



Never Stand Still

# Relevance of morphometric predictors and completeness of inventories in earthquake-induced landslide susceptibility

School of Civil and Environmental Engineering

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# Background

- The Gorkha Earthquake 2015 event triggered thousands of landslides in the central Nepal Himalayas.

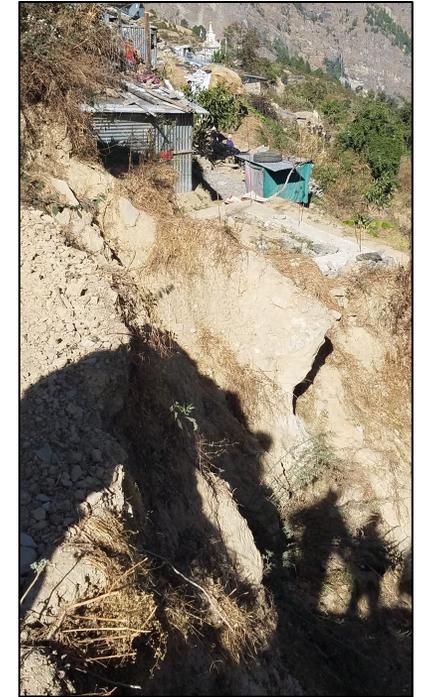
Mainshock: April 25, 2015 (7.8)

Biggest aftershock: May 12, 2015 (7.3)

- Nearly 25, 000 landslides were reported by different researchers.
- 14 out of 77 districts were severely affected.



# Landslides in Sindhupalchowk and Rasuwa districts



# Landslide Risk Management $\equiv$ Landslide susceptibility, hazard and risk zoning

*Shano et al., 2020; Australian Geomechanics Society Landslide Zoning Working Group, 2007*

Landslide susceptibility, therefore, is defined as the chance of occurrence of landslide in a geographic location for a given set of environmental factors.

Landslide Hazard is defined as:

$$H(v,t) = T(v,t)U(v,t)S(v,t)$$

where,

$v$  = set of environmental conditions or landslide causative factors

$t$  = time.

$T(v,t)$  = Time dependence (e.g. frequency)

$U(v,t)$  = the measure of landslide magnitude

$S(v,t)$  = landslide susceptibility .

# Roback and others (2017)

Map data of landslides triggered by the 25 April 2015 Mw 7.8 Gorkha, Nepal earthquake

## Geomorphic and geologic controls of geohazards induced by Nepal's 2015 Gorkha earthquake

J. S. KARGEL, G. J. LEONARD, D. H. SHUGAR, U. K. HARITASHYA, A. BEVINGTON, E. J. FIELDING, K. FUJITA, M. GEERTSEMA, E. S. MILES, [...] N. YOUNG

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SCIENCE • 8 Jan 2016 • Vol 351, Issue 6269 • DOI:10.1126/science.aac8353

## Zhang and others (2016)

Characteristics of landslides in Koshi River Basin, Central Himalaya

Published: 25 October 2016

Landslide susceptibility assessment of the region affected by the 25 April 2015 Gorkha earthquake of Nepal

[Amar Deep Regmi](#) , [Megh Raj Dhital](#), [Jian-qiang Zhang](#), [Li-jun Su](#) & [Xiao-qing Chen](#)

*Journal of Mountain Science* **13**, 1941–1957 (2016) | [Cite this article](#)

508 Accesses | 30 Citations | [Metrics](#)

## Gnyawali and others (2016)

Earthquake Induced Landslides triggered by 25 April 2015 Gorkha Earthquake, Mw 7.8, Nepal

Published: 28 March 2018

Assessment of co-seismic landslide susceptibility using LR and ANCOVA in Barpak region, Nepal

[Suchita Shrestha](#), [Tae-Seob Kang](#) & [Jung Chang Choi](#) 

*Journal of Earth System Science* **127**, Article number: 38 (2018) | [Cite this article](#)

261 Accesses | 10 Citations | [Metrics](#)

Short report | [Open Access](#) | Published: 05 April 2017

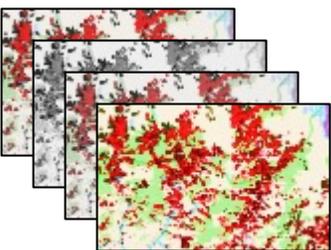
Landslide damage along Araniko highway and Pasang Lhamu highway and regional assessment of landslide hazard related to the Gorkha, Nepal earthquake of 25 April 2015

[Chong Xu](#) , [Yingying Tian](#), [Bengang Zhou](#), [Hongliu Ran](#) & [Gaohu Lyu](#)

*Geoenvironmental Disasters* **4**, Article number: 14 (2017) | [Cite this article](#)

2978 Accesses | 16 Citations | [Metrics](#)

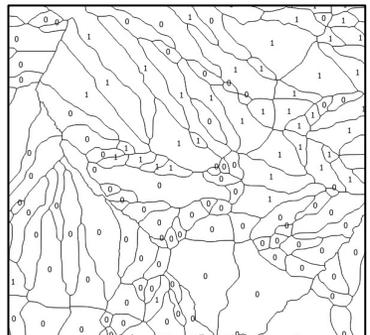
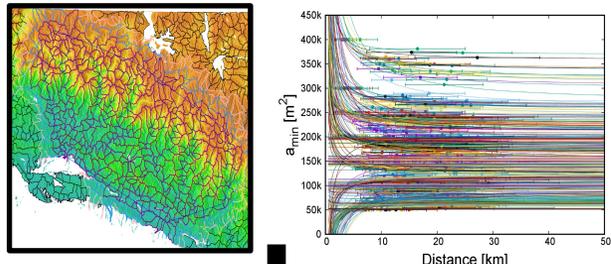
# Methodological framework



Collection of inventories

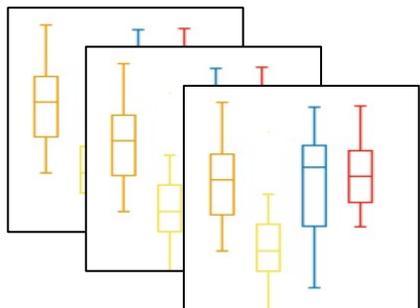
## Delineation of slope units (SU)

*Alvioli et al., 2016, 2020*



Characterization of slope units

## Selection of the causative factors

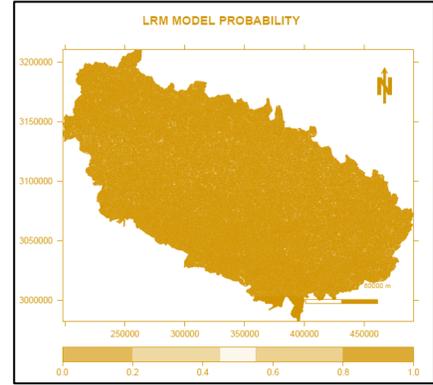
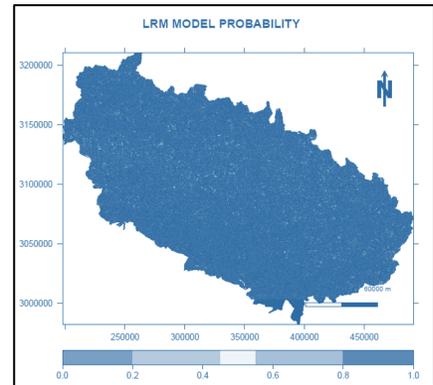


Type	Independent variables	GRASS GIS module/Reference
Dynamic	PGA	
Dynamic	PGV	
Dynamic	MMI	
Static	Slope	r.slope.aspect
Static	Topographic Wetness Index (TWI)	r.topidx
Static	Vector Ruggedness Measure (VRM)	r.vector.ruggedness
Static	Local relief	r.neighbors
Static	Landform classes	r.geomorphon
Static	Plan curvature	r.slope.aspect
Static	Profile curvature	r.slope.aspect

We obtained descriptive statistics and run a  $\chi$ -square test to calculate the p-values for all independent variables in 20 runs.

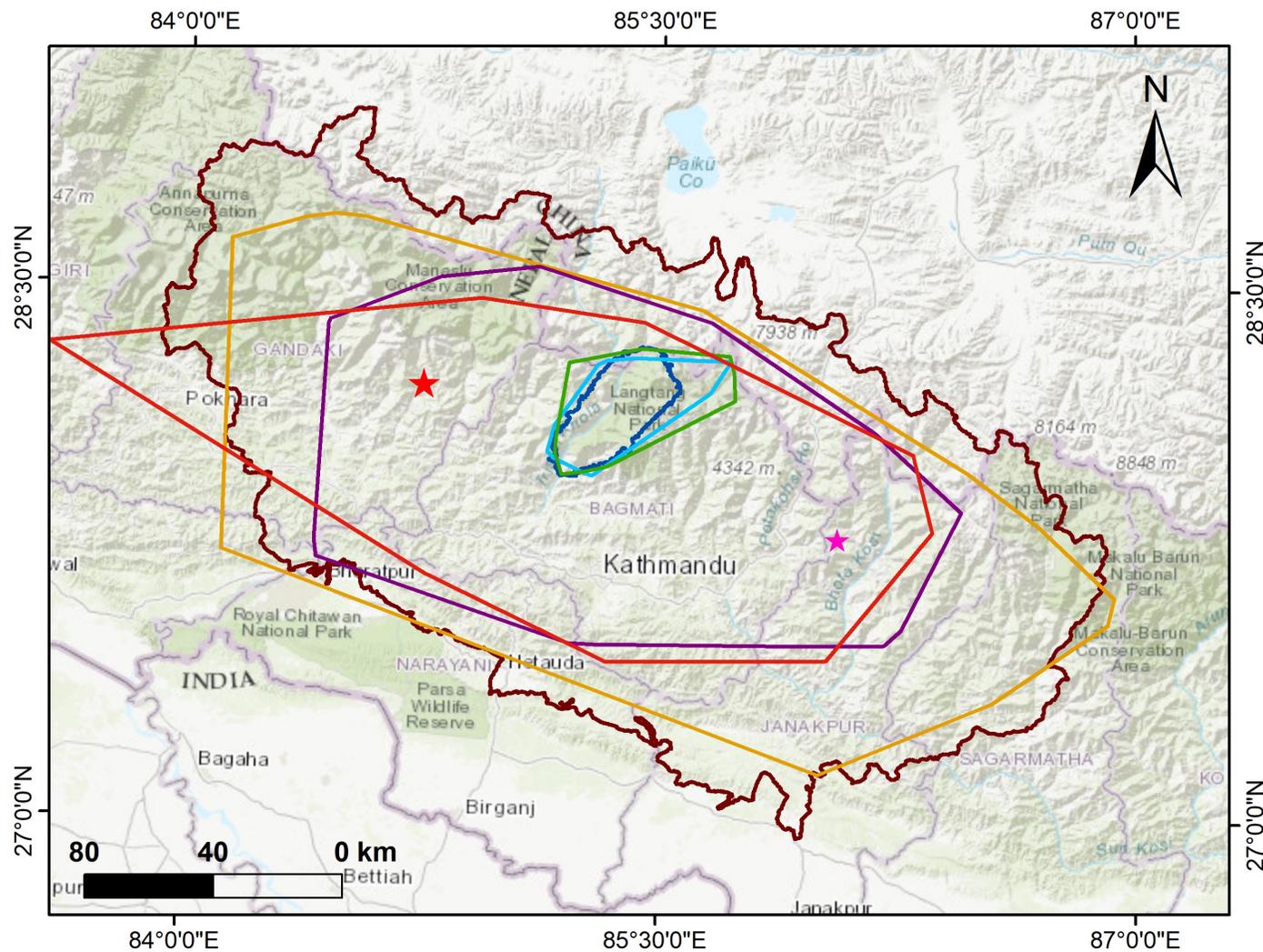
We selected variables that have straightforward interpretation in terms of their effect on landslides.

We run logistic regression in LAND-SE software to obtain Landslide susceptibility maps (LSMs).



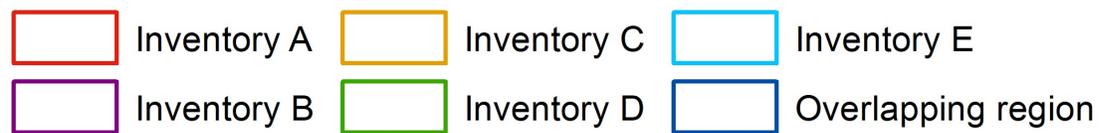
Comparing LSMs





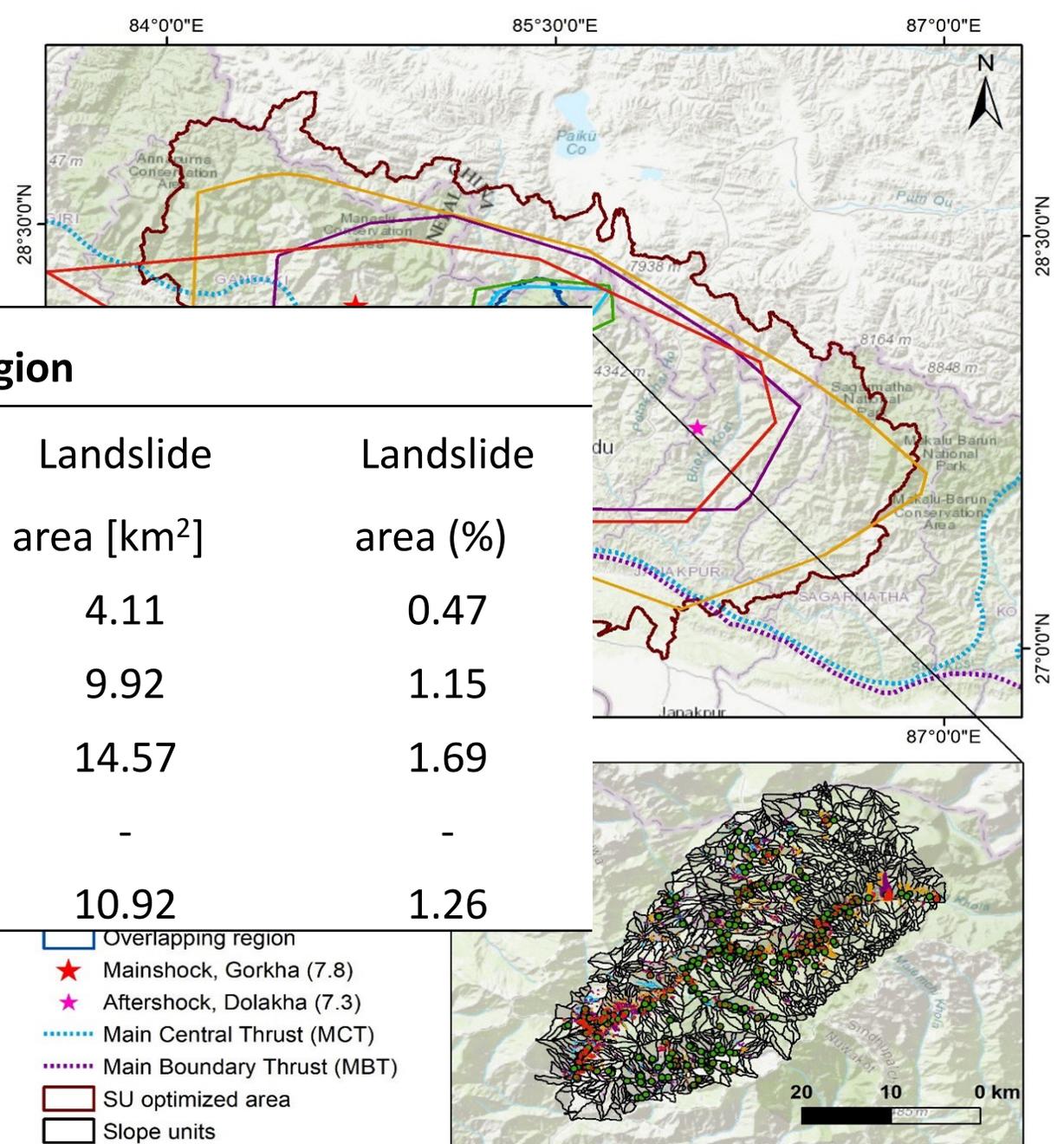
## Published inventories

- Inventory A: 2,645
- Inventory B: 17,638
- Inventory C: 24,915
- Inventory D: 4,312
- Inventory E: 1,416



*Zhang et al., 2016 (A), Gnyawali and Adhikari, 2017 (B), Roback et al., 2017 (C), Kargel et al. (2016), Pokharel and Thapa, 2019 (E)*

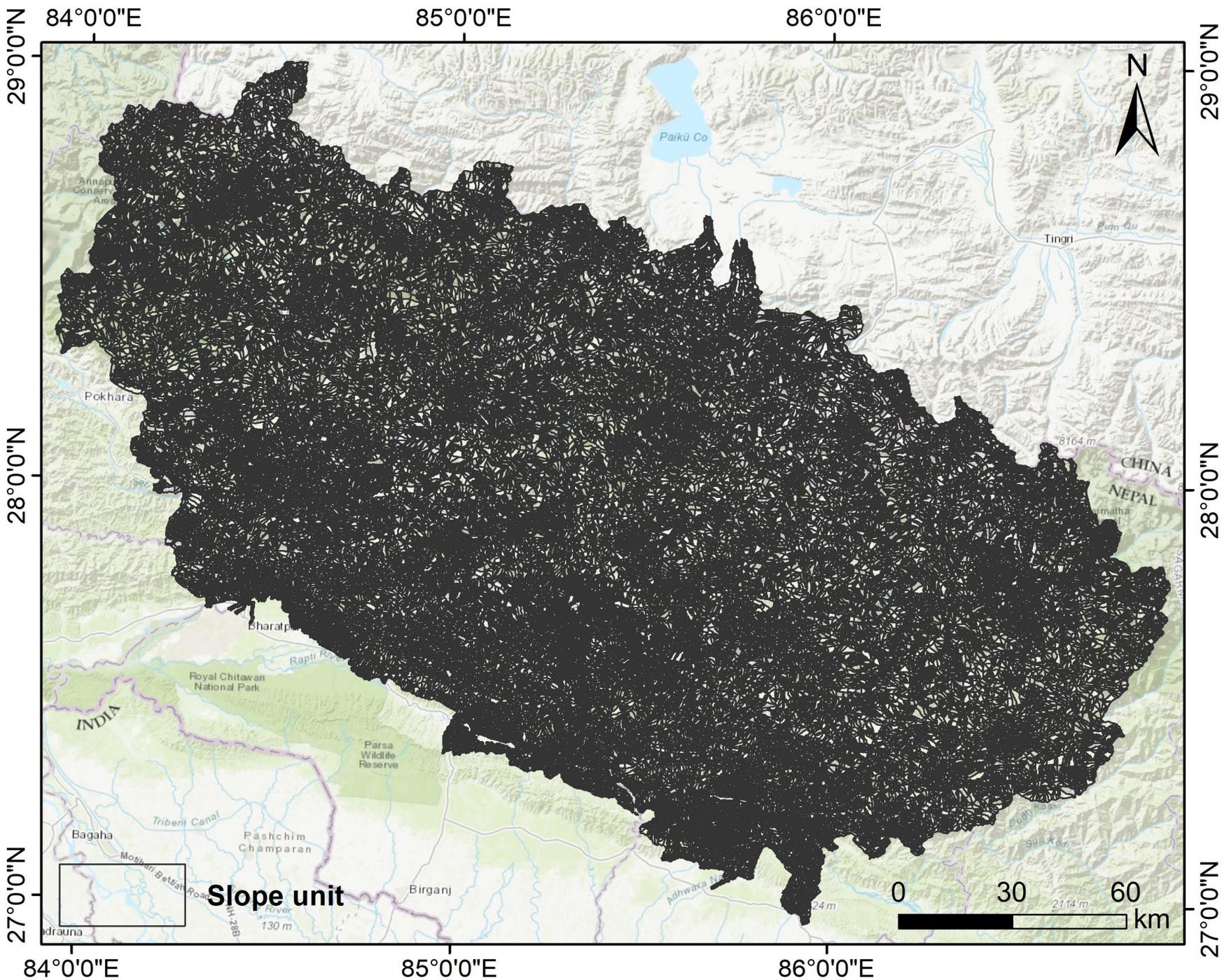
# Comparison of landslide susceptibility maps



## Details of overlapping region

Inventory	Number of Landslides	Number of Unstable SUs	Landslide area [km <sup>2</sup> ]	Landslide area (%)
A	2075	198	4.11	0.47
B	1,780	143	9.92	1.15
C	2,118	132	14.57	1.69
D	371	204	-	-
E	359	74	10.92	1.26

# Slope unit delineation



Total number: 91,947  
Total area area: 35,153.80 sq. km  
Av. Area: 0.38 sq. km

GRASS GIS 7.8.3

GRASS GIS 7.8.3 Layer Manager

GRASS GIS Map Display: 1 - UTM45\_SUs/bigger\_area

GRASS GIS Attribute Table Manager - <aaa\_no\_null@bigger\_area>

1 / Table aaa\_no\_null

Attribute data - right-click to edit/manage records

cat	su_area	presence	slope_aver	slope_stddev	twi_averag	twi_stddev	vrn_averag	vrn_stddev	relief_ave	relief_std	prof_avera	prof_stddev
1	343304.791579	0	11.735307212551	9.42932758182013	6.9829989025384	1.37273999405121	0.004881466603171	0.005728629592533	-0.597534999036108	9.18570156101056	-6.4155138618e-05	0.004850026055391
2	433325.730405	0	20.5766702862474	10.1695218707737	6.69402688650331	1.72363746460545	0.006800783720841	0.005392899511686	-0.832214364119818	13.0211757323682	-0.000974439818531	0.004995028769276
4	234319.462236	0	26.3411727344597	7.18837940192269	6.40239507587358	1.82046749678022	0.00589952602893	0.005523046790883	-3.31822659843555	19.51920412505	-0.000566626830444	0.005310653276242
6	540847.795988	0	15.1353858374745	9.10872527879628	7.08980475144656	1.78179306020884	0.003081659456674	0.00489262212653	0.315890927066236	8.12819870412981	-0.000218474116323	0.003432119160467
7	719526.984799	0	10.8203982021639	8.31276246634027	7.52484302557024	1.56562896627467	0.001456029188707	0.001667029167906	0.06416682281995	7.90542427101357	-0.00023335882825	0.002638689657872
9	1007492.135639	0	17.4541162638788	7.67708155199609	6.96708648628312	1.34657218754215	0.002559865482584	0.002777809035398	2.92690914569429	11.5833728091813	-2.913691862e-05	0.003127001097703
10	1533024.178385	0	25.279381337057	9.7654988527141	6.46168059274379	1.27628677261062	0.00800103146877	0.012451792879393	3.30155013825097	15.9413456866832	-0.000302941106722	0.004942681625435
11	307472.848309	0	4.73910591721849	2.29629349157192	7.25955874838837	1.73629808389782	0.001562300283652	0.001511511891182	-0.53123085853379	2.8949457824468	-8.7647235299e-05	0.002335610894879
12	974980.016799	0	21.5539831011384	7.52538641555606	6.80417422695632	1.34600203867008	0.003560894816594	0.006362382232093	5.73186749229907	18.9414149260301	-0.000154930850113	0.00313159241982
13	142257.246896	0	7.19729624376741	3.90093687520475	7.16109660508399	1.2916634845234	0.001942669192373	0.003502523705	-1.81084185767068	7.38204142273223	-5.7854424958e-05	0.003053934377819
14	131872.461053	0	14.8587216298032	9.54651428869778	7.18964667027883	1.52567316542992	0.007506402242816	0.007086037988943	-3.22484905120677	9.80252334085596	-0.000955655431499	0.005249972669575
16	224742.312116	0	12.873477944796	8.41853423028131	6.2138965848869	1.30788060138194	0.008732430366748	0.011324613975836	-0.540516530030381	11.936101177154	0.000853624571615	0.005413318125428
17	359783.442243	0	23.3946018064186	9.28069590999811	6.54666292549074	1.35537427628278	0.006887882933887	0.014525571778444	2.83911181740405	13.3352483841316	-0.000444923588164	0.005752930861608
18	434010.577372	0	7.85245555865901	4.93750052348704	7.21152403929534	1.2518341314191	0.001979609681957	0.002451126464288	0.29464560161793	5.11635435840535	3.3416328589e-05	0.003406039243975
19	141508.901363	0	20.9744431422307	5.31399246362865	6.63796607359413	1.51013432639258	0.005227258342901	0.003984086297034	-0.995108387855278	11.77591018591	-0.000145933902981	0.003291188538031

SQL Query

Simple Builder

cat =

GRASS GIS: <https://grass.osgeo.org/documentation/>

# Significance independent factors

*How we trained the LR model?*

Check for the smallest number between stable and unstable SUs among all inventories

74 unstable SUs (Inventory E)

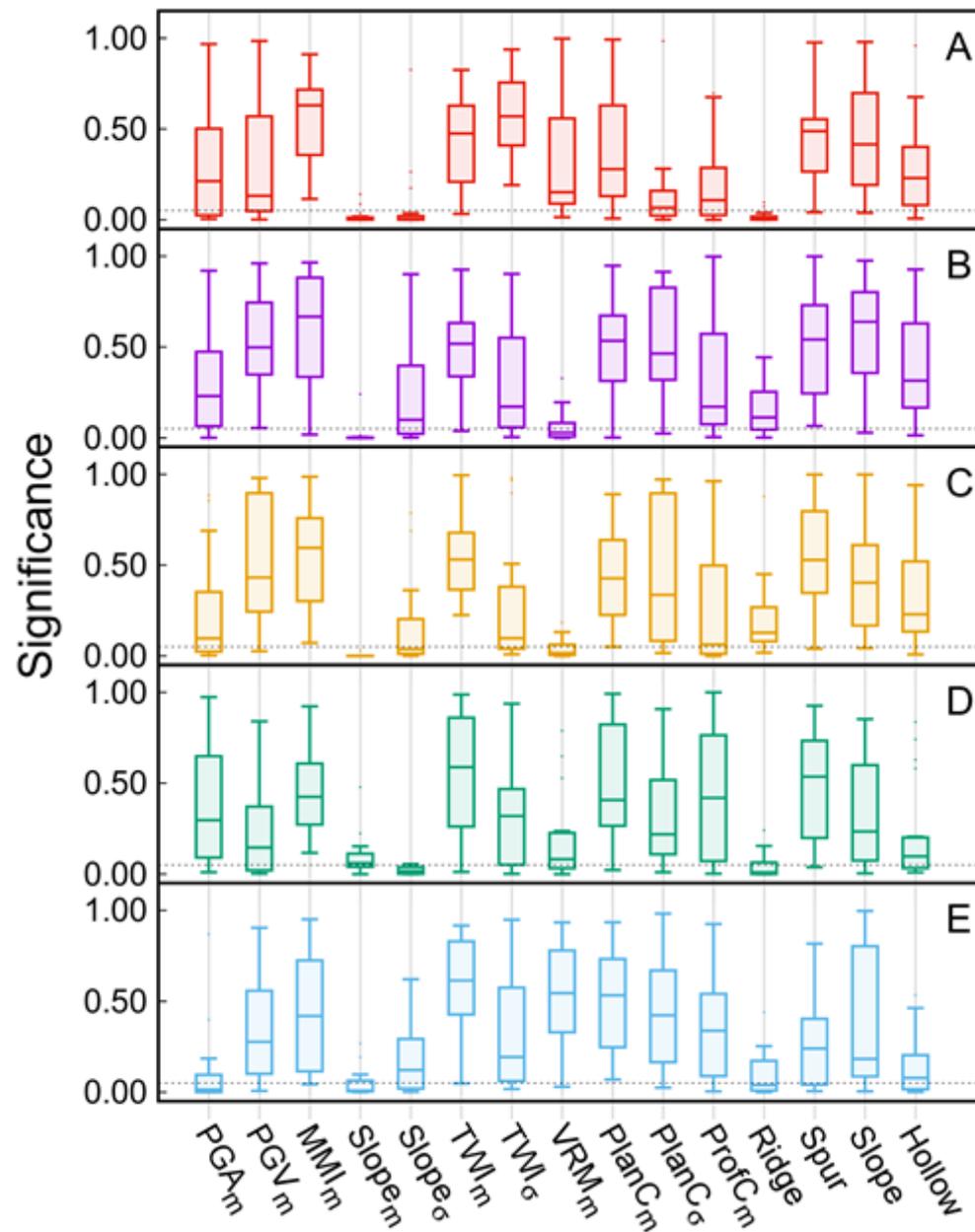
75% of 74 unstable SUs and equal number of stable SUs

*20 iterations*

Implementation of glm() function for 20 training samples

$\chi$ -square test to calculate p-values

*20 dataset*

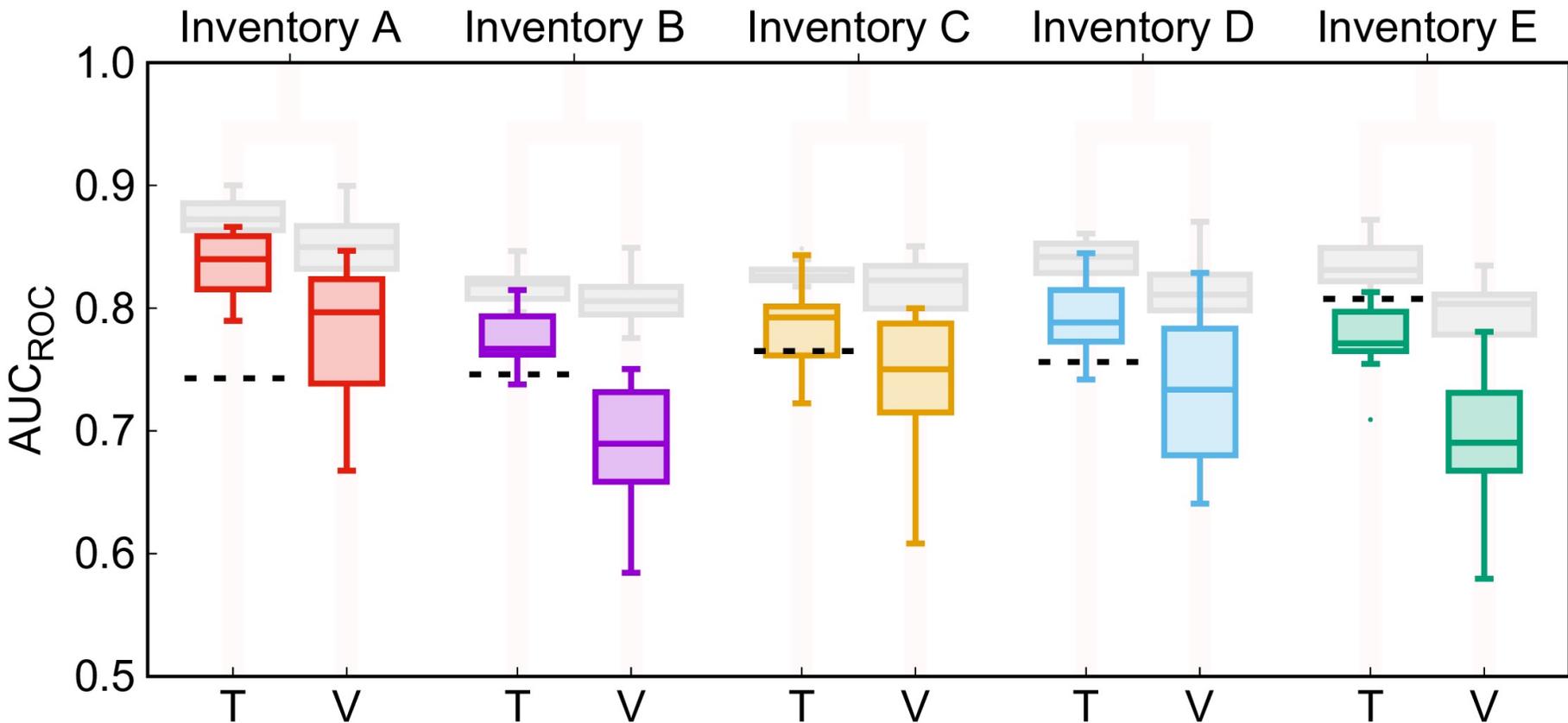


## Pair-wise validation

		Validated by Inventory				
		A	B	C	D	E
Trained with Inventory	A	<b>0.78±0.03</b>	0.80±0.03	0.82±0.03	0.82±0.04	0.80±0.02
	B	0.83±0.03	<b>0.74±0.01</b>	0.80±0.03	0.71±0.02	0.80±0.03
	C	0.83±0.02	0.77±0.02	<b>0.74±0.03</b>	0.77±0.02	0.79±0.02
	D	0.88±0.03	0.81±0.03	0.81±0.03	<b>0.71±0.03</b>	0.80±0.03
	E	0.83±0.03	0.78±0.03	0.80±0.03	0.78±0.03	<b>0.77±0.02</b>

*The table presents the mean with one standard deviation confidence level for the  $AUC_{ROC}$  obtained from each testing/validating pair, with 20-fold random selection.*

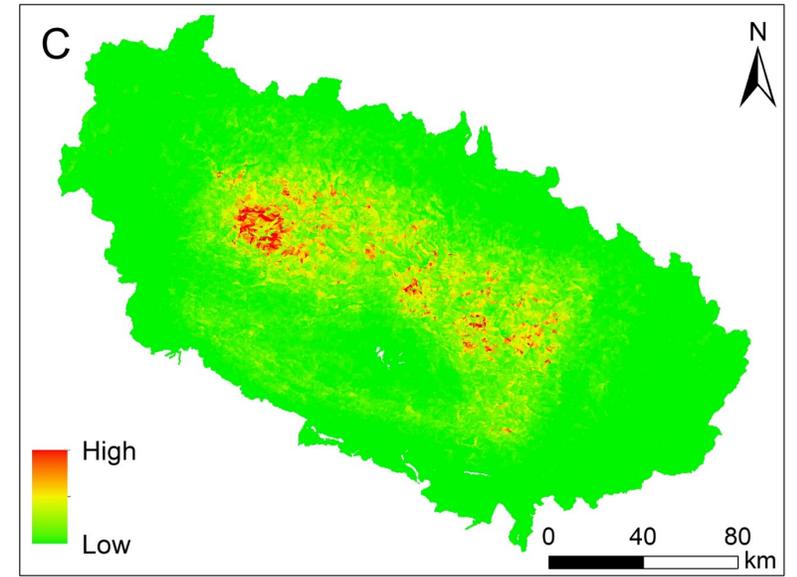
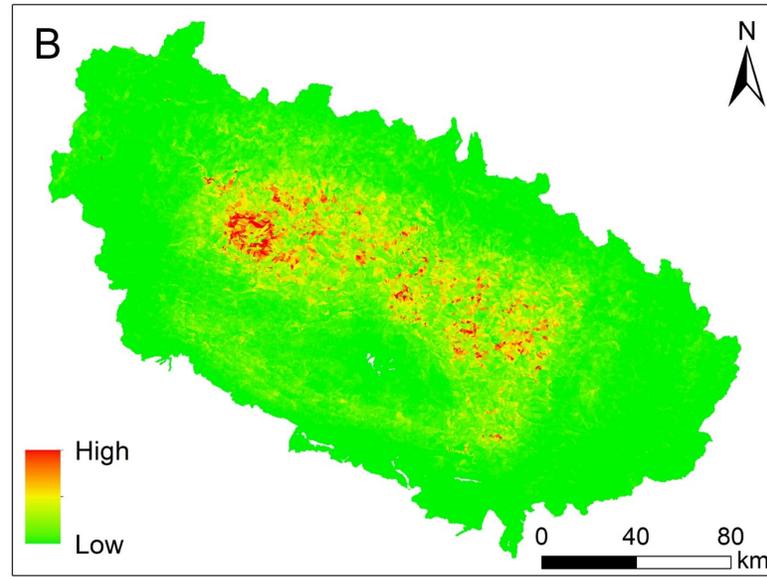
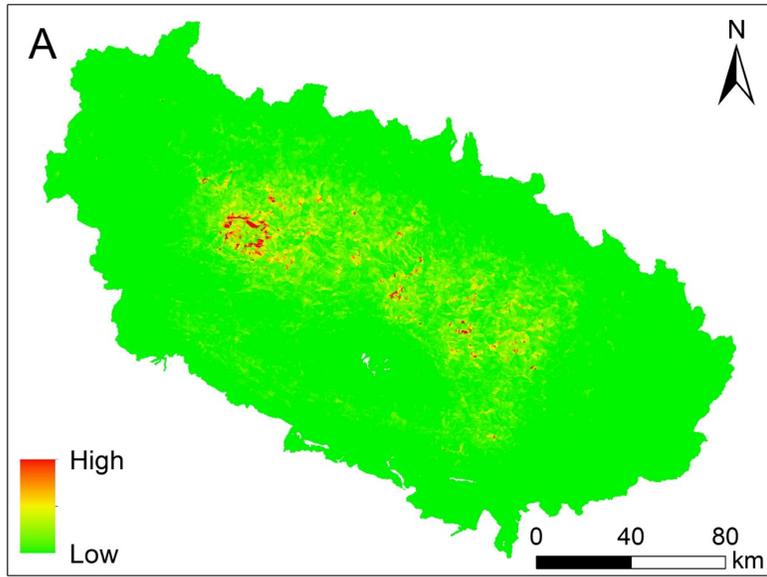
# Performance of LSMs



**Colored:** 70% of stable or unstable SU as training

**Grey:** Smallest of stable or unstable as training

**Dot:** All SU



- We used LAND-SE software (Rossi and Reichenbach, 2016) to generate LSM.
- Each SU is characterized by Landslide susceptibility index (LSI).
- The higher value of LSI indicates higher susceptibility.

Inventories	Mean	S.D
A	0.013	0.037
B	0.045	0.094
C	0.057	0.105

# Conclusions

1. Reliability and interpretation of landslide susceptibility maps are influenced by the differences in the significance of the predictors.
2. The values of  $AUC_{ROC}$  calculated from the different LSMs adopting different sampling techniques were also shown to have different average values and variability. All these points further exhibit that preparation of a landslide inventory is a subjective process.
3. The values of  $AUC_{ROC}$  calculated from the different LSMs adopting different sampling techniques were also shown to have different average values and variability. All these points further exhibit that preparation of a landslide inventory is a subjective process. Henceforth, the derived LSMs are subjective as well and depend on many factors.

# Significant outcomes

(1) SU will be available on <http://geomorphology.rpi.cnr.it/tools/slope-units>

(2) We have a paper close to be accepted in a high-rank journal.



Source: <https://www.slideshare.net/anupsingh3363/hvrc-analysis-for-school-safety>

**Thank you**



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