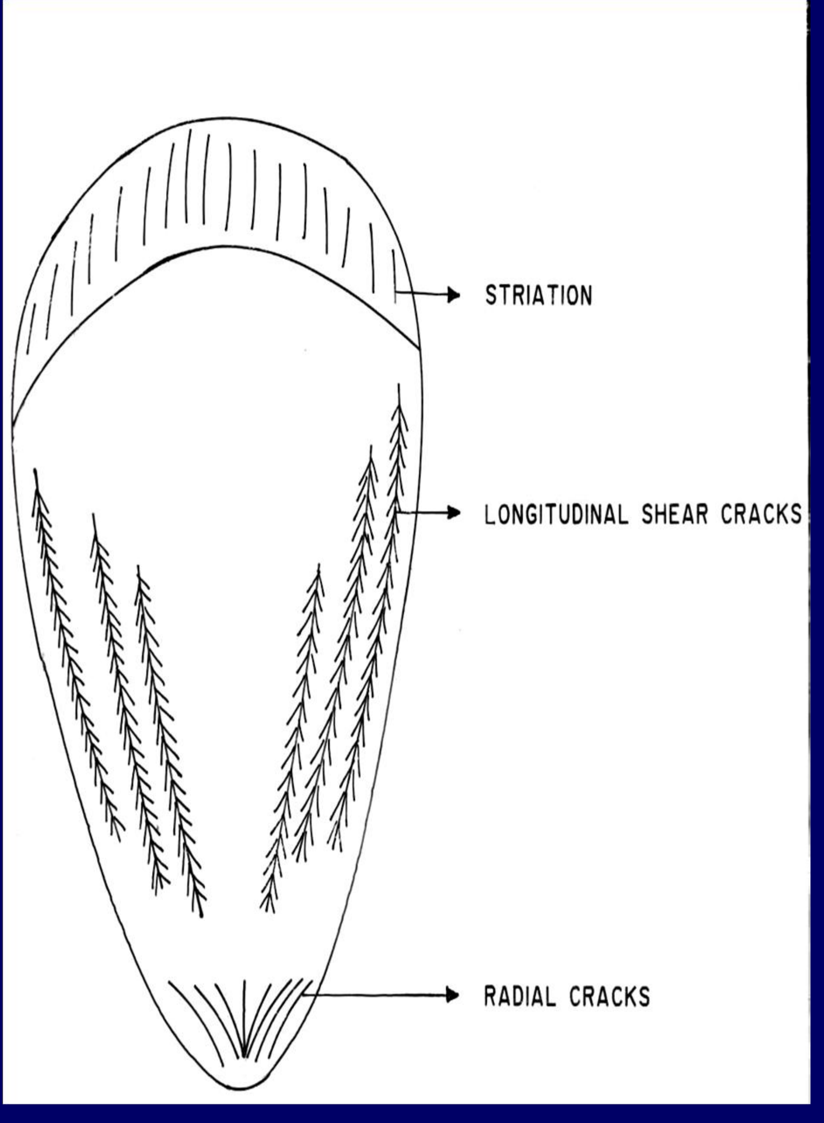


Morphology of Landslide ……..

6. **Toe:** **It is the line of intersection between the lowest part of surface of rupture and original surface**
7. **Foot:** **The portion of landslide that has moved beyond toe and lies over the original ground surface**
8. **Tip:** **The lowest point on the foot of landslide**
9. **Flanks:** **The sides of a landslide are called flanks. The left and right sides of landslides are termed as left and right flanks respectively**



Cracks and Fissure



Over the ruptured surface:

- striations in the direction of movement

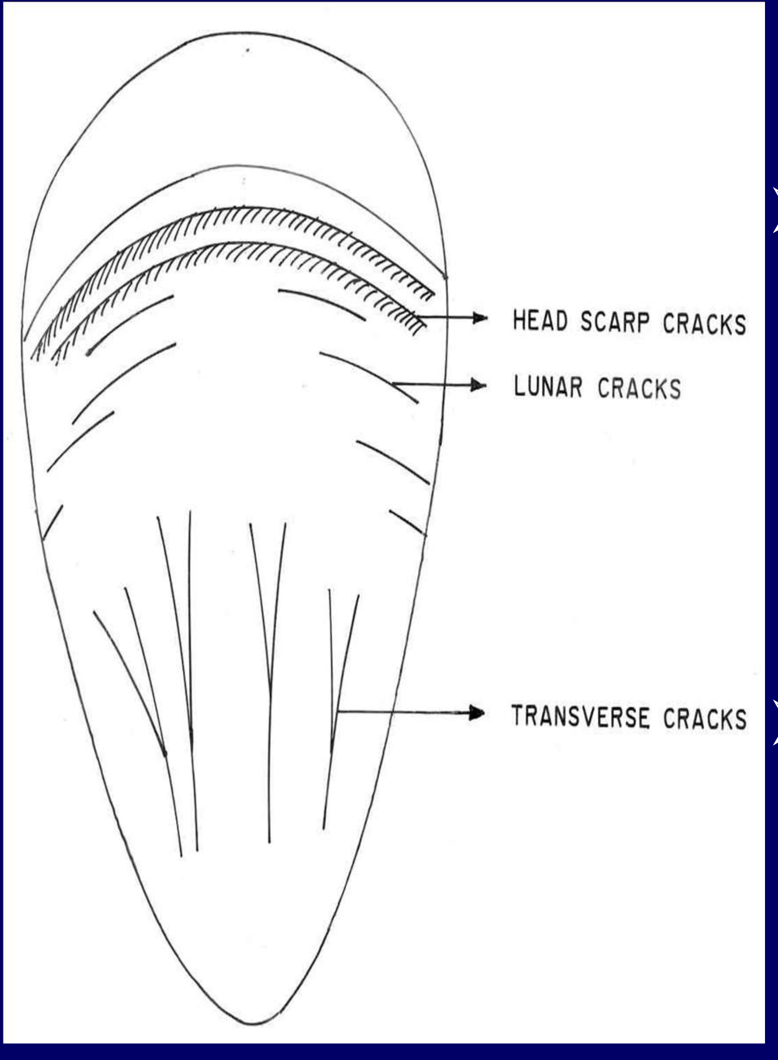
Flank area:

- Longitudinal shear cracks develop with minor lateral ridges squeezed out

Toe:

- Occasionally display radial cracks in relation to its arcuate outline

CRACKS AND FISSURES:



- **Near the Head scarp area:**
  - Curvilinear ruptured surface with slips
- **Over the root area:** (Lunar Cracks)
  - Perpend. to the direction of movements
  - enechelon downward from root area indicate the lateral extent of landslide
  - Appear before actual landslide
- **Over the displaced material:**
  - Set of transverse cracks
  - Opened up in the upper part
  - Closed / deformed in the lower part

CLASSIFICATION OF LANDSLIDES

- The landslide classification are great difficulties
- Because landslides are characterised by different causes, movements and morphology, and involving genetically different material.
- For this reason, landslide classifications are based on different discriminating factors, sometimes very subjective.

Different criteria are used for classifying landslides such as

- Type of movement
- Type of materials involved
- Size of materials
- Rate of movement
- Water content
- Texture of the material
- Relation of moving material to the solid surface.

However, the most commonly used classification is the one proposed by Varnes (1978).

This classification had been adopted by the landslide committee, Highway Research Board, Washington, USA.

This classification is based on two important parameters namely the type of movement and the type of material involved.

TYPES OF LADSLIDES (Modified after Varnes 1978

<table>
<tr><th colspan="3" rowspan="2">Type of movement</th><th colspan="3">Type of material</th></tr>
<tr><th>Rocks</th><th>Predominantly coarse - debris</th><th>Predominantly fine - soil</th></tr>
<tr><td colspan="3">Falls</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="3">Topples</td><td>Rock topple</td><td>Debris topple</td><td>Earth topple</td></tr>
<tr><td rowspan="3">Slides</td><td>Rotational</td><td></td><td>Rock slump</td><td>Debris slump</td><td>Earth slump</td></tr>
<tr><td rowspan="2">Translational</td><td>Few units</td><td>Rock block slide</td><td>Debris block slide</td><td>Earth block slide</td></tr>
<tr><td>Many units</td><td>Rock slide</td><td>Debris slide</td><td>Earth slide</td></tr>
<tr><td colspan="3">Lateral spreads</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td colspan="3" rowspan="3">Flows</td><td>Rock flow</td><td>Debris flow</td><td>Earth flow</td></tr>
<tr><td>Rock avalanche</td><td>Debris avalanche</td><td></td></tr>
<tr><td>Deep creep</td><td colspan="2">Soil creep</td></tr>
<tr><td colspan="3">Complex and compound</td><td colspan="3">Combination in time and/or space of two or more principal types of movement</td></tr>
</table>

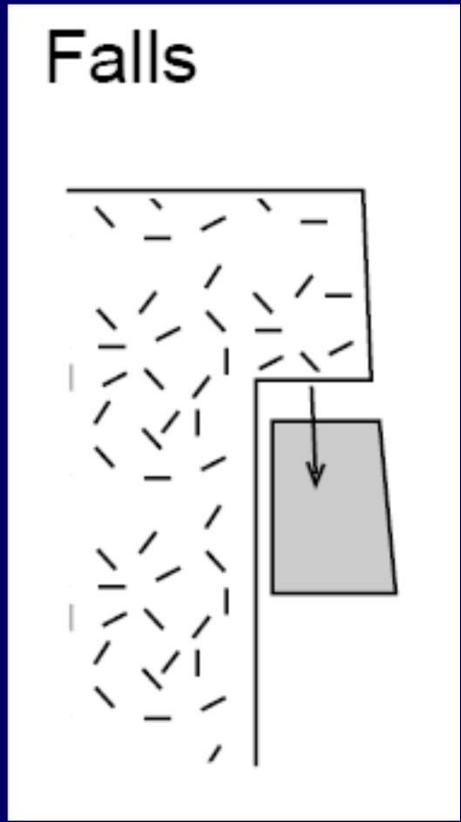
Fall

Description: "A fall starts with the detachment of soil or rock from a steep slope along a surface on which little or no shear displacement takes place. The material then descends mainly through the air by falling, bouncing, or rolling" (Varnes, 1996).
It may be rock fall, debris fall, soil fall, earth fall or boulder fall, depending upon the type of slope material involved

Secondary falls: "Secondary falls involves rock bodies already physically detached from cliff and merely lodged upon it" (Hutchinson, 1988)

Speed: ***from very to extremely rapid***
Type of slope: ***slope angle 45-90 degrees***
Causes: ***Vibration, undercutting, differential weathering, excavation, or stream erosion***

Rock falls occur when a piece of rock on a steep slope becomes dislodged and falls down the slope.

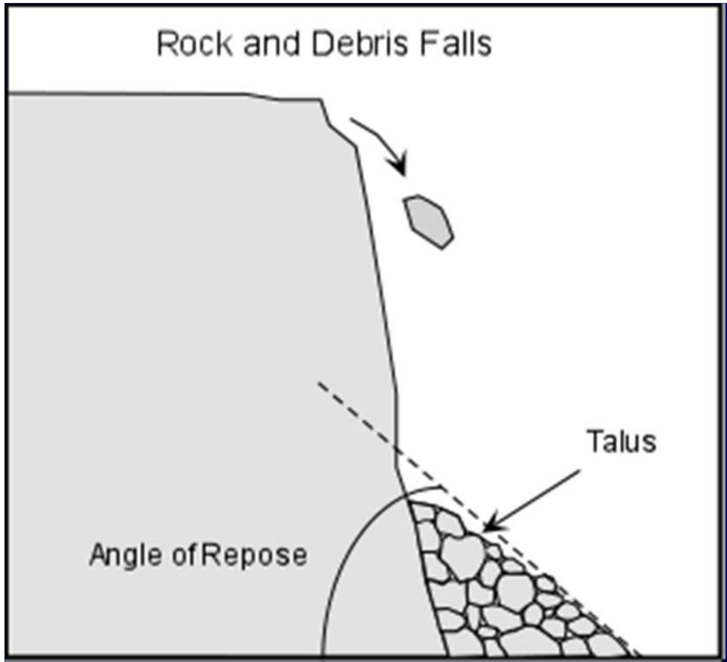


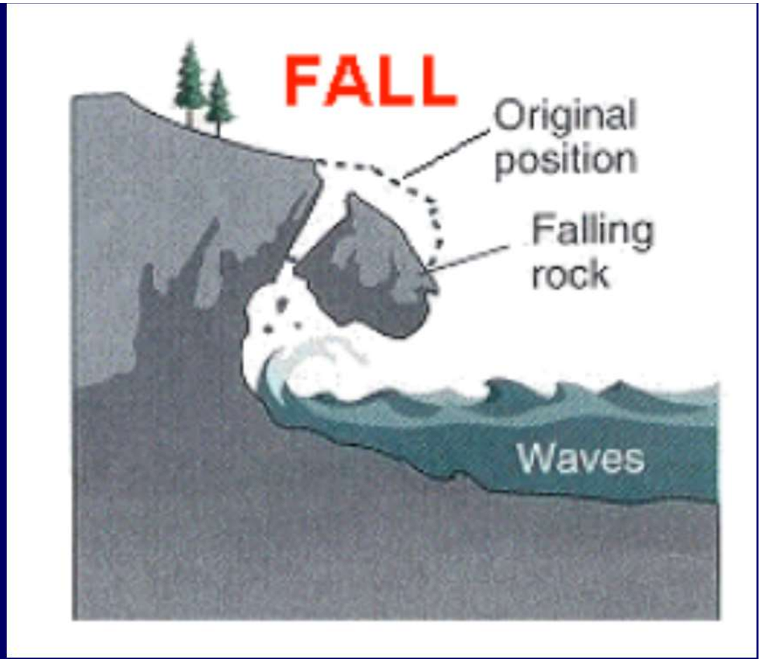
A rock fall may be a single rock or a mass of rocks, and the falling rocks can dislodge other rocks as they collide with the cliff.

Debris falls are similar, except they involve a mixture of soil, regolith, vegetation, and rocks.

Because this process involves the free fall of material, falls commonly occur where there are steep cliffs.

At the base of most cliffs is an accumulation of fallen material termed **talus.**





Castelmezzano - Italy. Landslide type: Rock fall

ROCKFALL

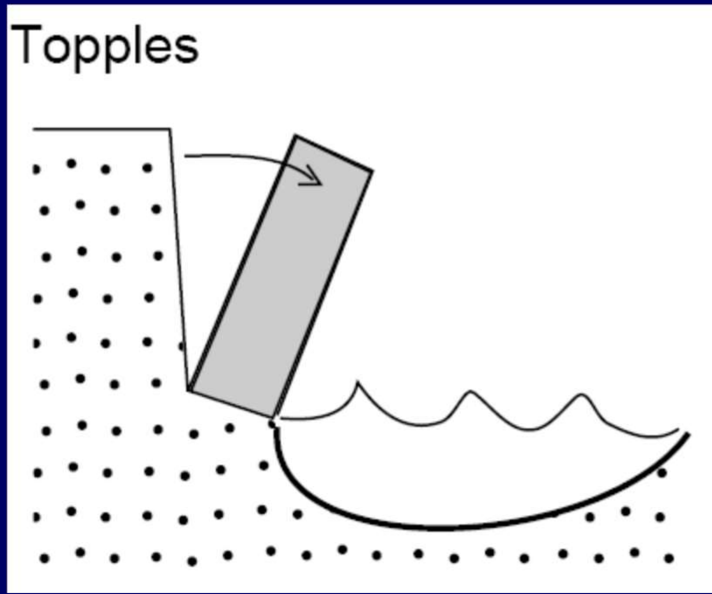
Topples

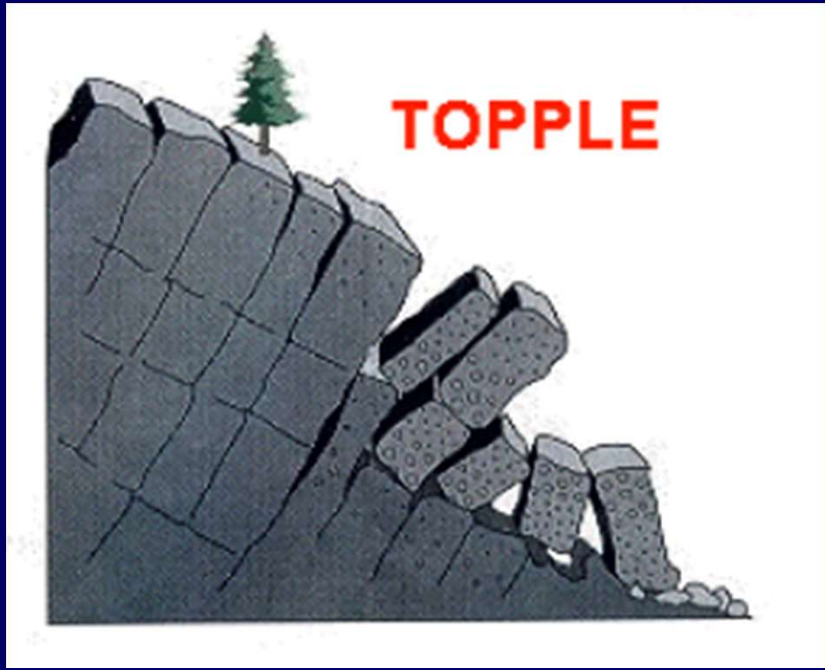
Topples refer to the type of movement, where blocks of rock tilt or rotate forward on a pivot or hinge and then separate from main mass by falling on the slope and subsequently bouncing and rolling down the slope

Speed: extremely slow to extremely rapid

Type of slope: slope angle 45-90 degrees

Causes: Vibration, undercutting, differential weathering, excavation, or stream erosion





Jasper National Park- Canada Landslide type: Topple

Slides

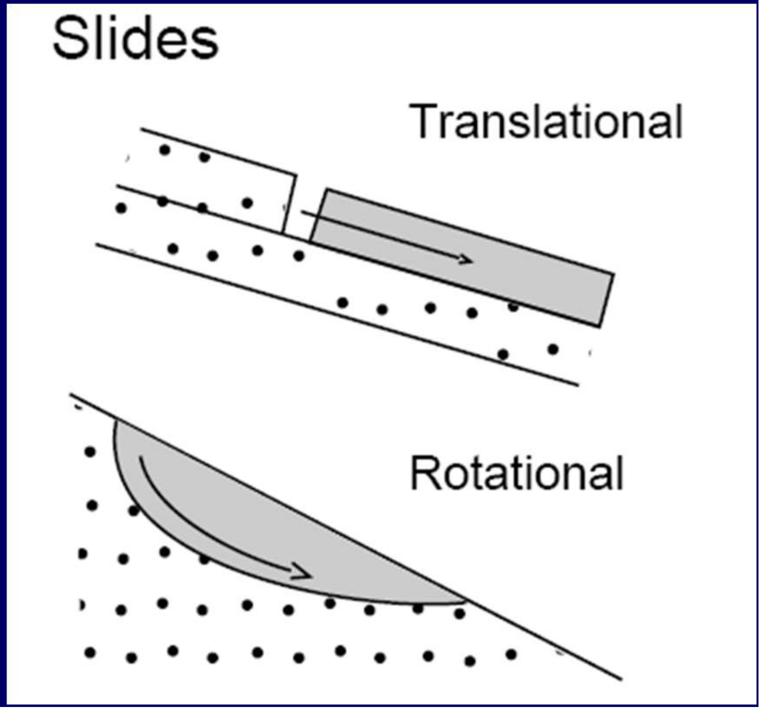
Rock slides and debris slides result when rocks or debris slide down a pre-existing surface, such as a bedding plane, foliation surface, or joint surface

"A slide is a downslope movement of soil or rock mass occurring dominantly on the surface of rupture or on relatively thin zones of intense shear strain." (Varnes, 1996)

These slides can be classified

in to two types

1. **Rotational slide**
2. **Translational slides**



Rotational slides

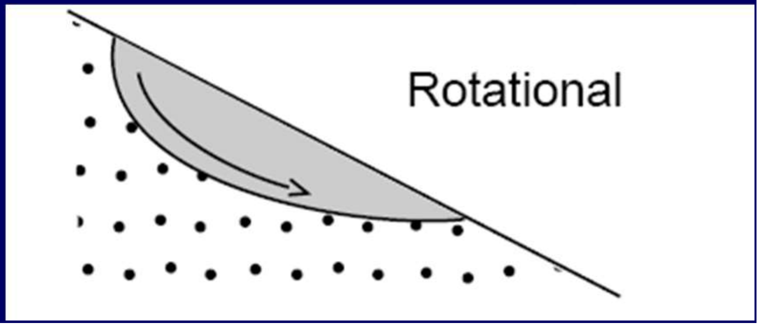
Rotational slides are those in which the surface of rupture is curved and concave upwards. They occur slopes comprised of nearly homogeneous soil and debris

Description: "Rotational slides move along a surface of rupture that is curved and concave" (Varnes, 1996)

Speed: extremely slow to extremely rapid

Type of slope: slope angle 45-90 degrees

Causes: Vibration, undercutting, differential weathering, excavation, or stream erosion

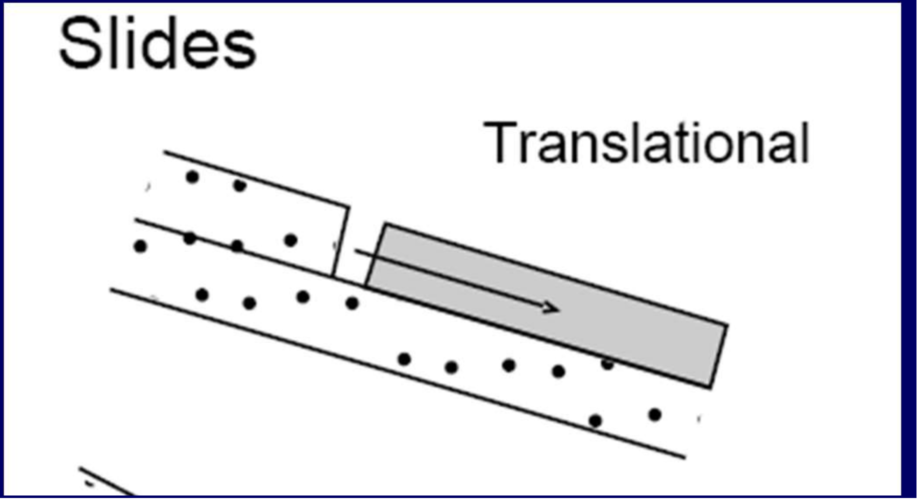


Translational slide

Translational slides are mass movements which include plane and wegde failures. The plane failure refers to a failure which is more or less planer in nature. The movement is controlled by surfaces of weakness such as bedding planes, joints, faults, shear zones and foliations.

Wedge failure is a failure where the movement basically controlled by two intersecting planes.

Block slide is also a type of translational failure where several plane or wedge blocks of rock may move down as a single unit.



Description: "In translational slides the mass displaces along a planar or undulating surface of rupture, sliding out over the original ground surface." (Varnes, 1996)

Speed: extremely slow to extremely rapid (>5 m/s)

Type of slope: slope angle 45-90 degrees

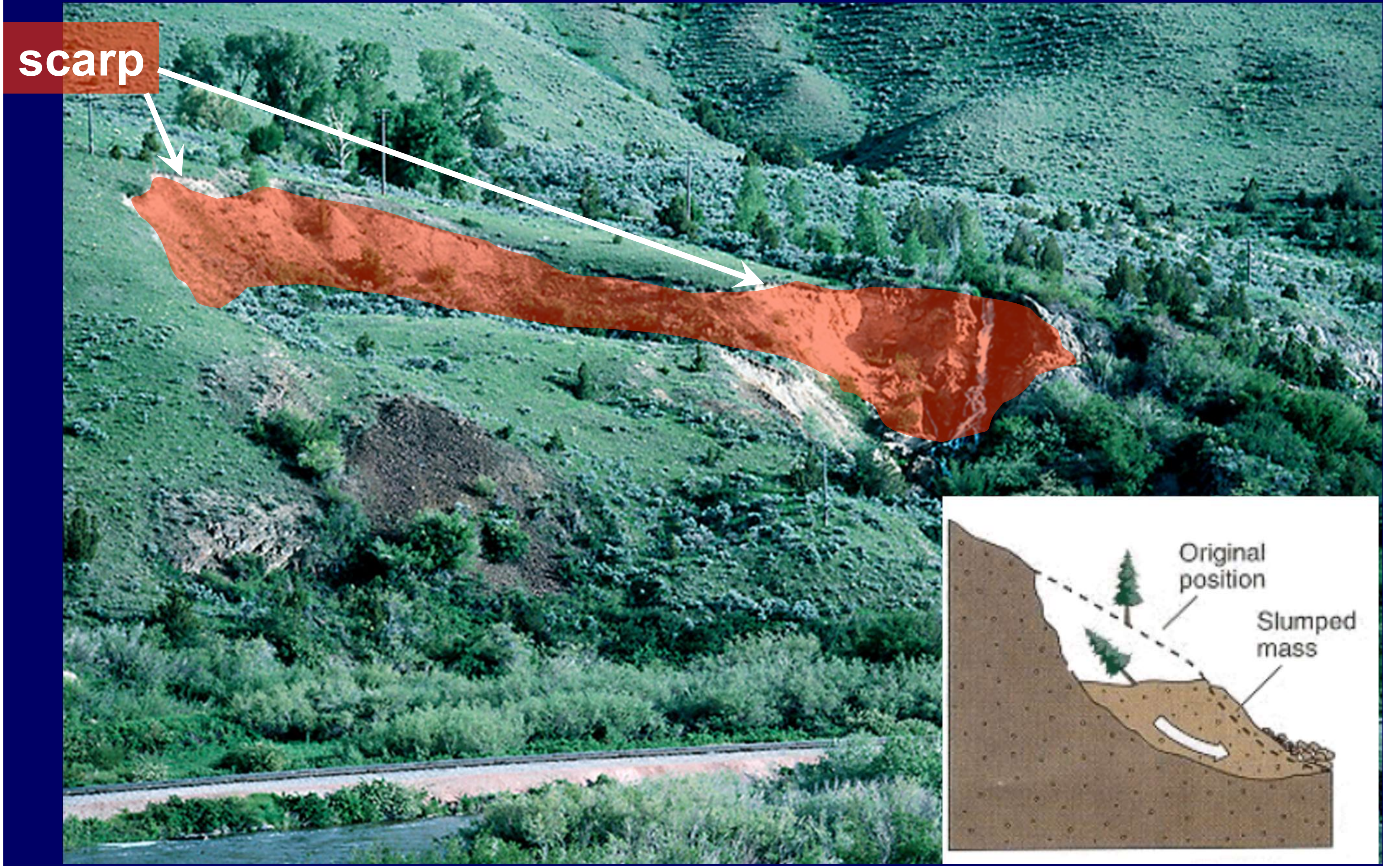
Causes: Vibration, undercutting, differential weathering, excavation, or stream erosion

Canada Landslide type: Rock Slide

Lauria- Italy Landslide type: Wedge failure

Lauria - Italy Landslide type: Slide

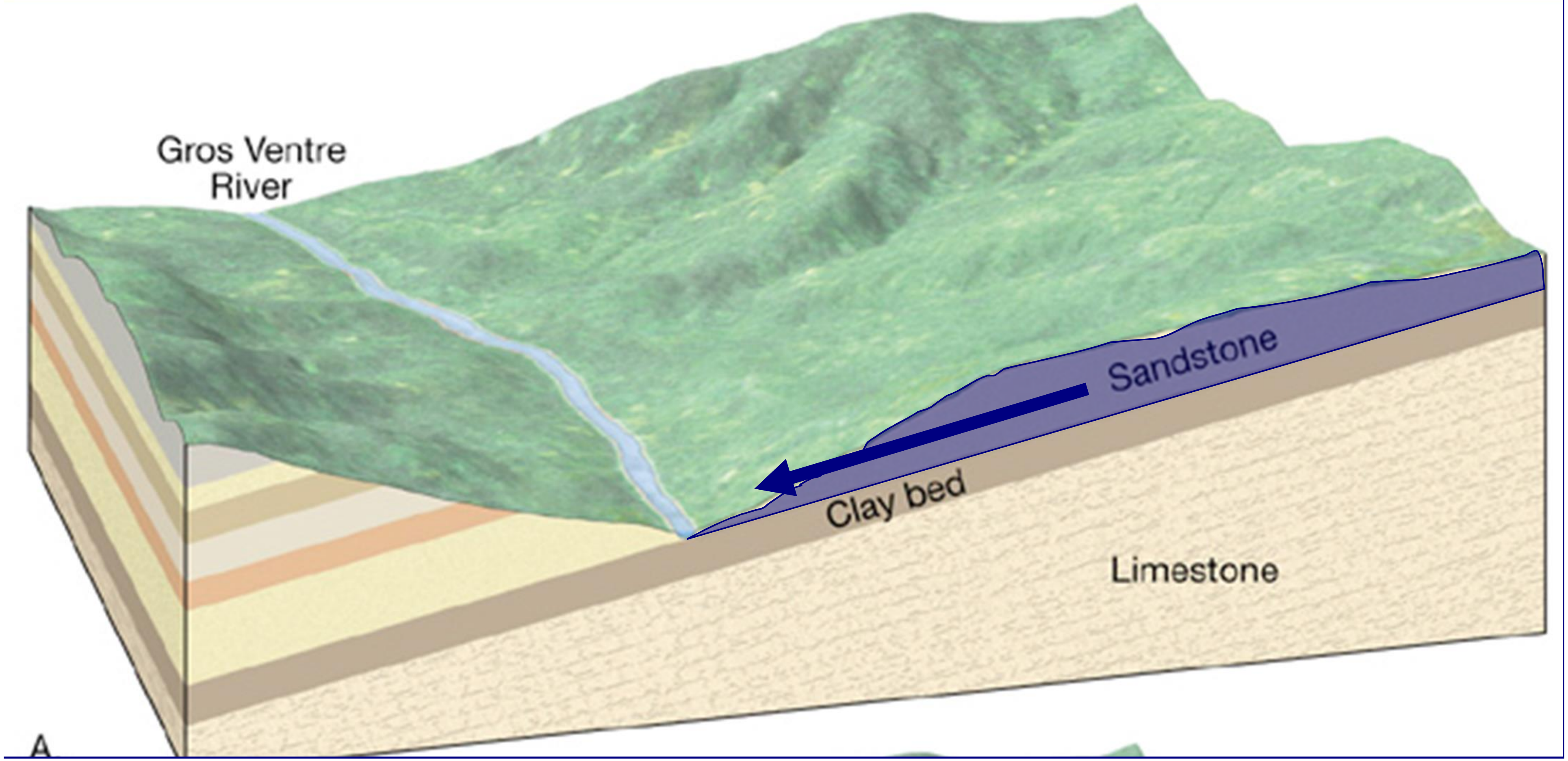
Slump is the slow to moderate movement of materials on a slope. In most cases the materials are unconsolidated or poorly consolidated. The motion is rotational and the plan of movement is curved



Slump in McClure Pass, CO.

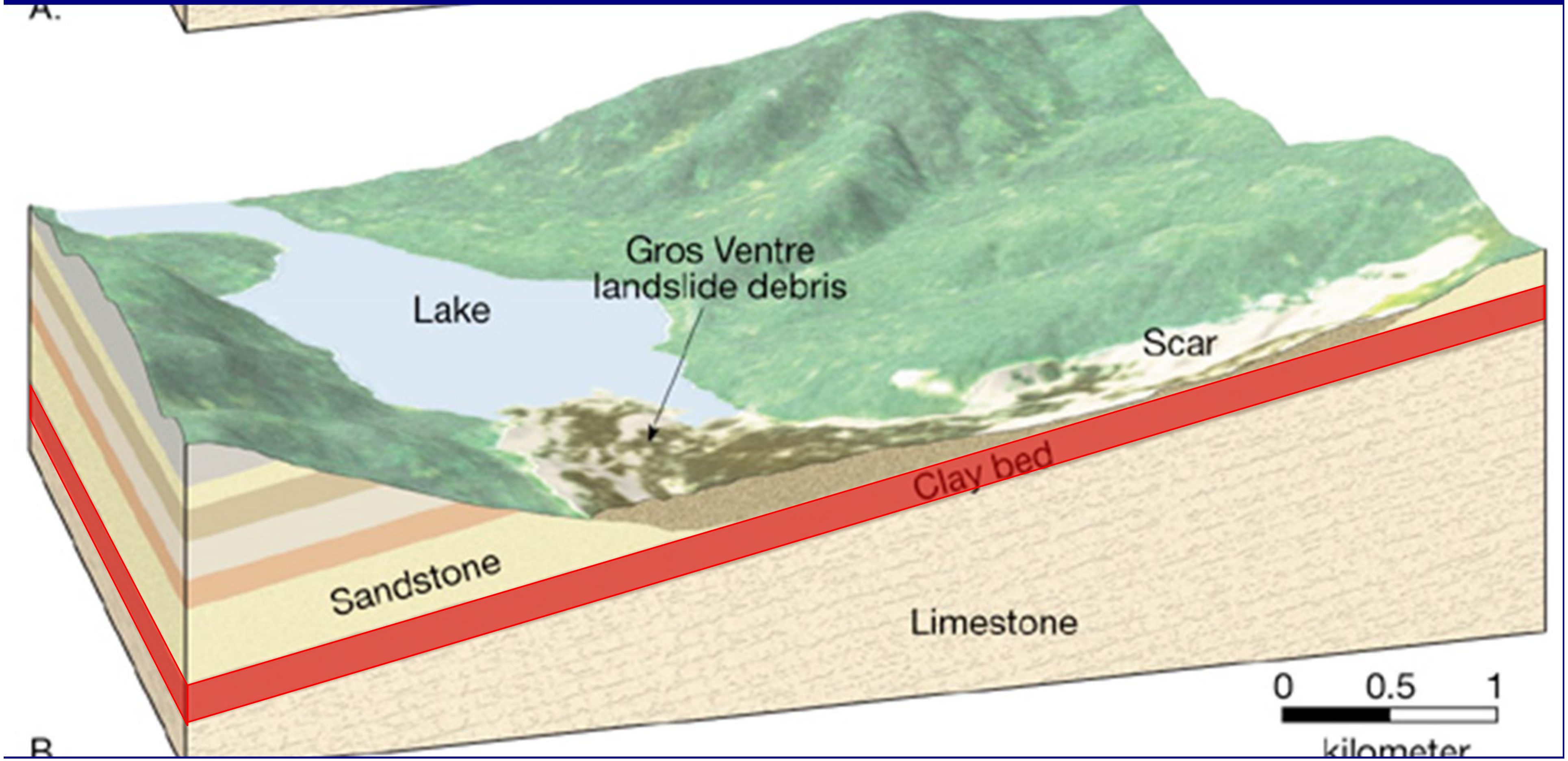
Rockslide

- Rock moves because there's nothing holding it back!
- Generally requires a pre-existing low-friction surface…



Rockslide

- like a clay layer, once it's wet…



Spreads

Description: These failures are caused by over saturation of loose, cohesionless soil or debris, which may be resulted by the processes of liquefaction. Rapid ground motions such as earthquakes may be responsible for these phenomena.

Speed: extremely slow to extremely rapid (>5 m/s)

Type of slope: angle 45-90 degrees

Causes: Vibration, undercutting, differential weathering, excavation, or stream erosion

Flows

Flows represent a rapid movement on a steep to fairly steep slopes, containing high proportion of water mixed with earth materials and air. Here the movement resembles that of a viscous fluid on steep slopes.

Flows in rock

Rock Flow

Description: "Flow movements in bedrock include deformations that are distributed among many large or small fractures, or even microfracture, without concentration of displacement along a fracture" (Varnes, 1978)

Speed: extremely slow

Type of slope: angle 45-90 degrees

Causes: Vibration, undercutting, differential weathering, excavation, or stream erosion

Rock avalanche

Description: "Extremely rapid, massive, flow-like motion of fragmented rock from a large rock slide or rock fall” (Hungr, 2001)

Speed: extremely rapid

Type of slope: angle 45-90 degrees

Causes: Vibration, undercutting, differential weathering, excavation or stream erosion

Flows in soil

Debris flow: It is a form of rapid movment involving loose soil, rocks and organic materials along with entrained air and water to form slurry which flows down the slopes. It is an important forms of movment in the Himalaya because it is often found to be associated with cloudburst phenomenon.

Speed: very rapid to extremely rapid (>5 m/s)
Type of slope: angle 20-45 degrees
Control factor: torrent sediments, water flows, loose rock and soil materials
Causes: High intensity rainfall

Debris avalanche: "Debris avalanche is a very rapid to extremely rapid shallow flow of partially or fully saturated debris on a steep slope, without confinement in an established channel." (Hungr et al., 2001)

Speed: very rapid to extremely rapid (>5 m/s)
Type of slope: angle 20-45 degrees
Control factor: morphology, regolith
Causes: High intensity rainfalls

Pozzano (Castellammare di Stabia) – Italy. Landslide type: Debris flow

Location: Quindici - Italy.
Debris flow deposits

Location: Quindici - Italy.
Debris flow deposits

Location: Positano, Sorrentine Peninsula - Italy Landslide type: Rock avalanche

Location: Sarno - Italy.
Landslide type: Debris flow

Debris flow

Debris flow

Earth flow: Earth flows have a characteristc bowl like depression at the head where slope forming materials becomes liquefied and flow out. The flow is generally channelised on the slopes and spreads out at toe. Usually the flow occurs in fine grained materials like clayey soils under saturated conditions

"Earth flow is a rapid or slower , intermittent flow-like movement of plastic, clayey earth." (Hungr et al.,2001)

Speed: *slow to rapid (>1,8 m/h)*
Type of slope: *slope angle 5-25 degrees*
Control factor: *lithology*

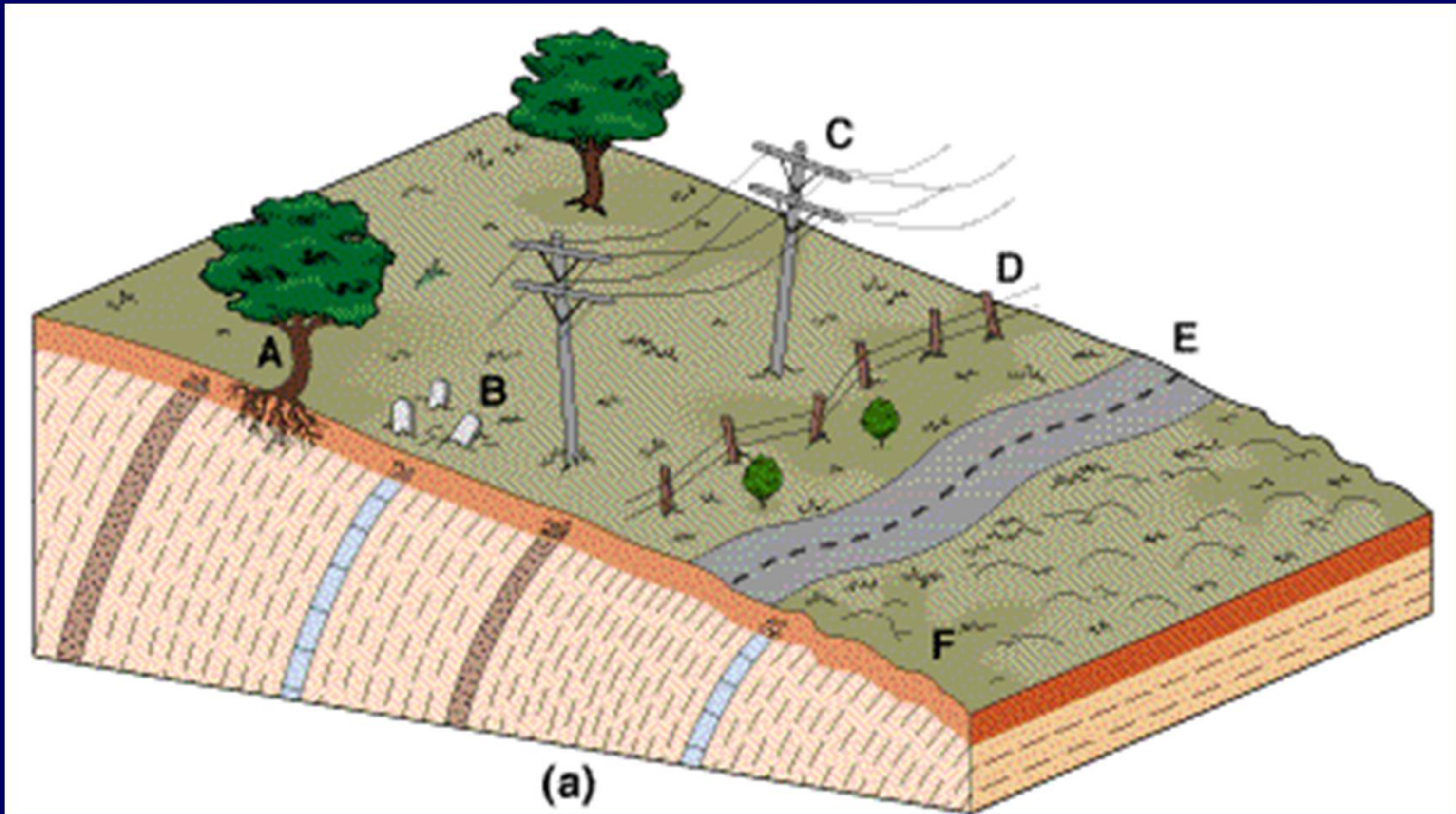
Mudflow : "Mudflow is a type of earth flow consisting of fine materials containing about half of silt and clay sized particles which are well saturated and flow rapidly

Speed: very rapid to extremely rapid (>5 m/s)
Type of slope: angle 20-45 degrees
Control factor: torrent sediments, water flows
Causes: High intensity rainfall

Location: Castelfranci - Italy
Landslide type: Earth flow

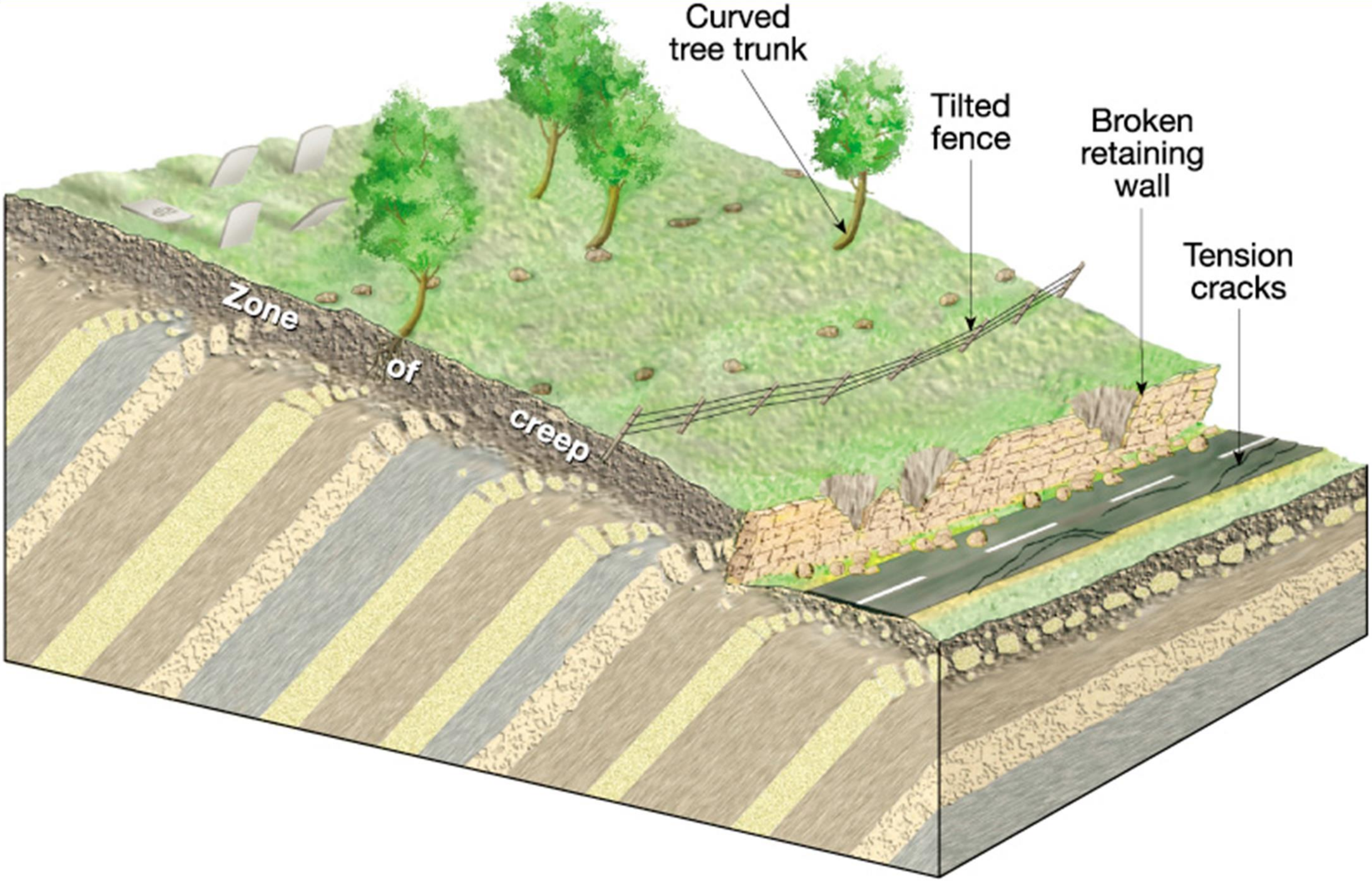
Earth flow

A Creep may be defined as an imperceptibly slow, steady, downward movement of slope forming materials. In case of creep, the movement essentially starts with permanent minor deformation but too small to cause a landslide



Some evidence of creep: (A) curved tree trunks; (B) displaced monuments; (C) power poles tilted downhill; (D) displaced and tilted fence; (E) roadway moved out of alignment; and (F) hummocky surface.

Creep



Curved tree trunk
Tilted fence
Broken retaining wall
Tension cracks
Zone of creep

Creep

Complex movement: Complex movement is a combination of falls, topples, slides, spreads and flows

Causes of landslides

- ➔ The causes of landslides are usually related to instabilities in slopes.
- ➔ It is usually possible to identify one or more landslide causes and one landslide trigger.
- ➔ The difference between these two concepts is subtle but important.
- ➔ The landslide causes are the reasons that a landslide occurred in that location and at that time.
- ➔ Landslide causes are include geological factors, morphological factors, physical factors and factors associated with human activity.

Causes of landslides…..

- Causes may be considered to be factors that made the slope vulnerable to failure, that predispose the slope to becoming unstable.
- The trigger is the single event that finally initiated the landslide.
- Thus, causes combine to make a slope vulnerable to failure, and the trigger finally initiates the movement.
- Landslides can have many causes but can only have one trigger

Causes of landslides…..

Ingeneral, the factors causing the landslides are categorized into

1. Natural factors
2. Anthropogenic factors

Natural factors are further subdivided into following categories

1. Inherent factors
2. External factors

Causes of landslides….

1. **Inherent factors:** These factors represent the inherent characteristics of hill slope and they can be studied and evaluated on the slope itself. These factors include geology, slope gradients, local relief, hydrological conditions, land use and land cover
2. **External factors:** As the name indicates, these are the outside factors, which can not be studied on a hill slope. They usually affect a larger area and hence called regional factors.

   These factors include concentrated rain fall and earthquakes. Since many a time these factors are responsible for initiation of landslide, they are also known as triggering factors

Causes of landslides….

Some of the inherent factors are discussed below

Change in slope gradient: This may be caused by natural or artificial interference in the processes of erosion.

The undercutting of banks by deeply incised rivers and streams causing steep bank slopes.

Some time the slope angle is steepened as a result of tectonic processes also such as subsidence or upliftment.

High relief along with increase in slope gradient is generally produced on hard rock slopes causing highly unstable conditions of slope stability. These slopes are highly potential slopes for rock falls

Causes of landslides….

Steep slope embankments of fills and soil heaps: Depending upon the type of soil and its inherent strength characteristics, the soil may be stable over a range of slope conditions. If the slope of embankment exceeds this limit, the soil may undergo slip circle failure, particularly when the saturation by water appreciably decreases the shear strength of this materials

Geology: Loose unconsolidated materials, highly fractured and sheared rocks (because of intense folding and faulting, which is common in the Himalayan terrain). Jointed rocks, Rocks having two or more set of joints may undergo plane or wedge failure. Moreover, extensive occurrence of weak rocks like slates and phyllites along with calcareous interlayers in these rocks may lead to high porosity and void formation due to leaching and dissolution of rock mass

Causes of landslides….

Changes in water content: Rain and snow melt water penetrates into joints and fractures of rocks, thus increasing the pore water pressure within rocks.

This in turn may also decrease shear resistance of rocks causing instability.

Clayey soils, when dry up get desiccated and shrunken which result in cracking of surface.

The surface readily percolates through these fractures. The increased subsurface water content may lead to plastic deformation.

Causes of landslides….

Frost effects: Water trapped in rock fissures and joints freezes causing increase in volume. This imparts a tremendous amount of pressure on the rock walls, leading to widening of joints and fractures. Freezing of water on the surface impedes drainage of slope and thus increasing pore water pressure

Weathering: Mechanical and Chemical weathering affects the strength of rock mass, which is also one of the contributory factors of landslide.

Causes of landslides….

Effects of Vegetation: The deforestation of slopes particularly soil slopes is one of the well known factors in inducing landslides. It exposes barren soil to erosion and destabilization.

On the contrary, Sometimes the growth of plants and other vegetation in the pre-existing plane of landslides or joints of the rocks may also cause excess stress on joint walls due to increase in size of roots. This phenomenon may push the slope materials out and cause landslides.

Anthropogenic factors

Among the anthropogenic factors, following are important ones

Deforestation: Plant roots have the tendency to bind soil and thus they are helpful to retard slope stability unless the failure plane is very deep i.e. beyond the root zone. This factor contributes for many Himalayan landslides as intensive deforestation is reported in many parts of the Himalaya.

Improper land use:

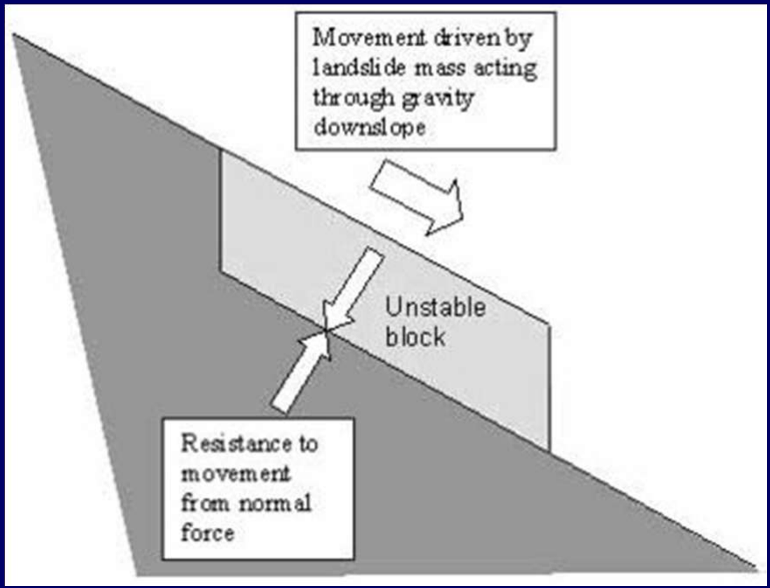
- Agricultural practices on steep slopes
- Irrigation on steep and vulnerable slopes
- Overgrazing
- Quarrying for construction materials without considering condition of the terrain

Construction Activities: Improper selection of site or lack of terrain capability evaluation before placement of infrastructures such as hill roads and canals

Triggers of landslides

Rain Fall

In the majority of cases the main trigger of landslides is heavy or prolonged rainfall.
Because the rainfall drives an increase in pore water pressures within the soil.



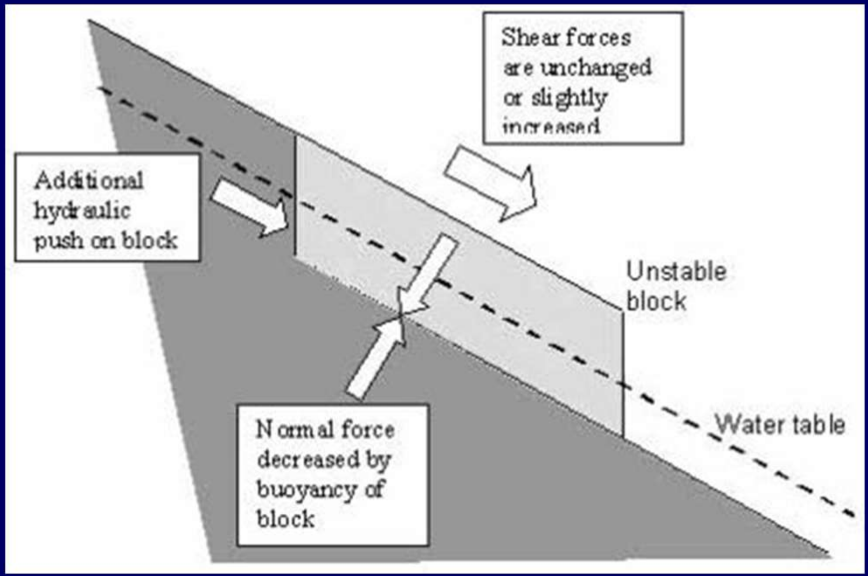


Diagram illustrating the resistance to, and causes of, movement in a slope system consisting of an unstable block

Snowmelt

In many cold mountain areas, snowmelt can be a key mechanism by which landslide initiation can occur.

This can be especially significant when sudden increases in temperature lead to rapid melting of the snow pack.

This water can then infiltrate into the ground, which may have impermeable layers below the surface due to still-frozen soil or rock, leading to rapid increases in pore water pressure, and resultant landslide activity.

This effect can be especially serious when the warmer weather is accompanied by precipitation, which both adds to the groundwater and accelerates the rate of thawing.

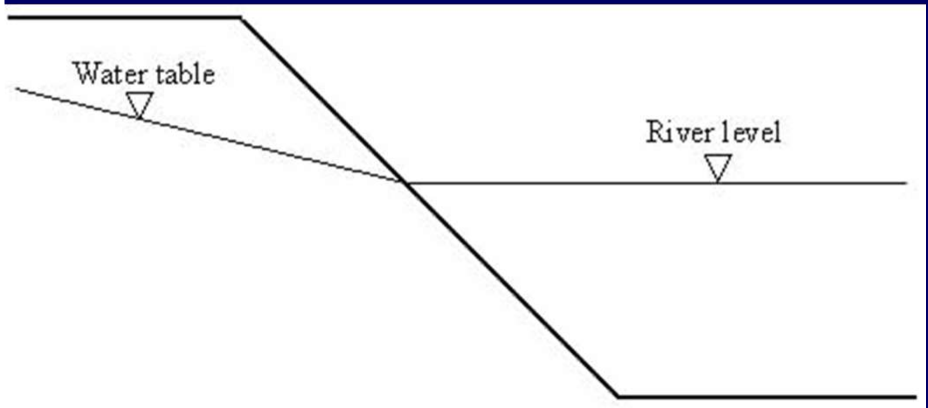
Water-level change

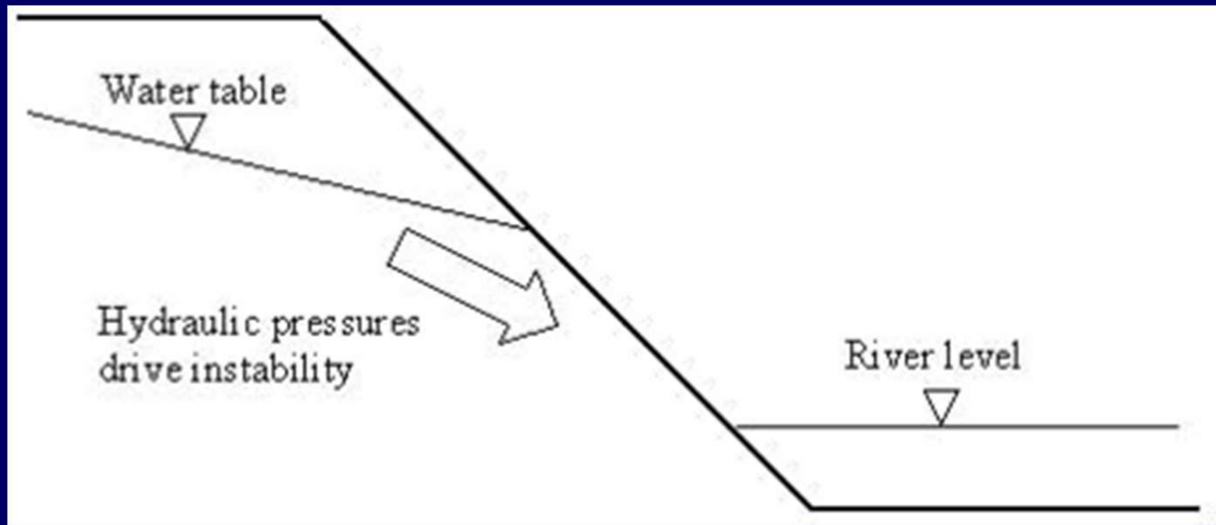
Rapid changes in the groundwater level along a slope can also trigger landslides.

This is often the case where a slope is adjacent to a water body or a river. When the water level adjacent to the slope falls rapidly the groundwater level frequently cannot dissipate quickly enough, leaving am artificially high water table.

This subjects the slope to higher than normal shear stresses, leading to potential instability.

This is probably the most important mechanism by which river bank materials fail, being significant after a flood as the river level is declining (i.e. on the falling limb of the hydrograph) as shown in the following figures.


Water table
River level


Water table
Hydraulic pressures
drive instability
River level

Rivers

In some cases, failures are triggered as a result of undercutting of the slope by a river, especially during a flood.

This undercutting serves both to increase the gradient of the slope, reducing stability, and to remove toe weighting, which also decreases stability.

For example, in Nepal this process is often seen after a glacial lake outburst flood, when toe erosion occurs along the channel. Immediately after the passage of flood waves extensive landsliding often occurs. This instability can continue to occur for a long time afterwards, especially during subsequent periods of heavy rain and flood events.

Seismicity

The second major factor in the triggering of landslides is seismicity. Landslides occur during earthquakes as a result of two separate but interconnected processes: seismic shaking and pore water pressure generation

The passage of the earthquake waves through the rock and soil produces a complex set of accelerations that effectively act to change the gravitational load on the slope

Liquefaction

The passage of the earthquake waves through a granular material such as a soil can induce a process termed liquefaction, in which the shaking causes a reduction in the pore space of the material.

This densification drives up the pore pressure in the material.

In some cases this can change a granular material into what is effectively a liquid, generating 'flow slides' that can be rapid and thus very damaging.

Alternatively, the increase in pore pressure can reduce the normal stress in the slope, allowing the activation of translational and rotational failures.

Volcanic activity

Some of the largest and most destructive landslides known have been associated with volcanoes.

These can occur either in association with the eruption of the volcano itself, or as a result of mobilisation of the very weak deposits that are formed as a consequence of volcanic activity. Essentially, there are two main types of volcanic landslide: lahars and debris avalanches, the largest of which are sometimes termed flank collapses.

An example of a lahar was seen at Mount St Helens during its catastrophic eruption on May 18, 1980.

Landslide Investigations and Mapping Techniques

Landslide Investigations are carried out on three different approaches namely 1. Analytical methods, Observational Methods and Empirical Methods. Depending on the importance of investigation, details used for analysis, scale, nature of output data.

Analytical Methods: Detailed Study on 1:1,000 to 1:2,000 scale. This is also called the microzonation

Require data on properties of rocks and soils and particularly on shear strength

Observational Methods: are based on monitoring of the slopes through instruments (extensometers, inclinometers, piezometers

Empirical Methods: is a a rapid hazard assessment technique, in this method, experience and knowledge gained from previous landslide investigations.

This also involves identification of causative factors of landslides and their influence in inducing instabilities.

Landslide Mapping Based on Themes and Scales

In the Himalayan or Nilgiri terrain, most of the landslides take place during monsoon period along road section and cause loss of life and property

Hence it is important to study and prognosticate vulnerable locations where landslides may take place. For that purpose, landslide investigations involve topographical and geological mapping in order to carry out stability analysis.

Landslide Mapping Based on Themes

Danger: Based on existing natural landslide phenomenon. It is also called as Landslide inventory map. This is only indicate the location of landslides

Hazard: refers to the probability of occurrence of a landslide places on the basis of various terrain parameters

Risk: refers to the nature of damage likely to be caused if failure occurs

Landslide Mapping Based on Scale

Mega Regional Mapping: 1:1,00,000 to 1:2,00,000

Regional Mapping: 1:50,000 to 1: 25,000

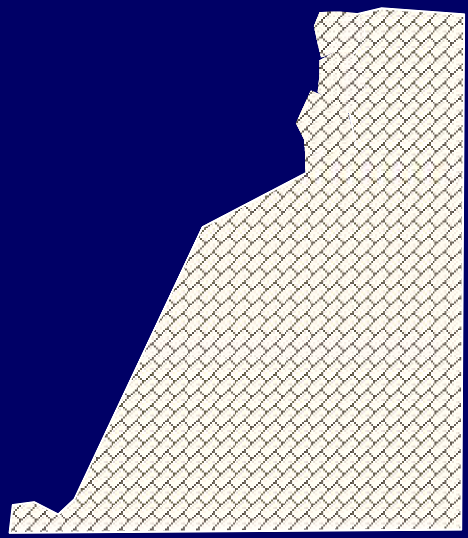
Semi – Detailed Mapping 1:10,000 to 1: 15,000

Detailed Mapping 1:1,000 to 1: 2,000

LANDSLIDE IDENTIFICATION FEATURES:

In cross section:

- **Convex bulged shape of the toe**



On the surface:

- **Typical cracks and fissures with distinct vegetation**

REMOTE SENSING IN LANDSLIDES

- Aerial photographs of 1:25,000 / 1:12,500 scale is good
- Panchromatic satellite data
- PAN + LISSIII merged data

to identify

- Paleoscars
- Active slopes
- Spatial distribution
- Their association with controlling parameters etc.

PHOTO CHARACTERS:

Head scarp:	Sharp break in slope between head scarp and displaced mass
Slide scars:	Light tone and the arcuate shape due to less vegetation
Disturbed mass:	Lobate forms, jagged of hummocky topography, mottled tone, minor ridges parallel to contour level common
Drainage :	Elongated, un drained depressions, haphazard pattern over the disturbed mass
Vegetation tone :	Light tone, clumsy vegetation, oriented vegetation parallel to contour in the disturbed area.

GIS IN LANDSLIDES

- Not a single parameter alone is responsible for landslides
- So it involves multi thematic layer analysis
- Hence Geographic Information system (GIS) for

  Data integration

  - To identify the Landslide hazard zones
  - To find out the causative factor
  - To suggest suitable measures to prevent landslide.

IN INDIA LANDSLIDES ARE COMMAN IN THREE MAJOR MOUNTAIN PRONVINCES

HIMALAYAS

WESTERN GHATS

NILGIRIS

LANDSLIDES IN INDIA :

PROVINCES	TRIGGERING PHENOMENON
Himalayan	Active tectonic zones
Western Ghat	Toe erosion and related mass movement
Nilgiri Massif	Pore pressure

Hence the studies and remedial measures must be a site specific after understanding its

- Actual functional parameters
- Causative factors

SOME OF THE DISASTROUS LANDSLIDES IN INDIA

Date/year	Location	Damage
September 1968	Himachal Pradesh	Active Maling slide- 1km of road and a bridge washed out
July 1968	Garhwal Himalaya	Active Kaliasaur slide- continuous damage to road
December 1982	Himachal Pradesh	Near Solding nallah 3 bridges & 1.5km length of road washed away
January 1982	Nashri, Jammu & Kashmir	Active slide from 1953. Every year road and communication network is damaged.
March 1989	Himachal Pradesh	Nathpa, 500m road section is frequently damaged during successive year
October 1990	Nilgris	36 people killed and several injured. Several buildings and communication network damaged
July 1991	Assam	300 people killed, road and buildings damaged, Millions of rupees
November 1992	Nilgiris	Road network and buildings damaged, Rs.5 million damage estimate
June 1993	Aizawal	Four persons were buried
July 1993	Itanagar Arunachal Pradesh	25 people buried alive 2 km road damaged
August 1993	Kalimpong, West Bengal	40 people killed, heavy loss of property
August 1993	Kohima, Nagaland	200 houses destroyed, 500 people died, about5km road stretch was damaged
November 1993	Nilgris	40 people killed, property worth several lakhs damaged
January 1994	Kashmir	National Highway 1A severely damaged
June 1994	Varundh ghat, Konkan Coast	20 people killed, breaching of ghat road damaged to the extent of 1km. At several places
May 1995	Aizwal Mizoram	25 people killed road severely damaged
June 1995	Malori Jammu	6 persons killed, NH 1A damaged
September 1995	Kullu, HP	22 persons killed and several injured about 1 km road destroyed
14,August 1998	Okhimath	69 people killed
18,August 1998	Malpa,Kali river	205 people killed road network to Mansarovar disrupted

LANDSLIDE HAZARD ZONATION

LANDSLIDE HAZARD ZONATION

- Landslide

Soil or rock materials move / slip down slope under the direct influence of gravitational forces

- Hazard

The probability of occurrence of a potential phenomenon within a specified period of time and within a given area

- Zonation

The division of land into homogeneous areas or domains and their ranking according to degrees of actual/potential hazard caused by mass movements

LANDSLIDE HAZARD ZONATION

➔ Landslide hazard zonation can be done by using following methods

1. Integrated Land system Analysis
2. GIS based Integrated Slope Method
3. Information Value
4. Weight of Evidence
5. Index Overlay and
6. BIS Methods

Integrated Land system Analysis and LHZ

Integrated Land system Analysis and LHZ

METHODOLOGY

Selection of test site of 300 -350 sq.km

Having at least 200 – 250 landslides/Scares

Interpretation of large format satellite data & topo sheets, geophysical survey, collection of collateral data and preparation of maps on

* Lithology
* Lineament Density, Lineament Frequency and Lineament intersection Density
* Geomorphology
* Slope
* Drainage density
* Soil
* Thickness of Top Soil & WZ
* Landuse / land cover

- Plotting of Landslide incidence over various thematic maps, histogram analysis and detection of threshold zones in each variables

- Preparation of buffered GIS images

- Integration of all GIS images and preparation of LHZ along with controlling variable

- This LHZ will have in numerable polygons of Land segments – each polygons having different combinations of Landslide inducing variables

- Validate this by cross referencing with Landslide incidence in that type area (check how many out of 200 landslides falls in priority area)

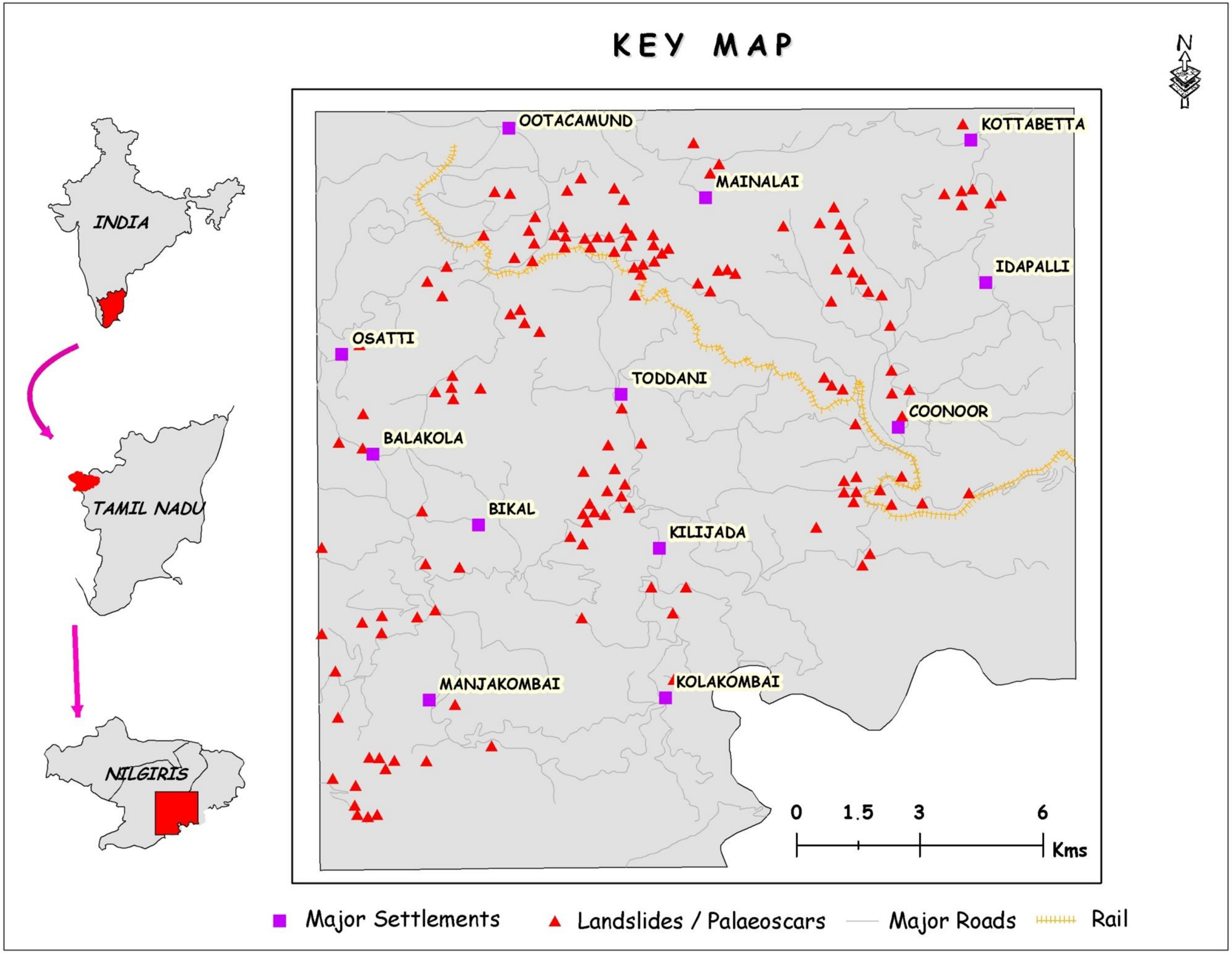
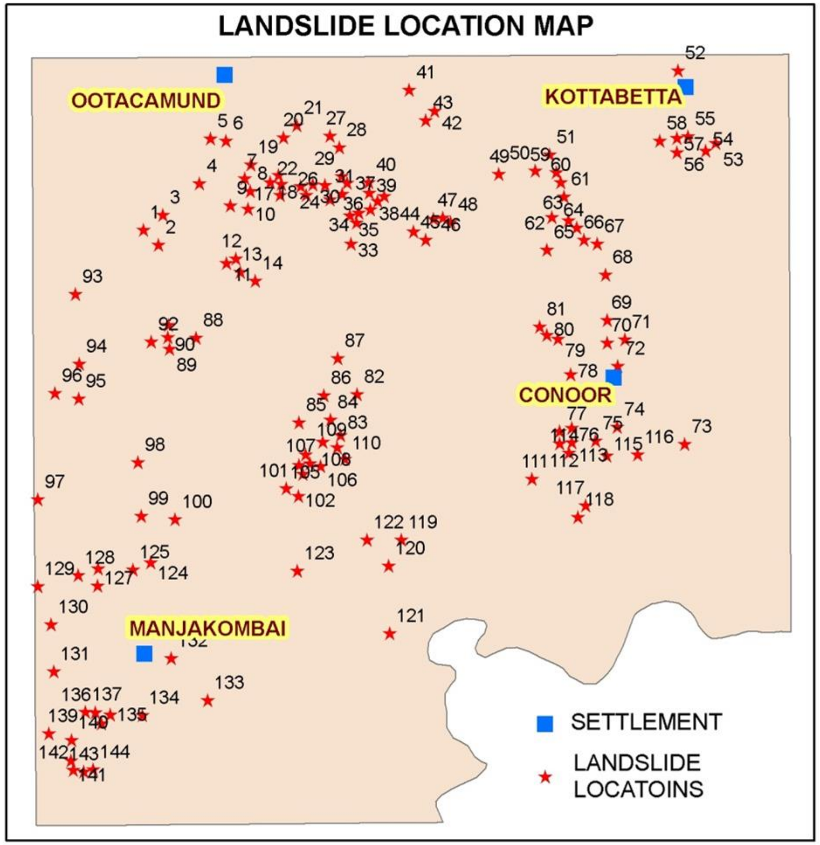
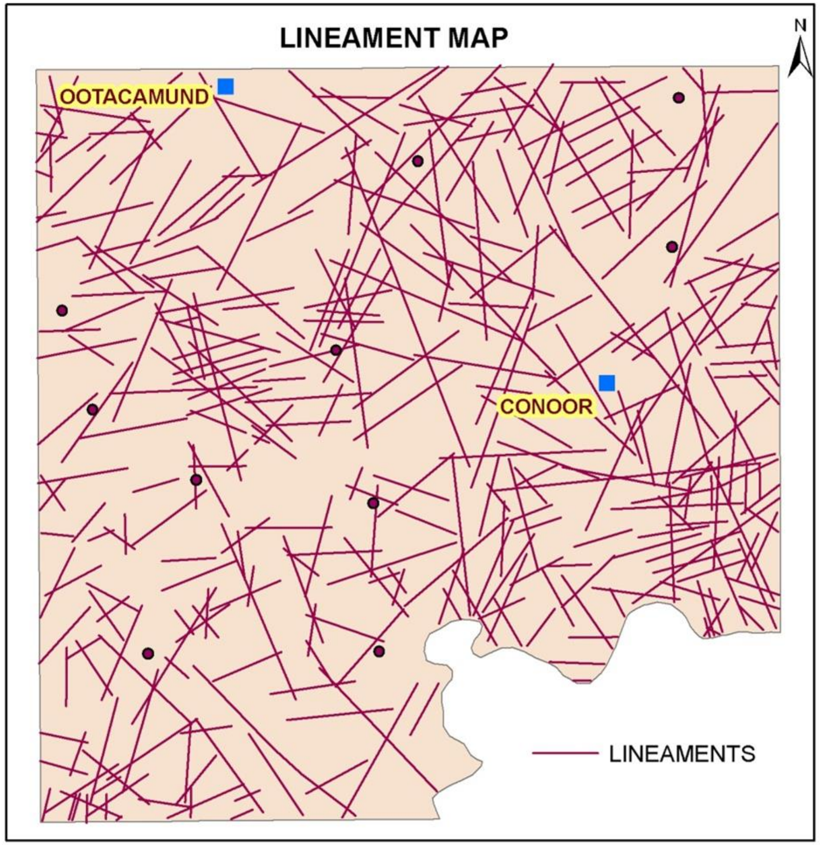

KEY MAP
N
INDIA
TAMIL NADU
NILGIRIS
OOTACAMUND
KOTTABETTA
MAINALAI
IDAPALLI
OSATTI
TODDANI
COONOOR
BALAKOLA
BIKAL
KILIJADA
MANJAKOMBAI
KOLAKOMBAI
0
1.5
3
6
Kms
Major Settlements
Landslides / Palaeoscars
Major Roads
Rail

FIG. 1



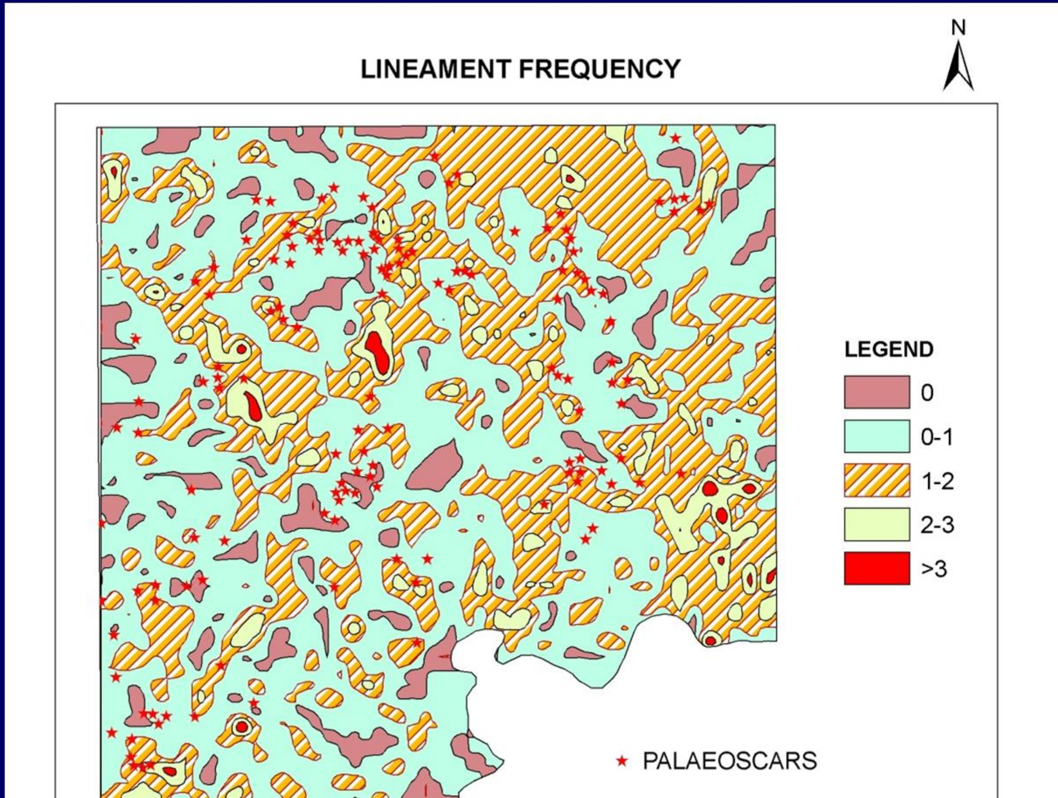
LANDSLIDE LOCATION MAP
OOTACAMUND
KOTTABETTA
CONOOR
MANJAKOMBAI
SETTLEMENT
LANDSLIDE
LOCATOINS

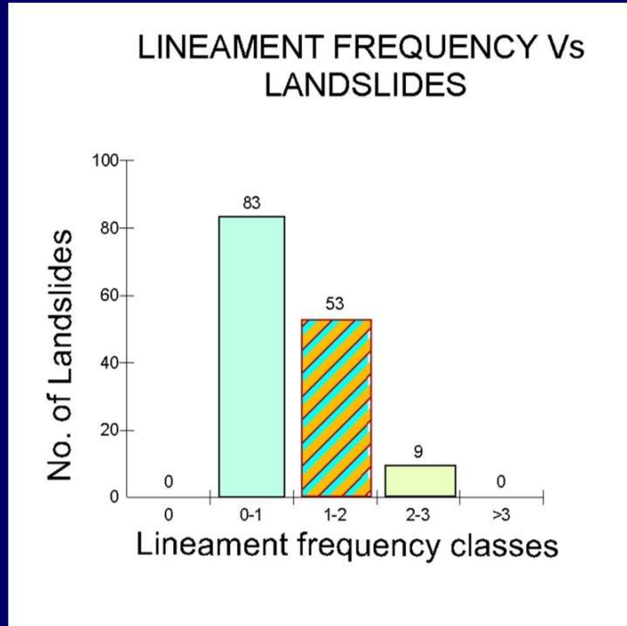
Fig. 2A

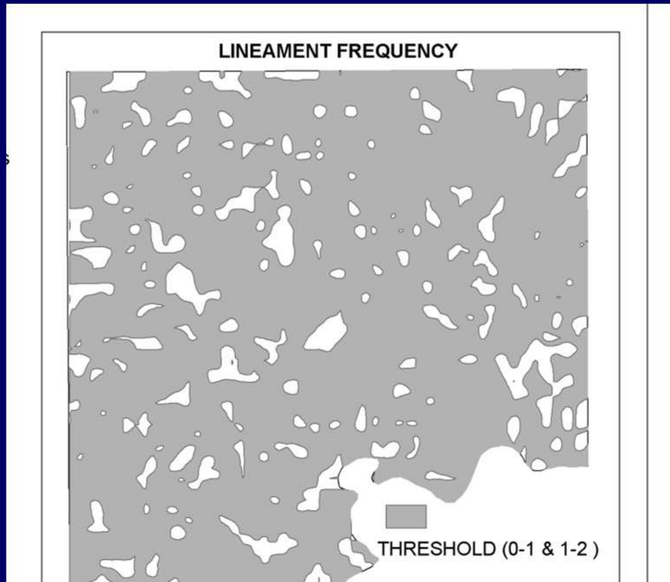


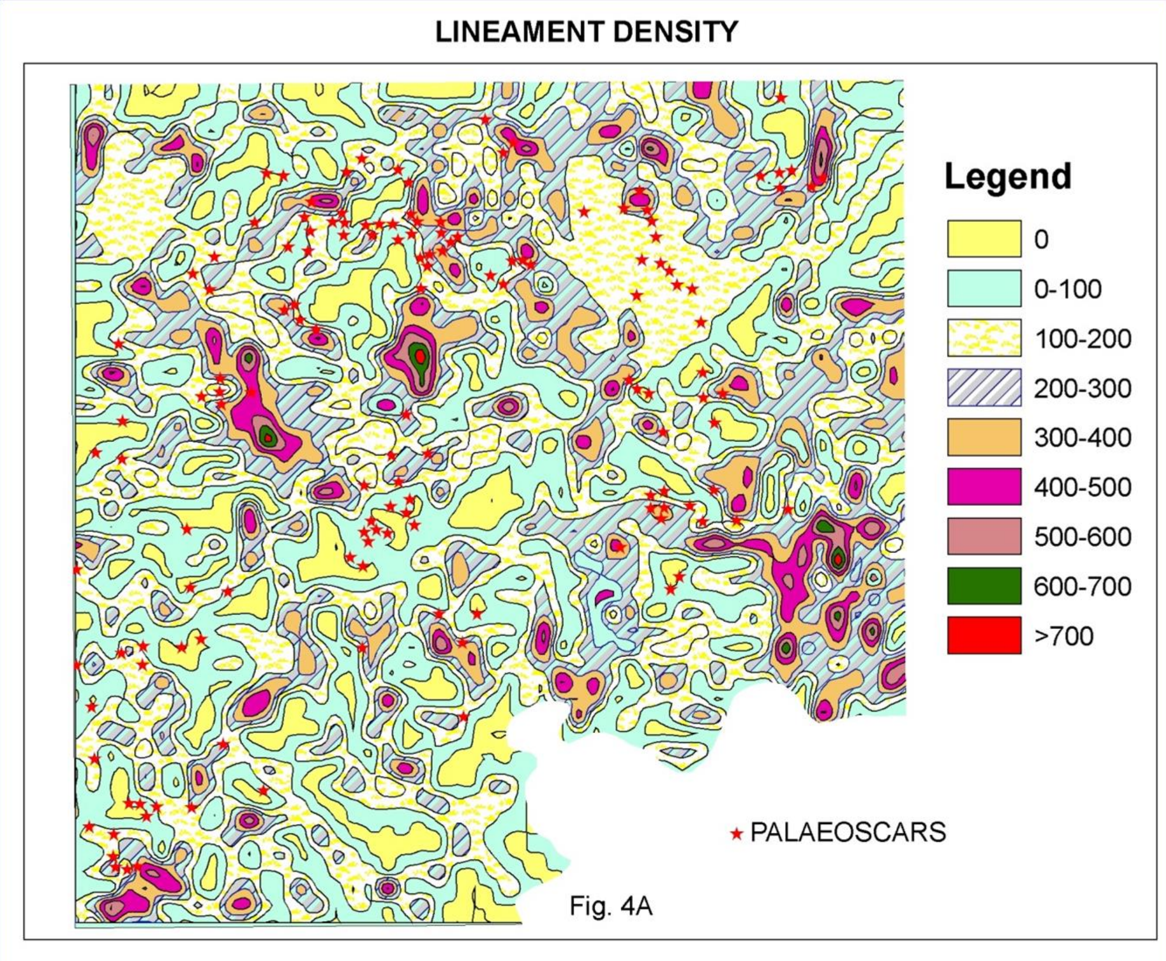
LINEAMENT MAP
N
OOTACAMUND
CONOOR
LINEAMENTS

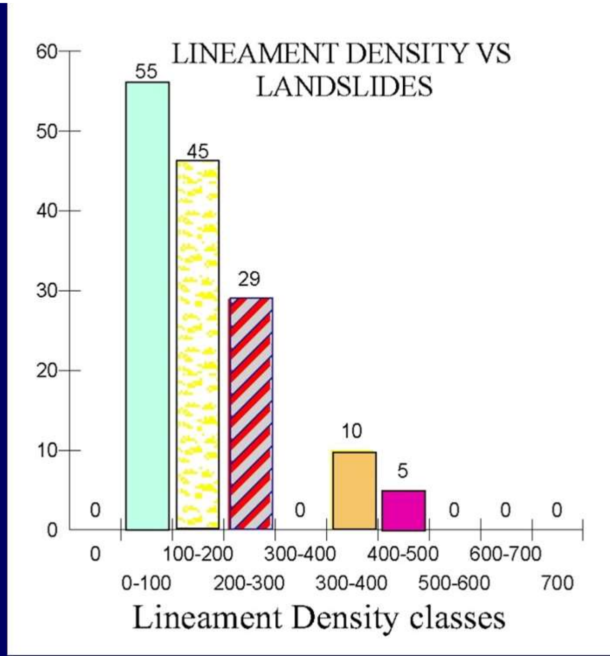
Fig. 2B

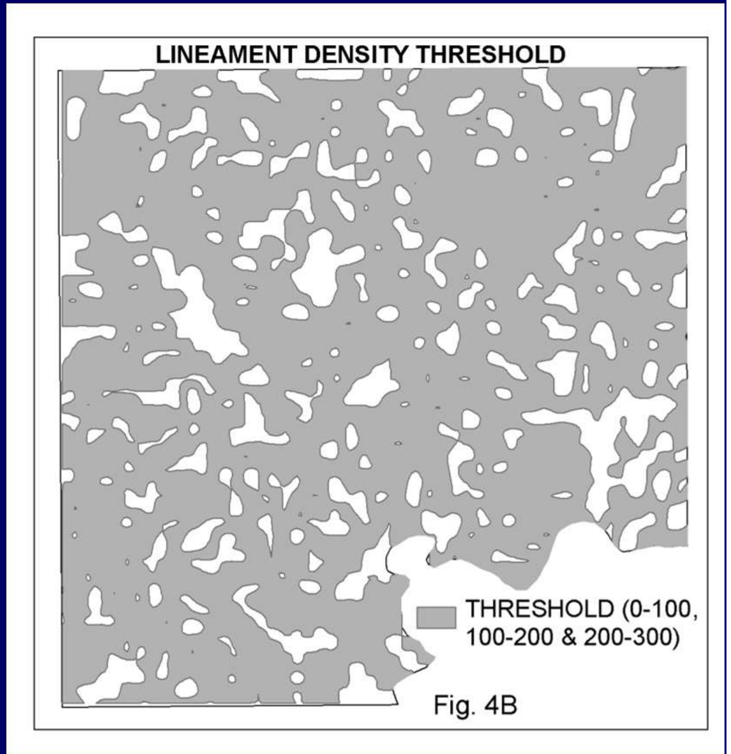

LINEAMENT FREQUENCY
N
LEGEND
0
0-1
1-2
2-3
>3
PALAEOSCARS
Fig. 3A

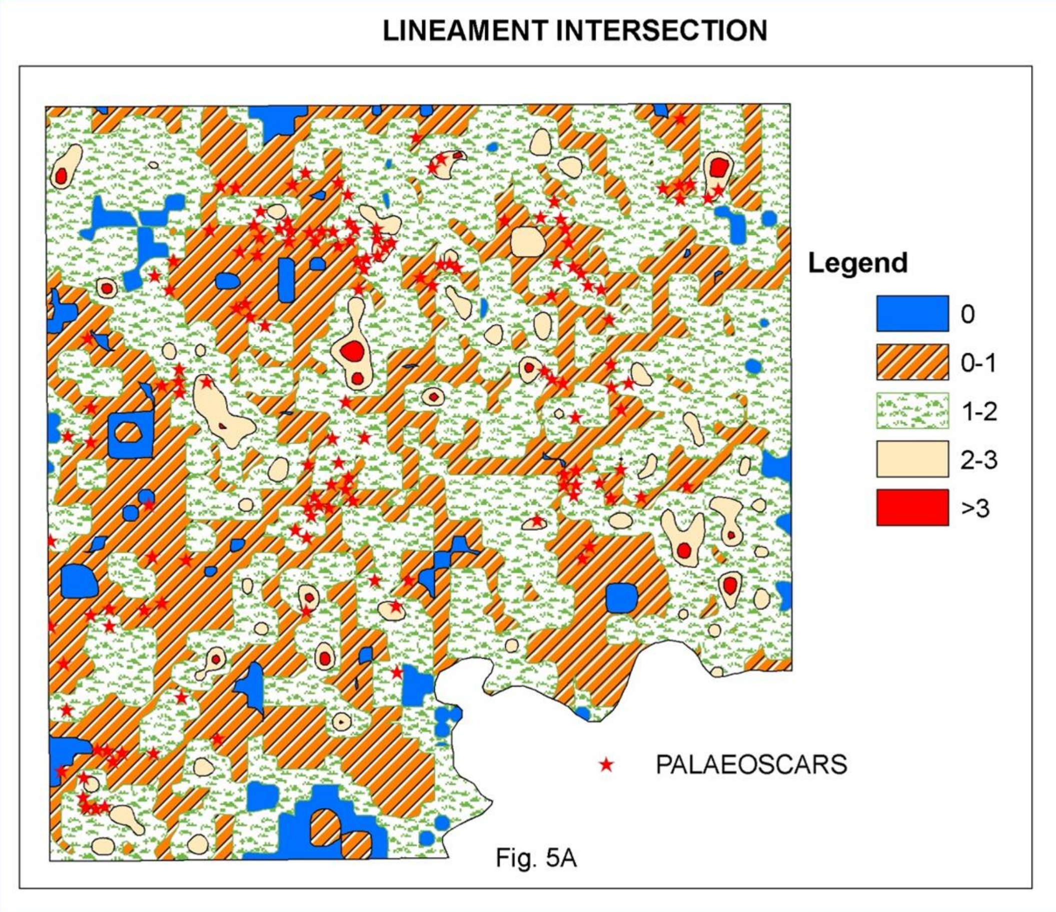

LINEAMENT FREQUENCY Vs LANDSLIDES
No. of Landslides
Lineament frequency classes
0
20
40
60
80
100
0
83
53
9
0
0
0-1
1-2
2-3
>3

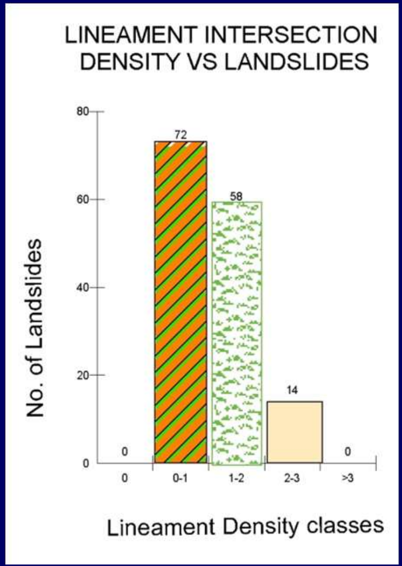

LINEAMENT FREQUENCY
THRESHOLD (0-1 & 1-2)
Fig. 3B

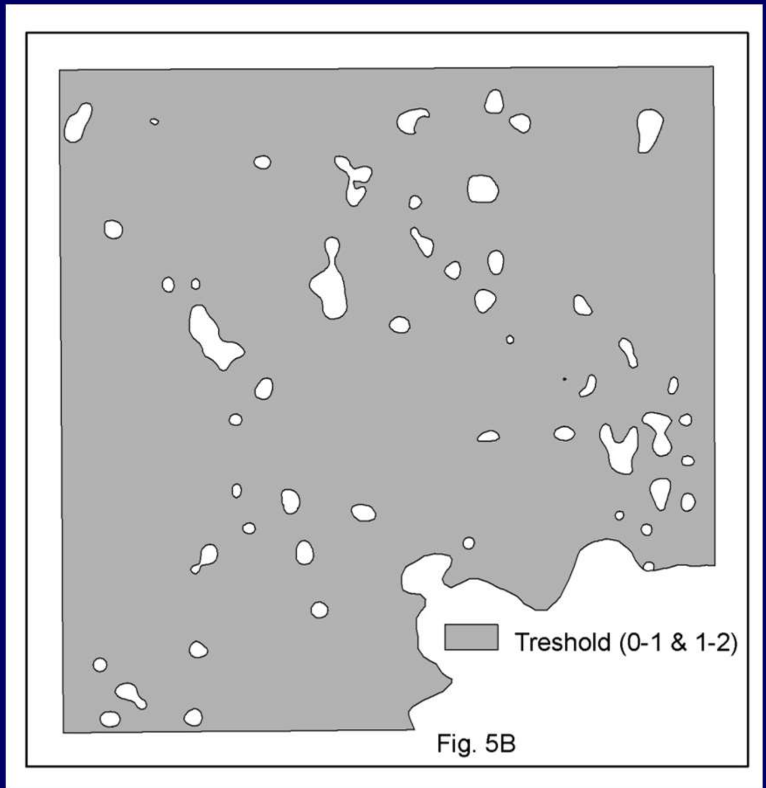

LINEAMENT DENSITY
Legend
0
0-100
100-200
200-300
300-400
400-500
500-600
600-700
>700
PALAEOSCARS
Fig. 4A


LINEAMENT DENSITY VS
LANDSLIDES
60
50
40
30
20
10
0
55
45
29
10
5
0
0
0
0
0
0
100-200
300-400
400-500
600-700
0-100
200-300
300-400
500-600
700
Lineament Density classes


LINEAMENT DENSITY THRESHOLD
THRESHOLD (0-100,
100-200 & 200-300)
Fig. 4B


LINEAMENT INTERSECTION
Legend
0
0-1
1-2
2-3
>3
PALAEOSCARS
Fig. 5A


LINEAMENT INTERSECTION
DENSITY VS LANDSLIDES
No. of Landslides
Lineament Density classes
0
72
58
14
0
0
0-1
1-2
2-3
>3


Treshold (0-1 & 1-2)
Fig. 5B

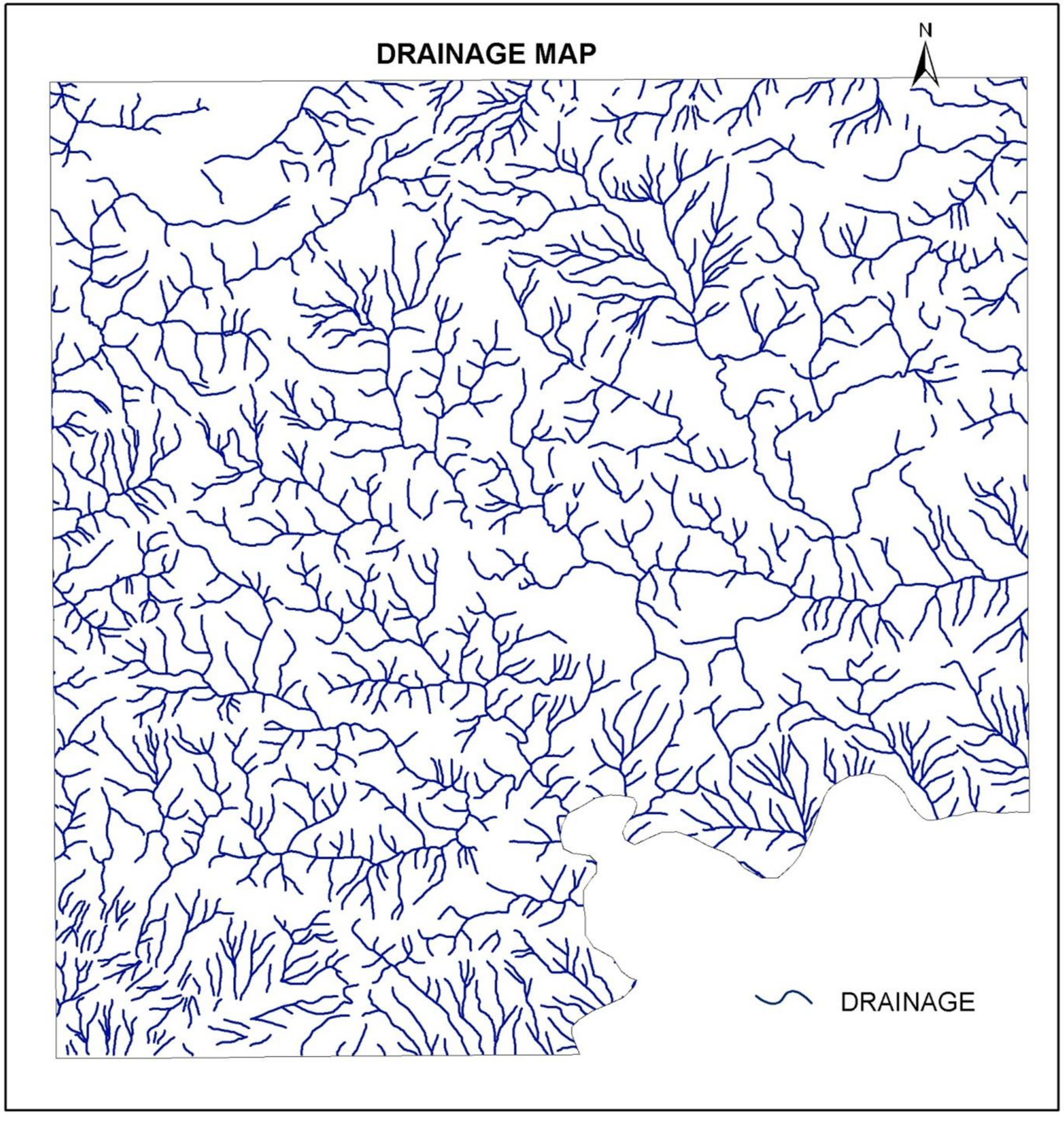
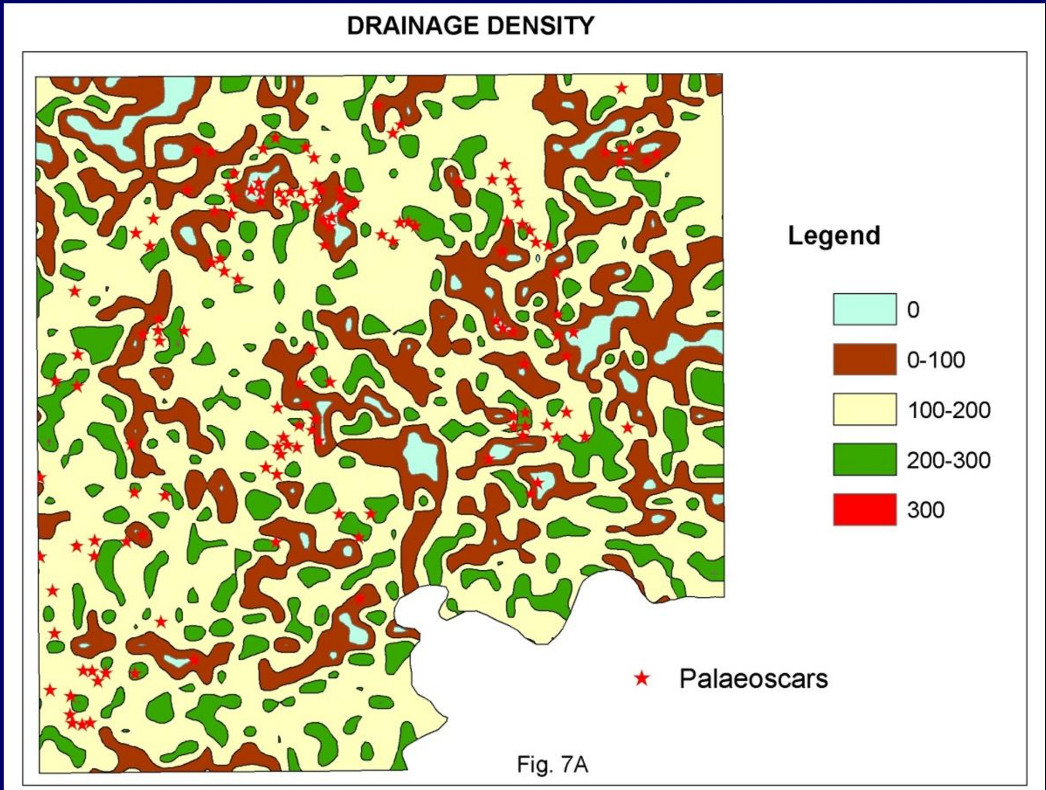
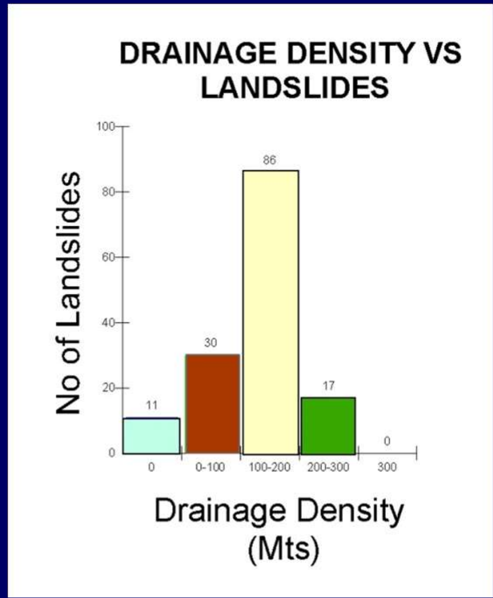
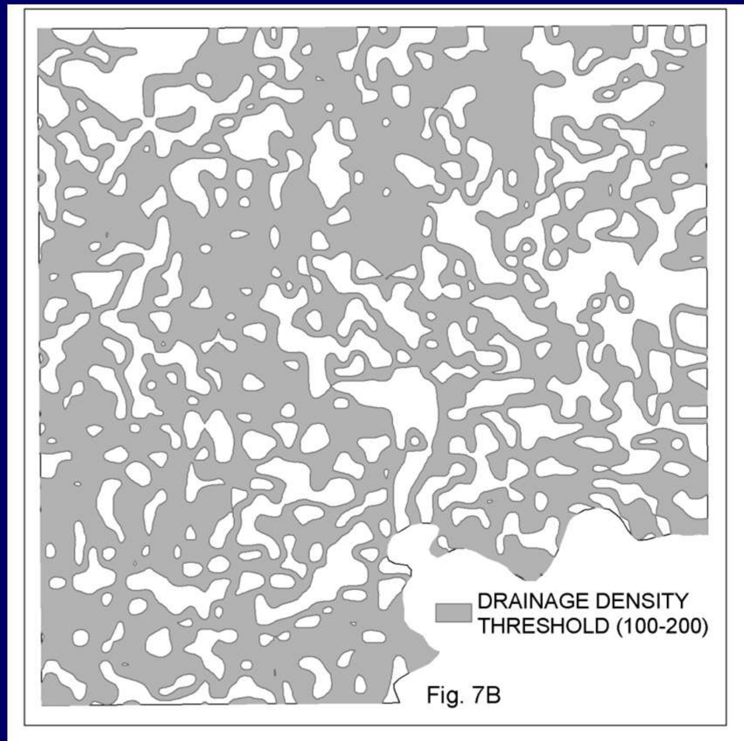
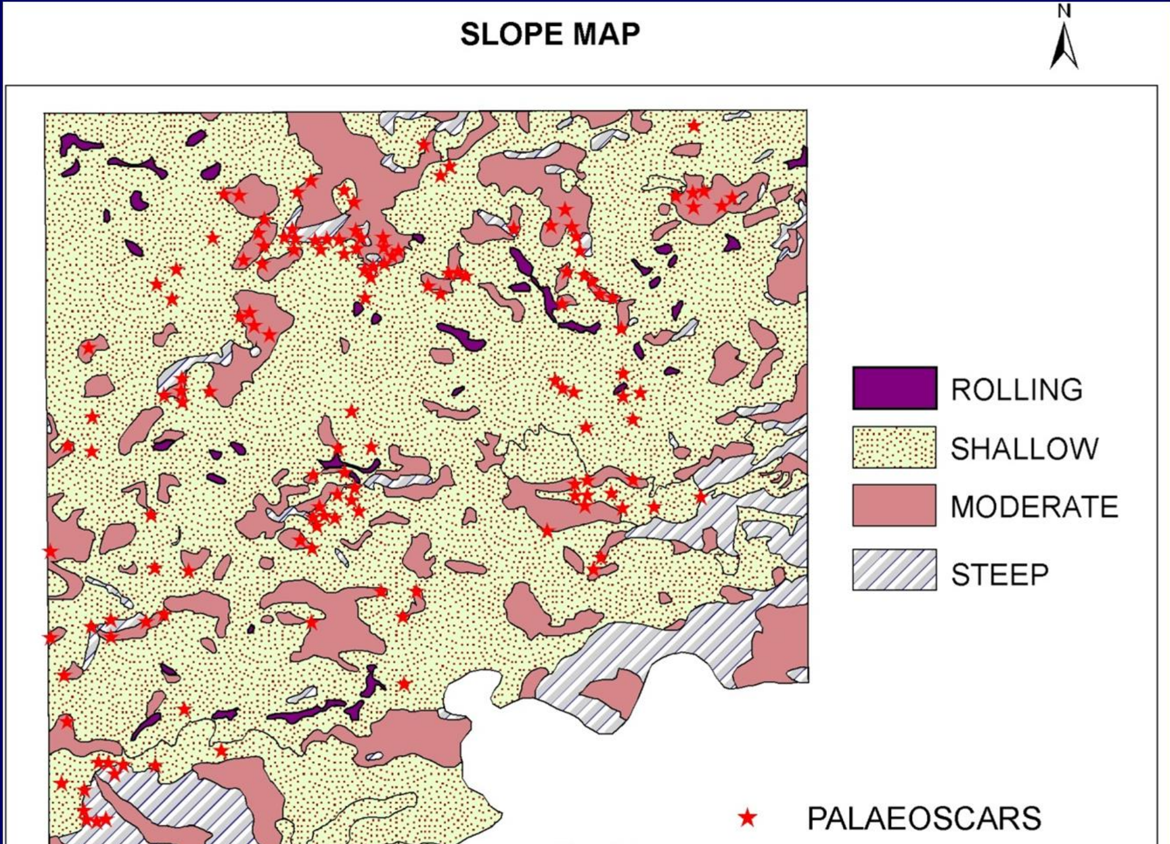


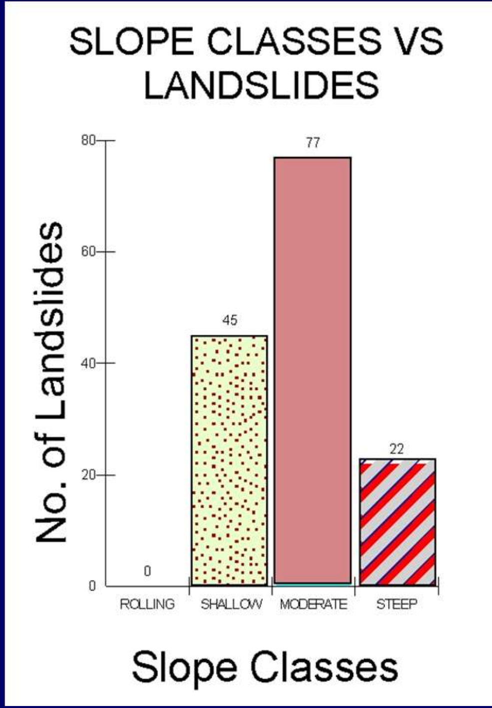
Fig. 6

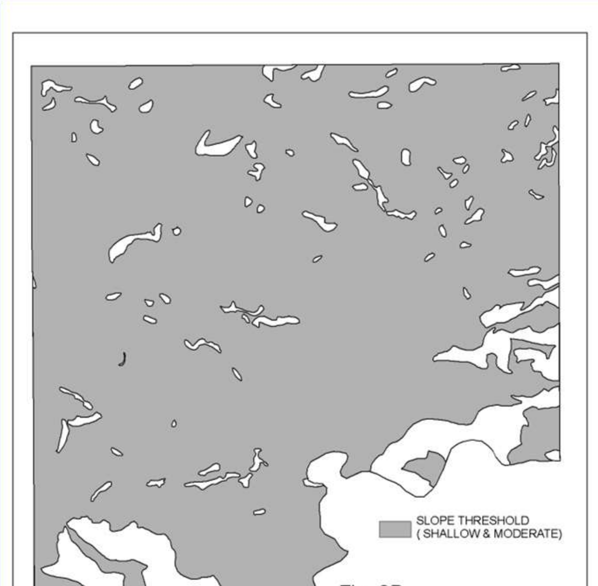

DRAINAGE DENSITY
Legend
0
0-100
100-200
200-300
300
Palaeoscars
Fig. 7A


DRAINAGE DENSITY VS LANDSLIDES
No of Landslides
100
80
60
40
20
0
11
30
86
17
0
0
0-100
100-200
200-300
300
Drainage Density (Mts)


DRAINAGE DENSITY THRESHOLD (100-200)
Fig. 7B


SLOPE MAP
N
ROLLING
SHALLOW
MODERATE
STEEP
PALAEOSCARS
Fig. 8A


SLOPE CLASSES VS LANDSLIDES
No. of Landslides
0
20
40
60
80
0
45
77
22
ROLLING
SHALLOW
MODERATE
STEEP
Slope Classes


SLOPE THRESHOLD
(SHALLOW & MODERATE)
Fig. 8B

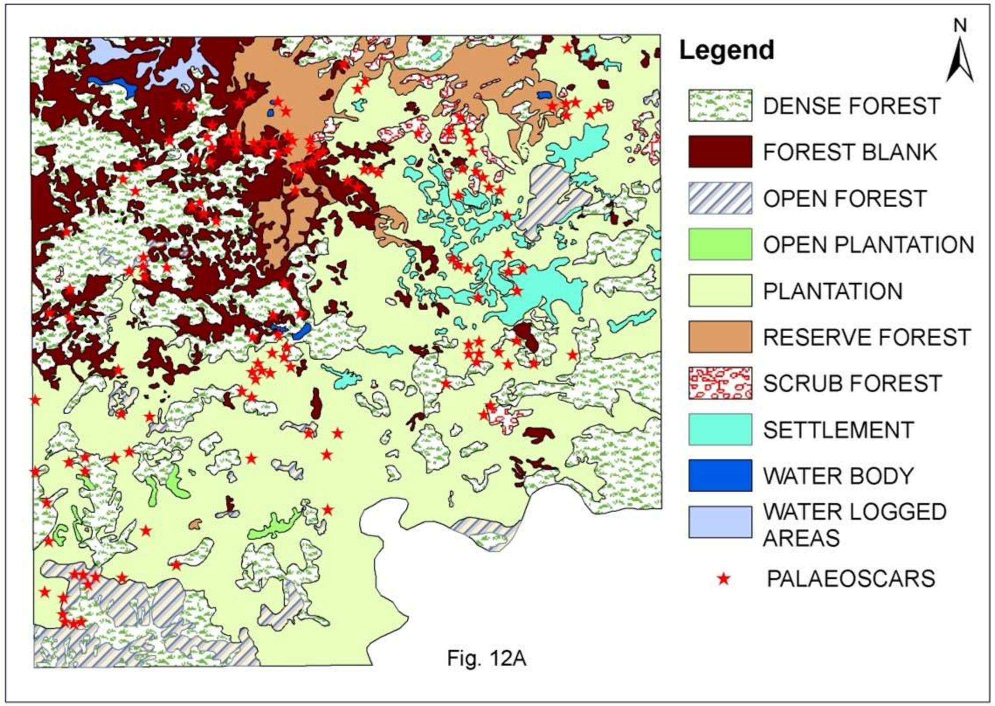
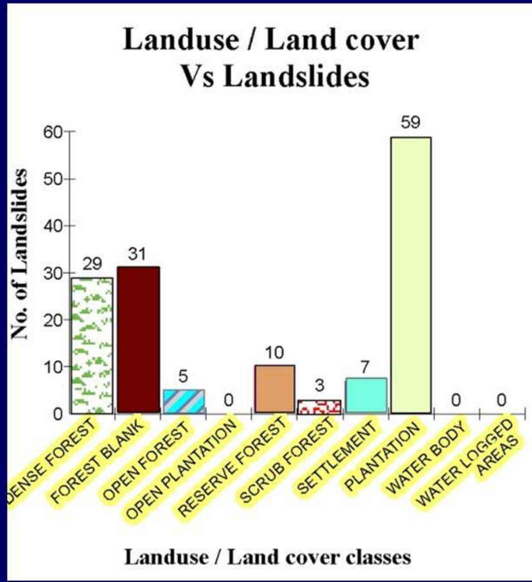


Fig. 12A



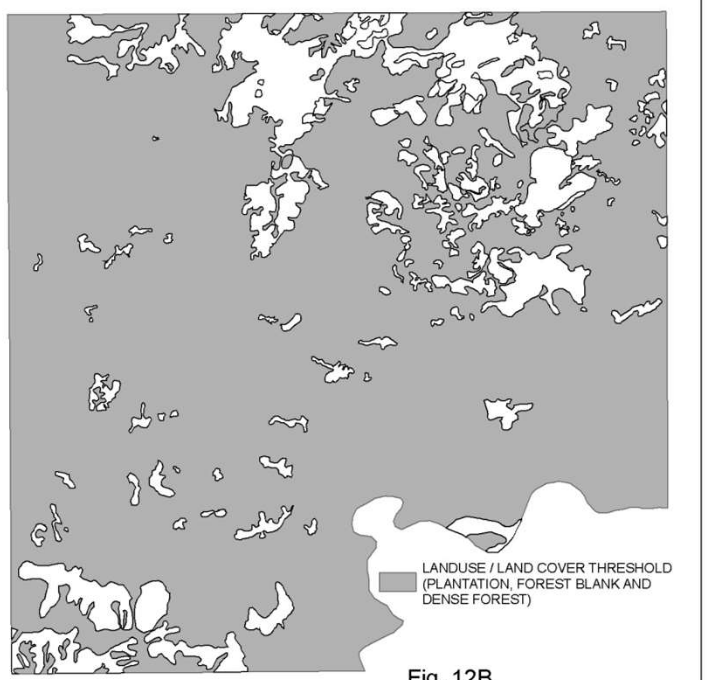


Fig. 12B

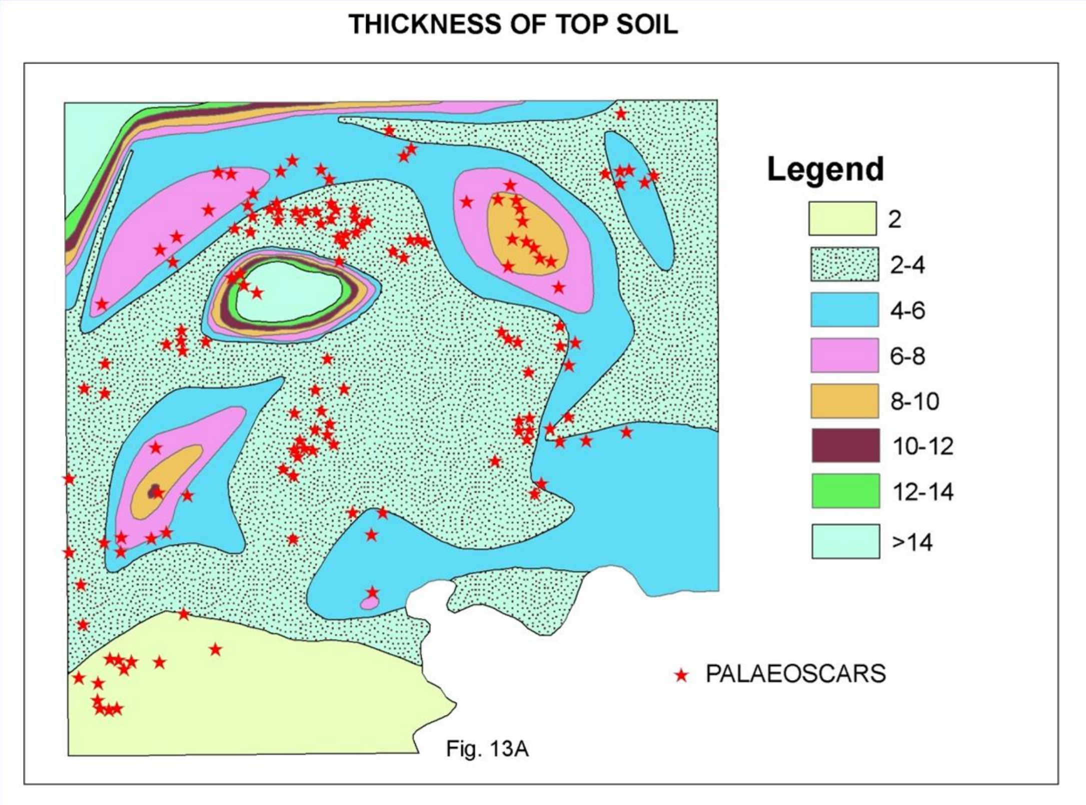
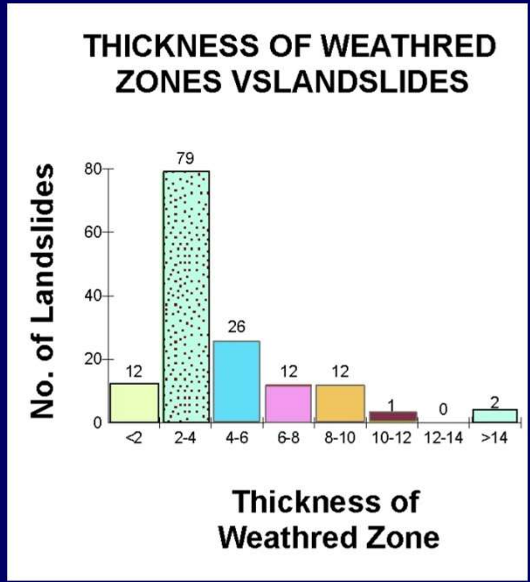


Fig. 13A



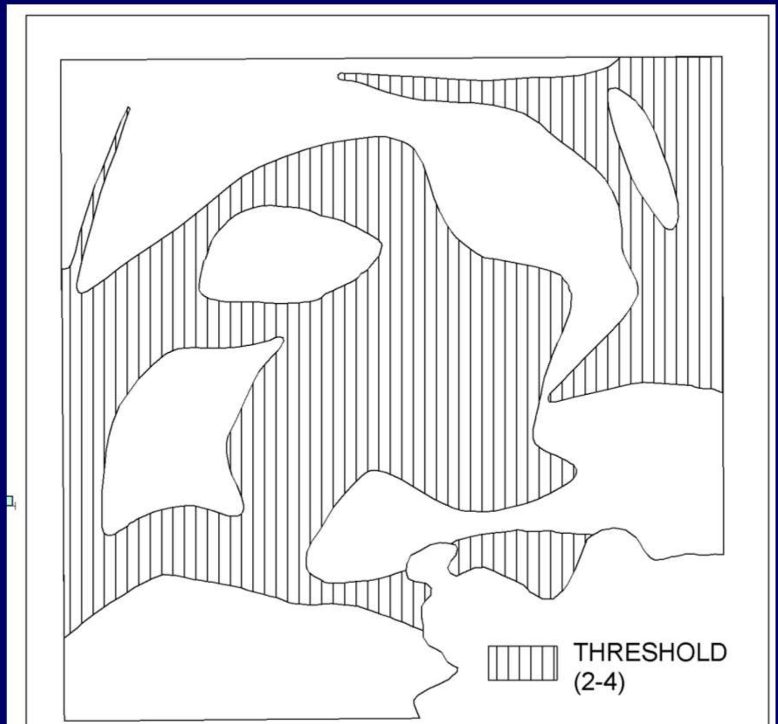


Fig. 13B

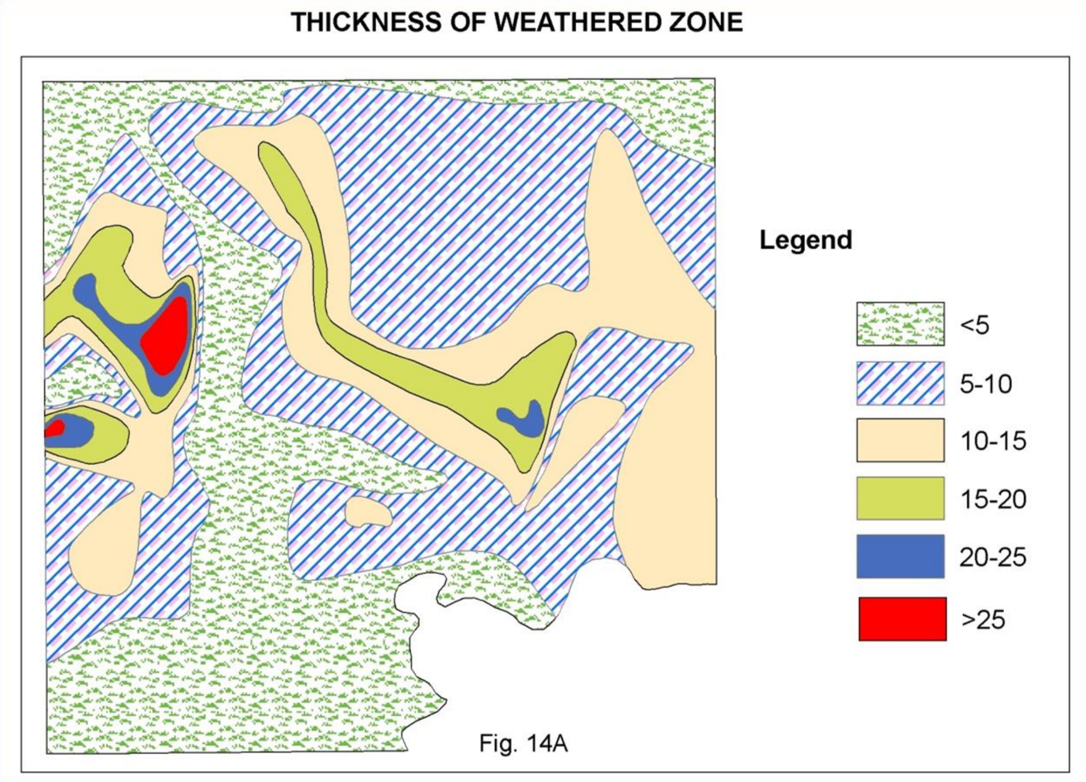
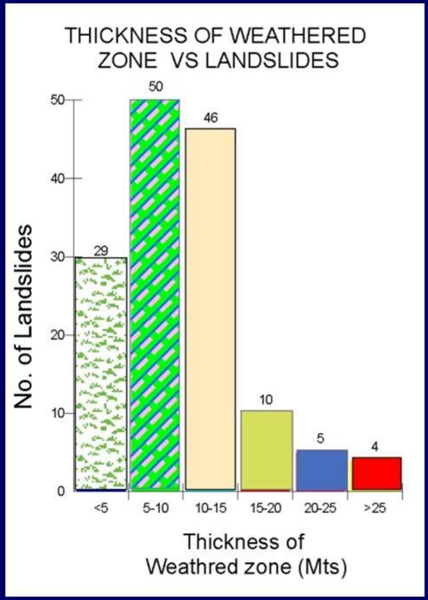


Fig. 14A



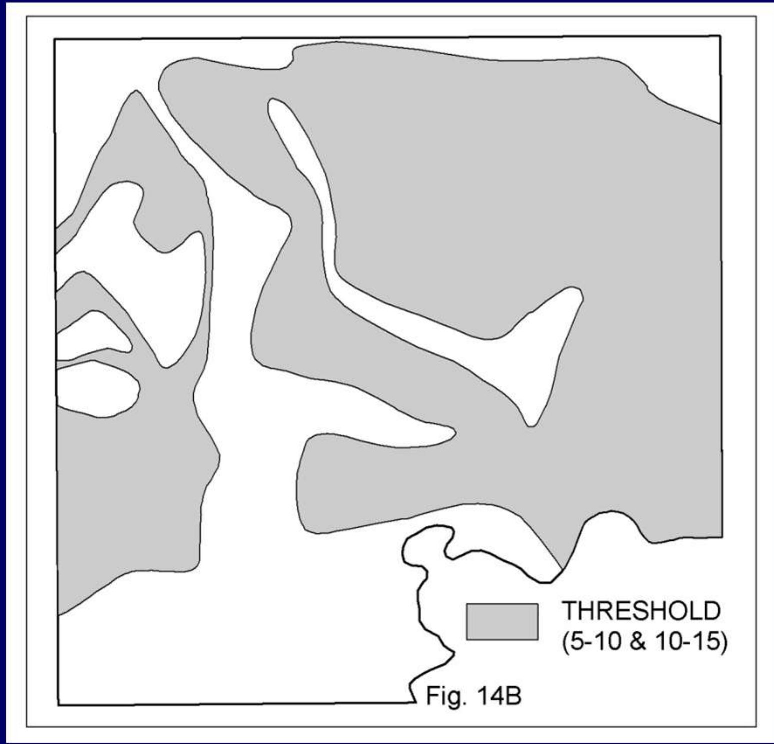


Fig. 14B

GIS MODELING

&

LANDSLIDE HAZARD ZONATION

LEVEL I GIS INTEGRATION:

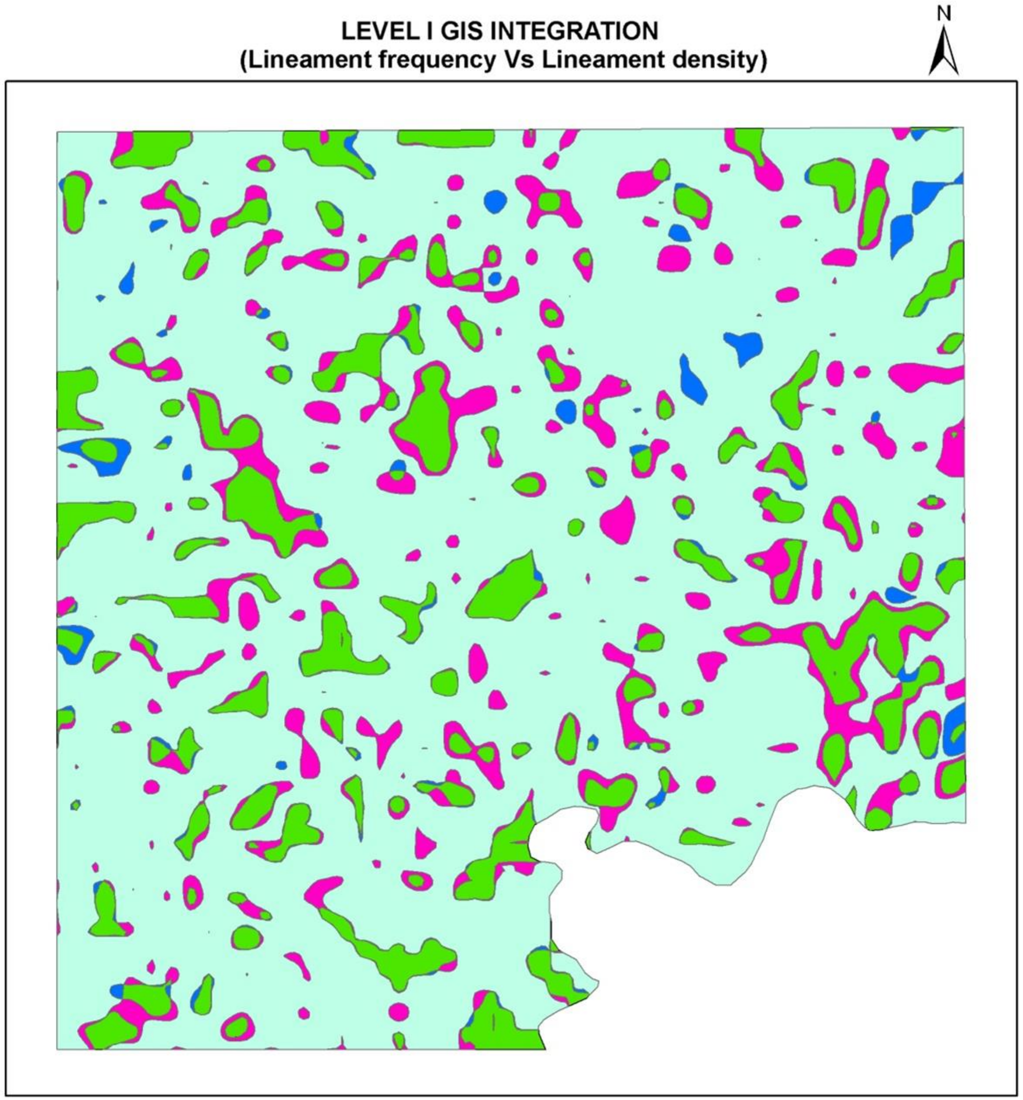
Buffered layer of lineament frequency

Vs

lineament density

1. Lineament frequency controlled landslide zones.
2. Lineament density controlled landslide zones.
3. Lineament frequency and lineament density controlled landslide zones.
4. Area falling out of the above zones (other areas).

LEVEL I GIS INTEGRATION
(Lineament frequency Vs Lineament density)



- Lineament frequency controlled Landslides zones
- Lineament density controlled Landslides zones
- Lineament frequency and density controlled Landslides zones
- Areas falling out of above three zones

Fig. 15

LEVEL II GIS INTEGRATION:

Buffered layer of Level I

Vs

lineament Intersection

1. Lineament frequency controlled landslide zones.
2. Lineament density controlled landslide zones.
3. Lineament intersection controlled landslide zones.
4. Lineament frequency and lineament density controlled landslide zones.
5. Lineament frequency and lineament intersection controlled landslide zones
6. Lineament intersection and lineament density controlled landslide zones.
7. Lineament frequency , lineament density and lineament intersection controlled landslide zones.
8. Area falling out of the above zones (other areas).

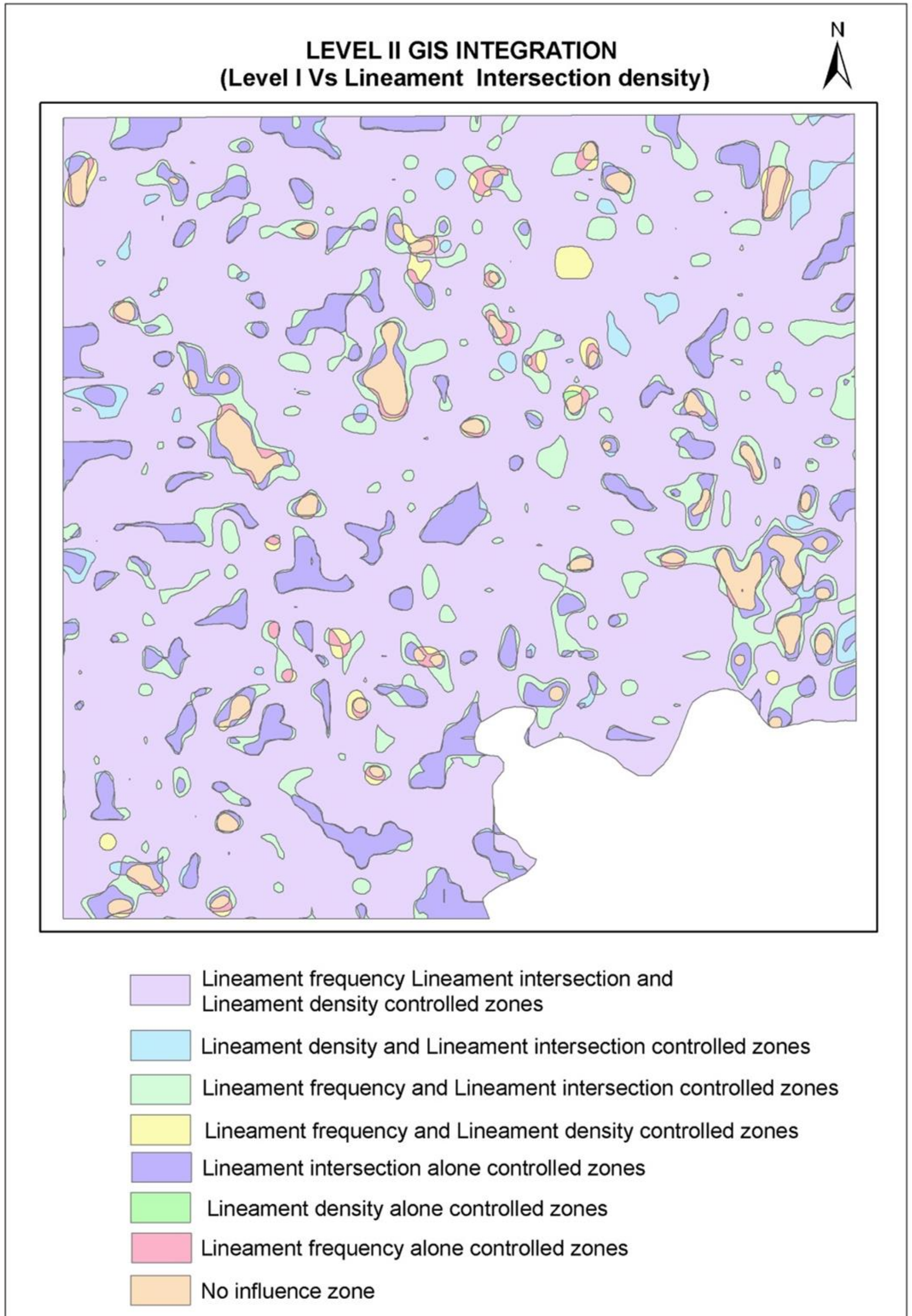

LEVEL II GIS INTEGRATION
(Level I Vs Lineament Intersection density)
N
Lineament frequency Lineament intersection and Lineament density controlled zones
Lineament density and Lineament intersection controlled zones
Lineament frequency and Lineament intersection controlled zones
Lineament frequency and Lineament density controlled zones
Lineament intersection alone controlled zones
Lineament density alone controlled zones
Lineament frequency alone controlled zones
No influence zone

Fig. 16

FINAL INTEGRATION:

Its yielded innumerable number of polygons loaded with 7, 6, 5 , 4 , 3, 2 & 1 Parameters

LANDSLIDE HAZARD ZONATION MAP

More than 5 parameters - Most

4 & 3 parameters - Moderately

Less than 2 parameters - least

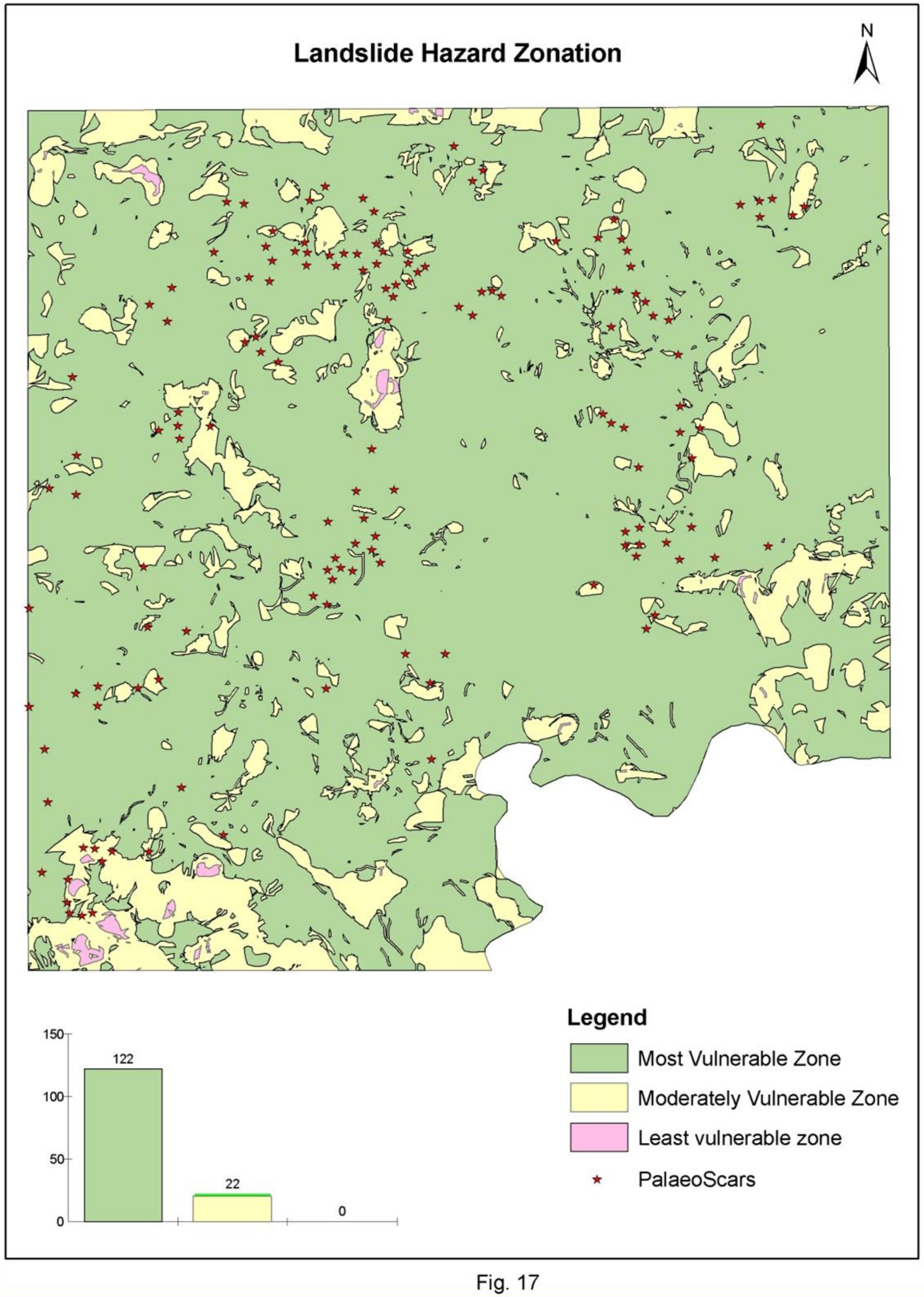

Landslide Hazard Zonation
N
150
100
50
0
122
22
0
Legend
Most Vulnerable Zone
Moderately Vulnerable Zone
Least vulnerable zone
PalaeoScars

Fig. 17

REMEDIAL MEASURES:

Rainfall: Surface drains, Placement of netting, Concrete of reinforced concrete blanketing

Recharge: Subsurface drains like drainage slots provided with filter fabric and rubble fills, parallel piping with perforated pipes and inter connecting catch water drains

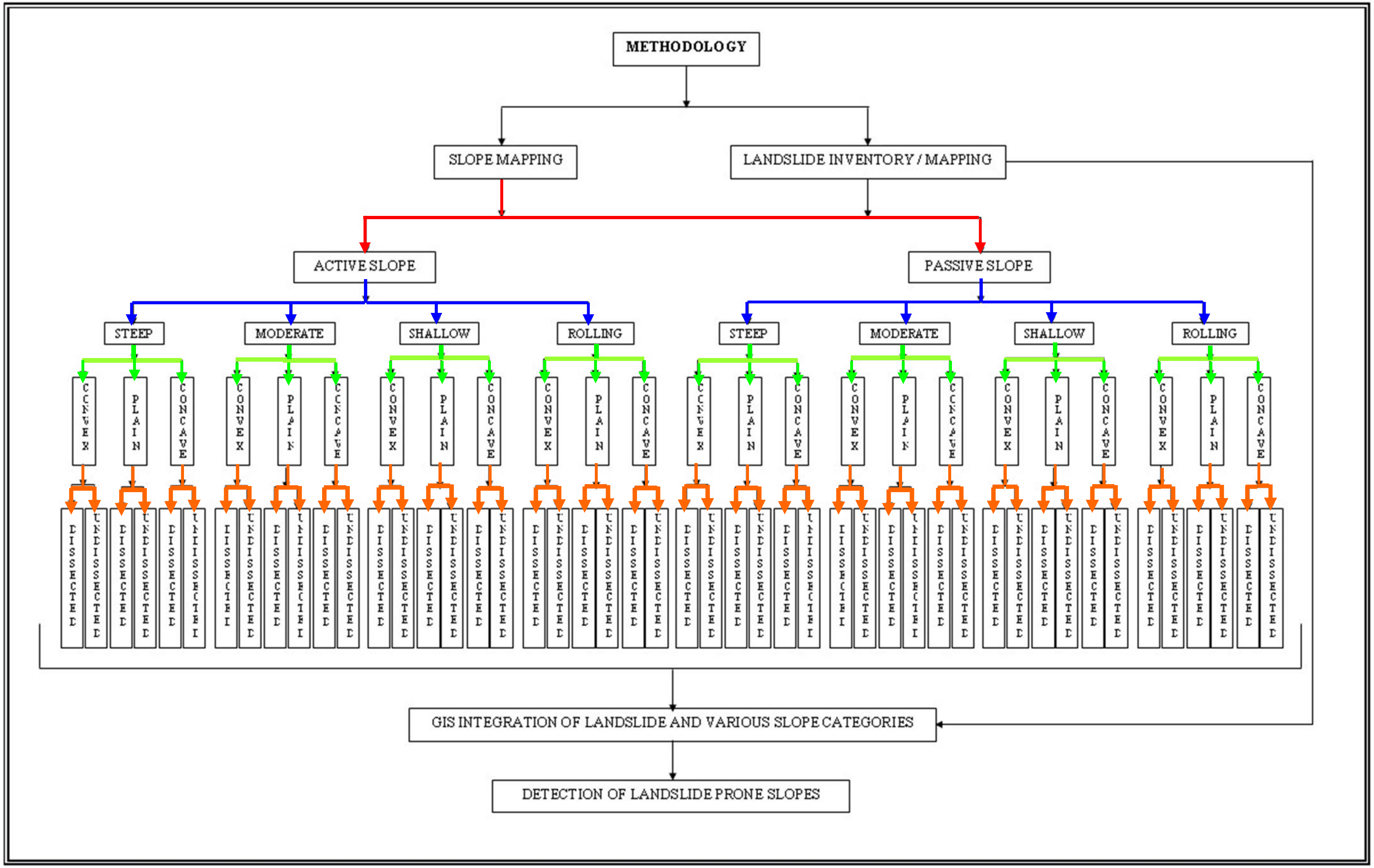
Soil Types: Geo textiling, physical compaction, chemical grouting and strengthening of soil by cement

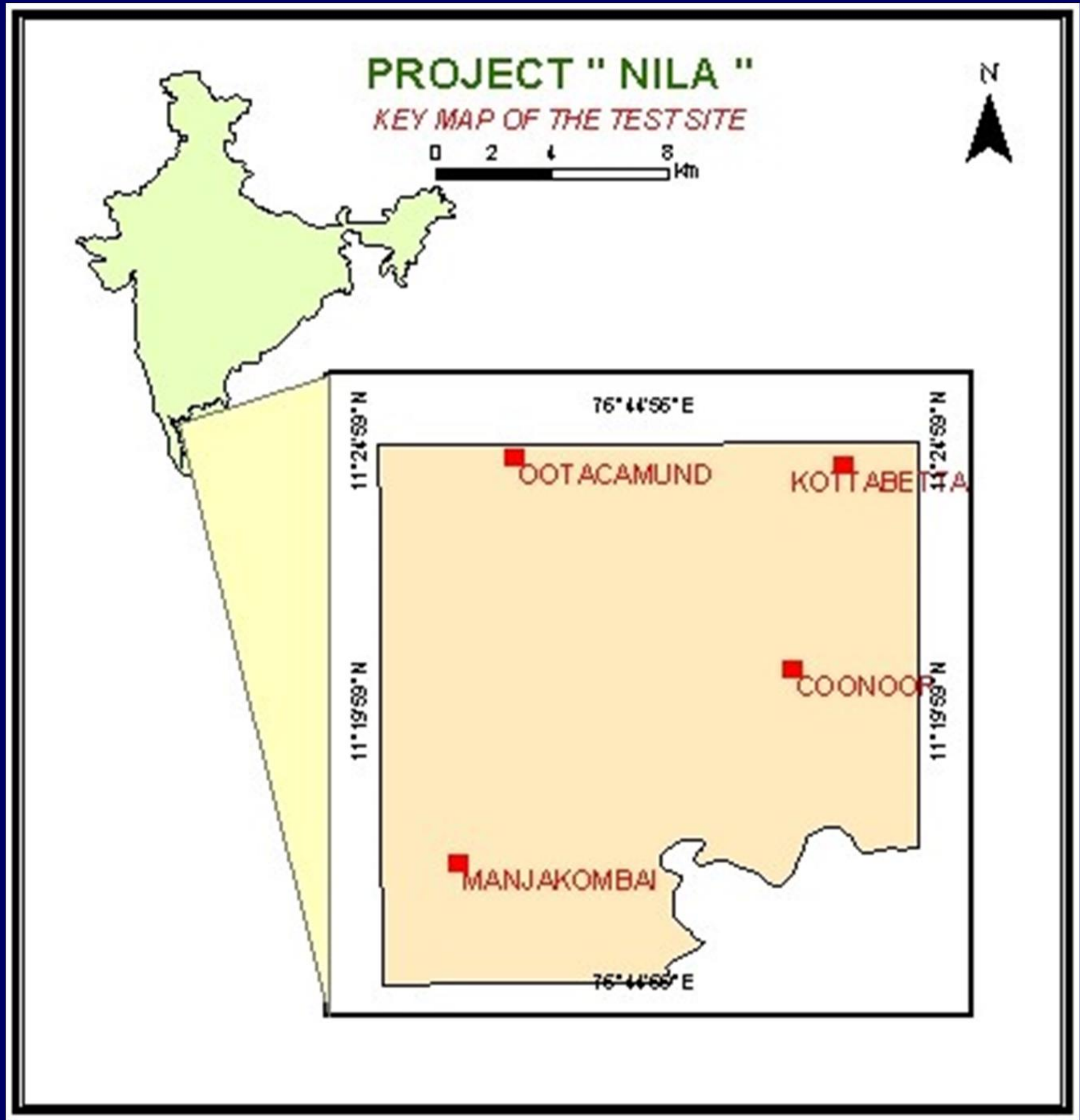
Thickness of fracture and weathered zones:
Nailing and concrete grouting

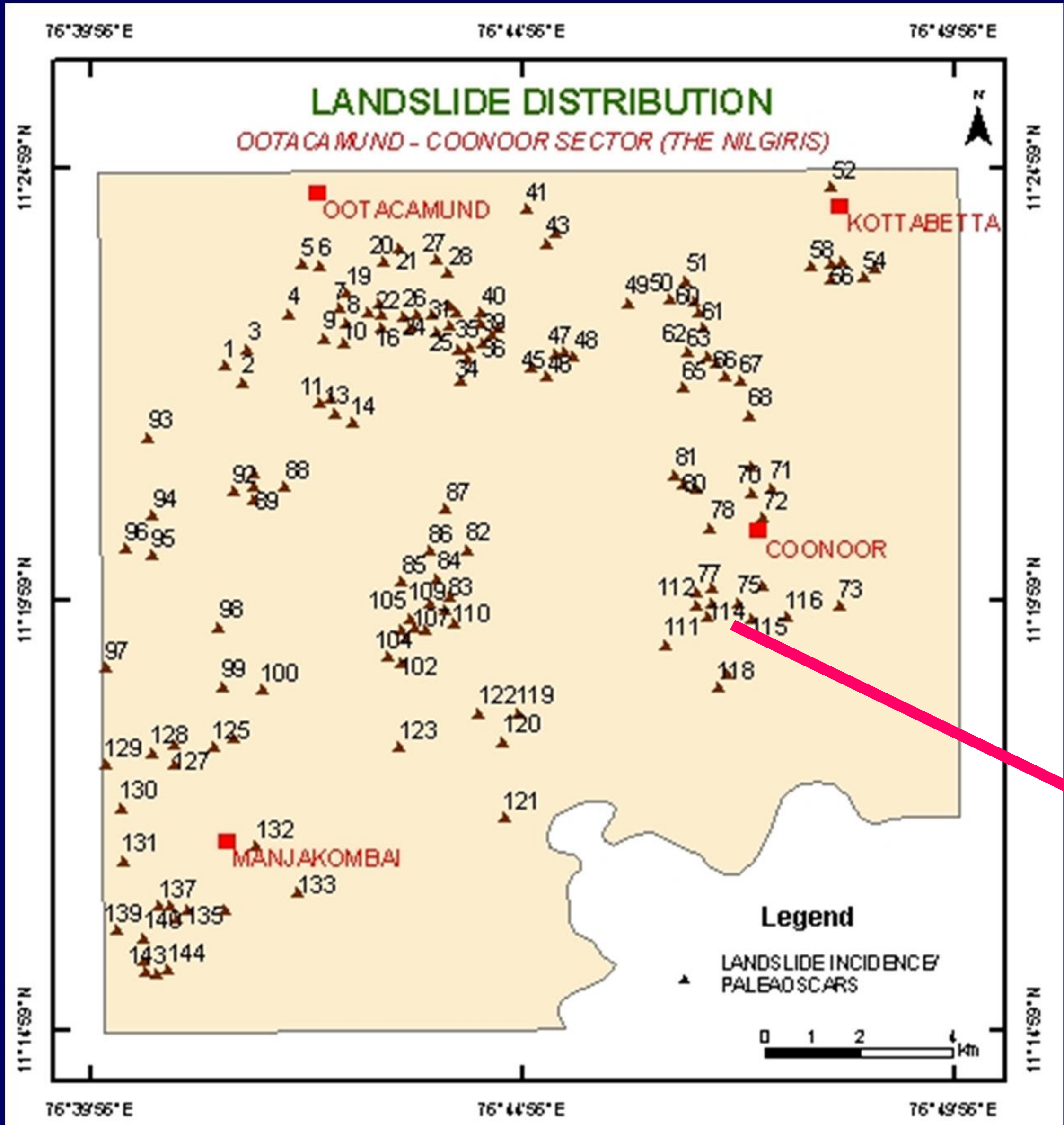
Lineament density :
Nailing, Gully filled vegetation

Slope: Retaining wall with ground anchor, reduction of load of the soil in the head of slope, stabilizing the toe by enlarging, terracing of the uneven downhill slope or flattening of the slope etc

LANDSLIDE HAZARD ZONATION USING NEW GIS BASED SLOPE CLASSIFICATION


METHODOLOGY
SLOPE MAPPING
LANDSLIDE INVENTORY / MAPPING
ACTIVE SLOPE
PASSIVE SLOPE
STEEP
MODERATE
SHALLOW
ROLLING
CONVEX
PLAIN
CONCAVE
DISSECTED
UNDISSECTED
GIS INTEGRATION OF LANDSLIDE AND VARIOUS SLOPE CATEGORIES
DETECTION OF LANDSLIDE PRONE SLOPES

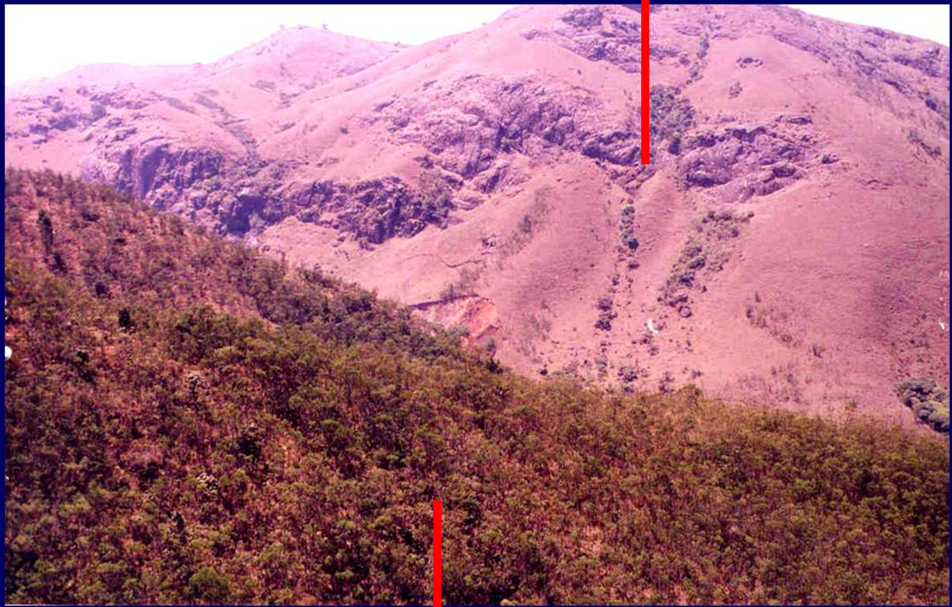

PROJECT " NILA "
KEY MAP OF THE TEST SITE
0 2 4 8
Km
N
76°44'56"E
11°24'59"N
11°19'59"N
OOTACAMUND
KOTTABETTA
COONOOR
MANJAKOMBAI

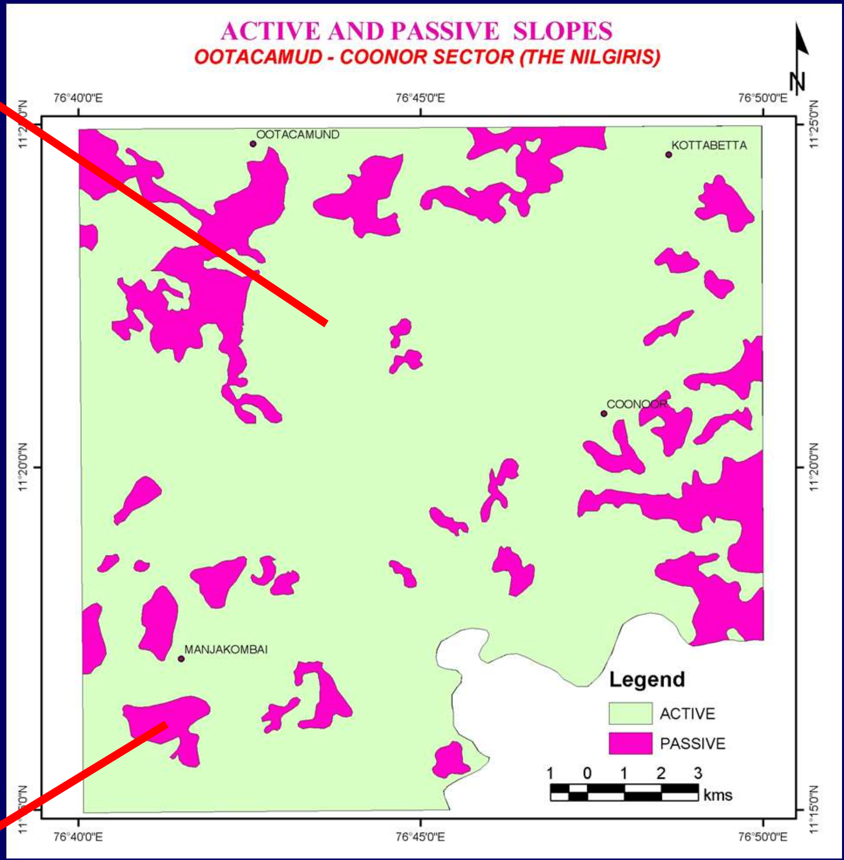


144 LANDSLIDES

ACTIVE – PASSIVE SLOPES

ACTIVE SLOPE





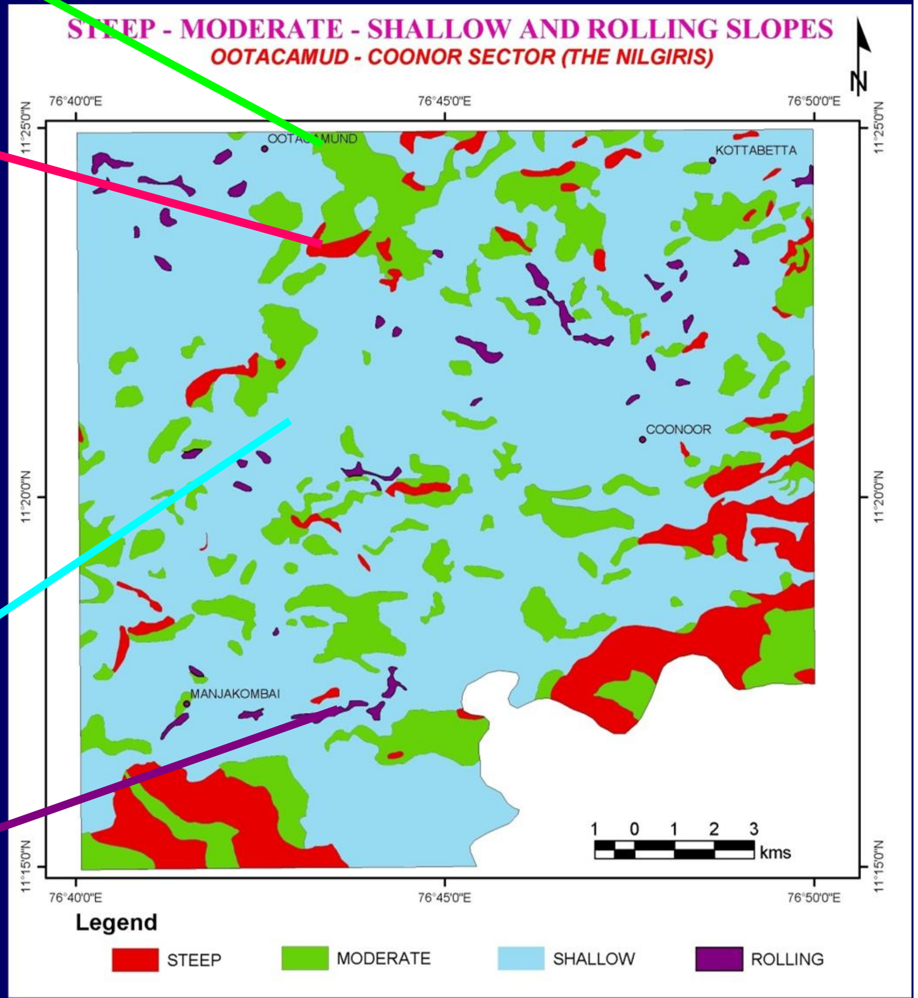
PASSIVE SLOPE

(VEGETATIVE COVER)

STEEP – MODERATE – SHALLOW - ROLLING SLOPES

MODERATE SLOPE

STEEP SLOPE



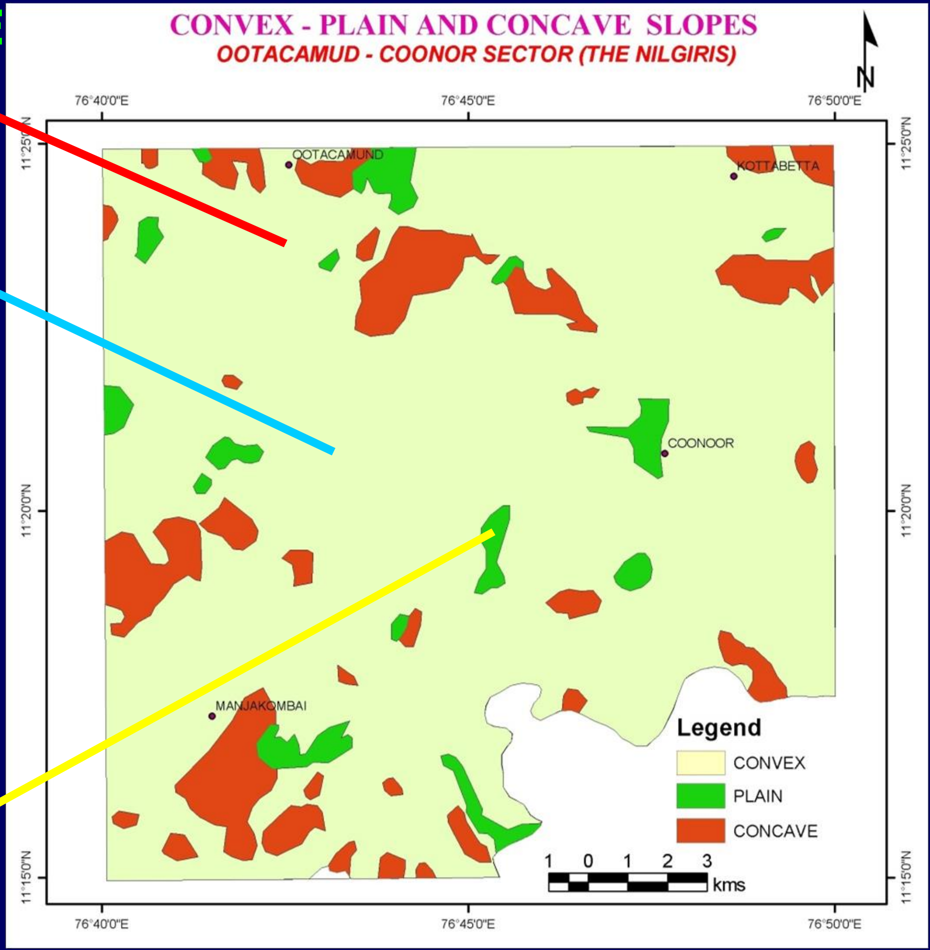
SHALLOW SLOPE

ROLLOING SLOPE

CONVEX – PLAIN - CONCAVE SLOPES

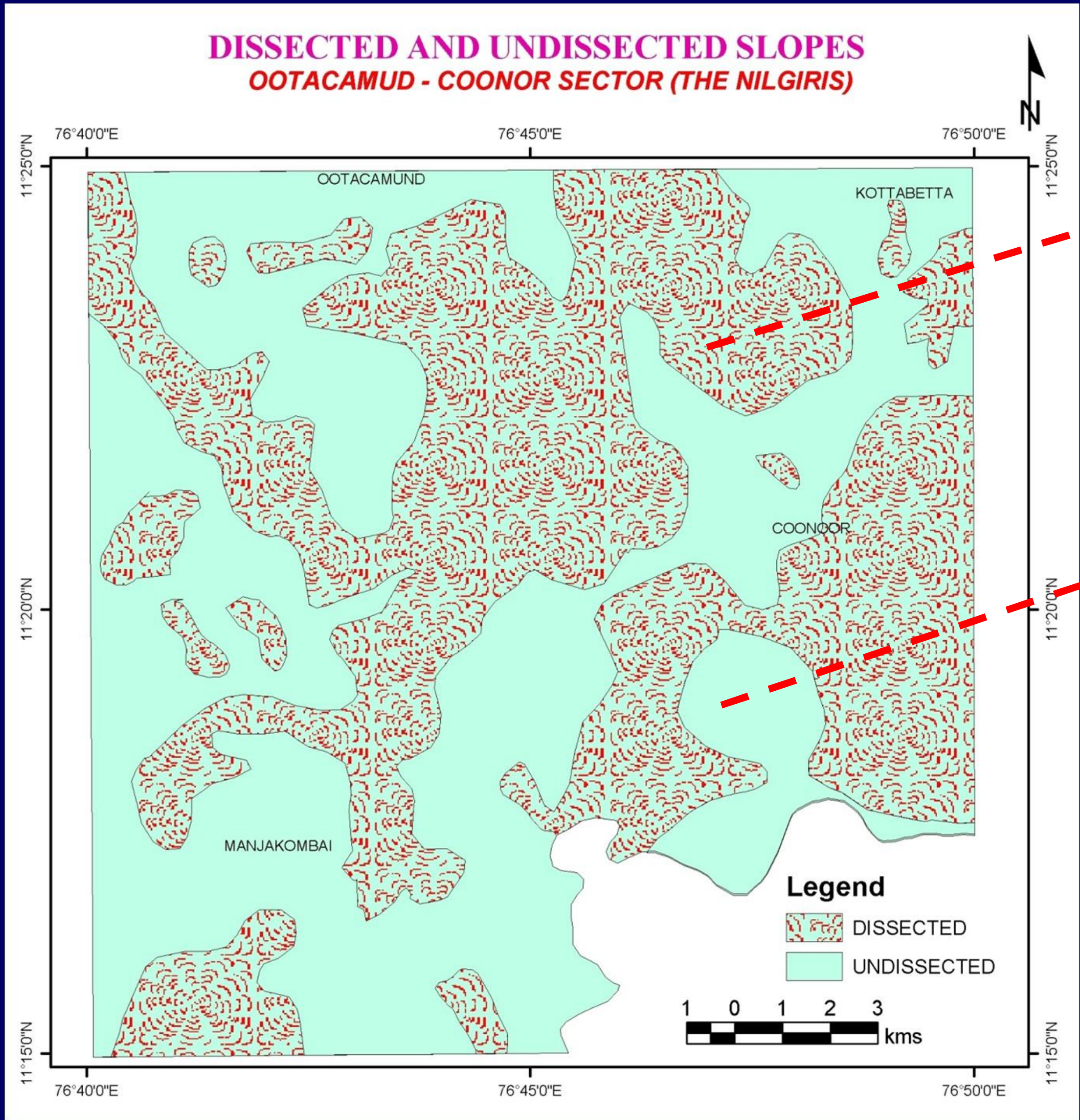
CONCAVE SLOPE

CONVEX SLOPE



PLAIN

DISSECTED - UNDISSECTED SLOPES



DISSECTED SLOPE

UNDISSECTED SLOPE

GIS INTEGRATION (LEVEL 1)

LAYER 1(2 CLASSES)

(ACTIVE & PASSIVE SLOPES)

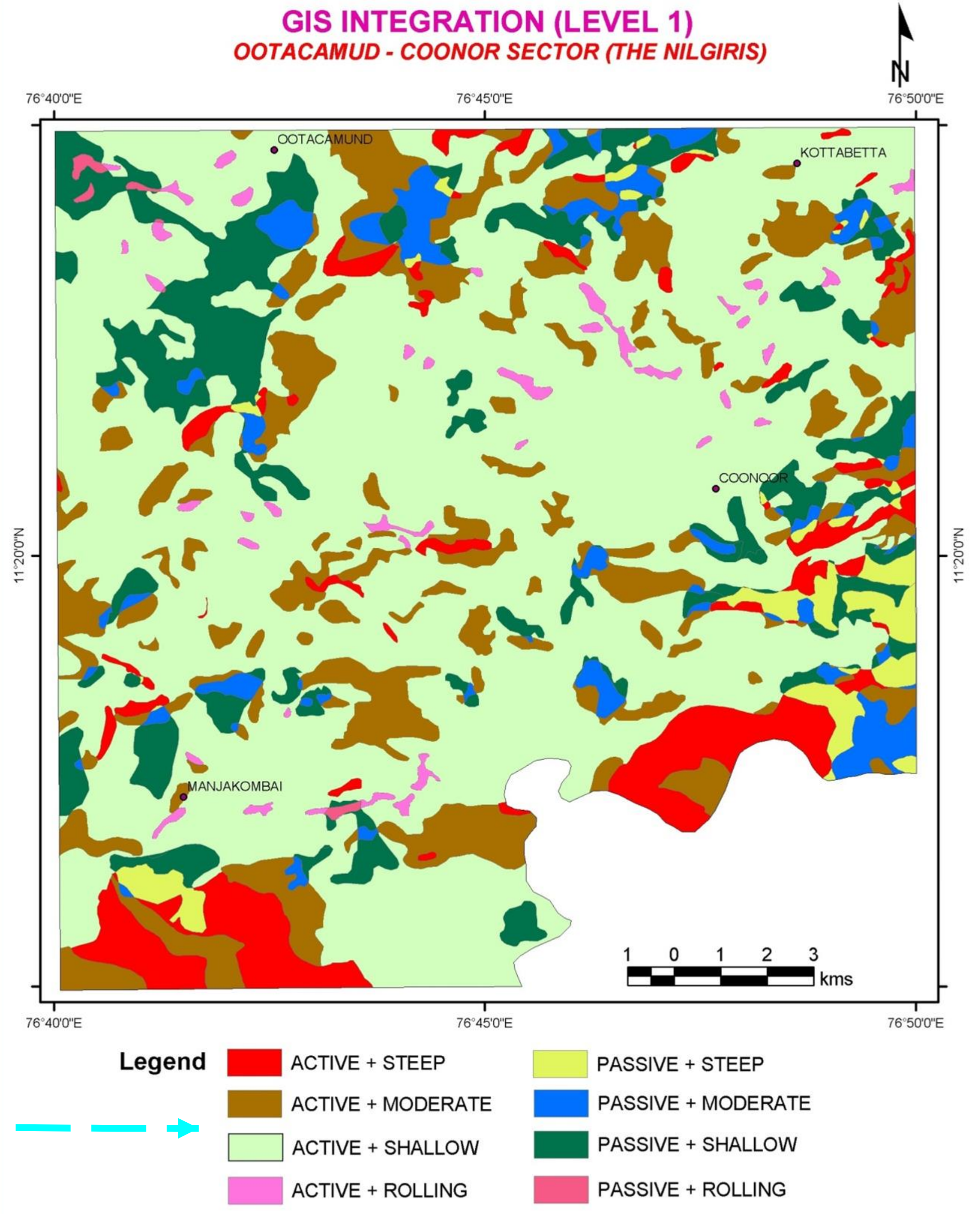
+

LAYER 2 (4 CLASSES)

(STEEP MODERATE, SHALLOW & ROLLING SLOPES)

OUTPUT

(8 CLASSES)



GIS INTEGRATION (LEVEL II)

OUTPUT OF GIS INTEGRATION LEVEL I

(8 CLASSES)

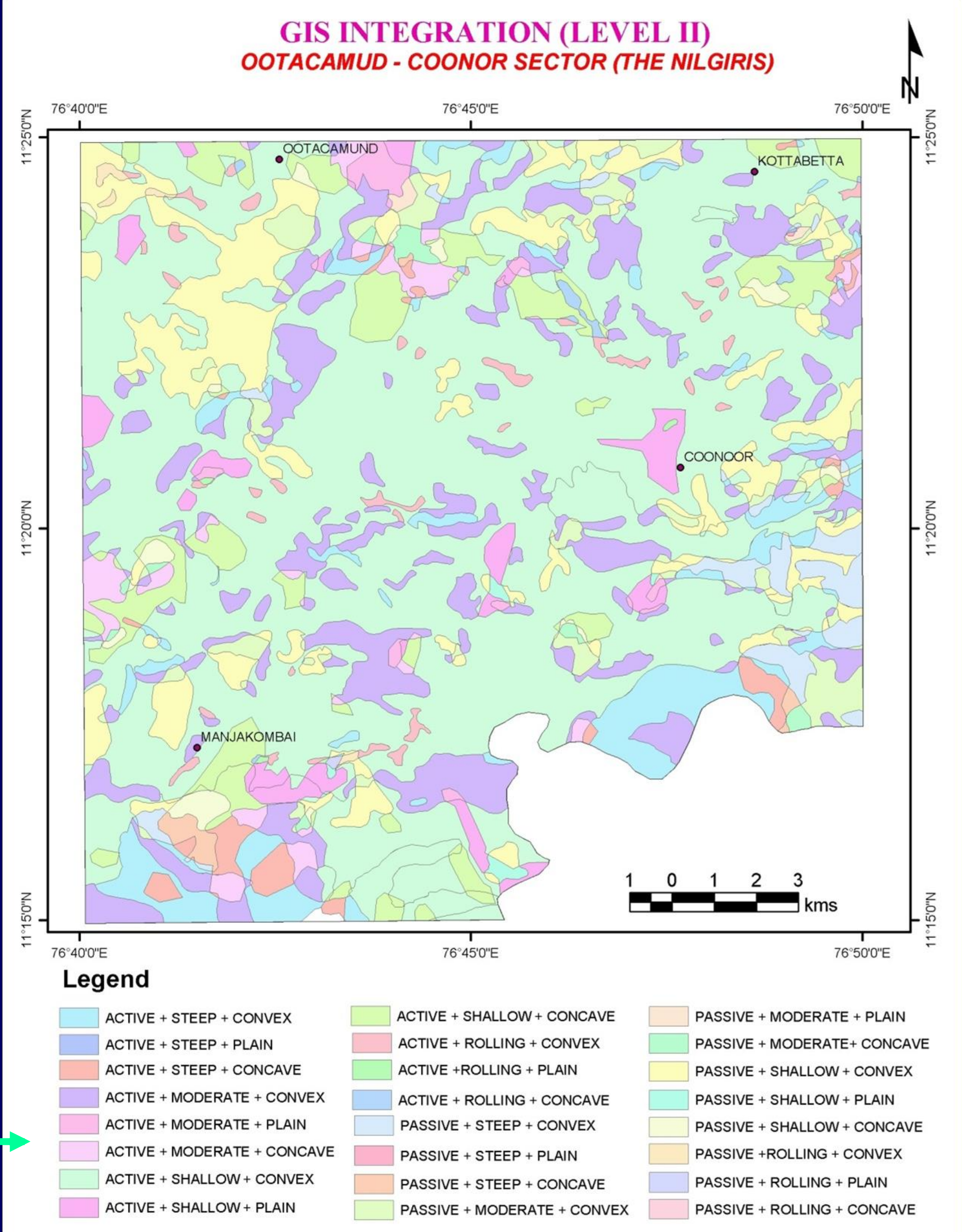
+

LAYER 3

(3 CLASSES)

OUTPUTS

(24 CLASSES)



GIS INTEGRATION (LEVEL III)

OUTPUT OF GIS INTEGRATION LEVEL II

(24 CLASSES)

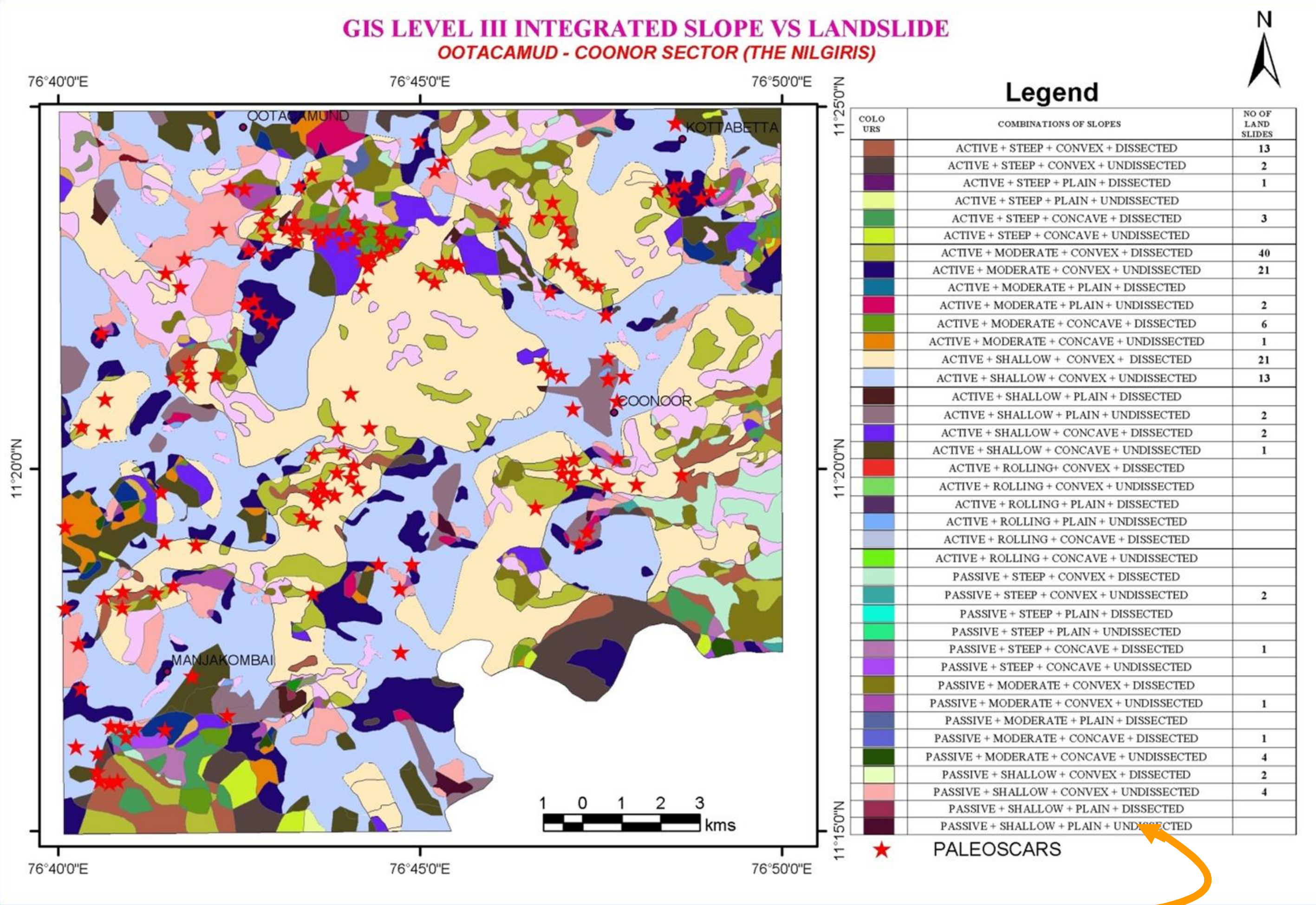
+

LAYER 4

(2 CLASSES)

OUTPUT

(46 CLASSES)



MOST VULNERABLE SLOPES

ACTIVE + MODERATE + CONVEX + DISSECTED--- 40

ACTIVE + MODERATE + CONVEX + UNDISSECTED---- 21

ACTIVE + SHALLOW + CONVEX + DISSECTED--- 21

ACTIVE + SHALLOW + CONVEX + DISSECTED---- 13

ACTIVE + STEEP + CONVEX +DISSECTED---- 13

CLASS NO	COMBINATIONS OF SLOPES	NO OF LAND SLIDES
MOST VULNERABLE SLOPES		
1	ACTIVE + MODERATE + CONVEX + DISSECTED	40
2	ACTIVE + MODERATE + CONVEX + UNDISSECTED	21
3	ACTIVE + SHALLOW + CONVEX + DISSECTED	21
4	ACTIVE + STEEP + CONVEX + DISSECTED	13
5	ACTIVE + SHALLOW + CONVEX + UNDISSECTED	13
MODERATE VULNERABLE SLOPES		
6	ACTIVE + MODERATE + CONCAVE + DISSECTED	6
7	PASSIVE + MODERATE + CONCAVE + UNDISSECTED	4
8	PASSIVE + SHALLOW + CONVEX + UNDISSECTED	4
9	ACTIVE + STEEP + CONCAVE + DISSECTED	3
10	ACTIVE + STEEP + CONVEX + UNDISSECTED	2
11	ACTIVE + MODERATE + PLAIN + UNDISSECTED	2
12	ACTIVE + SHALLOW + PLAIN + UNDISSECTED	2
13	ACTIVE + SHALLOW + CONCAVE + DISSECTED	2
14	PASSIVE + STEEP + CONVEX + UNDISSECTED	2
15	PASSIVE + SHALLOW + CONVEX + DISSECTED	2
16	ACTIVE + SHALLOW + CONCAVE + UNDISSECTED	1
17	ACTIVE + STEEP + PLAIN + DISSECTED	1
18	ACTIVE + MODERATE + CONCAVE + UNDISSECTED	1
19	PASSIVE + STEEP + CONCAVE + DISSECTED	1
20	PASSIVE + MODERATE + CONVEX + UNDISSECTED	1
21	PASSIVE + MODERATE + CONCAVE + DISSECTED	1
22	PASSIVE + SHALLOW + CONCAVE + UNDISSECTED	1

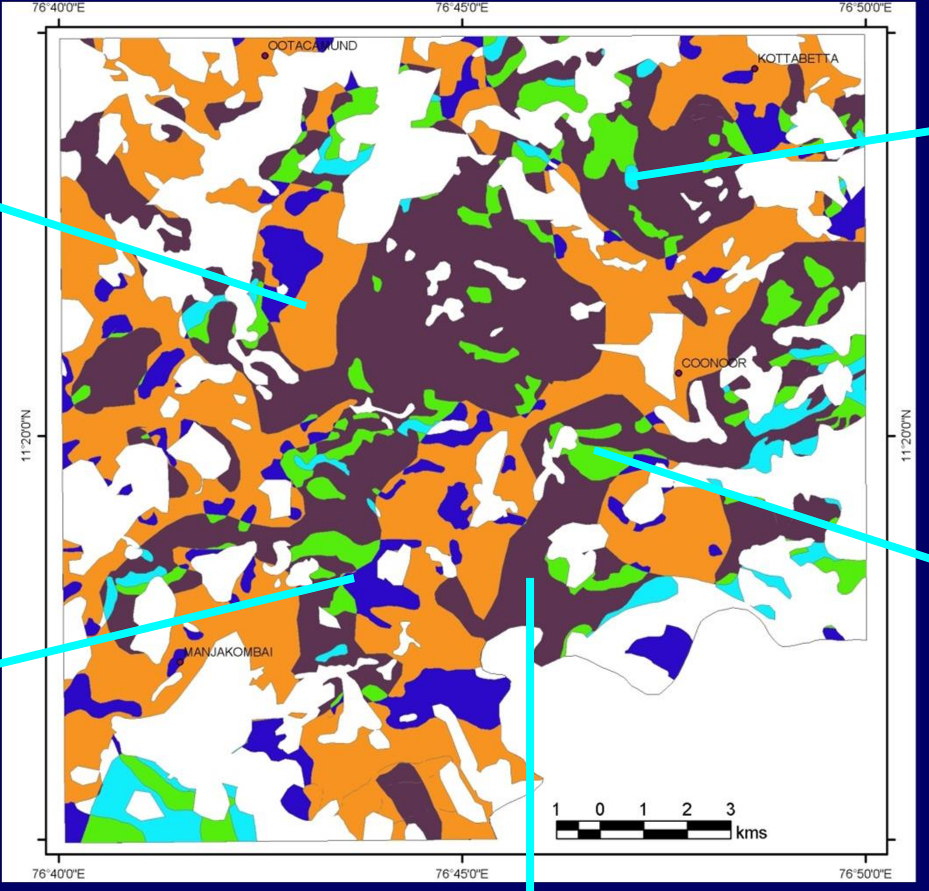
LEAST VULNERABLE SLOPES		
23	ACTIVE + STEEP + PLAIN + UNDISSECTED	
24	ACTIVE + STEEP + CONCAVE + UNDISSECTED	
25	ACTIVE + MODERATE + PLAIN + DISSECTED	
26	ACTIVE + SHALLOW + PLAIN + DISSECTED	
27	ACTIVE + ROLLING + CONVEX + UNDISSECTED	
28	ACTIVE + ROLLING + CONVEX + DISSECTED	
29	ACTIVE + ROLLING + PLAIN + DISSECTED	
30	ACTIVE + ROLLING + PLAIN + UNDISSECTED	
31	ACTIVE + ROLLING + CONCAVE + DISSECTED	
32	ACTIVE + ROLLING + CONCAVE + UNDISSECTED	
33	PASSIVE + STEEP + CONVEX + DISSECTED	
34	PASSIVE + STEEP + PLAIN + DISSECTED	
35	PASSIVE + STEEP + PLAIN + UNDISSECTED	
36	PASSIVE + MODERATE + PLAIN + DISSECTED	
37	PASSIVE + MODERATE + PLAIN + UNDISSECTED	
38	PASSIVE + STEEP + CONCAVE + UNDISSECTED	
39	PASSIVE + MODERATE + CONVEX + DISSECTED	
40	PASSIVE + SHALLOW + PLAIN + DISSECTED	
41	PASSIVE + SHALLOW + PLAIN + UNDISSECTED	
42	PASSIVE + SHALLOW + CONCAVE + DISSECTED	
43	PASSIVE + SHALLOW + CONVEX + DISSECTED	
44	PASSIVE + ROLLING + CONVEX + UNDISSECTED	
45	PASSIVE + ROLLING + PLAIN + DISSECTED	
46	PASSIVE + ROLLING + CONCAVE + DISSECTED	

MOST VULNERABLE SLOPE COMBINATIONS

(5 CLASSES)

ACTIVE + STEEP + CONVEX +DISSECTED

ACTIVE + SHALLOW + CONVEX + UNDISSECTED



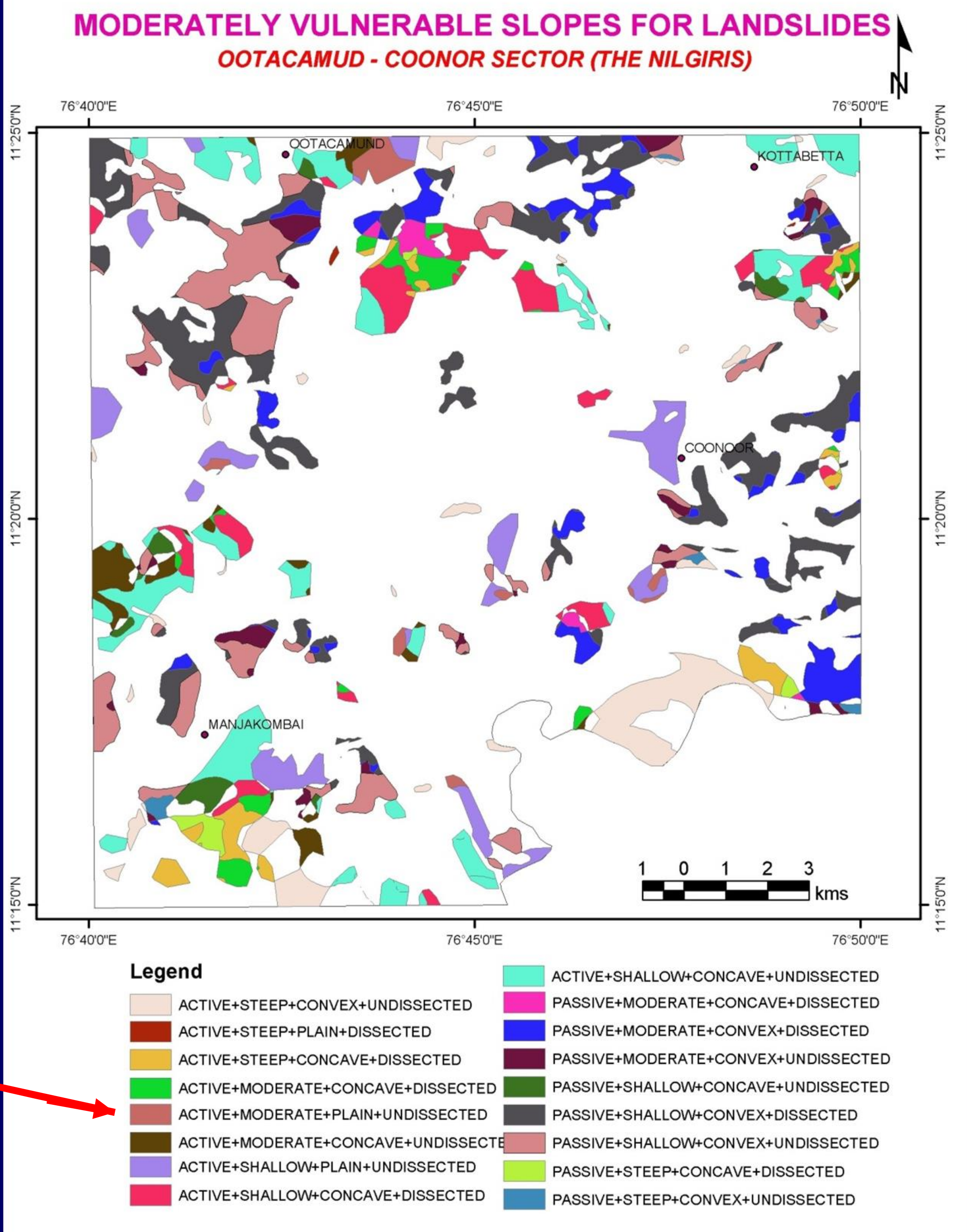
ACTIVE + MODERATE + CONVEX + DISSECTED

ACTIVE + SHALLOW + CONVEX + DISSECTED

ACTIVE + MODERATE + CONVEX + UNDISSECTED

MODERATE VULNERABLE SLOPE COMBINATIONS

(17 CLASSES)

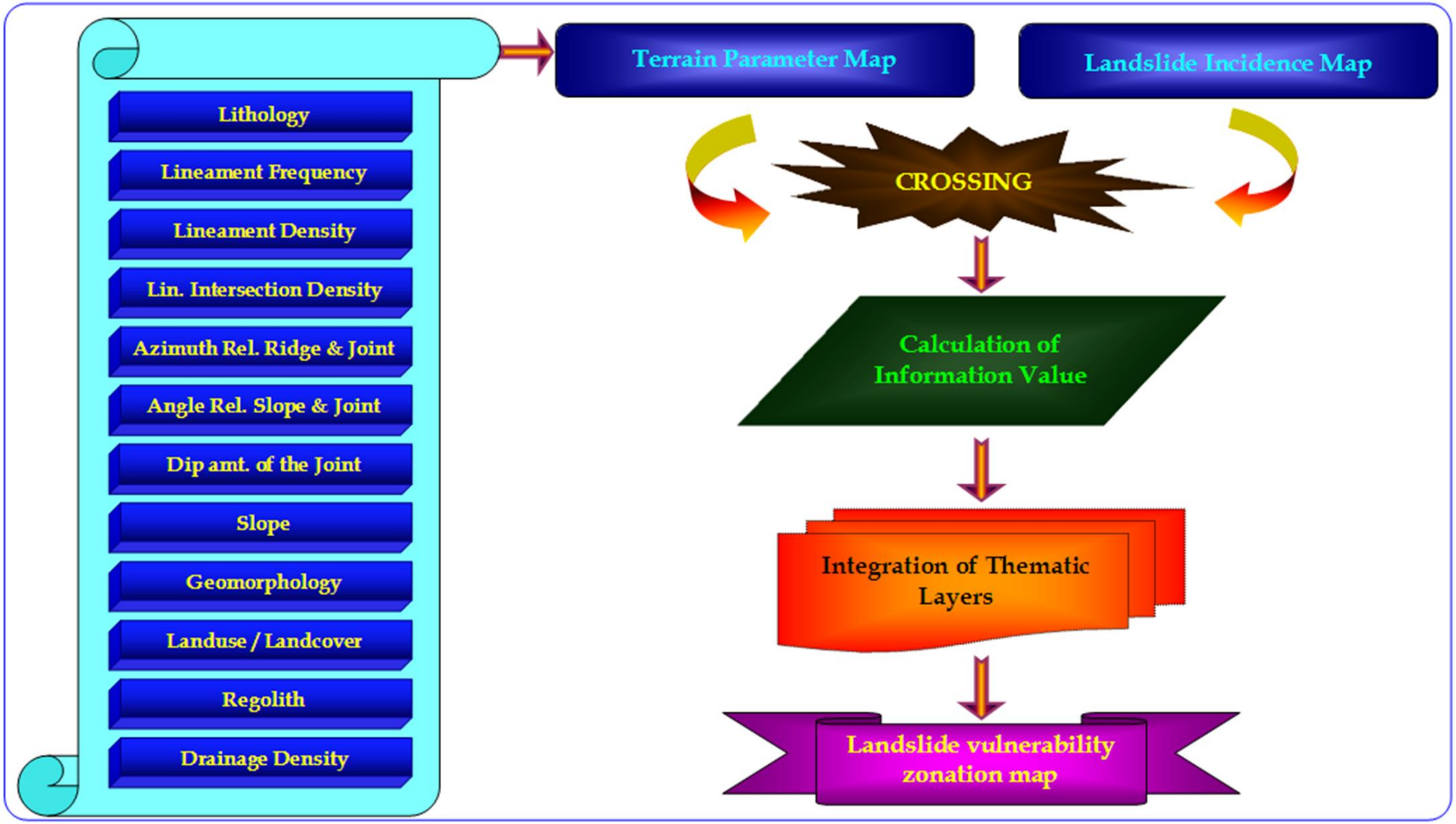


REMEDIAL MEASURES

Active slopes	Intensive Afforestation
Moderate and Shallow slopes	benching to steeping the slopes
Convex slope	slope flattening and convert them into plain slope or garland drainage in the upslope of the convex slopes

Information Value Method

INFORMATION VALUE BASED LVZ MAPPING - METHODOLOGY



Information value = log (Si/Ni) / (S/N)

$$\text{Information value} = \log (S_i/N_i) / (S/N)$$

Where,

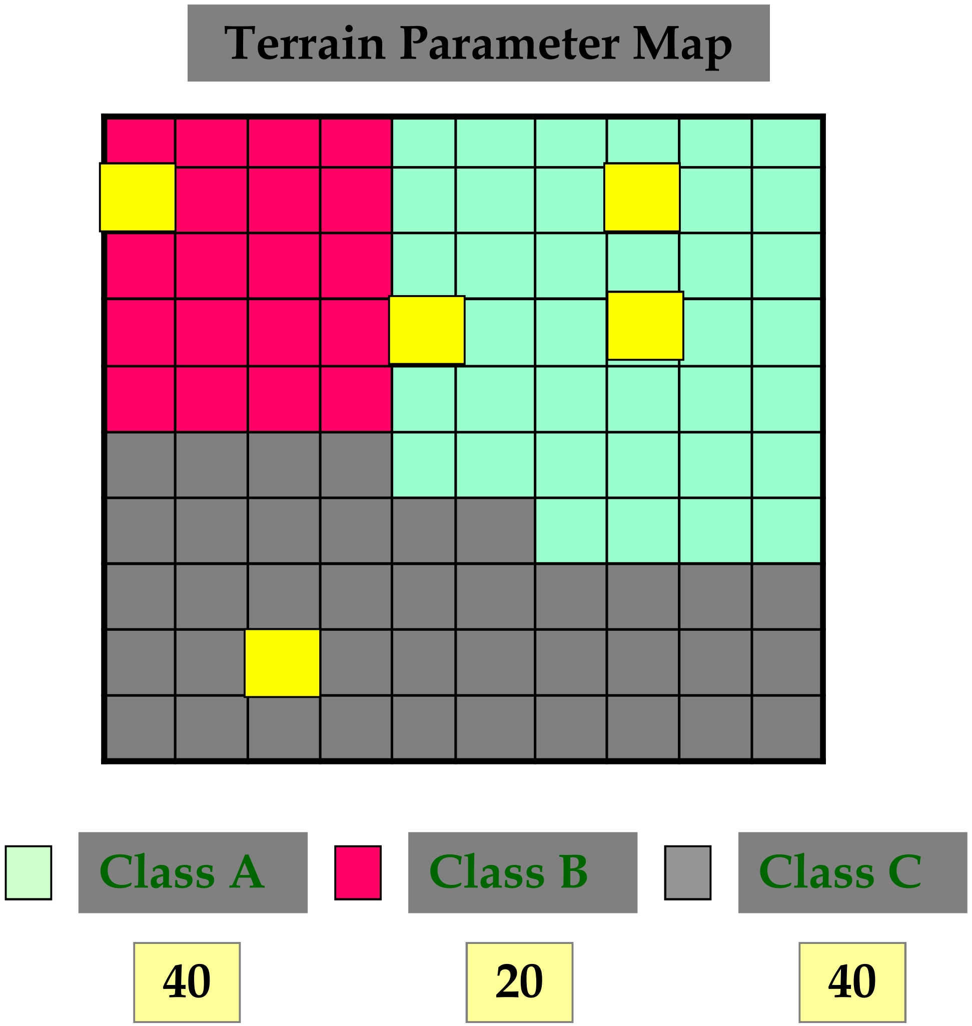
Si – Number of Landslides pixels in particular variable

Ni - Total number of pixels in the said variable

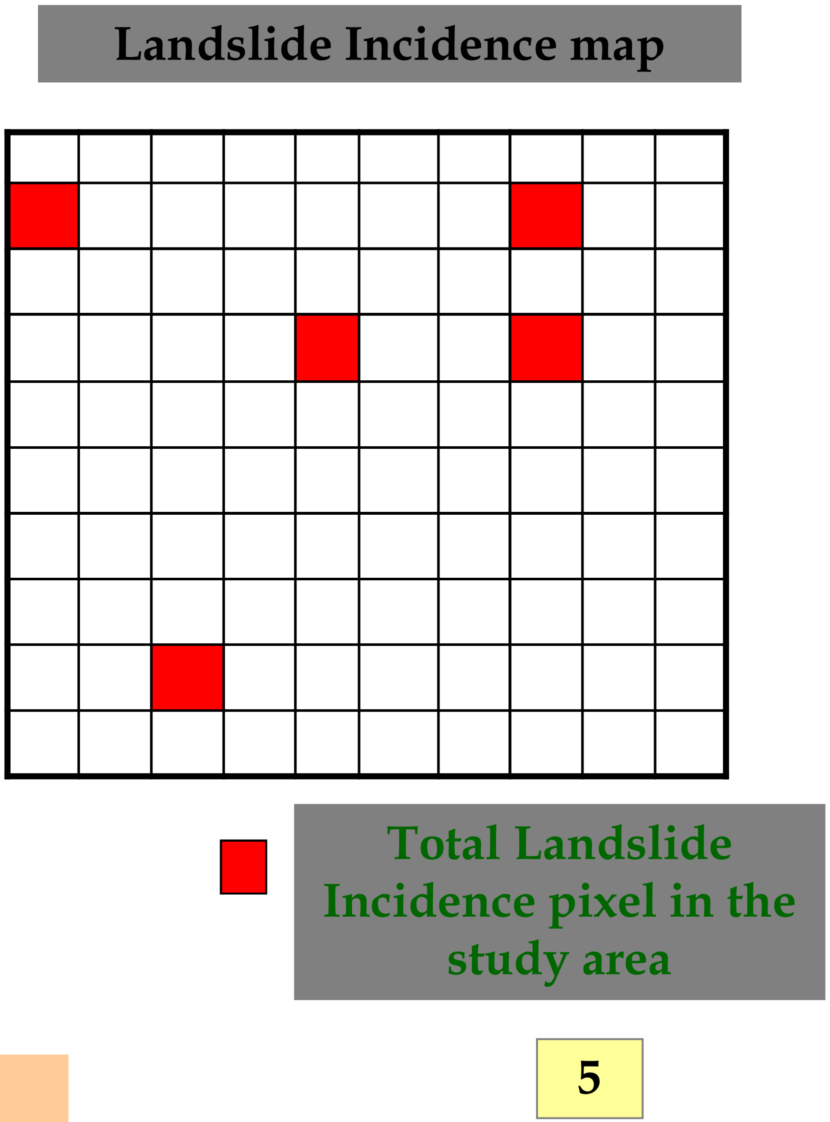
S - Total landslides pixels in the study area

N - Total number of pixels of the study area

Hypothetic Example



Total Pixel in the Study Area = 100 pixels



Hypothetic Example

Information value = log ((Si/Ni) / (S/N))

Info Value for Class A

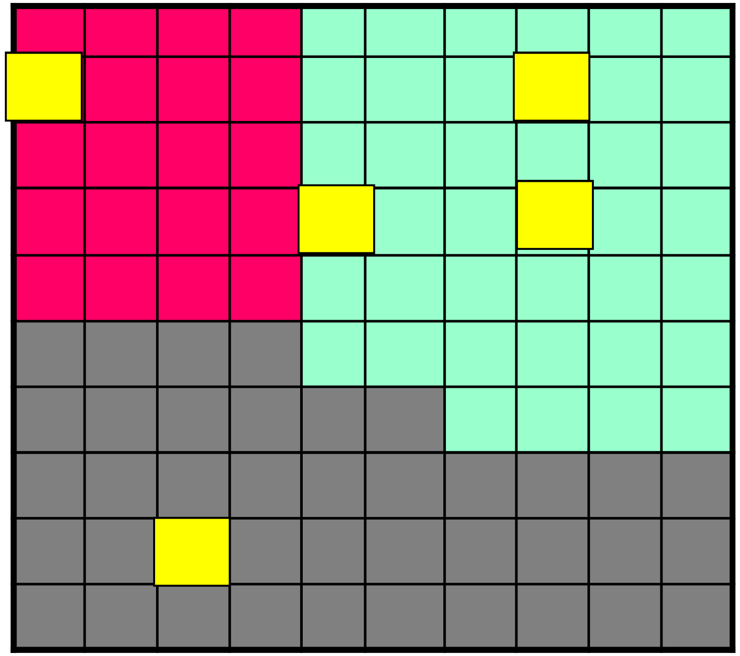
Si - number of Landslides pixels in the ClassA
3

Ni - Total number of pixels in the ClassA
40

S-Total Landslide pixels in Study area
5

N - Total number of pixels of the Study area
100

Terrain Parameter Map



log (Si/Ni) / (S/N) = Log ((3/40) / (5/100))

= Log (0.075 / 0.05)

= Log1.5 = 0.17609125

Class A	Class B	Class C
40	20	40

Total Landslide Incidence pixel in the study area: 5

Total Pixel in the Study Area = 100 pixels

Calculation of Information value method for Highly Weathered Charnockite

Information value of Highly Weathered Charnockite = log (Si / Ni) / (S / N)

Where,

(i) Si = Number of Landslide pixel present in Highly Weathered Charnockite (100)

(ii) Ni = Total number of pixels covered by Highly Weathered Charnockite (217983)

(iii) S = Total no landslide pixels in the map or study area (144)

(iv) N= Total number of pixel in the map or the study area (552456)

These values were substituted in the formula and the information value of 0.2456 was arrived for Highly Weathered Charnockite i.e., Information value for Highly Weathered Charnockite

= Log (100 /217983) / (144 /552456)
= Log (1.760) = 0.2456

Weightages assigned as per Information Value Method for Lithology (For Example)

Litho_Class	Si	Ni	S	N	(Si/Ni) / (S/N)	Information Value
Highly Weathered Charnockite	100	217983	144	552456	1.760	***0.245***
Moderately Weathered Charnockite	12	207817			0.222	***-0.654***
Poorly Weathered Charnockite	32	123084			0.997	***-0.001***

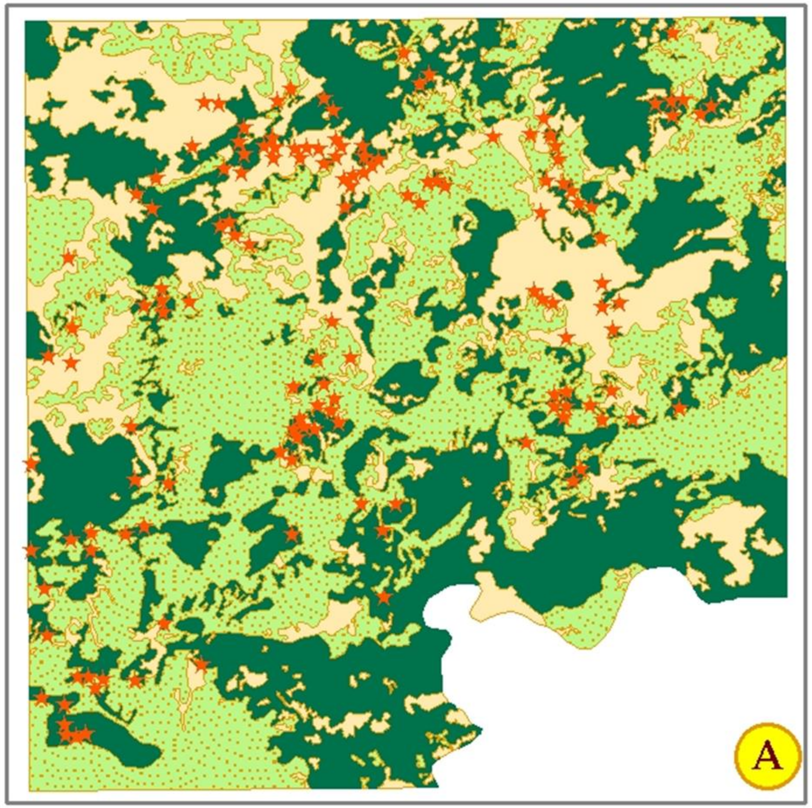


Fig.18 A. - Map showing the Lithology map

Highly Weathered Charnockite,

Moderately Weathered Charnockite

Poorly Weathered Charnockite and

★ Lanslides

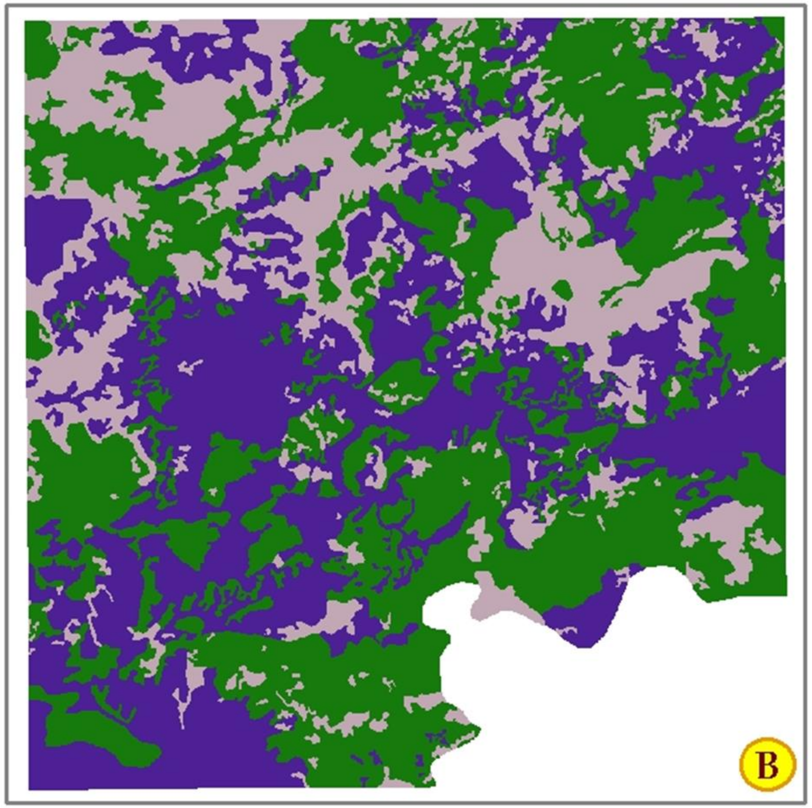


Fig. 18B. - Raster output of Lithology layer showing lithology pixels with

-0.65 Information Value

-0.001 Information Value

0.245 Information Value

The same way information value (Weightages) are assigned for the following theme

Lithology, Lineament Frequency, Lineament Density, Lineament Intersection density, Slope, Geomorphology, Azimuths of Ridgeline vs Joints, Angular relation between dip and slope, Amount of Dip etc

By integrating all, the landslide hazard zones brought out

The finally accrued information values were normalized from 1 to 10 and classified them into 5 zones of Landslide vulnerabilities like Very High (> 8), High (8 – 6), Moderate (6 – 4), Low (4 – 2) and Very Low (< 2).

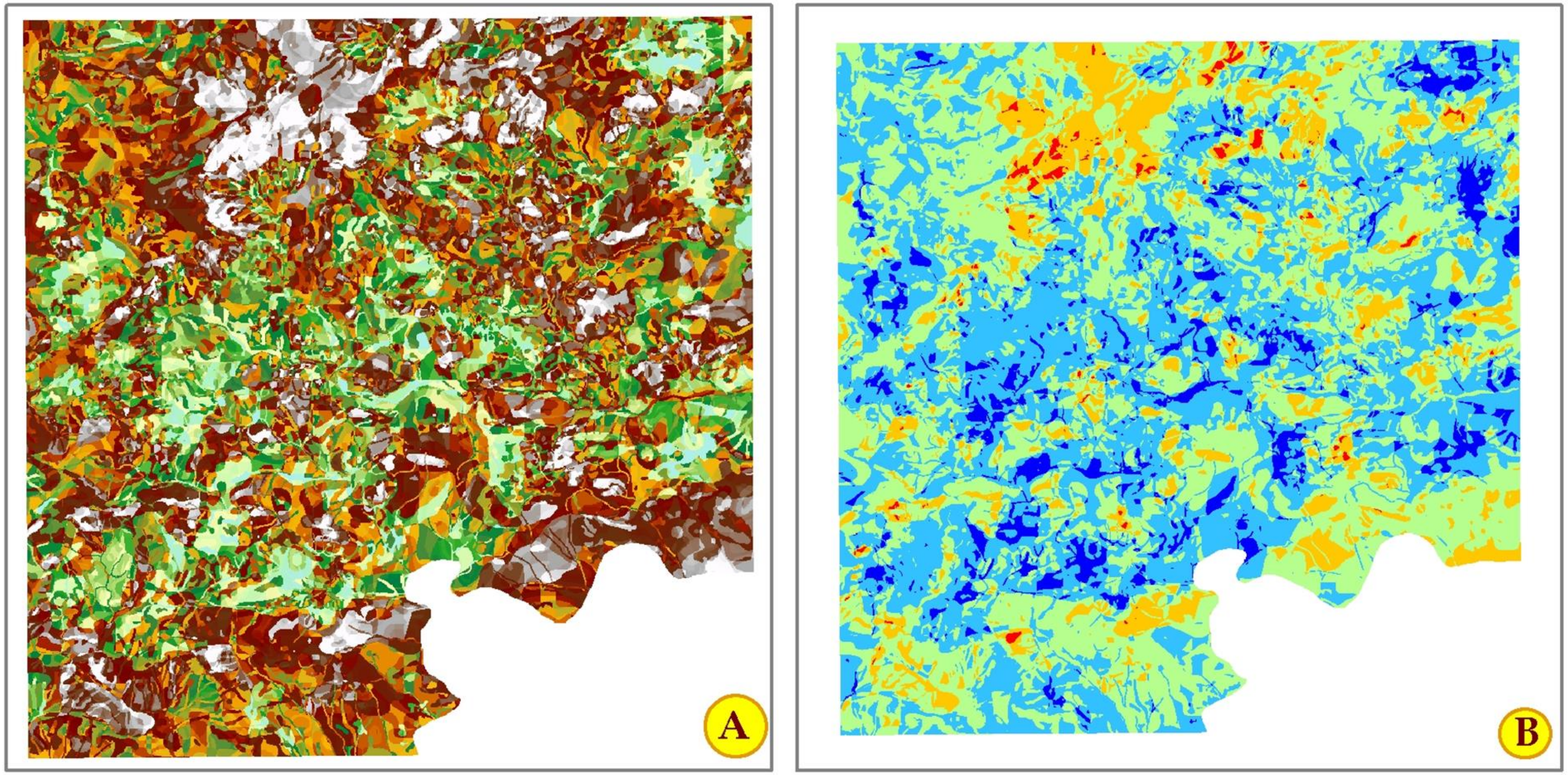
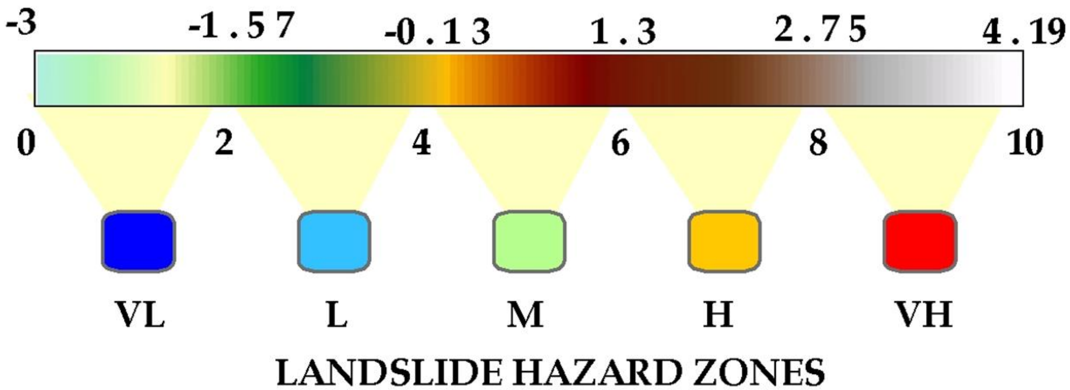


Fig. 22- Weight of Evidence Method Output(A) and LHZ(B)



Weights of Evidence

This method was developed by the Canadian Geological Survey (Bonham carter et al.; 1989Atenberg et al 1990) and was applied to the mapping of Mineral Potential.

Sabto (1991) applied this method for Landslide hazard analysis.

Weights of Evidence

$$W_i^{+} = \log_e \frac{\dfrac{Npix_1}{Npix_1 + Npix_2}}{\dfrac{Npix_3}{Npix_3 + Npix_4}}$$

$$W_i^{-} = \log_e \frac{\dfrac{Npix_2}{Npix_1 + Npix_2}}{\dfrac{Npix_4}{Npix_3 + Npix_4}}$$

Npix1 - Total number of Landslides pixels falling in (eg. highly weathered charnockite)

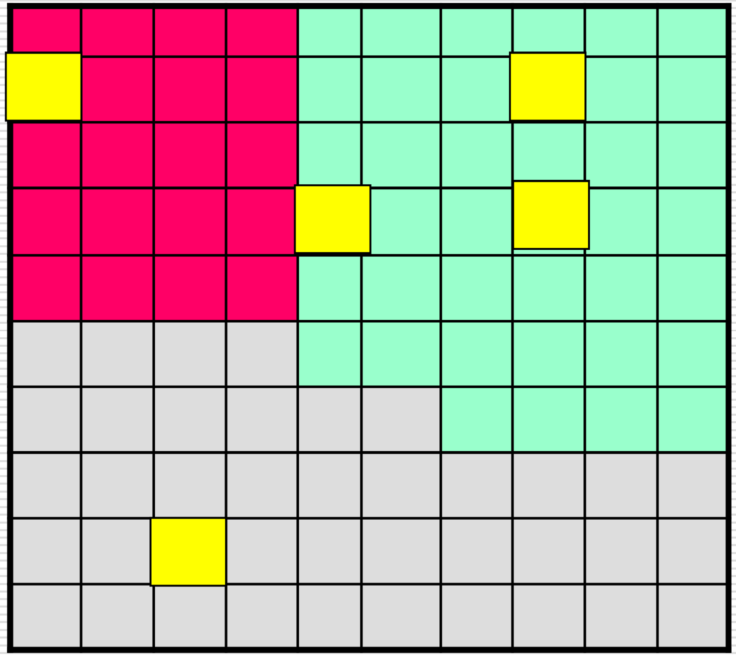
Npix2 - Total number of Landslides pixels not falling or falling outside highly weathered charnockite

Npix3 **-** Total number of highly weathered charnockite pixels free of Landslides or not having landslides

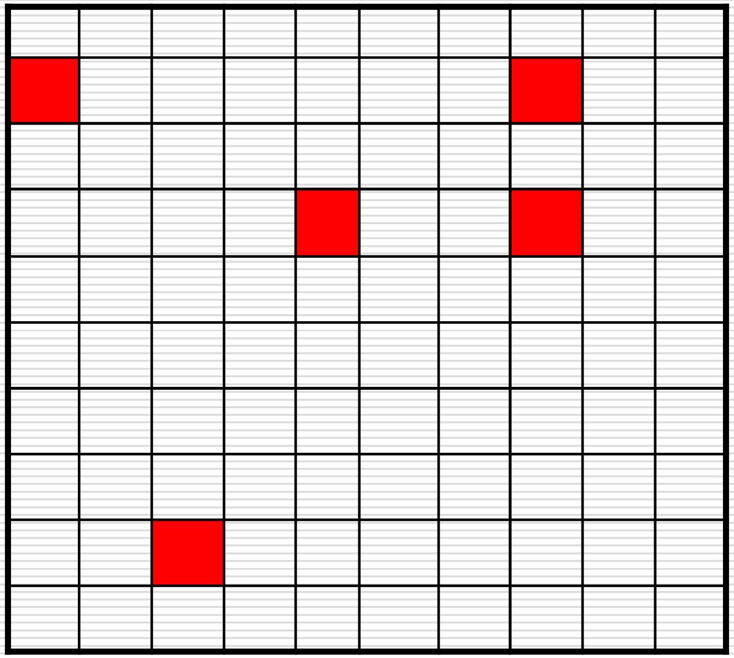
Npix4 - Total number of pixels not having Landslides and also not having highly weathered charnockite

Hypothetic Example

Terrain Parameter Map



Landslide Incidence map



Class A — 40

Class B — 20

Class C — 40

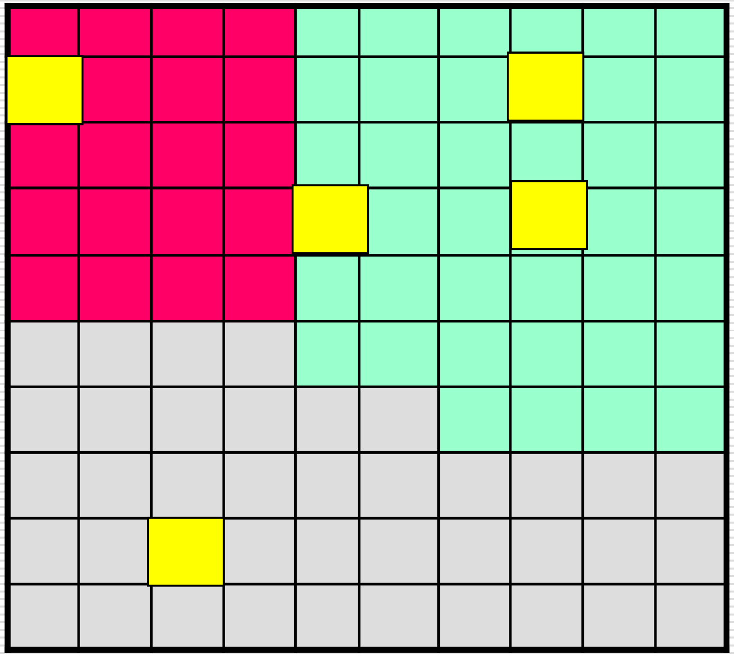
Total Landslide Incidence pixel in the study area — 5

Total Pixel in the Study Area = 100 pixels

Hypothetic Example

Final WOE for Class-A

Terrain Parameter Map



Npix1 - Total number of Landslides pixels falling in **Class A**

3

Npix2 - Total number of Landslides pixels falling outside **Class A**

2

Npix3 - Total number of **Class A** pixels not having landslides

(40 -3) = 37

Npix4 - Total number of pixels not having L.S. outside **Class A**

100-40 = 60, 60-2 = 58

$W_i^{+ve} = \log_e [3/(3+2)] / [37/(37+58)]$

$W_i^{-ve} = \log_e [2/(2+3)] / [58/(58+37)]$

Class-A → $W_i^{+ve} = 0.1876$; $W_i^{-ve} = -0.1836$

Class A	Class B	Class C
40	20	40

Total Landslide Incidence pixel in the study area: 5

Total Pixel in the Study Area = 100 pixels

Hypothetic Example

Class-A → $W_i^{+ve} = 0.1876$; $W_i^{-ve} = -0.1836$

Class-B → $W_i^{+ve} = 0$; $W_i^{-ve} = 0$

Class-C → $W_i^{+ve} = -0.3123$; $W_i^{-ve} = 0.1326$

For Calculating Final WOE to Class-A

$$= W_i^{+ve}(A) + \left\{ W_i^{-ve}(A) + W_i^{-ve}(B) + W_i^{-ve}(C) \right\} - W_i^{-ve}(A)$$

$$= (0.1876) + \{ (-0.1836) + (0) + (0.1326) \} - (-0.1836)$$

$$= (0.1876) + \{ (-0.1836) + (0) + (0.1326) \} + (0.1836)$$

$$= (0.1876) - (0.0510) + (0.1836)$$

$$= 0.3202$$

WOE for Class-A = 0.3202

Similarly ,

WOE for Class-B = 0.0510
WOE for Class-C = - 0.4959

Table 3-13 Weights of Evidence based based Landslide weightages of Lithology

S. No	Litho_Class	Npix1	Npix2	Npix3	Npix4	W +	W -	Weights of Evidence
1	Highly Weathered Charnockite	100	44	217883	334429	0.25	-0.300	***0.415***
2	Moderately Weathered Charnockite	12	132	207805	344507	-0.66	0.17	***-0.952***
3	Poorly Weathered Charnockite	32	112	123052	429260	- 0.001	0	***-0.131***
			Sum of negative weightage =				-0.13	

Final weight of Evidence of highly weathered charnockite =

positive weight +(sum(negative weight)) – negative weight of highly weathered charnockite

= 0.25+ (-0.30 +0.17 +0)- (-0.30)

= 0.25 + (-0.13) – (-0.30)

= 0.415

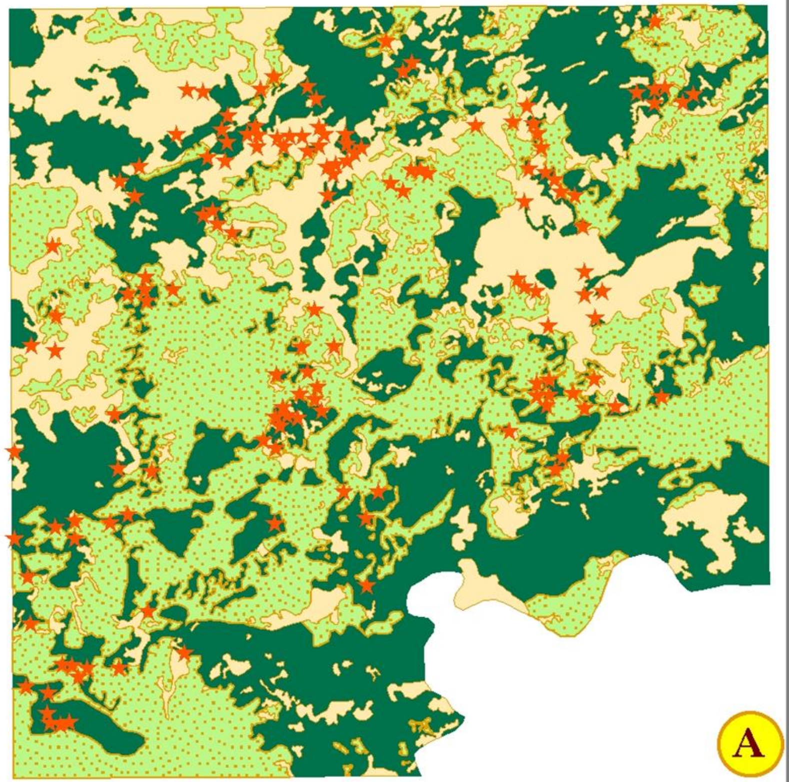


Fig.18 A. - Vector layer showing the Lithology map

Highly Weathered Charnockite,

Moderately Weathered Charnockite

Poorly Weathered Charnockite and

★ Lanslides superposed over them

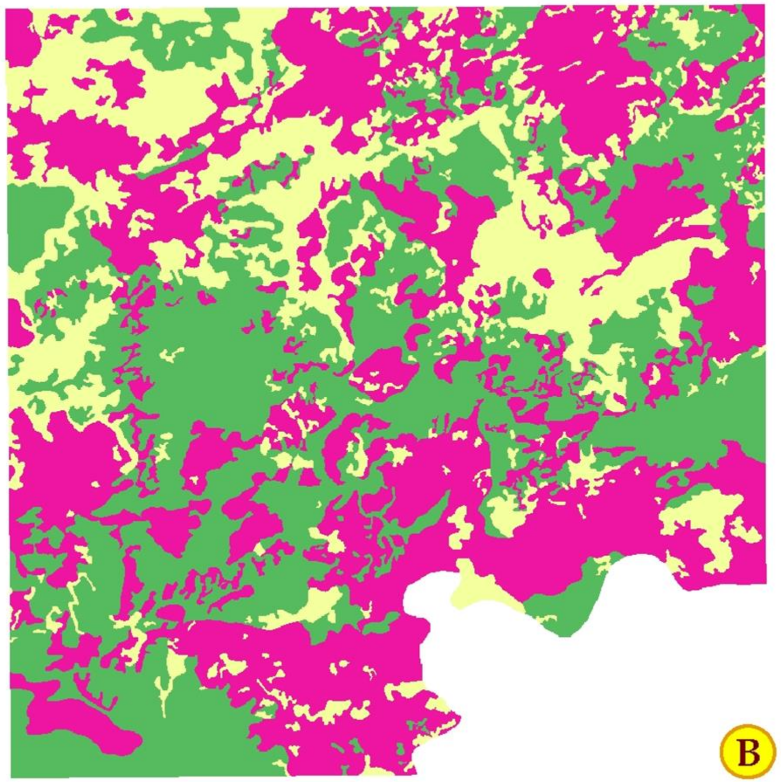


Fig. 18B. - Raster output of Lithology layer

Lithology pixel with .415 WOE Value

Lithology pixel with -0.95 WOE Value

Lithology pixel with -0.13 WOE Value

- **Work out weight of evidence for each polygon class of each of the 12 parameters**
- **Execute GIS add function**
- **Rescale the finally accrued value into 0 – 10.**
- **Classify them into 5 grades of landslide vulnerabilities**
- **Landslide Hazard Zonation, Very High, High, Moderate, Low and Very Low**

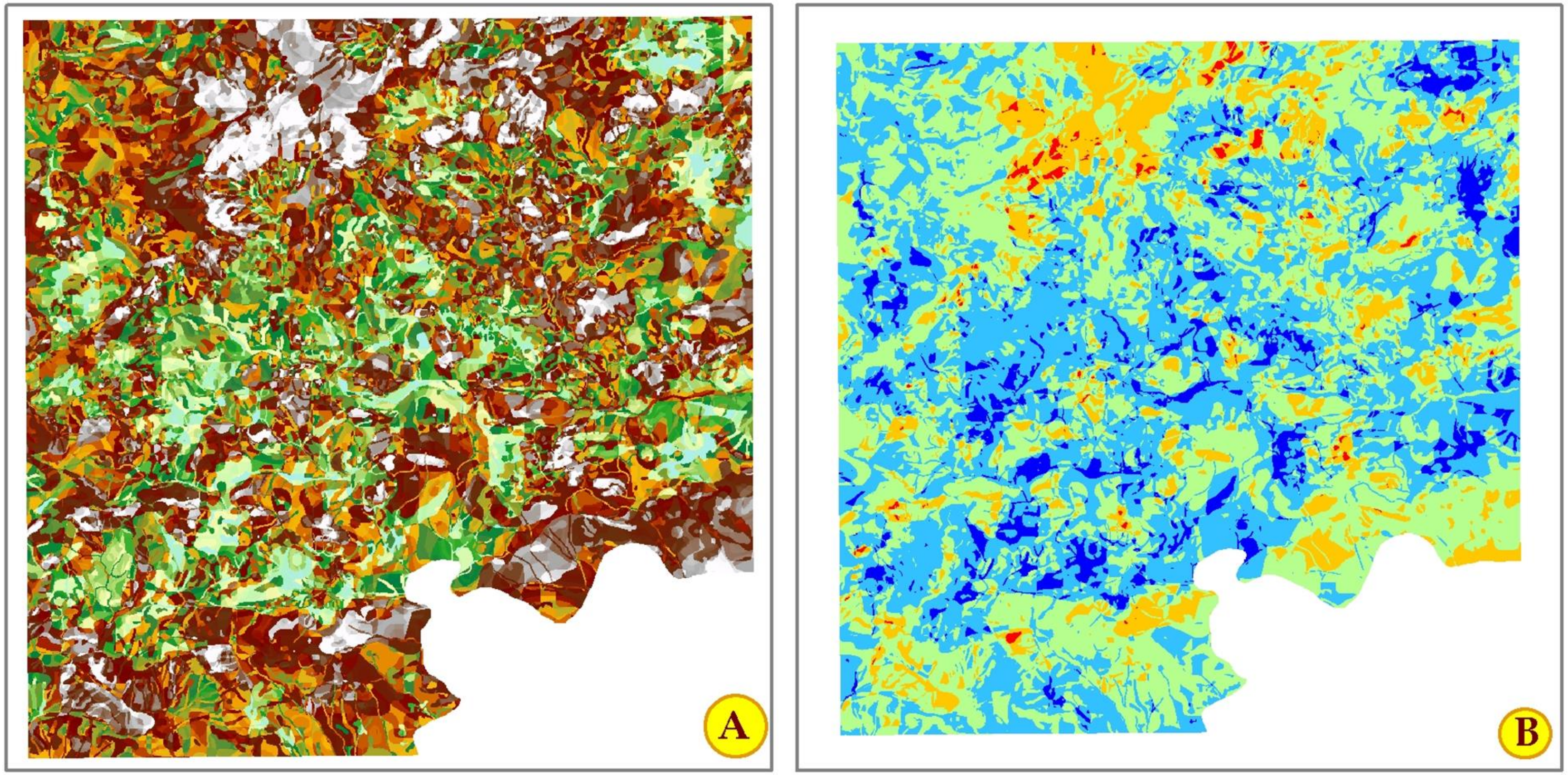
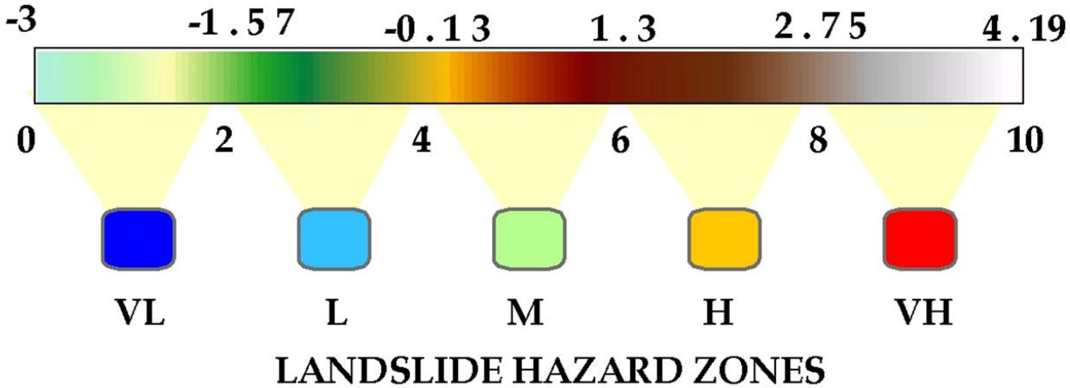
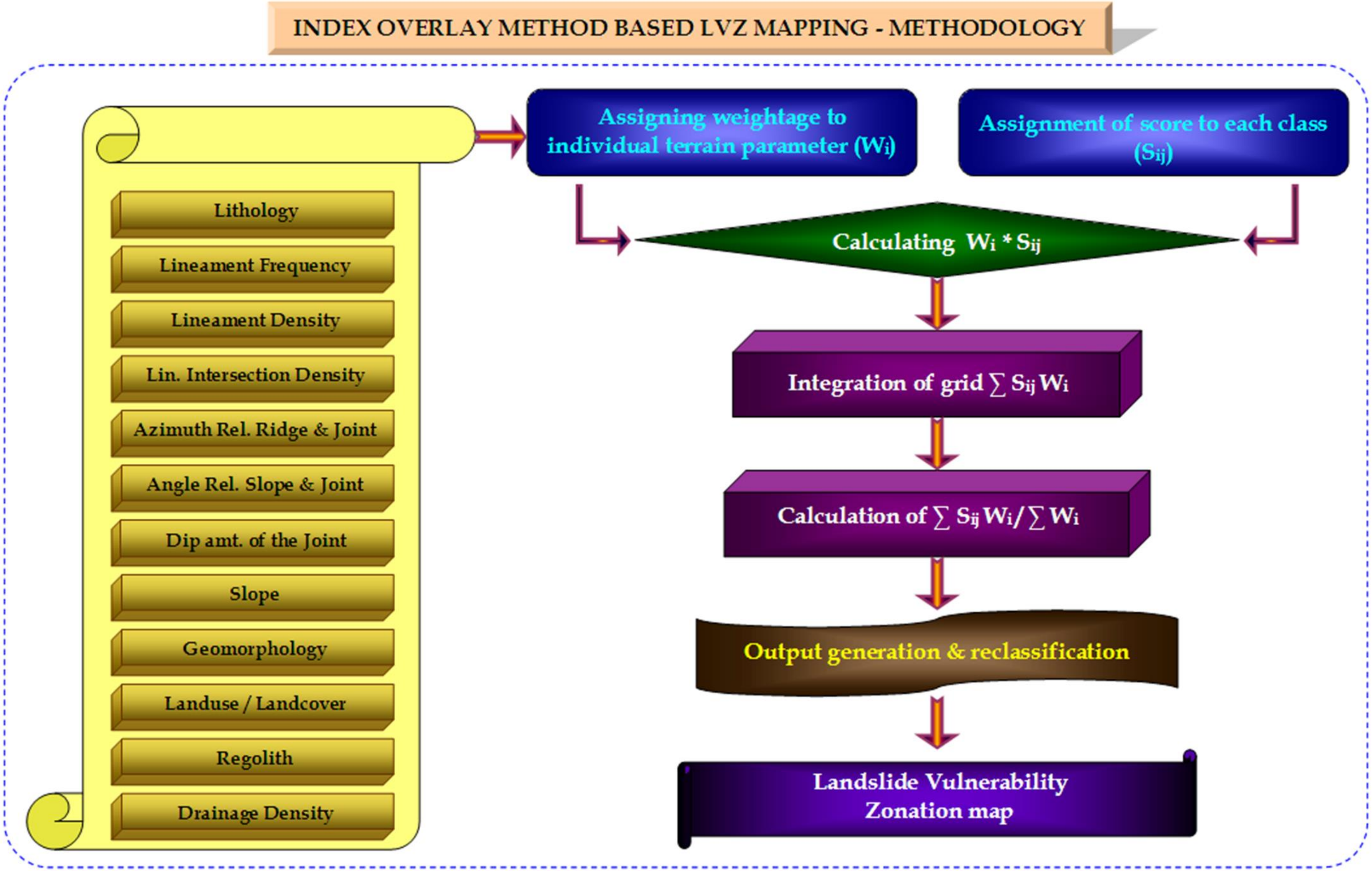


Fig. 22- Weight of Evidence Method Output(A) and LHZ(B)



Index Overlay Method


INDEX OVERLAY METHOD BASED LVZ MAPPING - METHODOLOGY
Lithology
Lineament Frequency
Lineament Density
Lin. Intersection Density
Azimuth Rel. Ridge & Joint
Angle Rel. Slope & Joint
Dip amt. of the Joint
Slope
Geomorphology
Landuse / Landcover
Regolith
Drainage Density
Assigning weightage to individual terrain parameter (Wi)
Assignment of score to each class (Sij)
Calculating Wi * Sij
Integration of grid ∑ Sij Wi
Calculation of ∑ Sij Wi/ ∑ Wi
Output generation & reclassification
Landslide Vulnerability Zonation map

Methodology

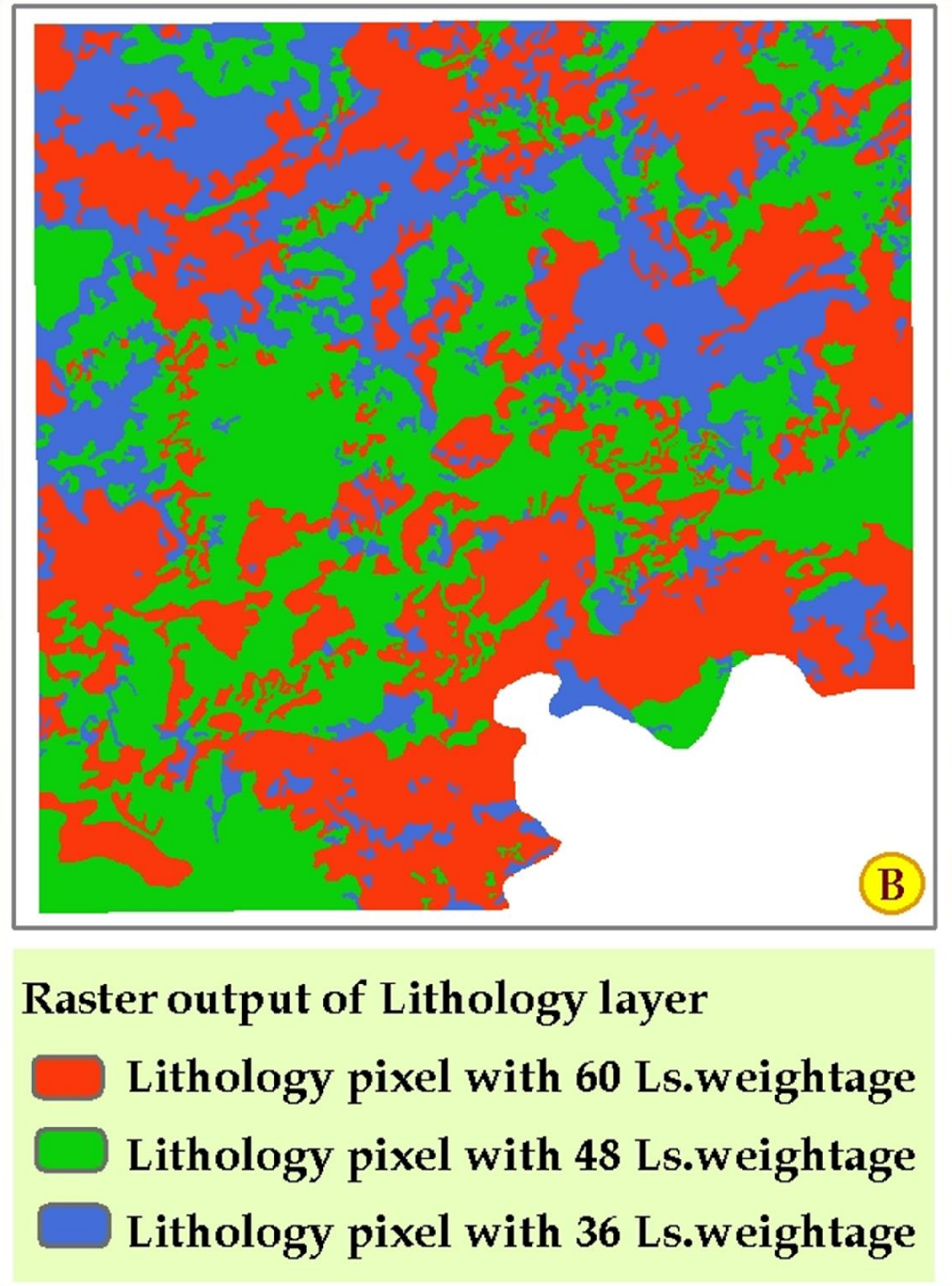
- Assignment of ranks to 12 geo-terrain thematic maps.
- Assignment of knowledge based weightages to each sub variables in each thematic map.
- Multiply the weightages of sub variables of the corresponding ranks and assign final weightage.
- Rasterise each weighted 12 thematic layers.
- Execute add function and rescale the final weightages from 0 – 10.
- Group them into 5 classes as 0 – 2 (Very Low), 2 - 4 (Low), 4 – 6 (Moderate), 6 - 8 (High) and 8 – 10 (Very High).

Ranks for 12 Layers

S.No	Parameters	Rank
1	Lithology	6
2	Structure- Azimuthal Relation	8
3	Dip-Slope Relation	8
4	Dip Only	8
5	Lineament Density	7
6	Lineament Frequency	7
7	Lineament Intersection	7
8	Slope	9
9	Geomorphology	7
10	Lu / Lc	6
11	Regolith	6
12	Drainage density	5

Final Weightages for Lithology

S.No	Lithology Class	Weightage	Rank	Final Weightages
1	Highly Weathered Charnockite	10	6	60
2	Moderately Weathered Charnockite	8	6	48
3	Poorly Weathered Charnockite	6	6	36



Weighted Lithology Layer –

Index overlay Method

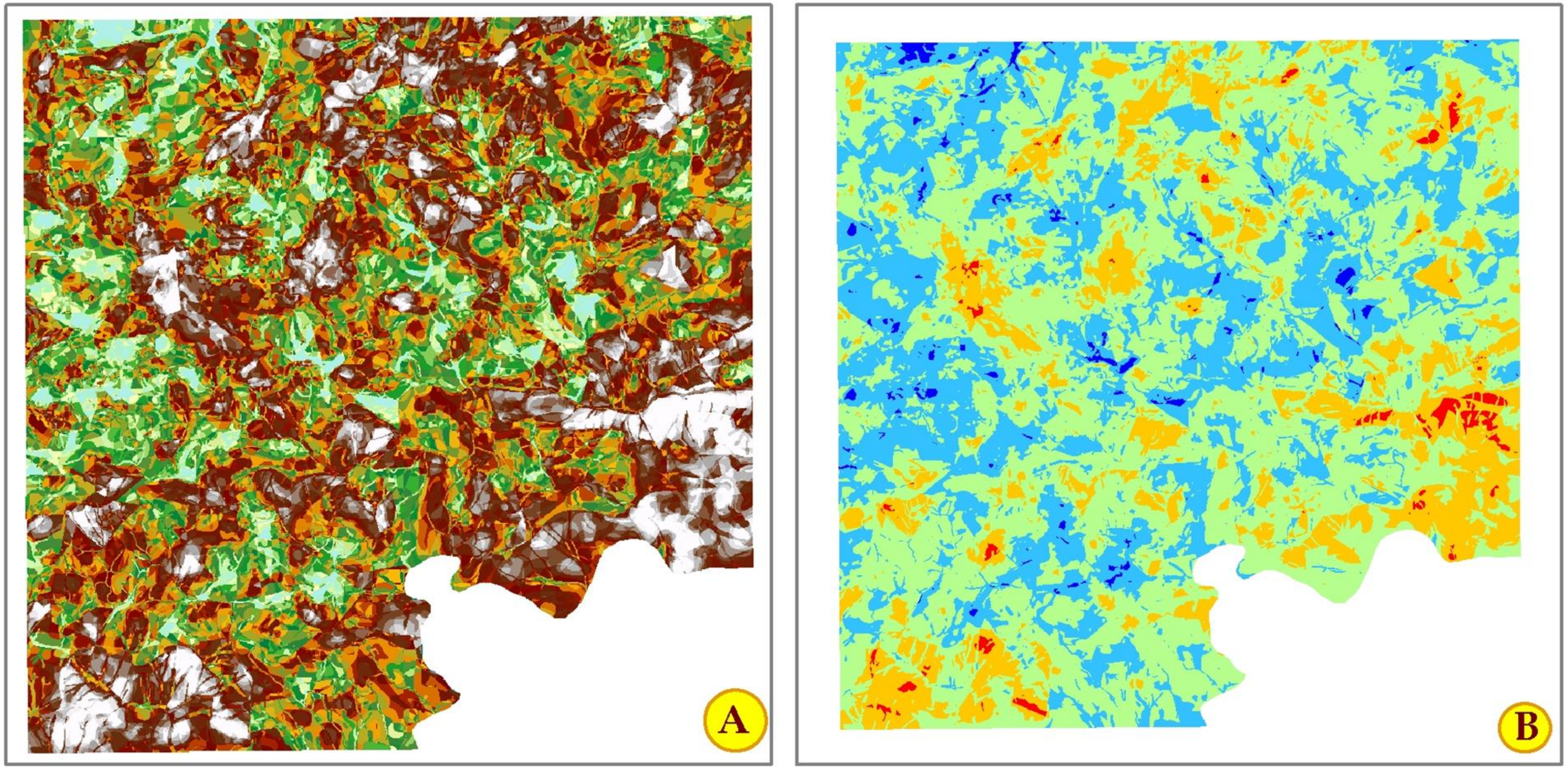
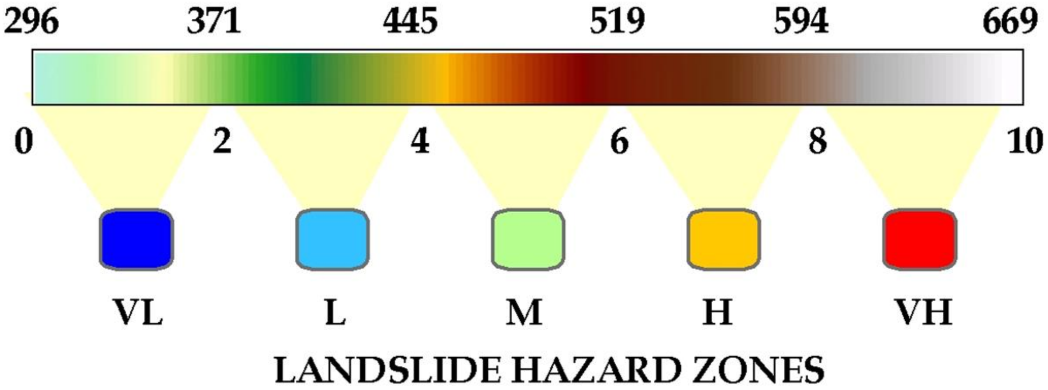


Fig. 22- Index Overlay Method Output(A) and LHZ(B)



BIS Method for LHZ

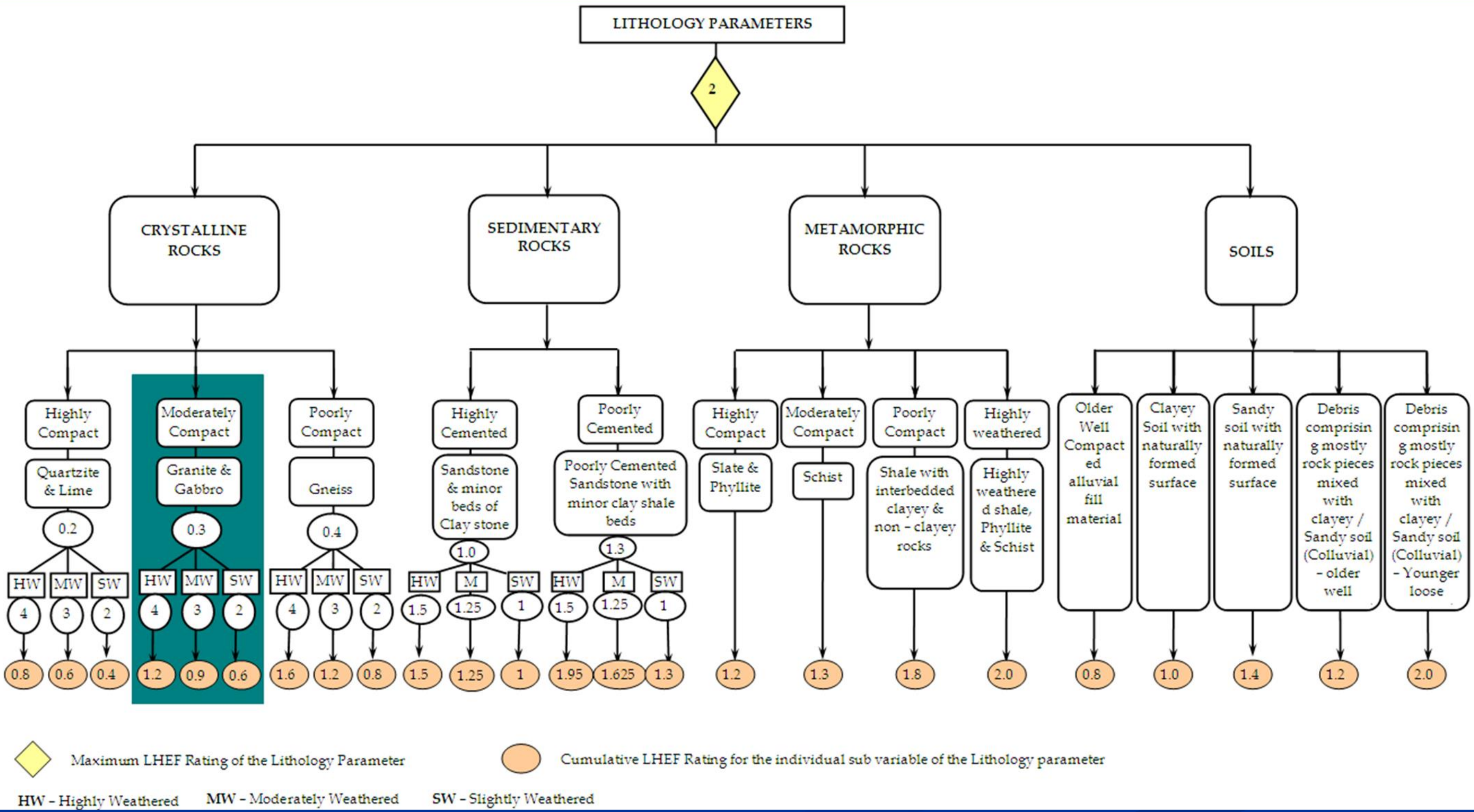
The Bureau of Indian Standard (BIS) Method developed by Anbazhagan (1992) has been used for preparing Landslide Vulnerability Zonation Mapping.

The worker has used 6 set of parameters such as Lithology, Structure, Slope Morphometry, Landuse and Land Cover, Relative Relief and Hydrological Conditions of the Terrain as shown in Table 4-14.

Wherever the raster GIS layers were available those were taken as such (from chapter-II) and in case of non availability, these were prepared freshly to execute the Landslide Vulnerability Zonation Map using BIS method.

Landslide Hazard Evaluation Factor (LHEF) Rating Scheme

S. No	Causative Factor	Maximum LHEF Rating
1	Lithology	2
2	Structure	2
3	Slope morphometry	2
4	Landuse / Landcover	2
5	Relative relief	1
6	Hydrogeological conditions	1


LITHOLOGY PARAMETERS
2
CRYSTALLINE ROCKS
SEDIMENTARY ROCKS
METAMORPHIC ROCKS
SOILS
Highly Compact
Quartzite & Lime
0.2
HW MW SW
4 3 2
0.8 0.6 0.4
Moderately Compact
Granite & Gabbro
0.3
HW MW SW
4 3 2
1.2 0.9 0.6
Poorly Compact
Gneiss
0.4
HW MW SW
4 3 2
1.6 1.2 0.8
Highly Cemented
Sandstone & minor beds of Clay stone
1.0
HW M SW
1.5 1.25 1
1.5 1.25 1
Poorly Cemented
Poorly Cemented Sandstone with minor clay shale beds
1.3
HW M SW
1.5 1.25 1
1.95 1.625 1.3
Highly Compact
Slate & Phyllite
1.2
Moderately Compact
Schist
1.3
Poorly Compact
Shale with interbedded clayey & non – clayey rocks
1.8
Highly weathered
Highly weathered shale, Phyllite & Schist
2.0
Older Well Compacted alluvial fill material
0.8
Clayey Soil with naturally formed surface
1.0
Sandy soil with naturally formed surface
1.4
Debris comprising mostly rock pieces mixed with clayey / Sandy soil (Colluvial) - older well
1.2
Debris comprising mostly rock pieces mixed with clayey / Sandy soil (Colluvial) - Younger loose
2.0
Maximum LHEF Rating of the Lithology Parameter
Cumulative LHEF Rating for the individual sub variable of the Lithology parameter
HW - Highly Weathered
MW - Moderately Weathered
SW - Slightly Weathered

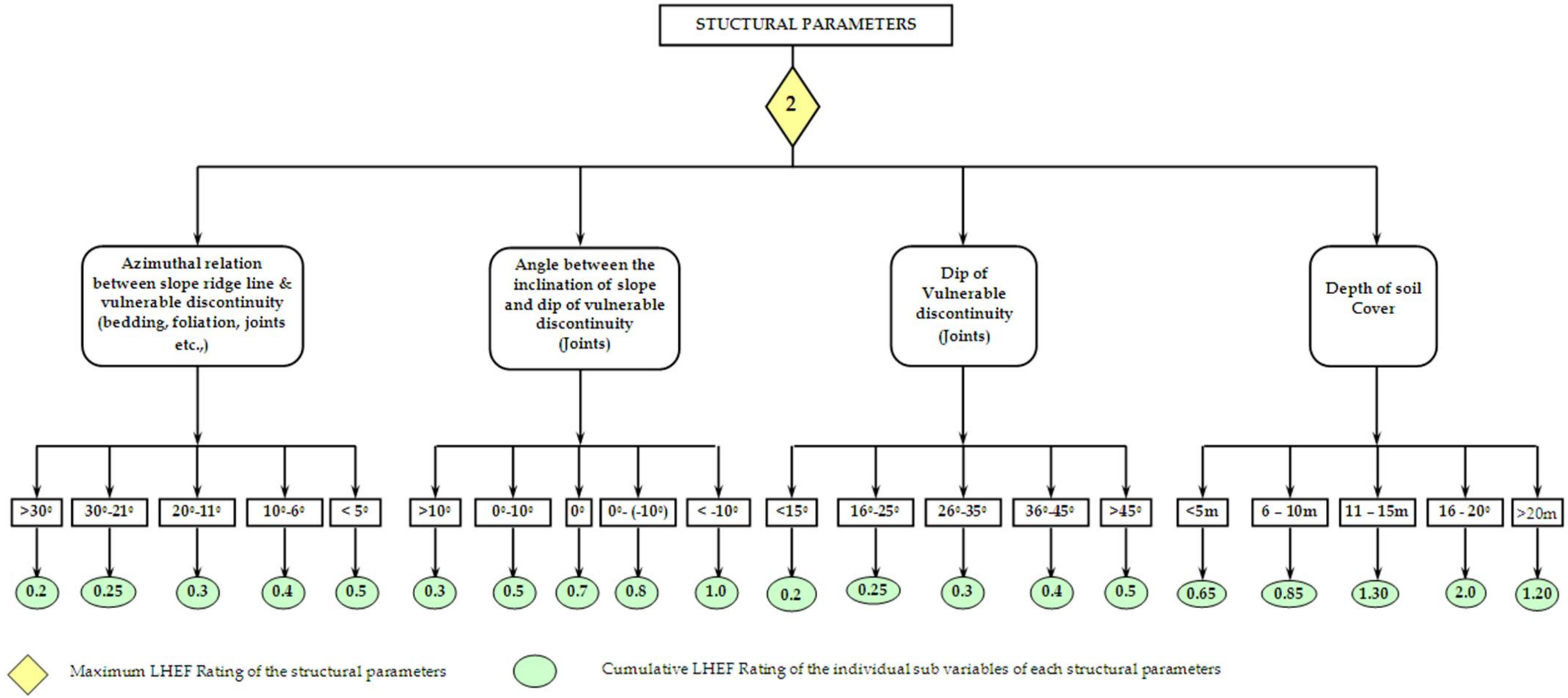
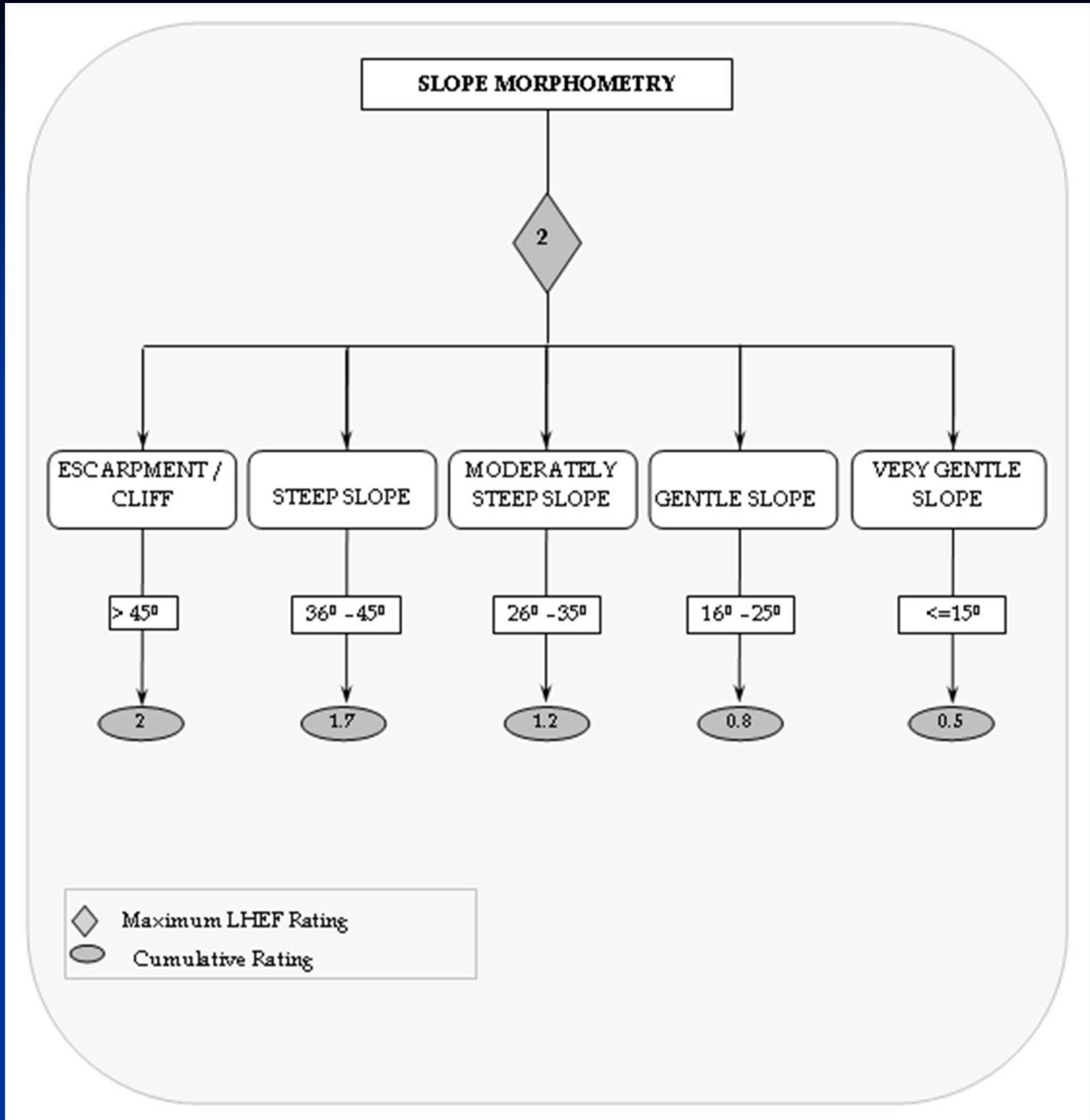
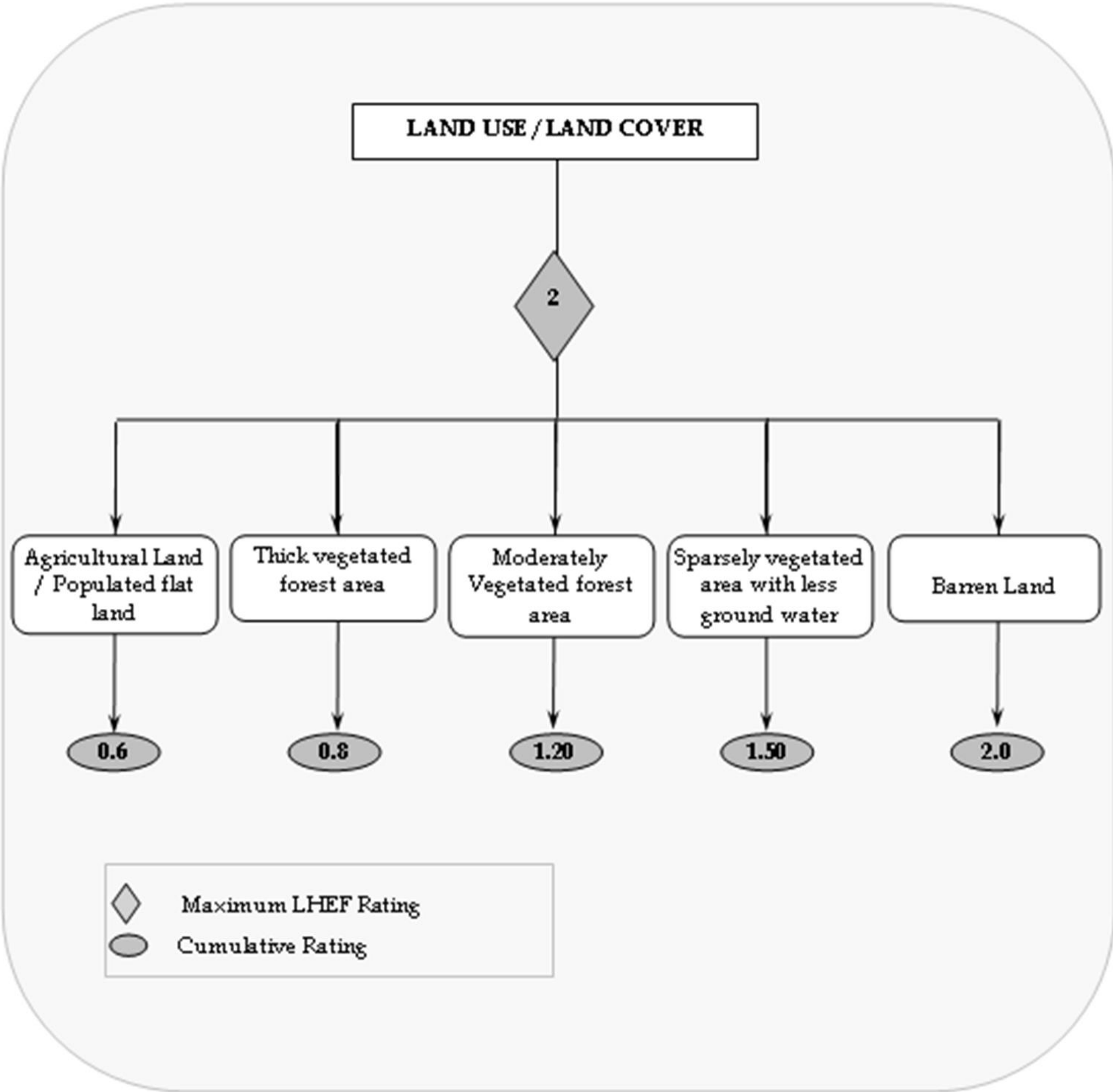
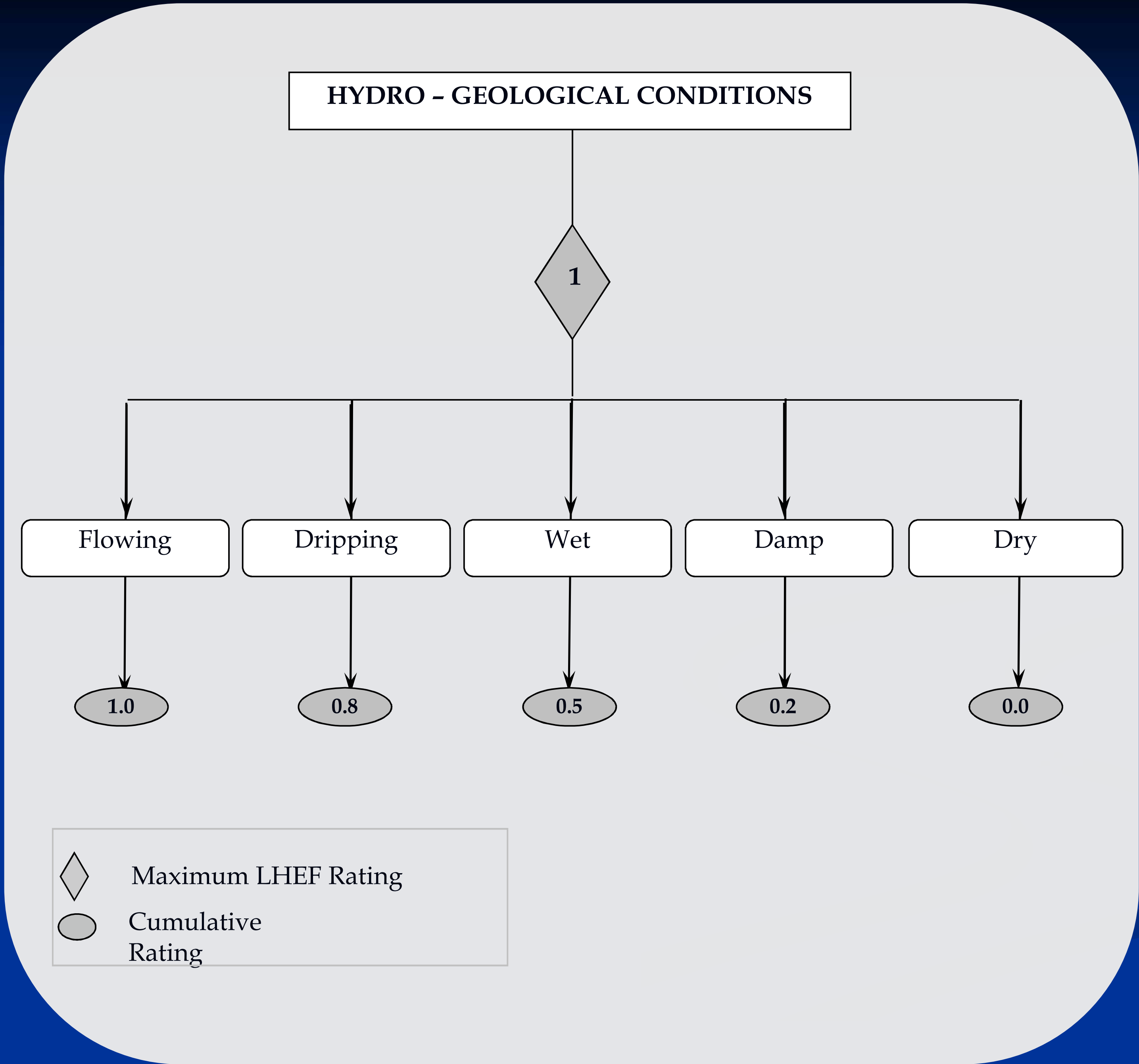


Fig. 4.5 LHEF schemes for Structural Parameters

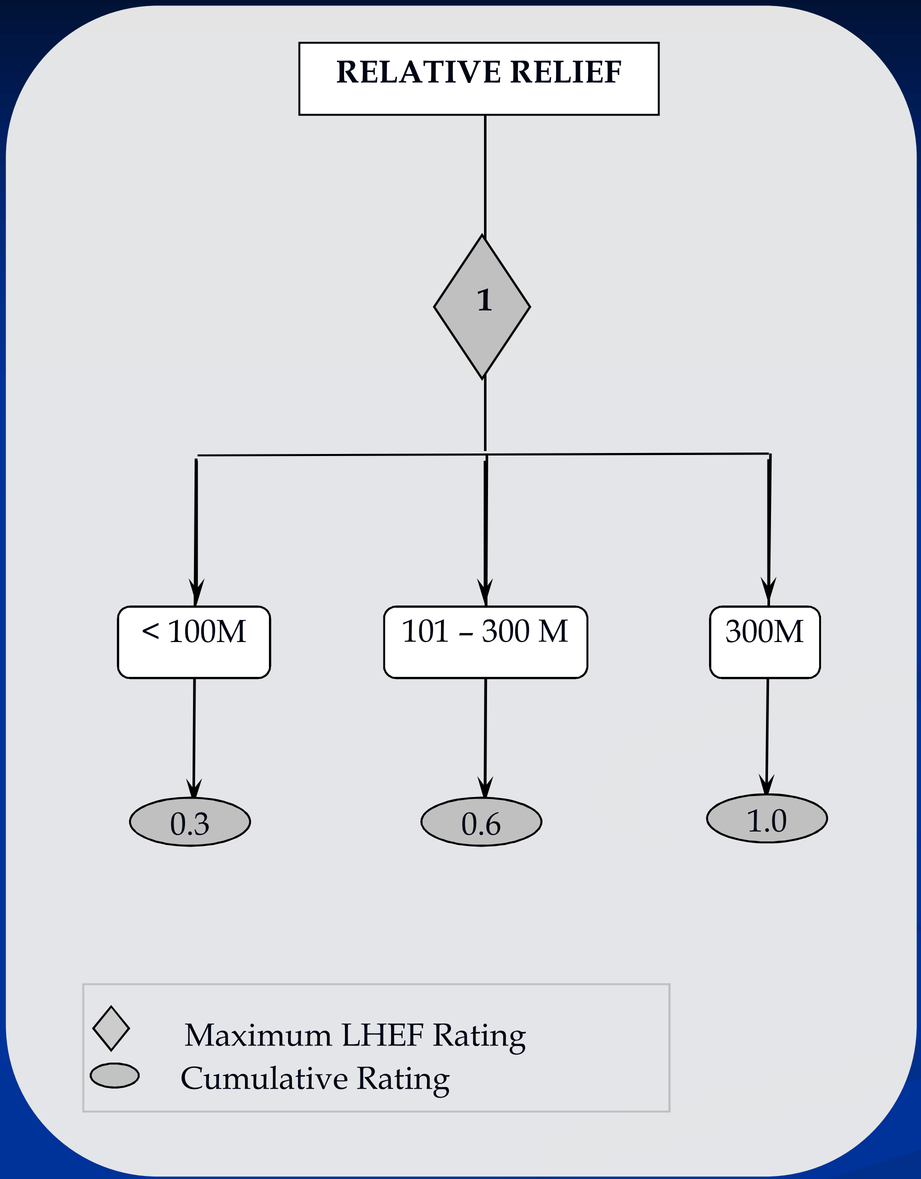


SLOPE MORPHOMETRY
2
ESCARPMENT / CLIFF
STEEP SLOPE
MODERATELY STEEP SLOPE
GENTLE SLOPE
VERY GENTLE SLOPE
> 45⁰
36⁰ - 45⁰
26⁰ - 35⁰
16⁰ - 25⁰
<=15⁰
2
1.7
1.2
0.8
0.5
Maximum LHEF Rating
Cumulative Rating


LAND USE / LAND COVER
2
Agricultural Land / Populated flat land
Thick vegetated forest area
Moderately Vegetated forest area
Sparsely vegetated area with less ground water
Barren Land
0.6
0.8
1.20
1.50
2.0
Maximum LHEF Rating
Cumulative Rating



HYDRO – GEOLOGICAL CONDITIONS
1
Flowing
Dripping
Wet
Damp
Dry
1.0
0.8
0.5
0.2
0.0
Maximum LHEF Rating
Cumulative Rating



RELATIVE RELIEF
1
< 100M
101 – 300 M
300M
0.3
0.6
1.0
Maximum LHEF Rating
Cumulative Rating

ZONE	THED VALUES	DESCRIPTION OF ZONES
1	< 3.5	Very Low Hazard (Vlh) Zones
2	3.5 To 5.0	Low Hazard (Lh) Zones
3	5.1 To 6.0	Moderate Hazard (Mh) Zones
4	6.1 To 7.5	High Hazard (Hh) Zones
5	>7.5	Very High Hazard (Vhh) Zones

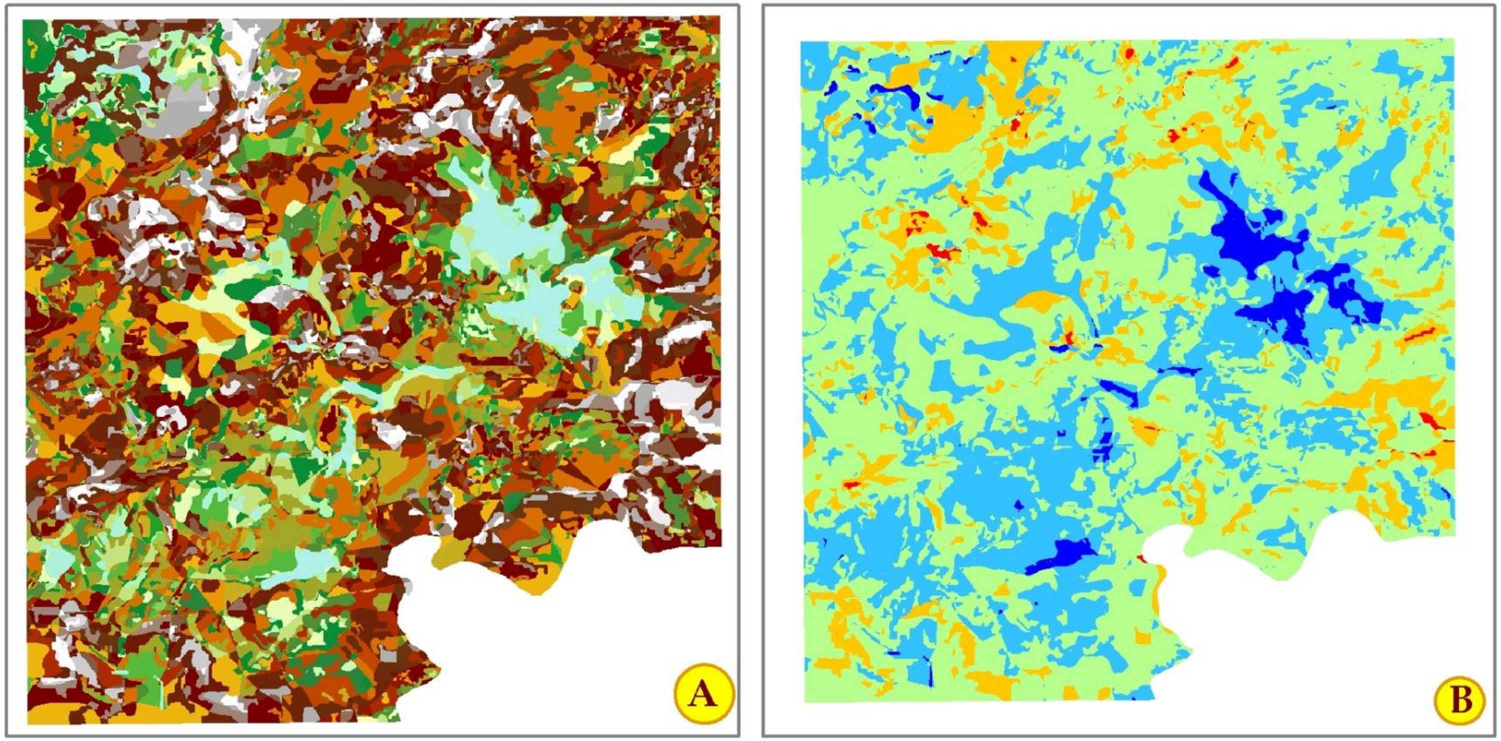


Fig. 22- Bureau of Indian Standard Model Output(A) and LHZ(B)

Values ranges from 7.6 to 3.65

VL L M H VH

LANDSLIDE HAZARD ZONES

FACTOR OF SAFETY

It describe the status of a particular slope and is based on the concept of limiting equilibrium

i.e. The condition at which forces tensing to induce sliding are exactly balanced by those forces resisting sliding.

So, F can be defined as the ratio of total force available to resist sliding to total force tending to induce sliding.

$$\text{Factor of safety} = \frac{\text{Total resisting force along plane of separation}}{\text{Total mobilizing force available to induce failure}}$$

F = 1: The slope is on the edge of failure,

F = > 1 : the slope is stable

F = <1 : the slope is unstable