# Development of a statistics-based nowcasting model for earthquake-triggered landslides in Taiwan

Ray Y. Chuang, Bing Sheng Wu, Hsiang-Chieh Liu, Hsin-Hua Huang, Chih-Heng Lu

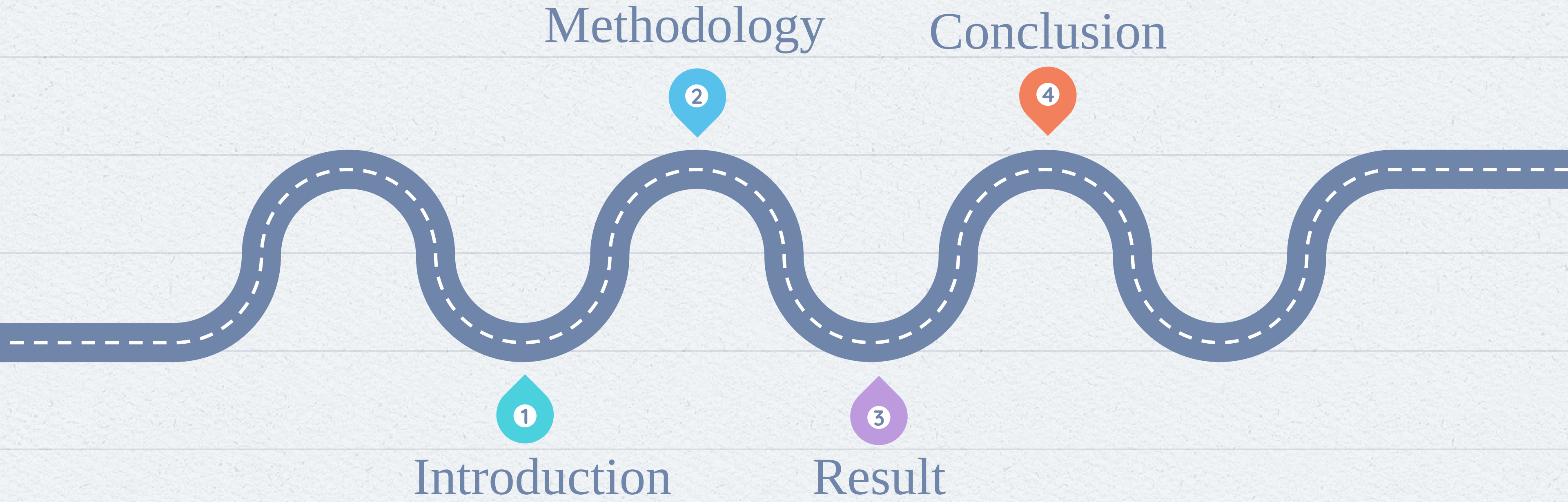
Engineering Geology 289 (2021) 106177

**Presenter: 沈楷庭(Kai-Ting SHEN)**

**Advisor: Pro. Jia-Jyun Dong**

**Date: 2022 / 06 / 10**

# Outline



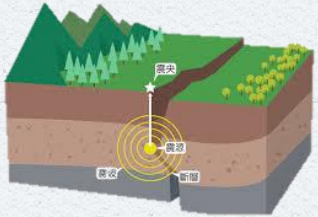
1.

# Introduction

# Introduction

Rapid identification of landslides is very important:

1. Assessment of earthquake impacts
2. Hazard mitigation



Earthquake

trigger

landslides

caused

fatality

In recent year:

Two kinds of models

| | physics-based of models | statistics-based of models |
|---|---|---|
| Method | mechanical and frictional properties | correlation between key driving factors and landslide |
| Parameters | ✖ more | ✔ less |
| References | (Jibson et al., 2000); (Gallen et al., 2017) | (Nowicki Jessee et al., 2018); (Robinson et al., 2018). |

# Objectives

Generate the Taiwan landslide susceptibility model

While global models have been applied to broad regions, the characteristics of earthquake-triggered landslides could vary with local geologic conditions

Increase model resolution

In Nowicki 2014, the resolution is about ~1km

↓

In this paper, the resolution increase to 40m

2.

# Methodolygy

# Process

Based on Nowicki et al., 2014; Nowicki Jessee et al., 2018

To reflect the complicated geomorphic and geologic conditions in Taiwan, he use high resolution topographic and geologic data of Taiwan to develop a nowcasting model

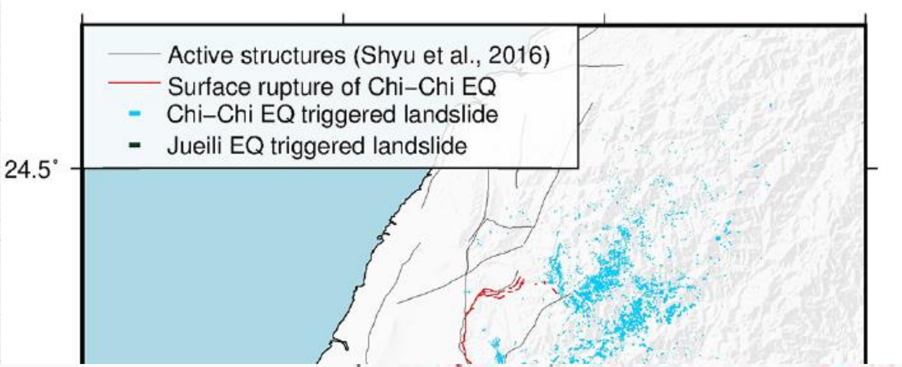
1. select candidate factors that could highly affect earthquake-triggered landslides
2. Calculate the correlation coefficient to determine the factor as a possible variable
3. test the significance of each variable using a logistic regression model and the goodness-of-fit criteria
4. the best fitting logistic model is defined to predict the possibility of earthquake-triggered landslides in Taiwan.

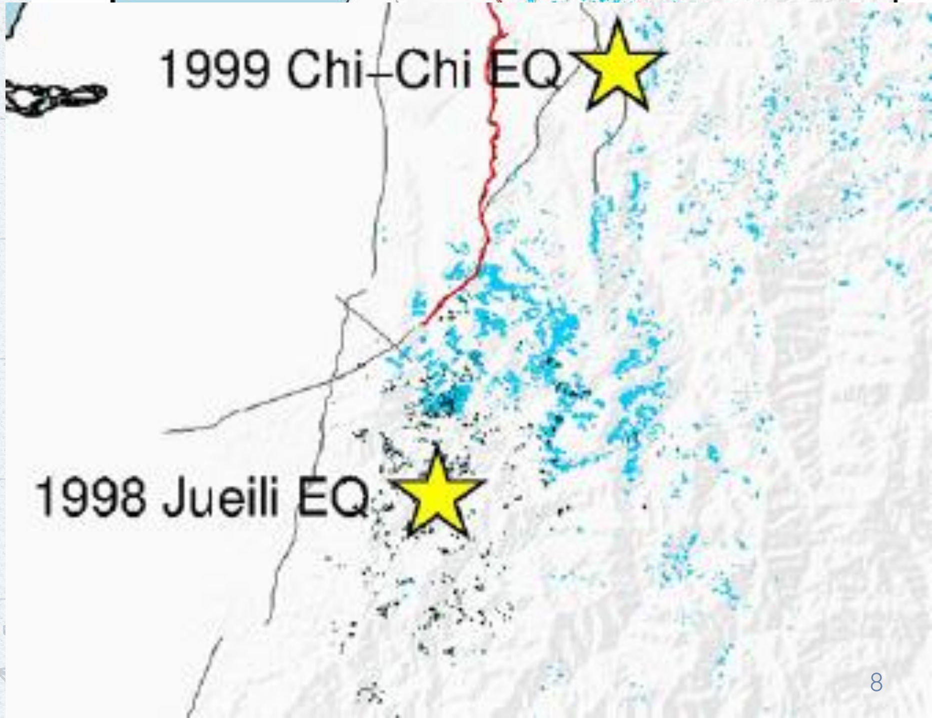
# Study Area

Landslide inventory used in this study:

1. Light blue polygons :
   show landslide distribution of the 1999 Chi-Chi earthquake (Liao and Lee, 2000)
2. Dark blue polygons :
   show landslide distribution of the 1998 Jueili earthquake (Huang and Lee, 1999)

Yellow stars denote the epicenters of the two earthquakes.



# Variables

**Seismic property:** quantitative measurements representing ground shaking

**Lithology:** is vital for the delivery of energy and affects the degree of landslides

**Wetness:** is adopted to represent friction of soil for the estimation of landslides (Nowicki et al., 2014).

**Table 1**
Candidate factors for the assessment of earthquake-triggered landslides.

| Type | Variable | Reference |
|---|---|---|
| **Seismic property** | PGA | Lin and Tung (2004); Budimir et al. (2015b); Nowicki et al. (2014); Umar et al. (2014); Nowicki Jessee et al. (2018) |
| | Arias Intensity (AI) | Campbell and Bozorgnia (2012); Liu et al. (2016); Lee et al. (2012); Liu et al. (2015) |
| | Wave and aspect direction | Khazai and Sitar (2004); Lin and Tung (2004); Meunier et al. (2008); Lee (2012) |
| **Lithology** | Lithologic data | Nowicki et al. (2014); Nowicki Jessee et al. (2018) |
| **Topography** | Elevation | Lin and Tung (2004); Chang et al. (2007); Umar et al. (2014); Budimir et al. (2015b) |
| | Aspect | Lin and Tung (2004); Lee and Evangelista (2006); Chang et al. (2007); Umar et al. (2014); Budimir et al. (2015b) |
| | Curvature | Umar et al. (2014); Budimir et al. (2015b) |
| | Plan curvature | Chang et al. (2007) |
| | Profile curvature | Chang et al. (2007) |
| | Roughness (3 × 3) | Budimir et al. (2015b) |
| | Roughness (5 × 5) | Budimir et al. (2015b) |
| | Distance to ridge | Chang et al. (2007); Budimir et al. (2015b) |
| | Slope angle | Lin and Tung (2004); Chang et al. (2007); Nowicki et al. (2014); Umar et al. (2014); Budimir et al. (2015b); Nowicki Jessee et al. (2018) |
| **Wetness** | CTI | Jibson (1993); Chang et al. (2007); Nowicki et al. (2014); Nowicki Jessee et al. (2018) |

**CTI**: Compound Topographic Index

# Choose factor

**There are two approaches to examine the impacts on landslides:**

1. **Point biserial Correlation coefficient:**

   appropriate for assessing relationships between topographic factors and landslides

   topographic factors → continuous

   Landslide data → binary

2. **Cramer's V:**

   used to examine the relationship between lithology data and landslide data.

   Lithology type → nominal

   Landslide data → binary

Form. : Formation

landslide data

Landslide

**(Binary)**

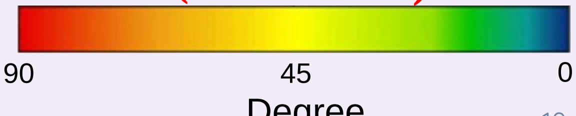
Non-landslide

Lithology **(nominal)**

| | |
|---|---|
| Form. A | Form. B |
| Form. C | Form. D |

topographic factors ex: slope

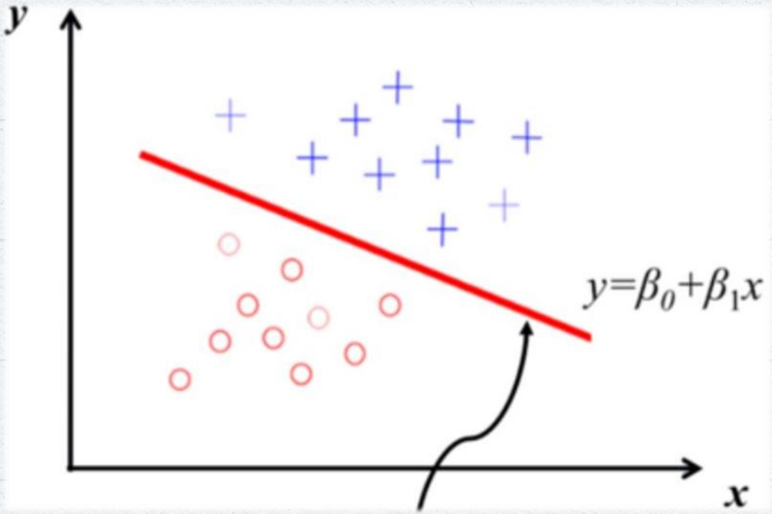
**(continuous)**



# Logistic Regression

$$susceptibility = \frac{e^y}{1 + e^y}$$

Sample points are randomly selected on landslide and non-landslide areas




Find a line that distinguishes two groups

To determine the most significant variables, approaches including:

1. Akaike information criteria (AIC)
2. area under the receiver operating curve (AUC)

$$y = a_0 + \sum_{k=1}^{n} a_k x_k$$

$a_0$: *constant intercept*

$a_k$: *weight of factor*

$x_k$: *the value of factor*

$n$ : *number of factor*

3.

# Result

# Determination of variables

Coefficient values >0.1 or < -0.1 →factor has a strong correlation with landslide occurrences (Nowicki Jessee et al., 2018).

**Table 2**
Correlation coefficient between each variable and earthquake-triggered landslides.

| Type | Variable | Coefficient | *p*-Value |
|---|---|---|---|
| **Seismic property** | PGA | **0.72** | 0.00 |
| | Arias Intensity (AI) | **0.61** | 0.00 |
| | Wave and aspect direction | 0.06 | 0.00 |
| **Lithology** | Lithologic data | **0.36** | 0.00 |
| **Topography** | Elevation | 0.05 | 0.00 |
| | Aspect | 0.02 | 0.00 |
| | Curvature | −0.06 | 0.00 |
| | Plan curvature | −0.06 | 0.00 |
| | Profile curvature | 0.06 | 0.00 |
| | Roughness (3 × 3) | **0.44** | 0.00 |
| | Roughness (5 × 5) | **0.45** | 0.00 |
| | Distance to ridge | −0.02 | 0.00 |
| | Slope angle | **0.43** | 0.00 |
| **Wetness** | CTI | −0.09 | 0.00 |

**Six Factors:**

1.PGA

2.Arias Intensity

3.Lithology

4.Roughness(3 × 3)

5.Roughness(5 × 5)

6.Slope angle

**Bold coefficient values denote a more significant correlation.**

# The nowcasting model of earthquake-triggered landslide

randomly select 2500 pixels on non-landslide areas and another 2500 pixels on landslide areas as the training data.

Lower AIC → Best model ← Higher AUC

**Table 3**
A test of the best-fit model.

| Variable | AIC | AUC |
|---|---|---|
| PGA + Roughness (5 × 5) + Lithology + PGA*Slope + PGA*Roughness (5 × 5) | 83,706 | 0.9435 |
| PGA + Roughness (5 × 5) + PGA*Roughness (5 × 5) + Lithology | 83,717 | 0.9434 |
| PGA + Slope + PGA*Roughness (5 × 5) + Lithology + PGA*Slope | 83,872 | 0.9433 |
| PGA + Slope + Lithology + Roughness (3 × 3) | 88,680 | 0.9361 |
| PGA + Slope | 93,471 | 0.9296 |
| Arias Intensity + Roughness (5 × 5) + Lithology | 97,639 | 0.7939 |

The final equation of this model is:

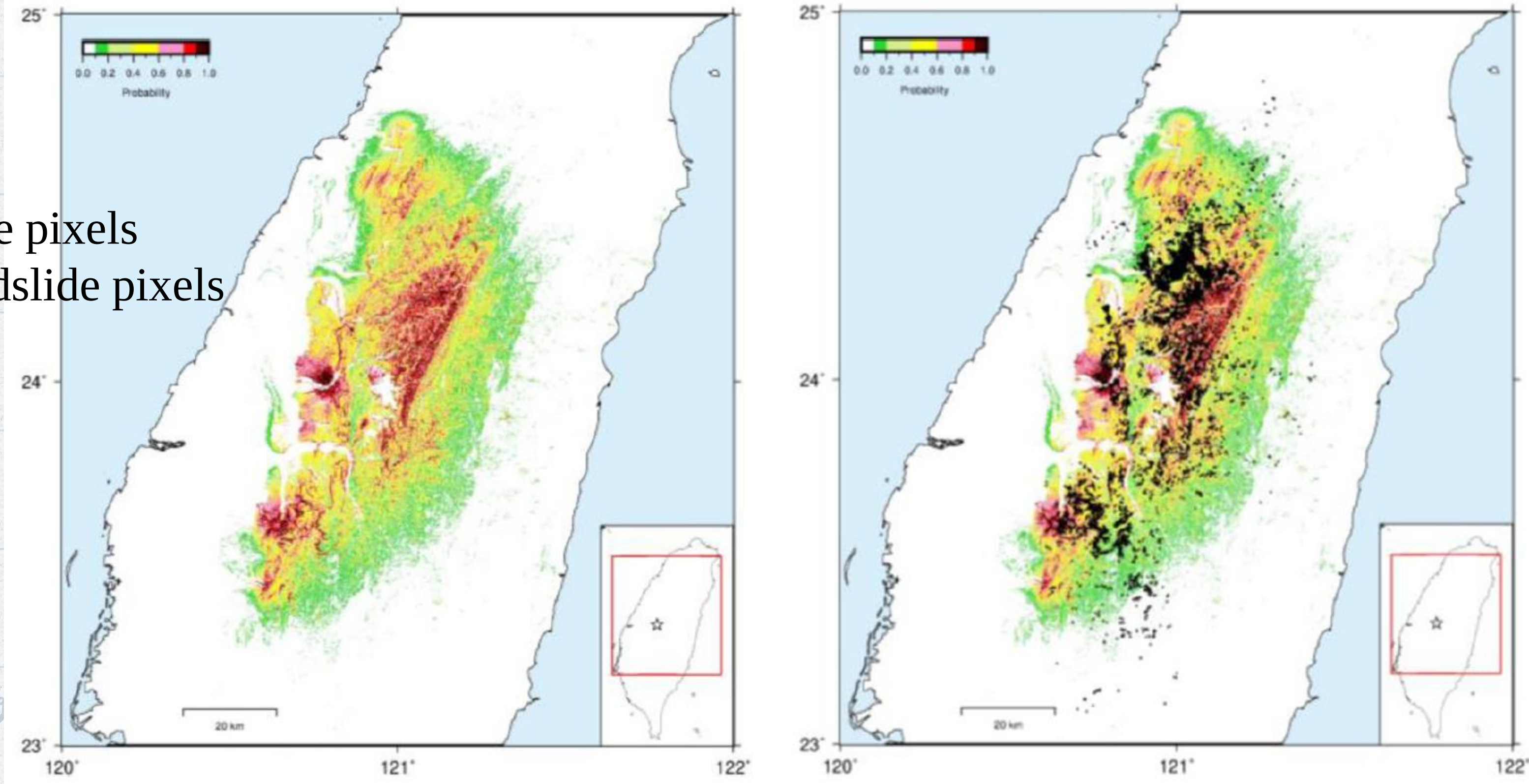
$$y = -3.469336 + 6.252418 X_{PGA} + 11.67491 X_{Roughness\,(5X5)} - 6.624769 X_{Lithology} - 0.6799484 X_{PGA*Slope} + 11.71126 X_{PGA*Roughness\,(5x5)} + \varepsilon \qquad (5)$$

$$Prob_{stable \rightarrow landslide} = \frac{e^{y}}{1 + e^{y}}$$

# The nowcasting model of earthquake-triggered landslide

After the development of the logistic regression model, we test this model on the Chi-Chi Earthquake.

140,000 landslide pixels
140,000 non-landslide pixels



# The nowcasting model of earthquake-triggered landslide

We vary the threshold of landslide probability from 0.1 to 0.9 in the interval of 0.1. If the probability of each pixel is higher than the threshold, the pixel is counted as a landslide pixel.

susceptibility

0.3 → Non-Landslide pixel

Assume Threshold = 0.5

0.8 → Landslide pixel

# The nowcasting model of earthquake-triggered landslide

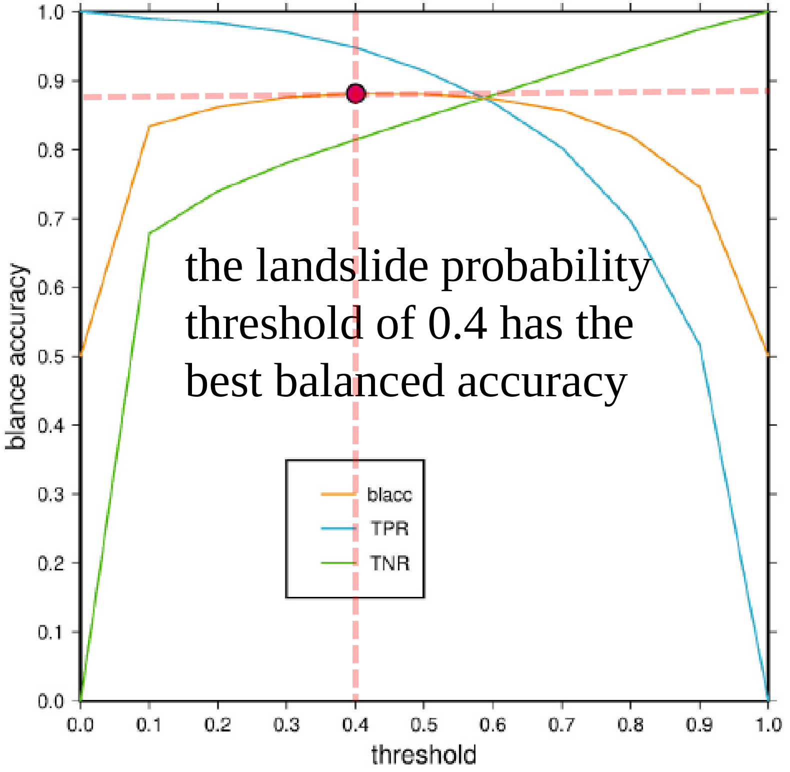



**Fig. 4.** Balanced accuracy of the nowcasting model based on Chi-Chi earthquake. Blacc: balanced accuracy; TPR: true positive rate; TNR: true negative rate.

If the threshold is set to a low value (e.g., 0.1), it may generate many false alarms, but instead, it avoids the occurrence of missing events.

$$Balance\ accuracy = \frac{TPR + TNR}{2}$$

**Table 5**
Balanced accuracy under various threshold of probability.

| Threshold | TPR | TNR | Balanced accuracy |
|---|---|---|---|
| 0.0 | 1.00000 | 0.00000 | 0.50000 |
| 0.1 | 0.99017 | 0.67818 | 0.83417 |
| 0.2 | 0.98383 | 0.73980 | 0.86181 |
| 0.3 | 0.97040 | 0.78101 | 0.87570 |
| 0.4 | 0.94812 | 0.81460 | 0.88136 |
| 0.5 | 0.91435 | 0.84710 | 0.88072 |
| 0.6 | 0.86844 | 0.87883 | 0.87363 |
| 0.7 | 0.80283 | 0.91146 | 0.85715 |
| 0.8 | 0.69960 | 0.94394 | 0.82042 |
| 0.9 | 0.51654 | 0.97461 | 0.74558 |

TPR: true positive rate; TNR: true negative rate.

# The nowcasting model of earthquake-triggered landslide

Use Chi-Chi earthquake (1999) model → Put into Jueili earthquake(1998)

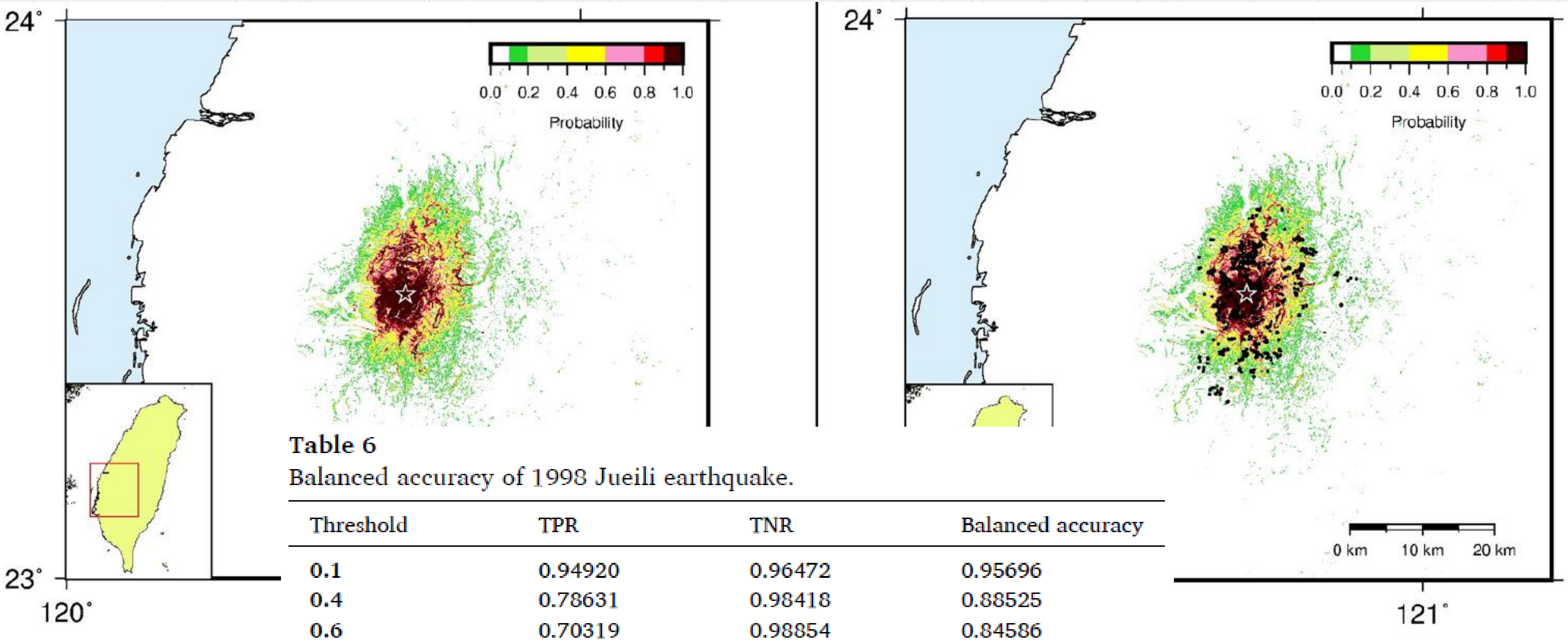



**Table 6**
Balanced accuracy of 1998 Jueili earthquake.

| Threshold | TPR | TNR | Balanced accuracy |
|---|---|---|---|
| 0.1 | 0.94920 | 0.96472 | 0.95696 |
| 0.4 | 0.78631 | 0.98418 | 0.88525 |
| 0.6 | 0.70319 | 0.98854 | 0.84586 |

**Fig. 5.** Probability of landslides triggered by the 1998 Jueili earthquake. Black polygons are mapped landslides from Huang and Lee (1999).

4.

# Conclusion

# Conclusion

1

2

Correlation coefficient between each variable and earthquake-triggered landslides.

| Type | Variable | Coefficient | *p*-Value |
|---|---|---|---|
| **Seismic property** | PGA | **0.72** | 0.00 |
| | Arias Intensity (AI) | **0.61** | 0.00 |
| | Wave and aspect direction | 0.06 | 0.00 |
| **Lithology** | Lithologic data | **0.36** | 0.00 |
| **Topography** | Elevation | 0.05 | 0.00 |
| | Aspect | 0.02 | 0.00 |
| | Curvature | −0.06 | 0.00 |
| | Plan curvature | −0.06 | 0.00 |
| | Profile curvature | 0.06 | 0.00 |
| | Roughness (3 × 3) | **0.44** | 0.00 |
| | Roughness (5 × 5) | **0.45** | 0.00 |
| | Distance to ridge | −0.02 | 0.00 |
| | Slope angle | **0.43** | 0.00 |
| **Wetness** | CTI | −0.09 | 0.00 |

2

In Jueili earthquake(1998), when threshold=0.1 →balance accuracy =0.95

**Table 6**
Balanced accuracy of 1998 Jueili earthquake.

| Threshold | TPR | TNR | Balanced accuracy |
|---|---|---|---|
| **0.1** | 0.94920 | 0.96472 | 0.95696 |
| **0.4** | 0.78631 | 0.98418 | 0.88525 |
| **0.6** | 0.70319 | 0.98854 | 0.84586 |

3

Increase resolution from 1km to 40m

# THANK YOU

# Appendix

## Cramer's V

Pearson's chi-squared test

$$Cramer's\ V = \frac{\sum \frac{(O_i - E_i)^2}{E_i}}{N \times [min(n,m)-1]}$$

$O_i$ = observed value
$E_i$ = expected value
$n$ = number of colume
$m$ = number of row
$N$ = Number of samples

| Cramer's V | |
|---|---|
| 0-0.4 | Lowly correlated |
| 0.4-0.7 | Moderately correlated |
| 0.7-1 | Highly correlated |

$$\sum \frac{(O_i - E_i)^2}{E_i} =$$

$$\frac{(2-2.66)^2}{2.66} + \frac{(18-17.33)^2}{17.33} + \frac{(2-1.33)^2}{1.33} + \frac{(8-8.66)^2}{8.66}$$

## observed value

| | Positive | Negative | Total |
|---|---|---|---|
| vaccine | 2 | 18 | 20 |
| No vaccine | 2 | 8 | 10 |
| Total | 4 | 26 | 30 |

## expected value

| | Positive | Negative | Total |
|---|---|---|---|
| vaccine | $20 * \frac{4}{30} = 2.66$ | $20 * \frac{26}{30} = 17.33$ | 20 |
| No vaccine | $10 * \frac{4}{30} = 1.33$ | $10 * \frac{26}{30} = 8.66$ | 10 |
| Total | 4 | 26 | 30 |

# Appendix

## Point biserial Correlation coefficient

$p = ratio\ of\ gender\ 1$
$q = ratio\ of\ gender2$

| Student | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| gender | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 0 |
| Score | 76 | 58 | 74 | 67 | 65 | 68 | 71 | 69 | 66 | 61 |

$\sigma_{score} = 5.48$

$\overline{gender_1} = 70.33$

$\overline{gender_2} = 63.25$

| Correlation coefficient | |
|---|---|
| 0-0.4 | Lowly correlated |
| 0.4-0.7 | Moderately correlated |
| 0.7-1 | Highly correlated |

$$r = \frac{\overline{X_p} - \overline{X_q}}{\sigma_x}\sqrt{pq} = \frac{70.33 - 63.25}{5.48}\sqrt{\frac{6}{10} * \frac{4}{10}} = 0.633$$

- **Logistic regression**

**SlidesCarnival icons are editable shapes.**

This means that you can:

- ✗ Resize them without losing quality.
- ✗ Change fill color and opacity.
- ✗ Change line color, width and style.

Isn't that nice? :)

Examples:

**Find more icons at** slidescarnival.com/extra-free-resources-icons-and-maps

# Diagrams and infographics

**You can also use any emoji as an icon!**

And of course it resizes without losing quality.

How? Follow Google instructions
https://twitter.com/googledocs/status/730087240156643328