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GEO SMART ASIA 2015

LANDSLIDE HAZARD ANALYSIS AT JELAPANG AND GUA TEMPURUNG OF NORTH-SOUTH EXPRESSWAY USING HIGH-RESOLUTION AIRBORNE LIDAR DATA

NORISAM ABD RAHAMAN

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INTRODUCTION

PLUS

PLUS

- Backbone of Malaysian road transport system:
  - ❖ Connects major industrial, commercial & transportation centers
  - ❖ Links major seaports and airports
- States serviced by the NSE make up 81% of population and 89% of GDP in Peninsular Malaysia

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

PLUS - Assets

Maintenance Management

Pavement

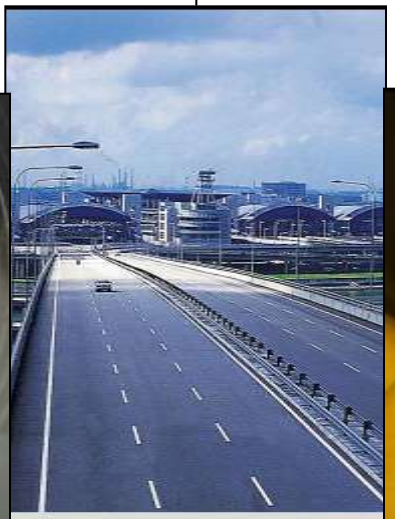
4291 lane-km

Slope

> 5,000 slopes

Drainage

> 4,000 culverts



Bridge

483 bridges

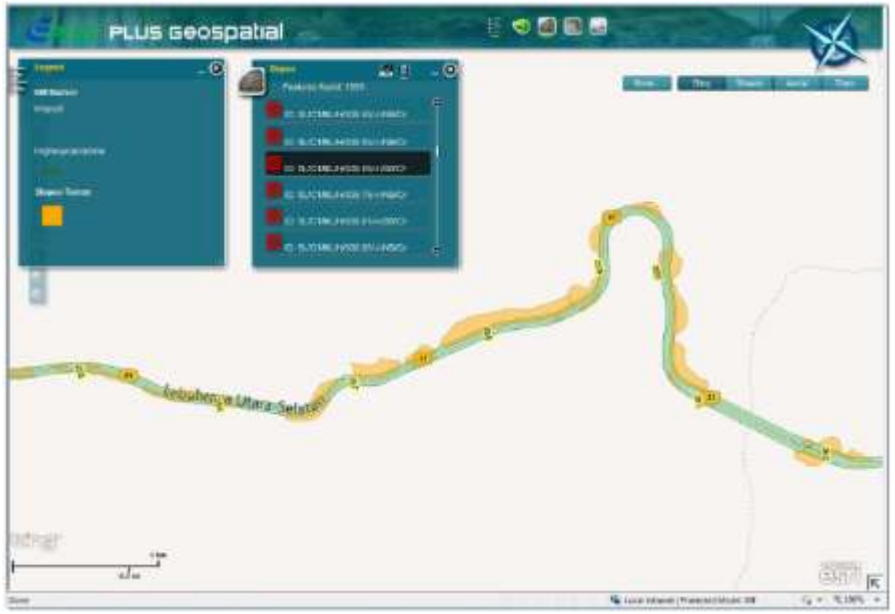
Tunnel

2 tunnels (861m & 832m)

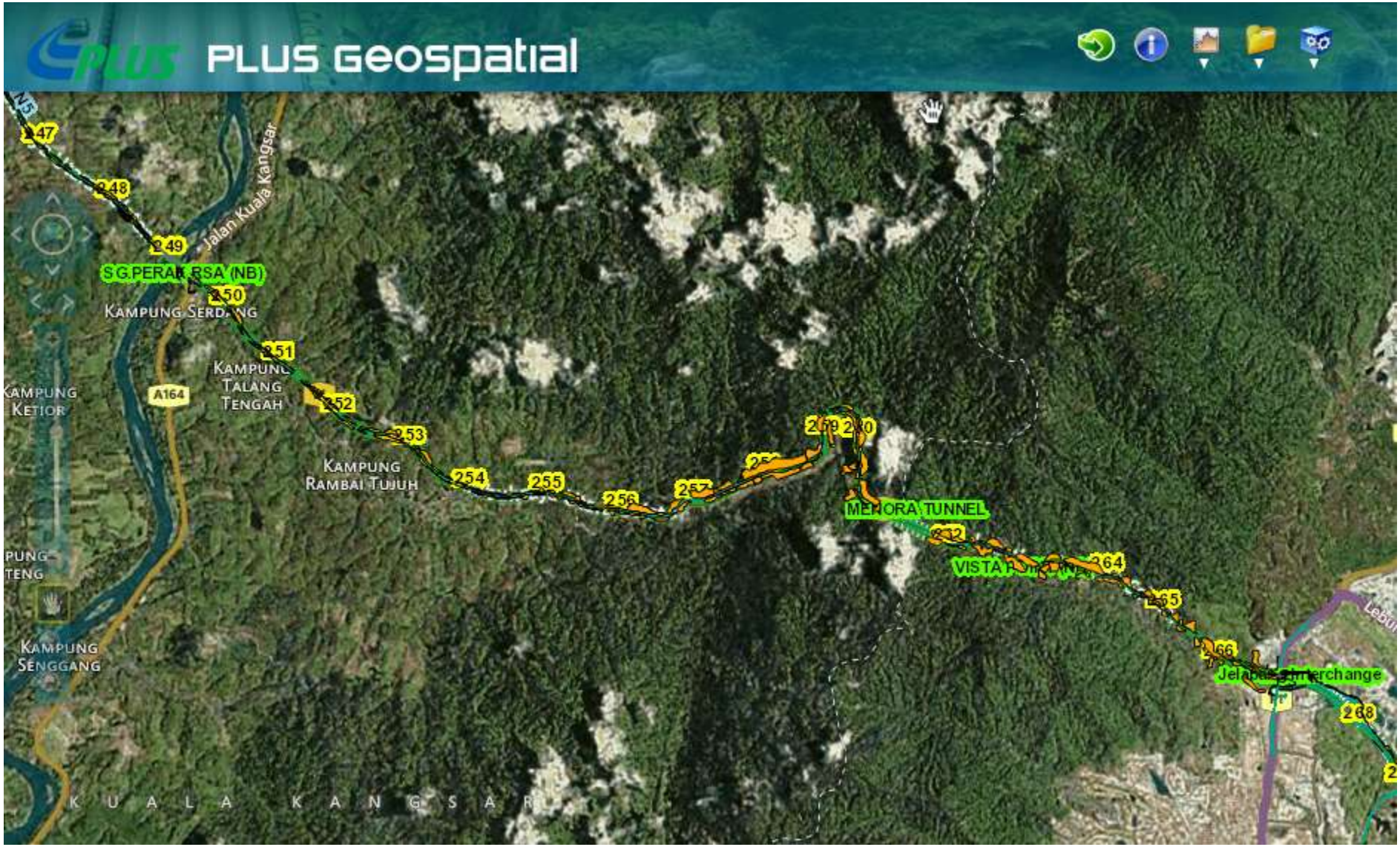
STUDY AREAS: JELAPANG & GUA TEMPURUNG

WHY?

- **Back-bone of PLUS**
- **Small maintenance corridor**
- **Impact of failure from outside**
- **Debris flow (2004)**



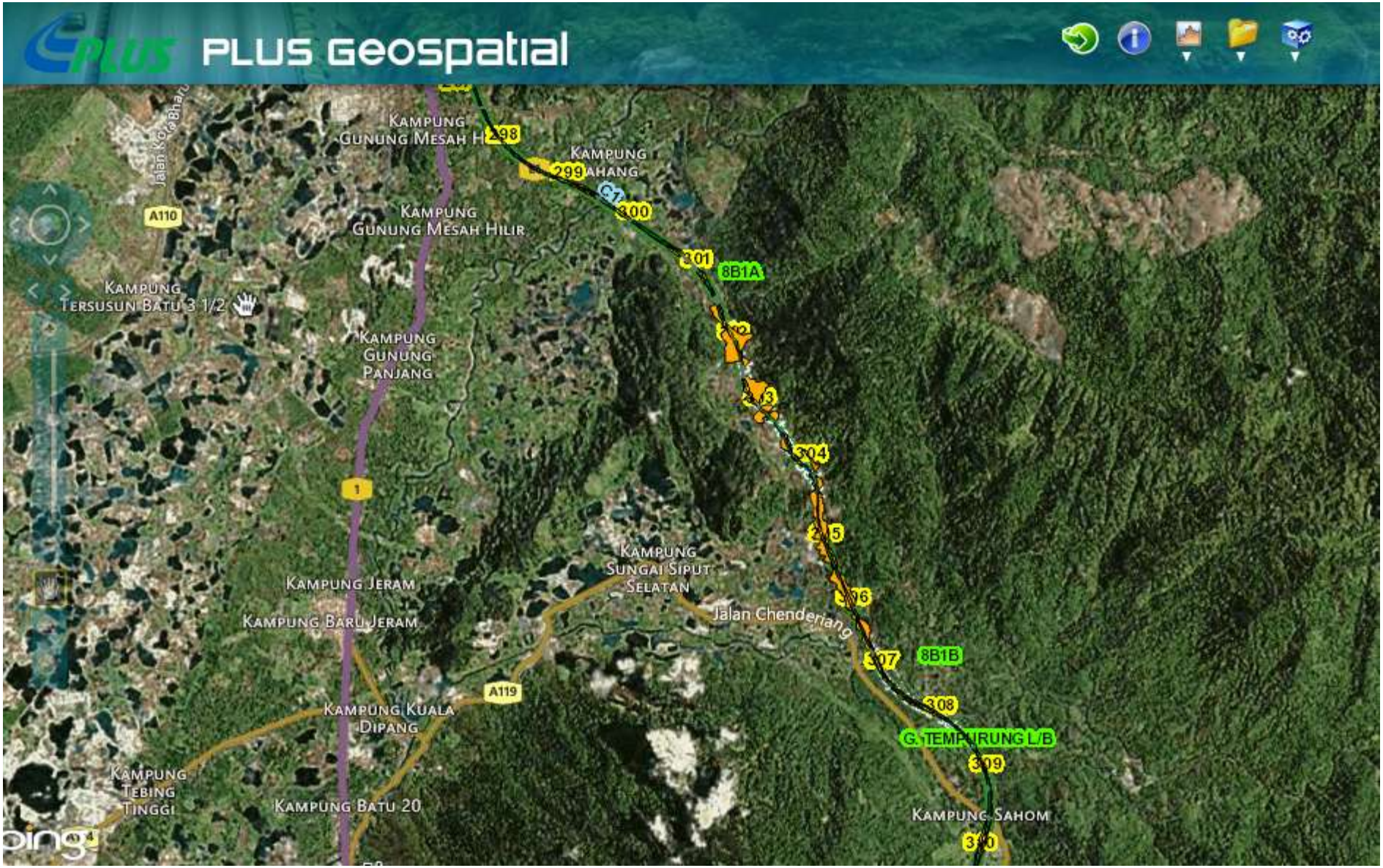
JELAPANG AREA – MAP LAYOUT



JELAPANG AREA – AERIAL PHOTOGRAPH

- Mountainous area
- Granitic Formation
  (part of Kledang Range)
- High cut rock slopes (shallow regolith)

GUA TEMPURUNG AREA – MAP LAYOUT

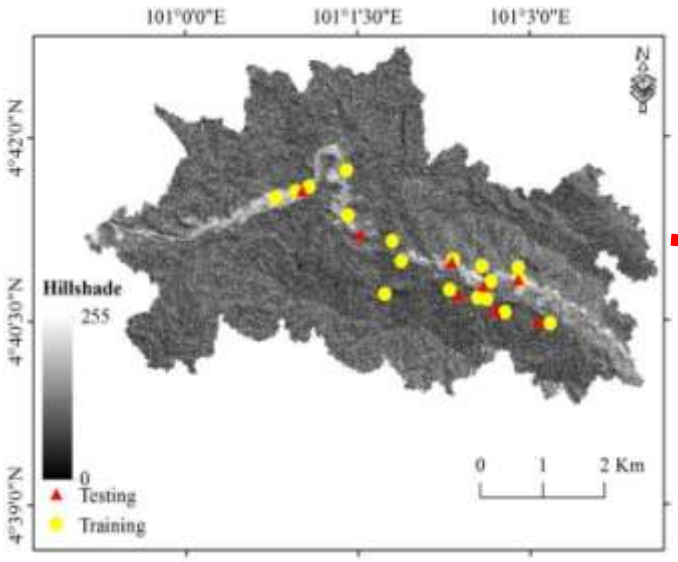


GUA TEMPURUNG AREA – AERIAL PHOTOGRAPH

- Boundary between Granitic Formation (north-east) and lime stone formation (south-west). Colluvium formation in between

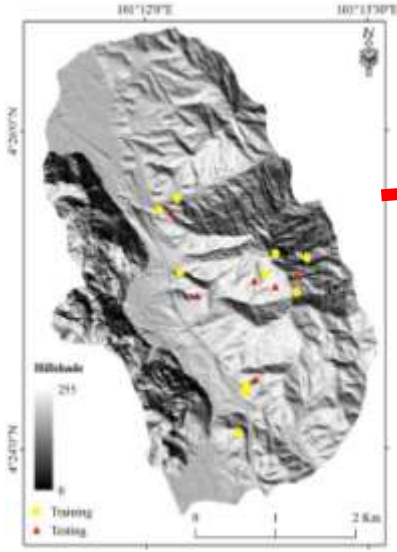
- High cut soil slopes (deep regolith)

STUDY AREAS



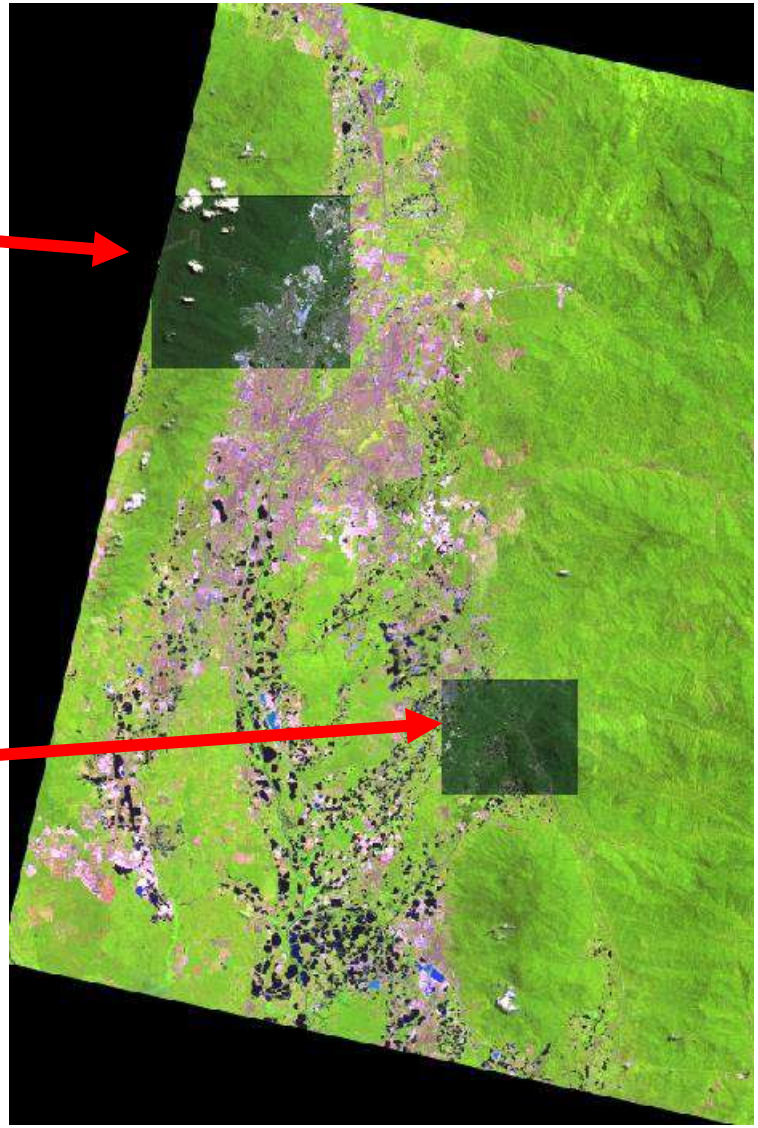
Jelapang

Area: 28.4 km^2



Gua Tempurung

Area: 15.30 km^2



LIDAR DATA ANALYSIS

PURPOSES

1. To define landslide conditioning parameters influencing the characters of landslides in the study areas.

2. Analysis for landslide susceptibility and hazard for the area:

   a) using probabilistic based model: evidential belief function (EBF)

   b) Analysis using statistical based model: Logistic Regression (LR) models;

3. To provide landslide hazard map for the pilot study areas.

Risk concept

- **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”.

$$Risk = f(hazard, vulnerability)$$

- **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.

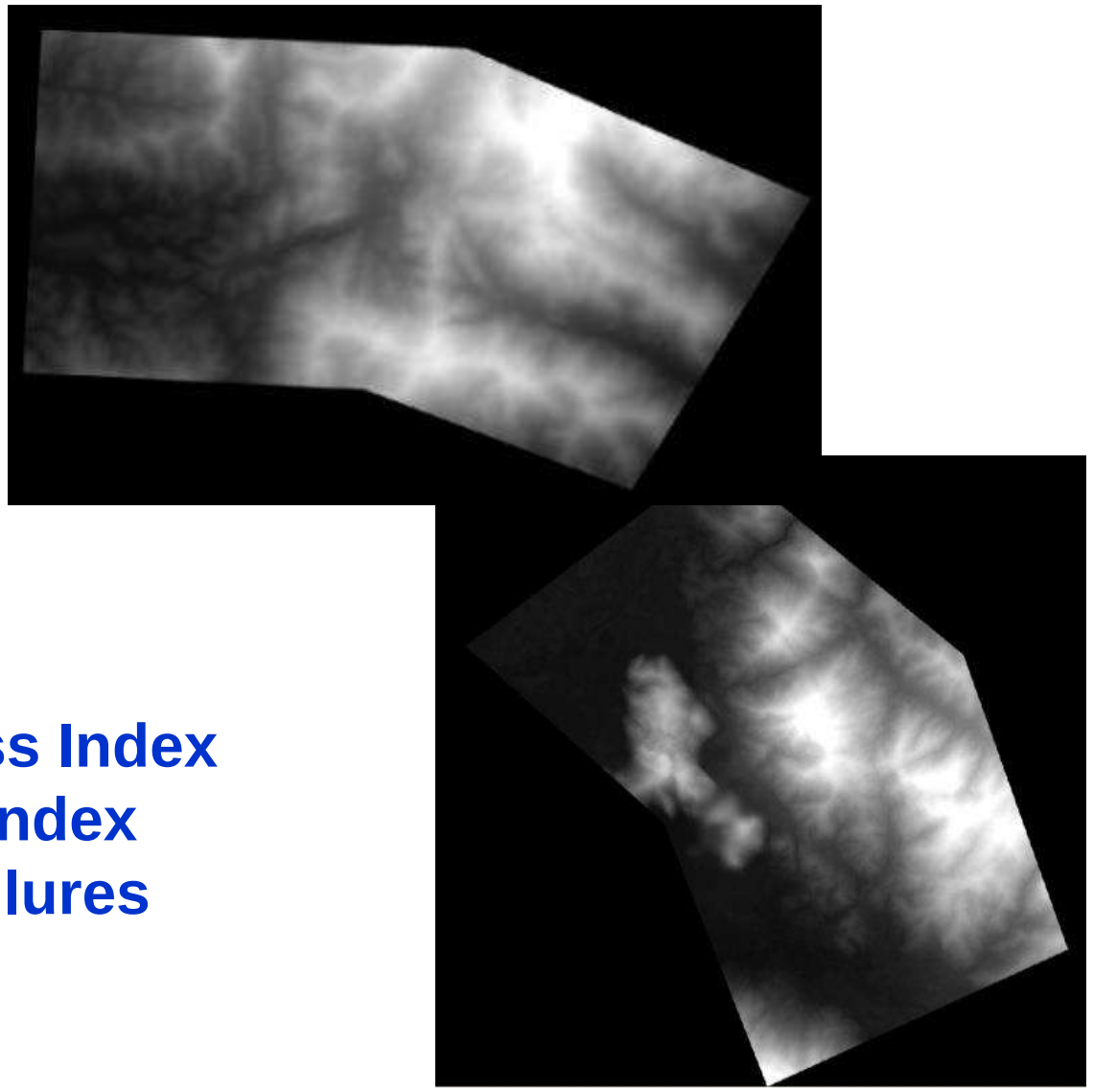
- ------ ***According to “The United Nations Office for Disaster Risk Reduction” (UNISDR)***
- ----***United Nations Department of Humanitarian Affairs, 1992***

GIS ANALYSIS

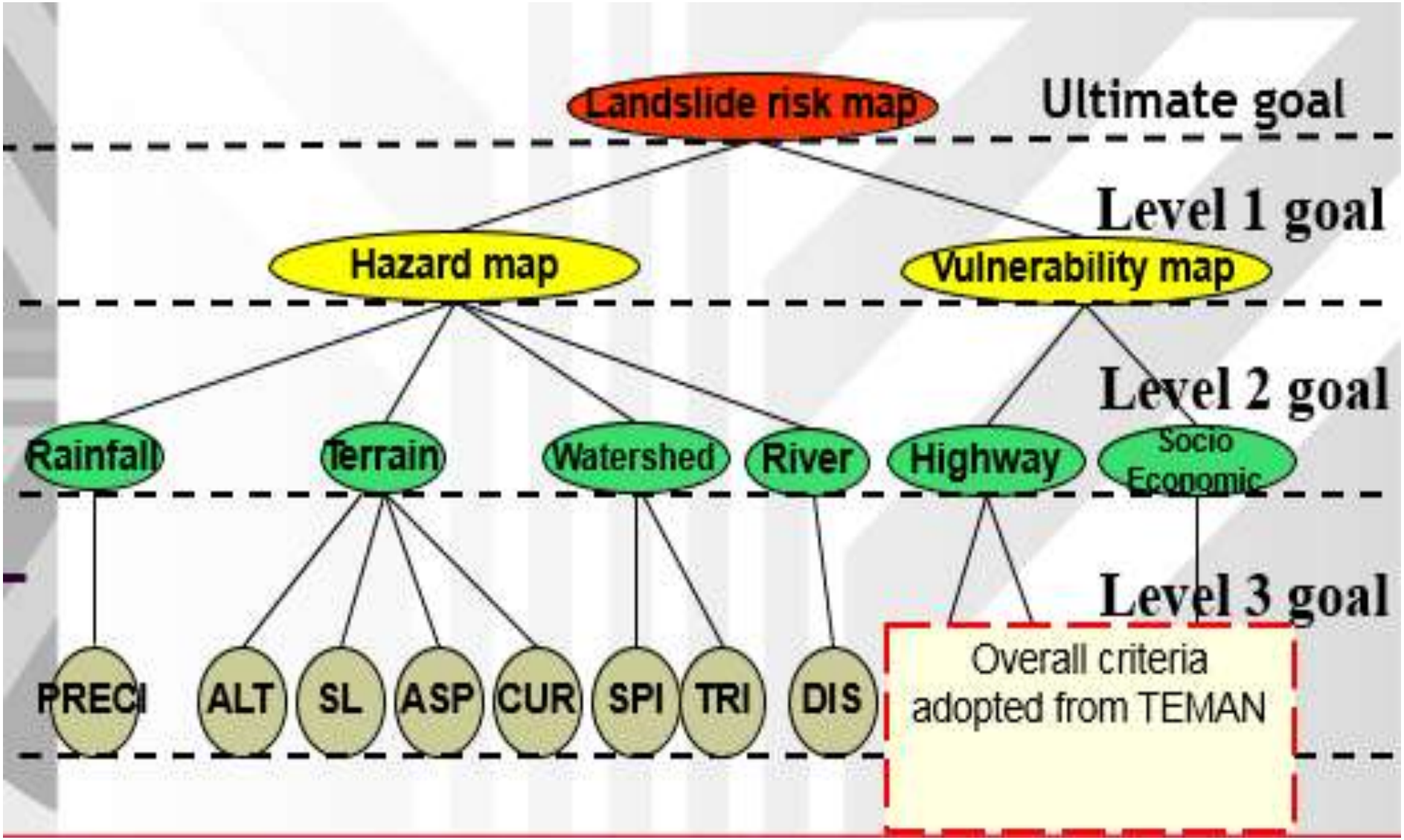
Methodology

- DSM and DTM (LIDAR)

- GIS Analysis
  - Altitude
  - Slope / Inclination
  - Aspect
  - Curvature
  - Stream Power Index
  - Topographic Wetness Index
  - Terrain Roughness Index
  - Records of slope failures

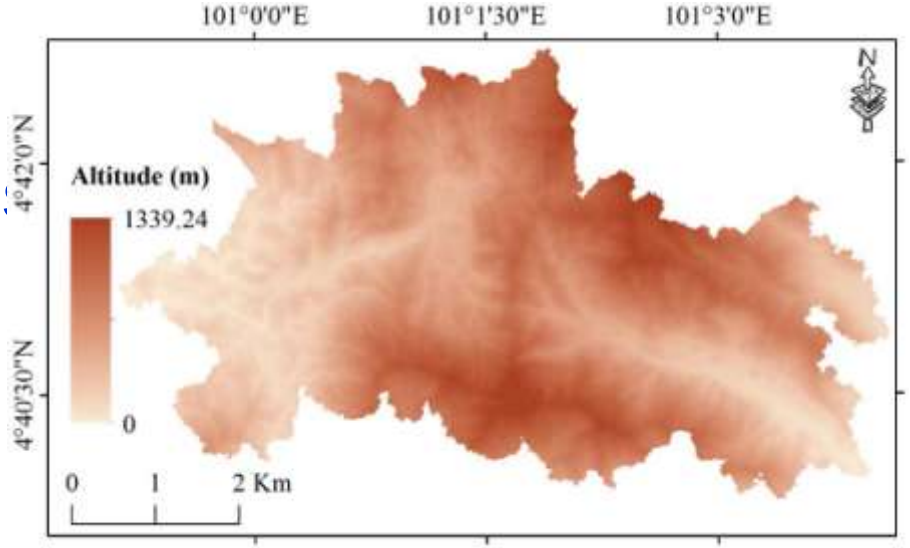


SYSTEM ANALYSIS

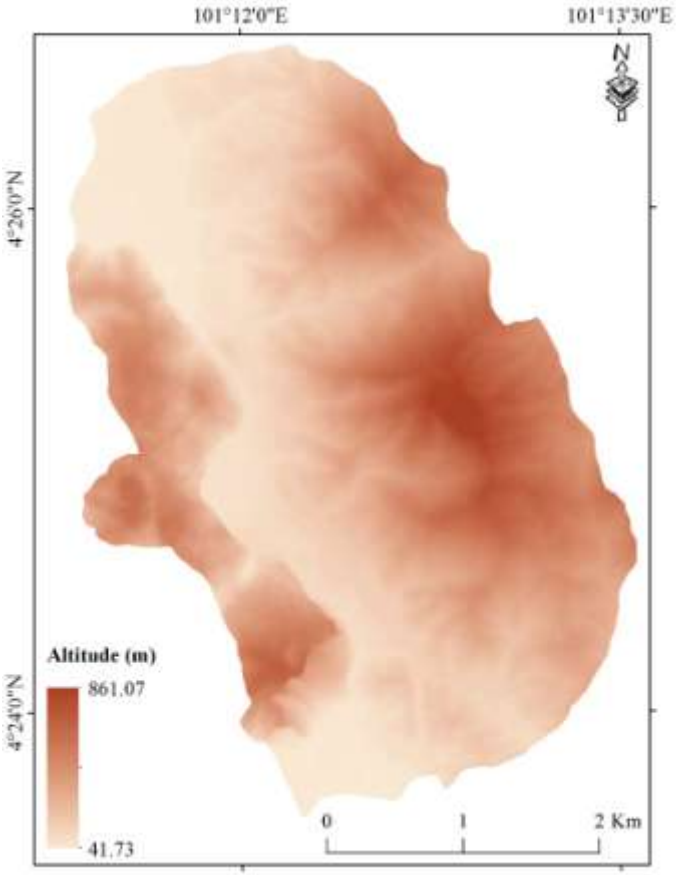


INPUT DATA LAYERS (ALTITUDE)

Jelapang

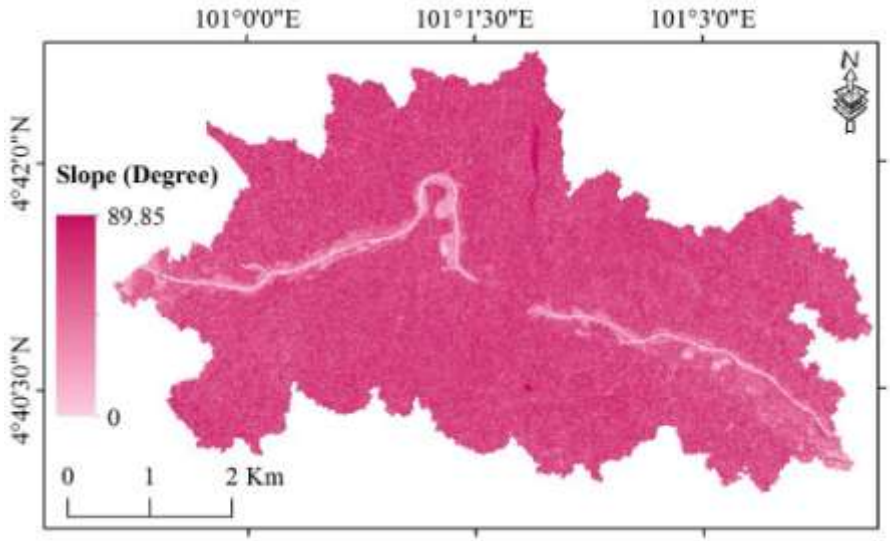


Gua Tempurung

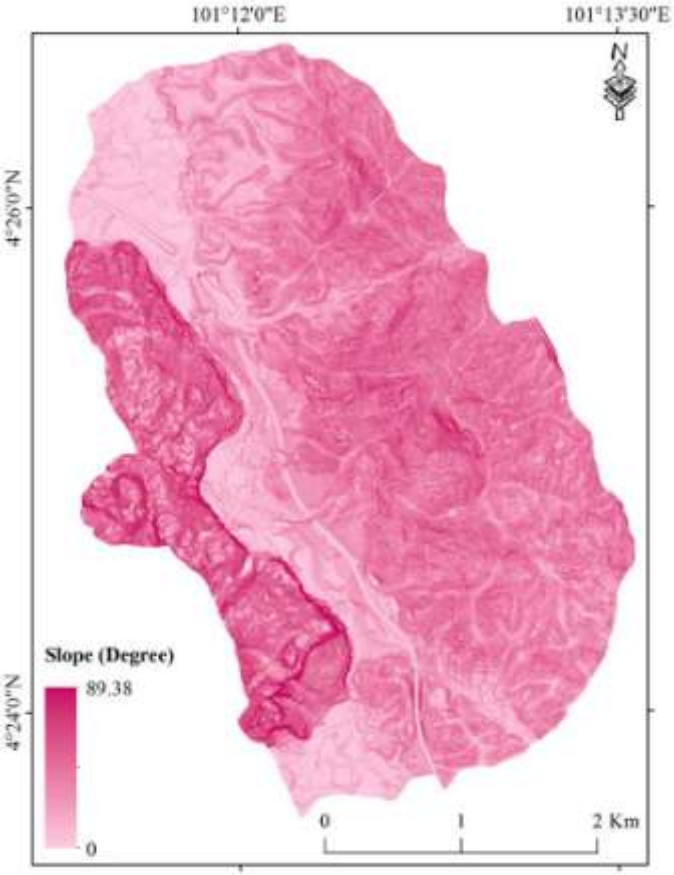


INPUT DATA LAYERS (SLOPE / INCLINATION)

Jelapang

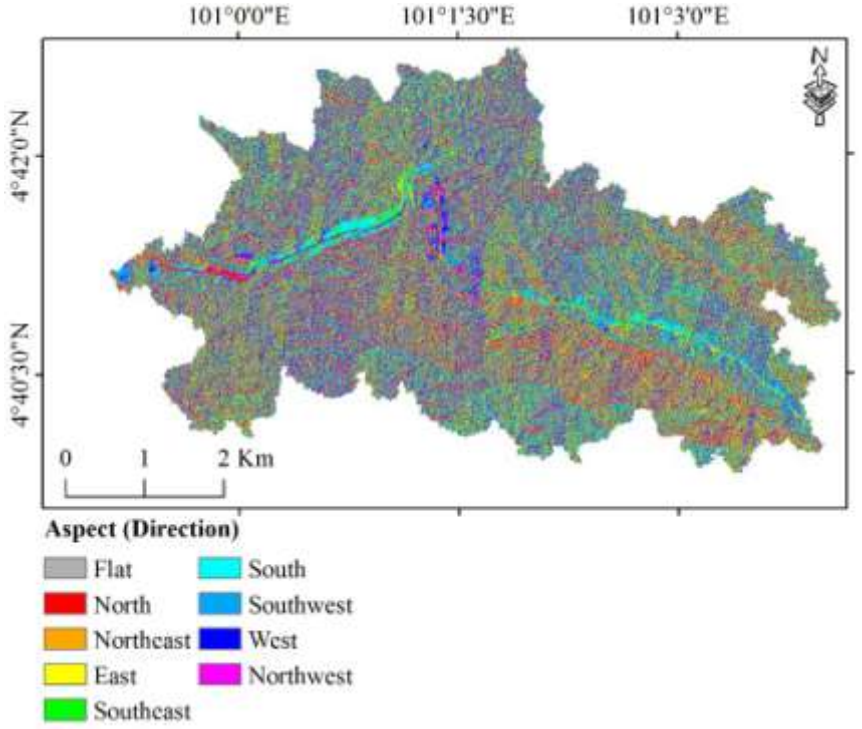


Gua Tempurung



INPUT DATA LAYERS (ASPECT)

Jelapang



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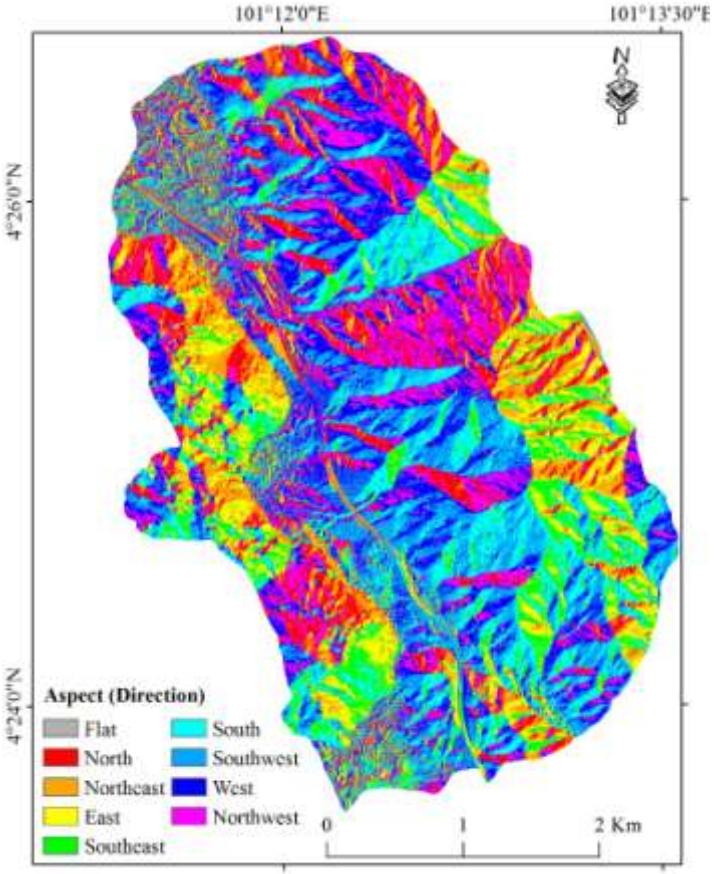
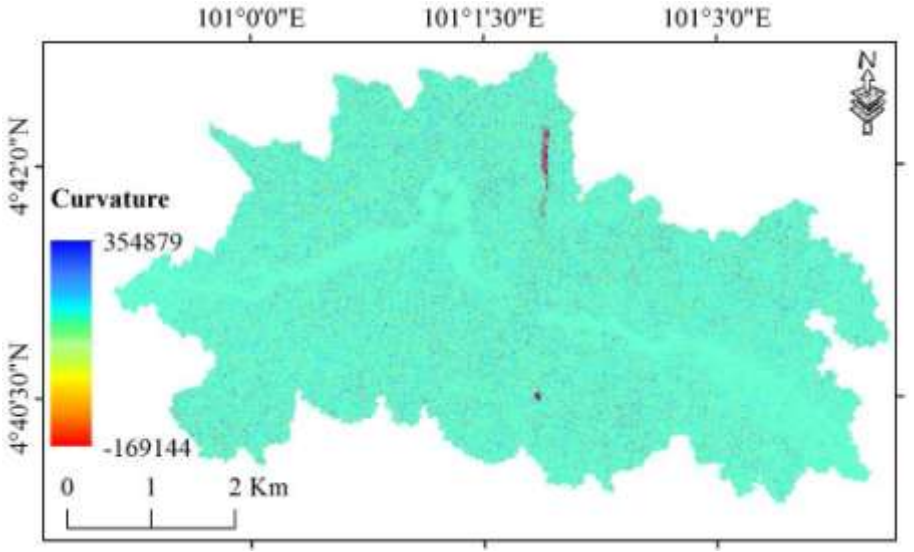


INPUT DATA LAYERS (CURVATURE)

Jelapang



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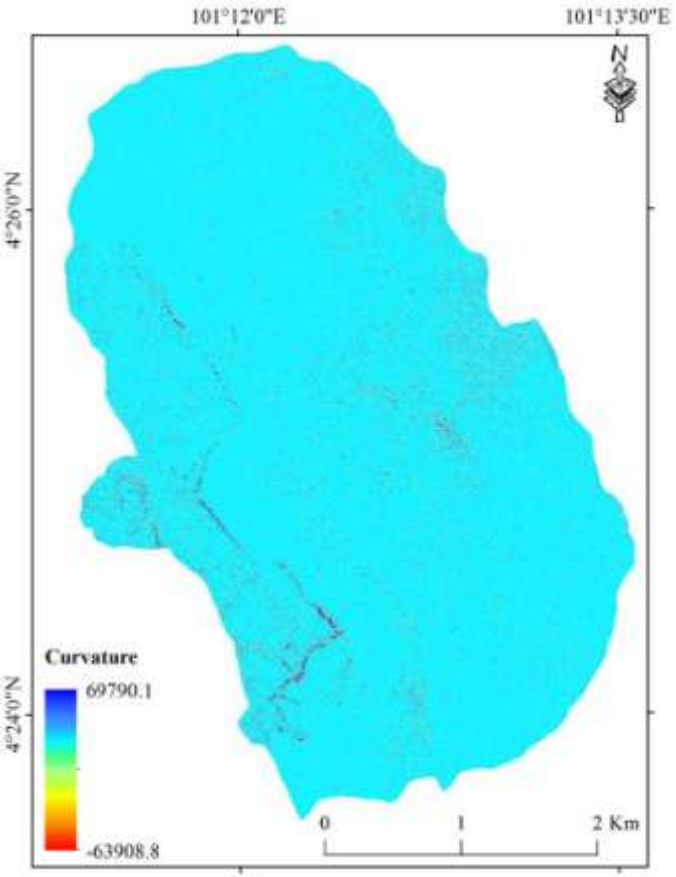


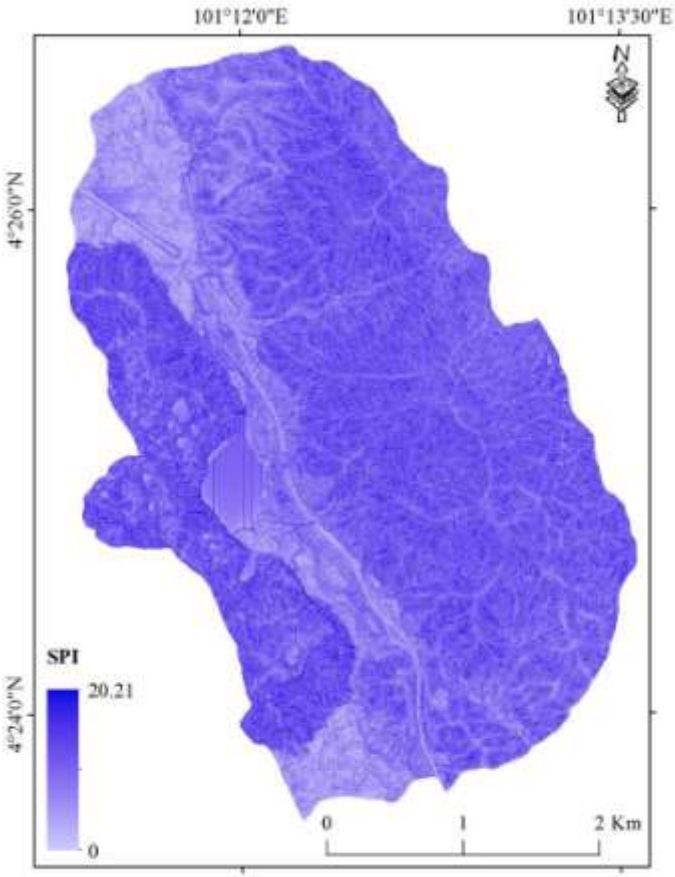
INPUT DATA LAYERS (STREAM POWER INDEX)

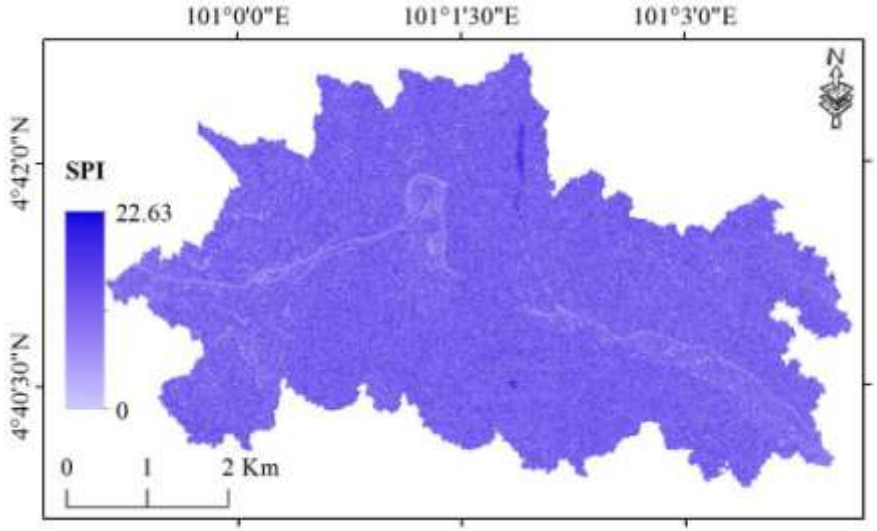
$$SPI = \ln(A * \tan\beta)$$

Where *As* is the upstream area.
β is the slope in the given cell

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

Gua Tempurung





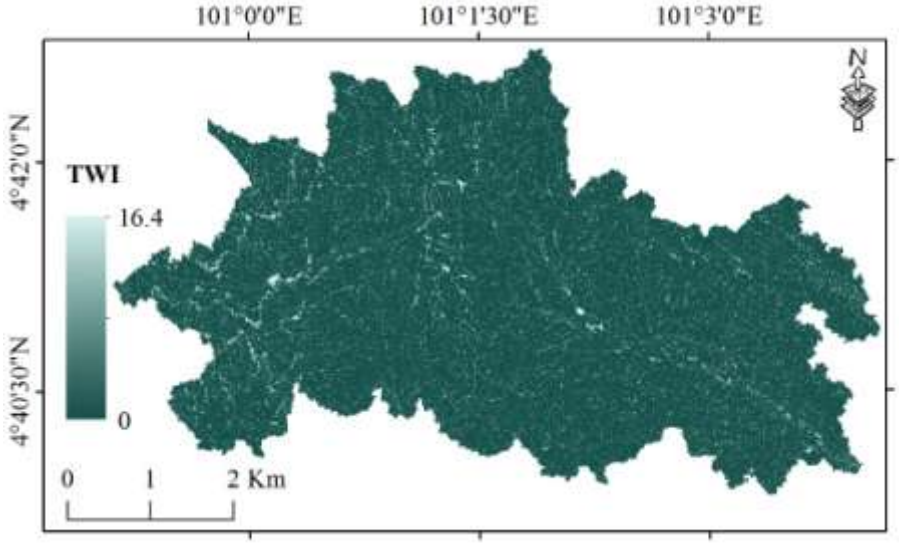
Jelapang

TOPOGRAPHICAL WETNESS INDEX

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

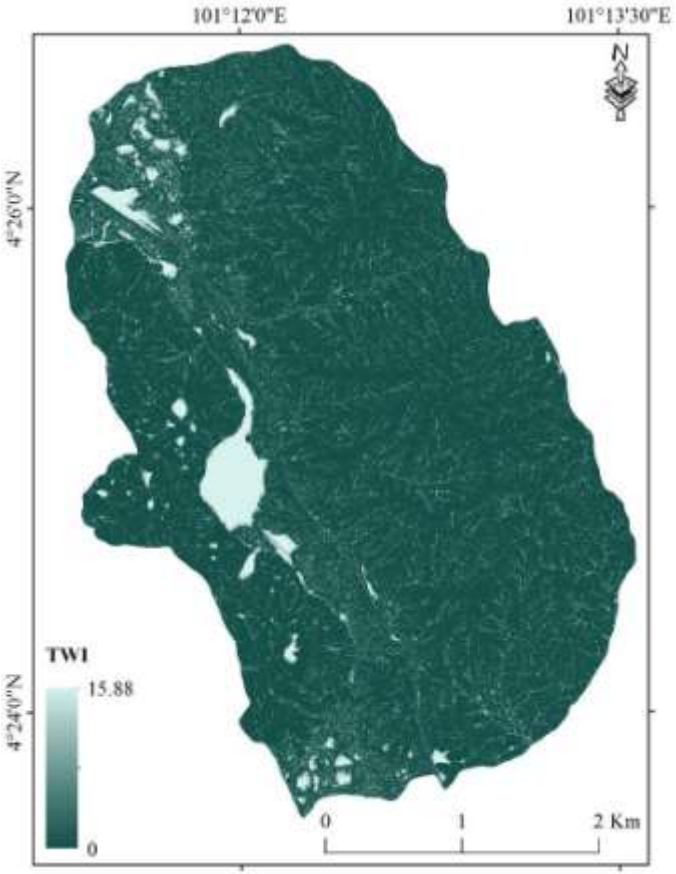
Where *As* is the upstream area.
β is the slope in the given cell

TWI describes the tendency for a site to be saturated to the surface given its contributing areas and local slope characteristics



Jelapang

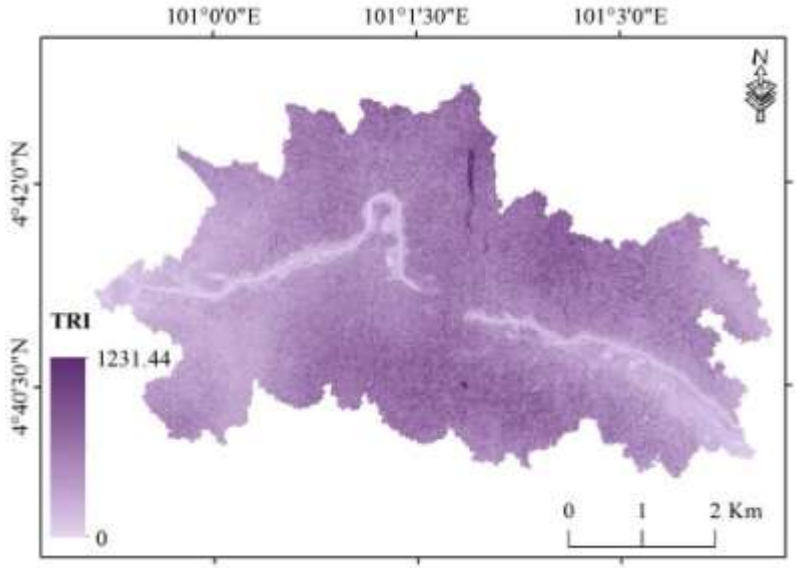
Gua Tempurung



TERRAIN ROUGHNESS INDEX

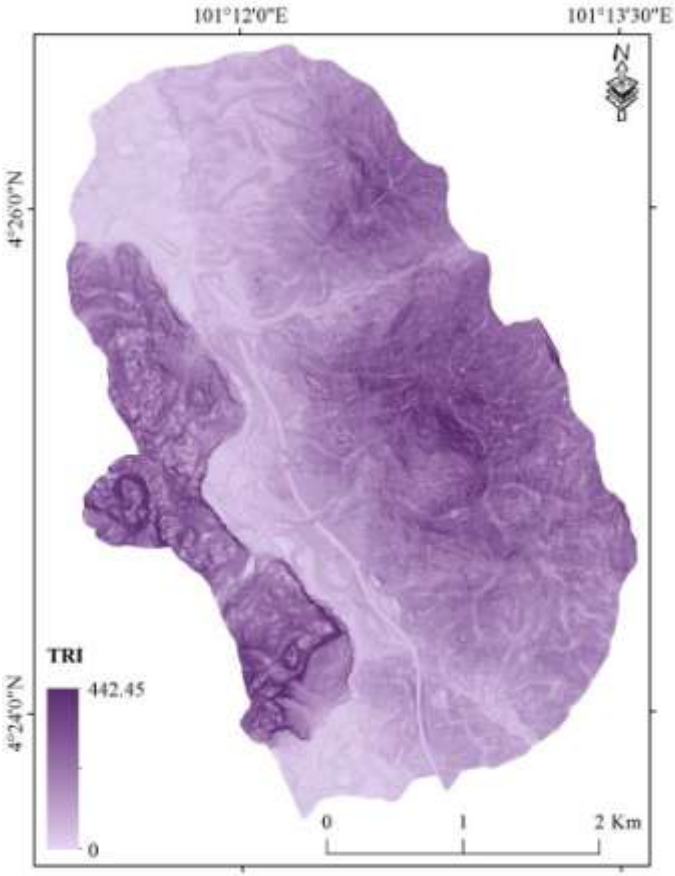
Topographic Roughness Index (TRI) is one of the morphological factors and which is broadly utilized in landslide analysis

$$TRI = \sqrt{Abs(max^2 - min^2)}$$

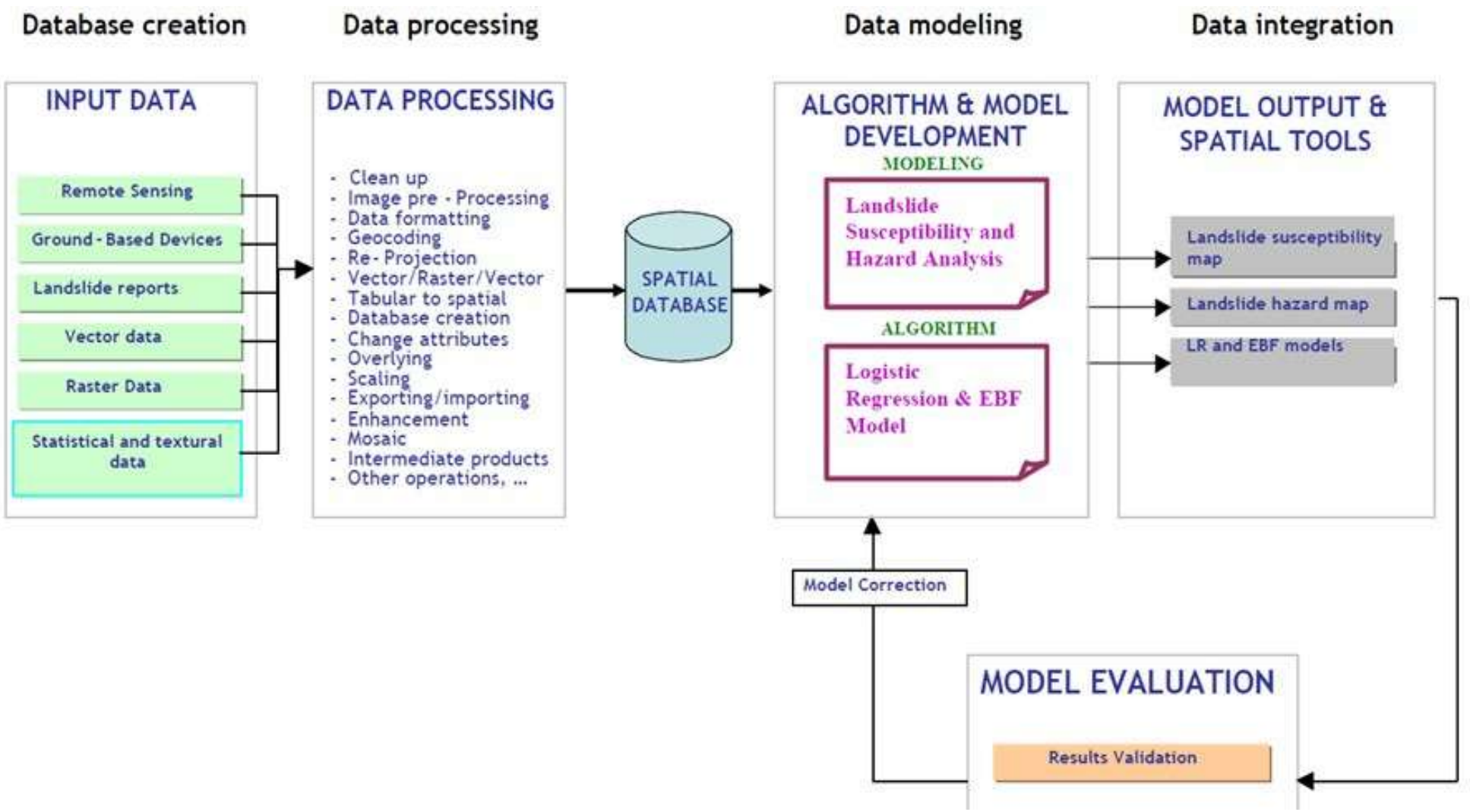


Jelapang

Gua Tempurung

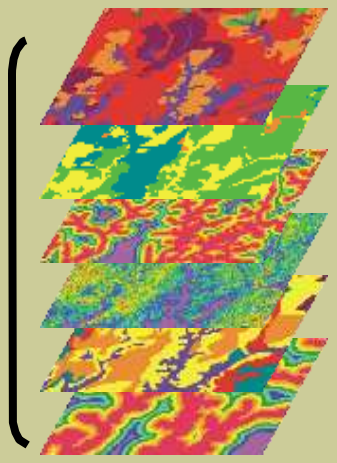


OVERALL METHODOLOGY



LANDSLIDE SUSCEPTIBILITY MODELING

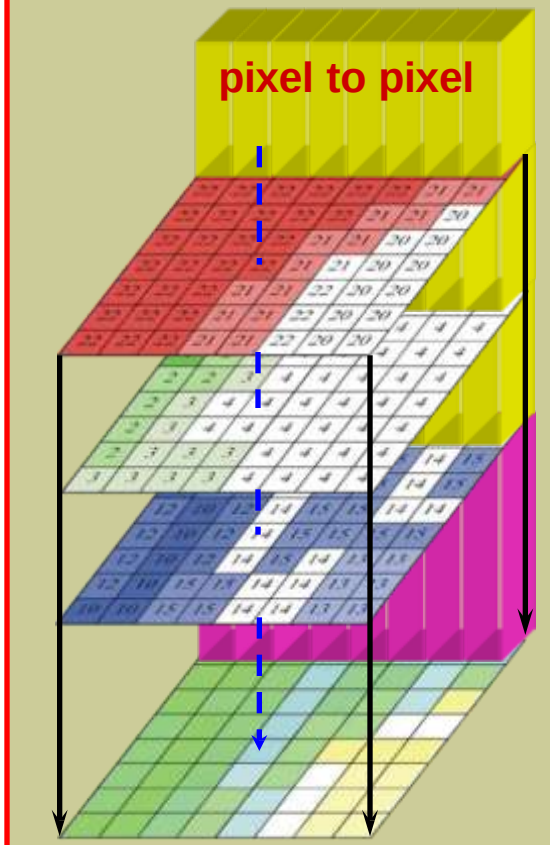
Extracted factors	Quantitative prediction models	Overlay analysis



- Altitude
- Slope
- Aspect
- Curvature
- SPI
- TWI
- TRI
- Drainage

- Landslide

Evidential Belief Function / Logistic Regression models

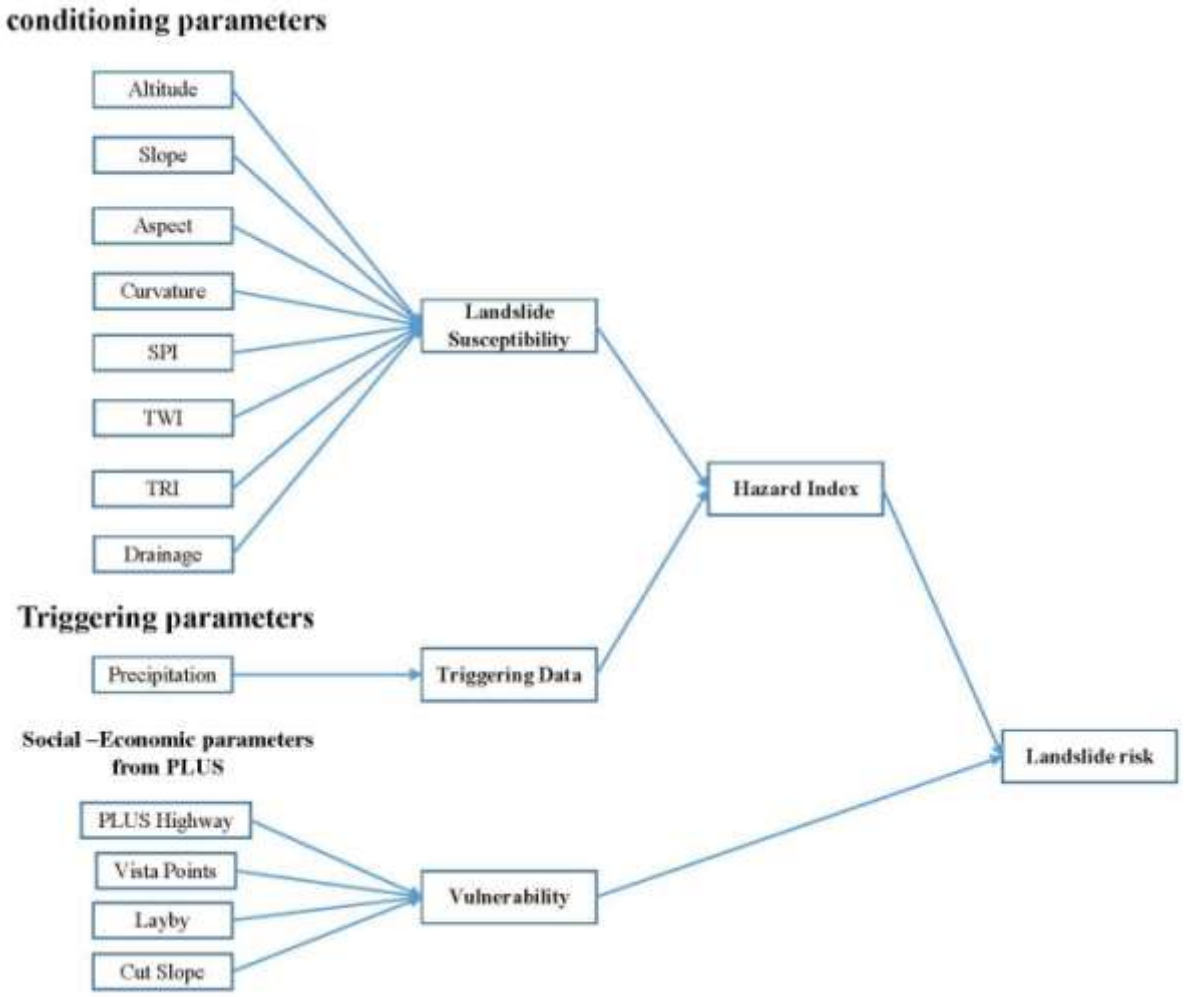


LANDSLIDE HAZARD & RISK MODELING

Landslide Hazard and Risk Modeling is designed following to the-
United Nations Department of Humanitarian Affairs, 1992

And…..

The United Nations Office for Disaster Risk Reduction" (UNISDR)



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]**

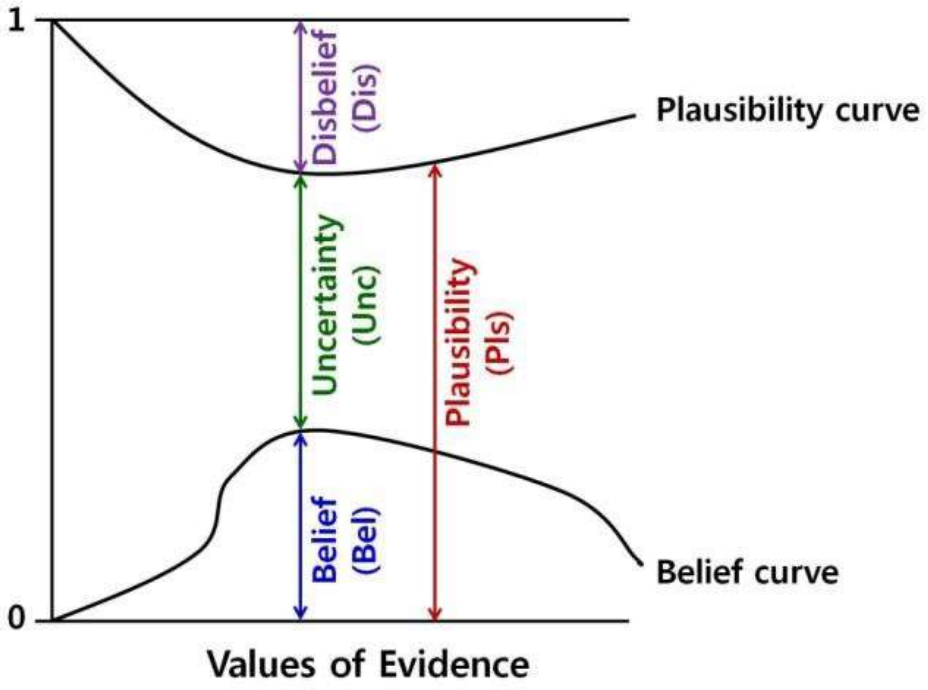
Belief (Bel) - lower degree of belief that attribute data support the proposition

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

EVIDENTIAL BELIEF FUNCTION (EBF) MODELING



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

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

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

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

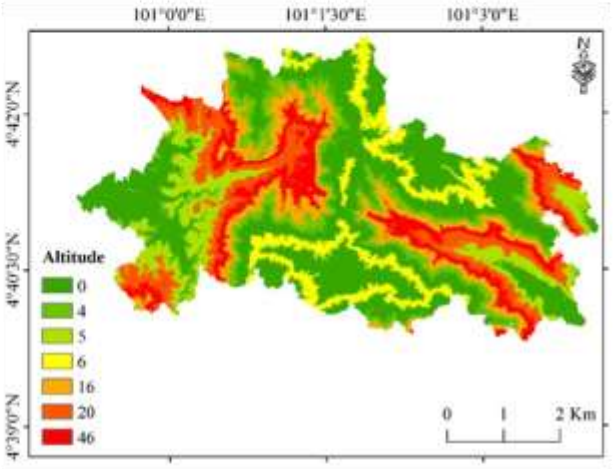
where $\beta = 1 - Bel_{X_1}Dis_{X_2} - Dis_{X_1}Bel_{X_2}$

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

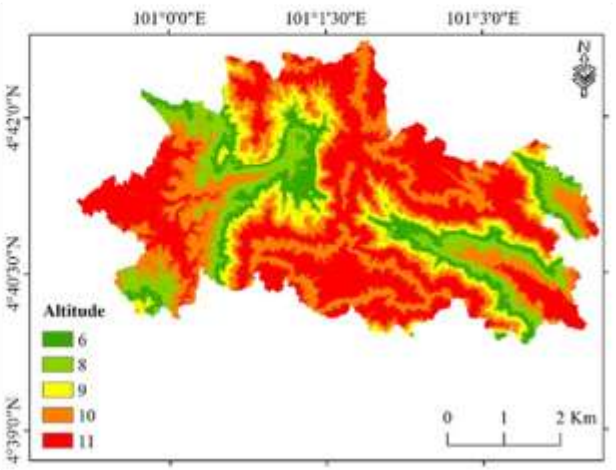
EBF MODEL OUTPUT (JELAPANG)

e.g. Altitude

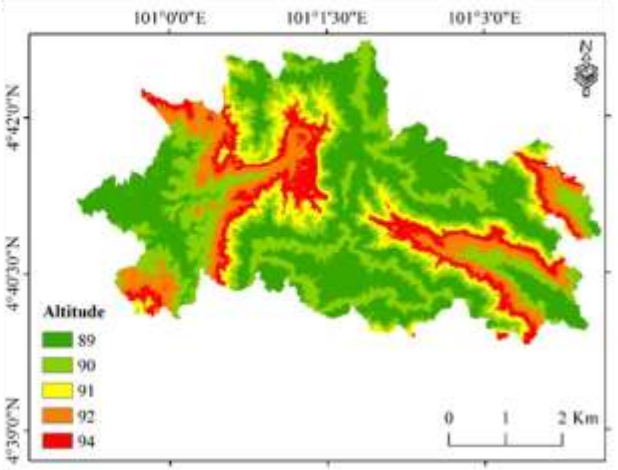
Belief



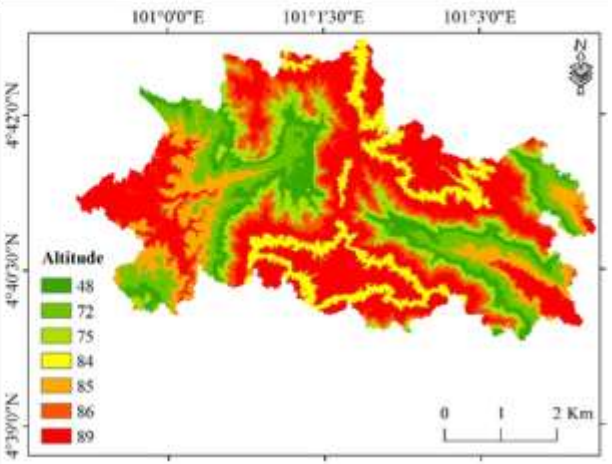
Disbelief



Plausibility



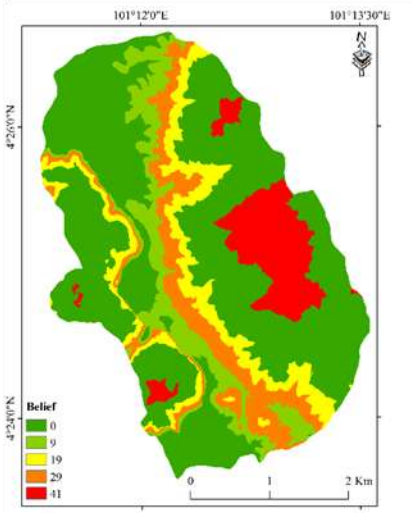
uncertainty



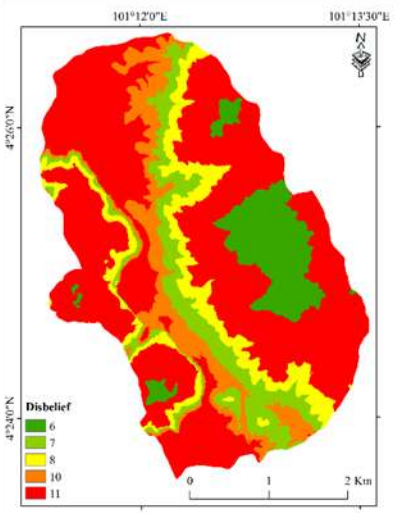
EBF MODEL OUTPUT (GUA TEMPURUNG)

e.g. Altitude

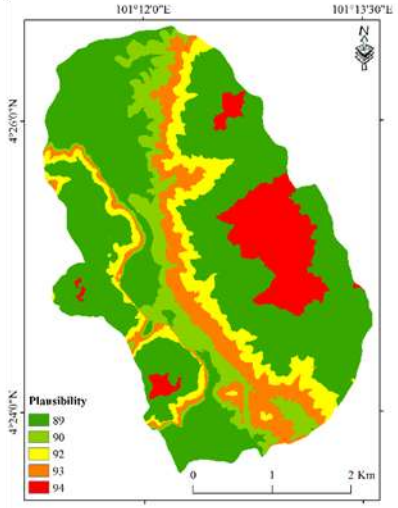
Belief



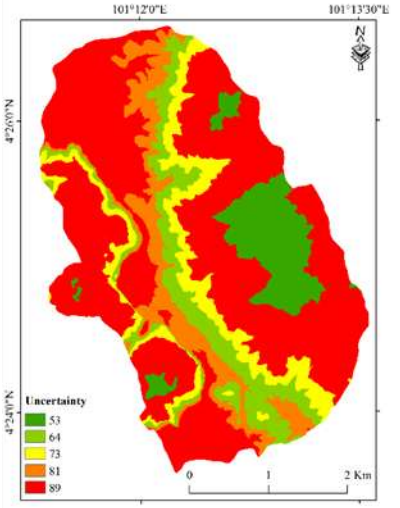
Disbelief



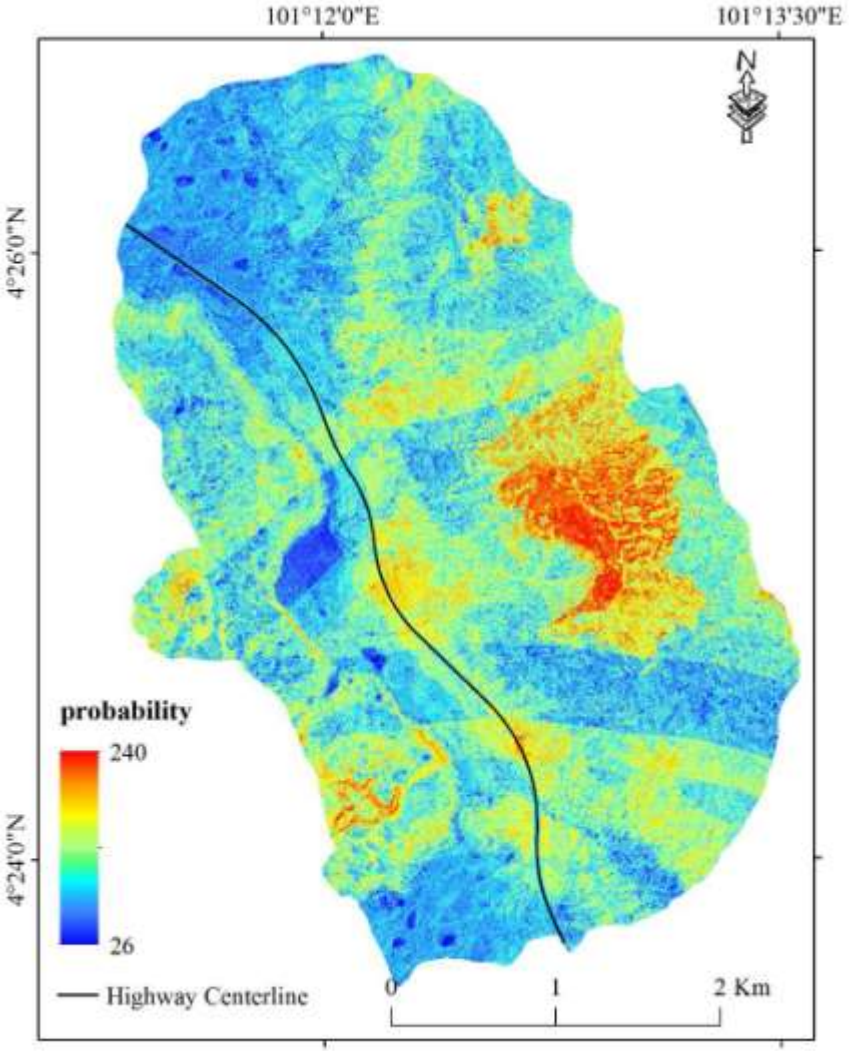
Plausibility

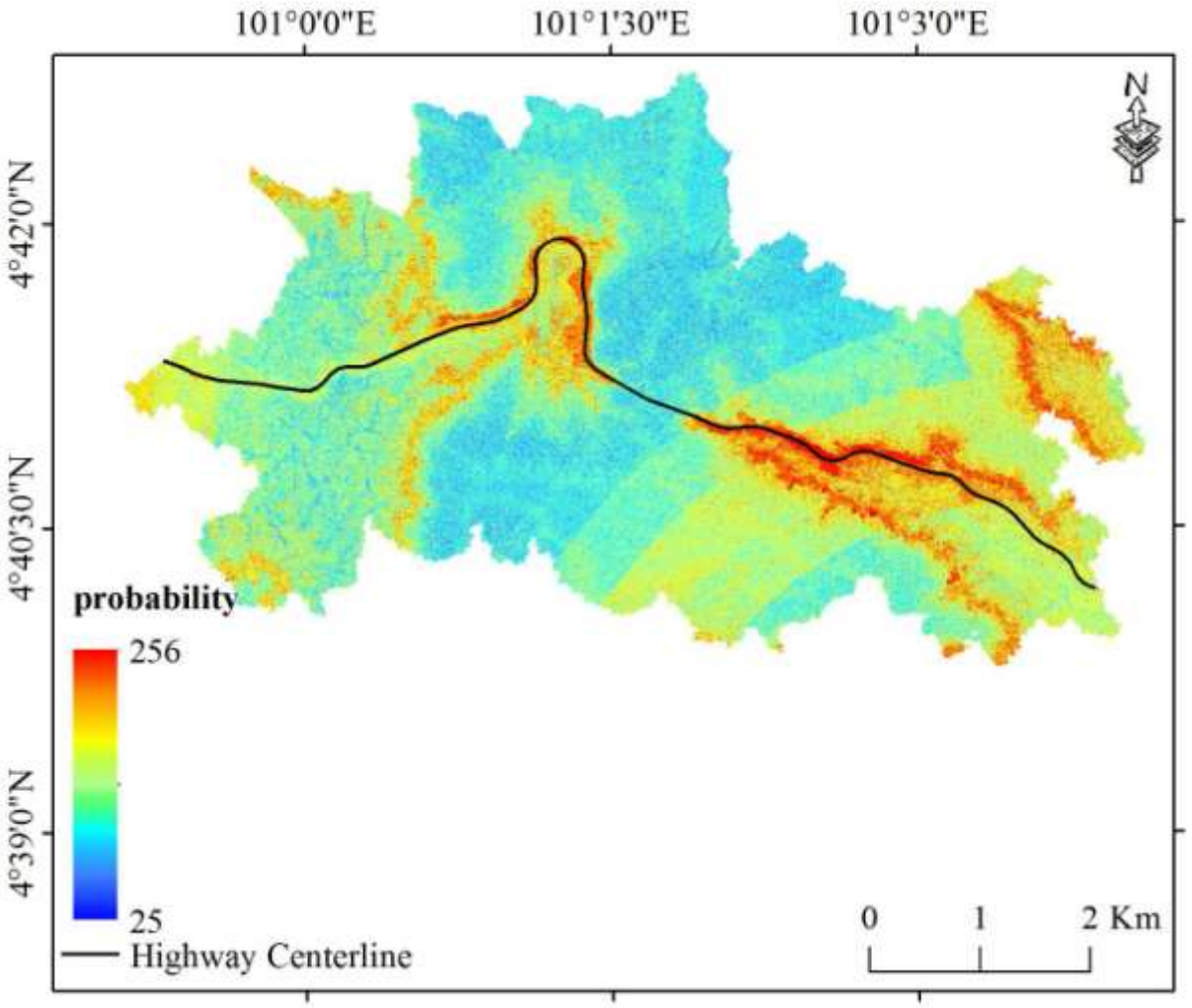


Uncertainty



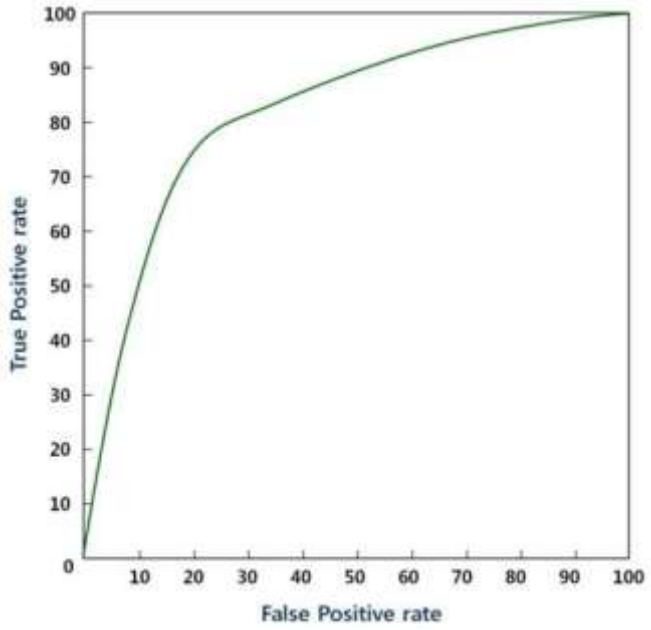
EBF MODEL PROBABILITY MAP



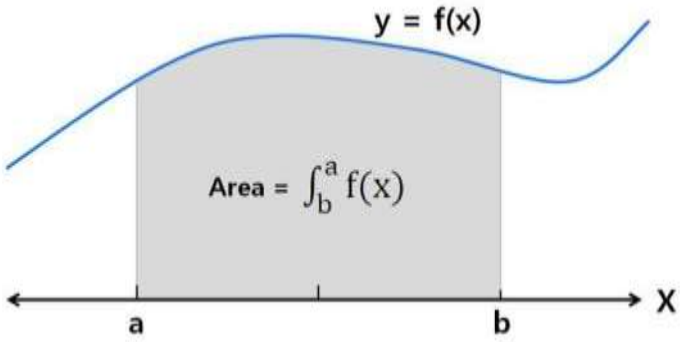


VALIDATION OF SUSCEPTIBILITY MAP

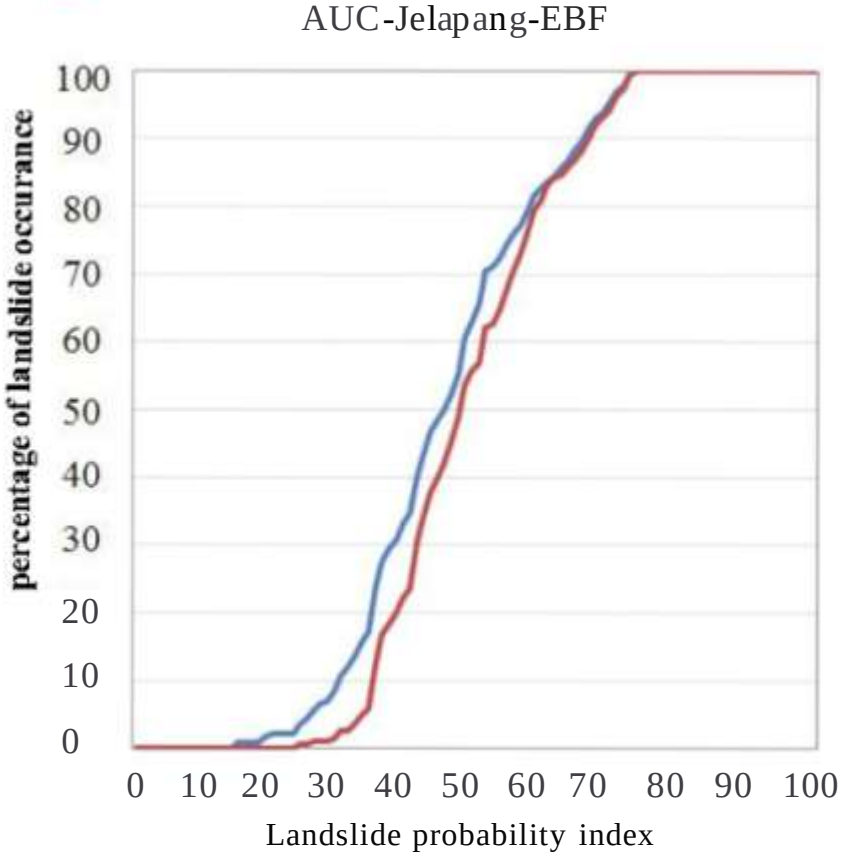
- ROC curve
  - In a ROC curve the true positive rate (Sensitivity) is plotted in function of the false positive rate (100-Specificity) for different cut-off points

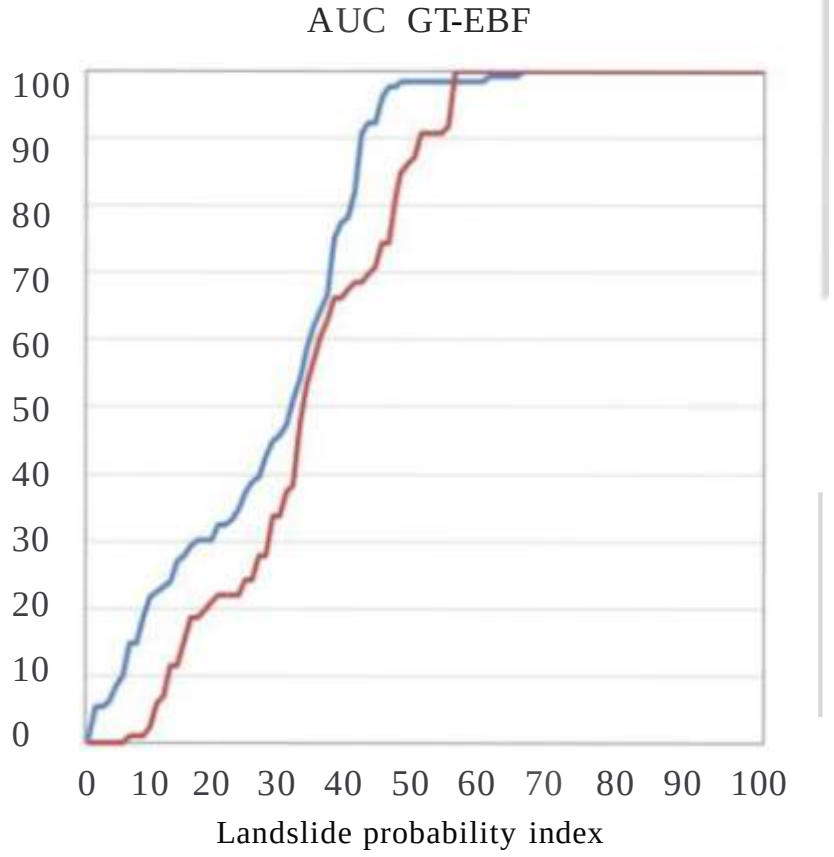


- Area Under Curve
  - The area between the graph of y = f(x) and the x-axis is given by the definite integral below. This formula gives a positive result for a graph above the x-axis, and a negative result for a graph below the x-axis.



EBF MODEL VALIDATION





LOGISTIC REGRESSION MODEL

Logistic Function:

$$\sigma(t) = \frac{e^t}{e^t + 1} = \frac{1}{1 + e^{-t}}$$

Simplified Logistic Function:

$$F(x) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x)}}$$

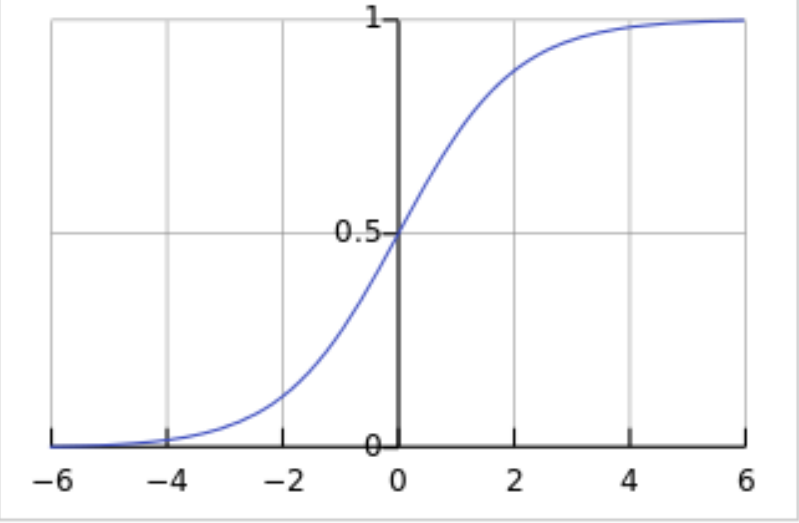
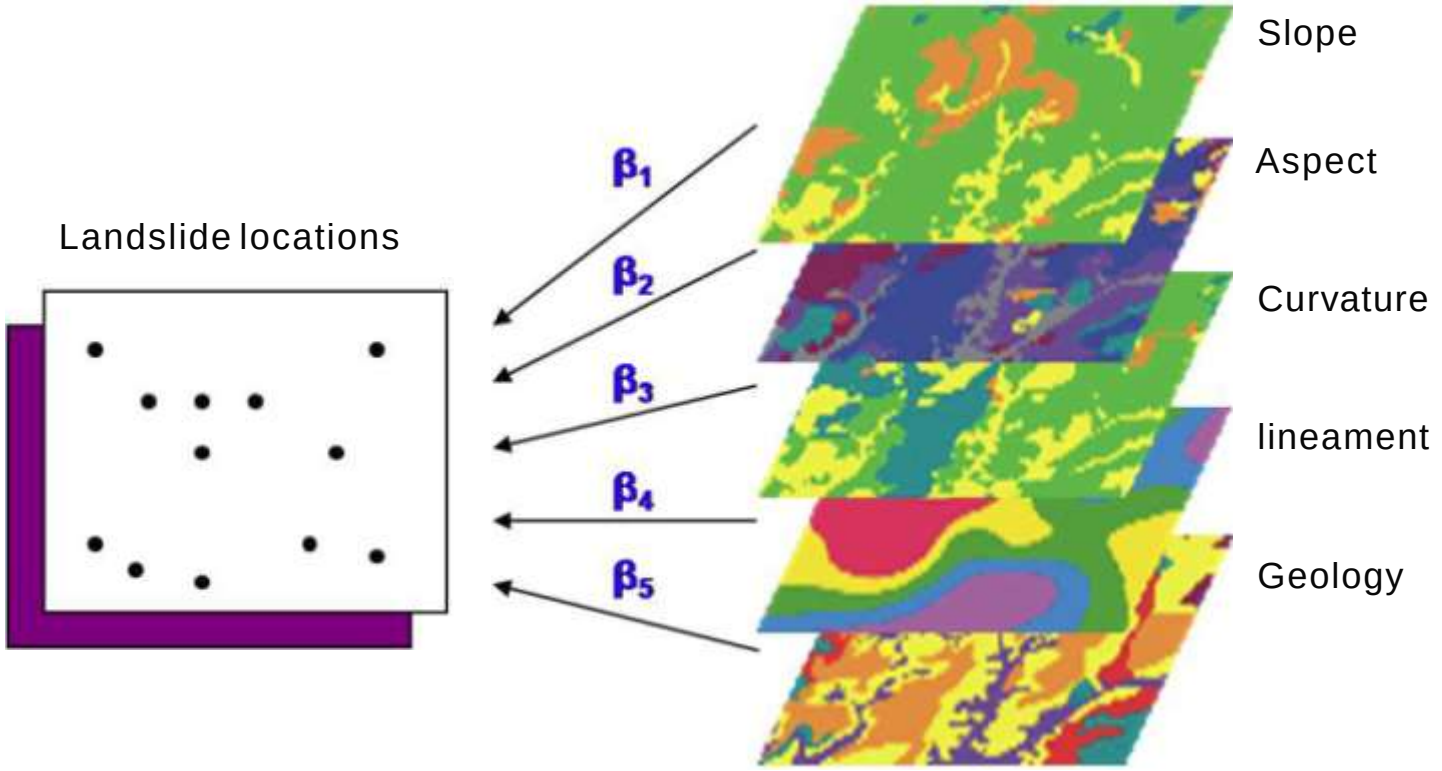


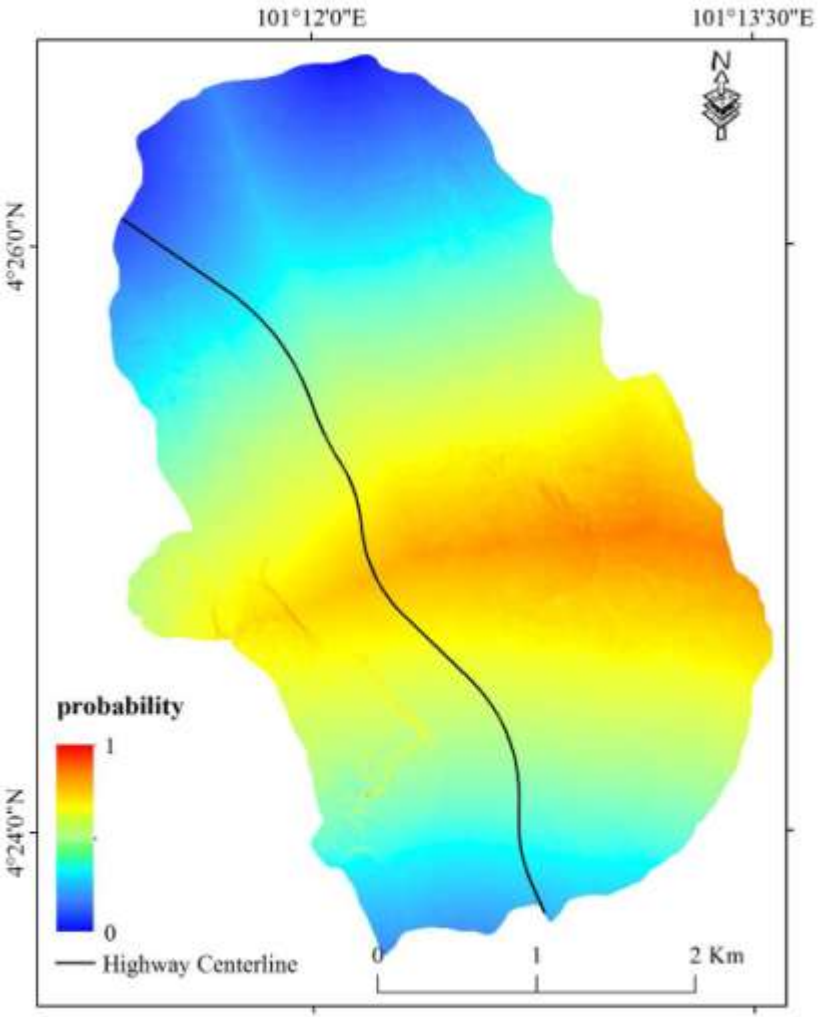
Figure 1. The standard logistic function $\sigma(t)$; note that $\sigma(t) \in (0,1)$ for all t.

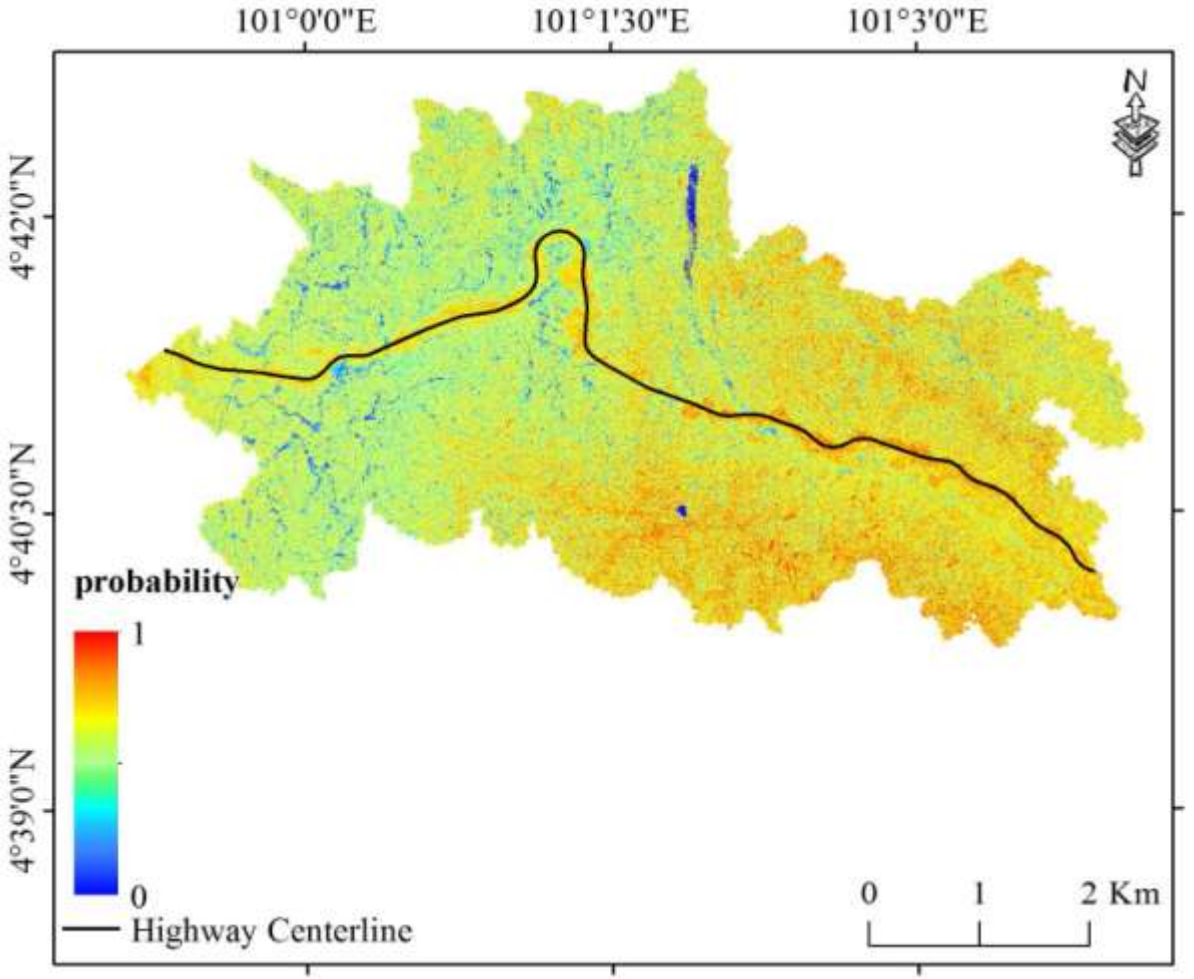
LOGISTIC REGRESSION MODEL



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

LR MODEL PROBABILITY MAP





Triggering factor

- The transformation of landslide susceptibility map into a hazard map requires consideration of landslide triggering parameters.
- For this purpose, One triggering parameter was taken into account i.e. *precipitation*.
- 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 two study areas.
- Inverse Distance Weight (IDW) was used and validated for this Purpose.

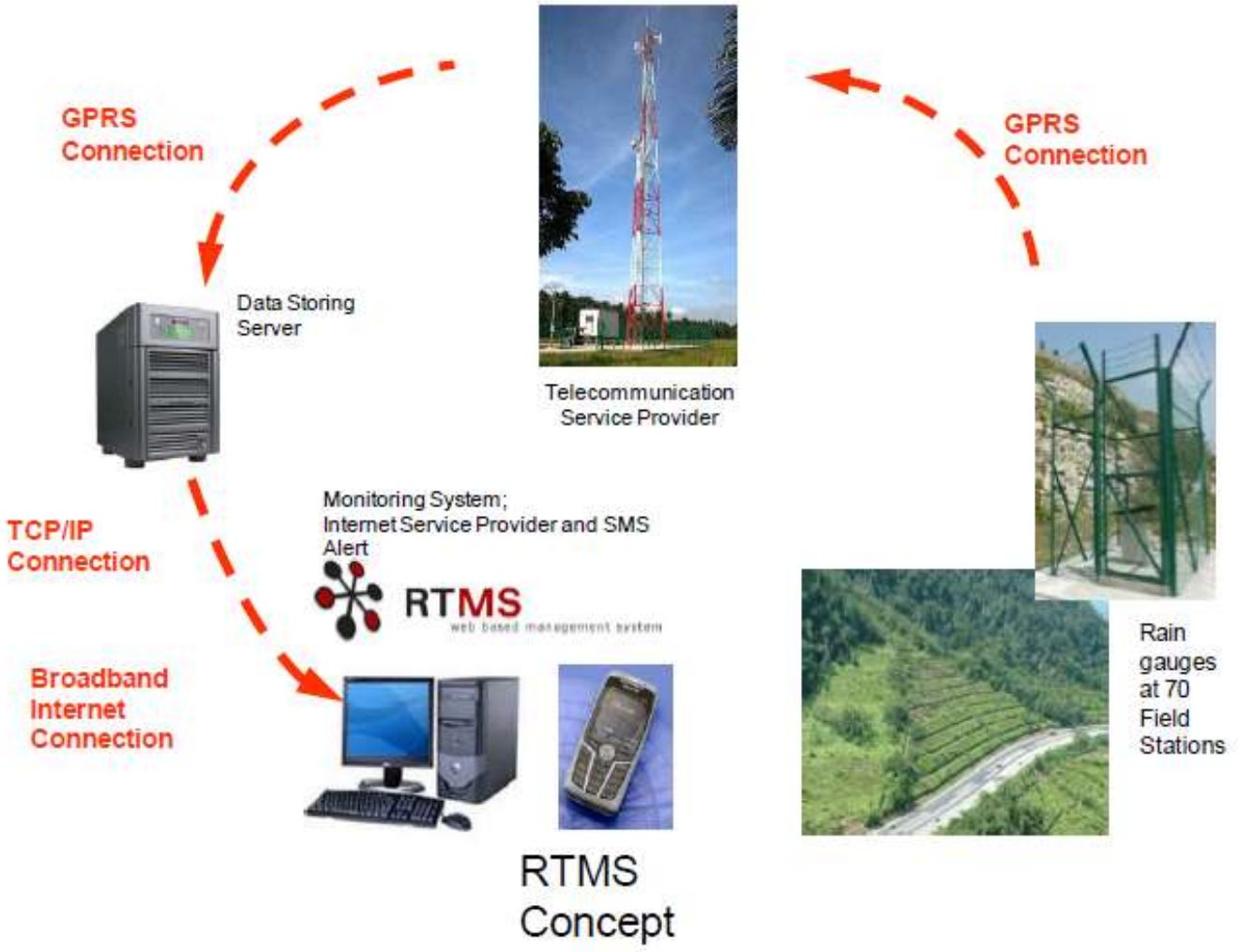
RTMS – TRIGGER PARAMETER

Equipment Installed

- Server System (HQ)

Slope monitoring
- RG stations (70)
- PM stations (12)

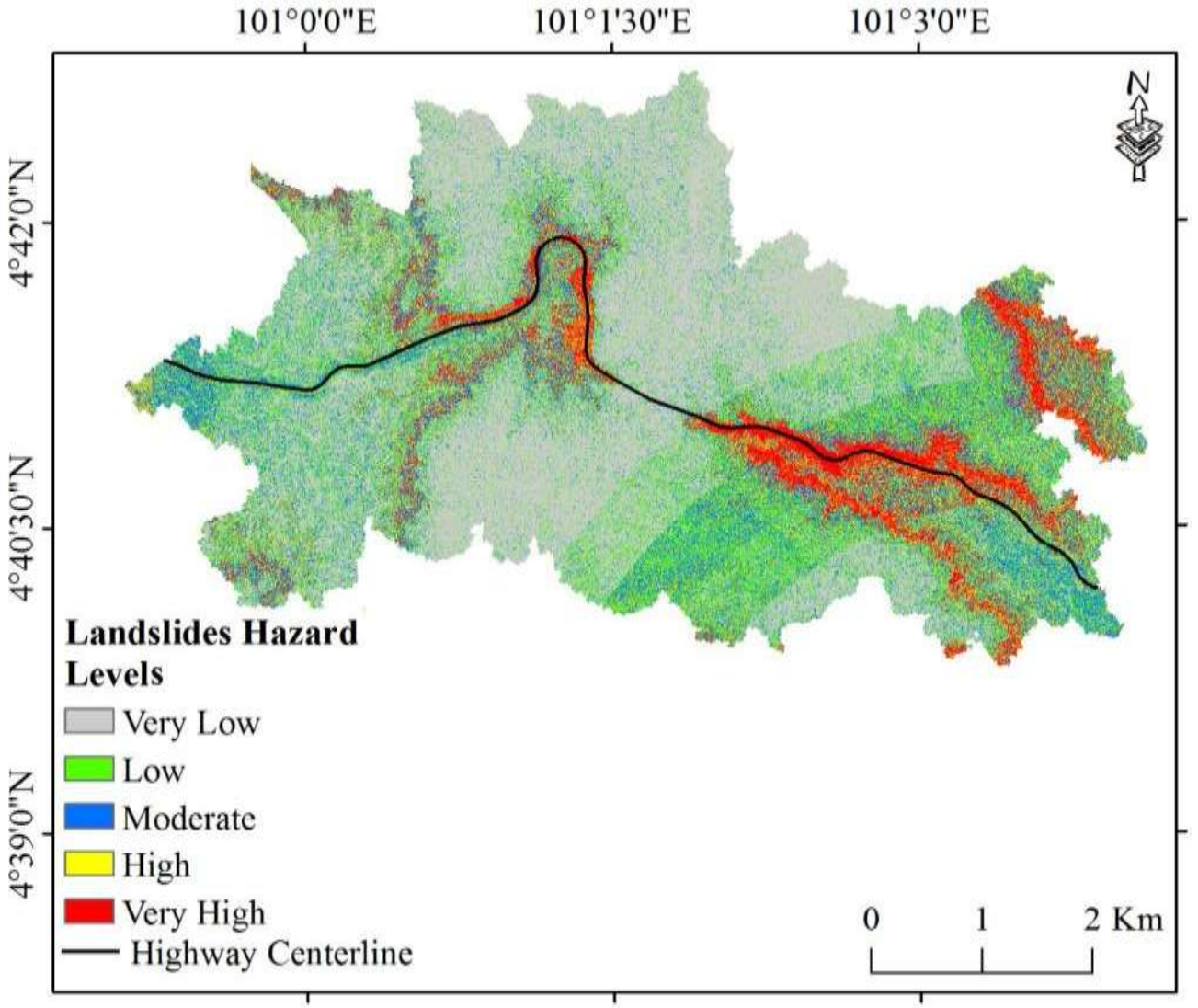
Flood monitoring
- RG stations (3)
- PM stations (5)



RTMS Concept

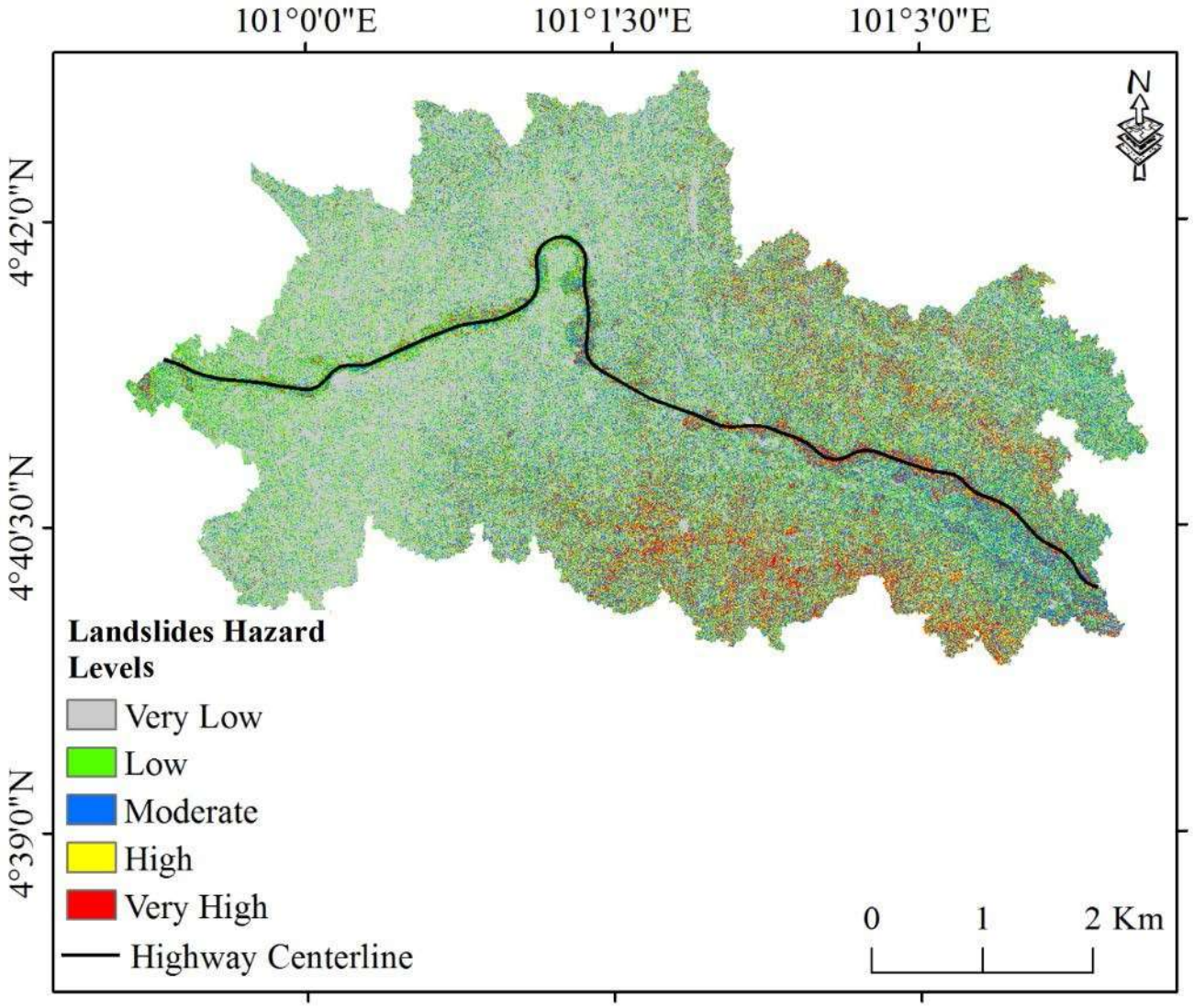
HAZARD MAP: EBF MODEL OUTPUT

JELAPANG AREA

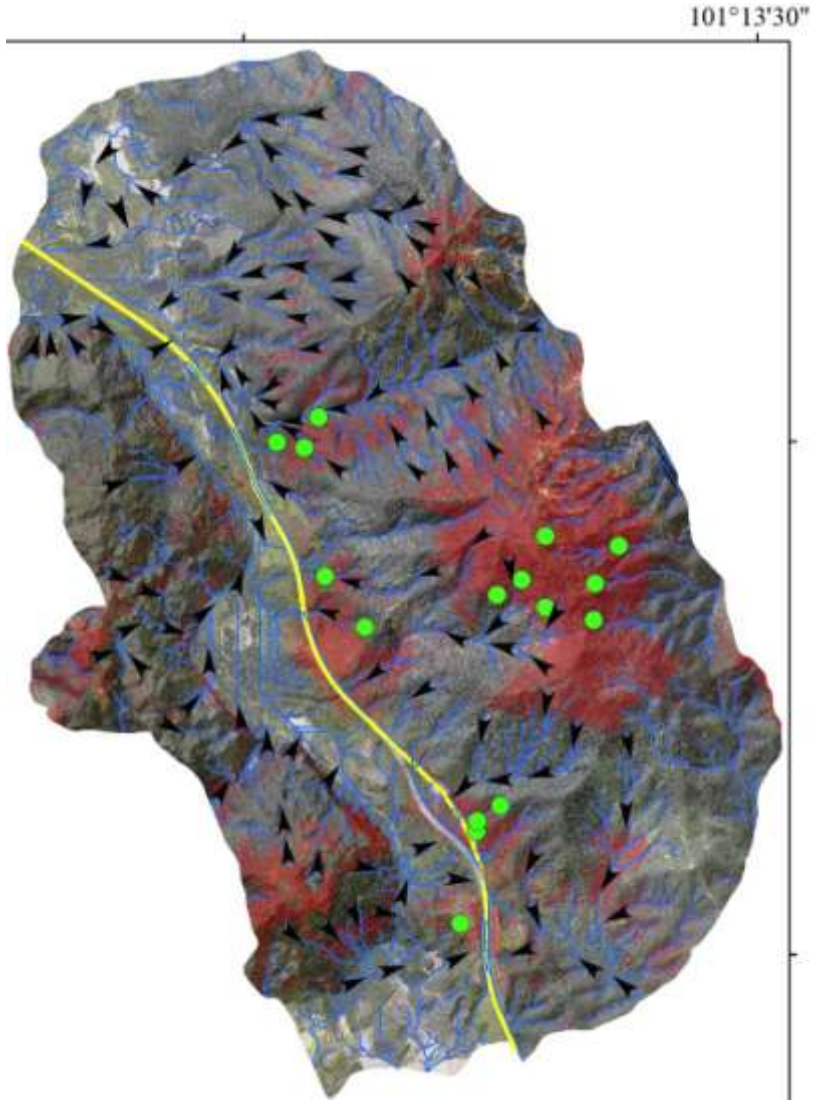


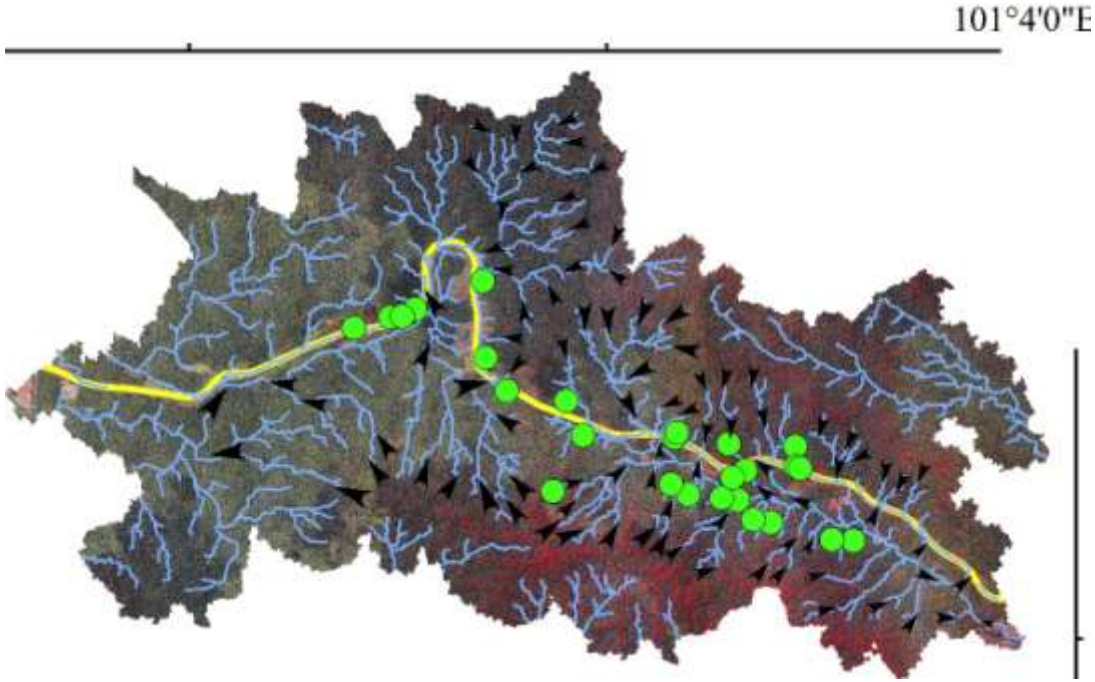
HAZARD MAP: LR MODEL OUTPUT

JELAPANG AREA

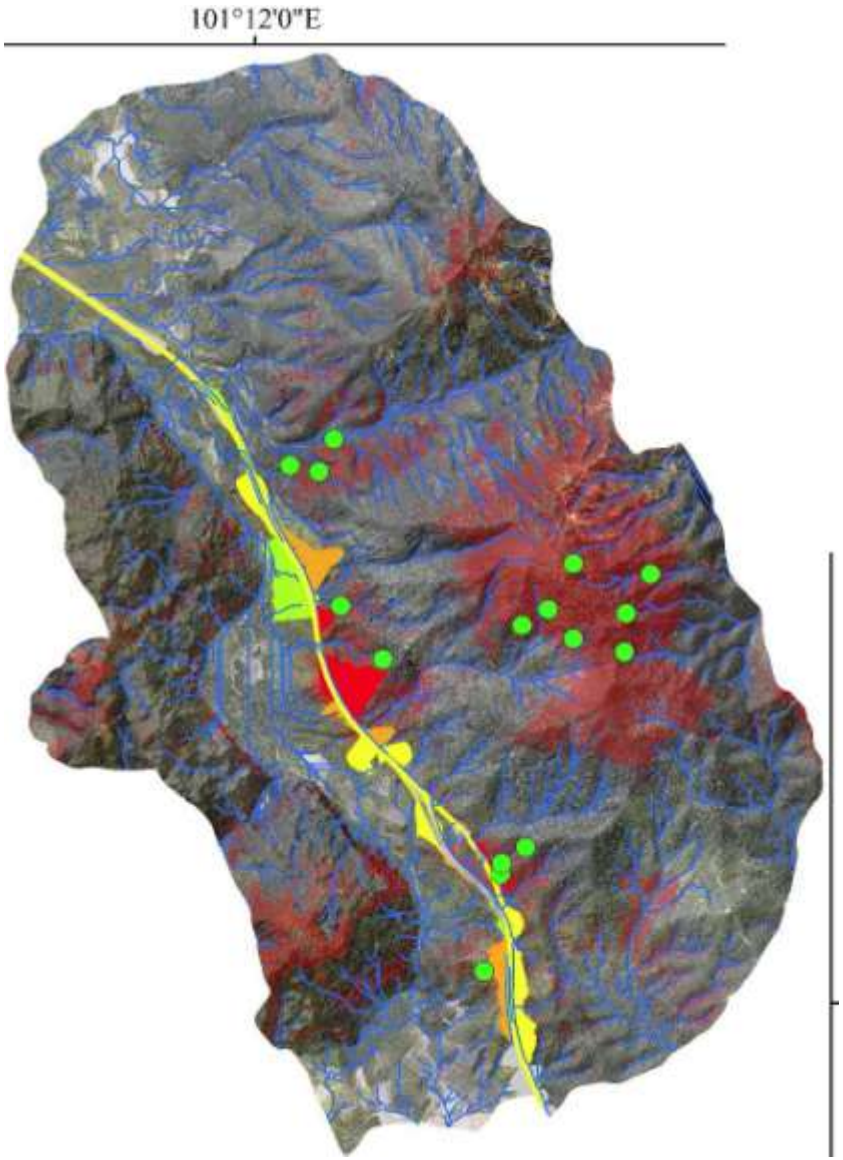


HAZARD MAP: HYDROGEOLOGY





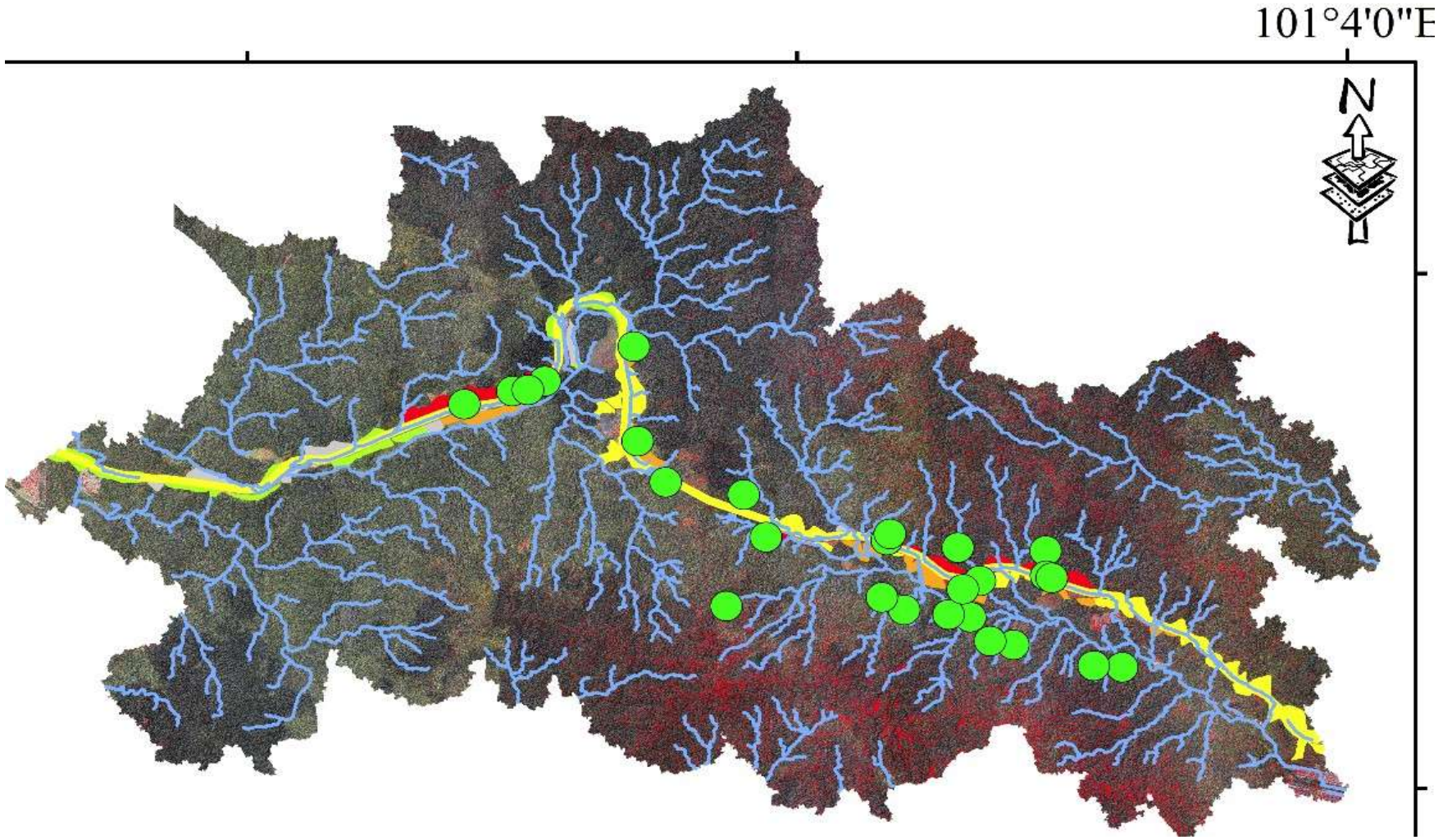
GUA TEMPURUNG: HAZARD MODELLING



Hazard Risk:

- Catchment Area
- Cut Slopes (ROW)

JELAPANG : HAZARD MODELLING



VALIDATION RESULTS

Slope Failure Records: 70% model training
30% validating

EBF MODEL

	Success Rate	Prediction Rate
Jelapang	53%	50%
Gua Tempurung	73%	67%

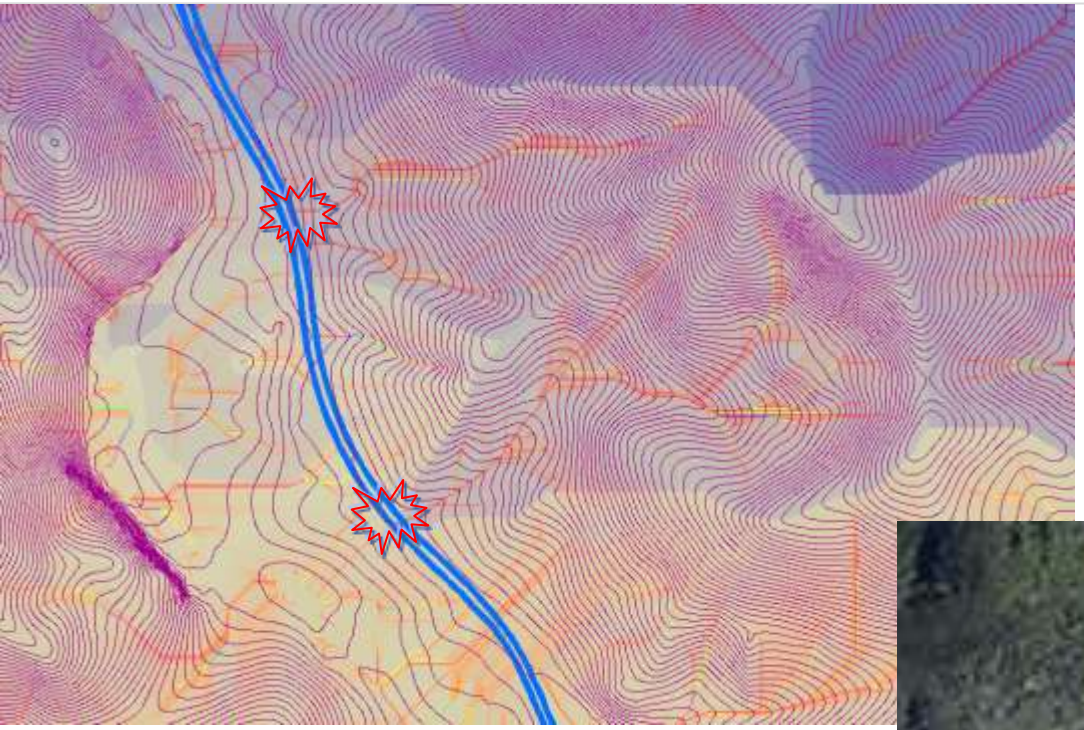
LR MODEL

	Success Rate	Prediction Rate
Jelapang	90%	88%
Gua Tempurung	85%	83%

NEXT?

The way forward

CASE STUDY – GUA TEMPURUNG AREA (CATCHMENTS - HYDROGEOLOGY)



Basin:

- **Catchment Mapping**
- **Funnel shape**
- **Small outlet**
- **Impact point**

CASE STUDY – GUA TEMPURUNG AREA (RAINFALL ANALYSIS – MULTIPLE SLOPE FAILURES)

Monthly rainfall data – Gua Tempurung

LOCATIONS	RG	2012						
		Jan	Feb	Mar	Apr	May	Jun	Jul
KM302.20SB - G. TEMPURUNG	RGC1-3	131.8	182.4	87.2	333.8	76.8	14.2	10.2
KM303.25NB - G. TEMPURUNG	RGC1-4	155.8	310.8	292.4	573.8	134.8	20.4	117.0
KM304.69SB - G. TEMPURUNG	RGC1-5	114.6	291.8	260.4	422.6	137.2	22.6	108.8
KM306.35NB - G. TEMPURUNG	RGC1-6	113.0	258.2	287.0	429.6	111.2	22.2	130.4

Daily rainfall data – Gua Tempurung

Location	Device	Year 2012							
		06-Apr	07-Apr	08-Apr	09-Apr	10-Apr	11-Apr	12-Apr	13-Apr
KM302.20SB - G. TEMPURUNG	RGC1-3	38.6	11.4	0.6	6.8	0.6	26.6	65.8	0.0
KM303.25NB - G. TEMPURUNG	RGC1-4	77.4	13.4	15.2	5.4	0.6	20.0	214.0	37.8
KM304.69SB - G. TEMPURUNG	RGC1-5	48.2	7.0	24.2	6.2	3.6	16.0	97.0	38.4
KM306.35NB - G. TEMPURUNG	RGC1-6	30.8	21.2	13.4	12.8	19.8	14.2	73.6	33.6
		195.0	53.0	53.4	31.2	24.6	76.8	450.4	109.8
Average		48.75	13.25	13.35	7.80	6.15	19.20	112.60	27.45

Area	Highest rainfall recorded (mm/hour)
Jelapang area	56.2 mm/hour
Gua Tempurung area (7 nos. of slope failures)	61.6 mm/hour

Hourly rainfall data – Gua Tempurung

- 1st cycle

RG	11-Apr-12					12-Apr-12							
	1900	2000	2100	2200	2300	0000	0100	0200	0300	0400	0500	0600	0700
RGC1-3		2.8	4.4	2.8	16.6	20.2	36.4	5.6	2.0	1.0	0.4	0.2	
RGC1-4		1.6	7.6	1.0	9.8	19.6	33.2	7.0	24.2	11.6	21.0	61.6	
RGC1-5			5.2	1.2	9.4	21.8	29.2	6.8	2.8	0.6	0.2		
RGC1-6			7.2	2.6	4.2	21.8	27.8	20.2	2.8	0.4	0.2	0.2	
	-	4.4	24.4	7.6	40.0	83.4	126.6	39.6	31.8	13.6	21.8	62.0	-
		1.10	6.10	1.90	10.00	20.85	31.65	9.90	7.95	3.40	5.45	15.50	

- 2nd cycle

RG	12-Apr-12				13-Apr-12			
	2000	2100	2200	2300	0000	0100	0200	0300
RGC1-3								
RGC1-4		5.8	7.2	19.6	30.2	7.0		
RGC1-5		0.4	1.4	33.8	37.4	0.2	0.2	
RGC1-6			0.2					
	-	6.2	8.8	53.4	67.6	7.2	0.2	-
		1.55	2.20	13.35	16.90	1.80	0.05	

Intensity / volume / duration

REINFORCED PREVENTIVE MEASURES

Preventive measures :

- Database updating
- Debris Flow Net
- Rainfall monitoring (RTMS & EWS)
- Aerial surveillence

THANK YOU