Examining the Potential for a Relationship between Fires and Landslides in the Koshi Basin, Nepal

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Thesis Defense

UAH Earth System Science Program

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The University of Alabama in Huntsville

Earth System Science

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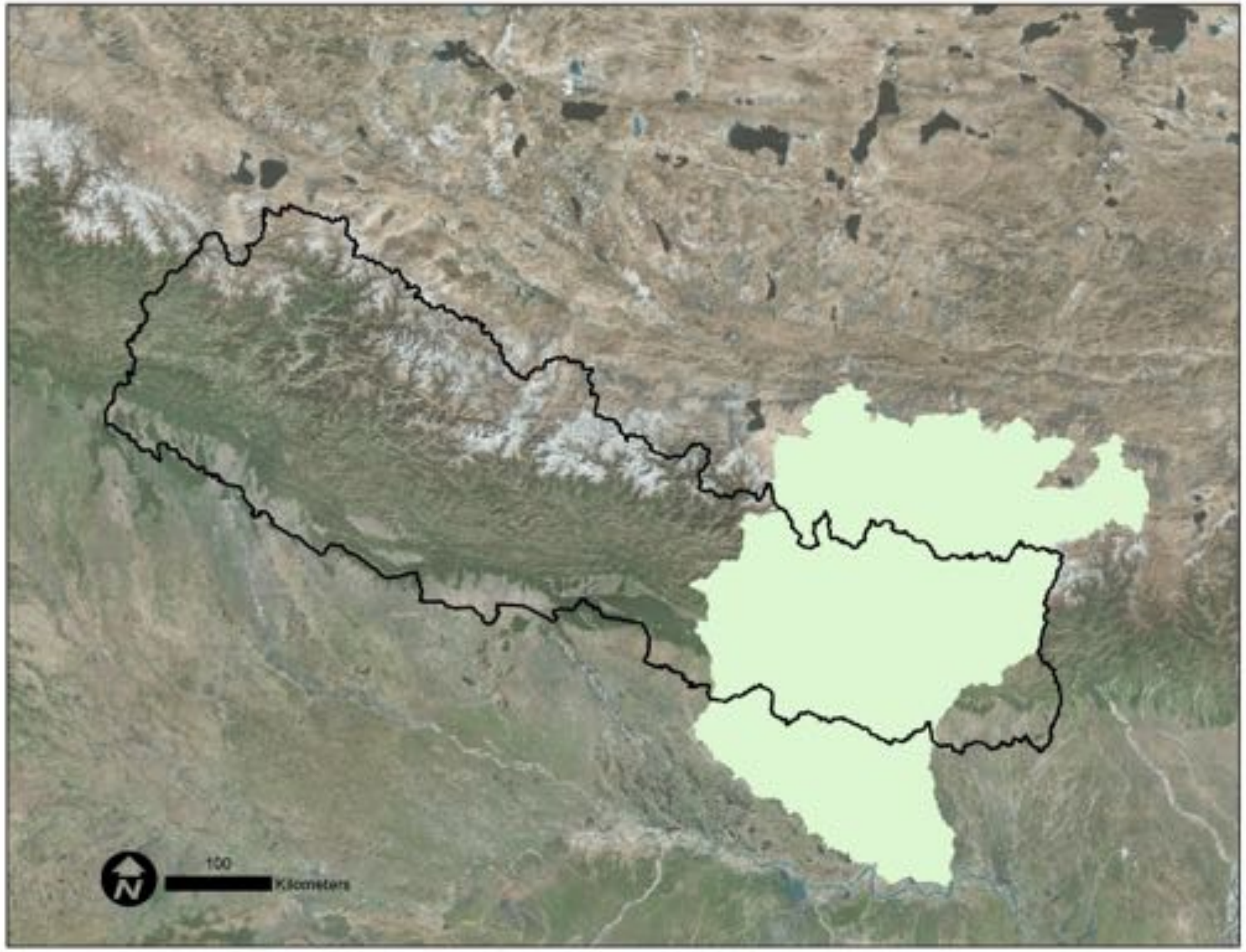
Koshi River Basin in Nepal



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Koshi River Basin Geography

- Basin and range topography: high elevation point (Mt. Everest) & low point (Kechana Kalan) less than 300 km apart

- 3 areas typical of Nepal as a whole: Terai, mid-mountains, high Himalayas

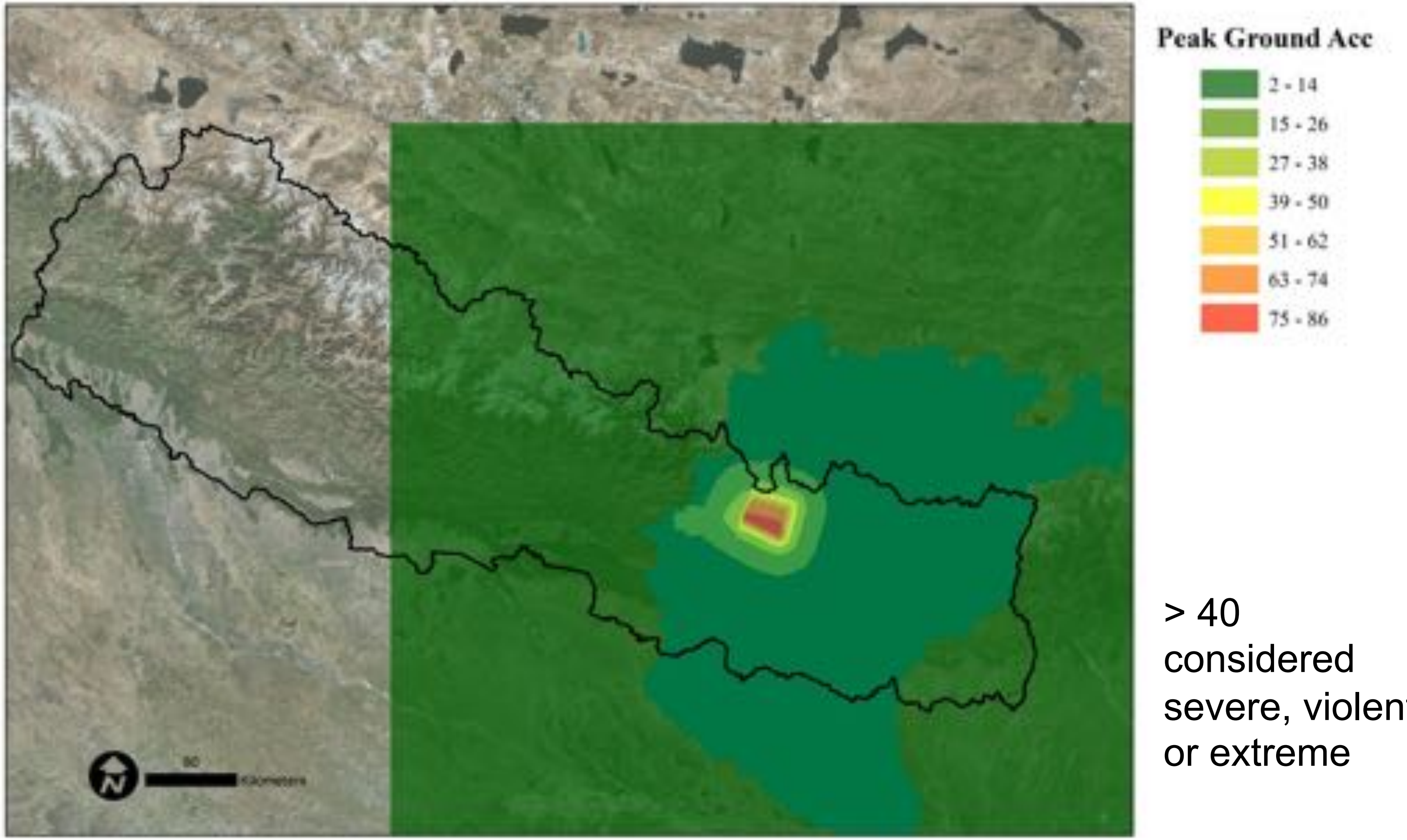
- Highly sloped area prone to landslide occurrence

Landslides

- Downslope movement of materials
- Primary trigger is often rainfall (large amounts of precip over a short period of time)
- Factors leading up to a landslide often build up in the time preceding the event

Source: http://monsoon.yale.edu/forthcoming-monsoon-rains-may-complicate-disaster-relief-efforts-in-nepal/

Gorkha Quake Aftershock: 7.3 Magnitude



> 40 considered severe, violent, or extreme

Justification for Research

- Post-fire landslide probability in the U.S. Great Basin can be modeled using GIS (Cannon, et al 2009).
- Burned Area Emergency Response (BAER) teams assess post fire threats to lives, property, and resources
- BAER landslide model inputs include burn severity, soils, and elevation data
- Fire/landslide link hasn't been investigated in Nepal

http://www.fondriest.com/news/modeling-tool-helps-minimize-flood-and-landslide-risks-after-wildfires.htm

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Nepal Fires

- Prolonged dry seasons and lower winter precipitation in Nepal have increased wildfire incidences
- Fire is a major cause of forest degradation in Nepal
- Many tree species here shed leaves during dry season, which leads to ground fuel buildups

(Das, 2011)

Nepal Landslides

- Around 300 deaths occur each year as a result of landslides & flooding
- Direct economic losses around 1208 million Nepalese Rupees per year (~$11.1 million)
- According to the government, poor construction practices and a **lack of preparation and awareness** contribute most to loss of life and property

(Nepal National Strategy for Disaster Risk Management, 2008)

Current Research

- Fire:
  - ICIMOD (Forest Fire and Monitoring app: http://apps.geoportal.icimod.org/NepalForestFire/) MODIS 2012-present
- Landslides:
  - ICIMOD: Gorkha Quake landslide/GLOF maps, hazard maps
  - ICIMOD Koshi Landslides (Zhang et al, 2016)
  - Kirschbaum: Global Landslide Catalog (Kirschbaum et al, 2010)
  - Kargel: Gorkha Quake landslide database & analysis (Kargel et al, 2015)

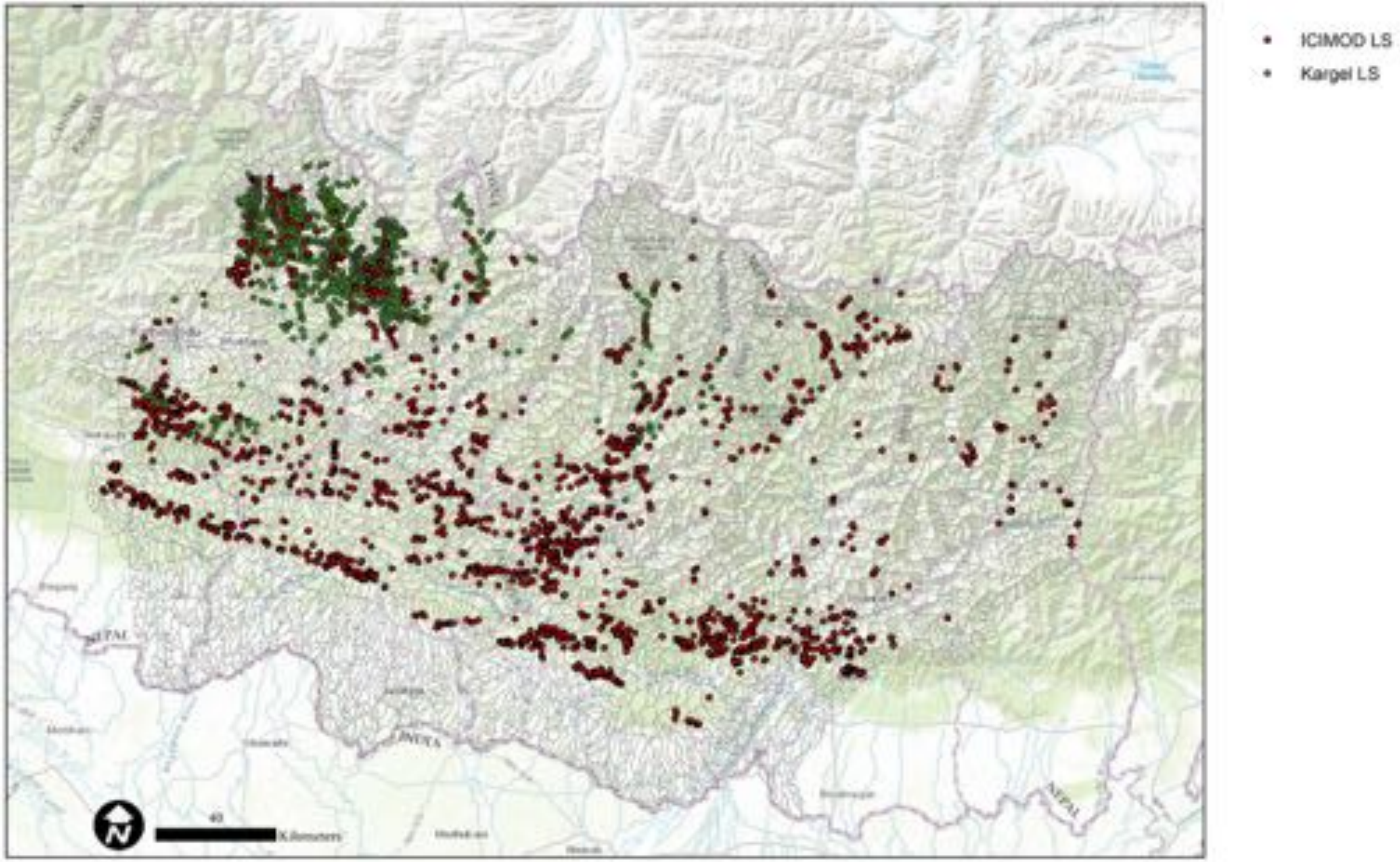
Research Questions

- Is there a relationship between fire frequency/severity and landslide occurrence in the Koshi Basin, Nepal? If so, what is it? How do we measure it?

- How does the relationship change when considering rainfall triggered landslides and those triggered by strong seismic events?

- Are there any implications on post-fire management strategies?

Landslide Databases



Research Gap

- There is a lack of research done to examine the potential for a relationship between fires and landslide occurrence in Nepal as a whole.

- Understanding this relationship, or the lack thereof, could improve existing landslide hazard models for this region, and would help mitigate post-fire landslide hazards. At the very least, there will be a better understanding of landslide causal factors here.

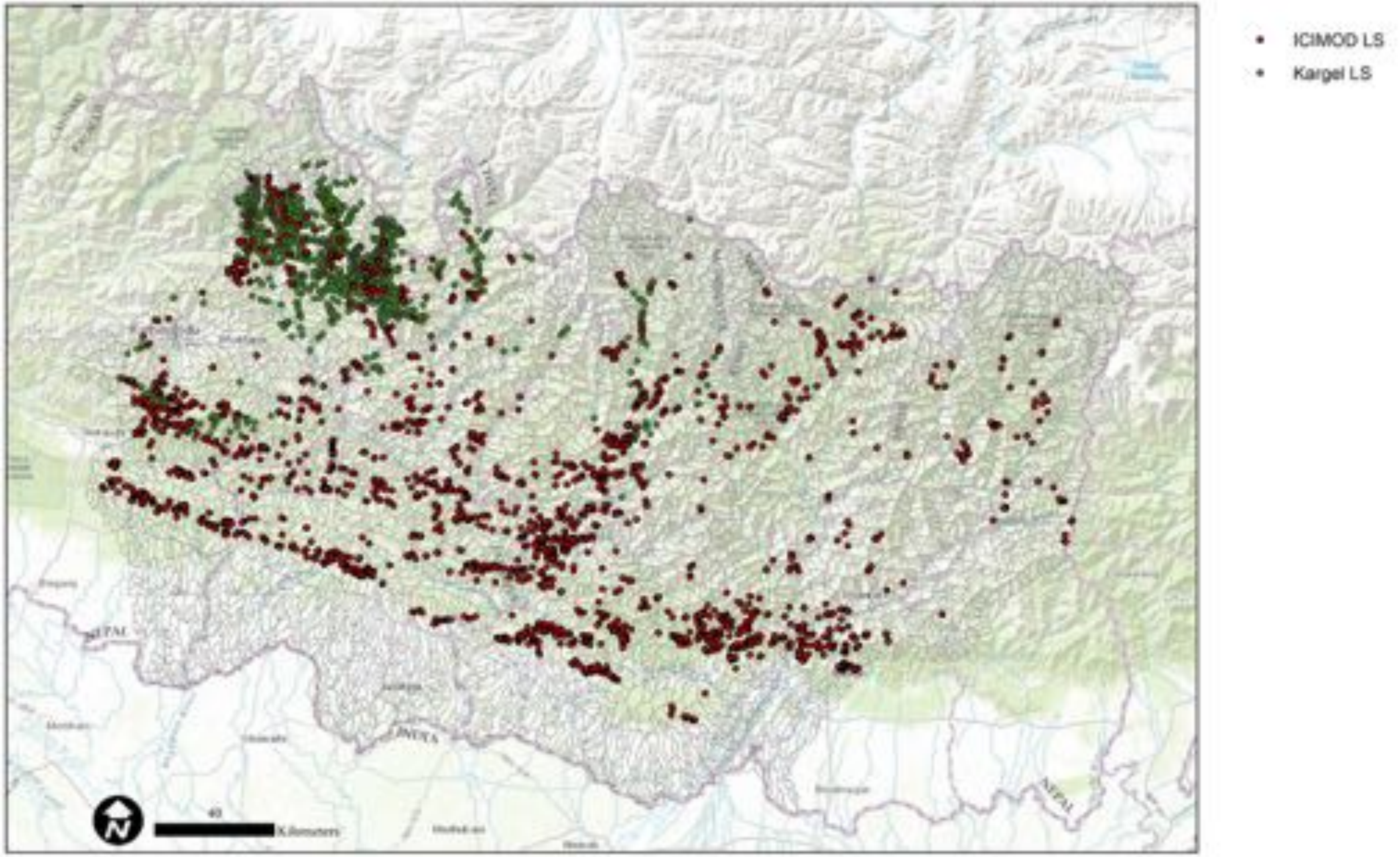
- This has the potential to save countless lives and property in the region.

Data Sources (explanatory variables)

Variable	Abbrev.	Data Source	Spatial Res	Time	Summary
Normalized Burn Ratio	NBR	LANDSAT 7	30 m	2003-2015	(SWIR-NIR)/(SWIR+NIR)
Fire Occurrence	Fires	MODIS MCD45A1	500 m	2003-2015	(Fires)/(catchment)
Drainage Density	DD	ALOS 5m DEM	5 m		(str length)/(A_s)
Topographic Wetness Index *	TWI	ALOS 5m DEM	5 m		$\ln(A_s/\tan\beta)$
Sediment Transport Index *	STI	ALOS 5m DEM	5 m		$(A_s/22.3)^m (\sin\beta/0.0896)^n$
Stream Power Index *	SPI	ALOS 5m DEM	5 m		$A_s\tan\beta$
Population Density	Pop Dens	Landscan	1 km	2010	(People)/(catchment)
Height Above Nearest Drainage	HAND	ALOS 5m DEM	5 m		Vertical distance
Slope	Slope	ALOS 5m DEM	5 m		(rise)/(run)
Euclidean Distance to Streams	Eucl Str	ALOS 5m DEM	5 m		Straight line distance
Aspect	Aspect	ALOS 5m DEM	5 m		Direction of slope
Profile Curvature	Prfl Crv	ALOS 5m DEM	5 m		Parallel to dir. max slope
Plan Curvature	Plan Crv	ALOS 5m DEM	5 m		Perpindicular to max slope
Flow Accumulation	Flow Acc	ALOS 5m DEM	5 m		Accum. pixel x pixel flow
CHIRPS	CHIRPS	CHIRPS Monthly	0.05°	2003-2015	Average monthly accum.
CHIRP	CHIRP	CHIRP Monthly	0.05°	2003-2015	Average monthly accum.

A_s = surface area of catchment; β = slope in degrees; $m = 0.6$; $n = 1.3$
(Moore et al, 1988)

Landslide Databases



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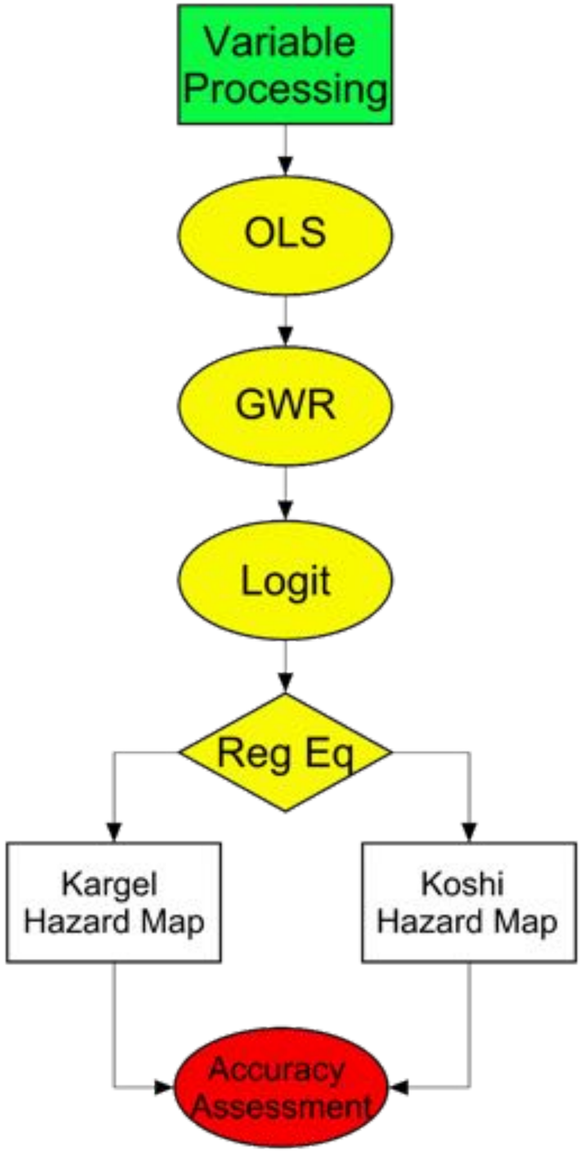
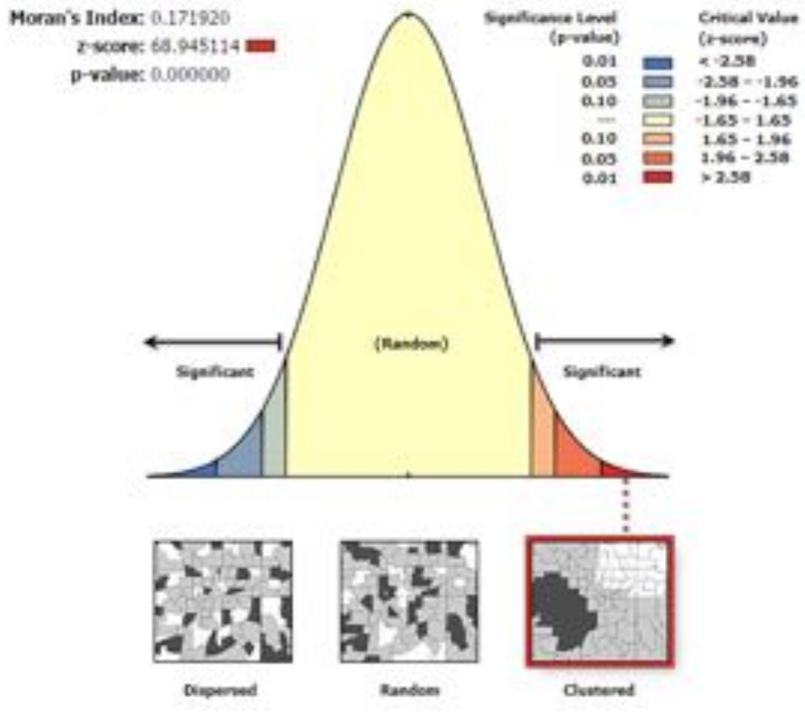
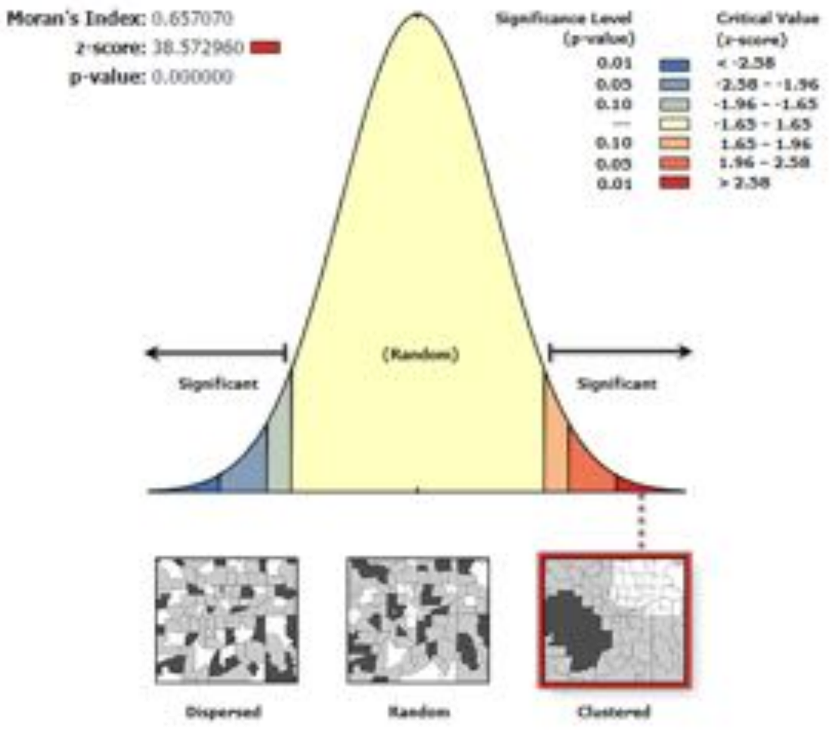
Methodology



OLS Linear Regression-Spatial Autocorrelation

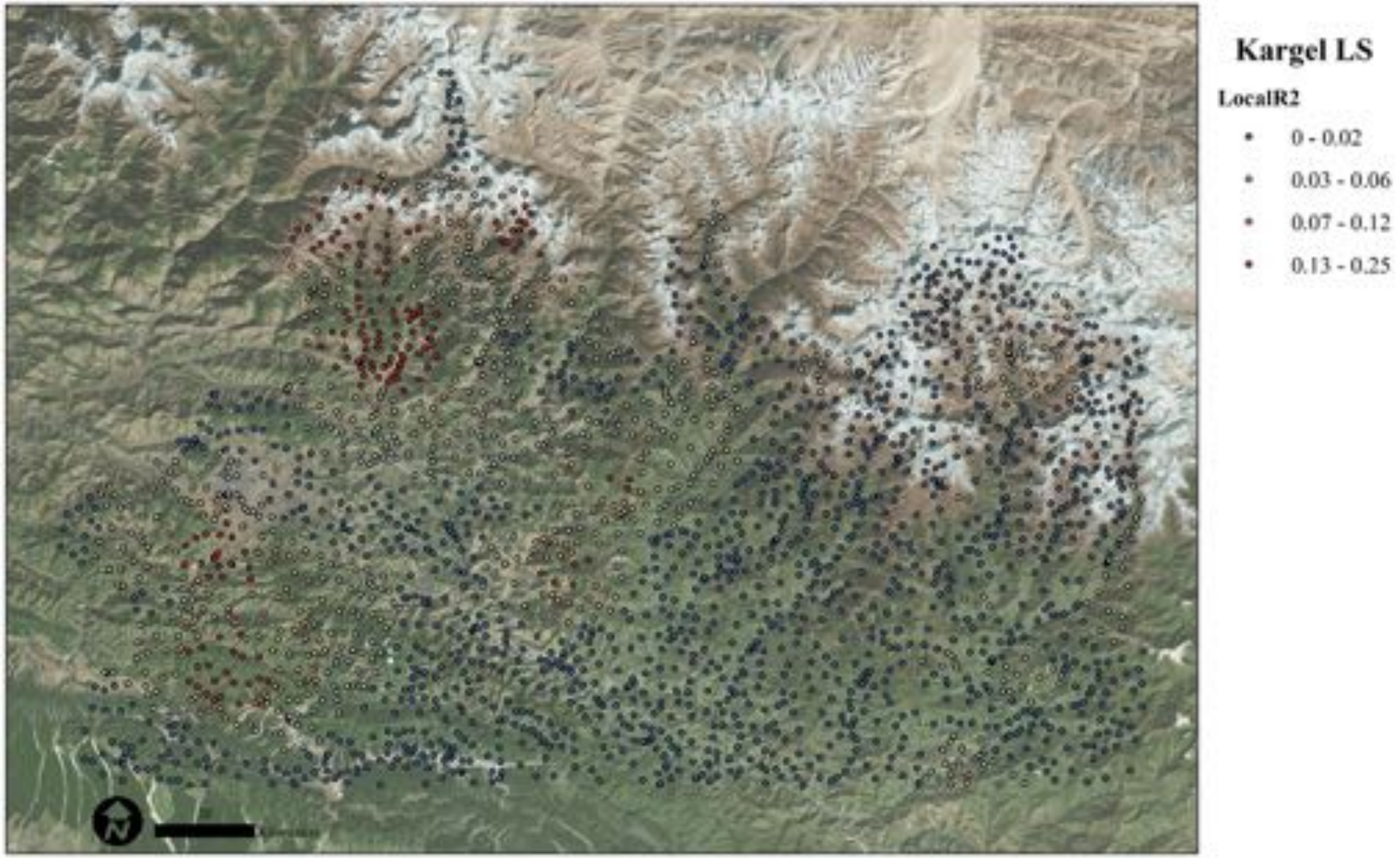


Kargel

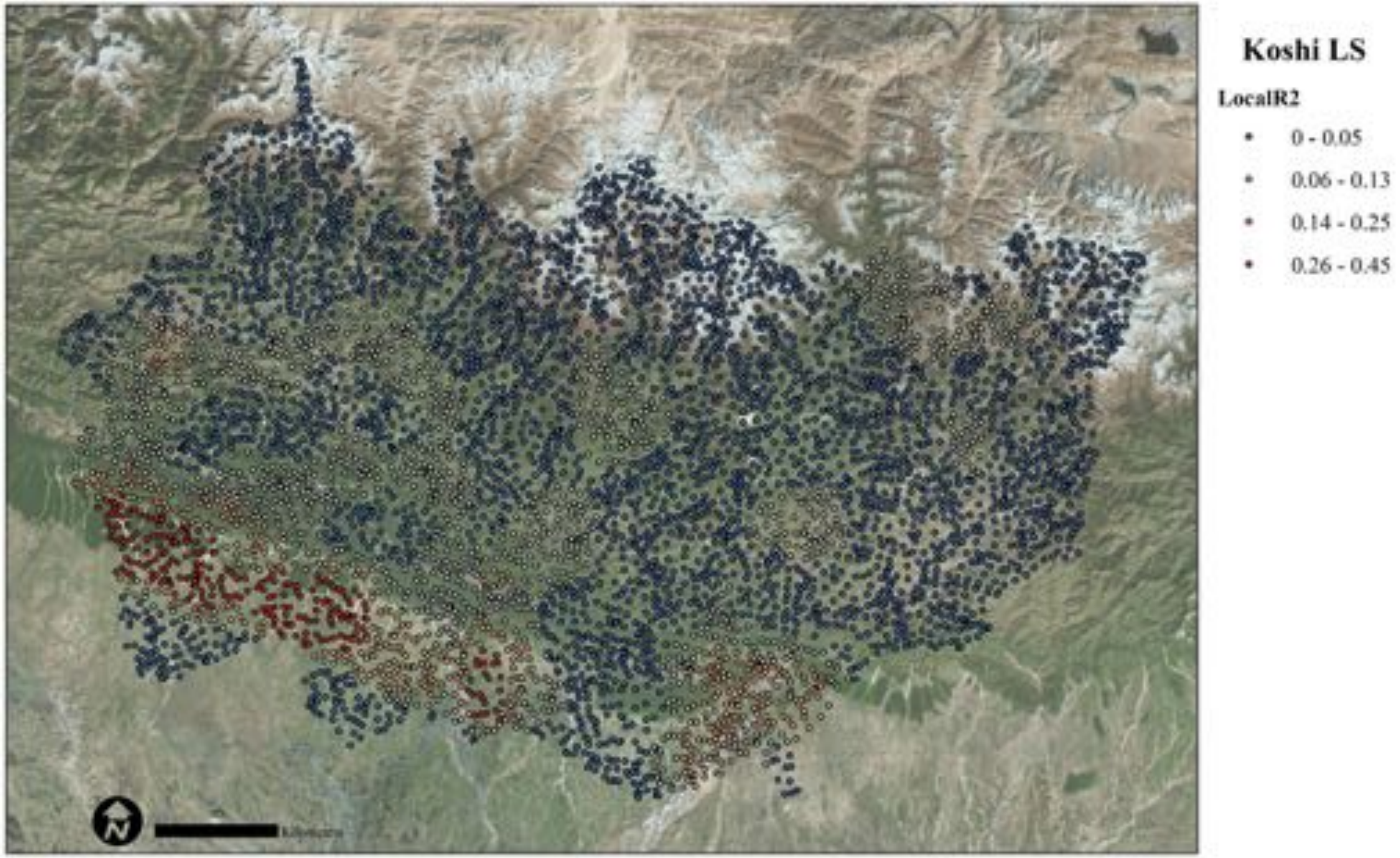


Koshi

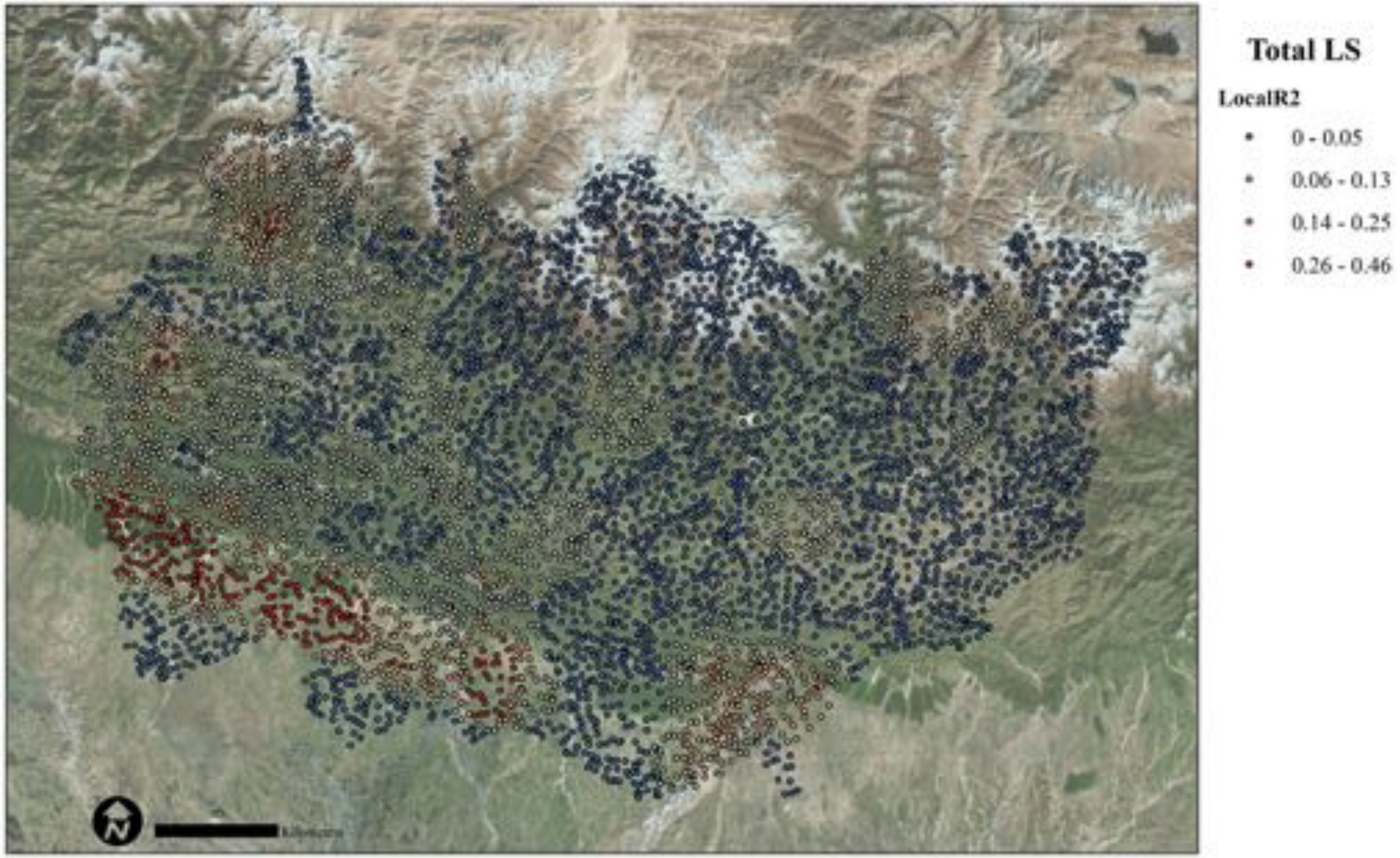
GWR Results Kargel Landslides



GWR Results Koshi Landslides



GWR Results All Landslides



Logistic Regression Results

Variable	p value	Mcfadden's Rho Sq	Area under ROC Curve
NBR	0	0.407	0.899
Slope	0	0.033	0.543
Drain Dens	1	0.642	0.906
SPI	0	0.103	0.5
Fires	0.896	0	0.509
TWI	1	0.53	0.859
STI	0.016	0.003	0.859
Pop dens	1	0.607	0.892
HAND	1	0.94	0.991
Eucl Str	1	0.606	0.892
Aspect	1	0.986	0.997
Profile Crv	0.987	0	0.5
Plan Crv	0.659	0	0.46
Flow Acc	0.468	0.001	0.501
CHIRPS	0	0.412	0.904
CHIRP	0	0.424	0.907

- Mcfadden's Rho Squared & Area under ROC Curve-measures of model performance
- P-value-indicates whether or not null hypothesis can be rejected

Kargel Regression Equations

Without NBR:

$$Y = -13.007 + (0.087 * Slope) + (0.077 * CHIRP)$$

With NBR:

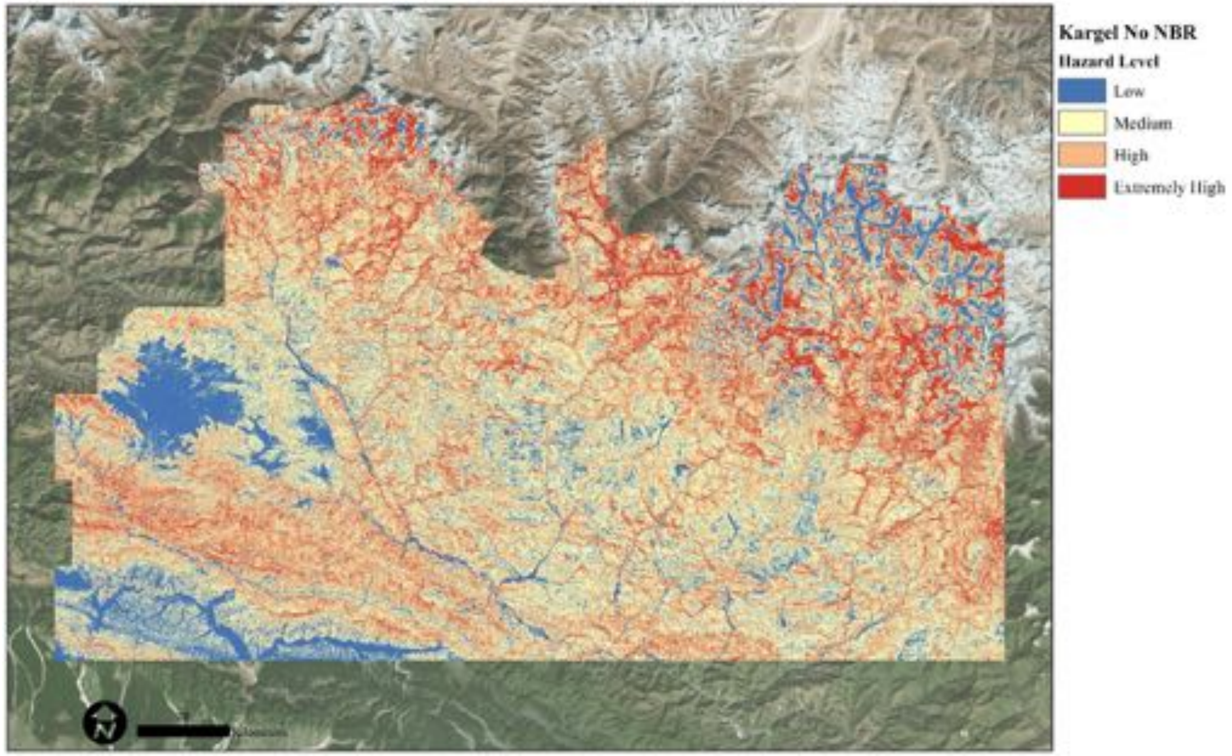
$$Y = -11.945 + (0.082 * Slope) + (0.079 * CHIRP) + (15.394 * NBR)$$

Equations do not represent likelihood of landslide occurrence, so a transformation is necessary to arrive at the probability of landslide occurrence:

$$\pi = Prob(Y = 1 | X = x_1, \ldots X_n = x_p) = \frac{e^{c_o + c_1 x_1 + \cdots + c_n x_n}}{1 + e^{c_o + c_1 x_1 + \cdots + c_n x_n}}$$

(Chatterjee et al., 2001; Peng and So, 2002)

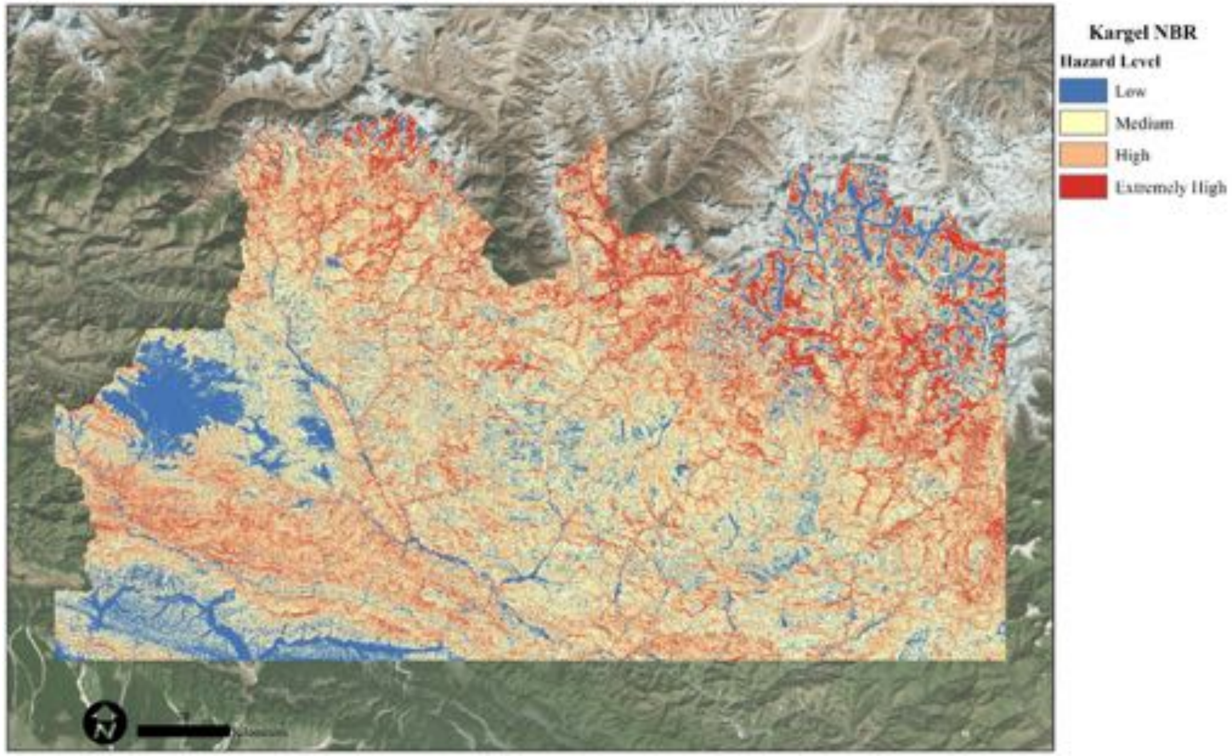
Kargel Model Results No NBR



		Predicted		Accuracy
		0	1	
Observed	0	304	223	57.70%
	1	125	594	82.60%

Overall Accuracy: 72.1%

Kargel Model Results NBR



		Predicted		Accuracy
		0	1	
Observed	0	363	211	63.20%
	1	118	601	83.40%

Overall Accuracy: 77.3%

ICIMOD Koshi Regression Equations

Without NBR:

$$Y = -1.203 + (0.044 * Slope) + (0.001 * CHIRP)$$

With NBR:

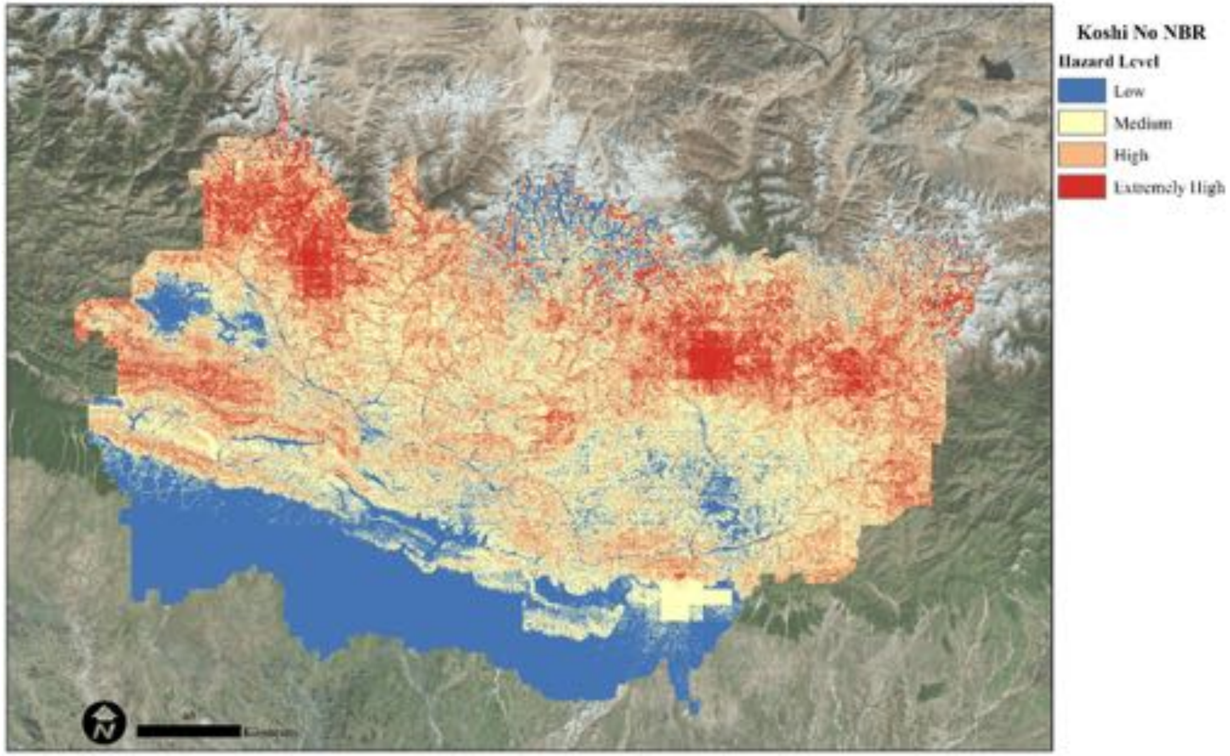
$$Y = -0.856 + (4.821 * NBR) + (0.047 * Slope) + (0.005 * CHIRP)$$

Equations do not represent likelihood of landslide occurrence, so a transformation is necessary to arrive at the probability of landslide occurrence:

$$\pi = Prob(Y = 1 | X = x_1, \dots X_n = x_p) = \frac{e^{c_o + c_1 x_1 + \cdots + c_n x_n}}{1 + e^{c_o + c_1 x_1 + \cdots + c_n x_n}}$$

(Chatterjee et al., 2001; Peng and So, 2002)

Koshi Model Results No NBR



		Predicted		Accuracy
		0	1	
Observed	0	564	426	57.00%
	1	378	613	61.90%

Overall Accuracy: 59.4%

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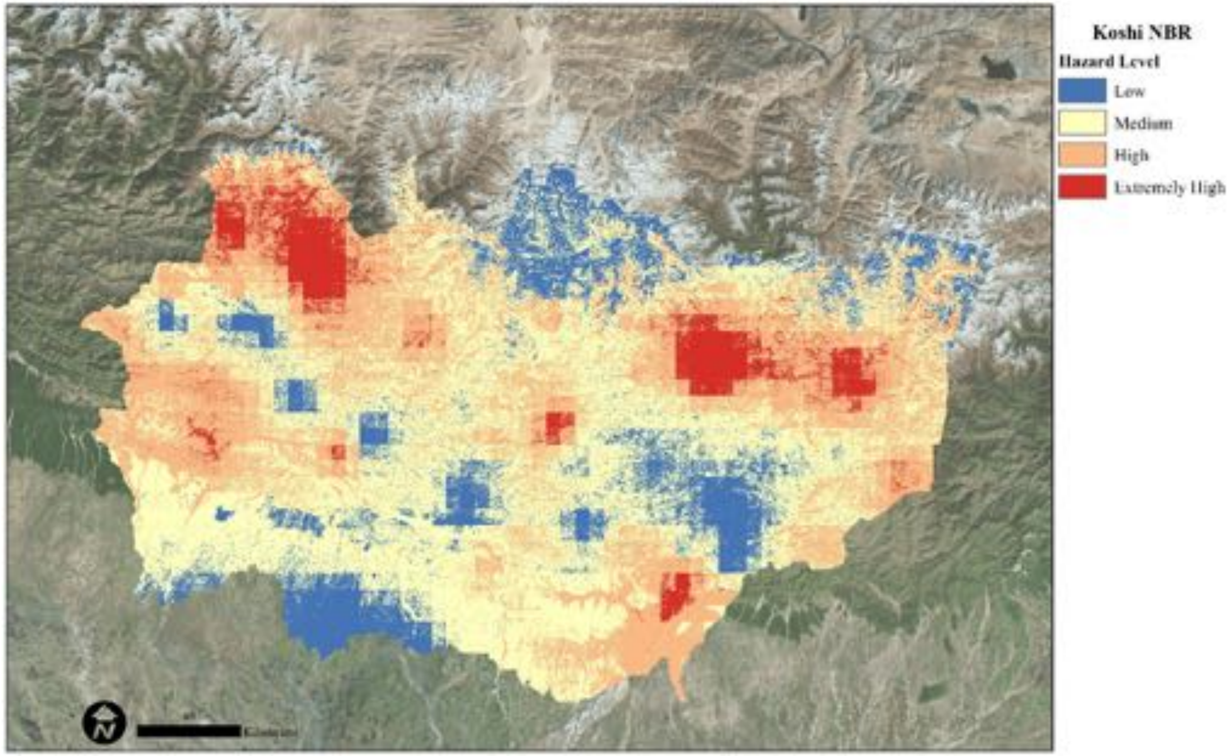
Koshi Model Results NBR



		Predicted		Accuracy
		0	1	
Observed	0	591	399	59.70%
	1	381	610	61.60%

Overall Accuracy: 60.6%

Known Errors

- Tried to fit linear regression model to some variables that were non-linear at the watershed catchment level
- Precipitation and remotely sensed data anomalies (complex terrain, etc.)
- Difficult to adequately summarize NBR over a long period of time. Need immediate post-burn in-situ measurements similar to BAER
- Models don’t account for time

Research Questions Revisited

1. Is there a relationship between fire frequency/severity and landslide occurrence in the Koshi Basin, Nepal? If so, what is it? How do we measure it?

2. How does the relationship change when considering rainfall triggered landslides and those triggered by strong seismic events?

3. Are there any implications on post-fire management strategies?

Research Questions Revisited

1. It would appear that there is a relationship between burn severity and landslide occurrence in the Koshi River Basin. In both logistic regression tests, NBR had the effect of lowering the amount of false postivies and increasing false negatives.

2. The basic models created did a better job of accounting for quake triggered landslides, but the effect of adding NBR to the equation was similar for both landslide databases.

3. The results could bring attention to the need for post-fire landslide hazard assessments in the region. In-situ measurements could drastically improve model results.

Implications

- Appears to be a relationship between burn severity and landslide occurrence in the Koshi Basin that should be investigated further.

- Possibility for a distinct relationship between fire occurrence and landslide occurrence as well, but could not be adequately determined from these results.

References

Cannon, S. and J. DeGraff (2009), The Increasing Wildfire and Post-fire Debris Flow Threat in the Western USA, and Implications for Consequences of Climate Change. In: Sassa, K., Canuti, P. (Eds.), Landslides-Disaster Risk Reduction, pp. 177-190.

Chatterjee, S., A. H. Hadi, and B. Price (2000), Regression Analysis By Example, 3rd Ed., John Wiley & Sons, Inc., New York.

Das AN. Causes , consequences and management strategy for Wildfires in Nepal. (GoN 2002).

Government of Nepal, National Strategy for Disaster Management, 2008.

Kargel JS, Leonard GJ, Shugar DH, Haritashya UK, Bevington A, Fielding EJ, Fujita K, Geertsema M, Miles ES, Steiner J, et al. Geomorphic and geologic controls of geohazards induced by Nepal's 2015 Gorkha earthquake. Science. 2016 Jan 8;351(6269):aac8353. doi: 10.1126/science.aac8353. PubMed PMID: 26676355.

Kirschbaum D, Stanley T, Zhou Y. Spatial and temporal analysis of a global landslide catalog. *Geomorphology*. 2015;249(October):4-15. doi:10.1016/j.geomorph.2015.03.016.

Peng, C.-Y. J., and T.-S. H. So (2002), Logistic Regression Analysis and Reporting: A Primer, in Understanding Statistics, pp. 31–70, Lawrence Erlbaum Associates.

Zhang J, Liu R, Deng W, et al. Characteristics of landslide in Koshi River Basin, Central Himalaya. *J Mt Sci*. 2016;13(10):1711-1722. doi:10.1007/s11629-016-4017-0.

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THANK YOU!

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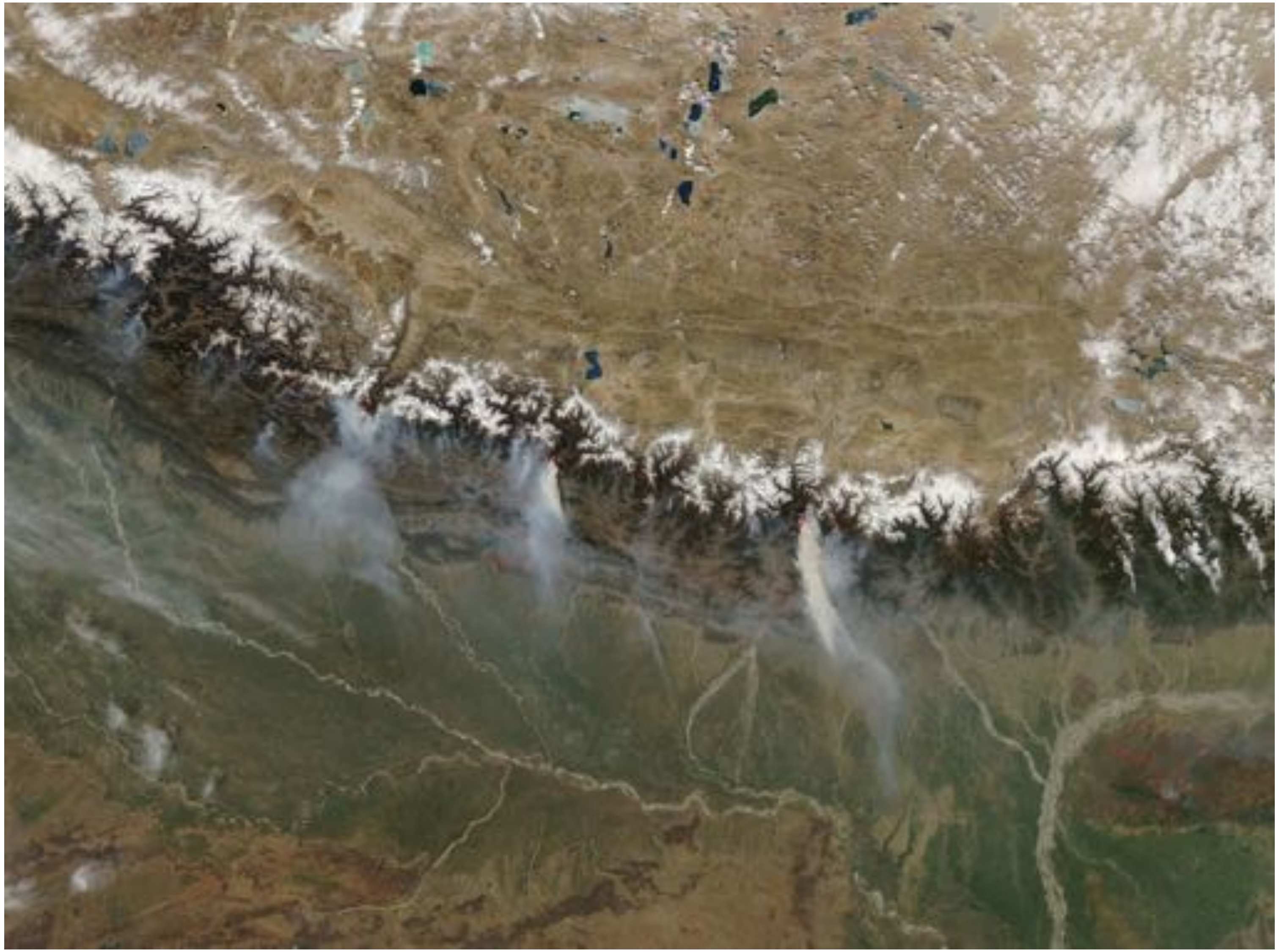
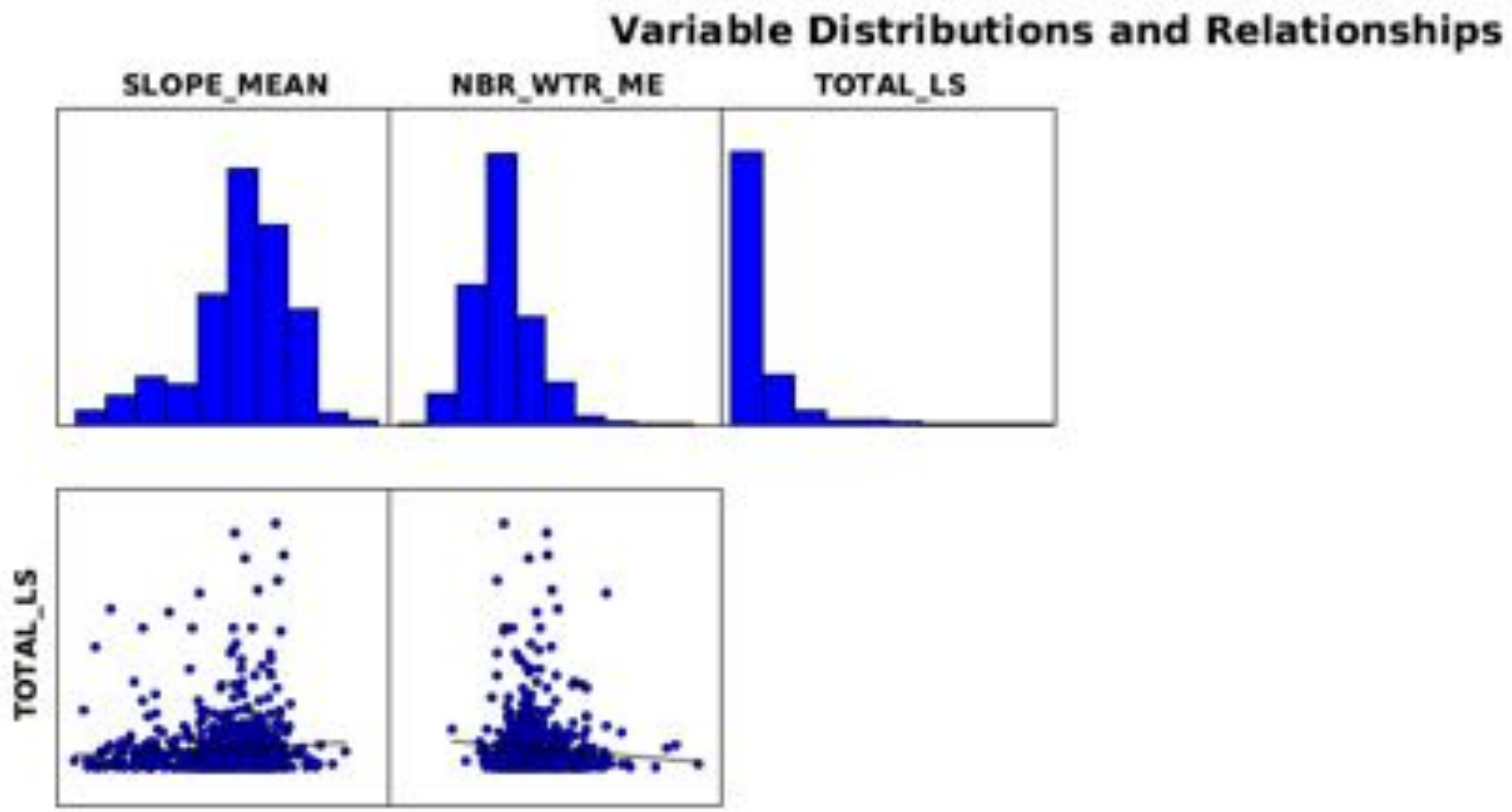
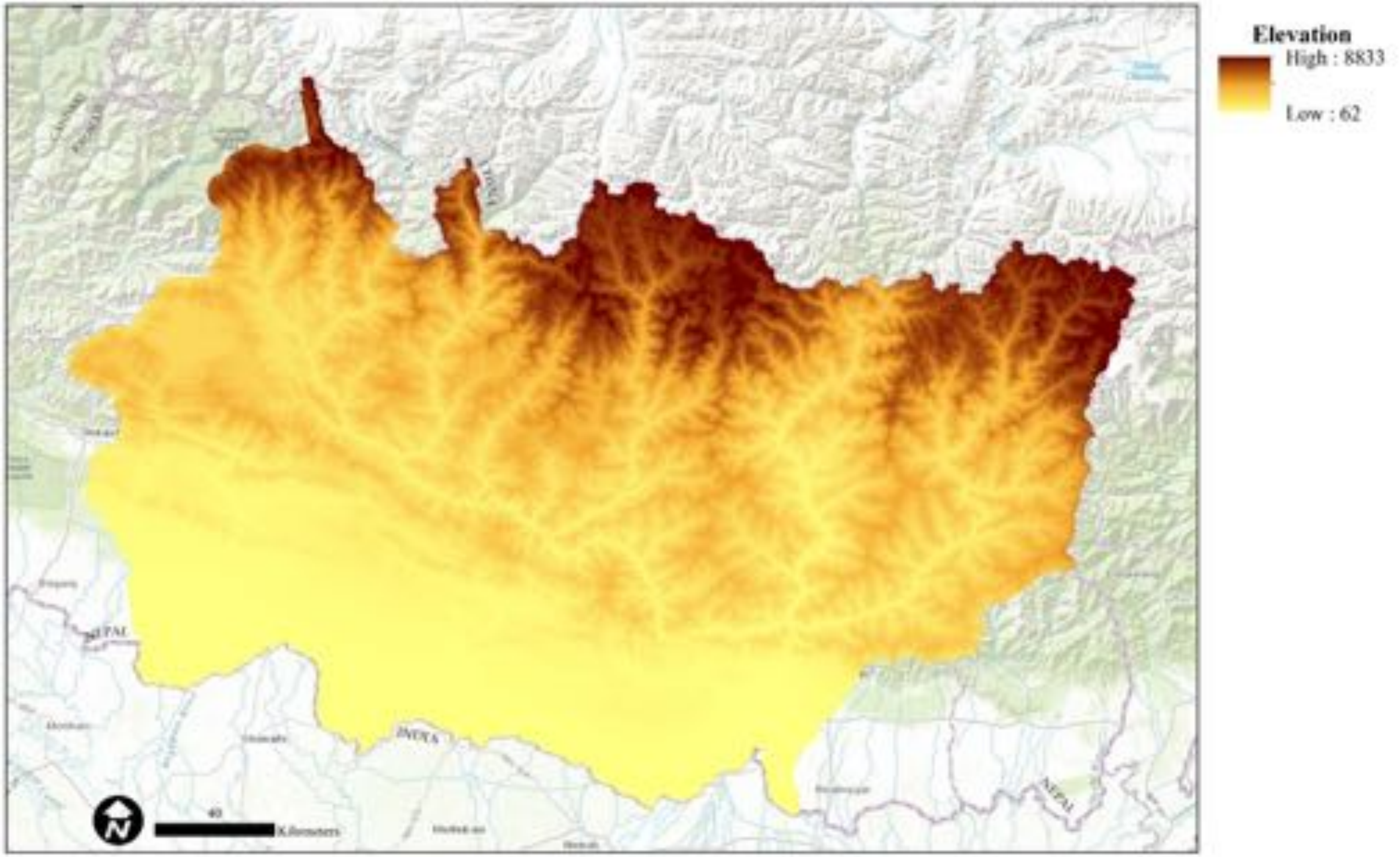


Source: NASA Earth Observatory



Variable Distributions and Relationships
SLOPE_MEAN
NBR_WTR_ME
TOTAL_LS
TOTAL_LS


Elevation
High : 8833
Low : 62
NEPAL
INDIA
NEPAL
40
Kilometers

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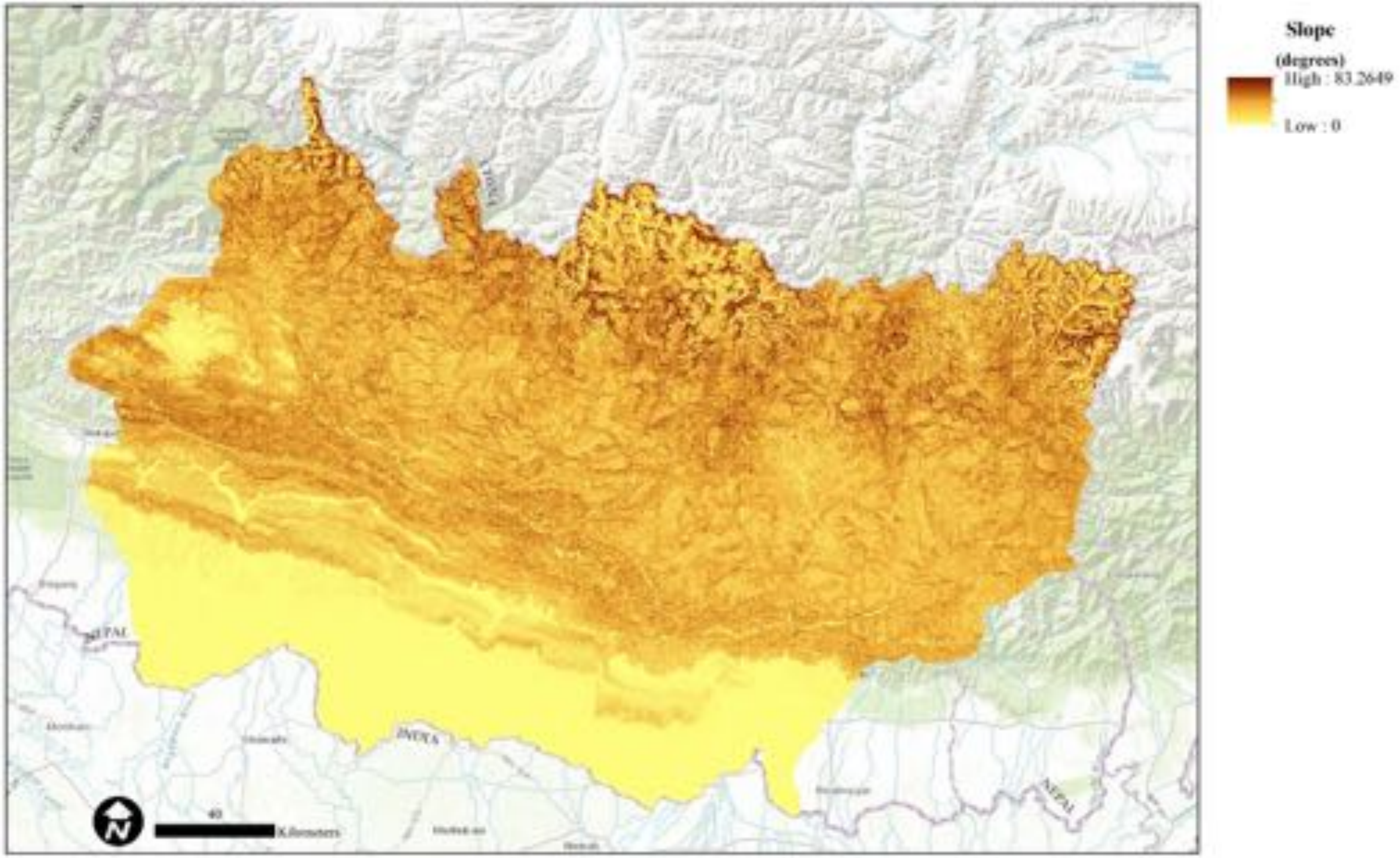
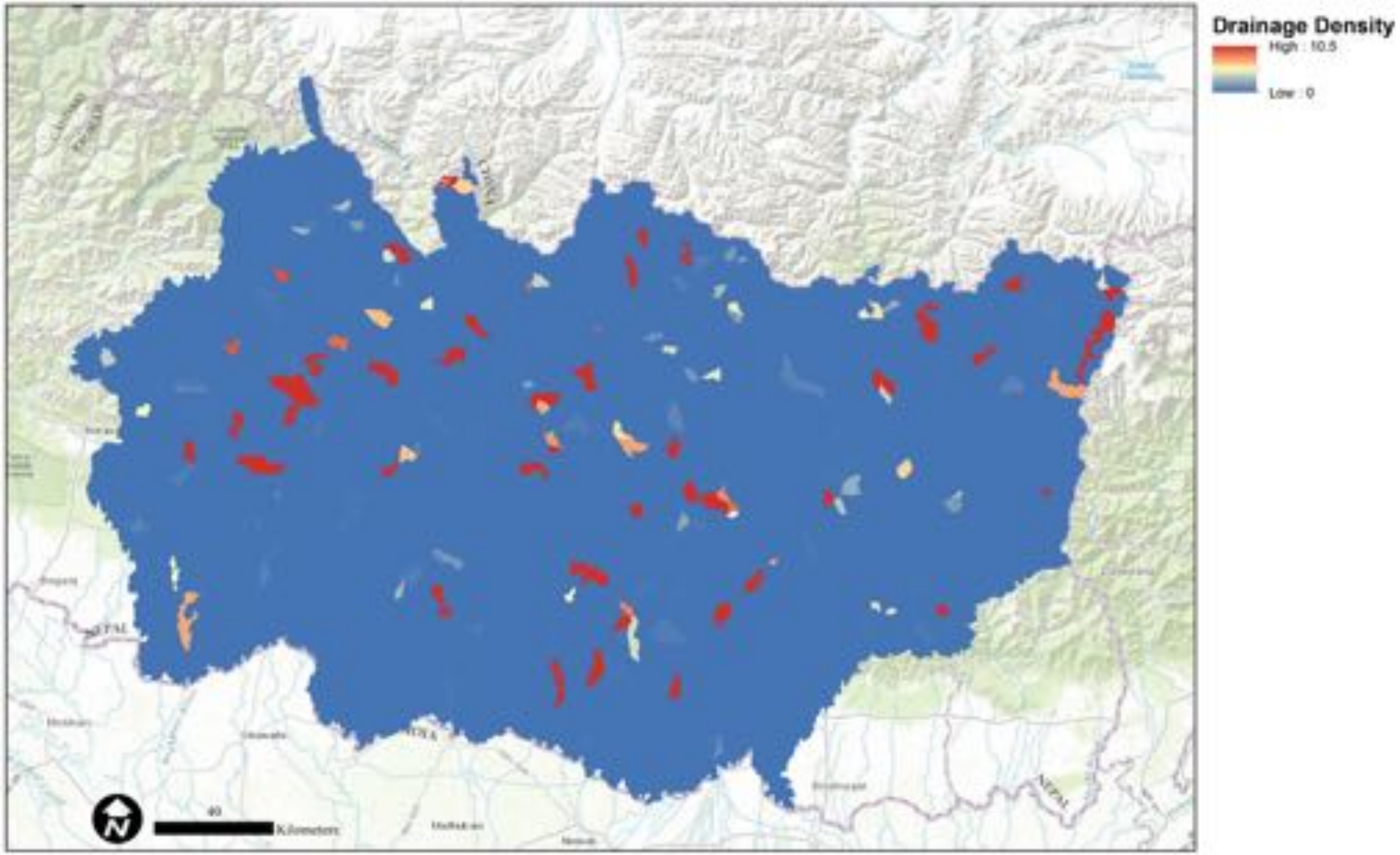
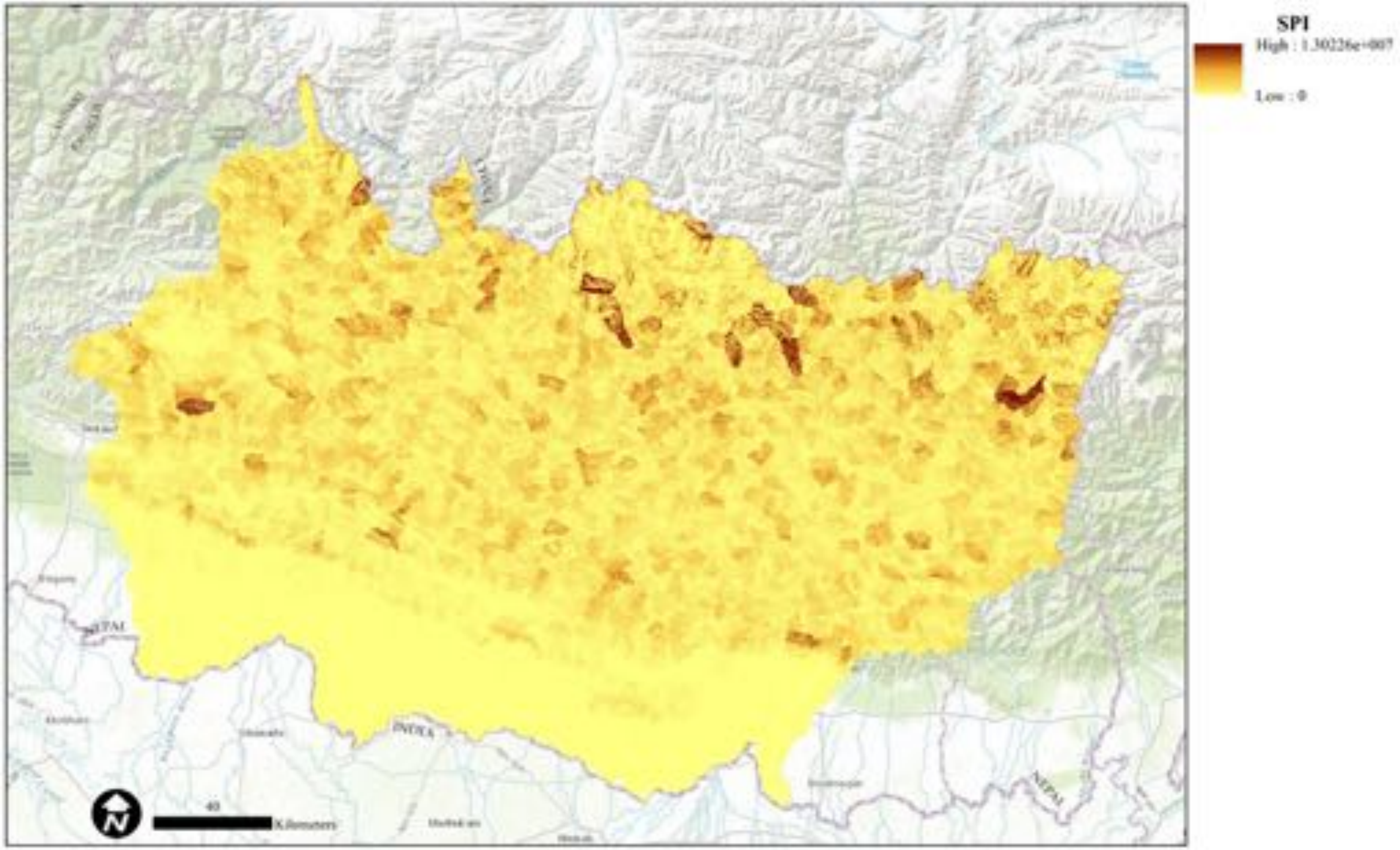
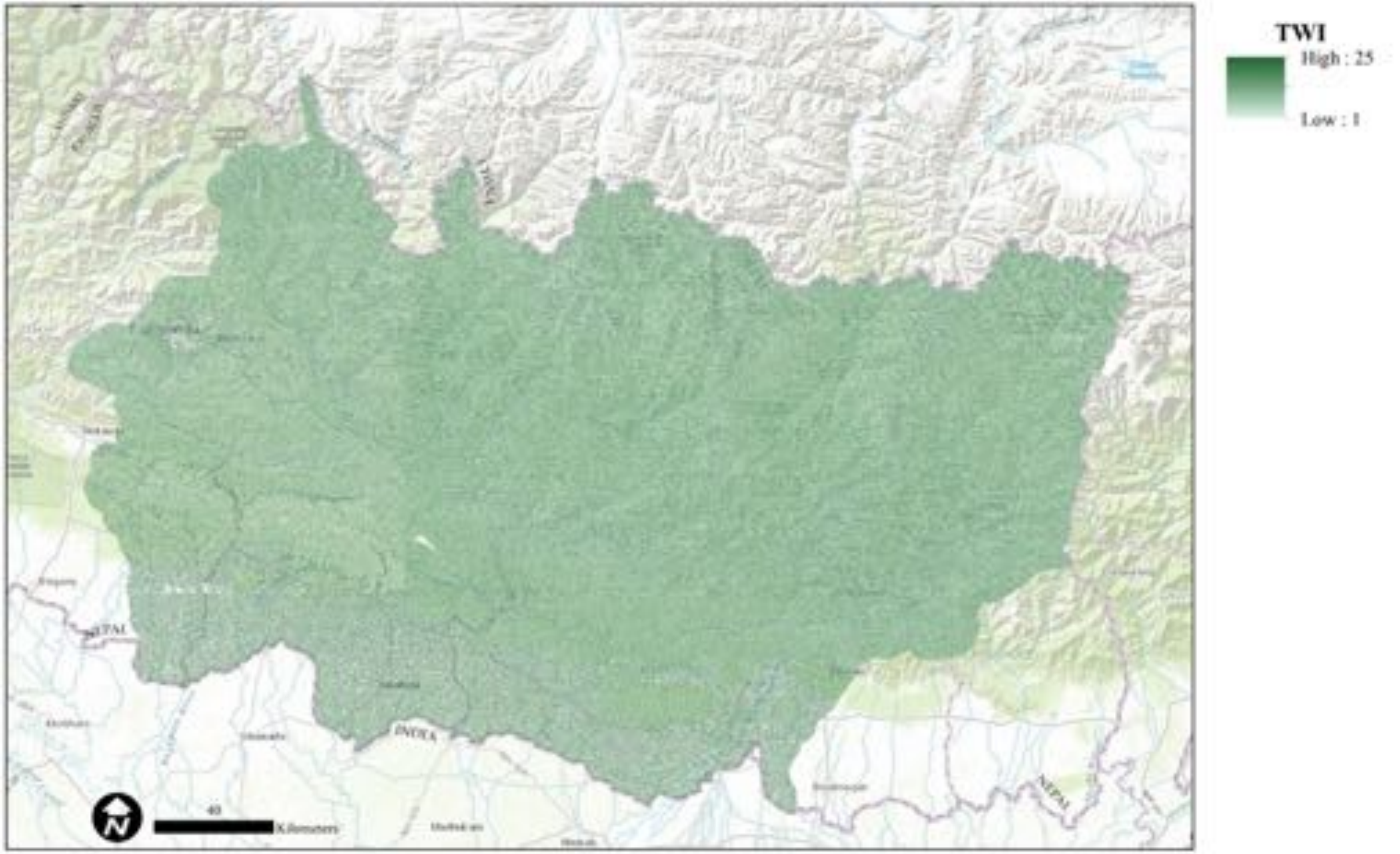



Drainage Density
High : 10.5
Low : 0
Kilometers



$$SPI = A_s tan\beta$$

$$STI = (\frac{A_s}{22.3})^m\ (\frac{sin\beta}{0.0896})^n$$



$$TWI = \ln(As/\tan\beta)$$

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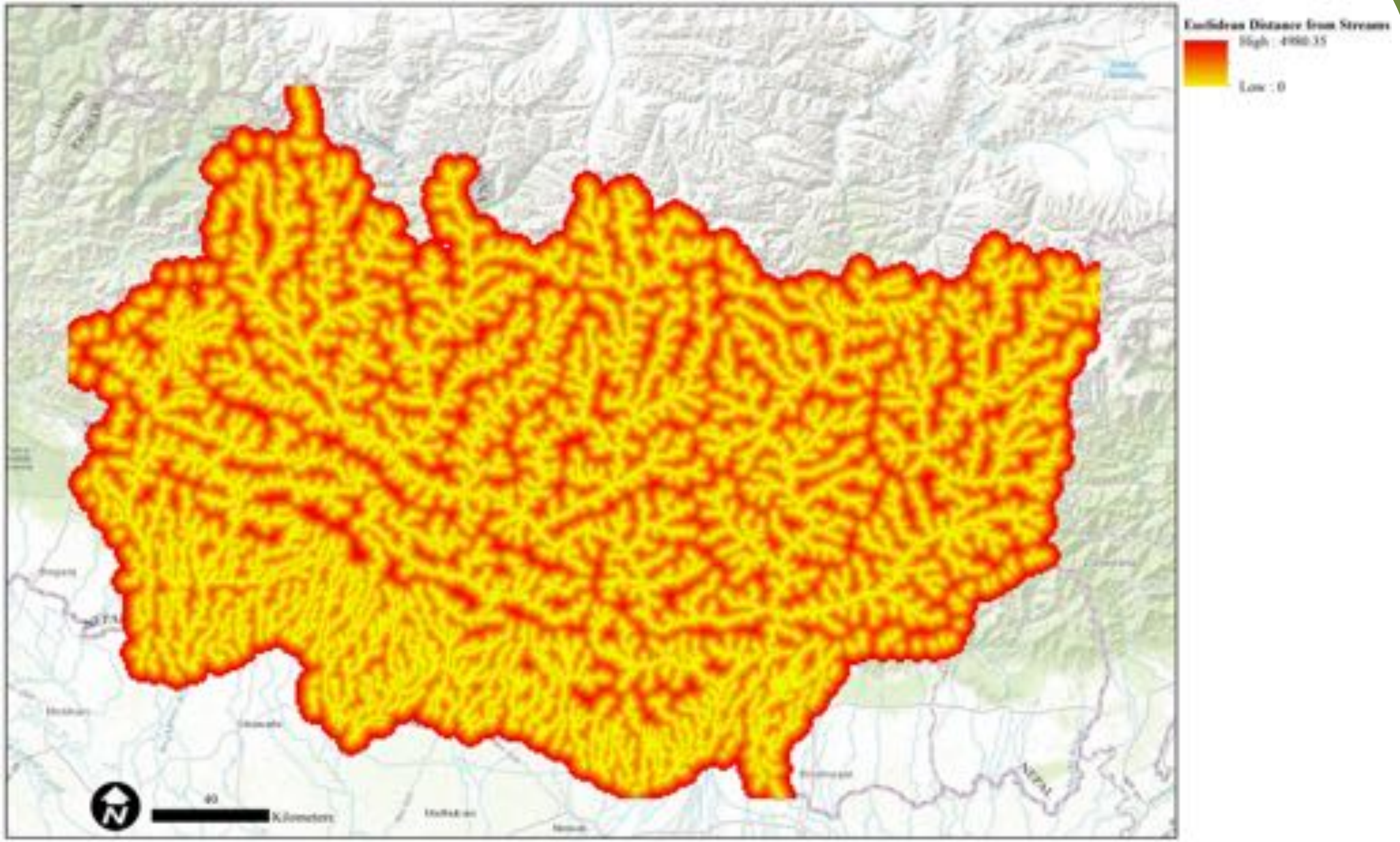
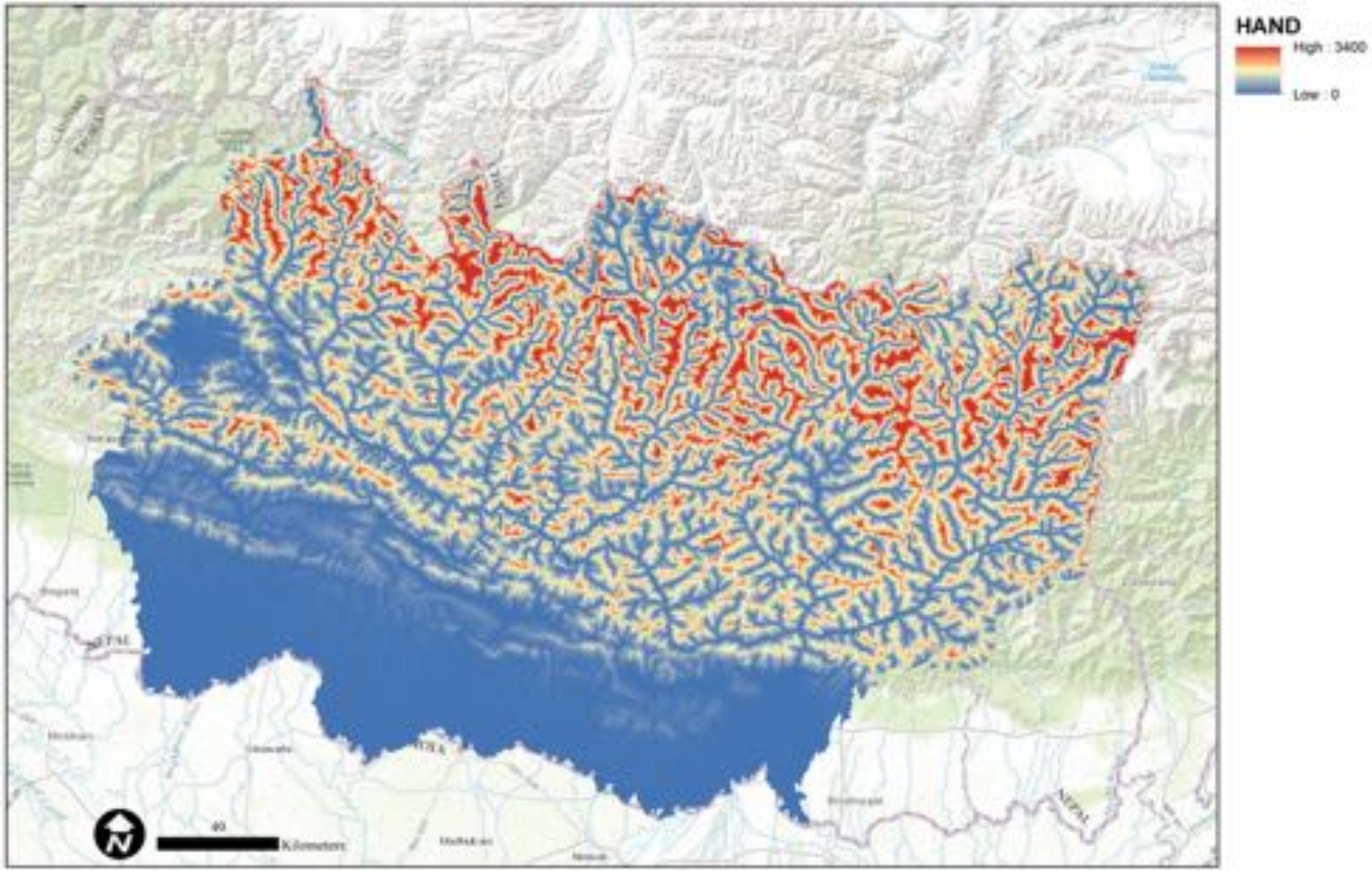
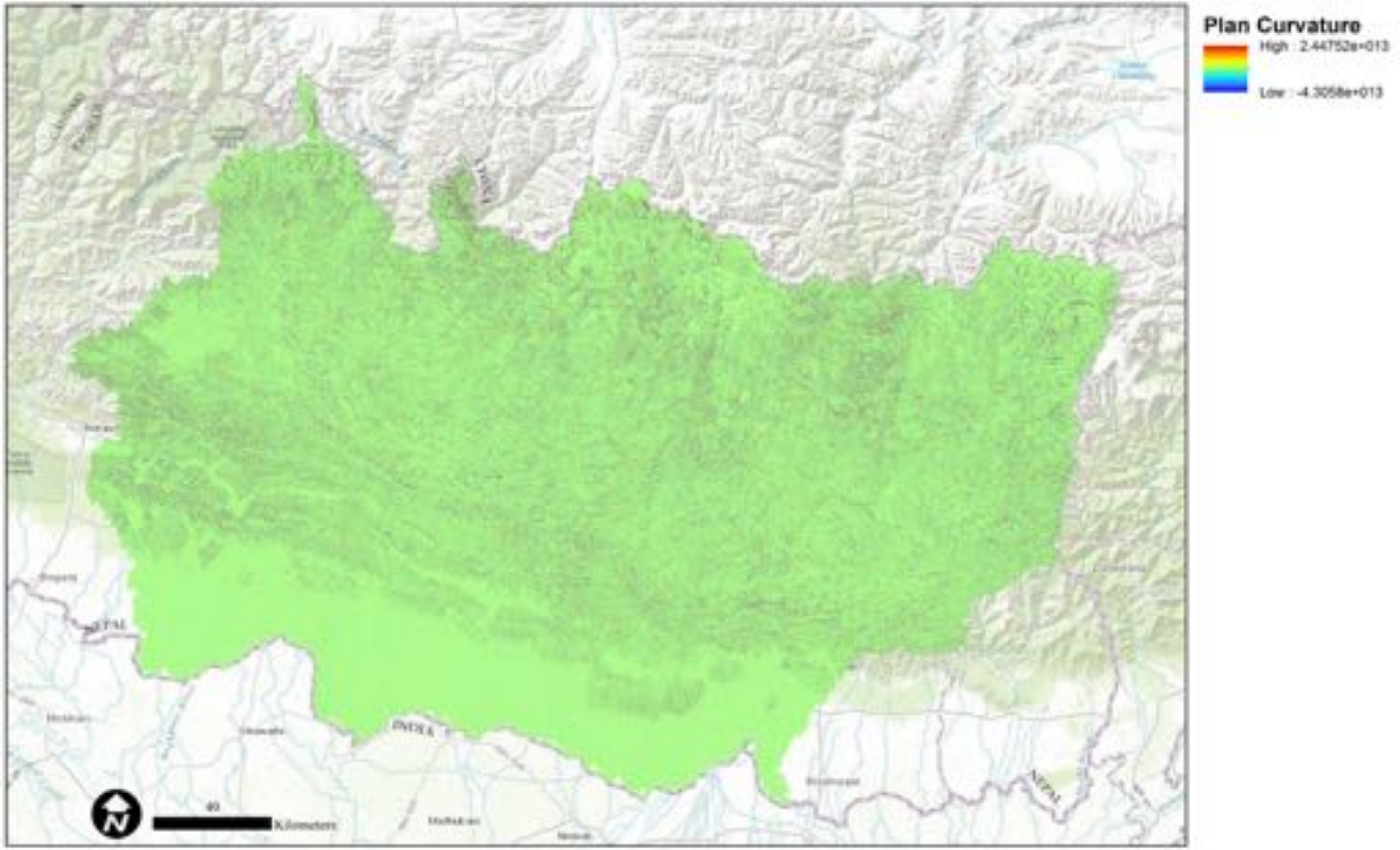
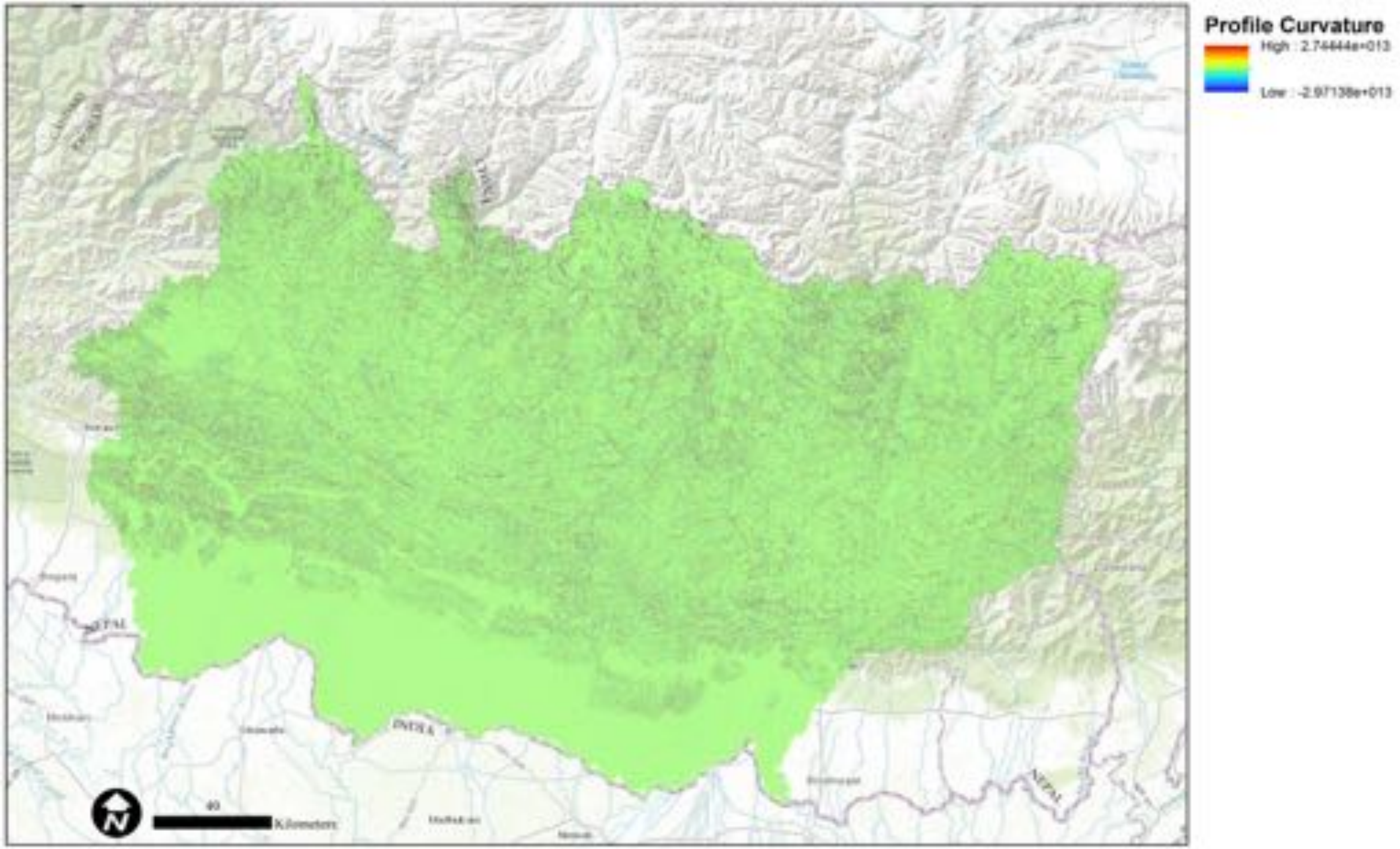
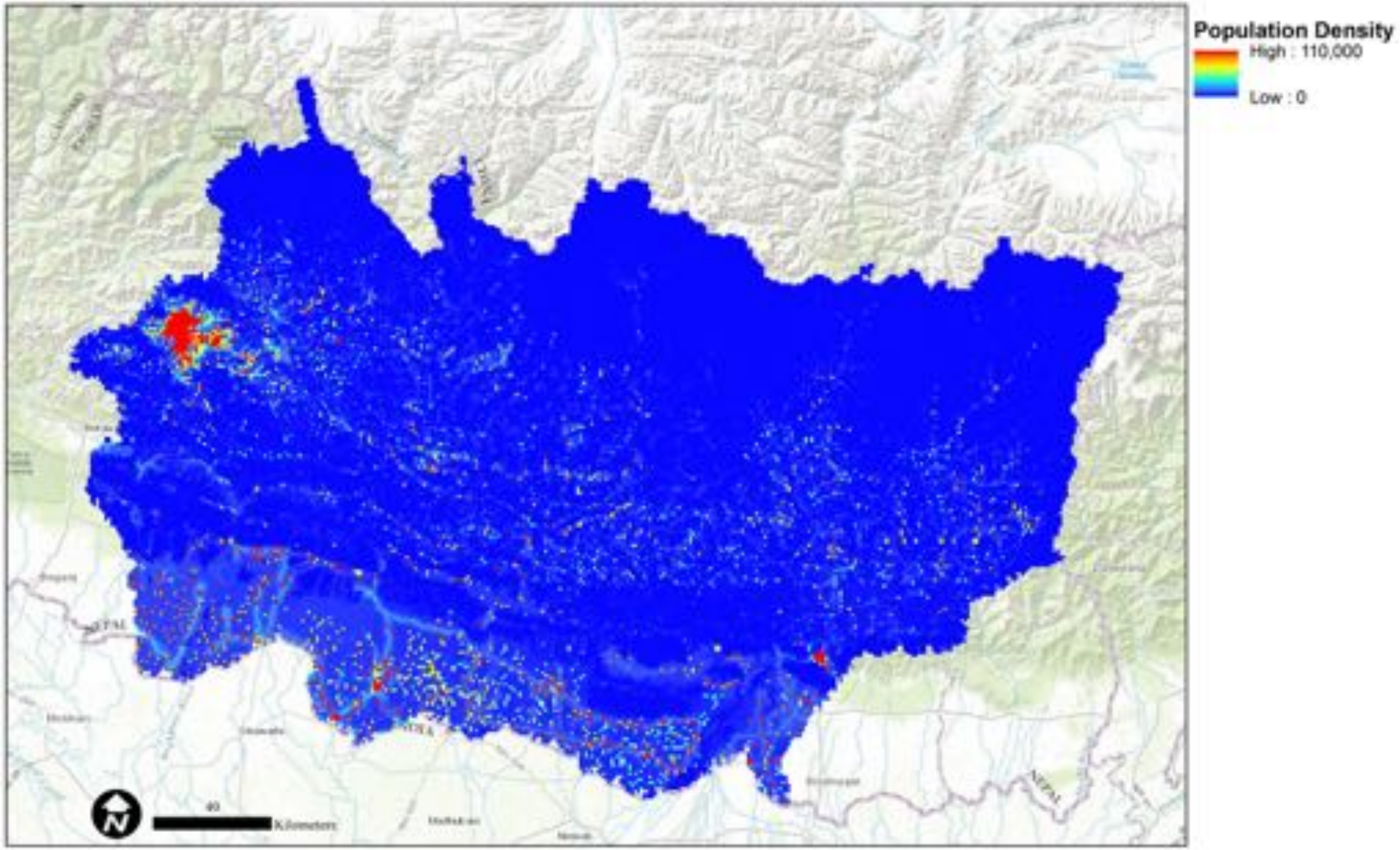
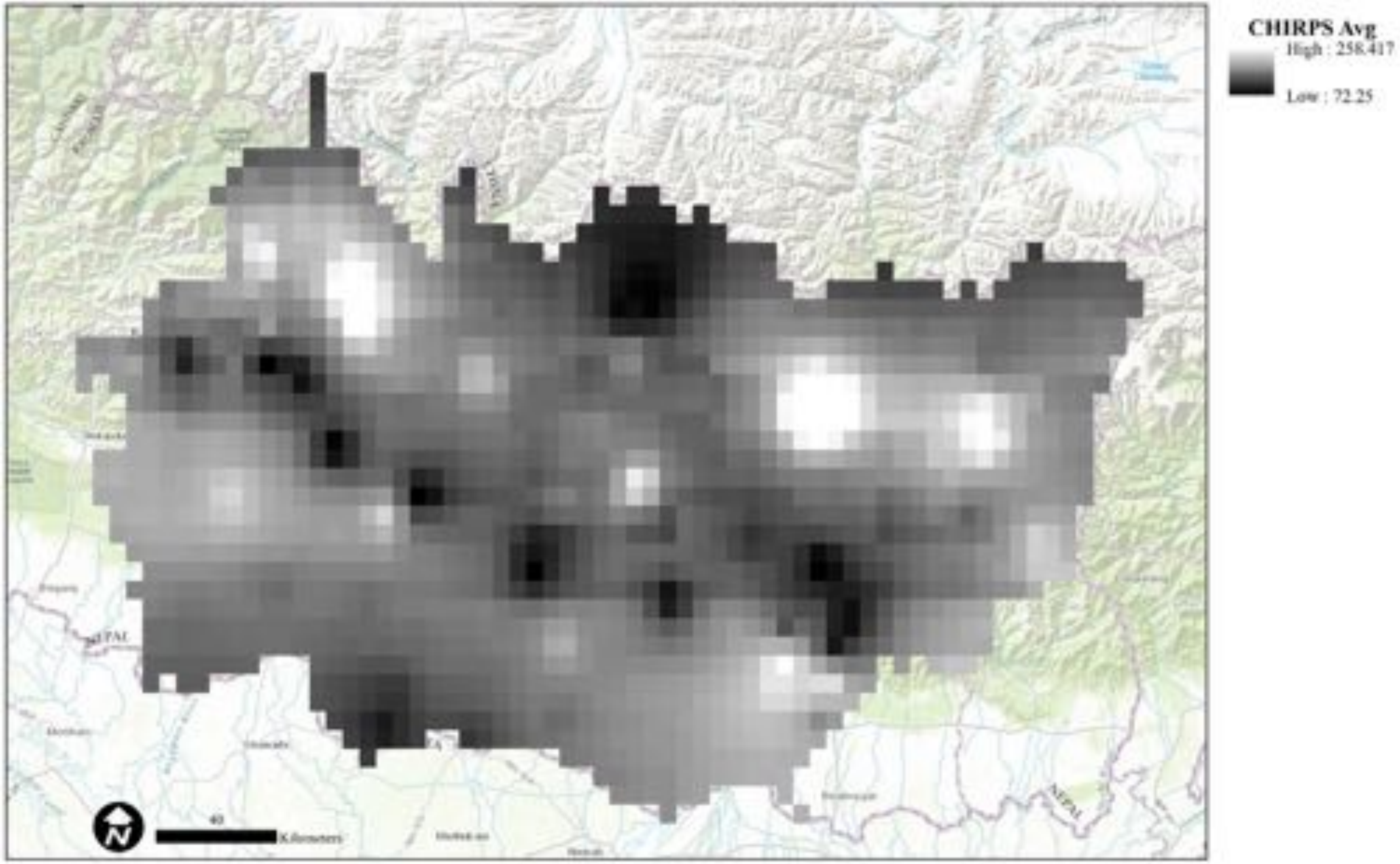


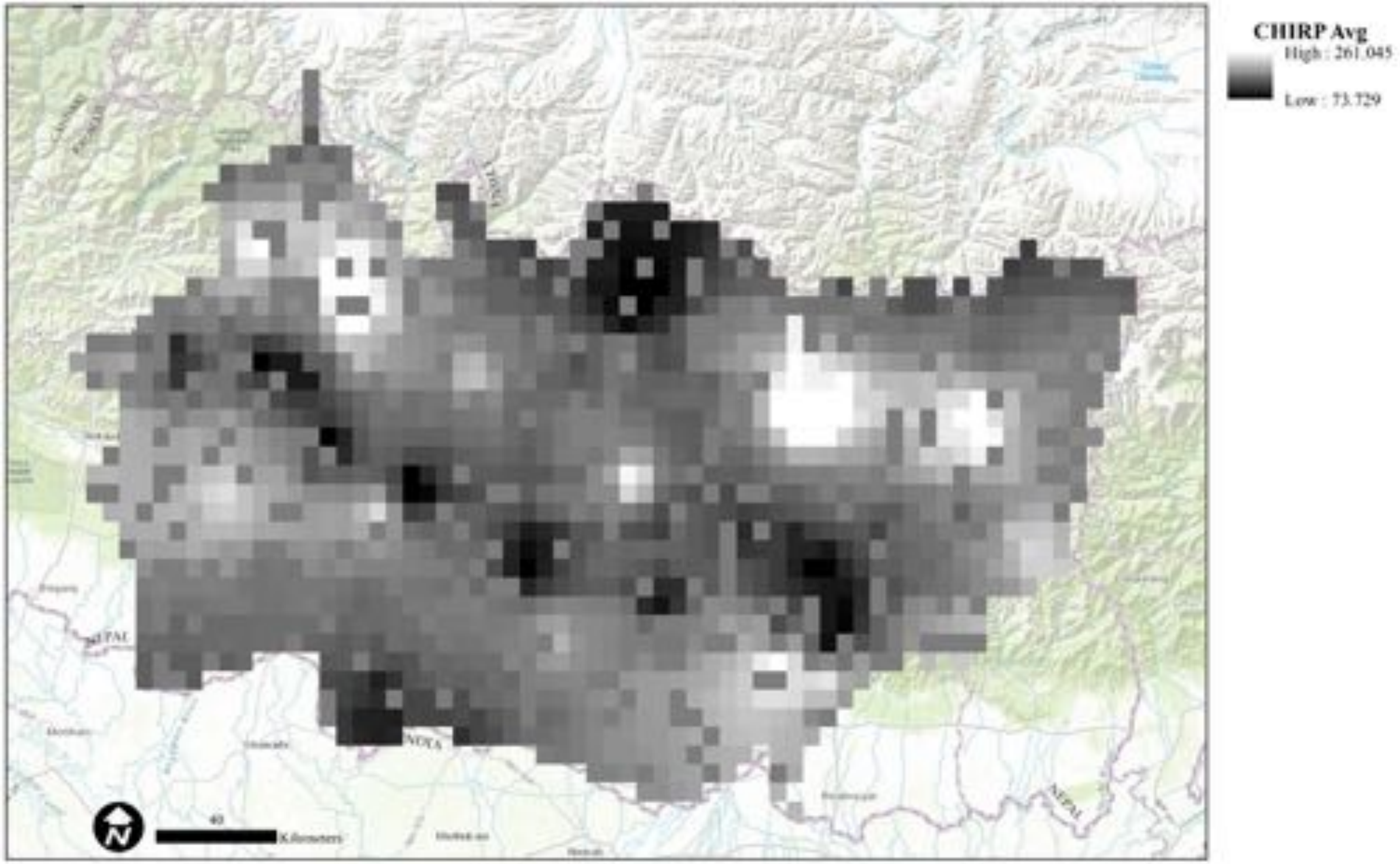

HAND
High : 3400
Low : 0
Kilometers

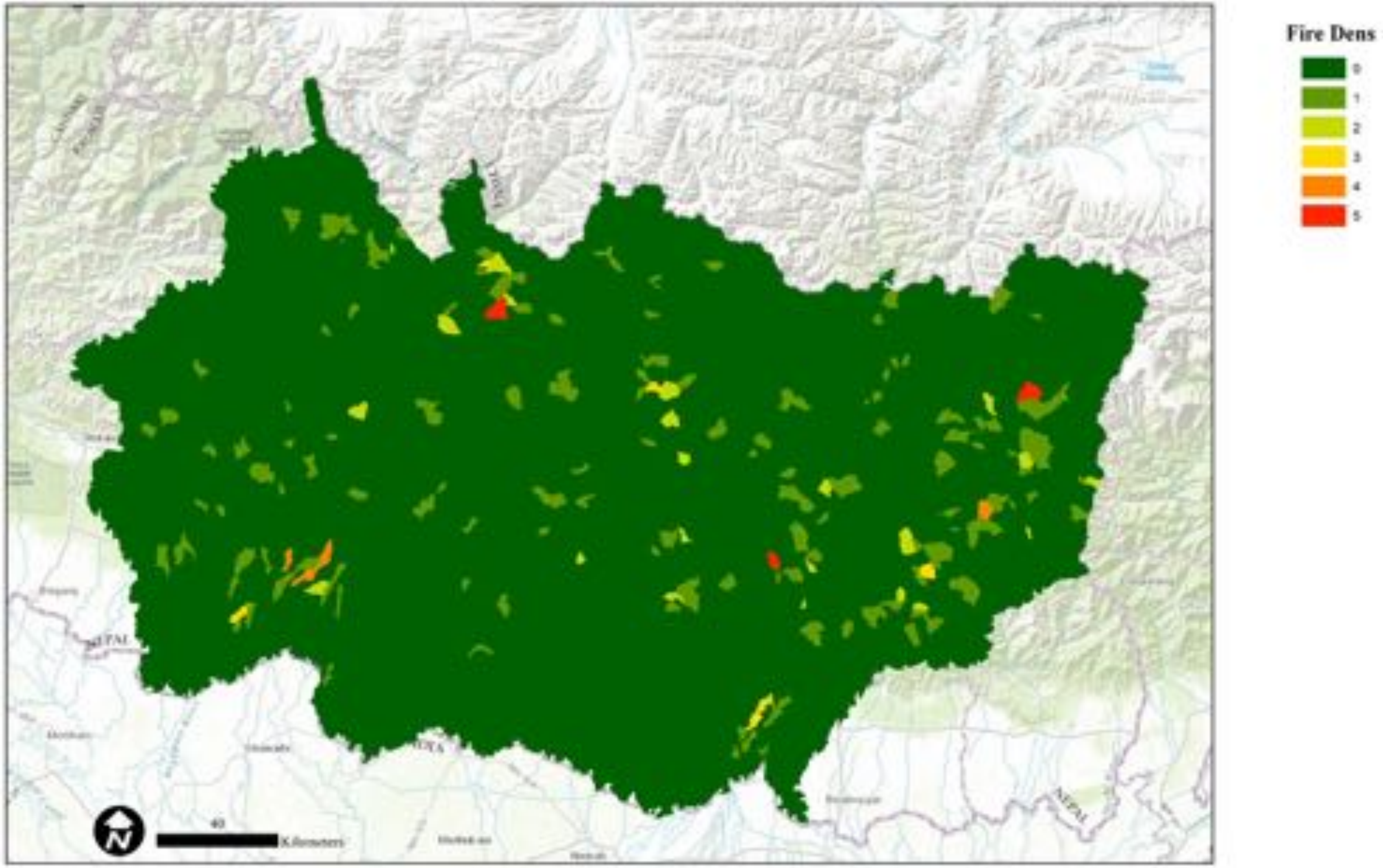

Plan Curvature
High : 2.44752e+013
Low : -4.3058e+013
INDIA
NEPAL
40
Kilometers

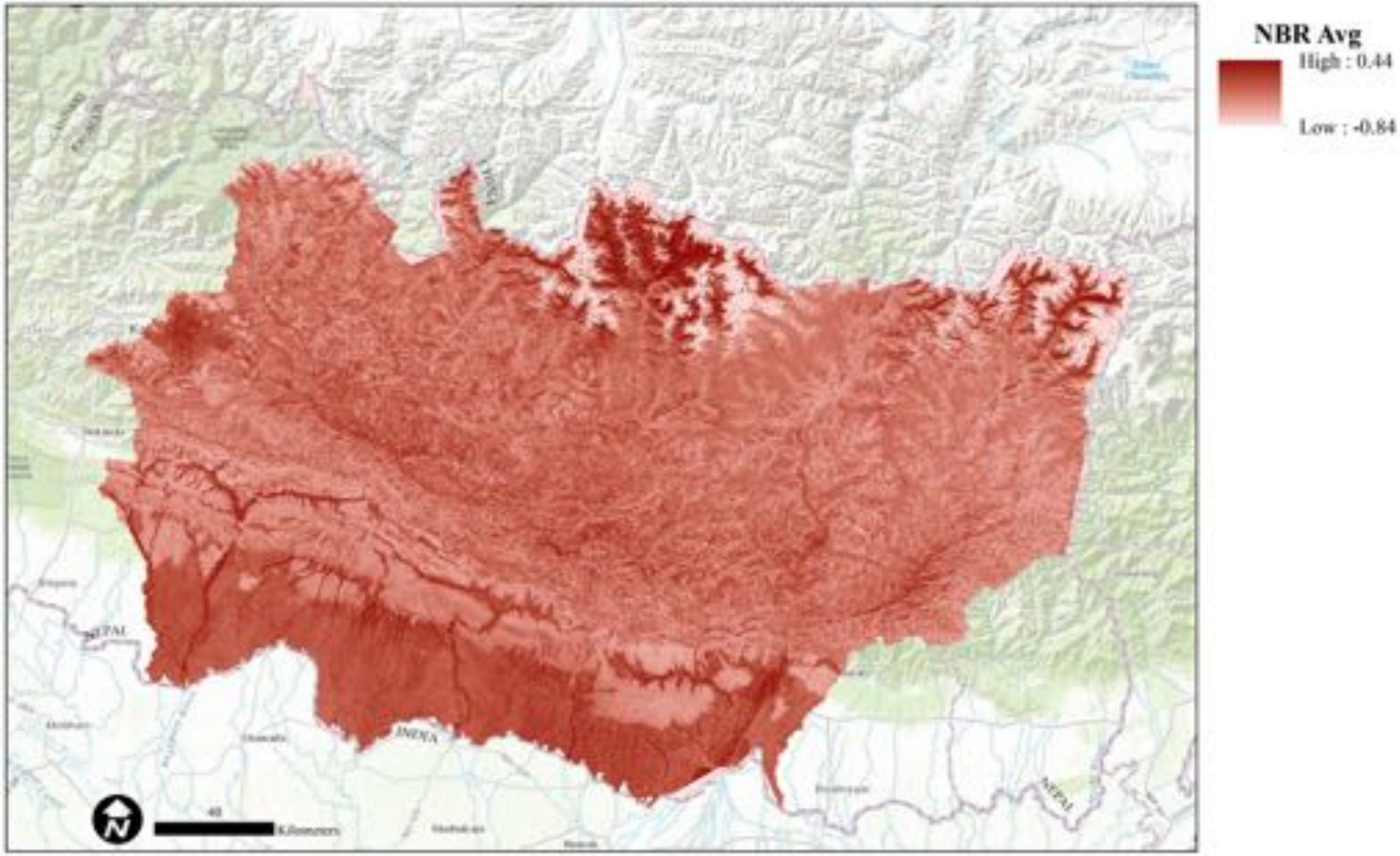

Profile Curvature
High : 2.74444e+013
Low : -2.97138e+013
INDIA
NEPAL
Kilometers


Population Density
High : 110,000
Low : 0
40
Kilometers


CHIRPS Avg
High : 258.417
Low : 72.25
NEPAL
40
Kilometers
NEPAL


CHIRP Avg
High : 261.045
Low : 73.729
Kilometers


Fire Dens
0
1
2
3
4
5
40
Kilometers
NEPAL
NEPAL

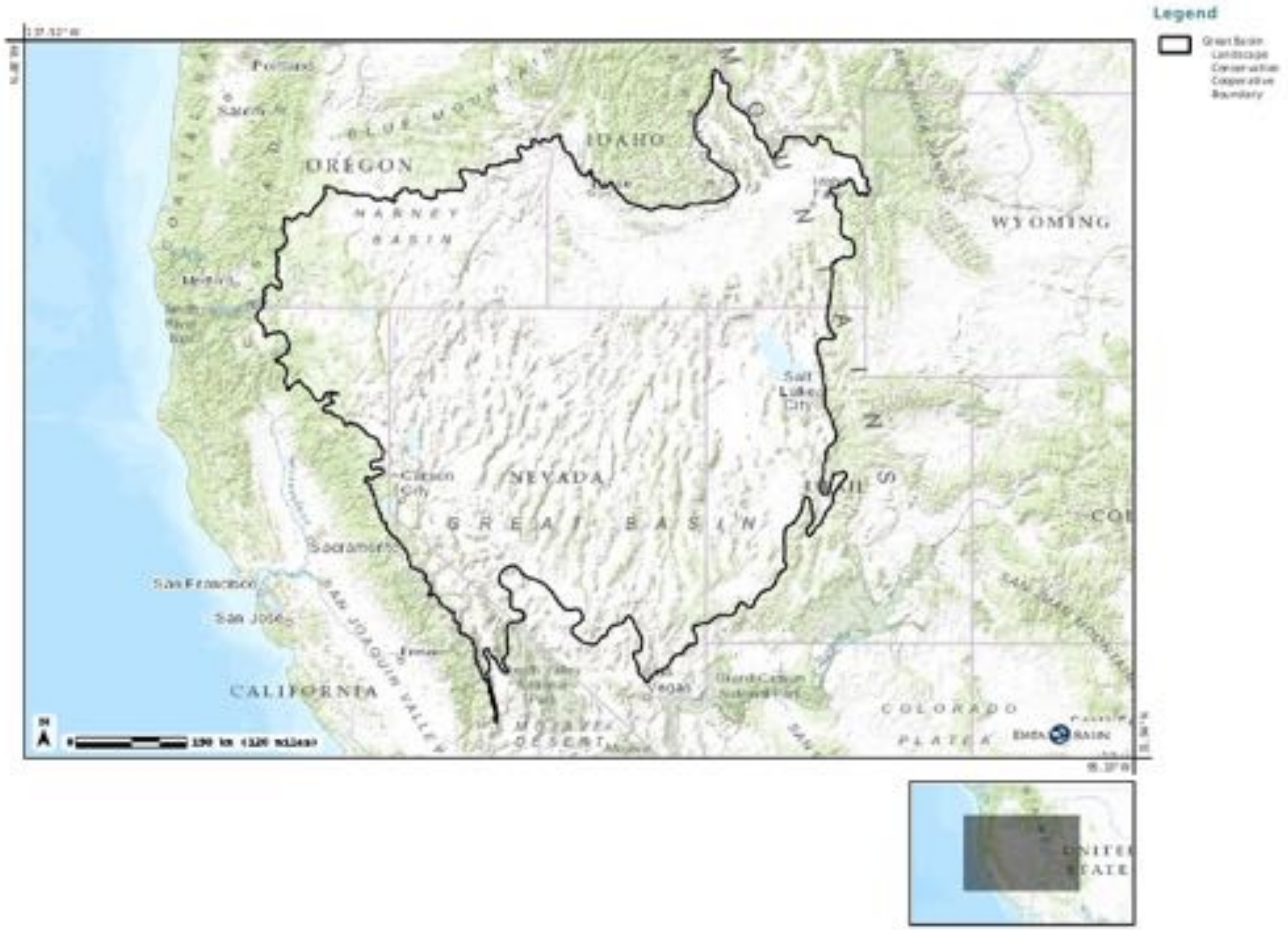

NBR Avg
High : 0.44
Low : -0.84
NEPAL
INDIA
NEPAL
Kilometers

United States Great Basin

- ~542,000 km^2

- Contains North America's lowest point (Badwater Basin-Death Valley) and the highest point in the contiguous United States (Mt. Whitney) separated by less than 200 km

- Contiguous watersheds-basin and range topography formed by collision of Pacific Plate with North American Plate


Legend
Portland
Salem
OREGON
HARNEY BASIN
IDAHO
WYOMING
Medford
Salt Lake City
Carson City
NEVADA
GREAT BASIN
Sacramento
San Francisco
San Jose
CALIFORNIA
MOJAVE DESERT
COLORADO PLATEAU

Great Basin Fire

- Fire is one of the biggest natural threats to ecosystems in this region
- Fire size and intensity in the region are increasing according to Federal Land Management agencies
- Changes in fire regime contribute to increased concern for landslide potential in recently burned basins (Cannon et al, 2009)
- When rain follows fire events, flooding and landslides often occur