Operationalising a national programme of landslide susceptibility mapping

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Workshop on "Use of EO Data in Disaster Management…" (8-11 March 2016, NRSC, Hyderabad)

What are landslides???

… the movement of a mass of rock, debris or earth down a slope due to the action of gravity

भारतीय भूवैज्ञानिक सर्वेक्षण
Geological Survey of India

Profuse loss of resources

Varied magnitudes … varied extent of effects … **A HAZARD!!!**

Society vs. Landslide

- Viewed as an individual problem
- Ignorance/lack of awareness
- Informal/formal settlements in hazardous areas
- Society accept the risk and live with it
- Makes society more vulnerable

How to manage landslide risk?

GSI's contribution

- Dates back to 1880 (Nainital landslide)
- Pre-disaster studies (for planning & preparedness)
  - 1:50/25k landslide susceptibility mapping
  - 1:10/5k landslide susceptibility mapping
- Post-disaster studies (for planning & remediation)
  - Landslide inventory mapping
  - 1:1/2k landslide mapping & slope stability studies
- Monitoring & Early Warning
- Awareness Programme
- Data management & dissemination
- Research & Development

GSI has been declared by GoI as the Nodal Agency for landslide studies w.e.f. 2004

Lesson learnt from recent events

- 2013 Uttarakhand event; 2014 Malin event; 2015 Darjeeling event
- All hill slopes may not be prone to landslides (initiation or run-out) ???
- Magnitude of triggers largely control landslide type, failure mechanism & distribution
- Many casualties are from new (= one-time) failures

How to reduce landslide risk?

Why NLSM?

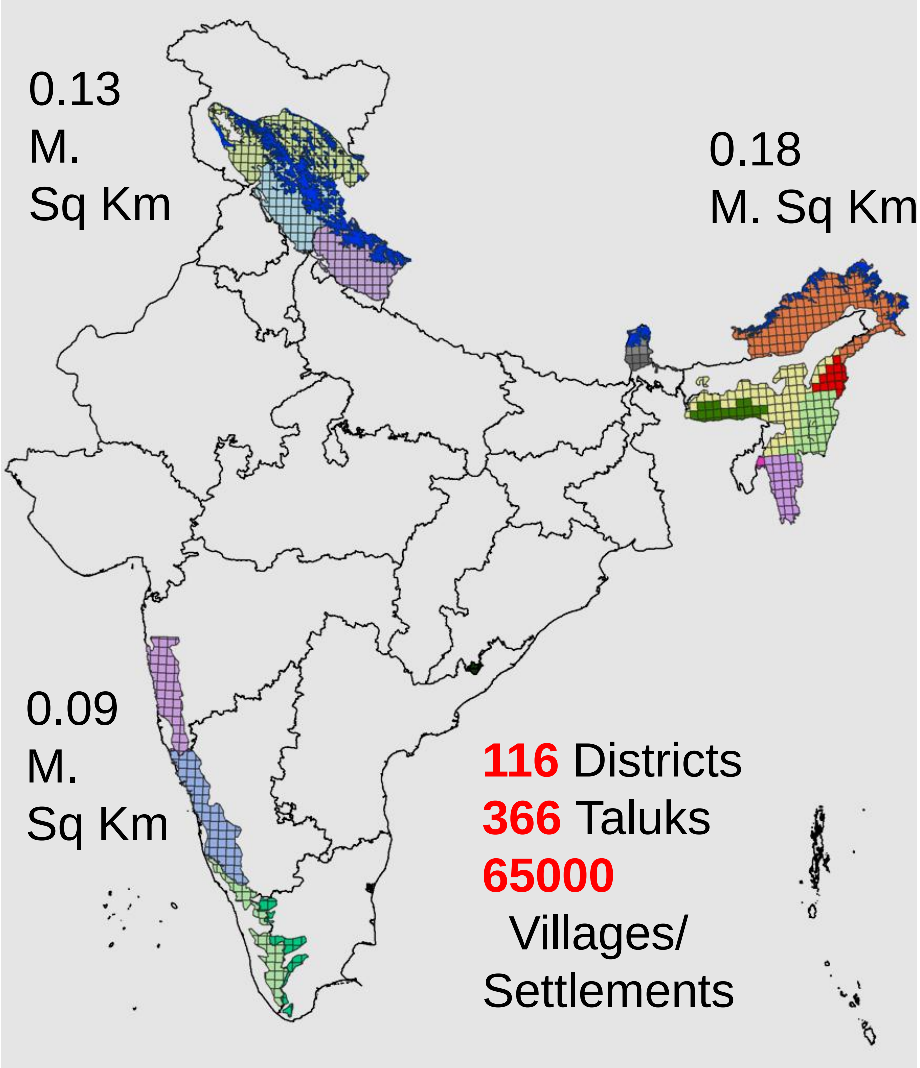
- Non-availability of seamless database on landslides
- No Pan-India Landslide Susceptibility Map
- Retrieval and updation difficult with available analog maps
- How to prioritize areas for detailed studies

Objective of NLSM

- To prepare GIS-based seamless Landslide Susceptibility Maps using inputs from RS data and fieldwork.
- Creation of a national repository on Landslide Inventory
- To facilitate easy retrieval, dissemination and updation of landslide susceptibility information

Creation of a dynamic **National Landslide Susceptibility Database** for India

NLSM Target & Challenges



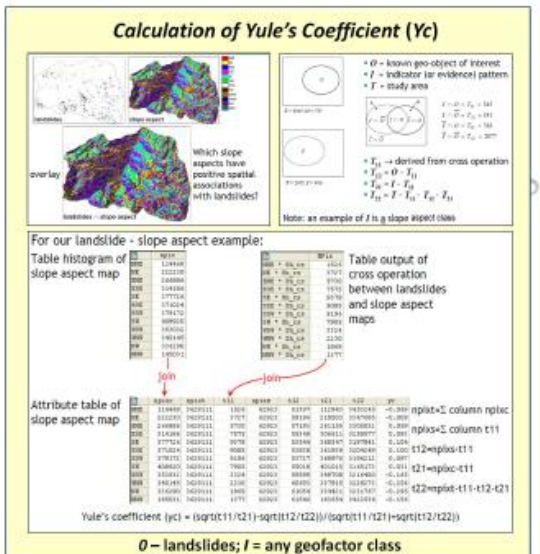
- Launched w.e.f. FS 2014-15
- Target area: 1034 toposheets (0.42 M. sq km)
- Seamless map generation.
- Inaccessibility, steep topography, extreme climate, complicated geomorphic and geodynamic set up
- Different conditions influencing susceptibility
- Different landslide types and movement

Training & Capacity Building (GHRM Cell)

A. Brain-storming session
B. Specialised Training Module
C. Interactive Orientation Programmes

82 Officers & 15 Supervisory Officers are now working for NLSM in GSI

MANUAL ON MACRO SCALE LANDSLIDE SUSCEPTIBILITY MAPPING



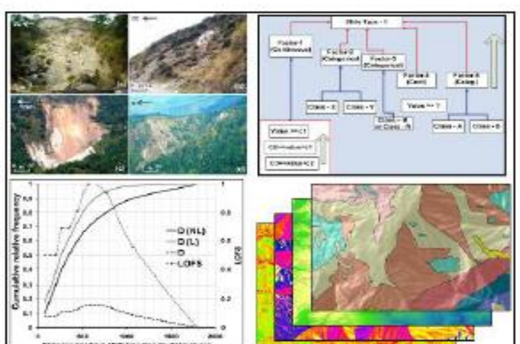
Yule's Co-efficient & LOFS (for Categorical variables)

Factor	Factor class	Sh_rs		Db_rs	
		Y_c	LOFS	Y_c	LOFS
Aspect	NNE	-0.112	0	-0.201	0
	NE	-0.060	0	-0.151	0
	ENE	0.081	0.68	-0.210	0
	ESE	0.119	1.00	-0.028	0
	SE	0.061	0.52	0.040	0.22
	SSE	0.043	0.36	0.042	0.24
	SSW	0.055	0.46	0.178	1.00
	SW	0.041	0.34	0.107	0.60
	WSW	-0.096	0	0.068	0.38
	WNW	-0.128	0	-0.047	0
	NW	-0.073	0	-0.228	0
	NNW	-0.174	0	-0.178	0

$$LOFS_{categorical} = \begin{cases} 0 & for \quad Y_c \le 0 \\ (Y_c)/(Y_{c_{max}}) & for \quad Y_c > 0 \end{cases}$$

1st DRAFT

An Exercise Manual On Training For National Landslide Susceptibility Mapping (NLSM)



GEOHAZARDS RESEARCH & MANAGEMENT (GHRM) CELL
GEOLOGICAL SURVEY OF INDIA, CHQ
KOLKATA

Report on the interactive orientation of National Landslide Susceptibility Mapping (NLSM) Programme (FS 2015-16) (11th May to 12th June 2015)

Geohazards Research & Management (GHRM) Cell
GSI, CHQ, Kolkata

As directed by the Director General, GSI, Geohazards Research & Management (GHRM) Cell, GSI, CHQ, Kolkata organised five interactive orientation programmes at different Regions/ SUs between 11th May and 12th June 2015 to facilitate smooth initiation and implementation of 36 items of National Landslide Susceptibility Mapping (NLSM) Programmes of GSI (FS 2015-16). The following five interactive orientation programmes were attended by the 61 field and supervisory level officers who are engaged in the on-going NLSM Programmes in five Regions – Eastern, Northeastern, Northern, Southern and Central (Annexure I).

Photo 1: Interactive orientation of NLSM at SU: K & G, Bangalore

Table 1: Schedule of five interactive orientation programmes

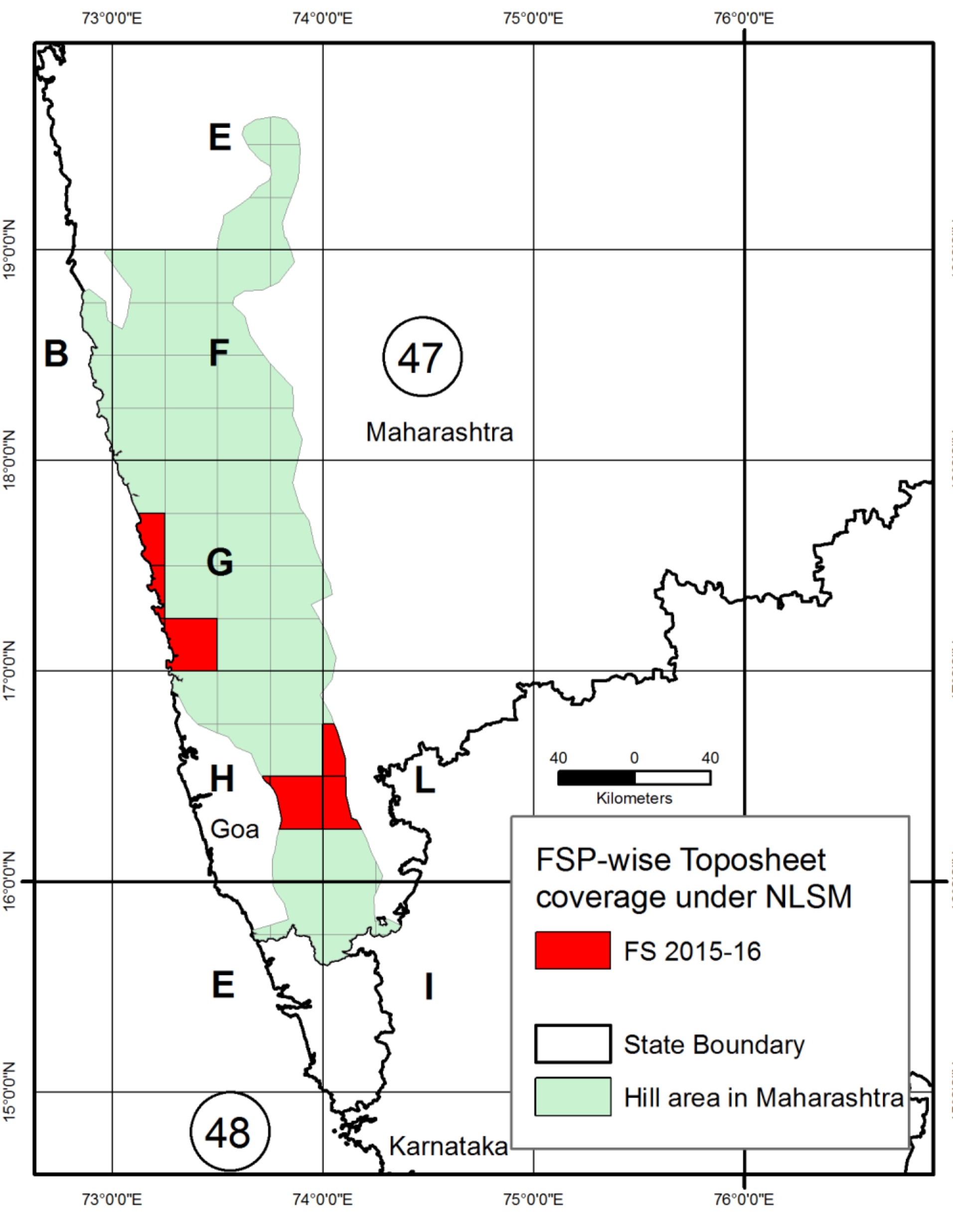
Sl No	Dates/ Places	States/ Regions
1	11th – 15th May 2015/ Bangalore	Kerala, Tamil Nadu, Karnataka & Goa, Southern Region
2	19th – 23rd May 2015/ Shillong	Manipur, Nagaland, Mizoram, Tripura & Meghalaya, Northeastern Region
3	25th – 29th May 2015/ Kolkata	Assam and Sikkim, Northeastern Region
4	1st to 5th June 2015/ Kolkata	Maharashtra, Central Region and West Bengal, Eastern Region
5	8th – 12th June 2015 / Chandigarh	Jammu & Kashmir, Uttarakhand & Himachal Pradesh, Northern Region

Total NLSM Target = 424.5 (x1000) km^2				
Target	**Priority 1**		**Priority 2**	
	Priority areas with settlement & roads (RS & detailed Field work)		Highly inaccessible & high altitude areas (Mainly RS with very limited field checks)	
	Toposheet	Area (in 1000 km^2)	Toposheet	Area (in 1000 km^2)
NR	158	75.4	207	74.5
ER	15	2.9	-	-
NER	233	109.3	167	71.2
SR	186	62.6	-	-
CR	68	28.6	-	-
Total	**660**	**278.8**	**374**	**145.7**

Priority 1 is presently in progress by GSI w.e.f. FS 2014-15

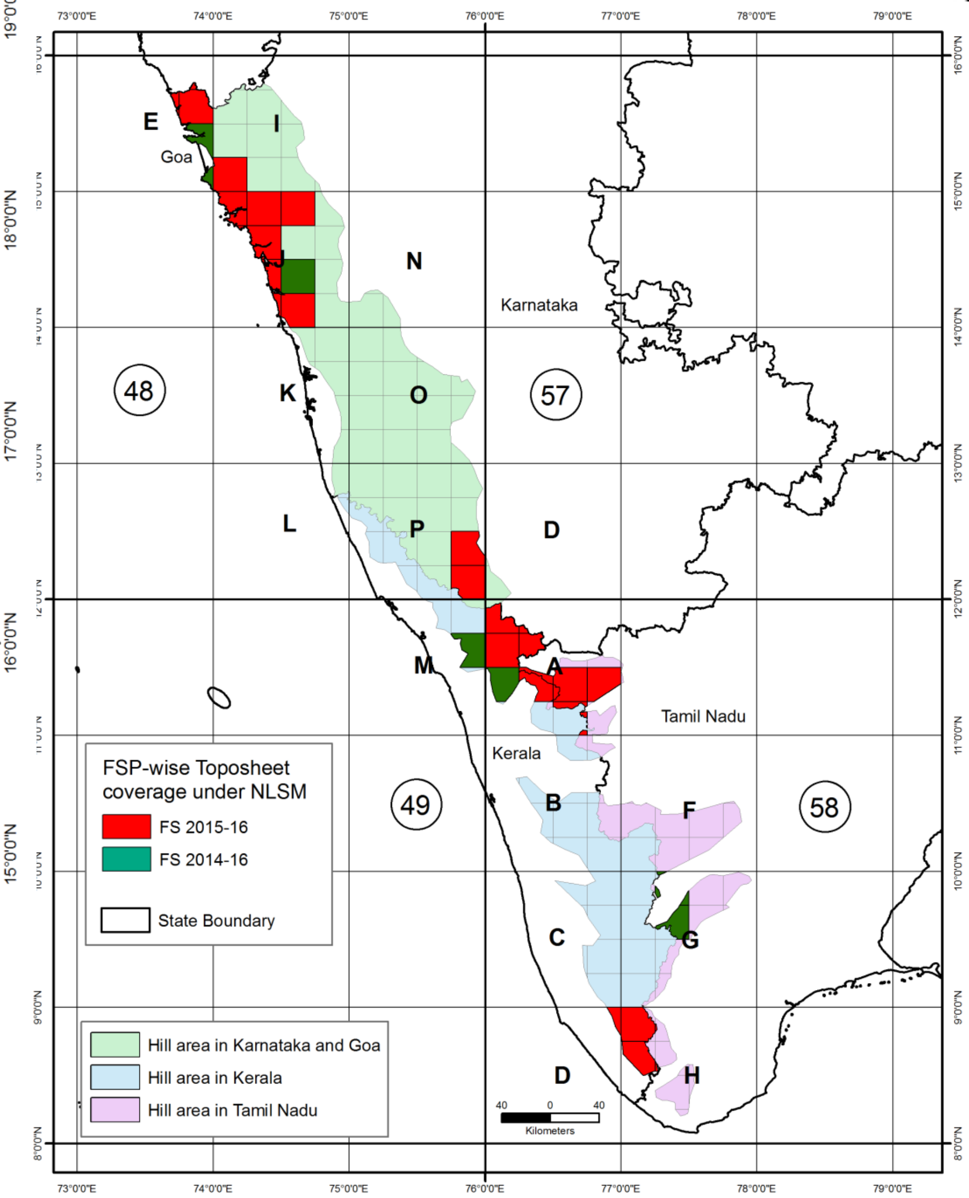
NLSM Progress & Perspective Plan (Priority 1)							
State/ Region	Area (in 1000 km²)	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
NR	75.3	16.48	11.53	12.39	13.02	13.01	8.86
ER	2.9	0	1.41	1.5	-	-	-
NER	109.3	0	18.78	21.16	23.12	23.12	23.12
SR	62.64	0	14.14	12.18	12.11	12.11	12.11
CR	28.61	0	2.46	4.12	7.34	7.34	7.34
Total	**278.8**	**16.48**	**48.32**	**51.09**	**55.59**	**55.59**	**51.43**
Cum target		**16.48**	**64.8**	**116.15**	**171.74**	**227.32**	**278.8**
Cum % of target		**6%**	**23%**	**42%**	**62%**	**82%**	**100%**

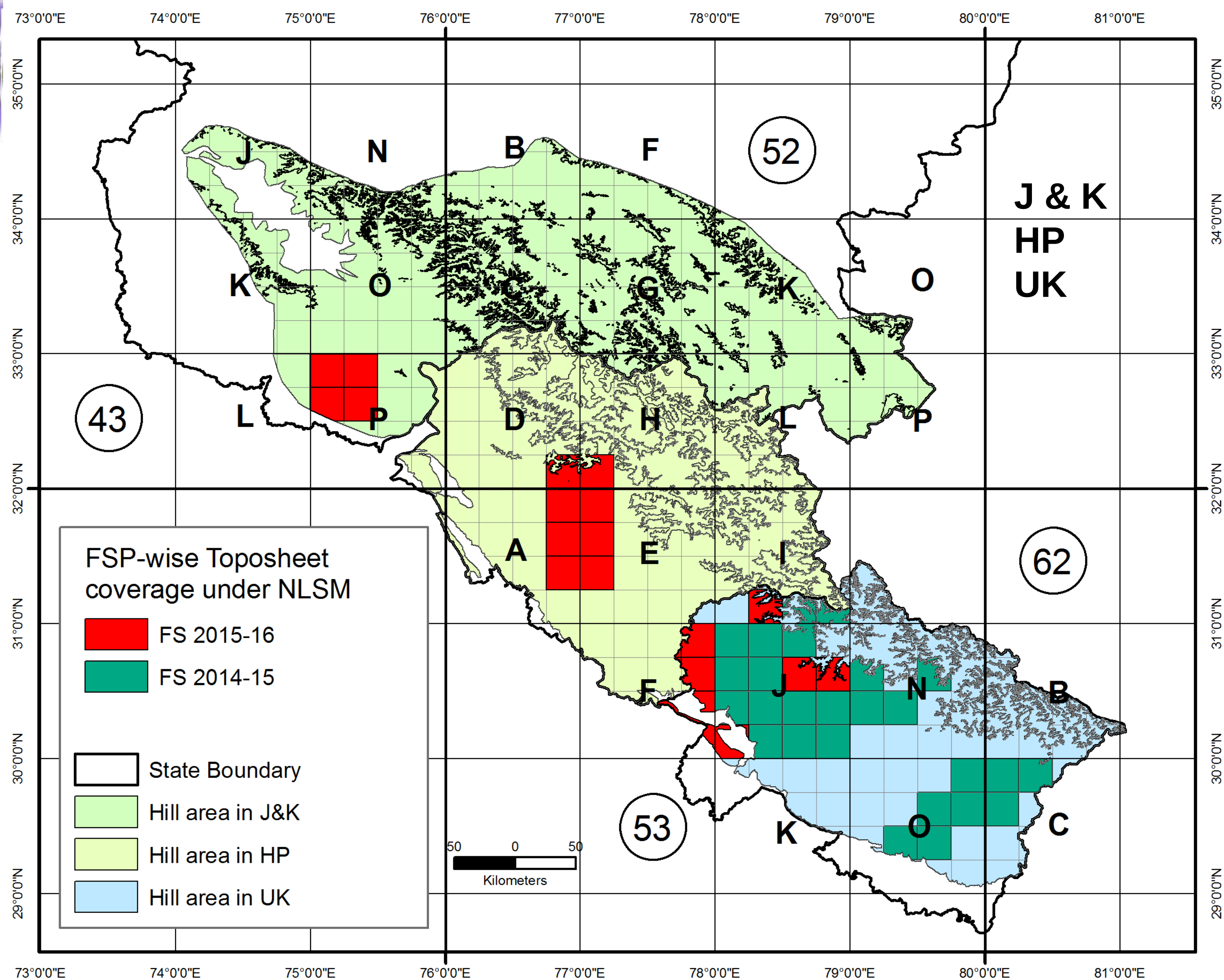
Green	**Already completed in FS 2014-15**
Blue	**Currently under execution in FS 2015-16**
Yellow	**Proposed for FS 2016-17; awaiting approval at CGPB Meeting, February 2016**
Grey	**Perspective Plan (for FS 2017-18, 18-19 & 19-20)**



Maharashtra

Tamil Nadu & Kerala





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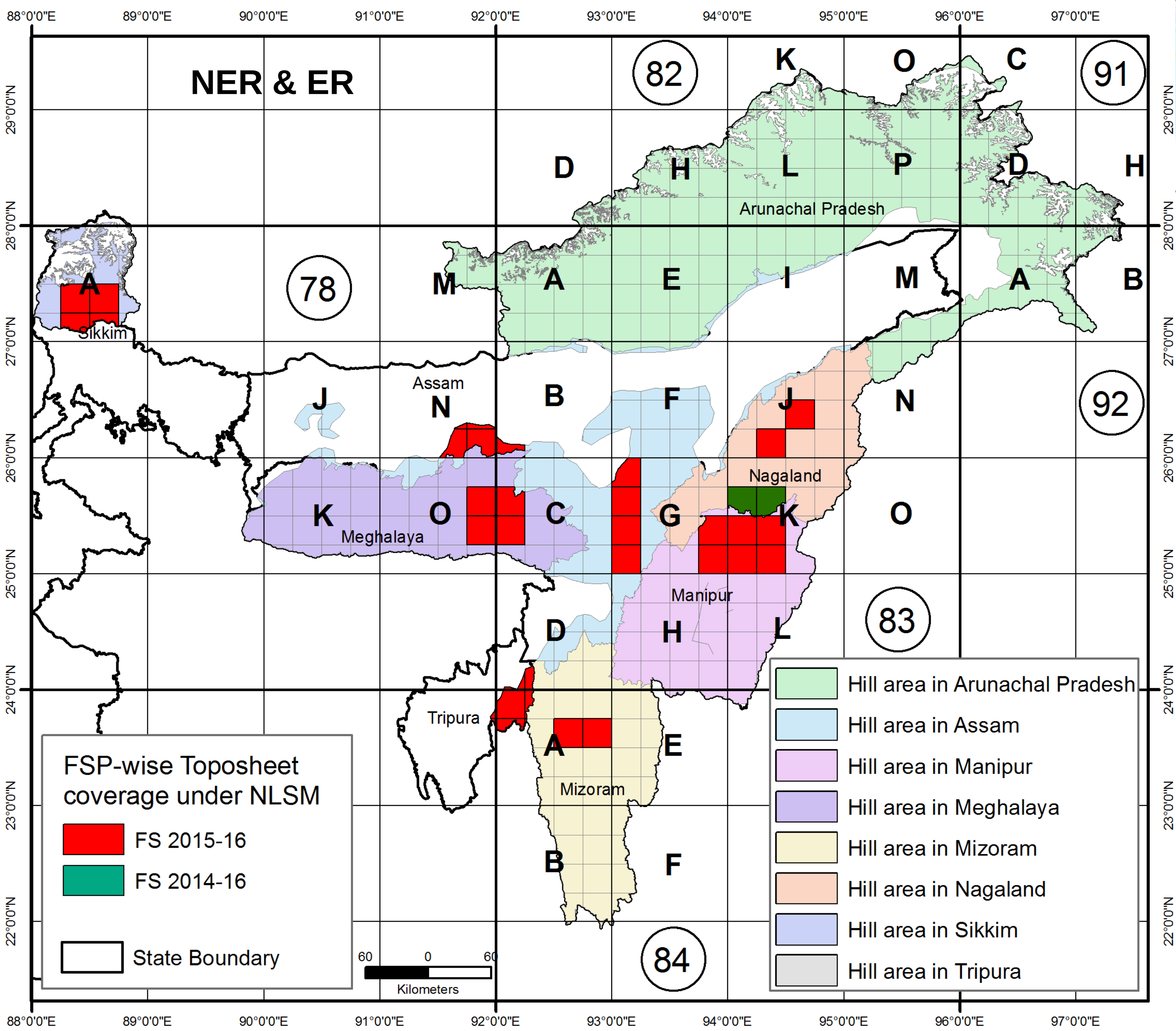
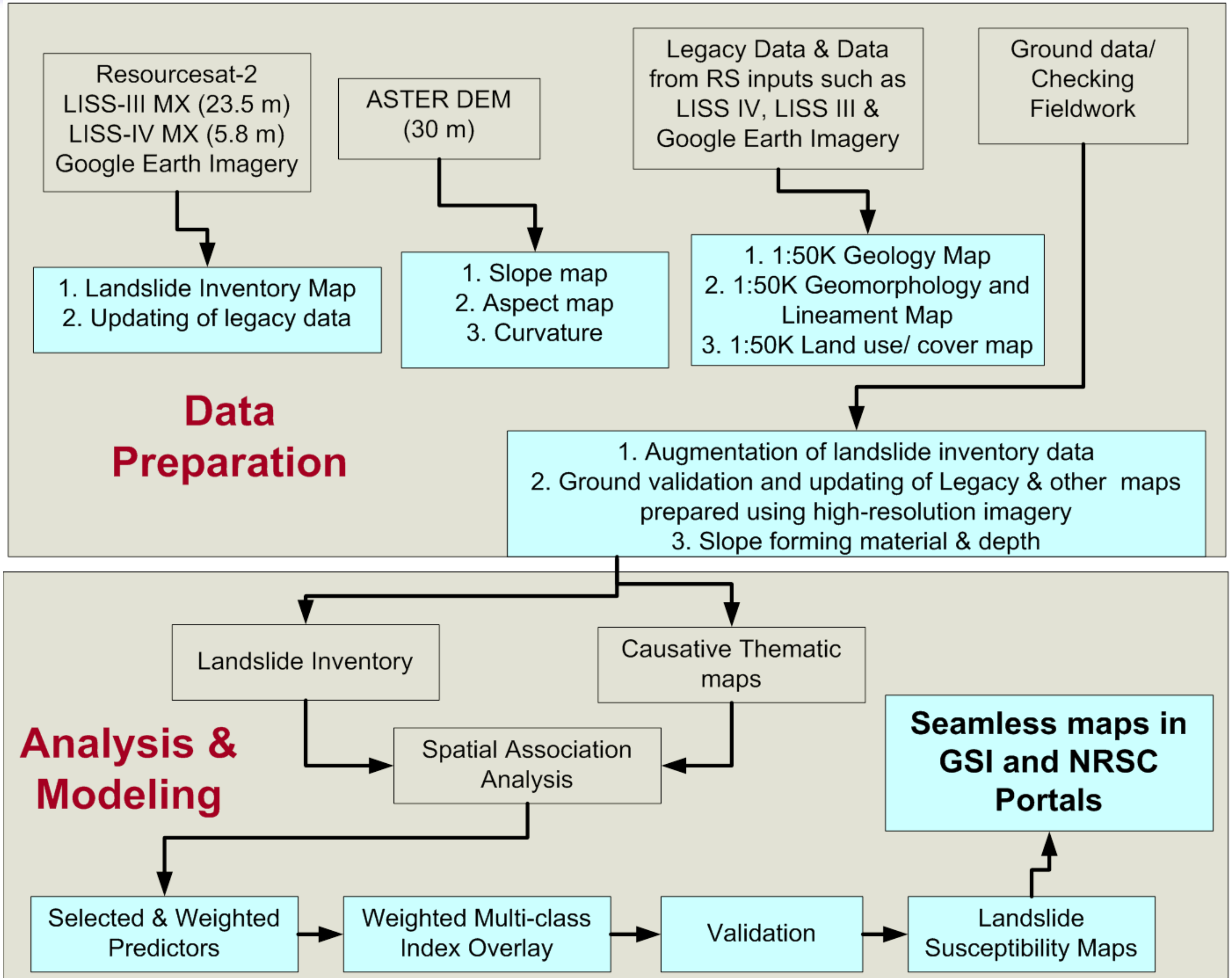
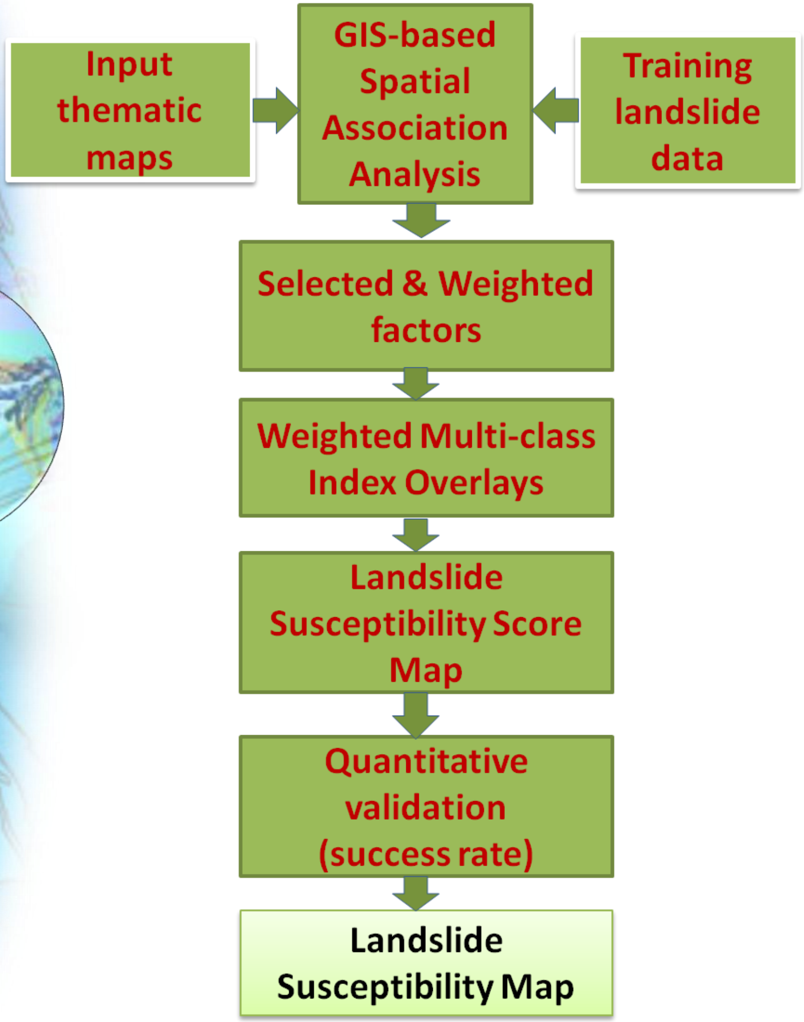
C
FSP-wise Toposheet coverage under NLSM
FS 2015-16
FS 2014-15
State Boundary
Hill area in J&K
Hill area in HP
Hill area in UK
50
0
50
Kilometers


NER & ER
82
91
78
92
83
84
Arunachal Pradesh
Sikkim
Assam
Meghalaya
Nagaland
Manipur
Tripura
Mizoram
FSP-wise Toposheet coverage under NLSM
FS 2015-16
FS 2014-16
State Boundary
Hill area in Arunachal Pradesh
Hill area in Assam
Hill area in Manipur
Hill area in Meghalaya
Hill area in Mizoram
Hill area in Nagaland
Hill area in Sikkim
Hill area in Tripura
Kilometers


Resourcesat-2
LISS-III MX (23.5 m)
LISS-IV MX (5.8 m)
Google Earth Imagery
ASTER DEM
(30 m)
Legacy Data & Data from RS inputs such as LISS IV, LISS III & Google Earth Imagery
Ground data/ Checking Fieldwork
1. Landslide Inventory Map
2. Updating of legacy data
1. Slope map
2. Aspect map
3. Curvature
1. 1:50K Geology Map
2. 1:50K Geomorphology and Lineament Map
3. 1:50K Land use/ cover map
Data Preparation
1. Augmentation of landslide inventory data
2. Ground validation and updating of Legacy & other maps prepared using high-resolution imagery
3. Slope forming material & depth
Landslide Inventory
Causative Thematic maps
Analysis & Modeling
Spatial Association Analysis
Seamless maps in GSI and NRSC Portals
Selected & Weighted Predictors
Weighted Multi-class Index Overlay
Validation
Landslide Susceptibility Maps

NLSM Modeling in landslide dominant areas (e.g., Himalayas)



Geofactor themes used

Slope
Aspect
Curvature
Land use/ cover
Geomorphology
Slope Forming Material (SFM) Thickness
Proximity to drainage
Proximity to roads
Proximity to faults/ fractures

&

Landslide inventory maps

NLSM Modeling in landslide deficient areas (e.g., South India)

Rating of geofactors using AHP

↓

Selected & Weighted factors

↓

Weighted Multi-class Index Overlays

↓

Landslide Susceptibility Score Map

↓

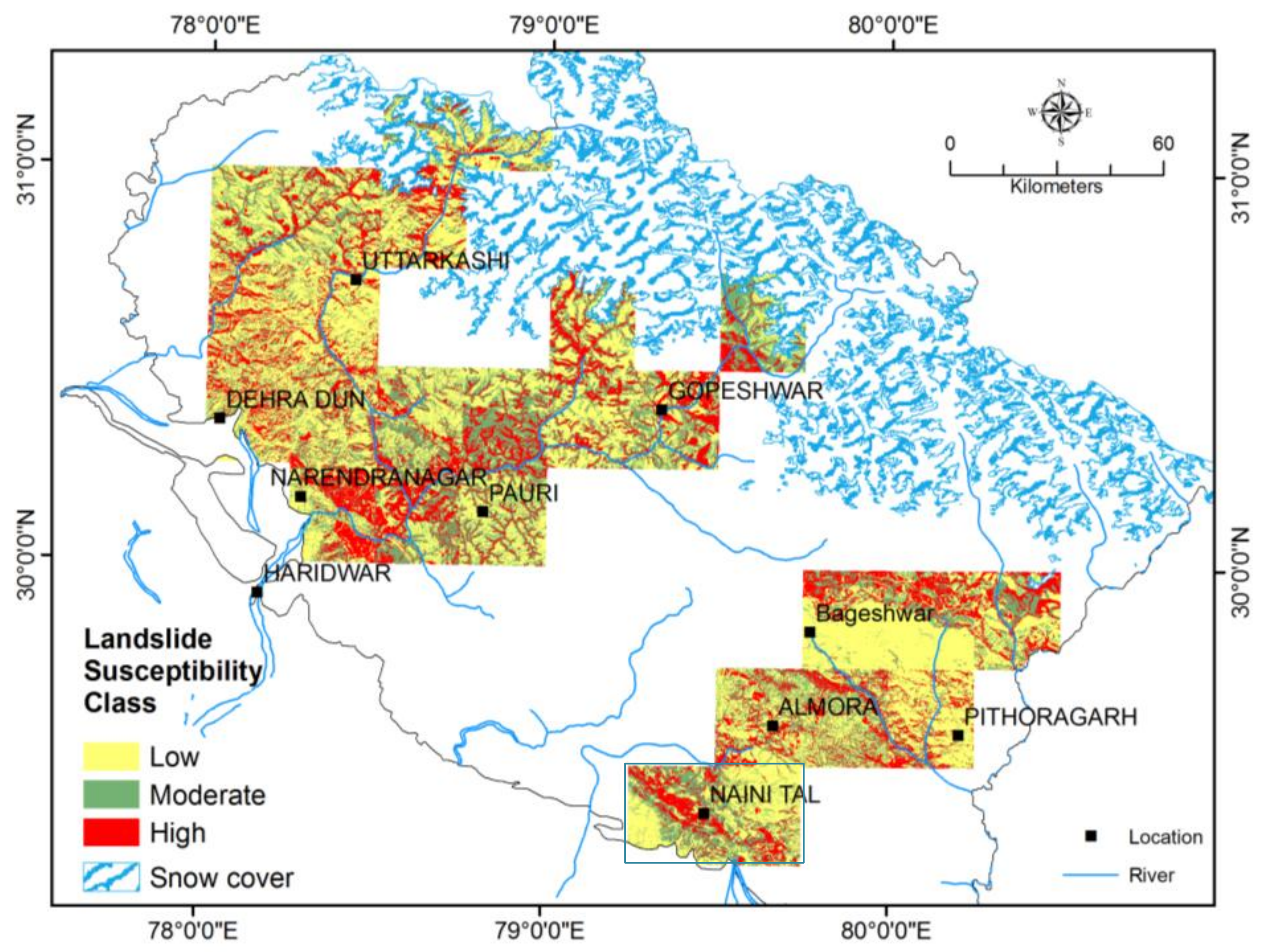
Quantitative validation (success rate)

↓

Landslide Susceptibility Map

Geofactor themes used

Slope
Aspect
Curvature
Land use/ cover
Geomorphology
Slope Forming Material (SFM)
Depth
Proximity to drainage
Proximity to roads
Proximity to faults/ fractures



78°0'0"E
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80°0'0"E
31°0'0"N
30°0'0"N
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Kilometers
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UTTARKASHI
DEHRA DUN
GOPESHWAR
NARENDRANAGAR
PAURI
HARIDWAR
Bageshwar
ALMORA
PITHORAGARH
NAINI TAL
Landslide Susceptibility Class
Low
Moderate
High
Snow cover
Location
River

Processes or steps for each NLSM

I. Preparation of Landslide Spatial Database

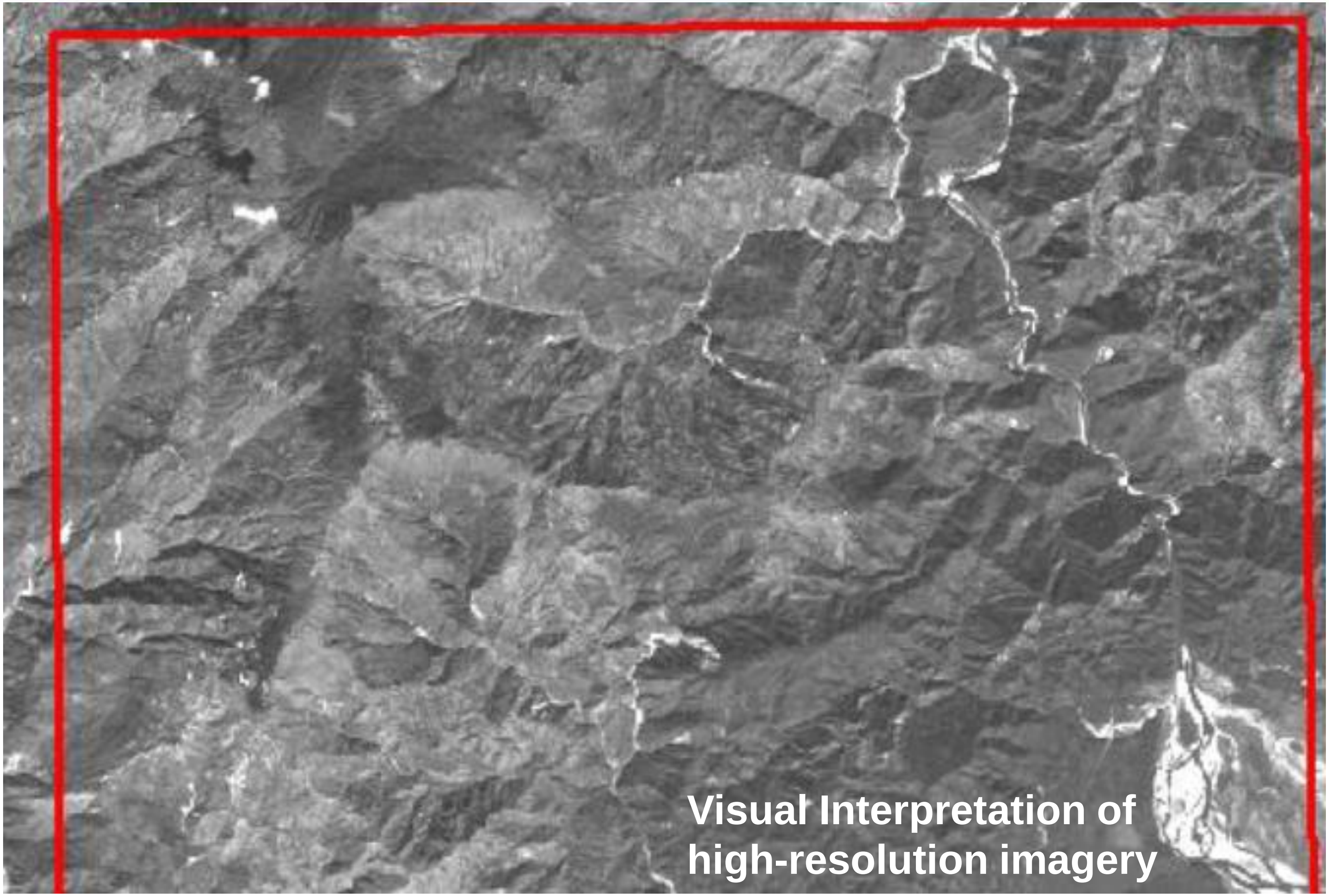
II. Preparation of Geofactor Spatial Database

III. Determining Rating and Weight of Geofactors

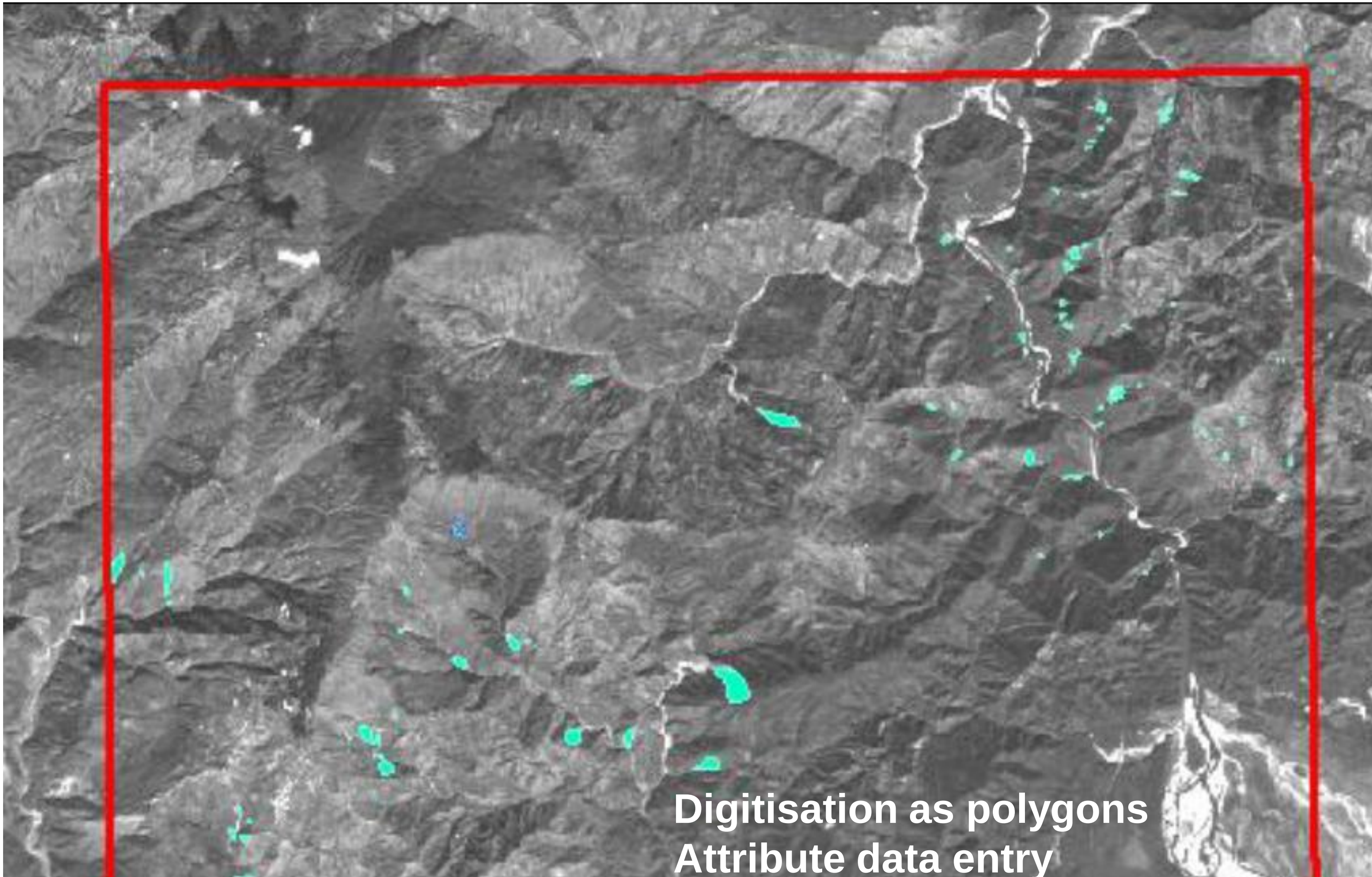
IV. Integration, validation & predictive modeling of landslide susceptibility

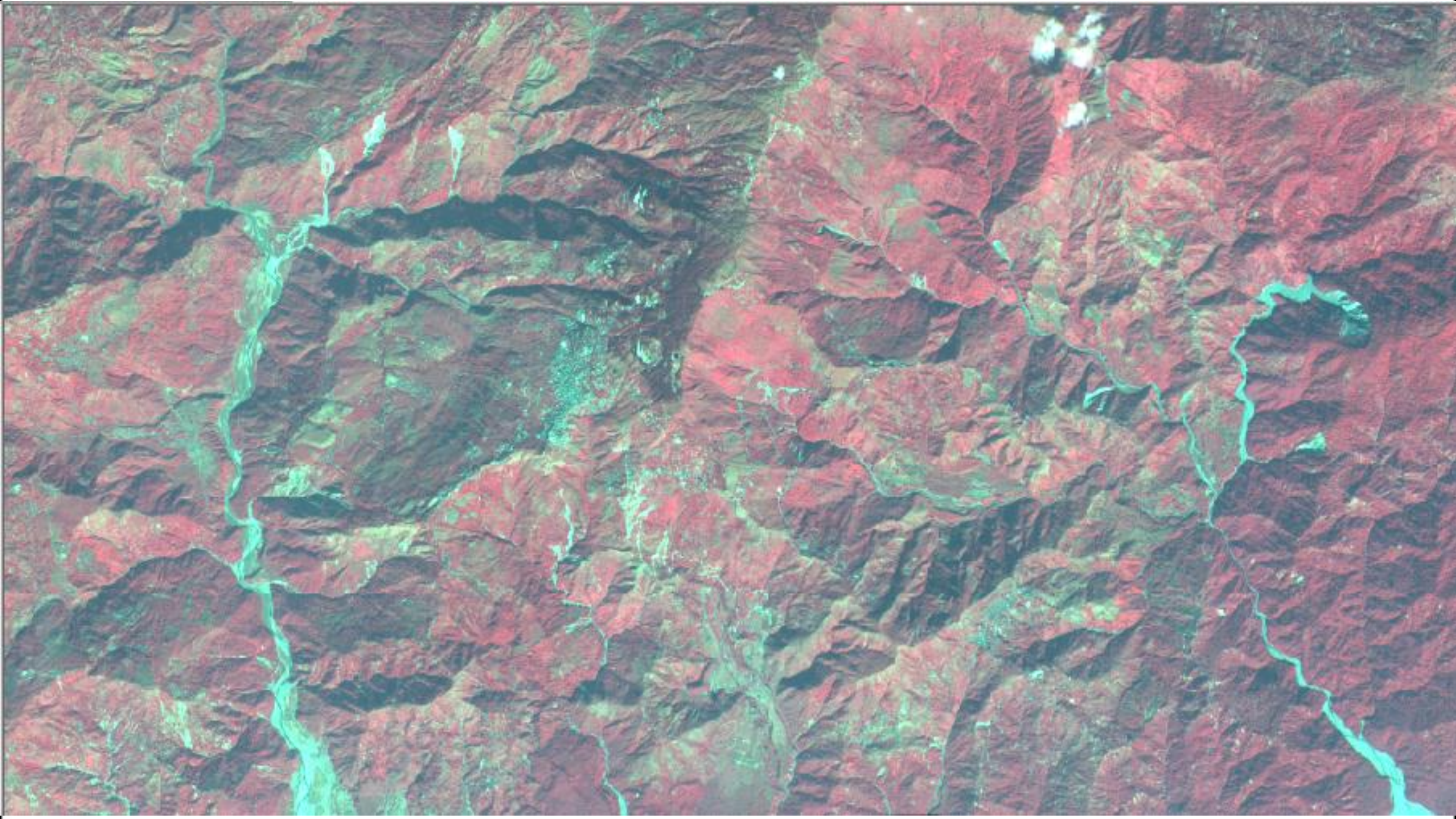
I. Preparation of Landslide Spatial Database

Source: Multiple

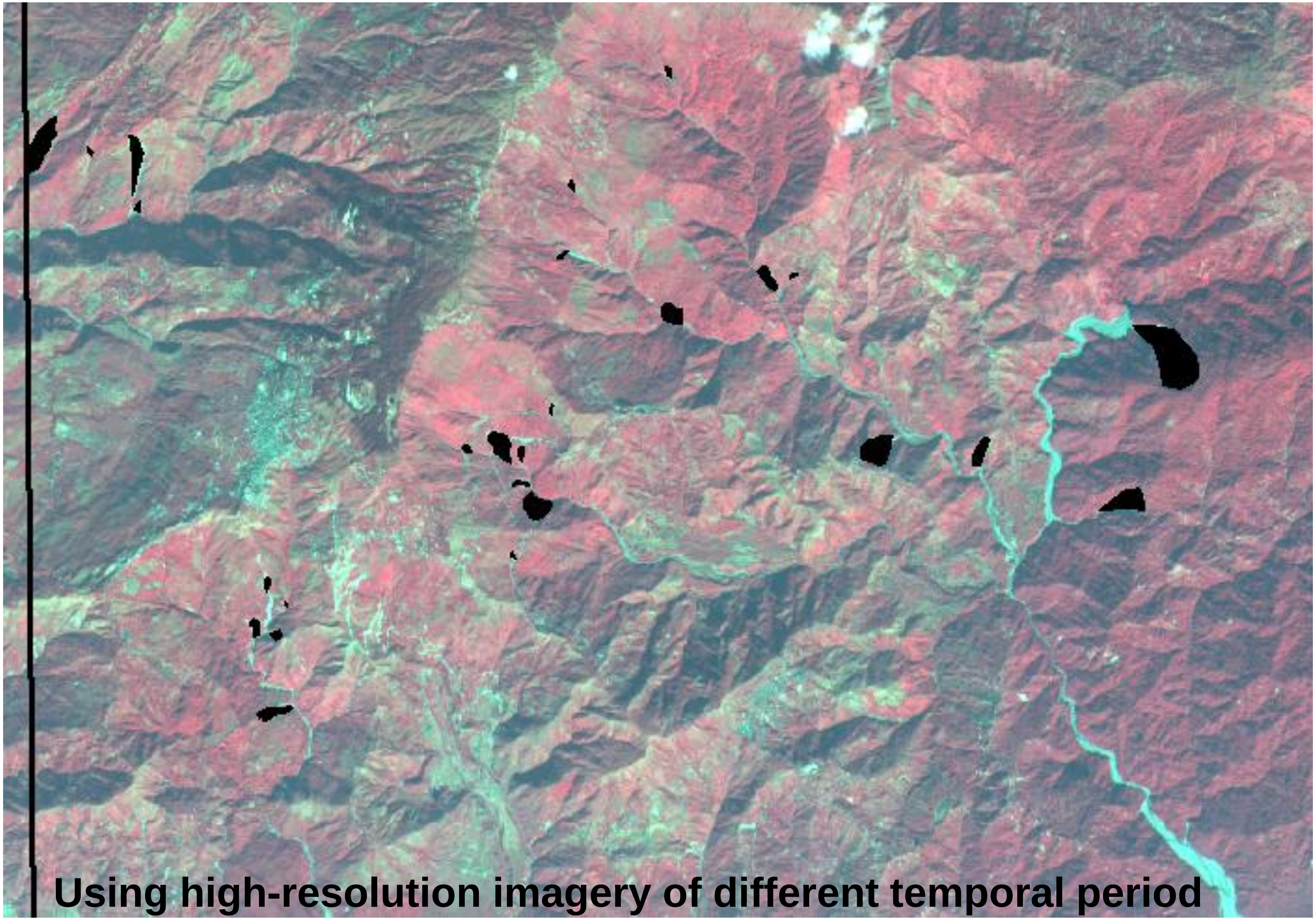

Visual Interpretation of
high-resolution imagery

Mapping landslides using Multi-temporal RS data of multiple time (2) (Main Source: NRSC)

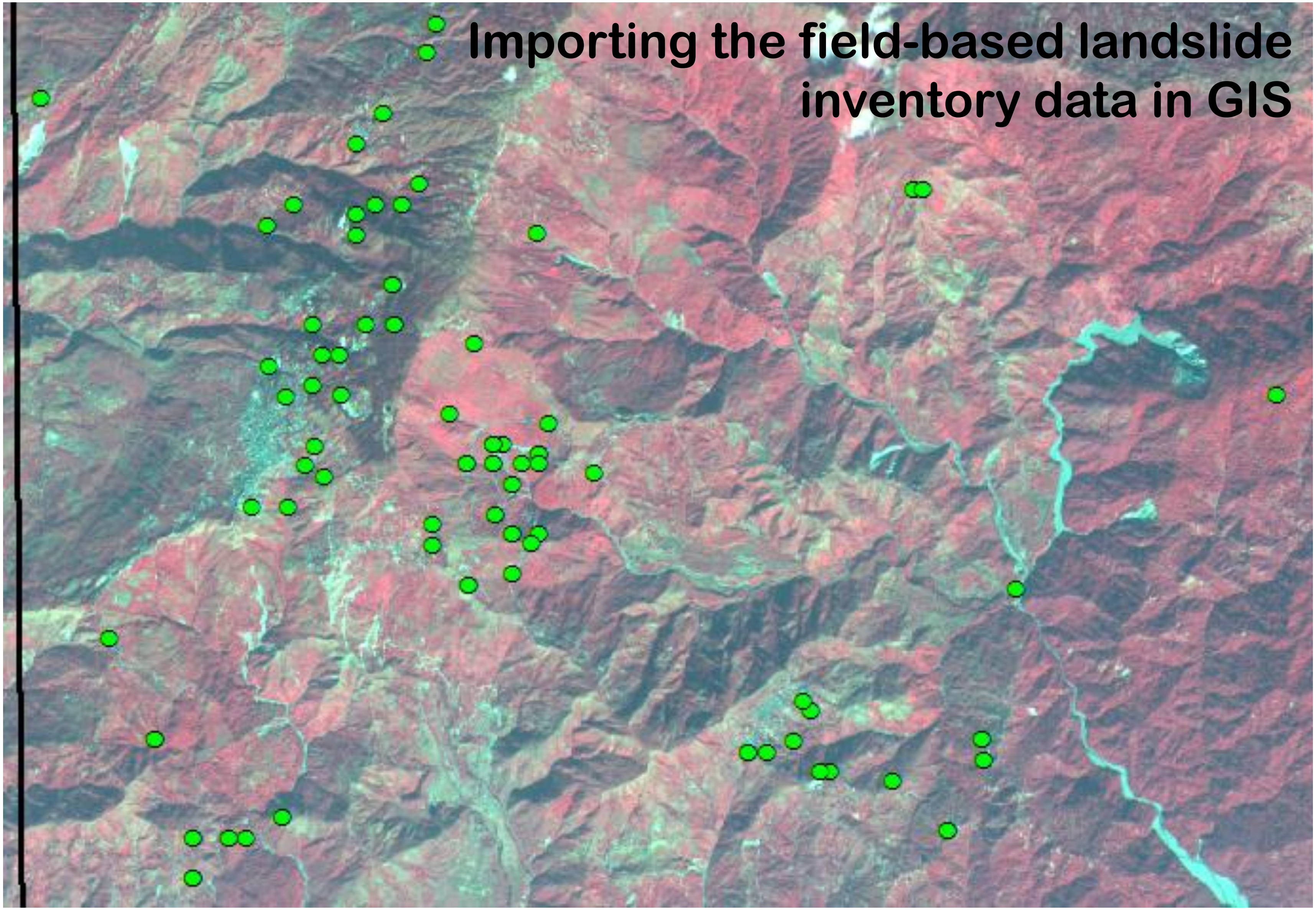


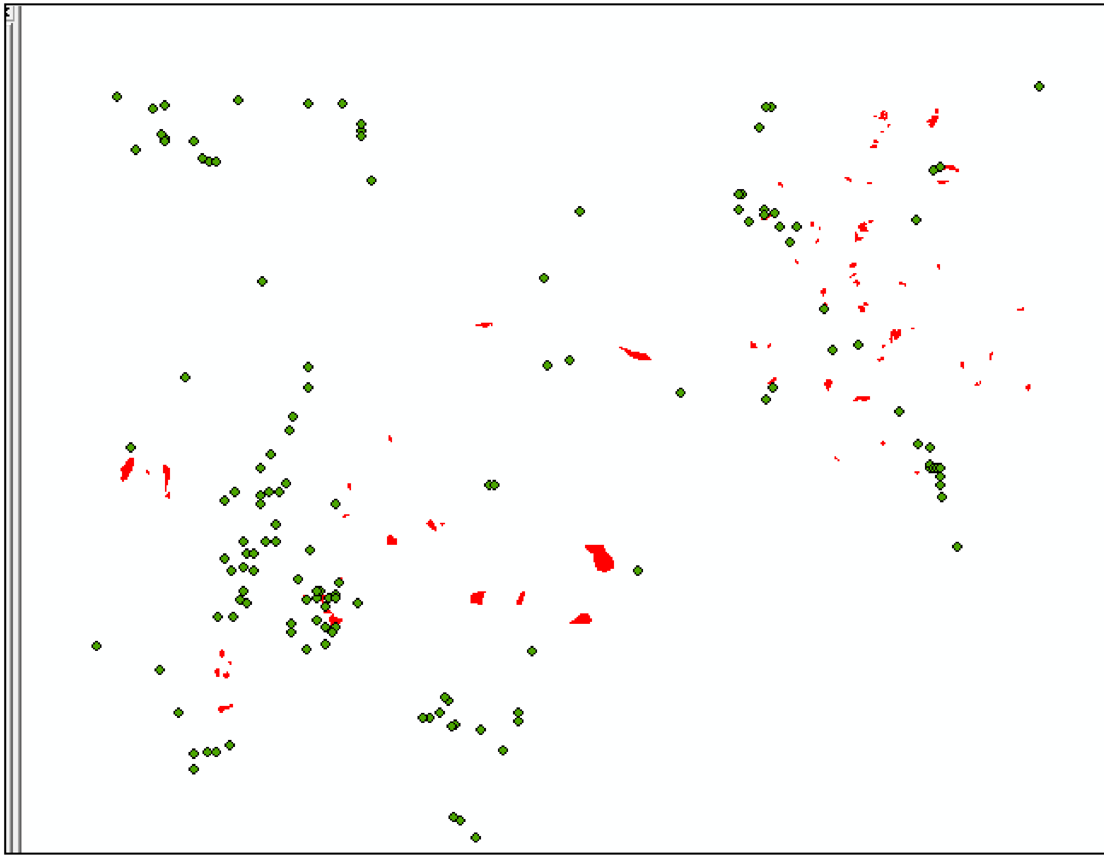


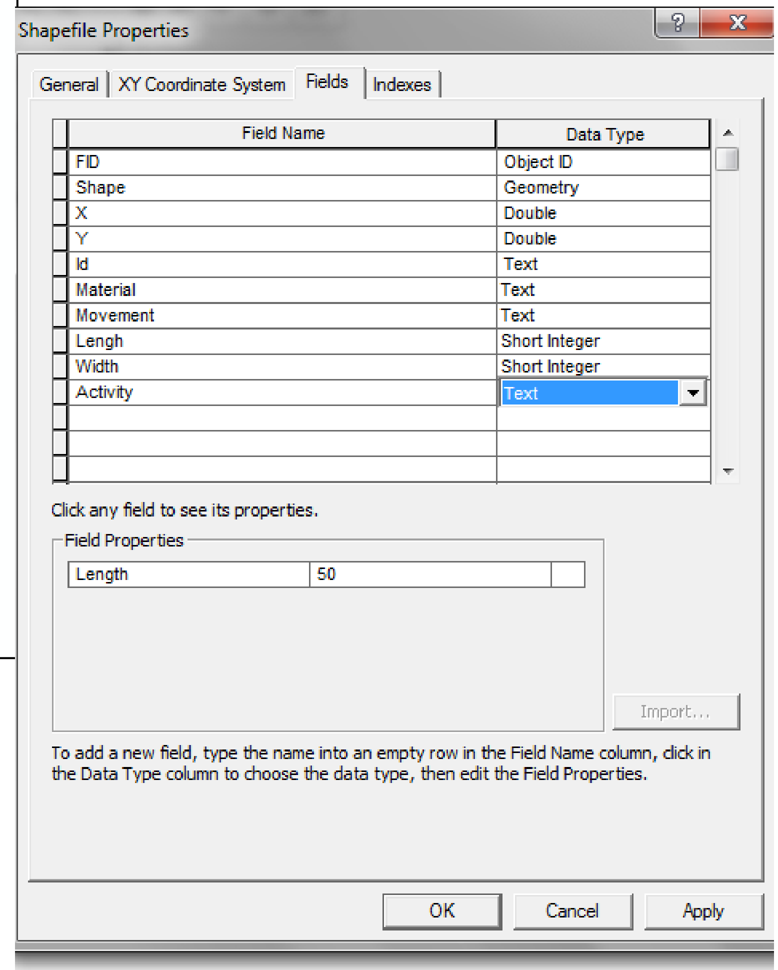
Using high-resolution imagery of different temporal period


Using high-resolution imagery of different temporal period

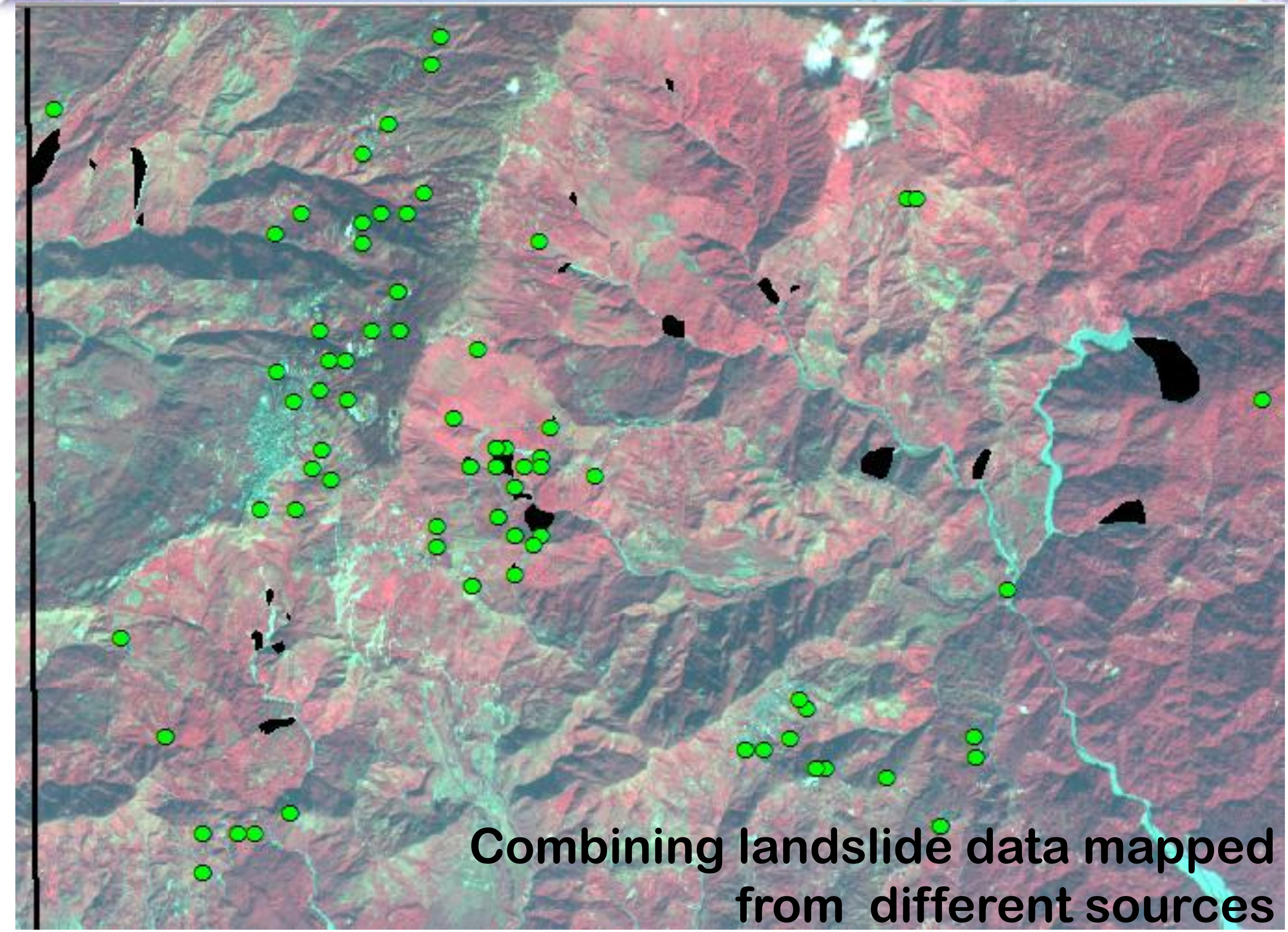
Importing the field-based landslide inventory data in GIS





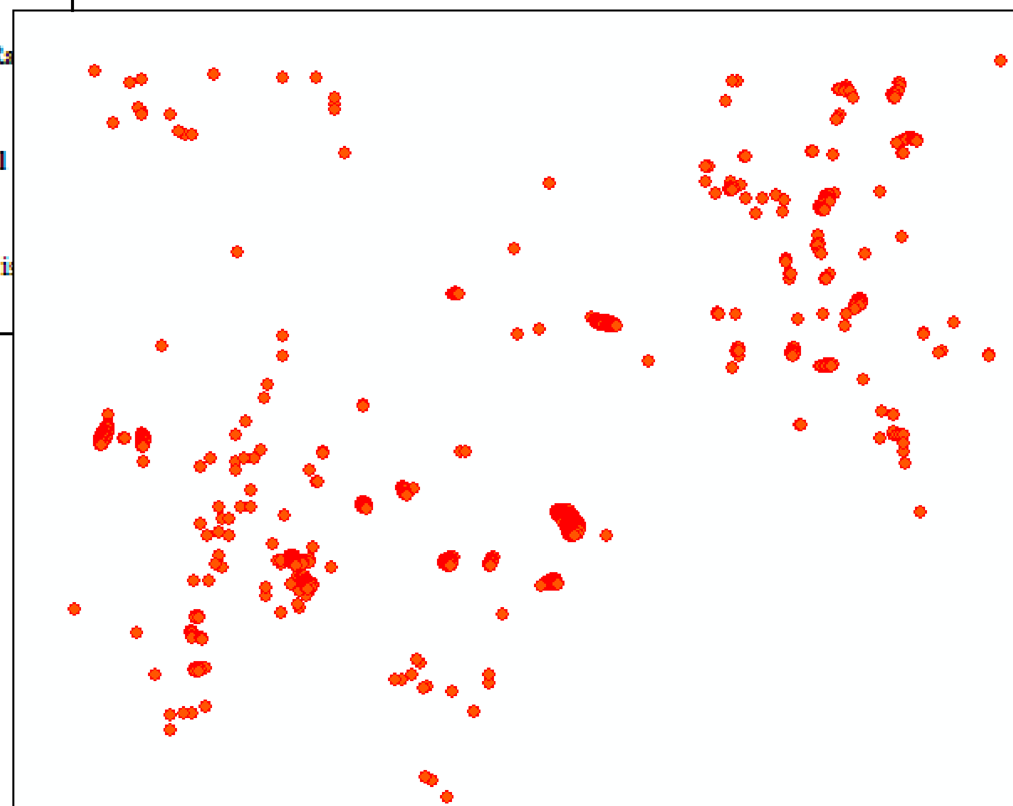


Adding attributes of landslides in GIS (41-point Geoparametric Data Format)

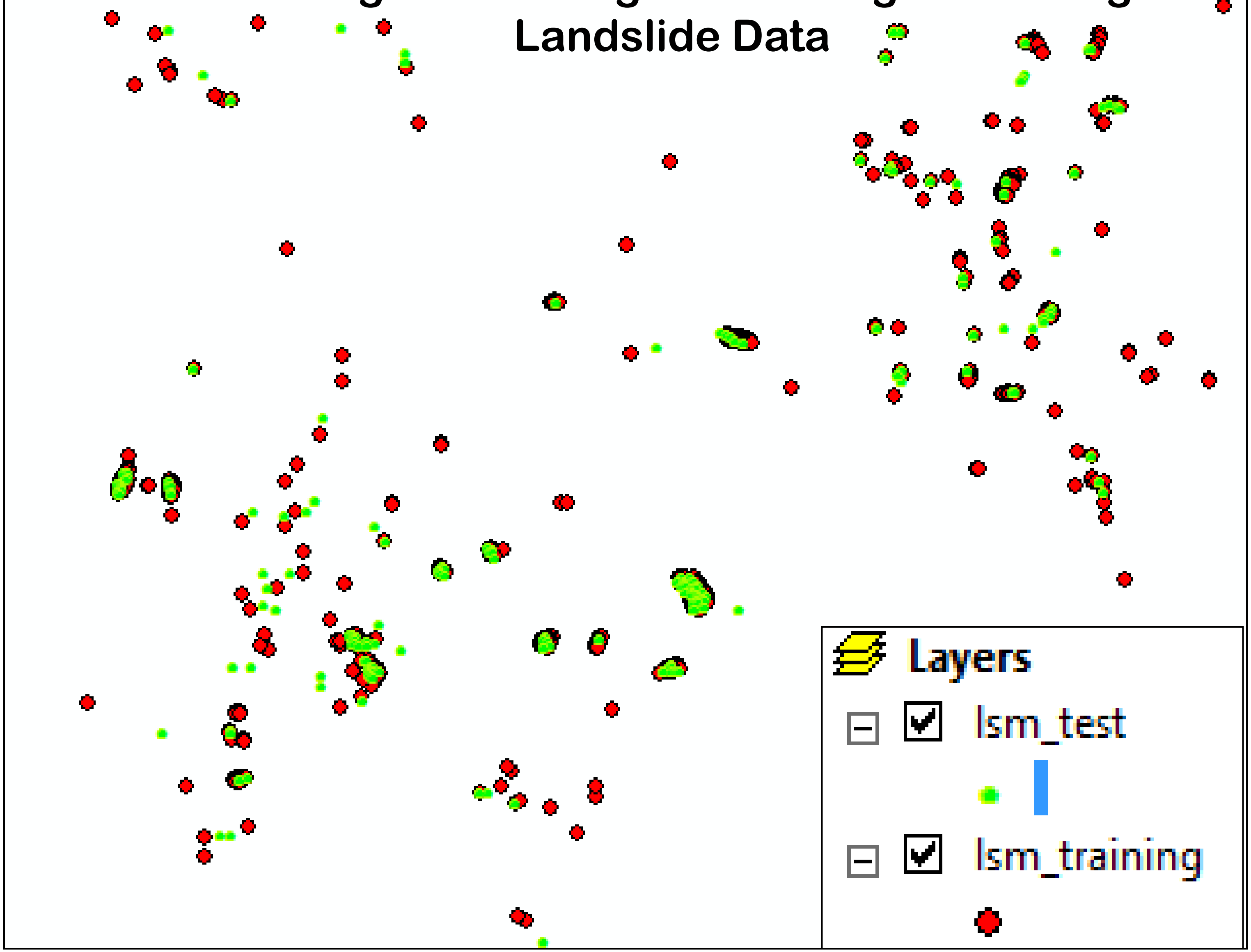

Combining landslide data mapped
from different sources

Preparation of landslide data (as points) for analysis & modeling (use of merging…)

- Open ArcMap and open RSpoly.shp
- In Arc Toolbox click and expand **Conversion Tools** and then **To Raster**
- Click **Polygon to Raster**
- Input Feature: add RSPoly
- Value Field: add **Id or FID**
- Output Raster Dataset: …\NLSM\Landslide\RSPoly.img
- Cell size: **50**
- Right Click raster RSPoly, click **Open Attribute Table**. Attribute table of RSPoly opened.
- In Arc Toolbox again click and expand **Conversion Tools** and then **From Ra** and then click **Raster to Point**
- Input Raster: RSPoly; Output Point Feature: **RSPolypt**
- In Arc Toolbox click and expand **Data Management Tools** and then **General** then click **Merge**
- In Merge dialog box **add** both the datasets RSPolypt and ls_pt
- Output Dataset: …\NLSM\Landslide\lsm.shp. merged landslide file lsm.shp is combined **landslide Point Data** for use in subsequent analysis



Training/ Calibrating and Testing/ Validating Landslide Data



II. Preparation of Geofactor Thematic Maps

Source: **Multiple**

Sl No	Thematic group	Geofactor themes	Thematic classes	Data type
1.	Slope morphometry	Slope Gradient	Reclassified as 5 degree intervals	Continuous
2.		Curvature	Classified into 5 to 6 classes	Categorical
3.		Aspect	NNE, NE, ENE, ESE, SE, SSE, SSW, SW, WSW, WNW, NW & NNW	Categorical

Source: 30 m resolution ASTER DEM or 10 m resolution CartoDEM after getting the layers from NRSC

4.	Geomorphology	Geomorphology **(Base 1:50K NGLM layer to be provided by GHRM Cell; Data for Target areas of FS 2014-15 already procured)**	Colluvial fan, Alluvial fan, Alluvial plain, Intermontane plateau, Lowly dissected valley, Moderately dissected valley , Highly dissected valley , Ridge and spur, Old river terrace, Denudational valley and niche, Steep escarpments, etc.	Categorical
5.	Slope forming material	Material (**1:50K Geology map already procured to be provided by GHRM Cell)**	Scree , Regolith, Lithomarge, Laterite, Alluvium mixed with colluvium, Colluvium, Talus, Alluvium, Older well compacted debris, Younger loose debris material, Different rock types (Fresh), Different rock types (weathered) … etc.	Categorical

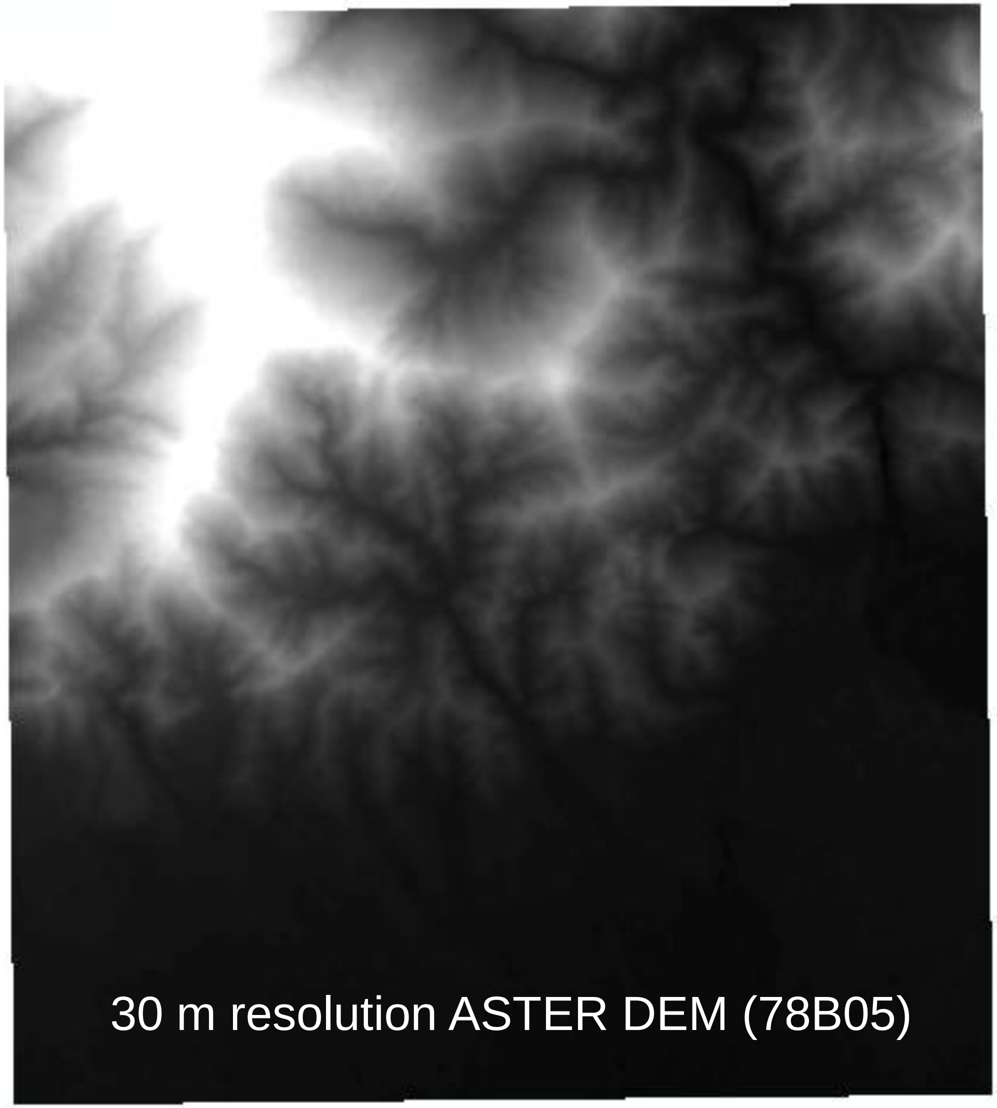
6.	Slope forming material	Thickness	0 -1 m >1 m & <= 5 m >5 m & <= 10 m >10 m & <= 20 m > 20 m	Categorical
7.	Structure	Fault/ Fracture	Distance to Fault/ Fracture	Continuous or Categorical
8.		Regional Thrust/ Shear	Distance to Regional Thrust/ Shear	Continuous or Categorical

Fault/ Fracture and Regional Thrust will be available from legacy maps (1:50K Geology and NGLM layers)

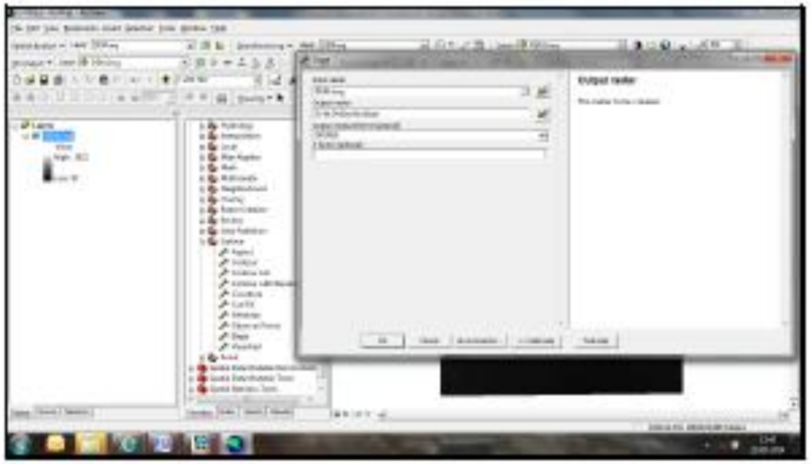
9.	Land use/ cover	Land use/ cover types	Barren, Agricultural land Plantation, Settlement Moderately vegetated forest, Thick forest, Sparsely vegetated forest … etc.	Categorical
10.		Major roads	Distance to road	Continuous or Categorical
11.	Geo-hydrology	Drainage	Distance to Drainage	Continuous or Categorical

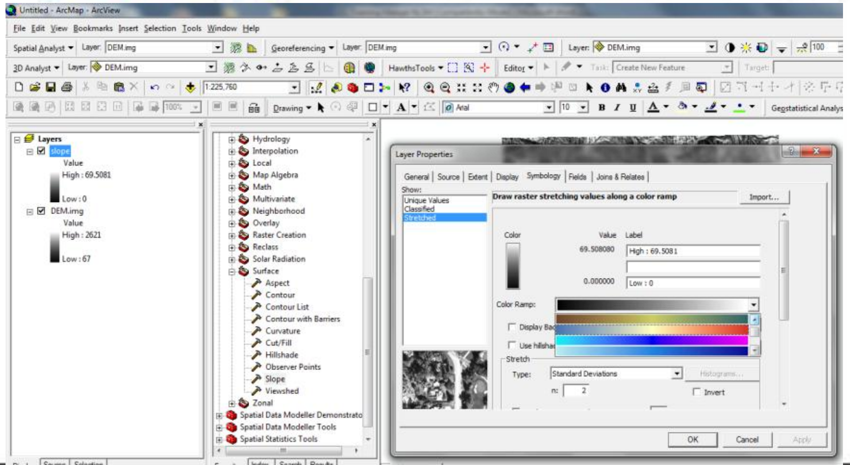
LU LC pre-field maps can be prepared using Toposheet/ available satellite imagery, Google Earth Data through visual interpretation only

DEM Data

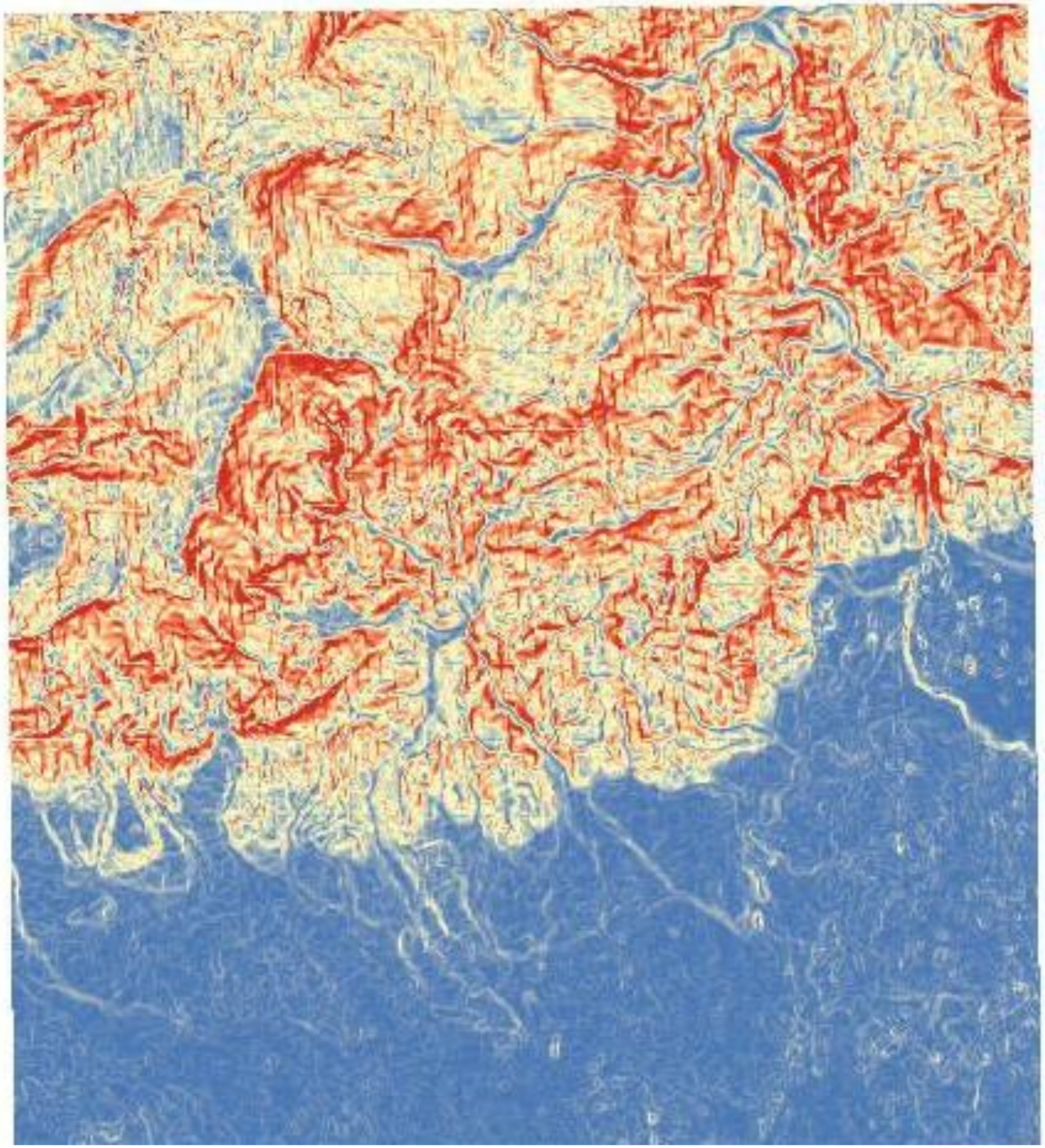


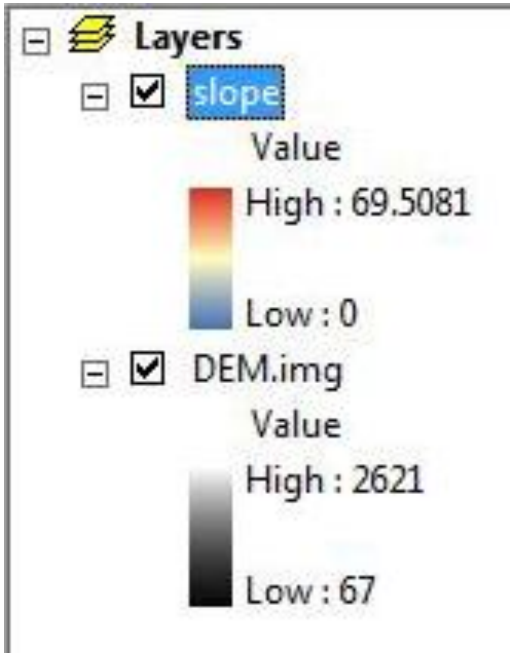
- **Preparation of *Slope Inclination* Raster**
  5. Select "**Spatial Analyst Tool**" from the Toolbox Menu
  6. Then expand it by clicking the "**+**" button on the left of the "**Spatial Analyst Tool**"
  7. Further expand "**Surface**" in the similar manner within expanded "**Spatial Analys Tool**"
  8. Click "**Slope**" tool within "**Surface**"



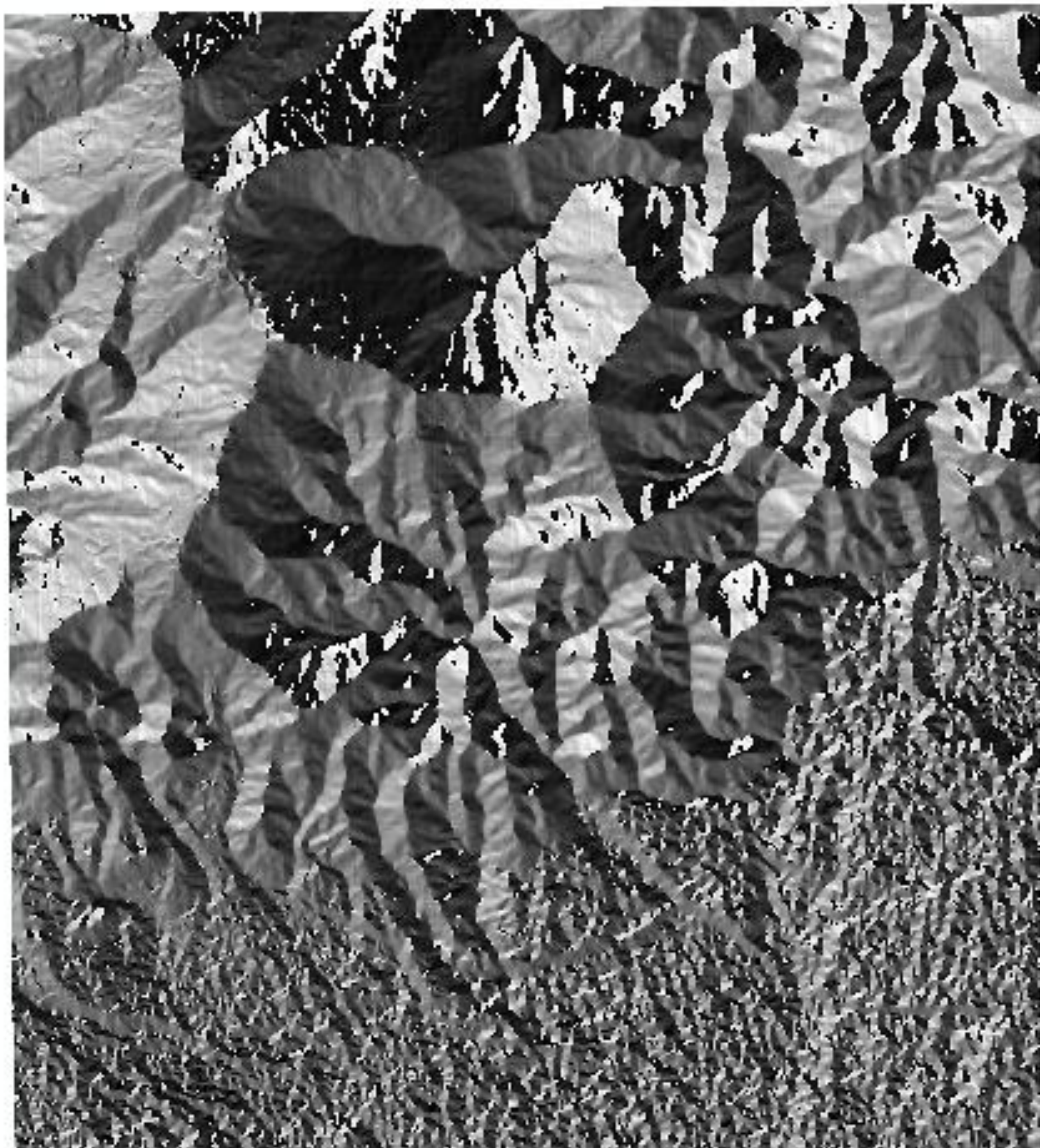


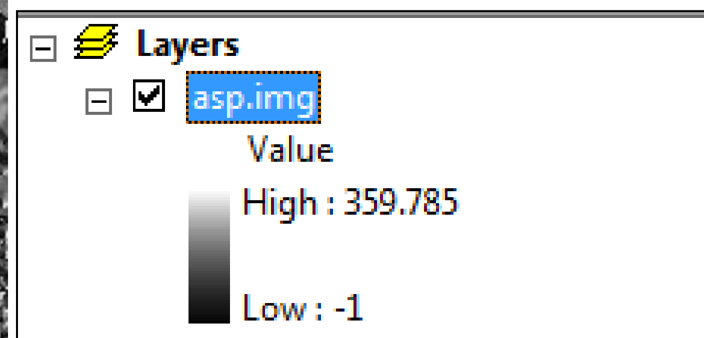
Slope



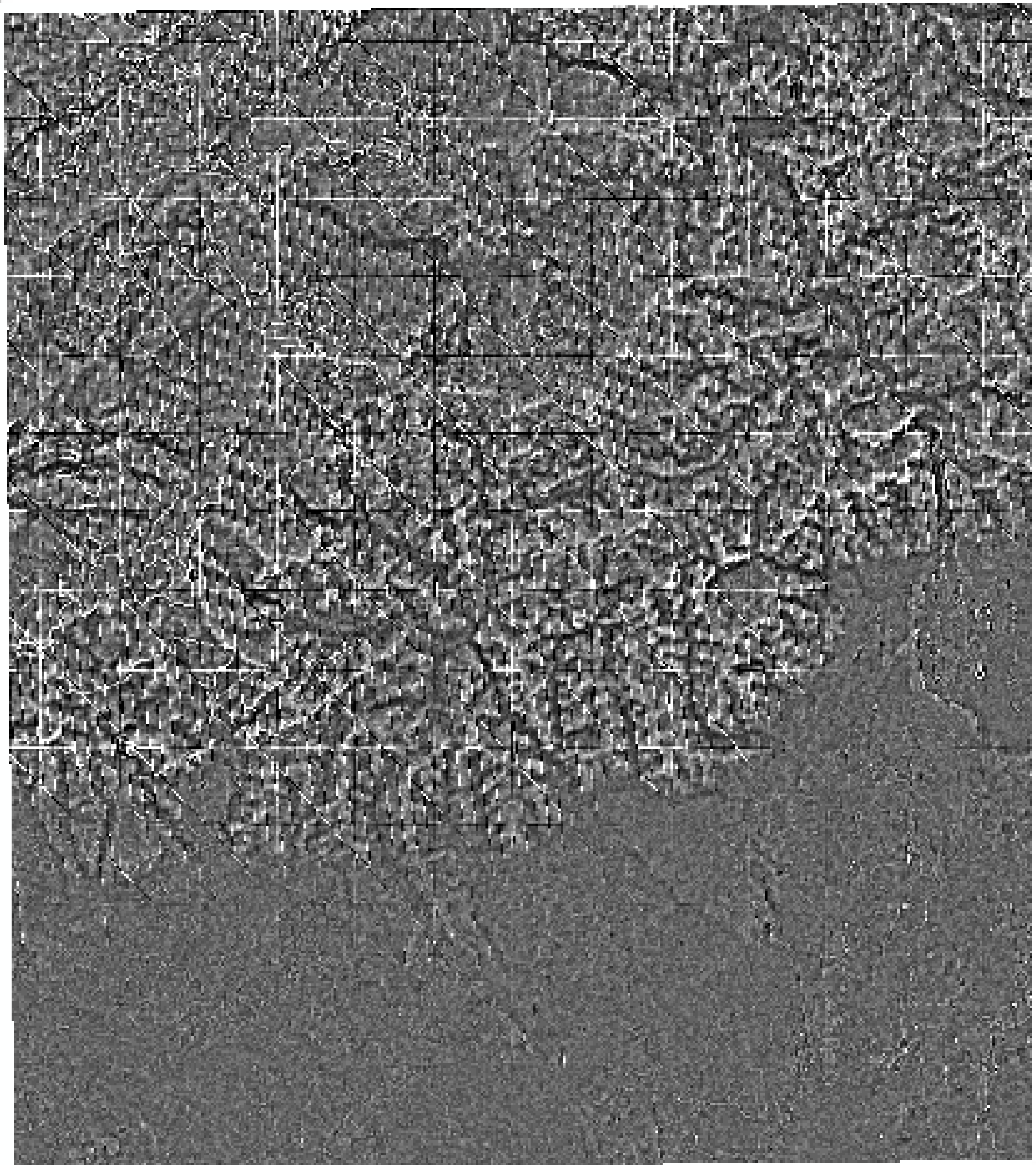

Layers
slope
Value
High : 69.5081
Low : 0
DEM.img
Value
High : 2621
Low : 67

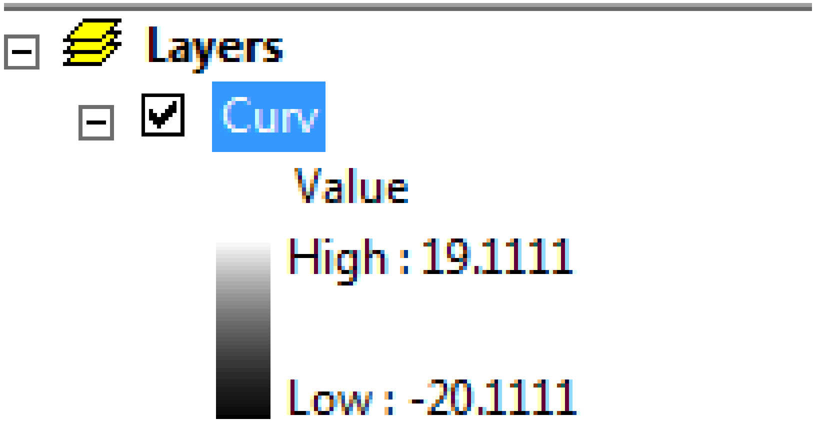
Aspect

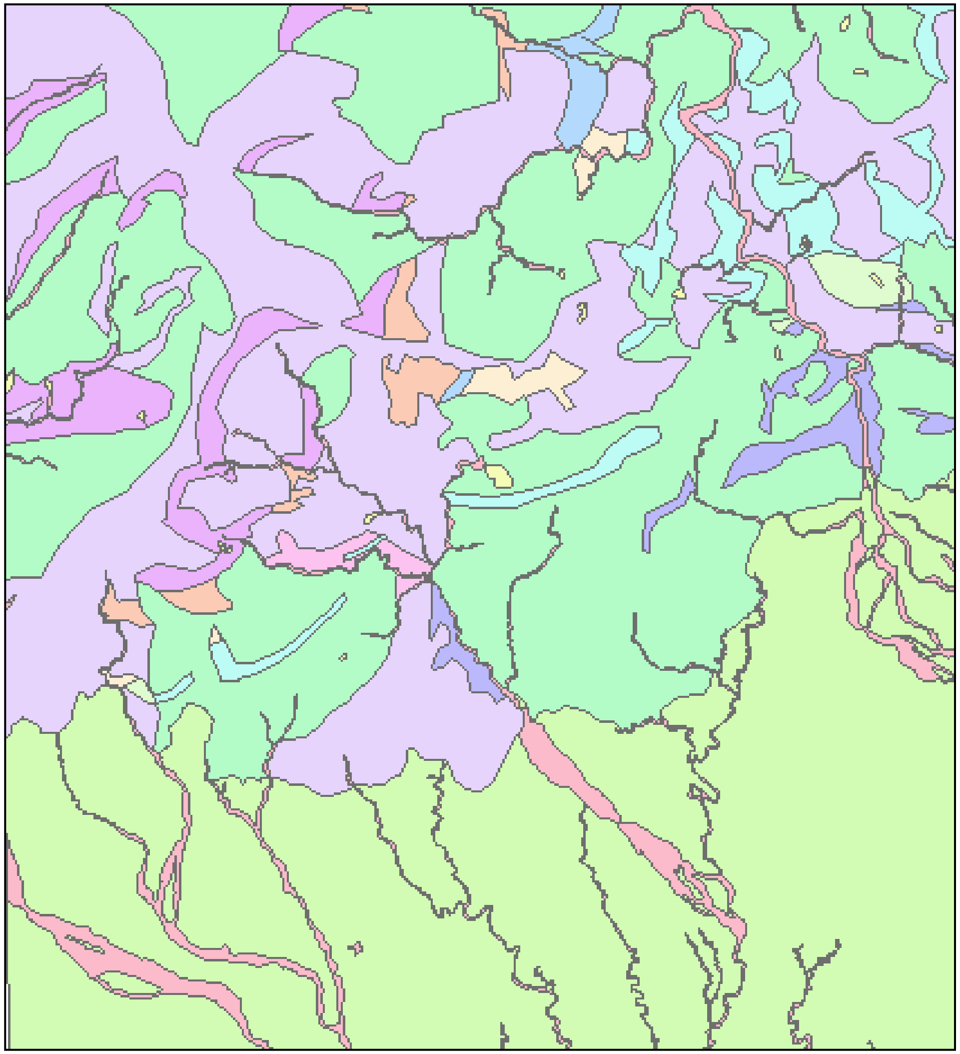


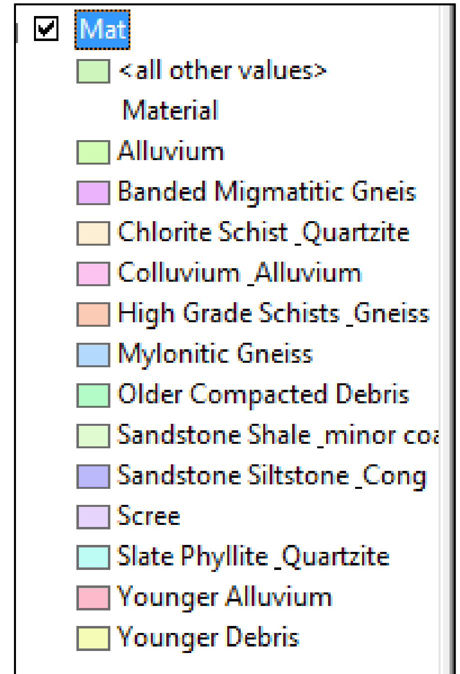


Curvature





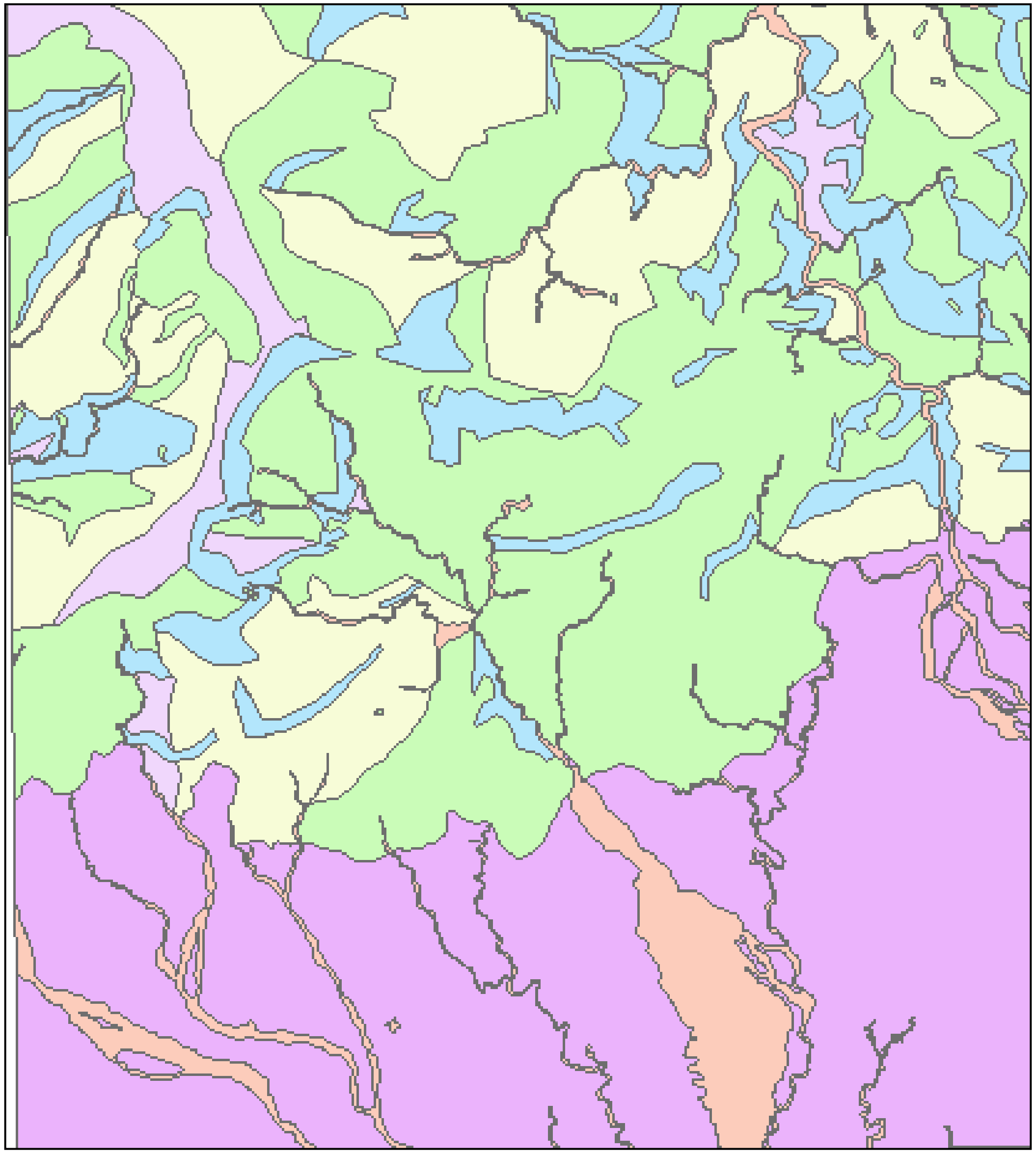


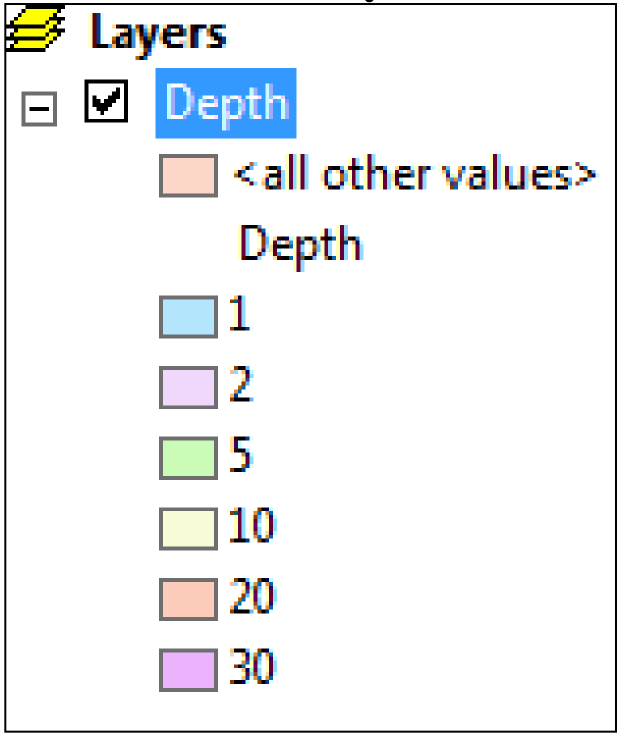


Pre-field Material/ SFM Map

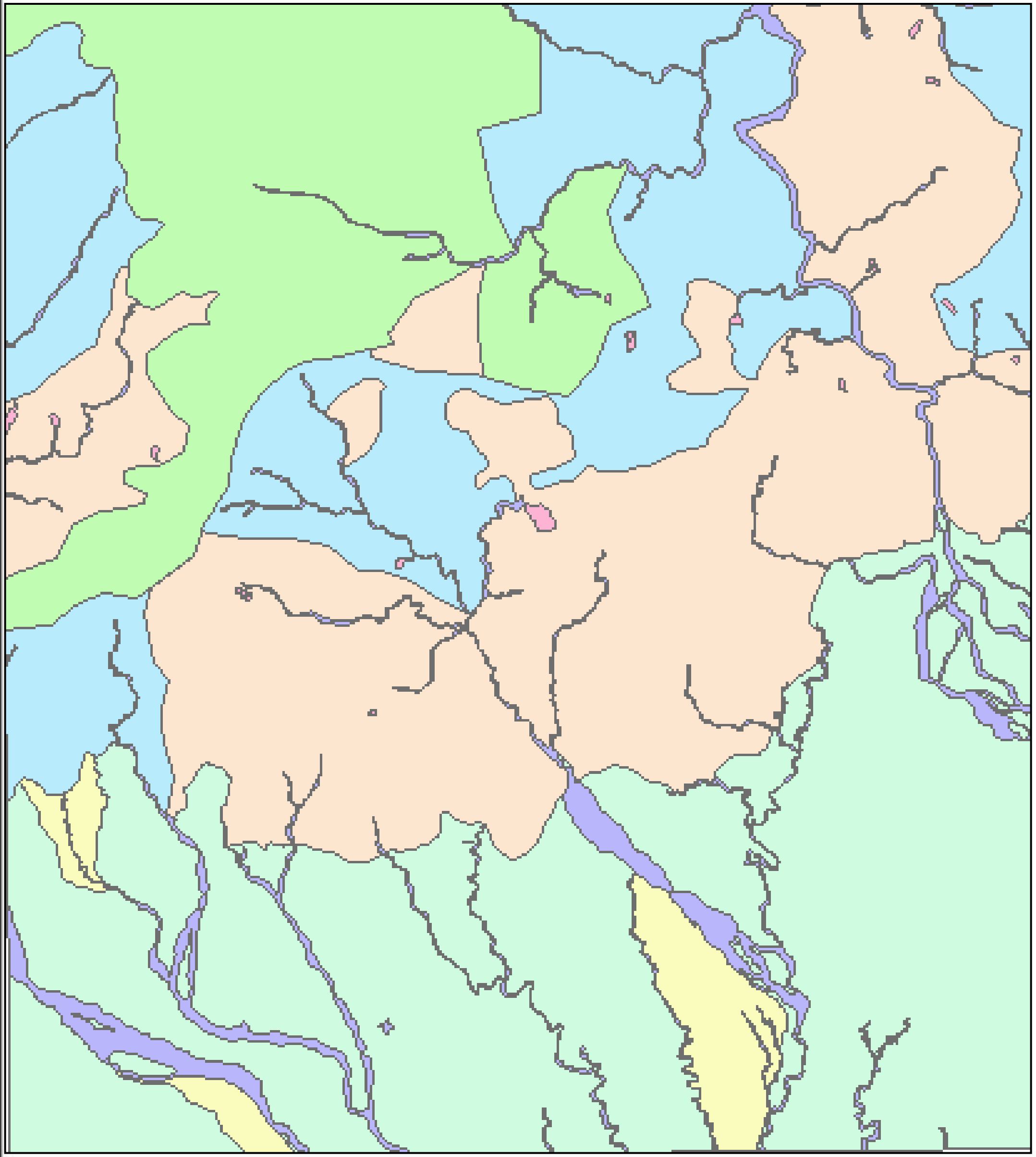
Prepared using Slope, Geomorphology, LU LC, Geology maps as **Proxies**

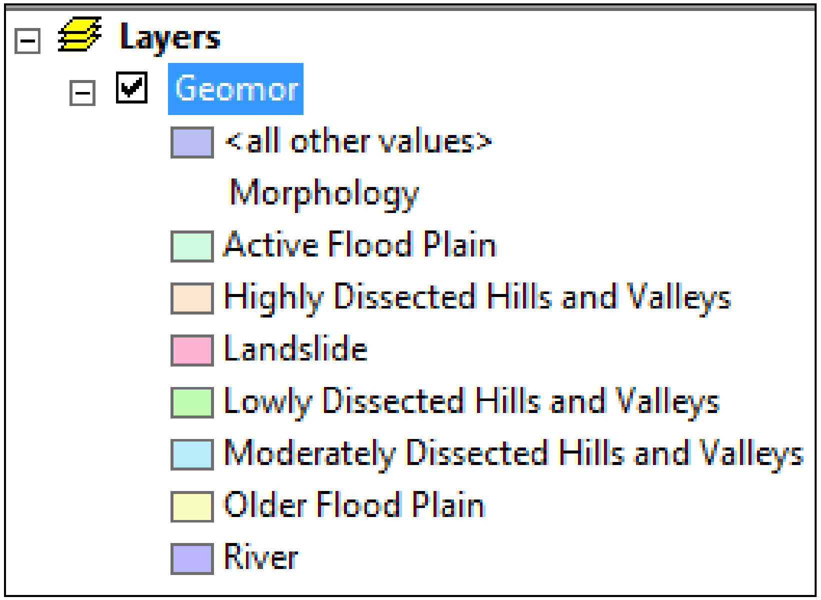
Pre-field Thickness Map

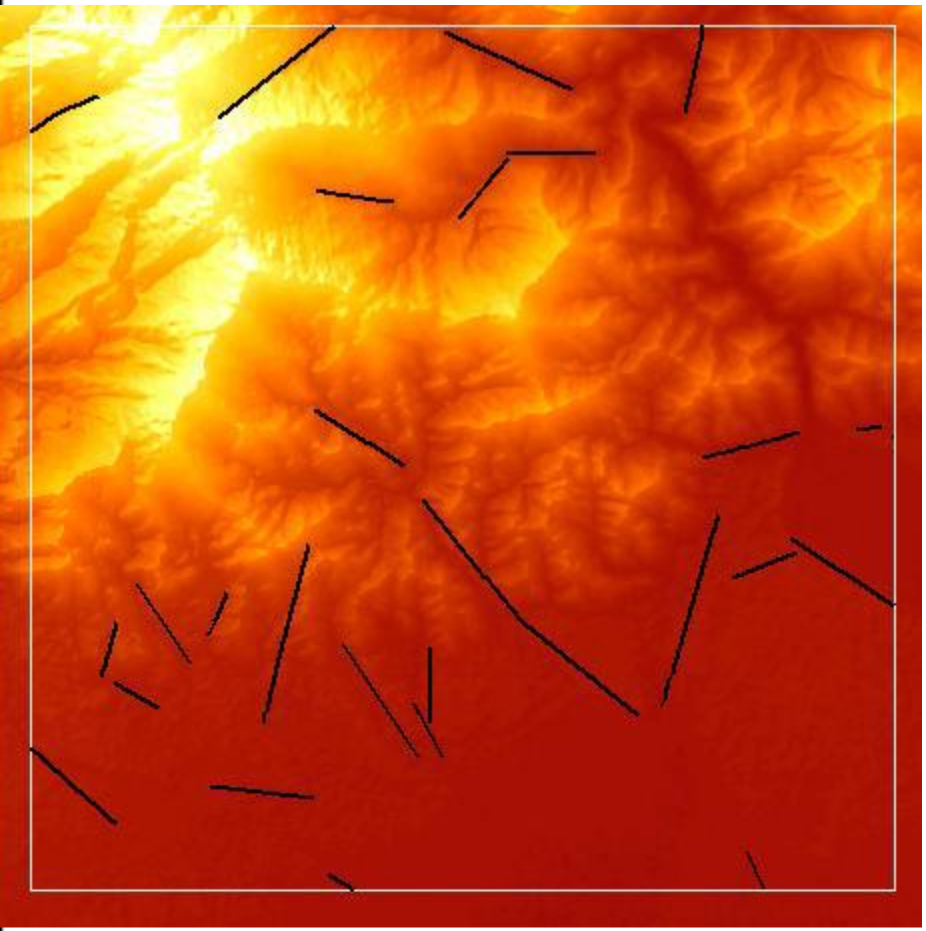


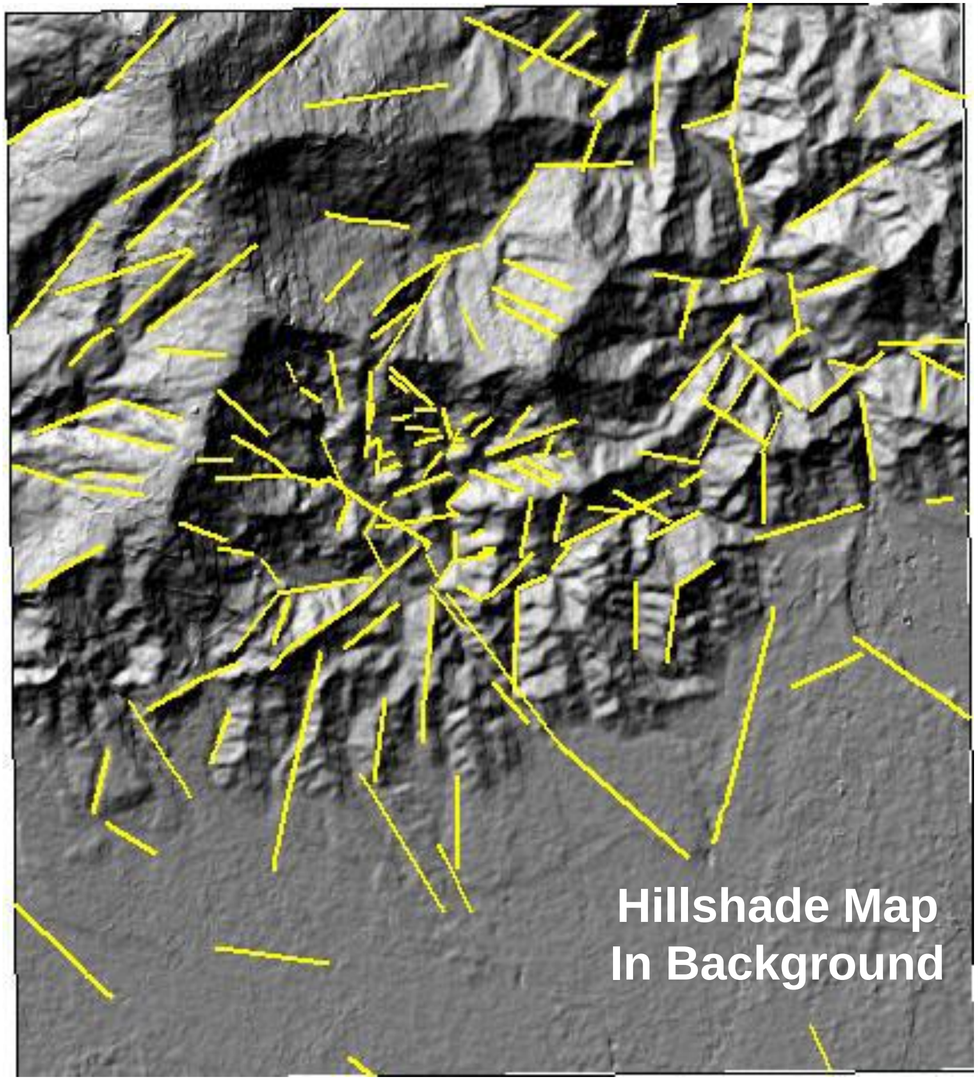


Pre-field Geomorphology Map



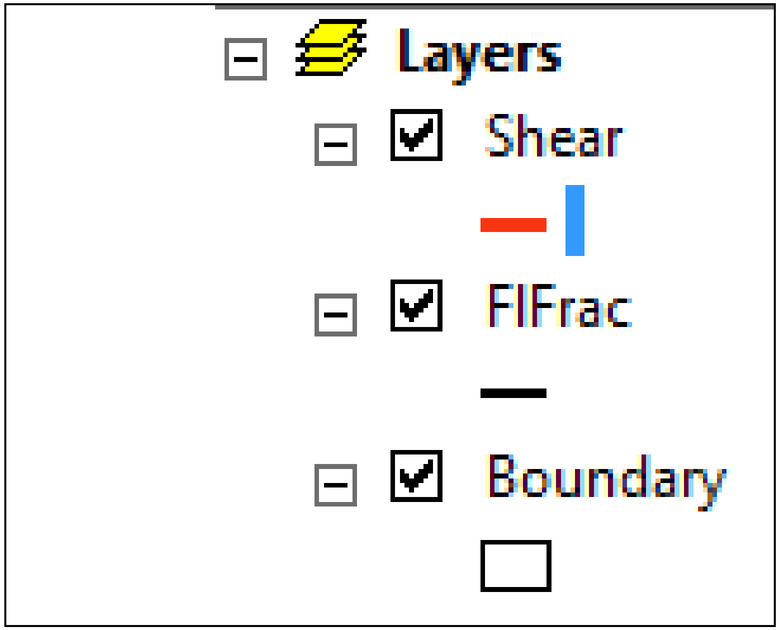






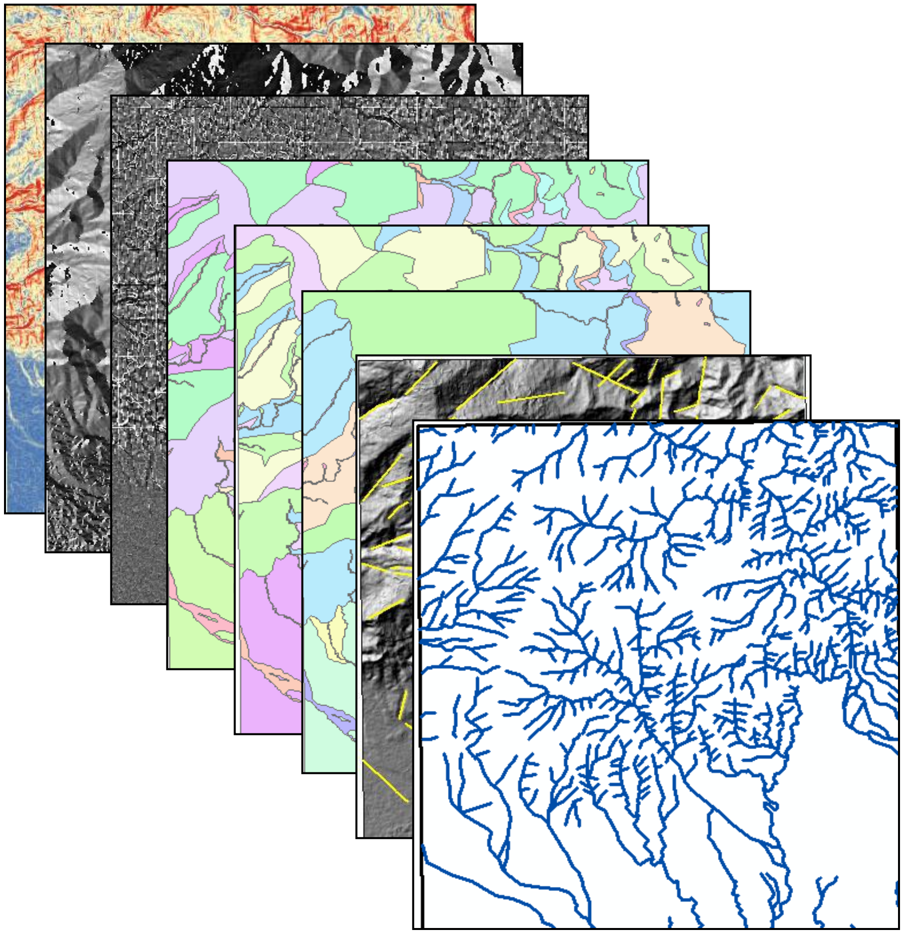
Updating Fault/ Fracture Map

Updated Fault/ Fracture Map

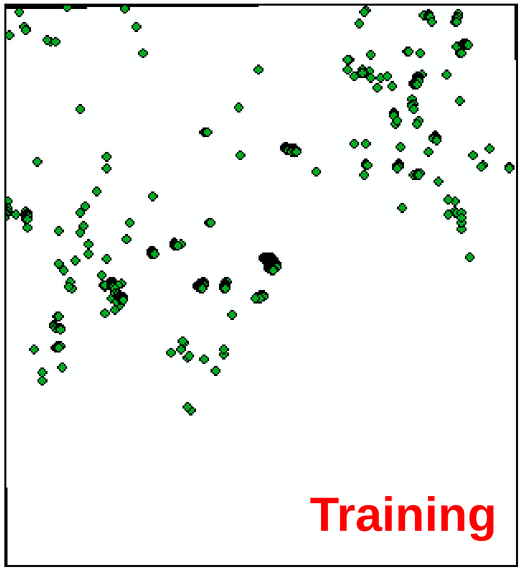


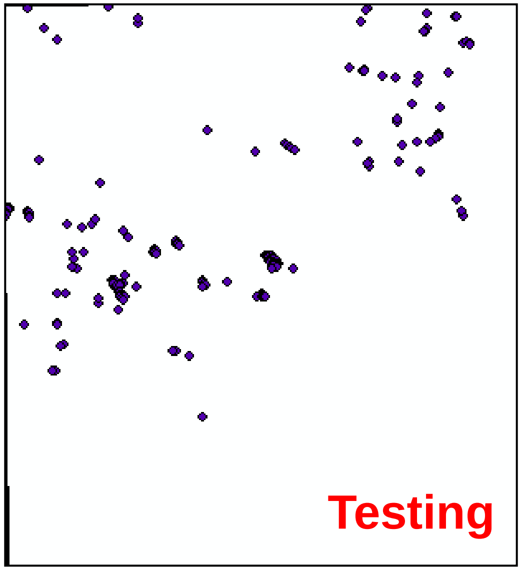
Geofactor & Landslide Spatial Database

Geofactor Spatial Database



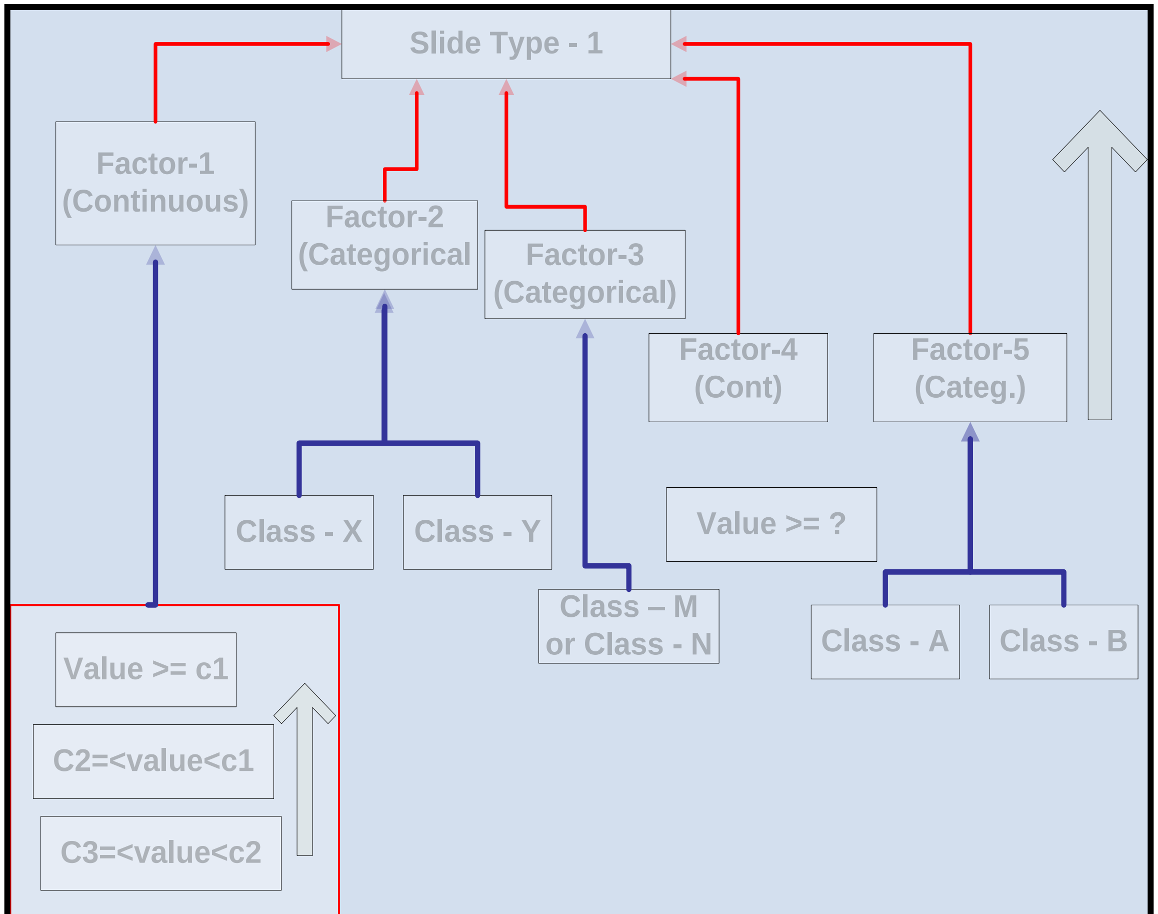
Landslide Spatial Database

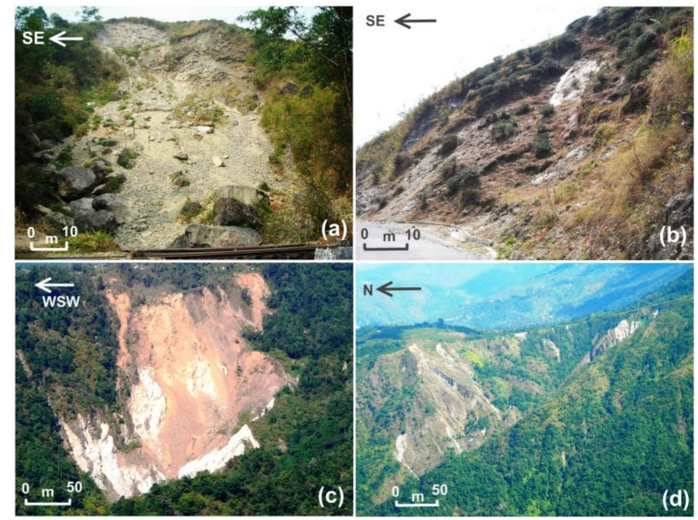


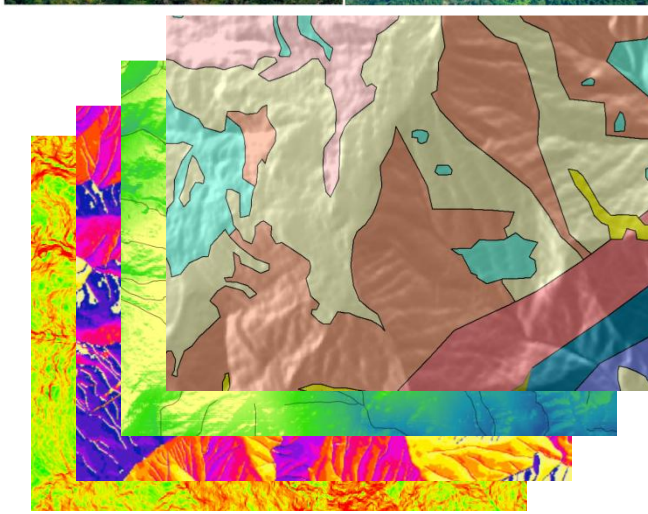


III. Determination of Rating & Weights

Conceptual Model

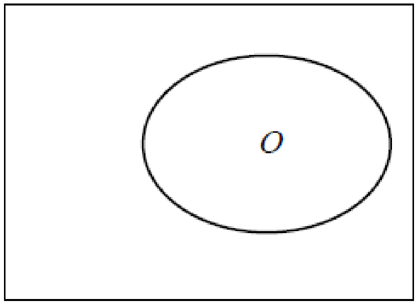




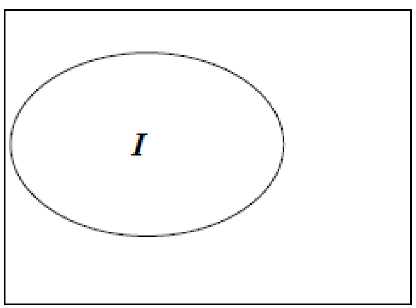


Yule's Co-efficient

(Yule, 1912; Fleiss, 1991; Bonham-Carter, 1994)

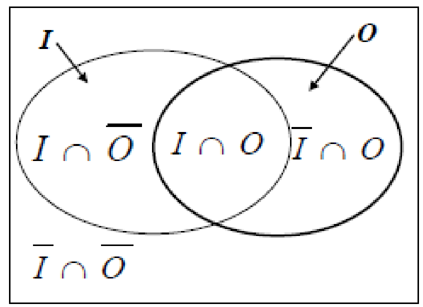


$T = 2945$; $O = 727$



$T = 2945$; $I = 486$

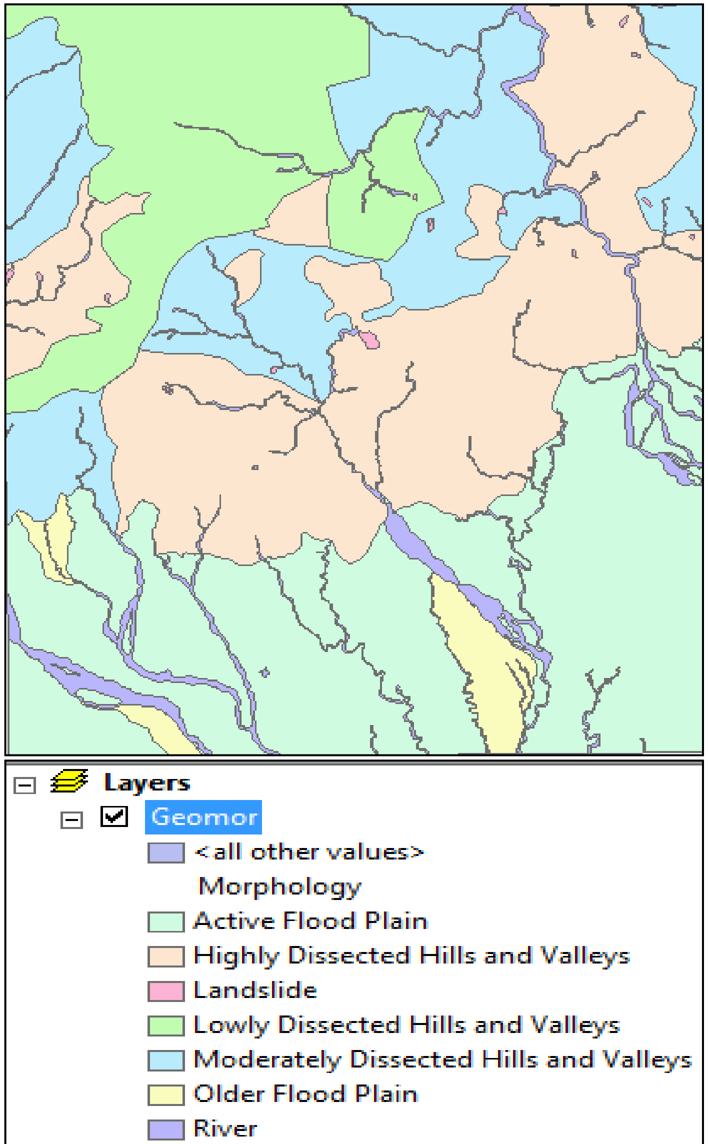
- O = known geo-object of interest
- I = indicator (or evidence) pattern
- T = study area



$$I \cap O = T_{11} = 345$$
$$I \cap \overline{O} = T_{21} = 141$$
$$\overline{I} \cap O = T_{12} = 382$$
$$\overline{I} \cap \overline{O} = T_{22} = 2077$$

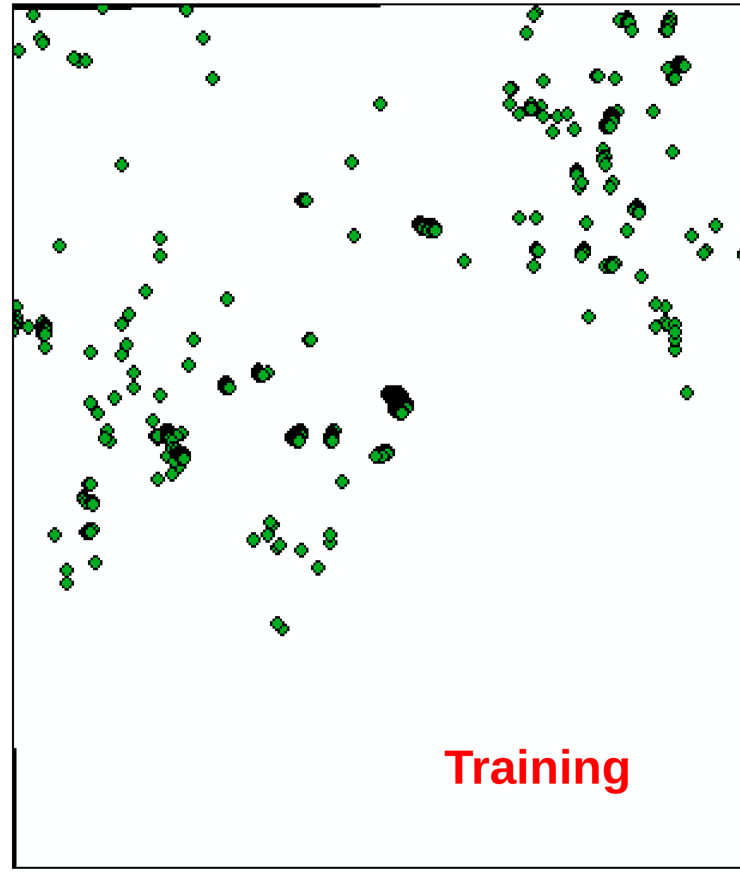
- T_{11} → derived from cross operation
- $T_{12} = O - T_{11}$
- $T_{21} = I - T_{11}$
- $T_{22} = T - T_{11} - T_{12} - T_{21}$

Note: an example of I is a slope aspect class



$\cap$

Overlay



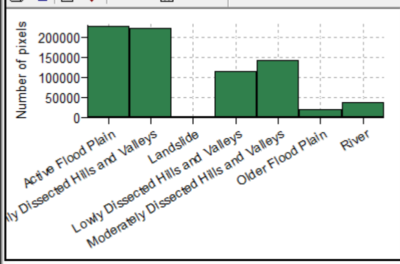
Which Geomorphology classes have positive spatial association with landslides

Analysis Table

Histogram Table of Geomorphology Theme (NpixC)

Histogram "Geomorphology" - TableHistogram(Geomorphology.mpr) - ILWIS

File Edit Columns Records View Help



	npix	npixpct	pctnotund	Area
Active Flood Plain	227078	28.98	29.71	204370200
Highly Dissected Hills and Valleys	222887	28.44	29.16	200598300
Landslide	905	0.12	0.12	814500
Lowly Dissected Hills and Valleys	115470	14.74	15.11	103923000
Moderately Dissected Hills and Valleys	141876	18.11	18.56	127688400
Older Flood Plain	18936	2.42	2.48	17042400
River	37129	4.74	4.86	33416100
Min	905	0.12	0.12	814500
Max	227078	28.98	29.71	204370200
Avg	109183	13.94	14.29	98264700
StD	93983	11.99	12.29	84584531
Sum	764281	97.55	100.00	687852900

Cross Table of Geomorphology and Training Landslide Data (T11)

Dependent Table "GeomXLS" - TableCross(Geomorphology.mpr,LS.mpr,IgnoreUndefs) - ILWIS

File Edit Columns Records View Help

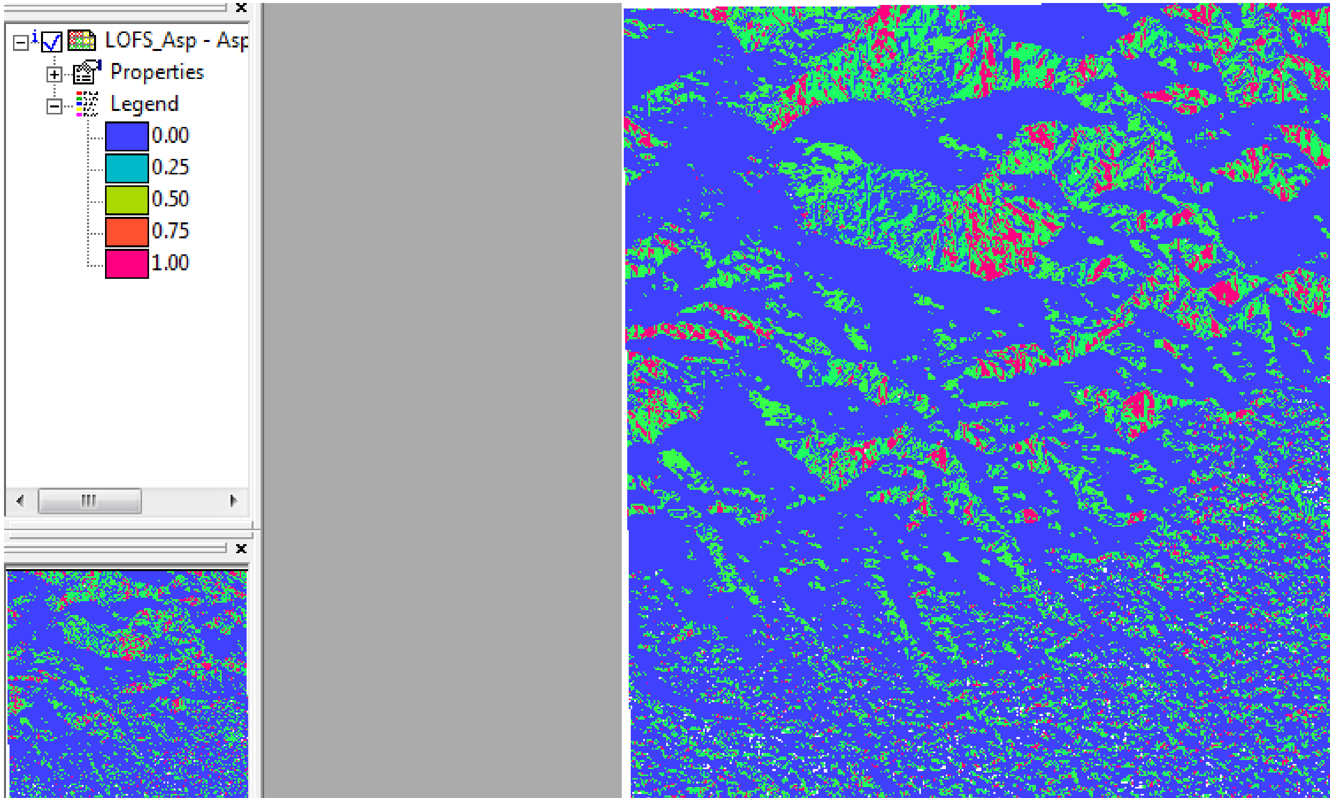
	Geomorphology	LS	NPix	Area
Active Flood Plain * Slide	Active Flood	Slide	27	24300
Highly Dissected Hills and Valleys *	Highly Dissec	Slide	3170	2853000
Landslide * Slide	Landslide	Slide	29	26100
Lowly Dissected Hills and Valleys * S	Lowly Dissect	Slide	1716	1544400
Moderately Dissected Hills and Valley	Moderately Di	Slide	2574	2316600
Older Flood Plain * Slide	Older Flood P	Slide	5	4500
River * Slide	River	Slide	266	239400

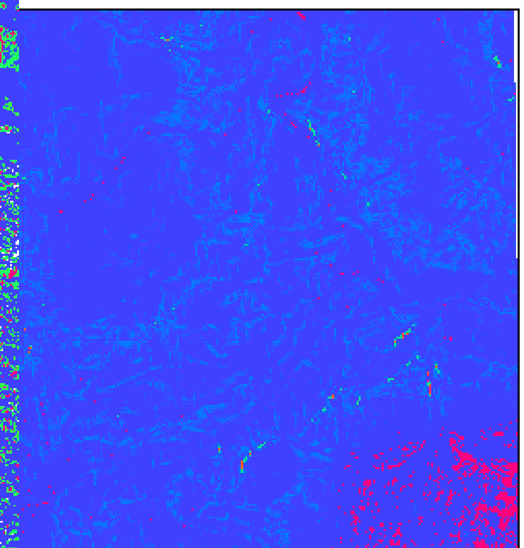
T12 = NpixLS – T11 T21 = NpixC– T11 T22 = NpixT – T11-T12-T21

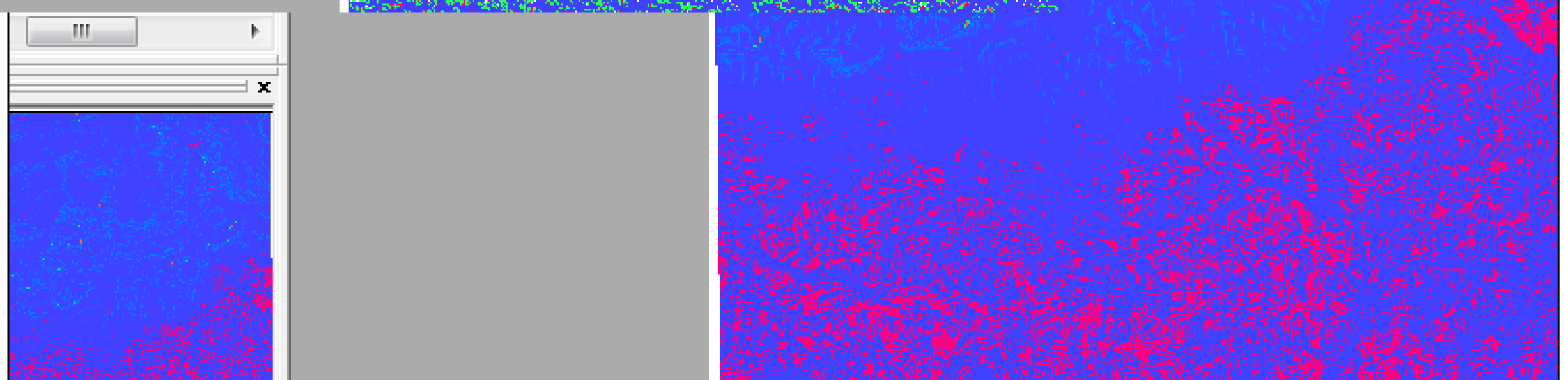
	NpixC	NpixT	T11	T21	NpixLS	T12	T22	Yc	LOFS
Active Flood Plain	227078	764281	27	227051	7787	7760	529443	-0.835	0.00
Highly Dissected Hills and Val	222887	764281	3170	219717	7787	4617	536777	0.129	0.45
Landslide	905	764281	29	876	7787	7758	755618	0.285	1.00
Lowly Dissected Hills and Val	115470	764281	1716	113754	7787	6071	642740	0.117	0.41
Moderately Dissected Hills and	141876	764281	2574	139302	7787	5213	617192	0.193	0.68
Older Flood Plain	18936	764281	5	18931	7787	7782	737563	-0.727	0.00
River	37129	764281	266	36863	7787	7521	719631	-0.092	0.00
Min	905	764281	5	876	7787	4617	529443	-0.835	0.00
Max	227078	764281	3170	227051	7787	7782	755618	0.285	1.00
Avg	109183	764281	1112	108071	7787	6675	648423	-0.133	0.36
StD	93983	0	1356	93217	0	1356	93217	0.458	0.39
Sum	764281	5349967	7787	756494	54509	46722	4538964	-0.931	2.54

Yc = (SQRT(T11/T21)-SQRT(T12/T22))/(SQRT(T11/T21)+SQRT(T12/T22))

LOFS Maps







Inter-predictor Weights

	A	B	C	D	E	F
1	Theme	MinYC/MinDiff	Max YC/ MaX Diff	Index	Weight	IntWt
2	Material	-0.831	0.461	1.292	1.0	10
3	Geom	-0.835	0.285	1.12	0.9	9
4	Slope	0	0.35	0.35	0.3	3
5	Aspect	-0.087	0.132	0.219	0.2	2
6	Depth	-0.824	0.247	1.071	0.8	8
7	Curvature	-0.113	0.201	0.314	0.2	2
8	Dist_Drainage	0	0.23	0.23	0.2	2
9	Dist_Shear	-0.01	0.19	0.2	0.2	2
10	Dist_Road	0	0.12	0.12	0.1	1
11	Dist_Frac	0	0.09	0.09	0.1	1
12						39

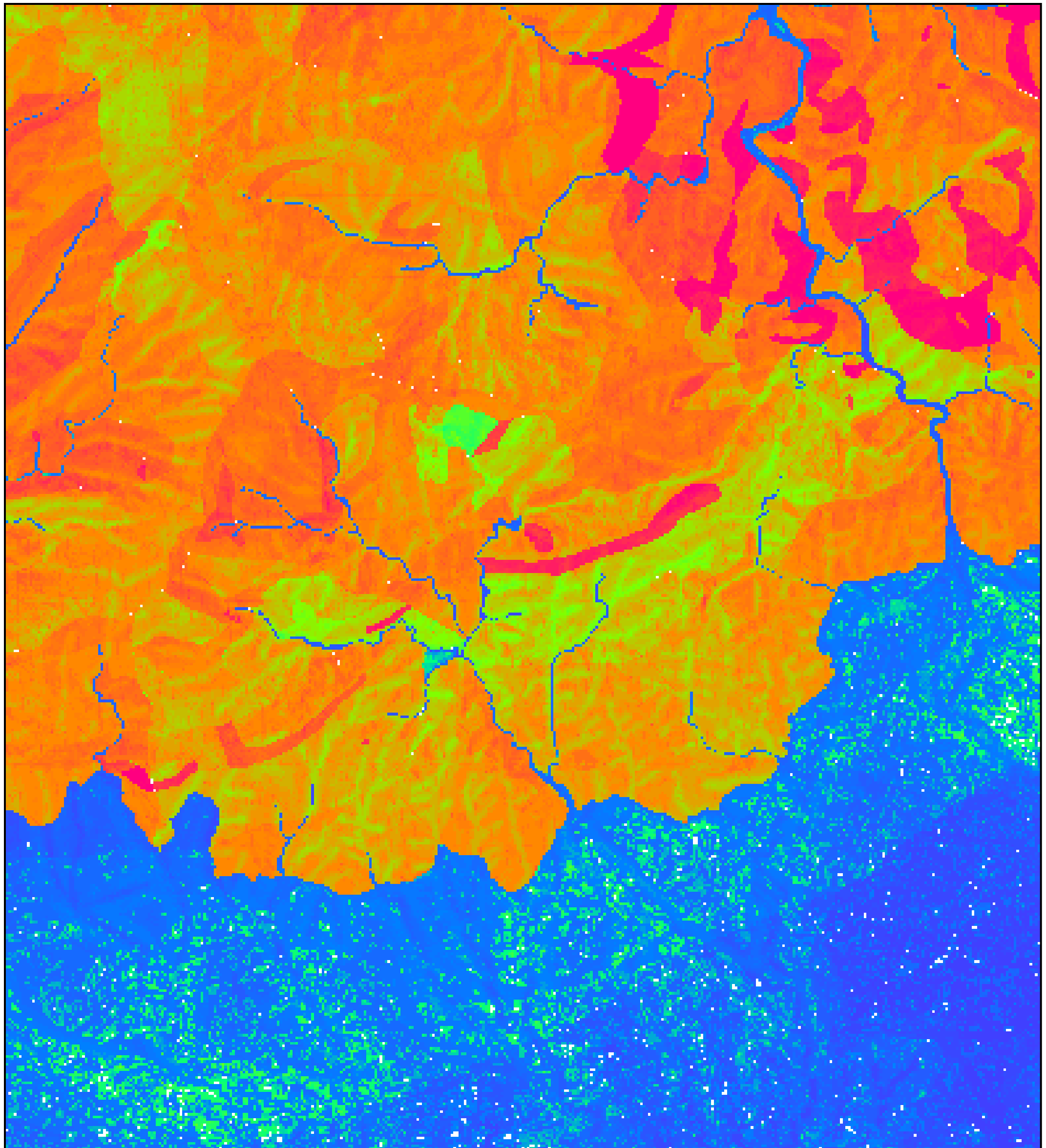
IV. Integration, Validation & Creation of Susceptibility Maps

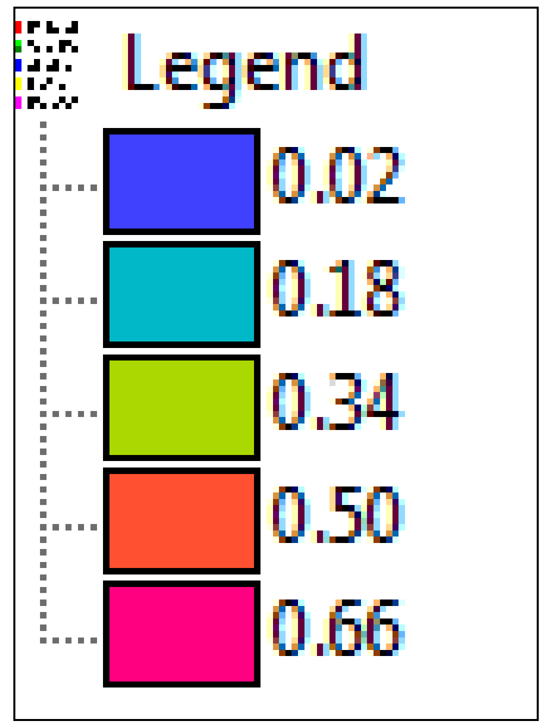
Weighted Multi-class Index Overlay

$$\overline{S} = \sum_i^n (LOFS_{ij} \times W_i) \Big/ \sum_i^n W_i$$

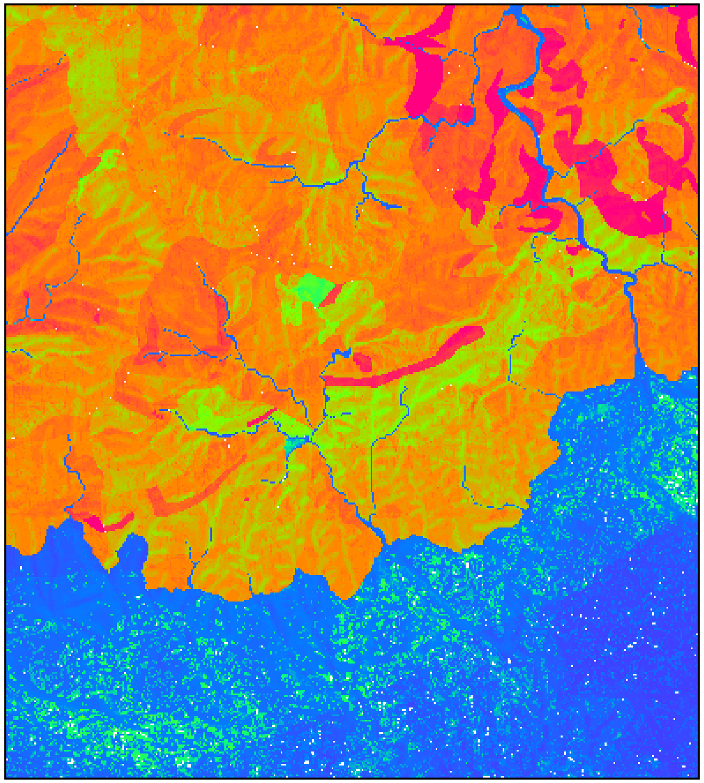
Susc=(10*LOFS_mat+9*LOFS_Geom+3*LOFS_Slope+2*LOFS_Asp+8*LOFS_Depth+2*LOFS_curv+2*LOFS_Dr+2*LOFS_SH+1*LOFS_Rd+1*LOFS_frac)/39

Susceptibility Score Map



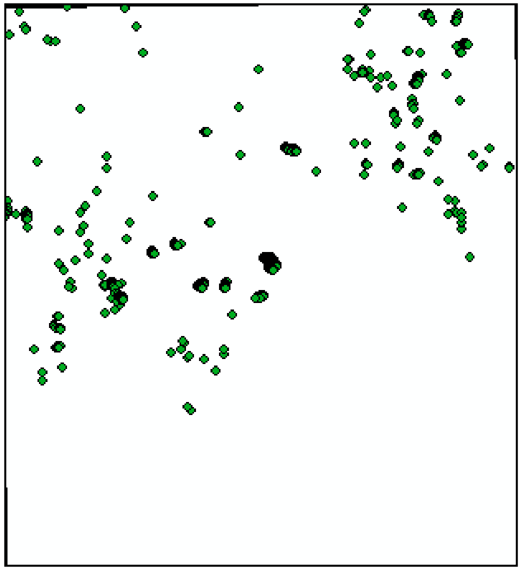


Validation



Susceptibility Score Map

Cross or Overlay



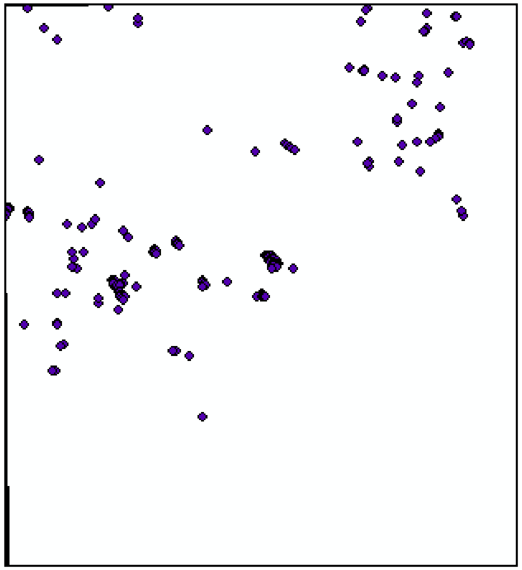


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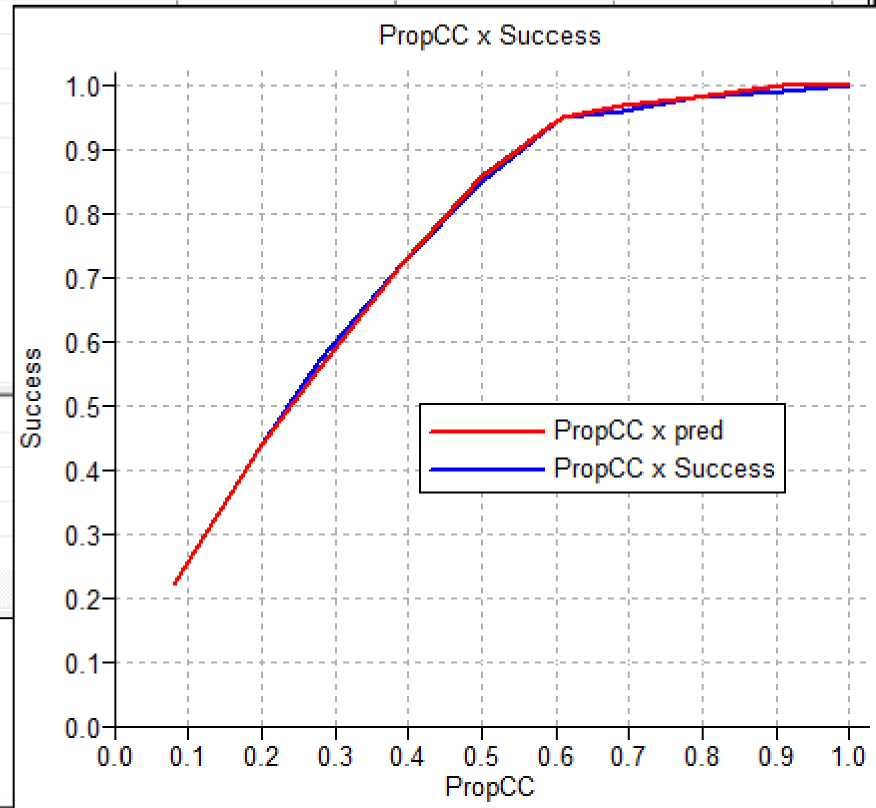
Table "Success" - Susccess Rate & Prediction Rate - ILWIS

File Edit Columns Records View Help

	Susc	npixc	npixcc	npixt	Propcc	npixls	npixlscc	npixs	Success
1	0.85	70876	70876	760000	0.09	1892	1892	7782	0.24
2	0.46	69873	140749	760000	0.19	1364	3256	7782	0.42
3	0.43	70554	211303	760000	0.28	1087	4343	7782	0.56
4	0.41	86070	297373	760000	0.39	1262	5605	7782	0.72
5	0.39	82956	380329	760000	0.50				
6	0.37	72246	452575	760000	0.60				
7	0.34	78646	531221	760000	0.70				
8	0.15	60801	592022	760000	0.78				
9	0.12	89599	681621	760000	0.90				
10	0.08	78379	760000	760000	1.00				
Min		60801	70876	760000	0.09				
Max		89599	760000	760000	1.00				
Avg		76000	411807	760000	0.54				
StD		8730	232482	0	0.31				
Sum		760000	4118069	7600000	5.43				



Success & Prediction Rate Curves
(Chung & Fabbri, 1999)

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Geological Survey of India

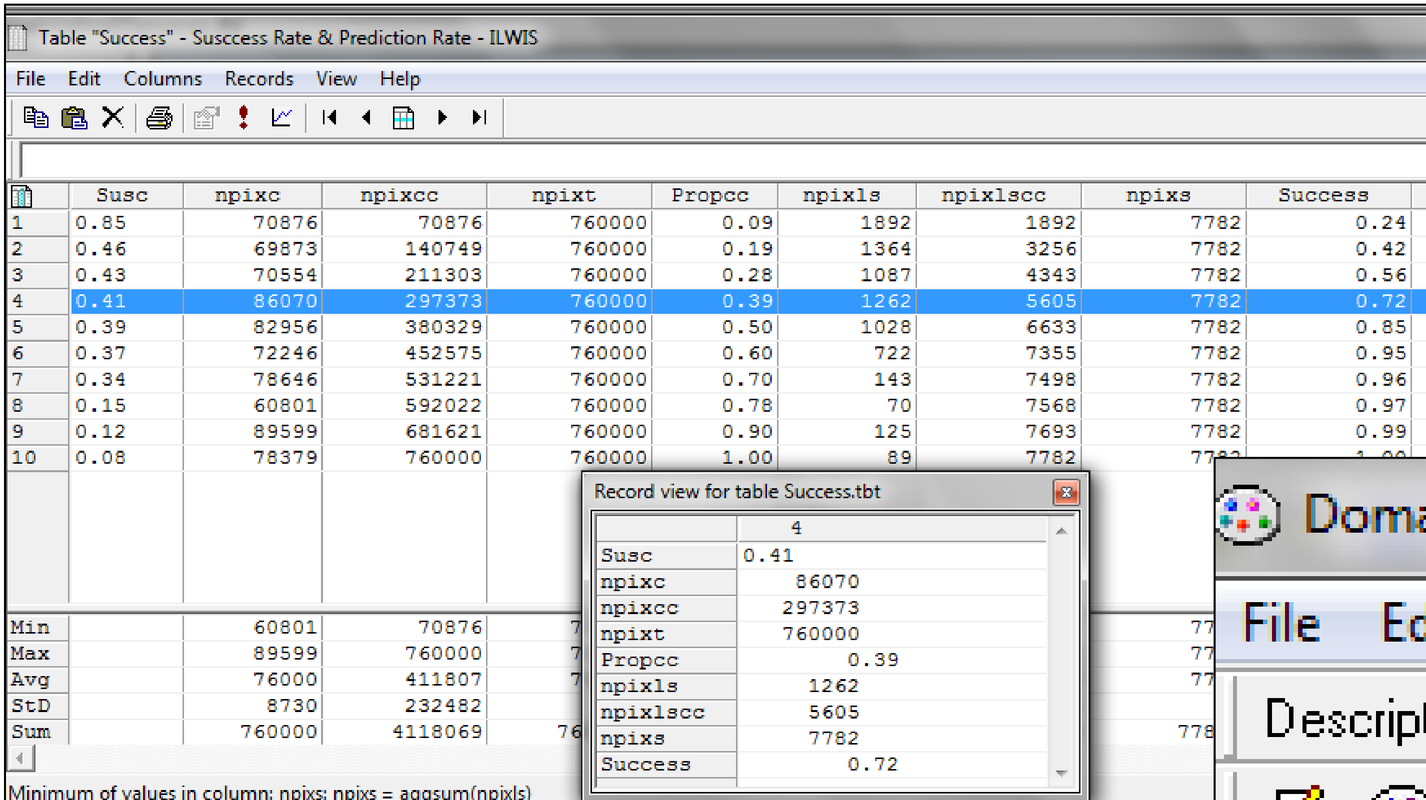


Table "Success" - Suscess Rate & Prediction Rate - ILWIS

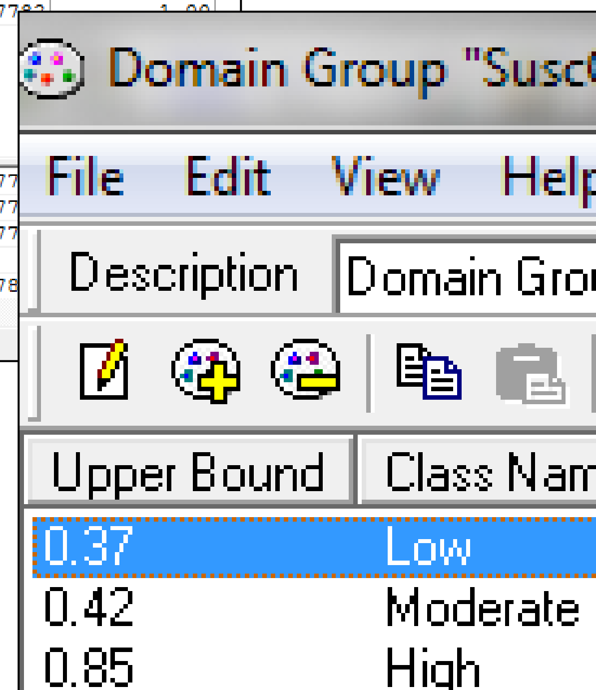
	Susc	npixc	npixcc	npixt	Propcc	npixls	npixlscc	npixs	Success
1	0.85	70876	70876	760000	0.09	1892	1892	7782	0.24
2	0.46	69873	140749	760000	0.19	1364	3256	7782	0.42
3	0.43	70554	211303	760000	0.28	1087	4343	7782	0.56
4	0.41	86070	297373	760000	0.39	1262	5605	7782	0.72
5	0.39	82956	380329	760000	0.50	1028	6633	7782	0.85
6	0.37	72246	452575	760000	0.60	722	7355	7782	0.95
7	0.34	78646	531221	760000	0.70	143	7498	7782	0.96
8	0.15	60801	592022	760000	0.78	70	7568	7782	0.97
9	0.12	89599	681621	760000	0.90	125	7693	7782	0.99
10	0.08	78379	760000	760000	1.00	89	7782	[illegible]	[illegible]
Min		60801	70876	[illegible]				[illegible]	
Max		89599	760000	[illegible]				[illegible]	
Avg		76000	411807	[illegible]				[illegible]	
StD		8730	232482						
Sum		760000	4118069	[illegible]				[illegible]	

Minimum of values in column: npixs: npixs = aggsum(npixls)

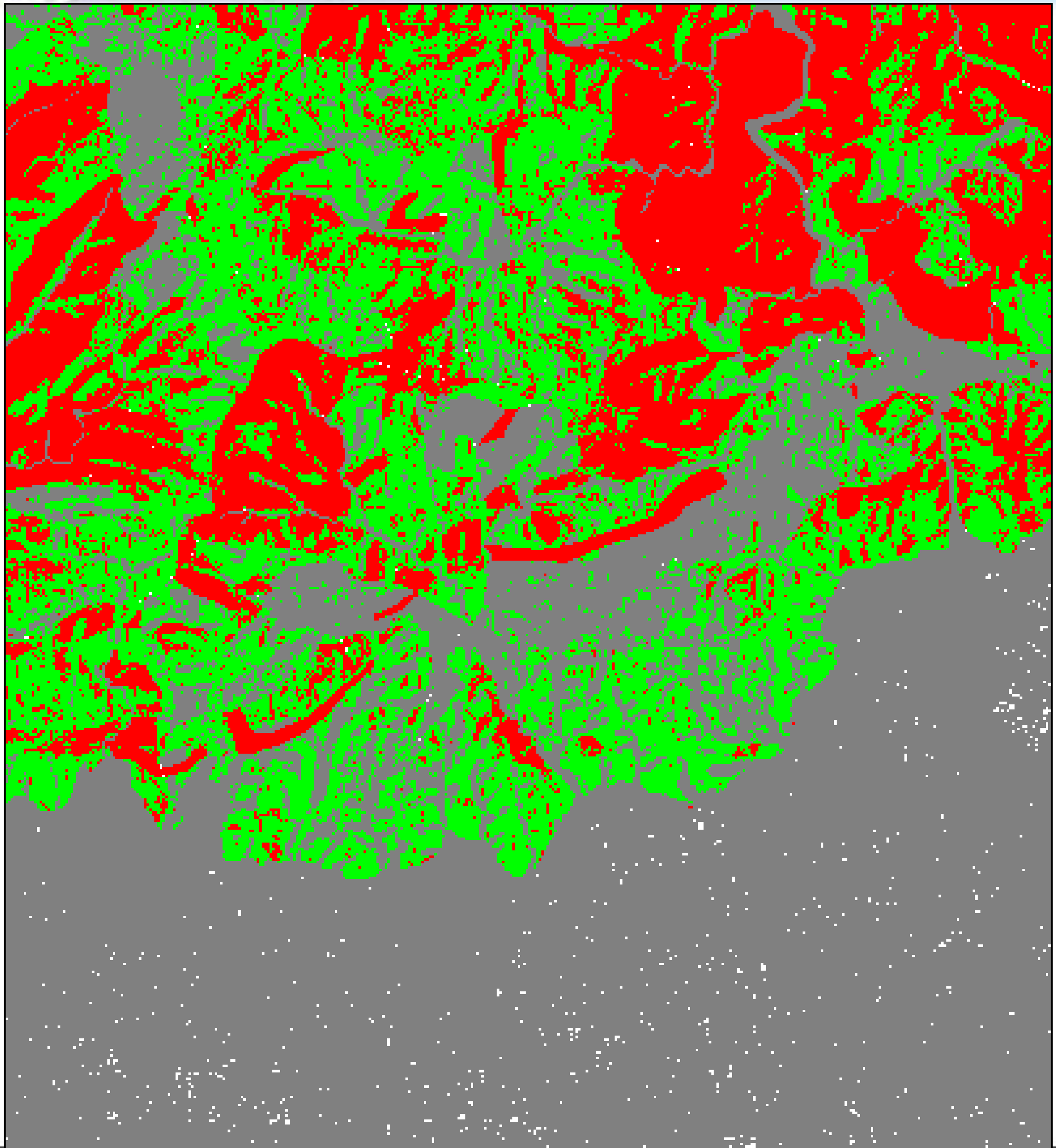
Record view for table Success.tbt

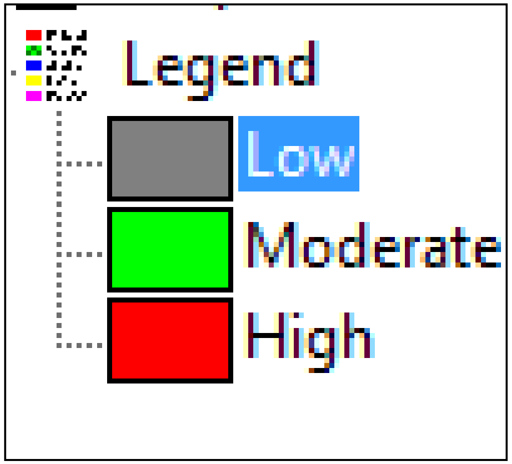
	4
Susc	0.41
npixc	86070
npixcc	297373
npixt	760000
Propcc	0.39
npixls	1262
npixlscc	5605
npixs	7782
Success	0.72

Classification to prepare qualitative landslide susceptibility map



Final landslide susceptibility map





Landslide hazard

- According to Varnes (1984) & UNESCO's IAEG Commission on landslides and other mass movements and Guzzetti (1999), "landslide hazard" is defined as the **probability of occurrence of a damaging landslide of a certain magnitude in a given area and in a given period of time.**
- Therefore, landslide hazard in a given area is a function of three parameters, namely, **spatial**, **temporal** and **magnitude** probabilities of landslide occurrence.

Landslide hazard Analysis

- **Spatial Prediction**: **Where** will a landslide occur ???
- **Temporal Prediction**: **When** or **How often** will it occur ???
- **Magnitude Prediction**: **How large** or how big that landslide/ the landslide event could be ???

Landslide Susceptibility Analysis/ Mapping (LSA/ LSM)

- **To predict/ determine the spatial locations of future landslides… a pre-requisite for hazard analysis**

Regional landslide hazard mitigation: A Way Forward

- **Identify the most appropriate geofactors for multi-scale landslide susceptibility analysis**
- **Identify landslide susceptibility scenarios based on landslide failure mechanisms, magnitudes and triggers.**
- **Developing methodologies to convert landslide susceptibility maps into true hazard and risk maps in a data-scarce environment.**
- **Developing Regional Early Warning System (EWS) for landslide hazards using InSAR and through threshold modeling of climatic triggers**
- **Quantifying the effect and extent of landslide susceptibility owing to rapid land use changes.**

Site-specific landslide hazard mitigation: A Way Forward

- Deterministic slope stability modeling aiming at to model variable hydrologic situations
- Long-term instrument-aided monitoring and development of thresholds
- Designing relevant retaining structures based on different slope stability conditions and scenarios
- Rockfall stability modeling and designing the relevant rockfall retaining structures


THANK YOU