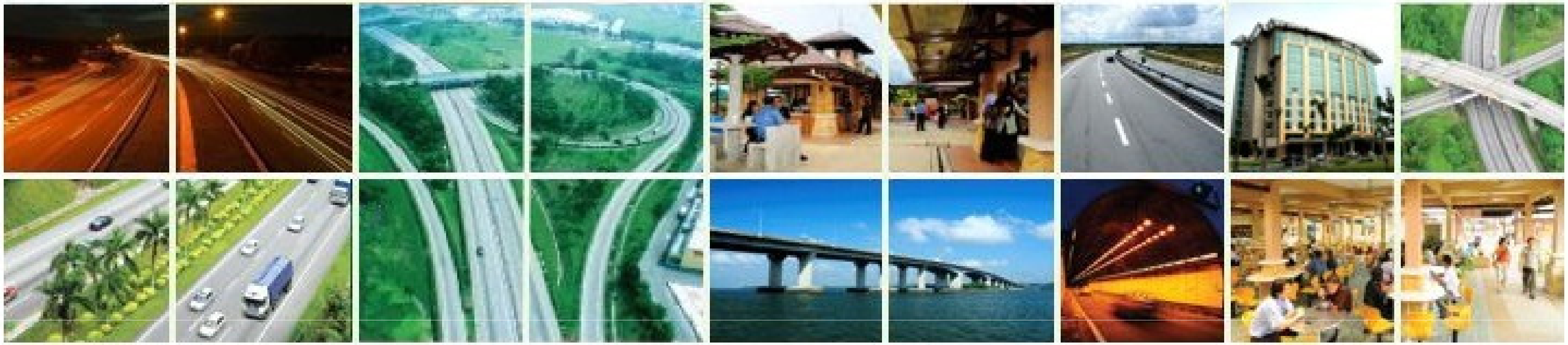


Landslide Hazard Analysis at Jelapang of North-South Expressway in Malaysia Using High Resolution Airborne LiDAR Data

NORBAZLAN MOHD YUSOF

GEOSPATIAL WORLD FORUM 2015
Geospatial World Forum, Portugal
25-29 MAY 2015

CONTENT

OVERVIEW OF UEM GROUP BERHAD

Khazanah Nasional Berhad is the investment holding arm of the Government of Malaysia, with investments in over 50 major companies in Malaysia and abroad.

KHAZANAH NASIONAL

100 %

UEM

EXPRESSWAYS	TOWNSHIP/ PROPERTY DEVELOPMENT	ENGINEERING & CONSTRUCTION	ASSET & FACILITIES MANAGEMENT
			
PLUS Projek Lebuhraya Usahasama Bhd. PLUS PLUS Malaysia Berhad	UEM SUNRISE	UEM BUILDERS OPUS CIMA	OPUS PROPEL

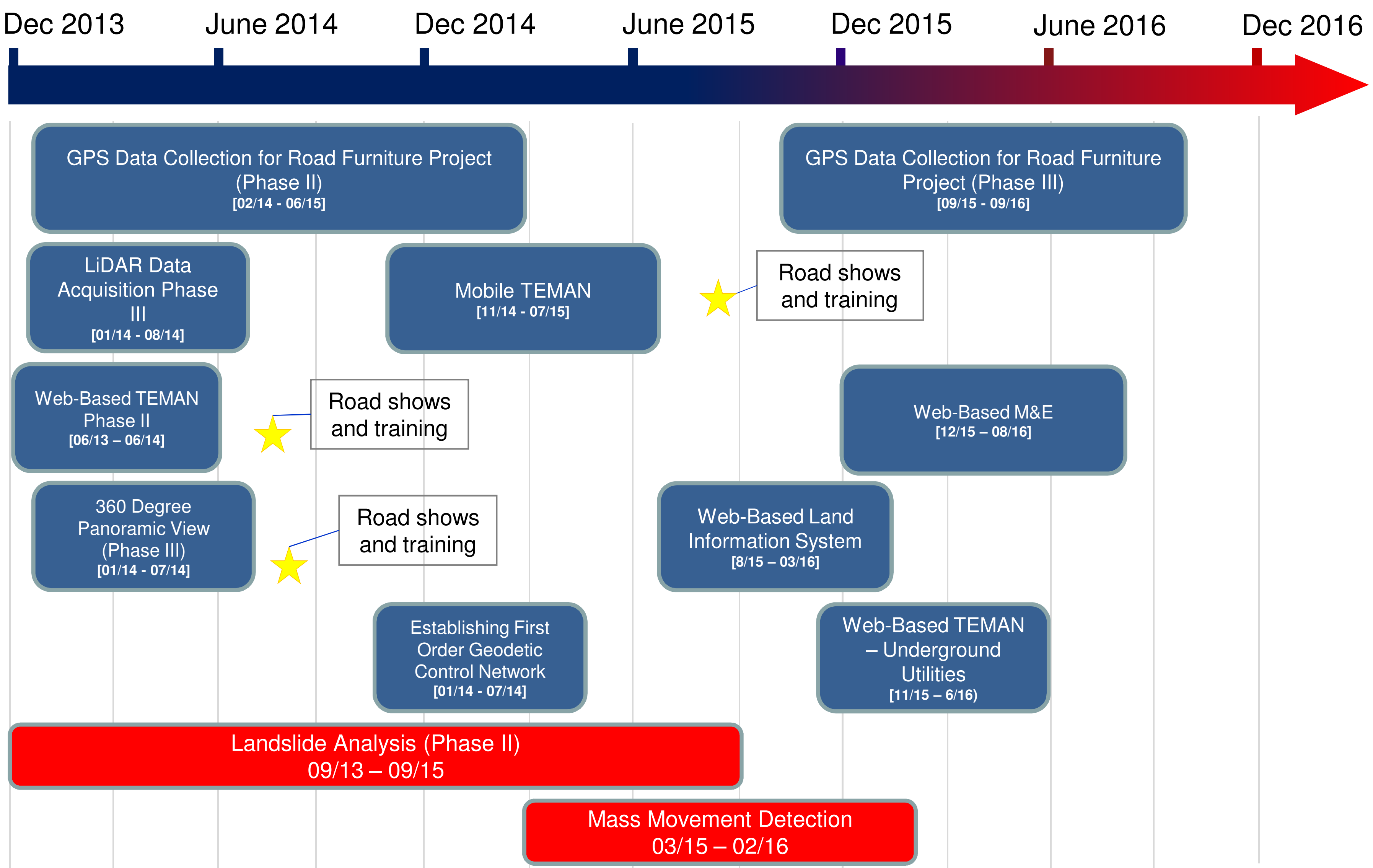
Listed on Bursa Malaysia (3)

LARGEST EXPRESSWAY OPERATOR IN MALAYSIA & ASIA WITH MORE THAN 25 YEARS OF EXPERIENCE

		Length
PLUS	North-South Expressway	846 km
ELITE	NSE Central Link	63 km
LINKEDUA	Malaysia-Singapore Second Crossing	47 km
BKE	Butterworth-Kulim Expressway	17 km
PBSB	Penang Bridge	13.5km
		986.5 km

Open Toll System: Generic to *city* highways
Close Toll System: Generic to *interurban* highways

PLUS GIS : Improvement Plan (IP) 2013 - 2016

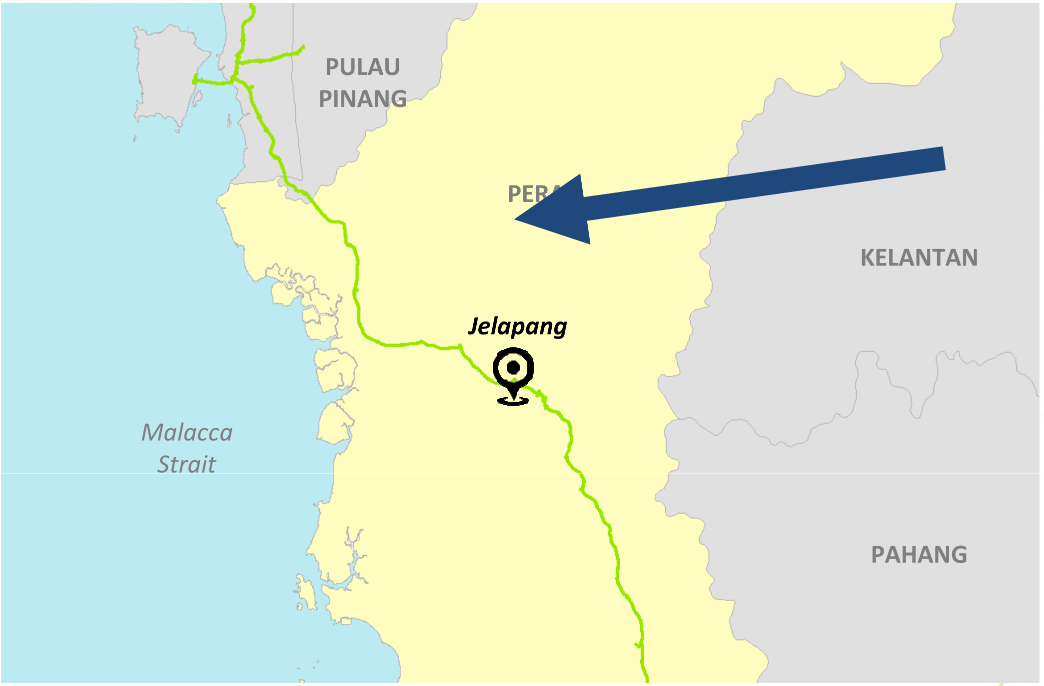


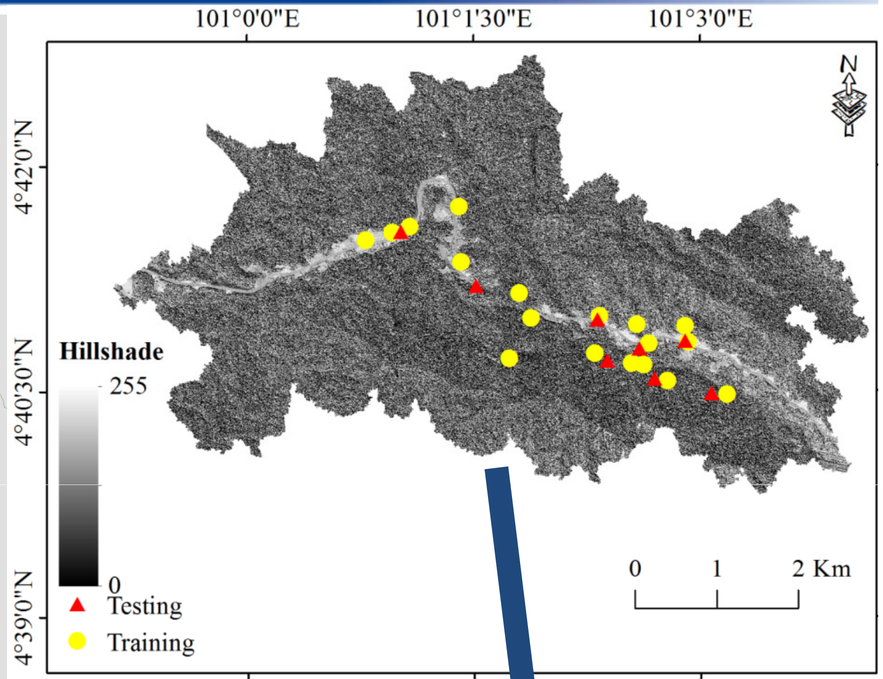
- Overview
- **Research Methodology**
- Analysis
- Conclusion & Way Forward

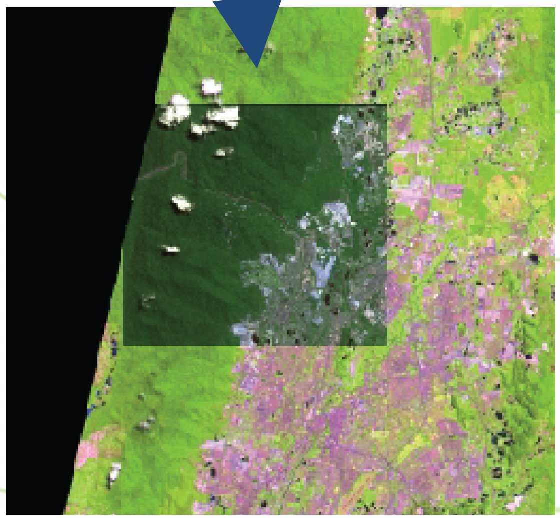
OBJECTIVES

1. To define landslide conditioning parameters influencing the characters of landslides in the study areas;
2. To analyse various types of landslide related data in a Geographic Information System (GIS), at site specific scale as well as using remote sensing data;
3. To assimilate remote sensing data; data from PLUS Highways Berhad and field data into a GIS format for quantitative modelling;
4. To provide landslide risk map for the pilot study areas;
5. To design and develop probabilistic based evidential belief (EBF) and statistical based logistic regression (LR) models for landslide susceptibility and hazard analysis for the study areas;

STUDY AREA
JELAPANG (28.4KM^2)







Records and observation from 2004 to 2011 found that:

i. Many scars of hillside slope failures on the eastern side of the expressways are also occurred at outside of the Right of Way (ROW).
ii. There are many lineament across Jelapang area which may give impact to slope stability of surrounding rock formation.
iii. Different characteristics on the water catchments.

TERMS

Risk = f (hazard , vulnerability)

RISK

Expected losses (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period. Based on mathematical calculations, **Risk is the product of hazard and vulnerability.**

HAZARD

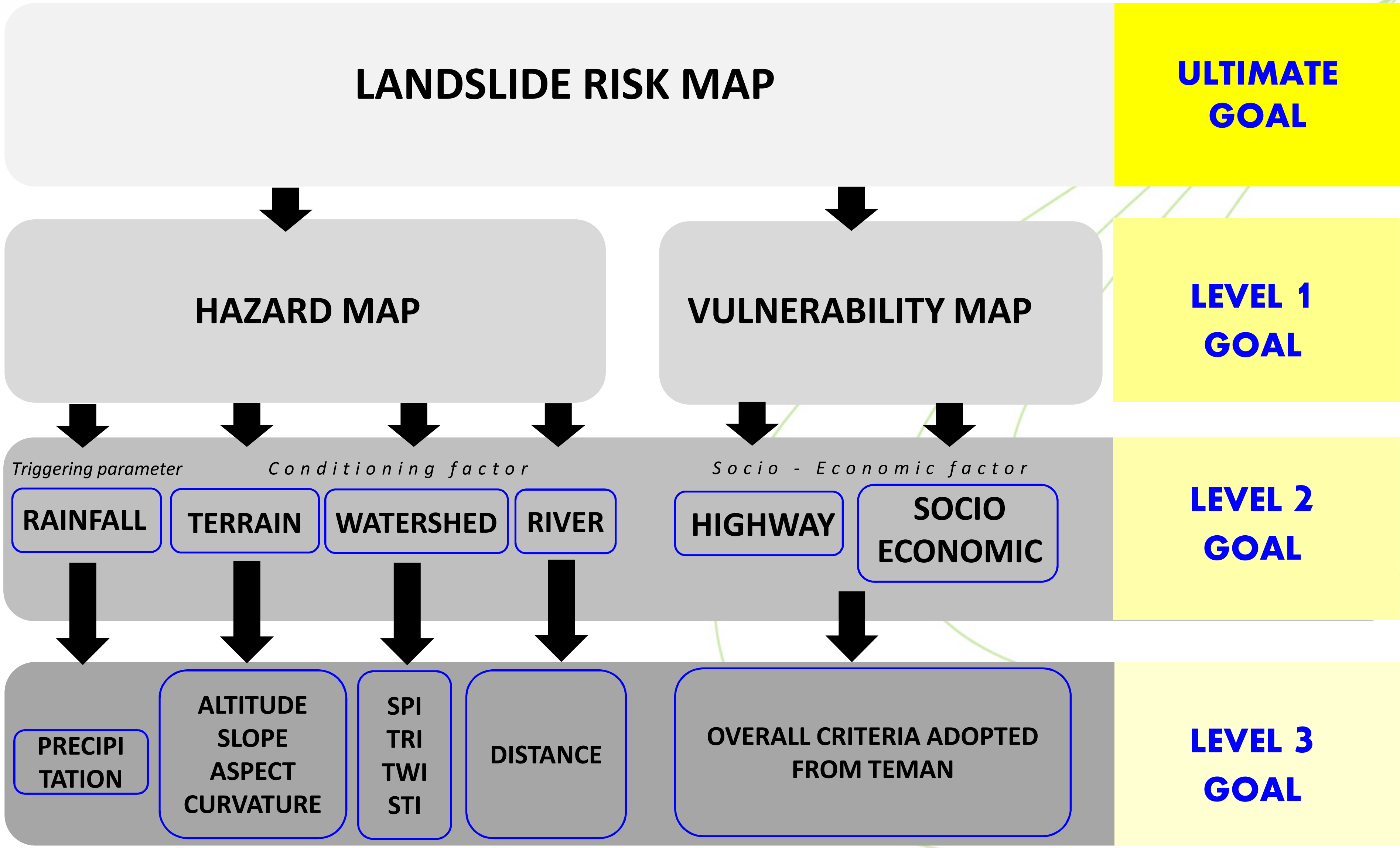
A threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area.

VULNERABILITY

Degree of loss resulting from a potentially damaging phenomenon.

Source : The United Nations Office for Disaster Risk Reduction (UNISDR), United Nations Department of Humanitarian Affairs, 1992

FACTOR SYSTEM



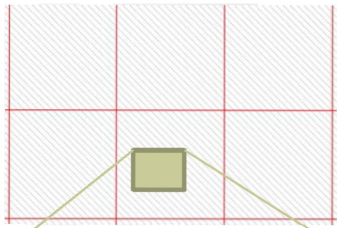
DATA USED *[1]*

	LiDAR	Drainage	Road	Rainfall	Historical Landslide	Element at Risk
ORIGINAL LAYER	**LiDAR**	**Drainage**	**Road**	**Rainfall**	**Historical Landslide**	**Element at Risk**
RESULTED LAYER	❑ DEM / Altitude ❑ Slope Angle ❑ Aspect ❑ Curvature ❑ Stream Power Index (SPI) ❑ Topographic Wetness Index (TWI) ❑ Terrain Roughness Index (TRI)	Distance from drainage	Distance from road	Precipitation Map	Landslide inventory map	Adopted from TEMAN system e.g. Vista point, Lay-by, Highway, Cut Slope

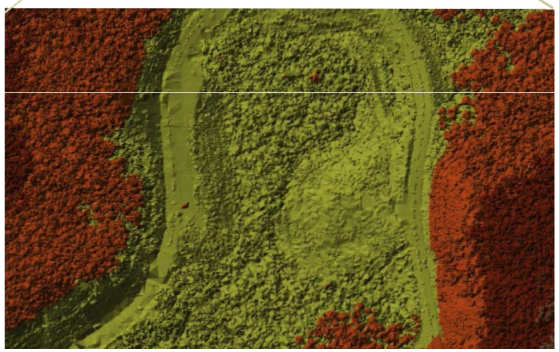
DATA USED *[2]*

UK413352
UK413353
UK413355
UK413356
UK413357
UK413358
UK413359
UK413360

Find the scenes



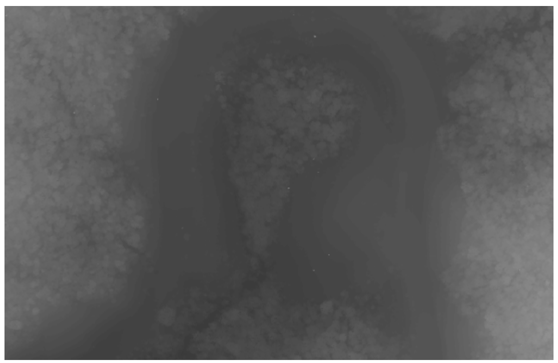
Create LAS dataset



Elevation

- 54.05 - 450.43
- 52.577 - 54.05
- 51.104 - 52.577
- 49.631 - 51.104
- 48.159 - 49.631
- 46.686 - 48.159
- 45.213 - 46.686
- 43.74 - 45.213
- 25.18 - 43.74

LAS dataset to DEM



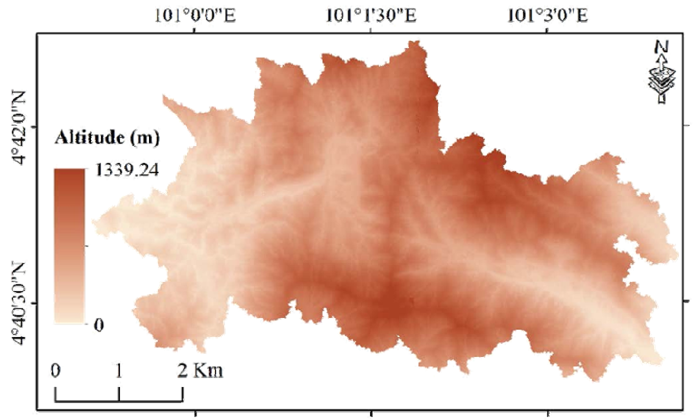
LiDAR Data Processing

- ❑ Creating LAS Dataset
  - ✓ Finding the scenes which cover the study areas
  - ✓ Create LAS dataset
- ❑ LAS dataset to DEM
- ❑ Masking the DEM using the study area layer
- ❑ Derive the topological parameters

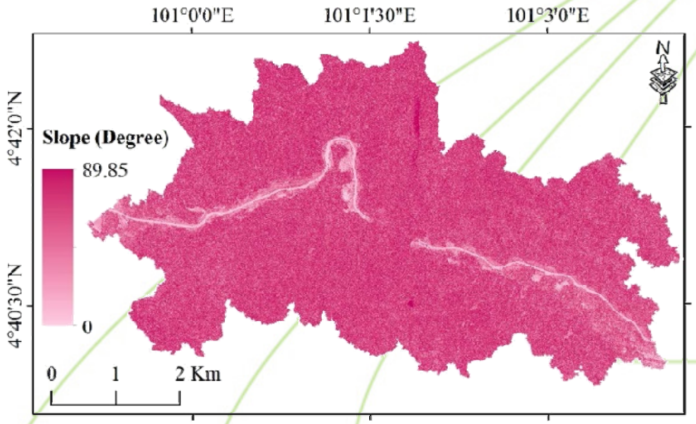
DATA USED *[3]*

Input Data Layers

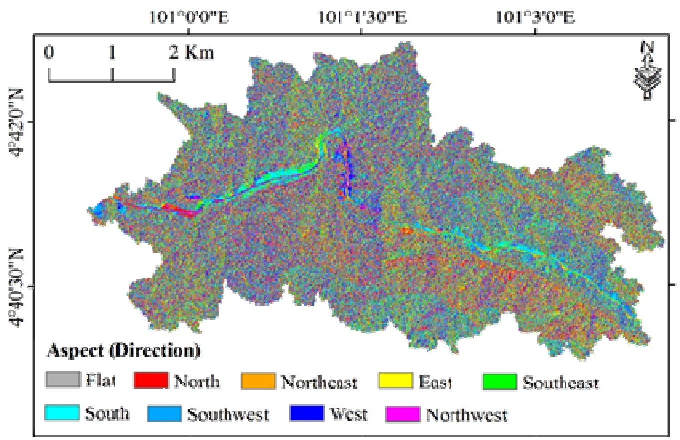
ALTITUDE



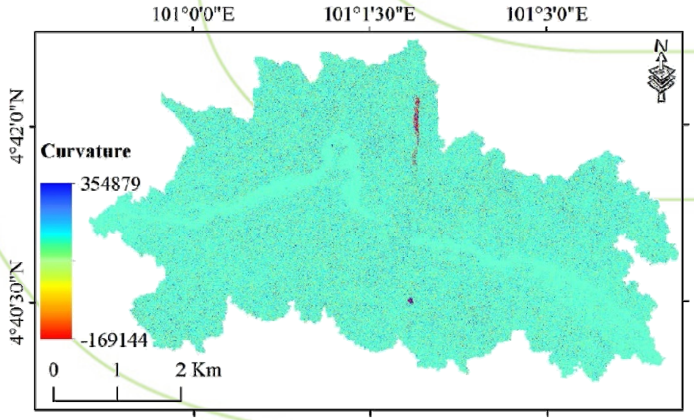
SLOPE



ASPECT



CURVATURE



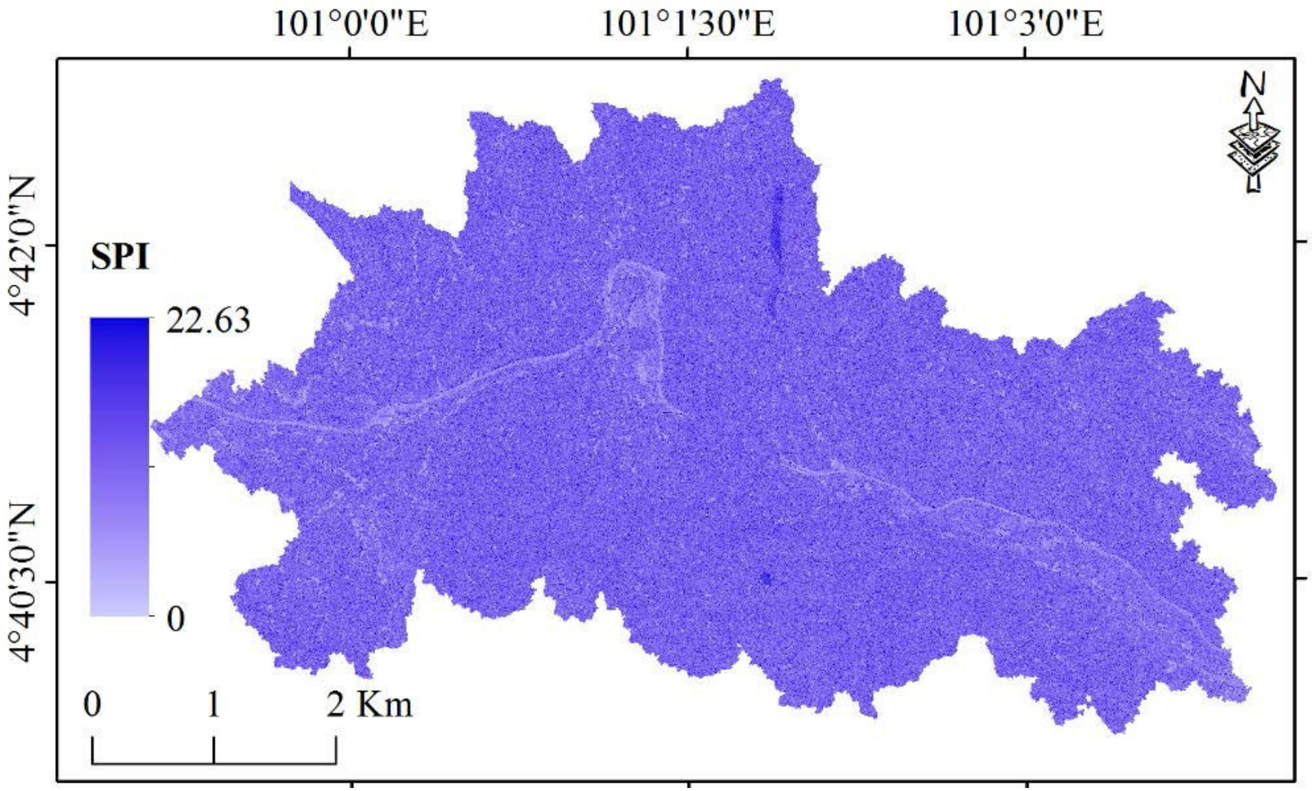
Input Data Layers

STREAM POWER INDEX (SPI)

Describe the potential flow erosion at the given point of the topographic surface.

$$SPI = \ln (A_s * \tan \beta)$$

Where;
A_s is the upstream area
β is the slope in the given cell



DATA USED *[5]*

Input Data Layers

TOPOGRAPHIC WETNESS INDEX (TWI)

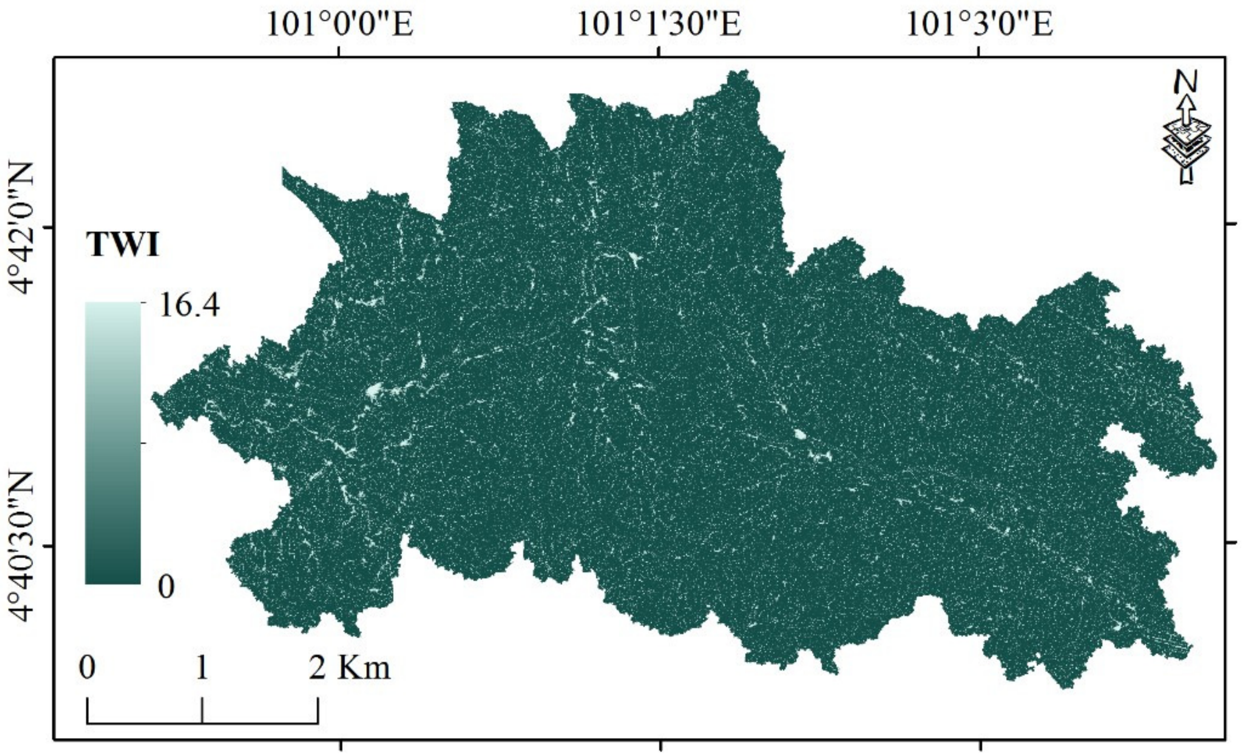
Describe the propensity for a site to be saturated to the surface given its contributing area and local slope characteristics.

$$\textbf{TWI} = \ln (A_s / \tan \beta)$$

Where;

A_s is the upstream area

β is the slope in the given cell



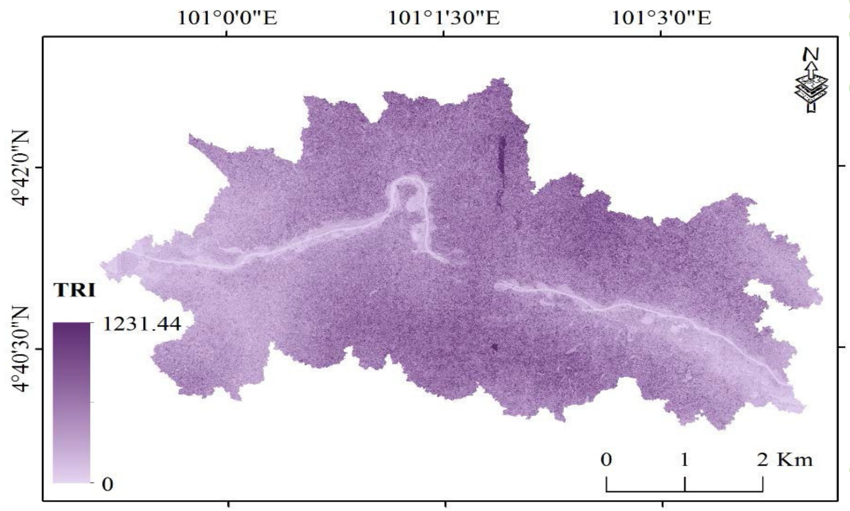
DATA USED *[6]*

Input Data Layers

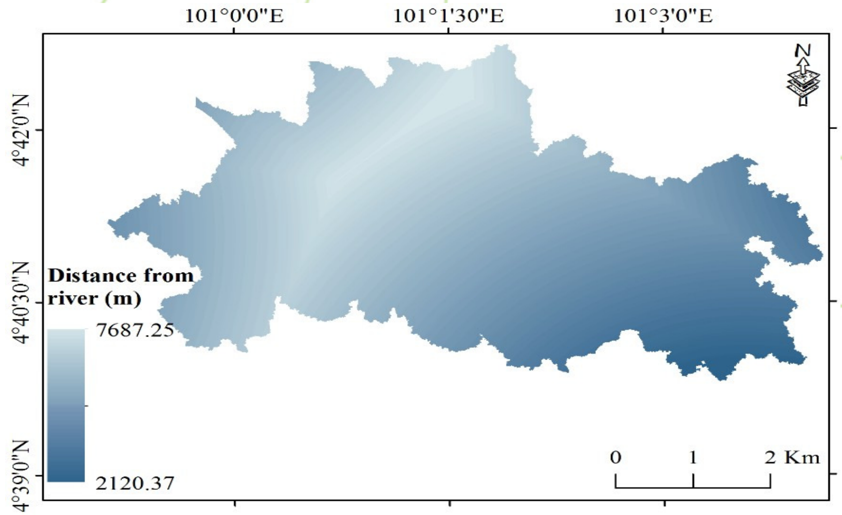
TERRAIN ROUGHNESS INDEX (TRI)

TRI is one of the morphological factors and which is broadly utilized in landslide analysis.

$$\mathbf{TRI} = \sqrt{\mathrm{Abs}\,(max2 - min2)}$$

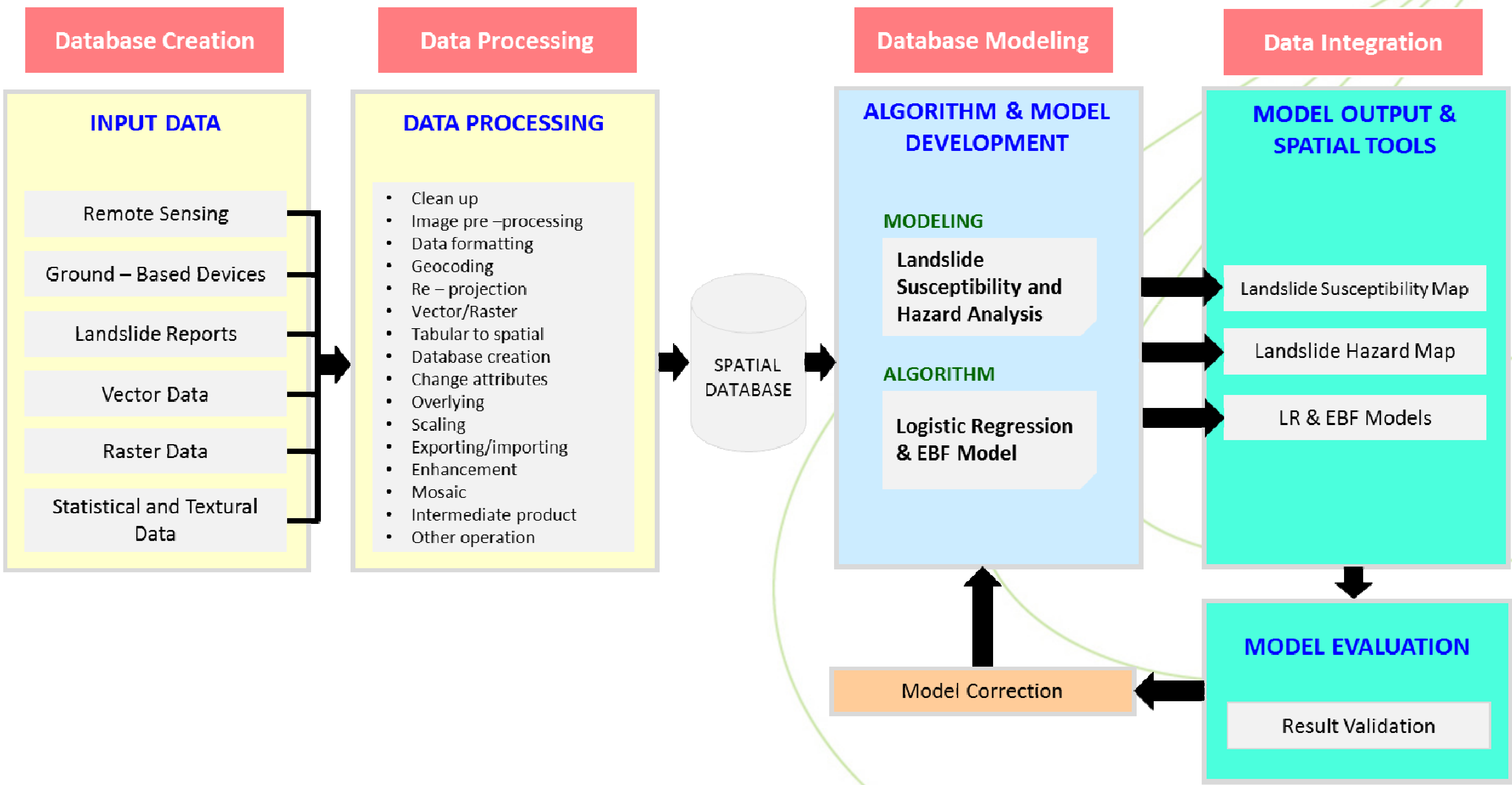


DISTANCE FROM DRAINAGE



- Overview
- Research Methodology
- **Analysis**
- Conclusion & Way Forward

METHODOLOGY FLOWCHART



Evidential Belief Function (EBF) Modeling

The framework of the EBF model is based on the Dempster-Shafer theory of evidence. Estimation of EBFs of evidential data always relates to a proposition. EBFs involve degrees of belief (Bel), uncertainty (Unc), disbelief (Dis), and plausibility (Pls) in the range [0, 1].

Belief (Bel)
lower degree of belief that attribute data support the proposition

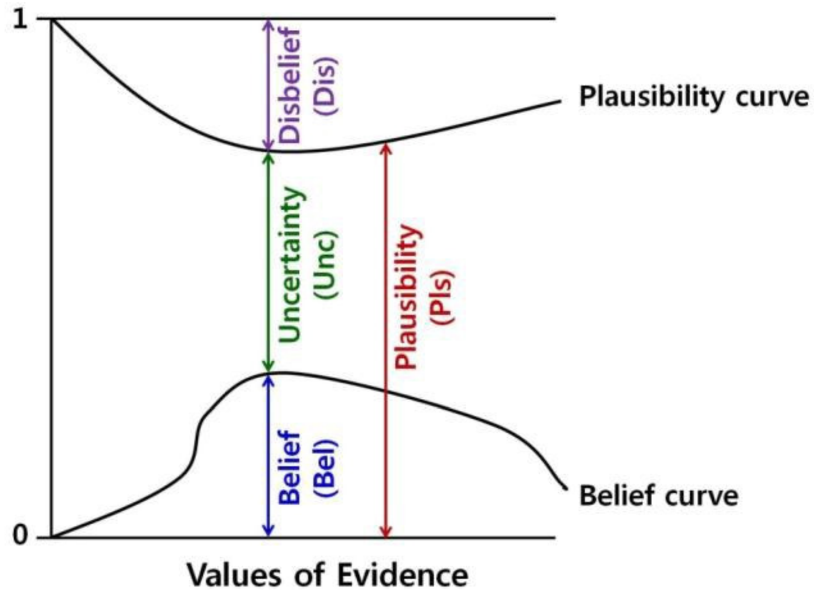
Disbelief (Dis)
degree of disbelief that attribute data support the proposition

Uncertainty (Unc)
'ignorance' whether attribute data support the proposition or not

Plausibility (Pls)
higher degree of belief that attribute support the proposition

DATA MODELING *[2]*

Pls ≥ Bel
Pls – Bel = Unc
Bel + Dis +Unc = 1
Dis = 1-Unc – Bel



$$Bel_{X_1X_2} = \frac{Bel_{X_1}Bel_{X_2} + Bel_{X_1}Unc_{X_2} + Bel_{X_2}Unc_{X_1}}{\beta}$$

$$Dis_{X_1X_2} = \frac{Dis_{X_1}Dis_{X_2} + Dis_{X_1}Unc_{X_2} + Dis_{X_2}Unc_{X_1}}{\beta}$$

$$Unc_{X_1X_2} = \frac{Unc_{X_1}Unc_{X2}}{\beta}$$

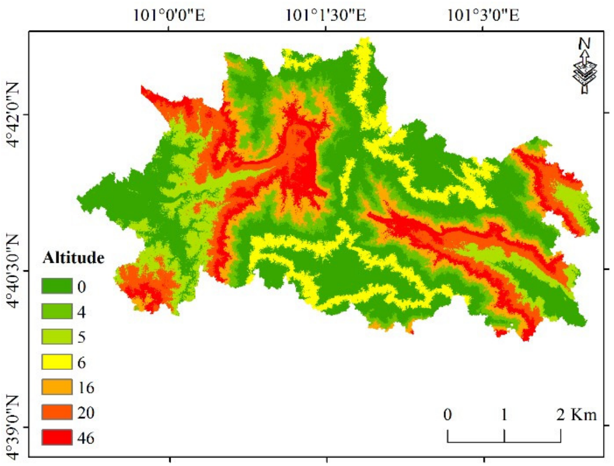
where $\beta = 1 - Bel_{X_1}Dis_{X_2} - Dis_{X_1}Bel_{X_2}$

is a normalizing factor that ensures $Bel + Unc + Dis = 1$

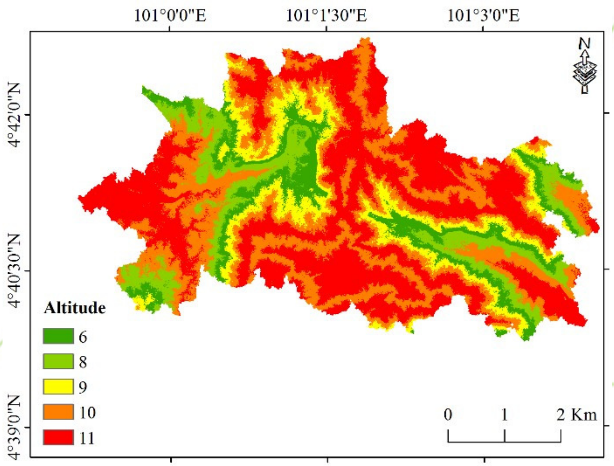
DATA MODELING *[3]*

EBF Model Output e.g : ALTITUDE

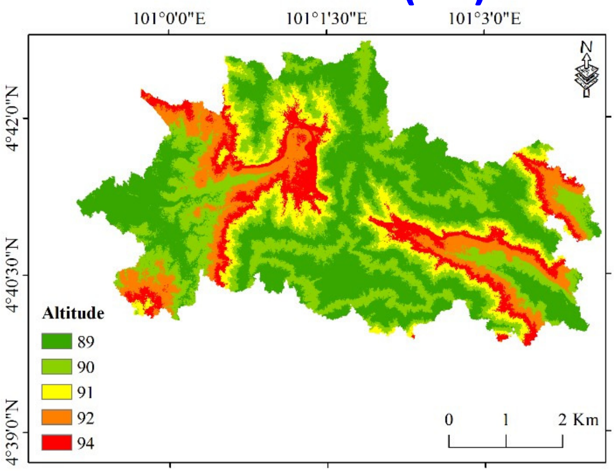
BELIEF (Bel)



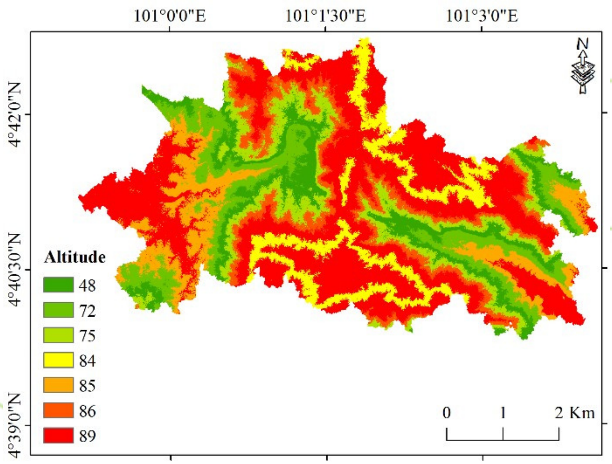
DISBELIEF (Dis)



PLAUSIBILITY (Pls)

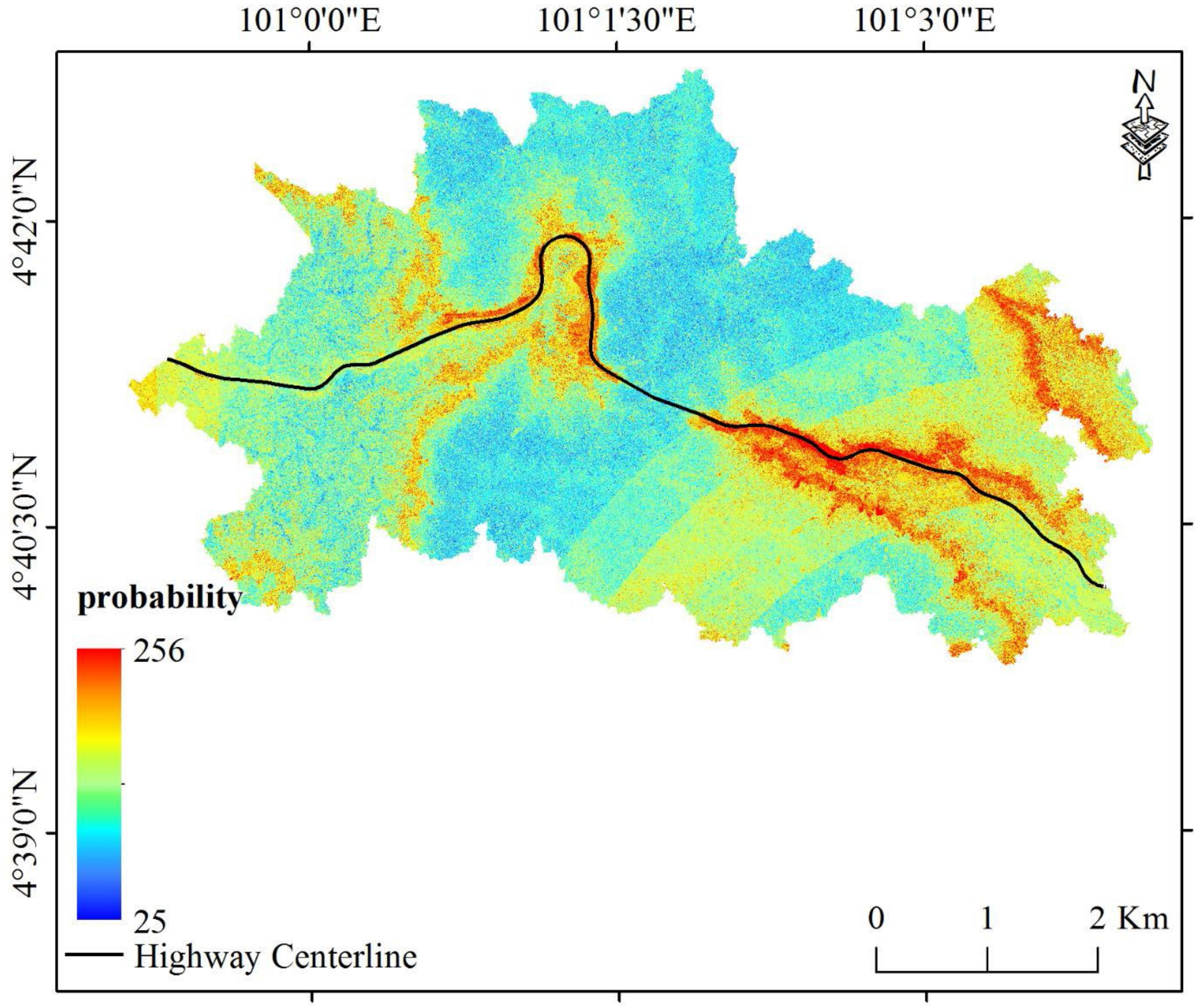


UNCERTAINTY (Unc)



DATA MODELING *[4]*

EBF Model Probability Map



Logistic Regression (LR) Modeling

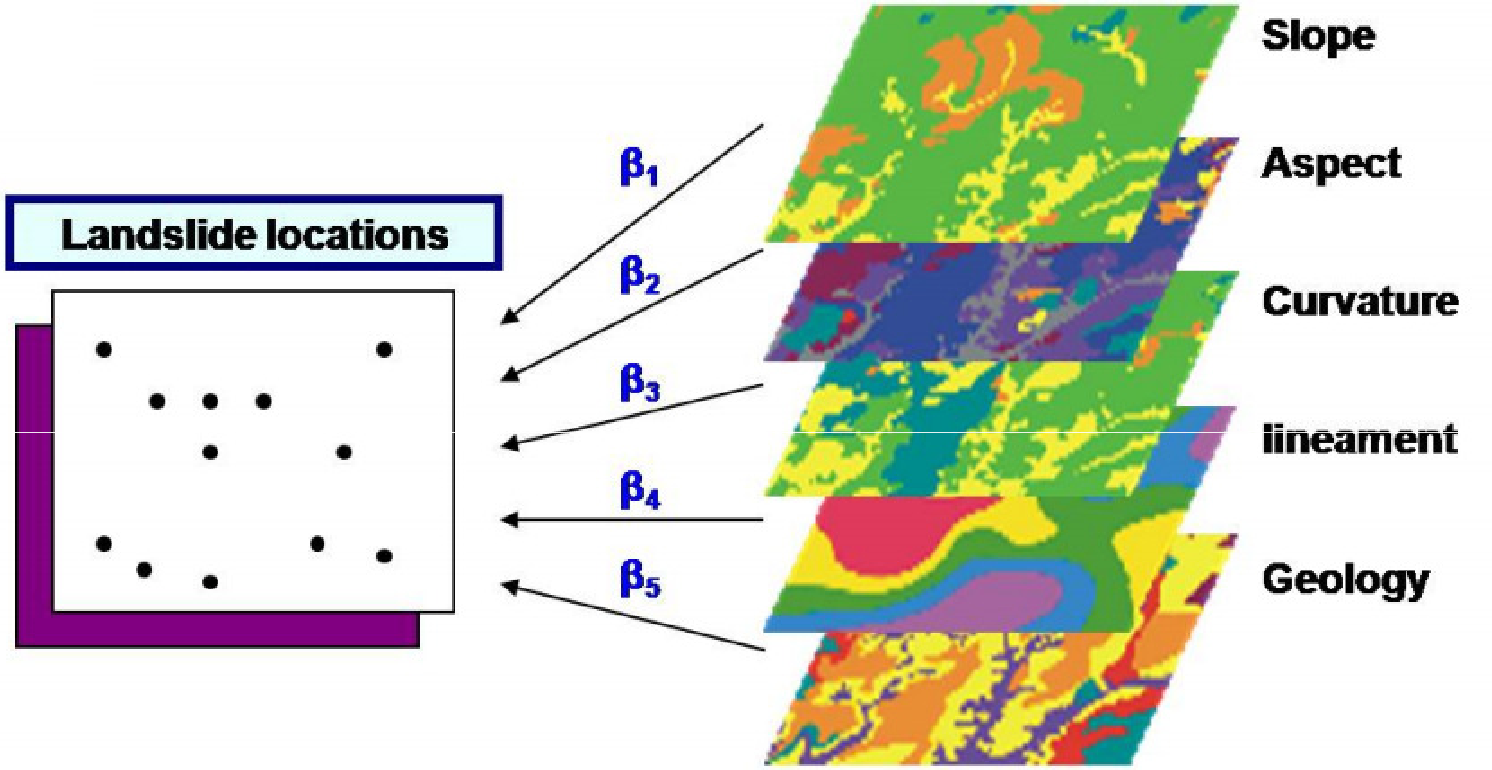
Among the wide range of statistical methods, LR analysis has proven to be one of the most reliable approaches. The approach is to analyze the relationship between the categorical or binary response variable and one or more continuous or categorical or binary explanatory variables derived from samples.

The equation below was used to calculate the *logistic regression coefficients* with landslides (Y) and conditioning factors

$$Y = b_0 + b_1 x_1 + b_2 x_2 + \cdots + b_n x_n$$

Where;
bi= (i= 0, 1, 2, … , $_n$), bi(i = 0, 2, … , $_n$) represents the LR coefficients,
and xi(i = 0, 1, 2, … , $_n$) denotes the conditioning factors

DATA MODELING *[6]*



Type	Dependent variables	Independent variables
Binary value	Landslide	-
Continuous value	-	Slope, lineament
Category value	-	Aspect, curvature, geology

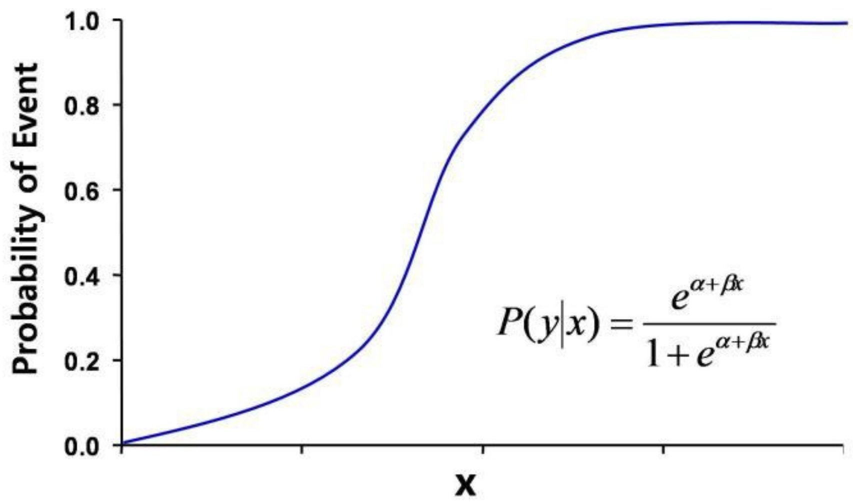
DATA MODELING [7]

To predict the possibility of a landslide event in each pixel, the probability index was measured by using the equation below:

$$p = 1/(1+e^{-Y})$$

Where;

P is the landslide probability attained between 0 and 1 on an S-shaped curve.



DATA MODELING *[8]*

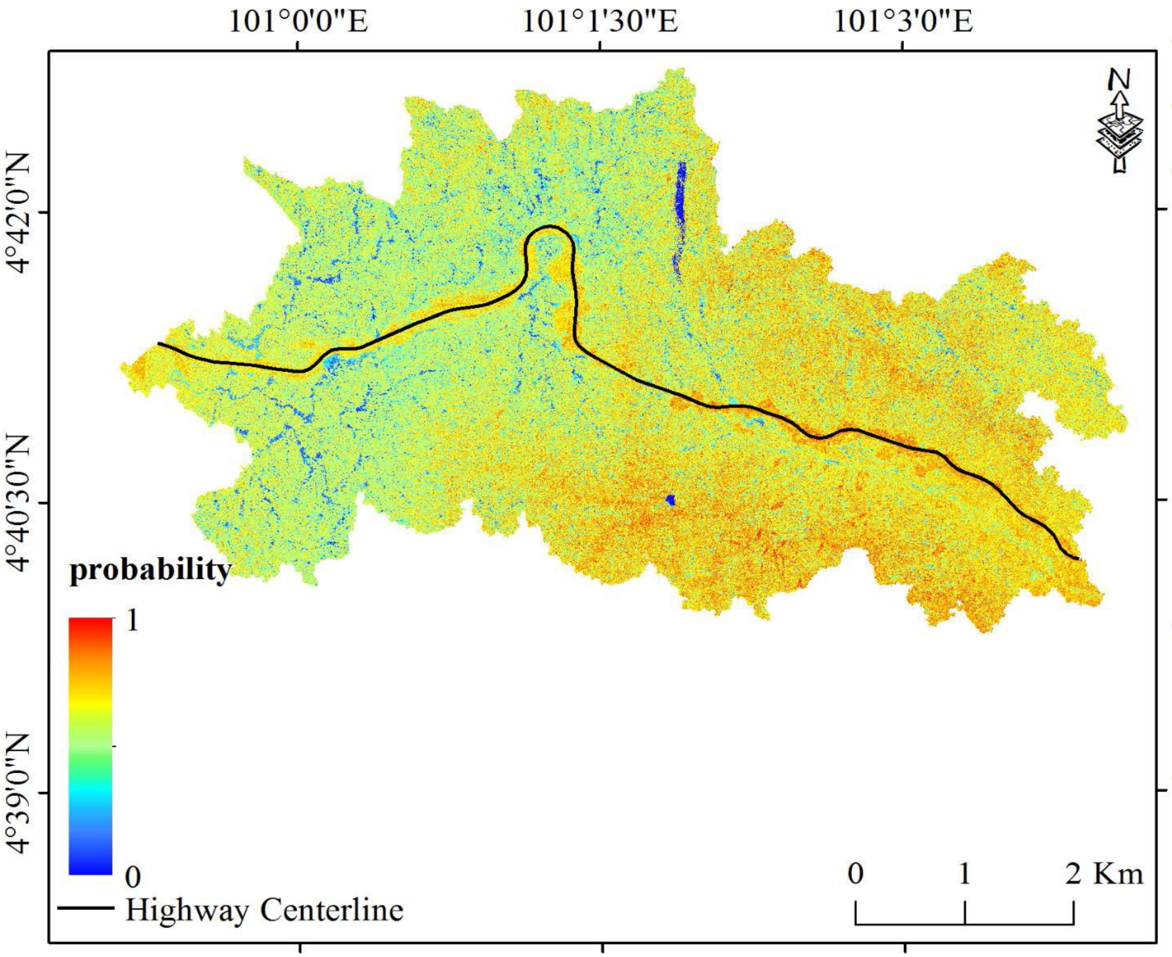
The resulted equation:

(0.003640 * "Altitude") - (0.019112 * "Slope") - (0.000193 * "Aspect") + (0.000033 * "Curvature") + (0.384703 * "SPI") - (0.433722 * "TWI") - (0.018751 * "TRI") - (0.000210 * "Distance from drainage") + 0.214791

Parameter	**Altitude**	**Slope**	**Aspect**	**Curvature**	**Distance from River**
LR coefficient	0.00364	0.019112	0.000193	0.000033	0.00021
Parameter	**SPI**	**TWI**	**TRI**	**Constant**	
LR coefficient	0.384703	**0.433722**	0.018751	0.214791	

DATA MODELING [9]

LR Model Probability Map

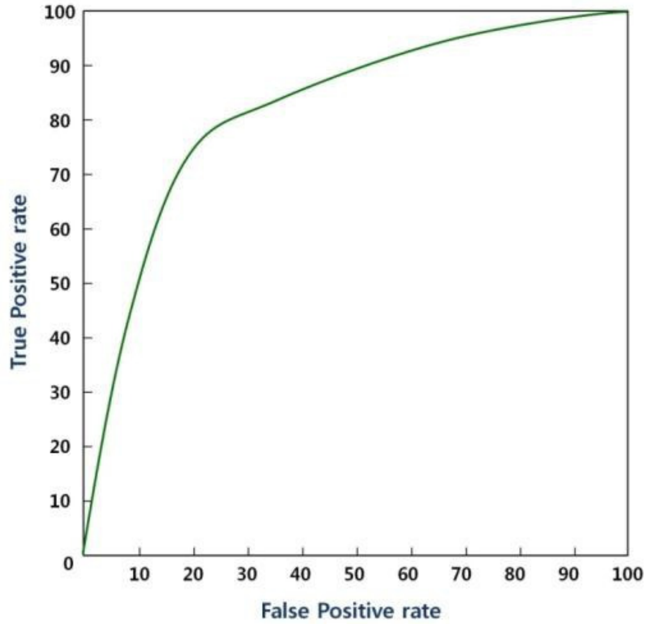


VALIDATION [1]

Model Validation [EBF vs. LR]

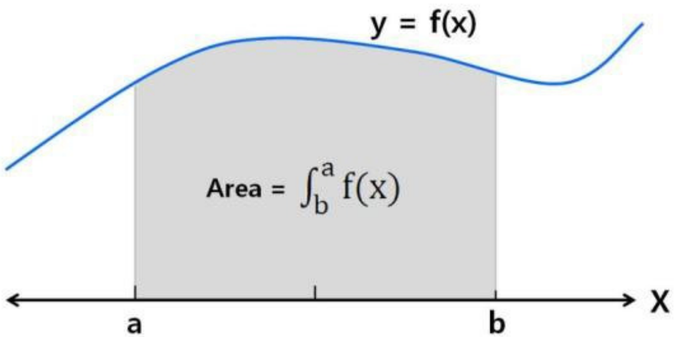
ROC Curve

In a ROC curve the true positive rate (Sensitivity) is plotted in function of the false positive rate (100- Specificity) for different cut- off points



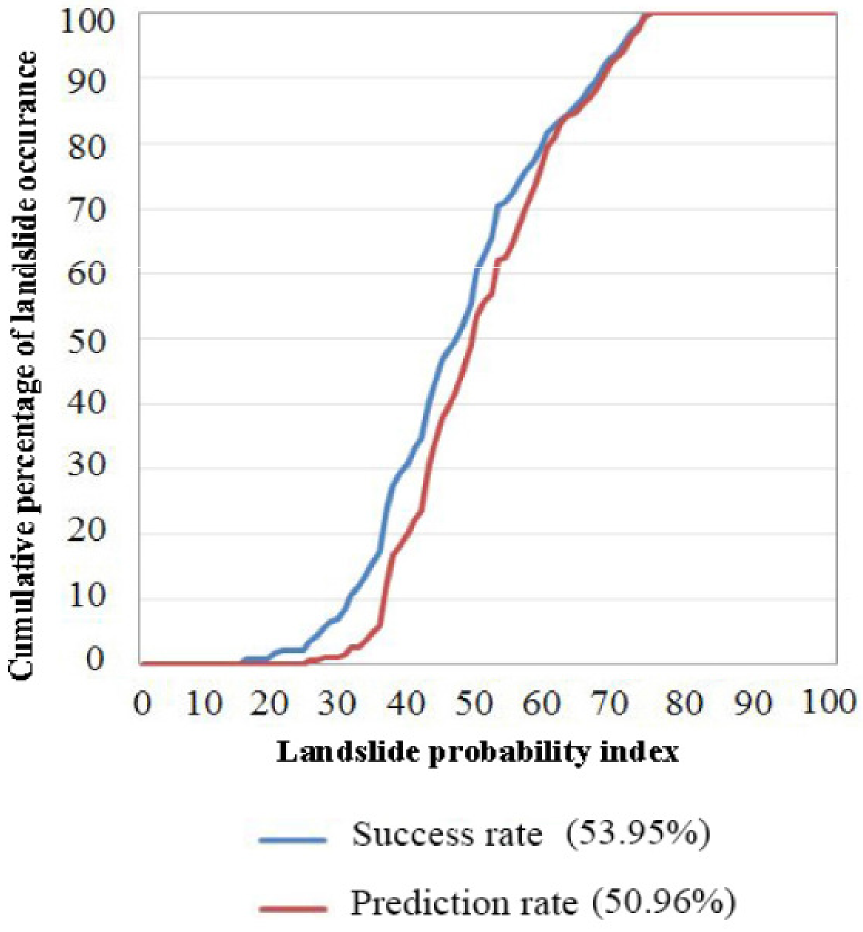
Area Under Curve

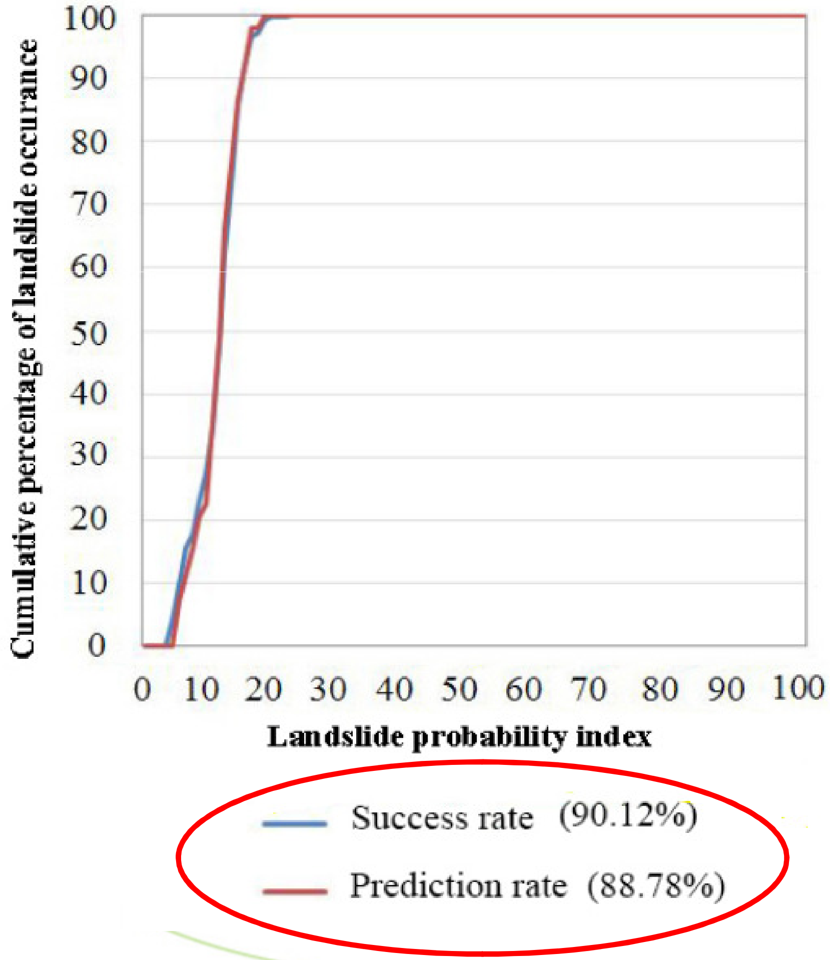
The area between the graph of y = f(x) and the x-axis is given by the definite integral below. This formula gives a positive result for a graph above the x-axis, and a negative result for a graph below the x-axis.



VALIDATION *[2]*

EBF *vs.* LR



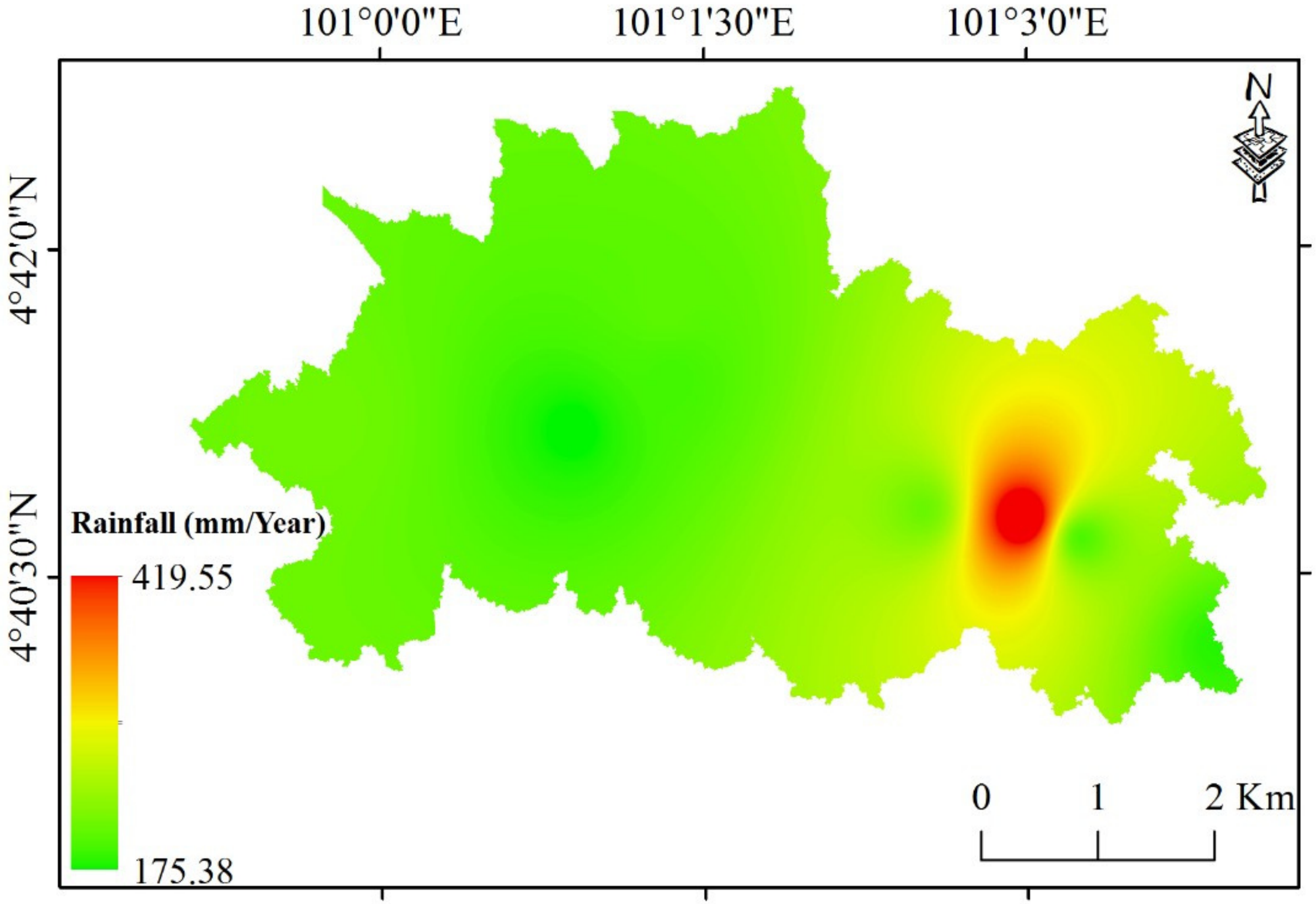


HAZARD MODELING [1]

Triggering factor

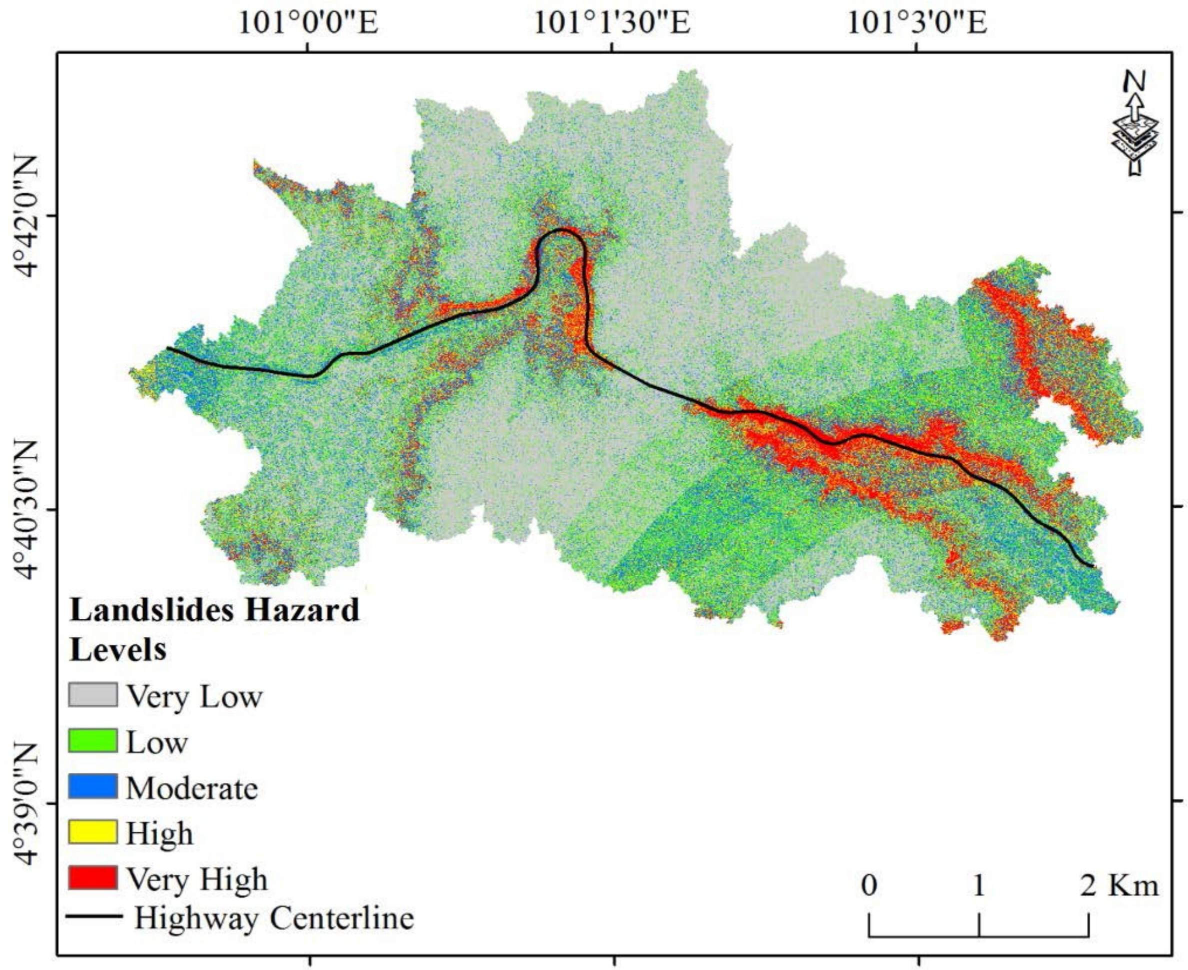
- ✓ The transformation of landslide susceptibility map into a hazard map requires consideration of landslide triggering parameters.
- ✓ For this purpose, precipitation is a triggering factor and was taken into account.
- ✓ We analyzed the annual average precipitation values for the period of 2014.
- ✓ The annual average precipitation density map was made by the data obtained from 15 rainfall stations in and around the study area.
- ✓ Inverse Distance Weight (IDW) was used and validated for this Purpose.

Precipitation Map Using IDW Interpolation



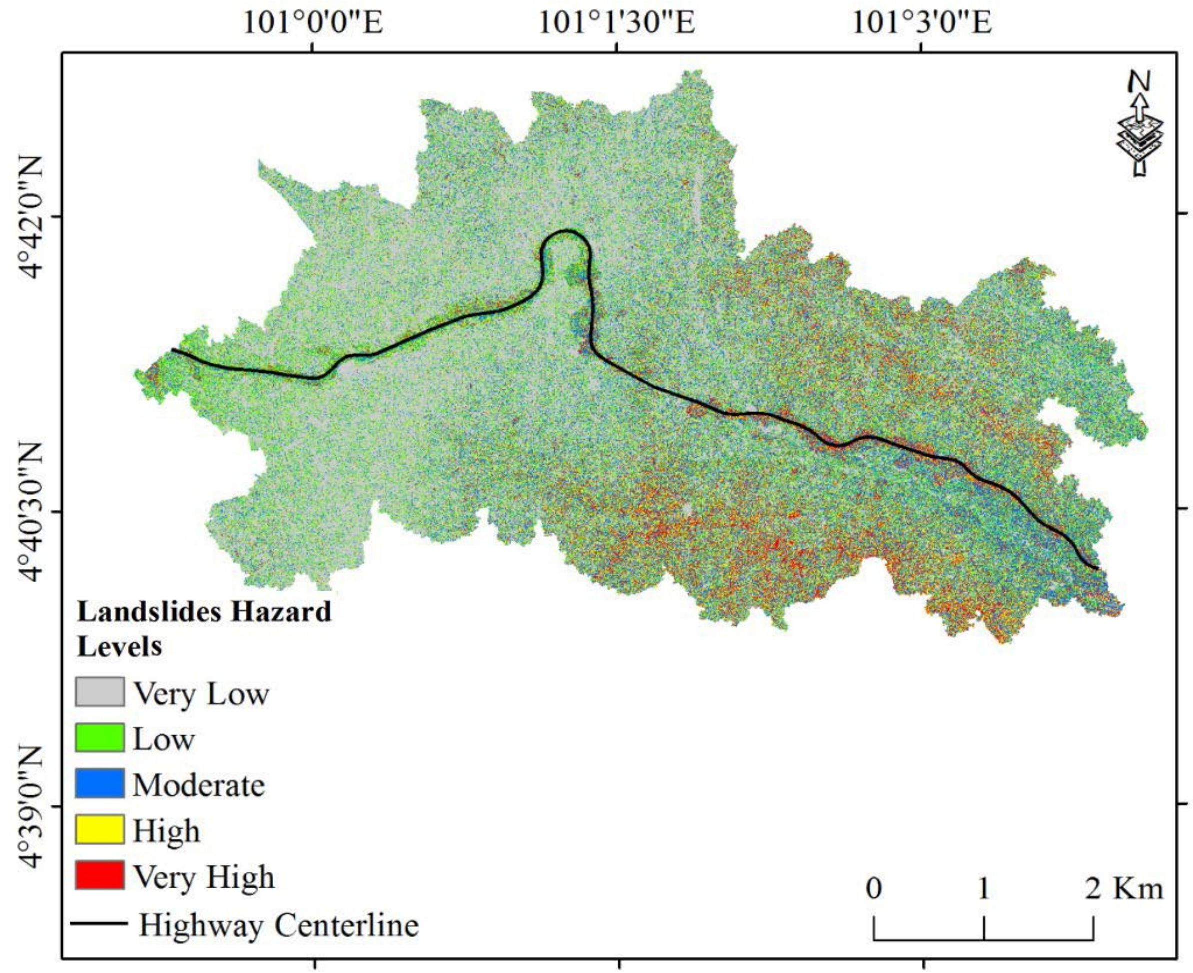
HAZARD MODELING *[3]*

Hazard Map Using EBF Model Output



HAZARD MODELING *[4]*

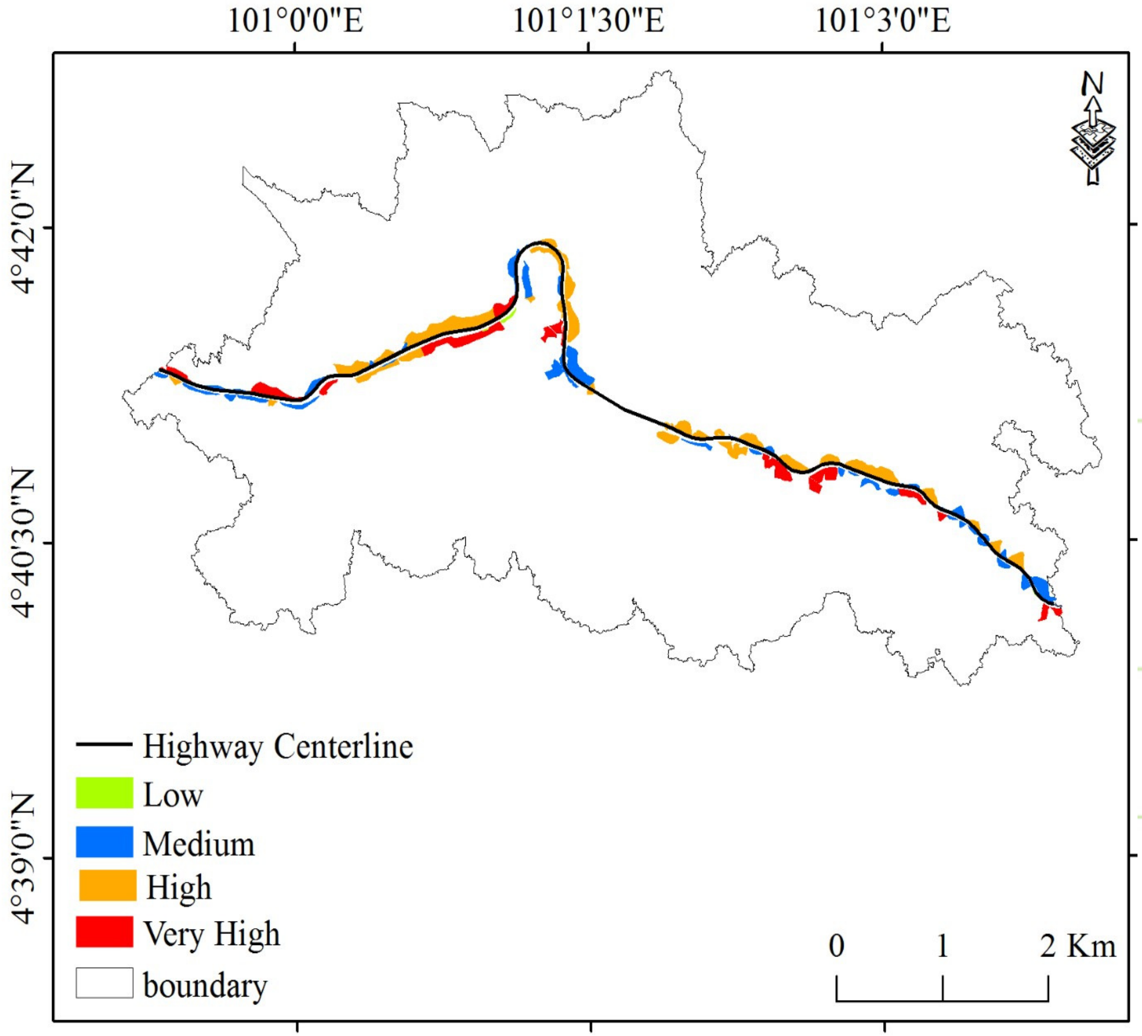
Hazard Map Using LR Model Output



HAZARD MODELING *[5]*

Existing Hazard Map from TEMAN

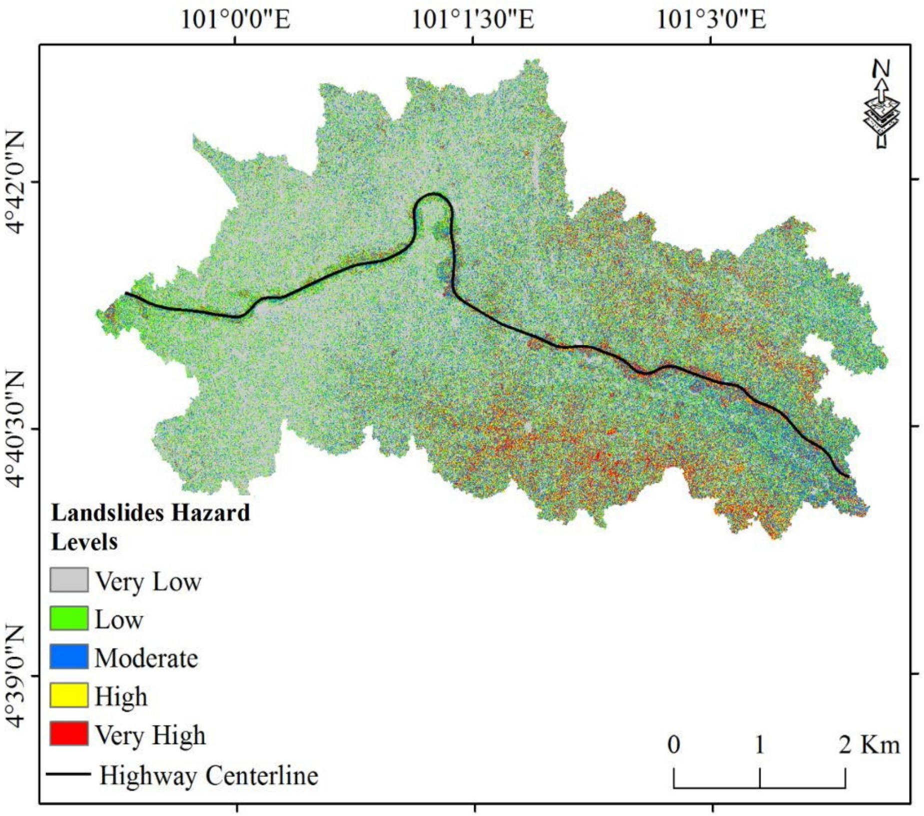
- ✓ Covers the cut slope only.
- ✓ No analysis for the Highway itself.
- ✓ No analysis outside the study area.
- ✓ High and very high hazard classes are inflated.

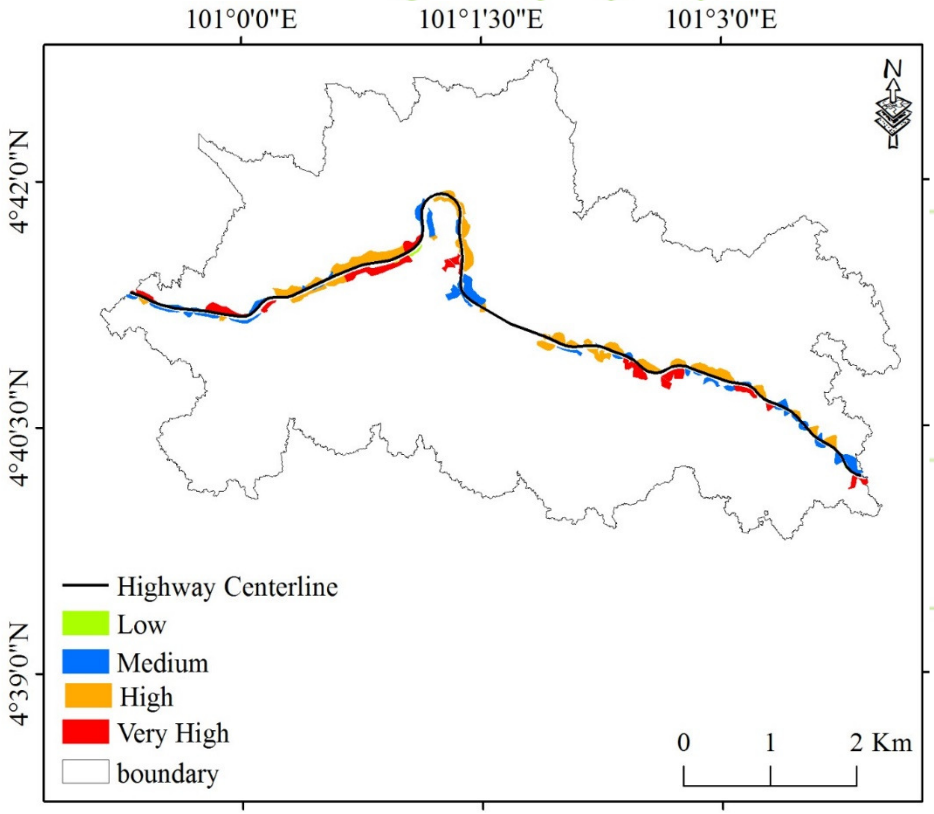


HAZARD MODELING *[6]*

Hazard Map : Comparison

LR Model Output *vs.* **TEMAN**





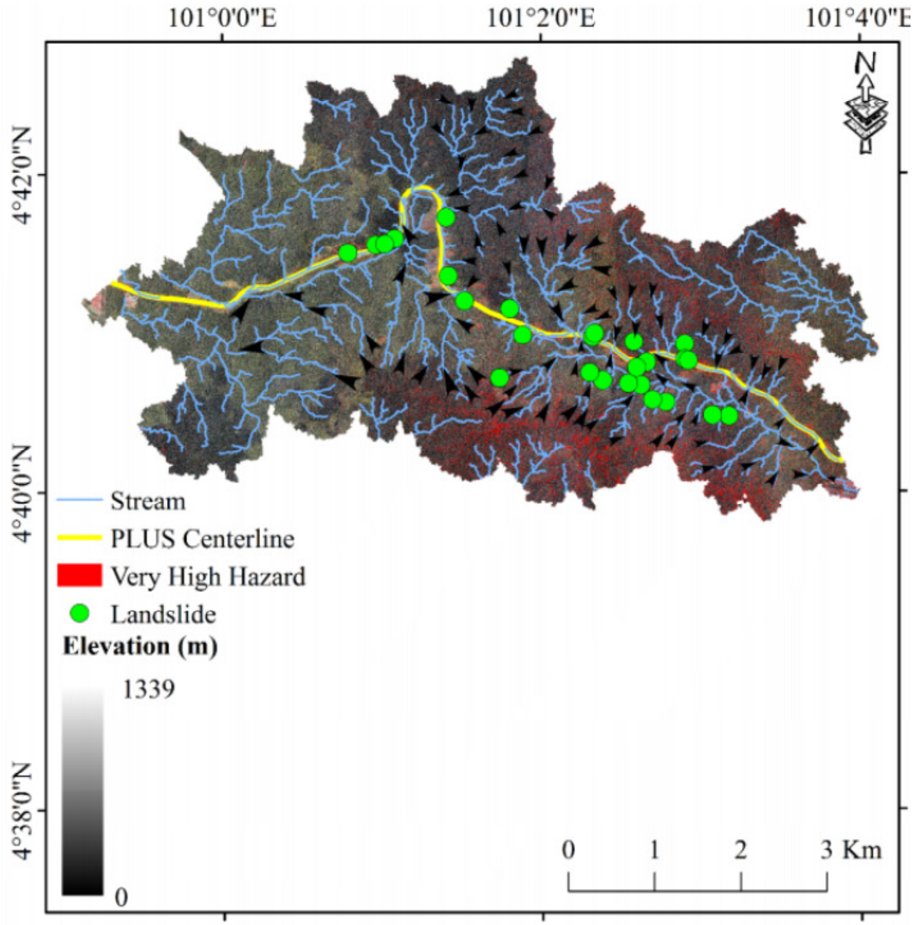
HAZARD MODELING *[7]*

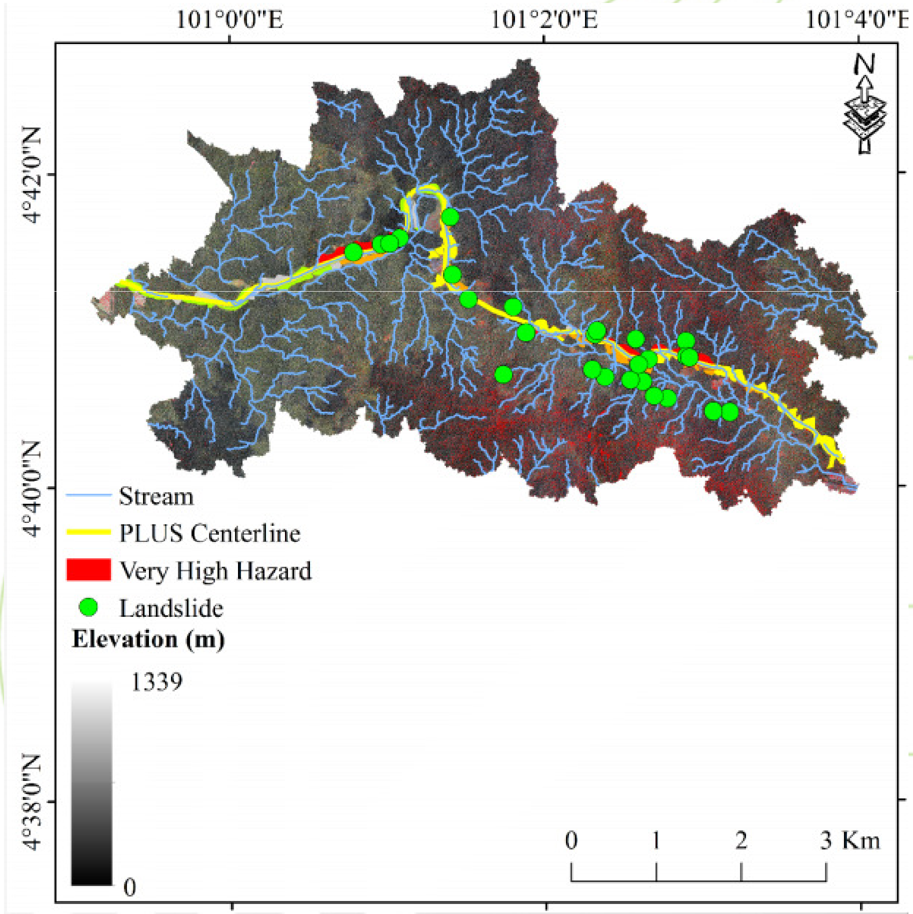
Hazard Map : Field Investigation


Slope ID SL/C1/ML/H/305.04/-/-/NB/E/-


HAZARD MODELING *[8]*

Hazard Modeling





Term

- ✓ When attempting to assess landslide risk, vulnerability to landslide is often considered as equivalent to complete loss of the assets or total destruction of the elements at risk.
- ✓ Mathematically, landslide vulnerability (VL) can be expressed as;

$$V_L = P\ [D_L \geq 0\ [L]\ ,\ 0 \leq D_L \leq 1]$$

Where DL is the assessed (definite) or the expected (forecasted) damage to an element given the occurrence of a hazardous landslide

VULNERABILITY MODELING *[2]*

Adopted Criteria (TEMAN)

Risk to Road User

Possibility of inflicting injury or damage to the property and the road users

Relative Risk of Failure

Possibility of an existing failure enlarging and affecting other parts of the slope or the stability itself

Likely Effect on Traffic

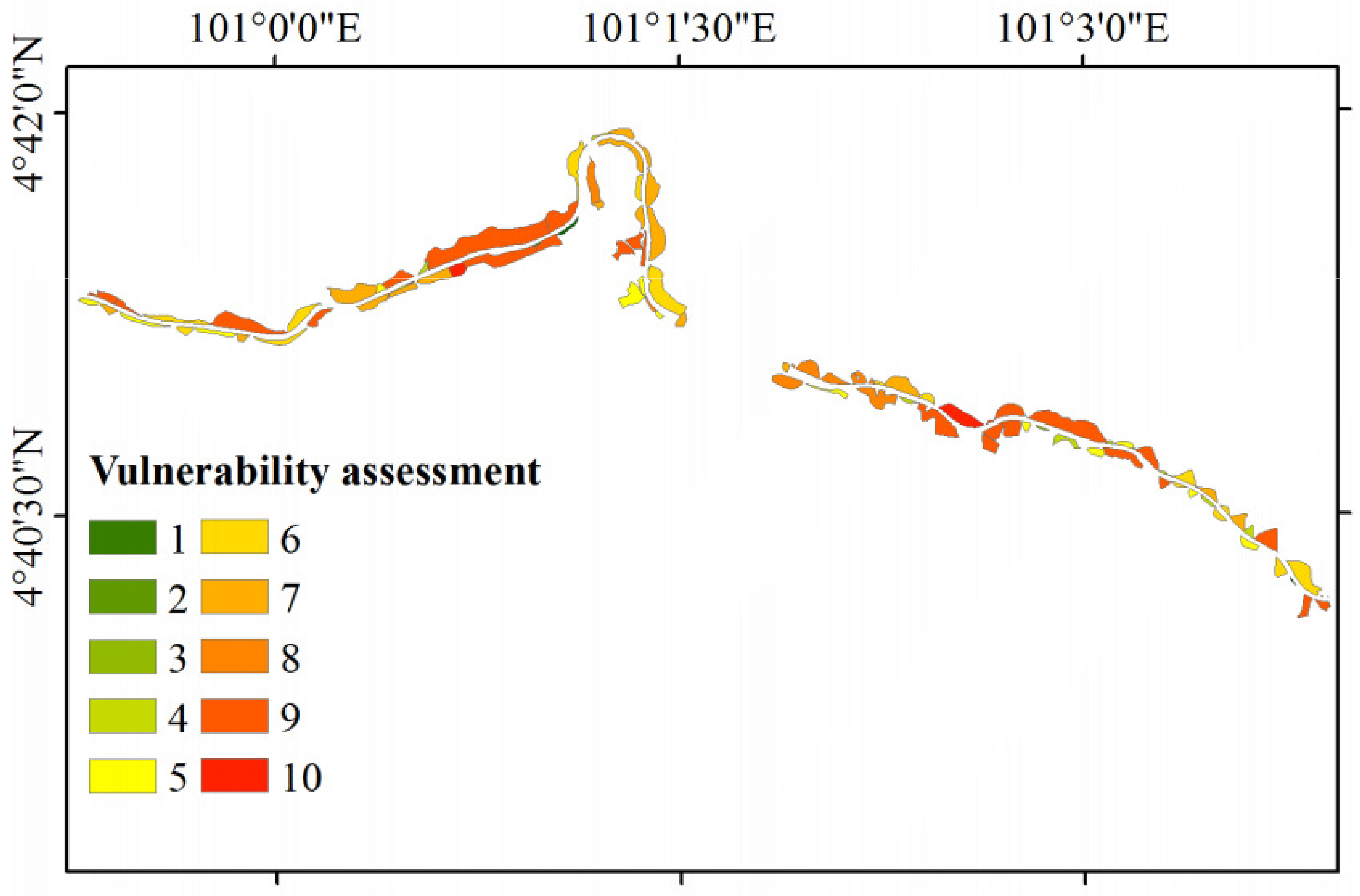
Possibility of failure encroaching onto expressway, existence of alternative route to bypass that particular location

Likely Repair Costs

Relates to possible volume of earthwork, sufficient space for access / construction and complexity of earthwork

VULNERABILITY MODELING *[3]*

Vulnerability Map of TEMAN



RISK MODELING *[1]*

What is Risk

- Landslides Risk analysis aims to determine :
  - ✓ the probability that a specific hazard will cause harm, and it investigates the relationship between the frequency of damaging events and the intensity of the consequences.
  - ✓ the expected degree of loss due to a landslide and the expected number of lives lost, people injured, damage to property and disruption of economic activity.
  - ✓ landslide risk is commonly expressed by the product of landslide hazard (HL) and landslide vulnerability (VL),

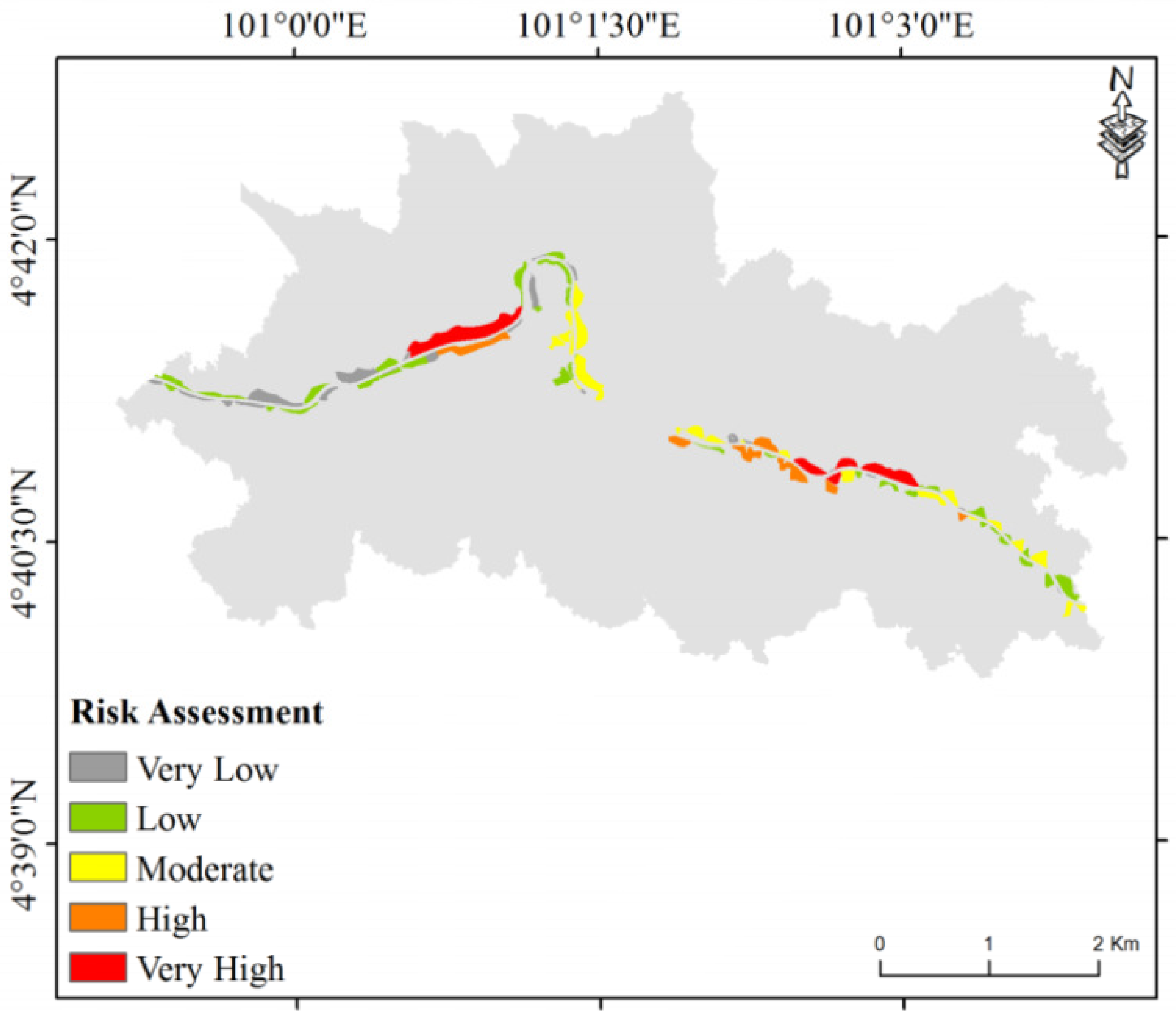
Risk = f (hazard, vulnerability)

Or it can be expressed in the following equation

$$R_S = H_L \times V_L$$

Where HL is the hazard probability and VL is the probability of the vulnerability

Risk Map of TEMAN



- Overview
- Research Methodology
- Analysis
- **Conclusion & Way Forward**

CONCLUSION

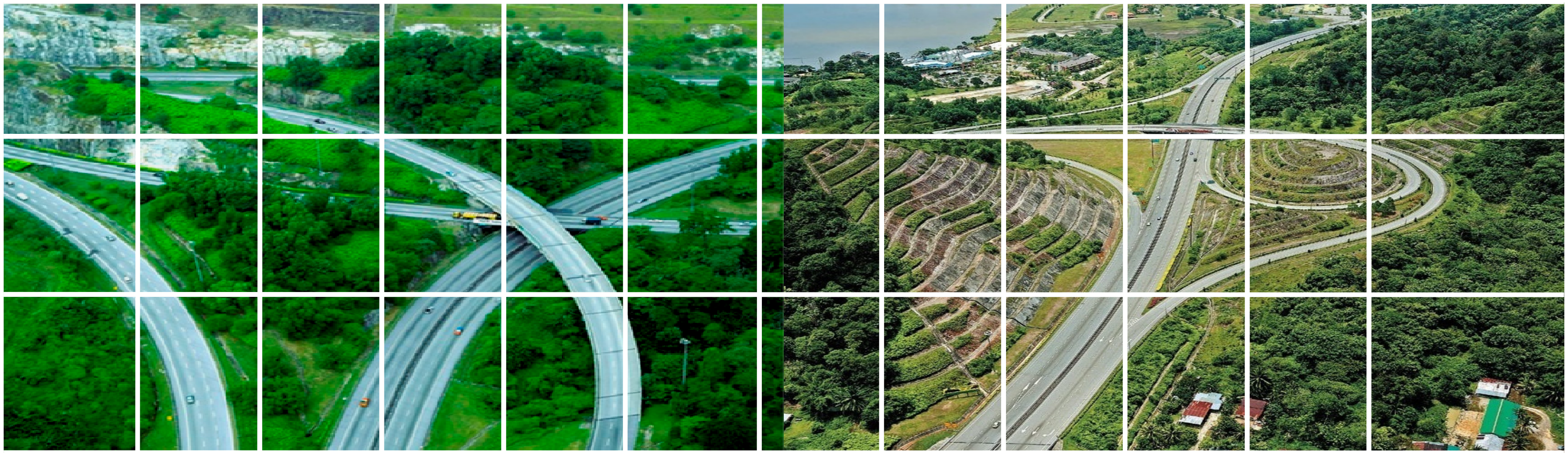
- ✓ Landslide susceptibility, hazard and risk maps were scientifically produced for the study areas using high resolution of LiDAR data.

- ✓ The comparison between the produced hazard maps and the existing TEMAN shows:

  - ➢ Very high and high hazardous areas are inflated in the TEMAN. This may incur more cost for maintenance of areas which are not necessarily high risk areas.
  - ➢ The resultant risk map can help PLUS to cut cost on maintenance by focusing more on the high risky areas.

- ✓ PLUS will embark on prediction landslides model in the future.

THANK YOU








PRESENTATION ON : Landslide Hazard Analysis At Jelapang Of North-South Expressway in Malaysia Using High Resolution Airborne LiDAR Data

PLUS