METEOR TRAINING

Creation of hazard and susceptibility maps in Nepal

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METEOR project

Modeling Exposure Through Earth Observation Routines

- Three-year project
- Funded by UK Space Agency
- Aims to develop innovative application of Earth Observation (EO) technologies to improve understanding of exposure
- Specific focus on pilot countries Nepal and Tanzania
- Consortium of eight organizations

funded by:

UK SPACE AGENCY

project consortium:

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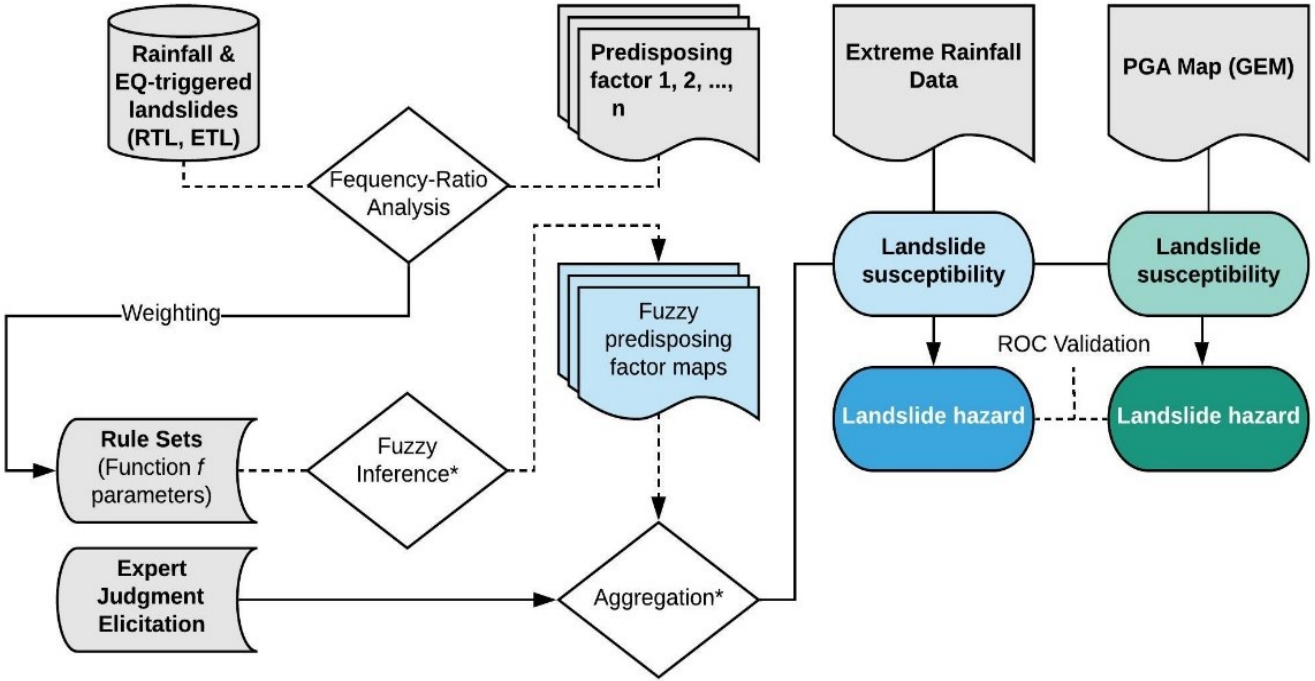
Creation of landslide susceptibility and hazard maps in Nepal

- Landslide susceptibility map creation.
  I. Frequency ratio method.
  II. Fuzzy logic.
  III. Expert Elicitation.
  IV. Aggregation of thematic maps.
- Landslide hazard map creation.

Landslide Susceptibility in Nepal



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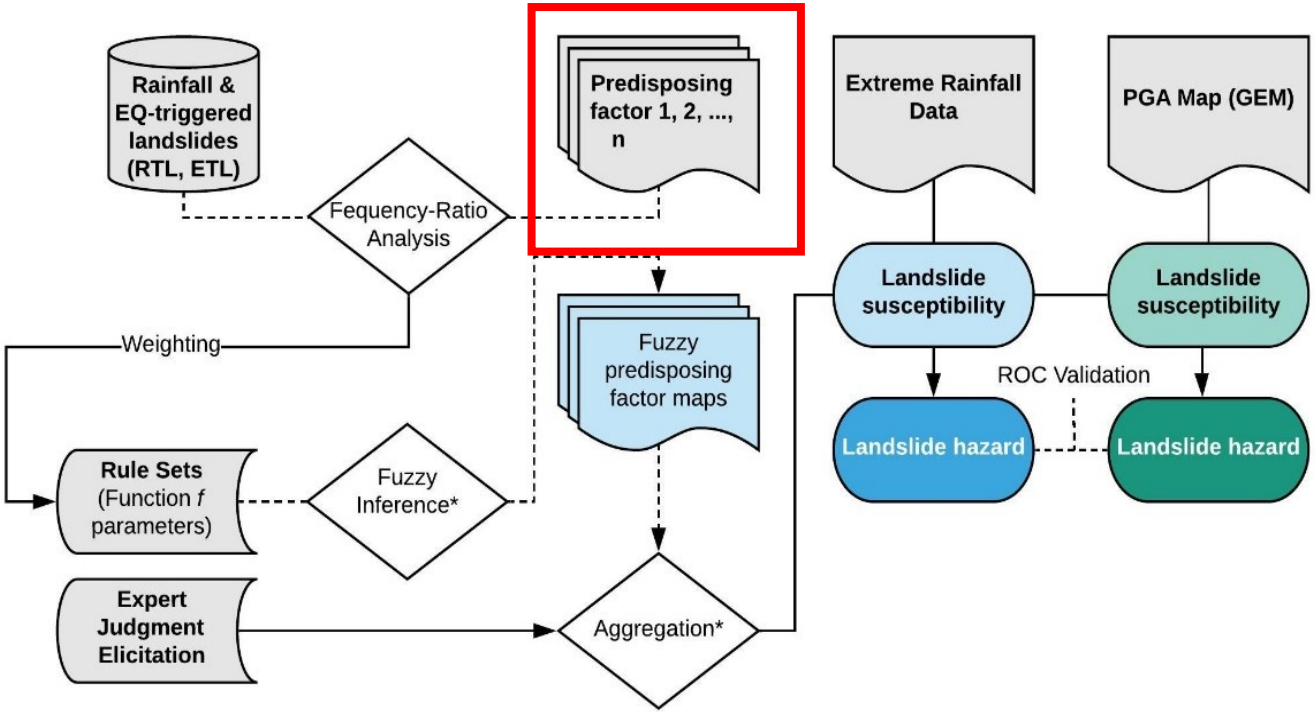
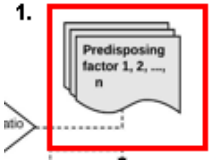
1. Predisposing/Preparatory data

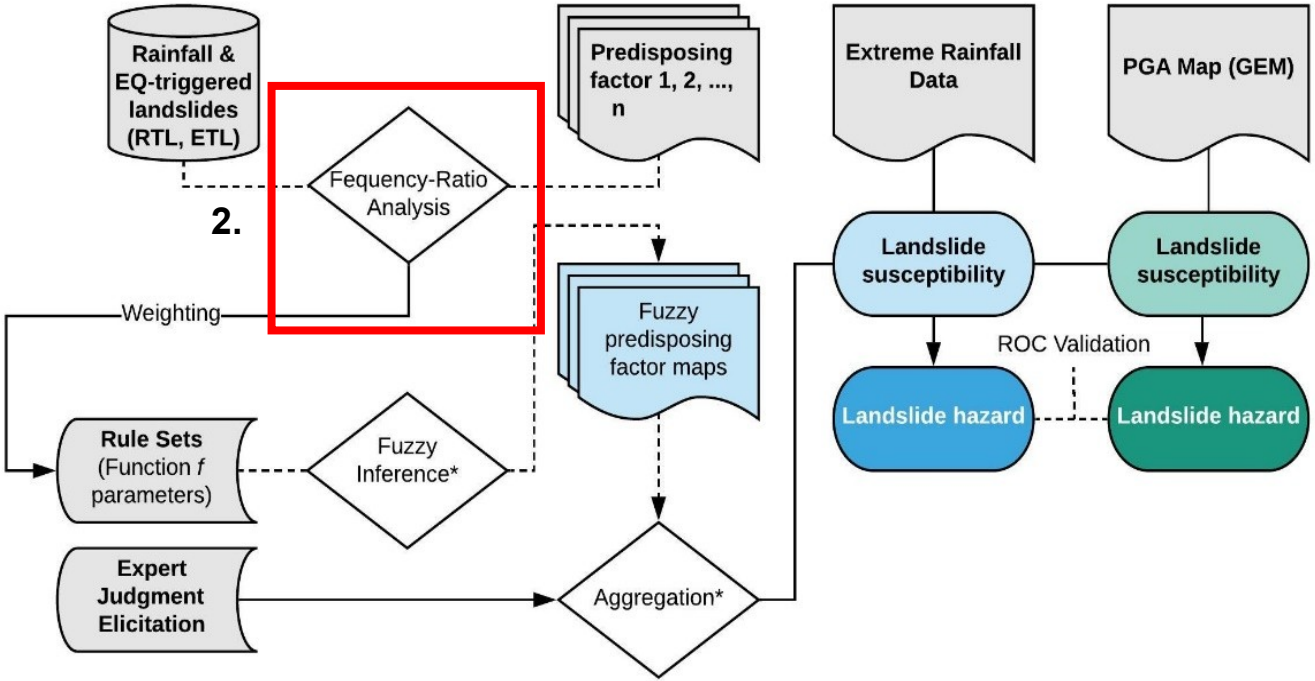


1. Predisposing/Preparatory data

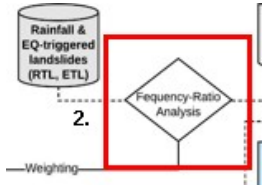


No	Type of Data	Source organisation	Scale/resolution
1	Geological map	Geological Map of Nepal. Department of Mines and Geology	National; 1:1,000,000 scale
2	Faults and lineaments	Global Active Faults Catalogue (GEM), Geological Map 1:1M (1994)	Global; national
3	Landslide inventory (rainfall-induced)	Global Landslide Catalogue (NASA)	Global
4	Landslide inventory (earthquake induced)	ICIMOD (2016)	Regional (14 districts)
		BGS & Durham University (post-Gorkha inventory)	Regional
		USGS (Open Source Repository)	National
5	Drainage Density	Derived from ICIMOD River Network of Nepal	National; 1:250,000
6	Land Cover	Uddin et al., 2015- Land Cover map of Nepal 2010	National
7	DEM derivatives (Slope, Aspect)	MERIT DEM	National; 90m
8	Annual Mean Rainfall*	Marahatta et al., (2009)	

2. Frequency Ratio Analysis



2. Frequency Ratio



Frequency ratio can be defined as "*the ratio of the probabilities of a landslide occurrence to a non-occurrence for a given attribute*" (Lee and Talib, 2005).

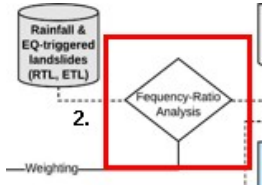
$$FR_i = \frac{PL_i}{PF_i}$$

$$\frac{the\ frequency\ of\ landslides\ in\ the\ F_i\ area}{the\ frequency\ of\ the\ F_i\ area}$$

$$\frac{the\ area\ of\ landslides\ in\ the\ F_i \div the\ area\ of\ landslides\ in\ the\ study\ area}{the\ area\ of\ the\ F_i\ area \div the\ area\ of\ the\ study\ area}$$

(Li *et al.*, 2017)

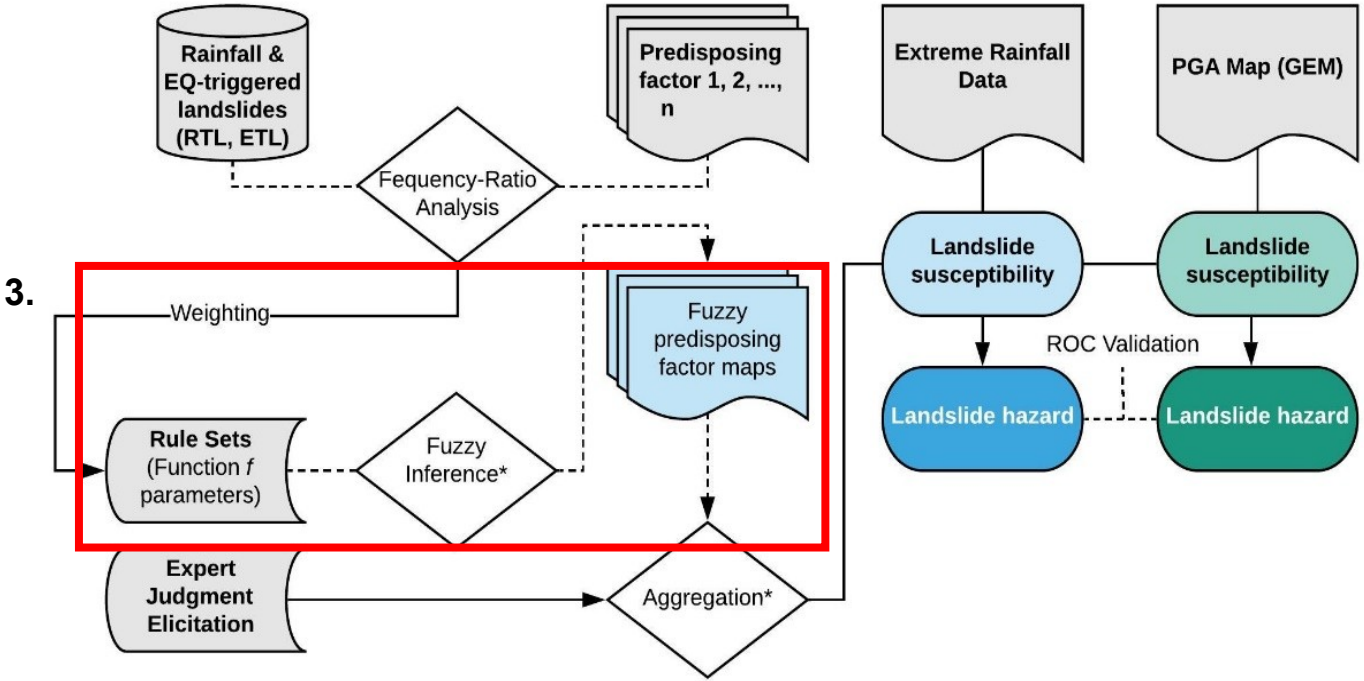
2. Frequency Ratio Analysis



Predictor	Class	Frequency Ratio (FR)	
		R	EQ
Slope gradient (°)	0 – 15	0.86	0.06
	15 – 20	1.35	0.83
	20 – 35	1.22	1.10
	35 – 45	0.61	2.65
	>45	0.45	3.05
Aspect	Flat	0.00	0.62
	N –NE	0.54	0.62
	NE - E	0.73	0.93
	E – SE	0.89	1.35
	SE – S	1.26	1.43
	S – SW	1.32	1.21
	SW -W	1.68	0.95
	W – NW	1.02	0.71
	NW - N	0.53	0.59

The higher the ratio the stronger the relationship is between the conditioning factor and the occurrence of landslides.

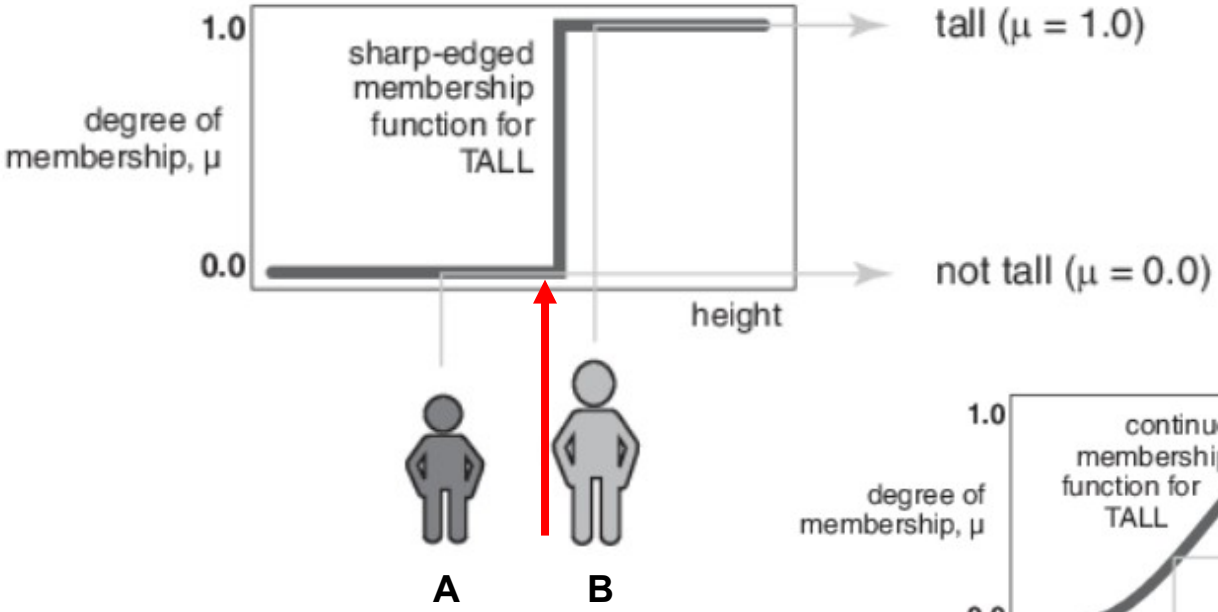
3. Fuzzy Logic

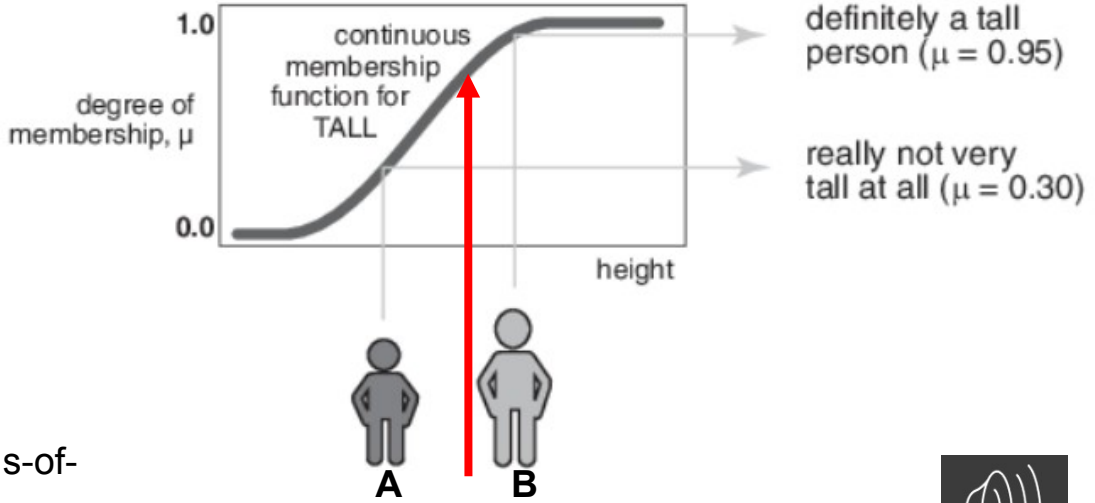


3. Fuzzy Logic

- In classical set theory a value of 0 or 1 is assigned.
- In fuzzy sets a value can be assigned between 0 and 1 showing the varying degree of membership to a set.
- For landslides this means assigning pixels for each factor as having a value between 0 (not susceptible) and 1 (susceptible) reflecting the certainty degree of the membership
- Values can be user defined or defined using a technique such as frequency ratio.
- Allows you to deal with subjective uncertainty and is tolerant of imprecise data- boundaries of classes don't have to be a single figure.
- Fuzzy logic can be blended with expert knowledge and other techniques.

Fuzzy Membership Function

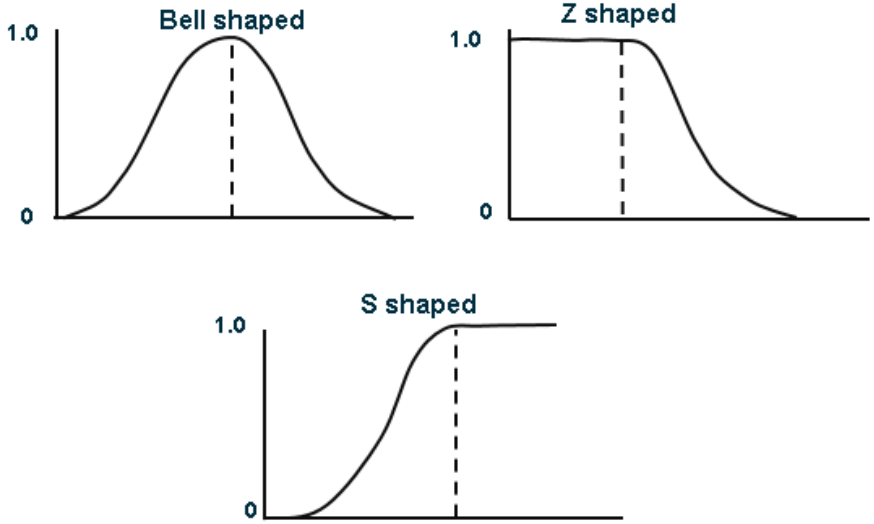




https://uk.mathworks.com/help/fuzzy/foundations-of-fuzzy-logic.html

Fuzzy Logic Rule Sets

A membership function associated an input value to its appropriate membership value.



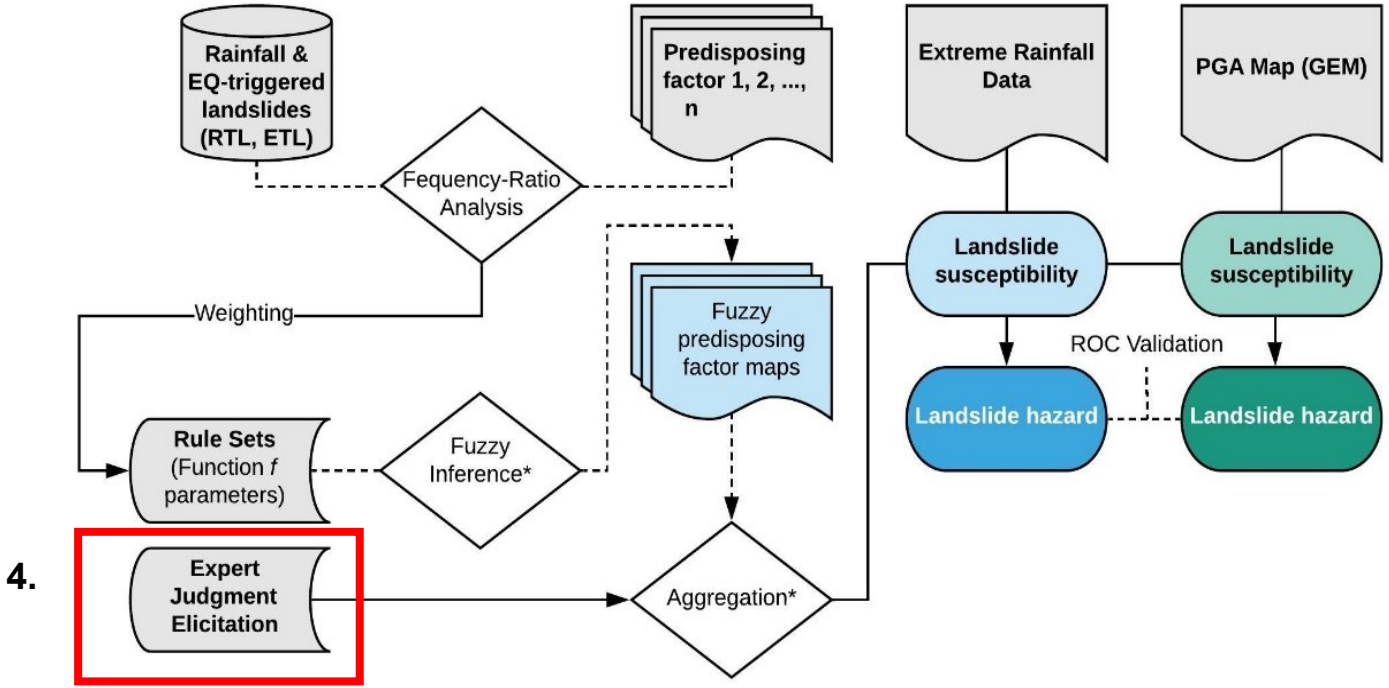
Used the frequency ratio results and expert elicitation to guide assigning the membership function : bell shaped, S shaped, Z shaped.

Bell shaped used for factors that have an optimal value or a range of optimal values.

For Z and S shaped curves – used where the factor has a threshold at which the susceptibility reaches a maximum

The function describes how landslide susceptibility varies in relation to cha in predisposing factor.

4. Expert Elicitation



4. Expert Judgment Elicitation

Expert elicitation is the process of obtaining probabilistic belief statements from experts about unknown quantities or parameters.

Possible goals for using structured judgement method in a decision-support role:

- To reach a compromise on scientific issues
- To generate a census of scientists opinions
- To develop a rational evidence-based consensus on a particular scientific issue of concern.

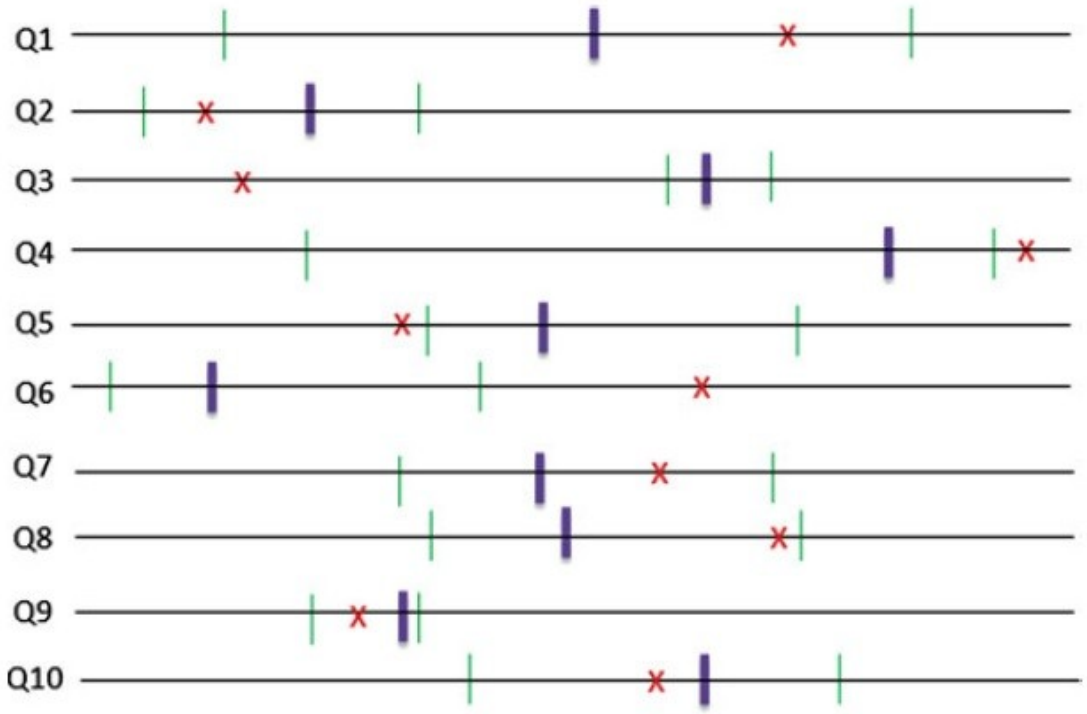
The Cooke Classical Method

Aim – to generate a weighted average (across multiple experts) of subjective probability distributions for values of interest and is comprised of 3 steps:

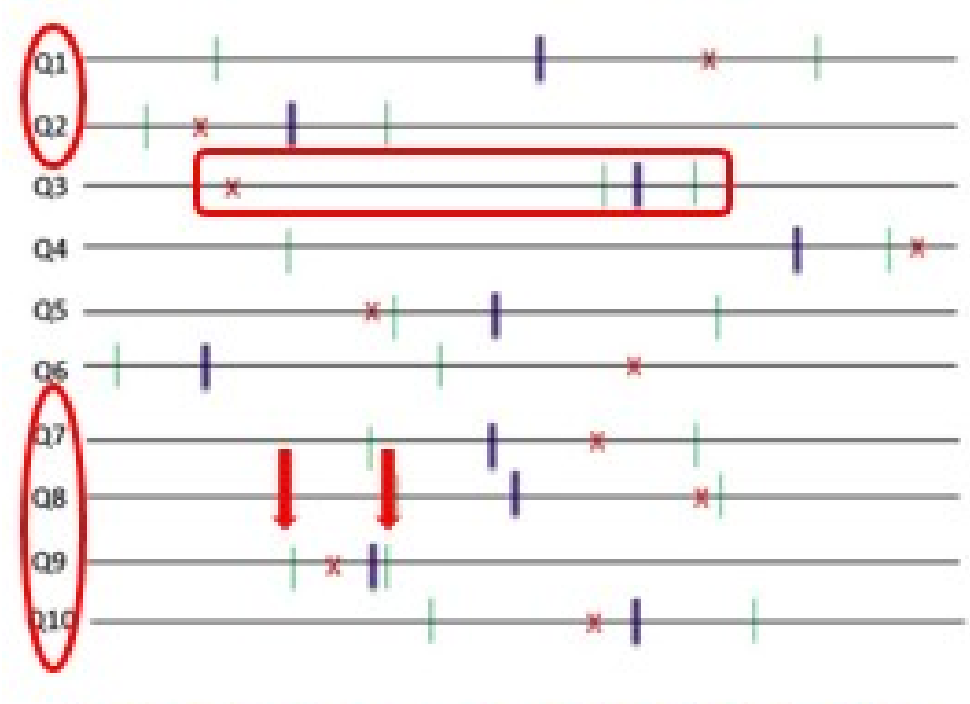
1. Measuring statistical accuracy
2. Measuring informativeness
3. Weighting

For every question, each expert gives their estimates of three quartiles (5%, 50%, 95%). The results can be pooled to define the range that spans the groups responses.

Example: Expert A



Example: Expert A



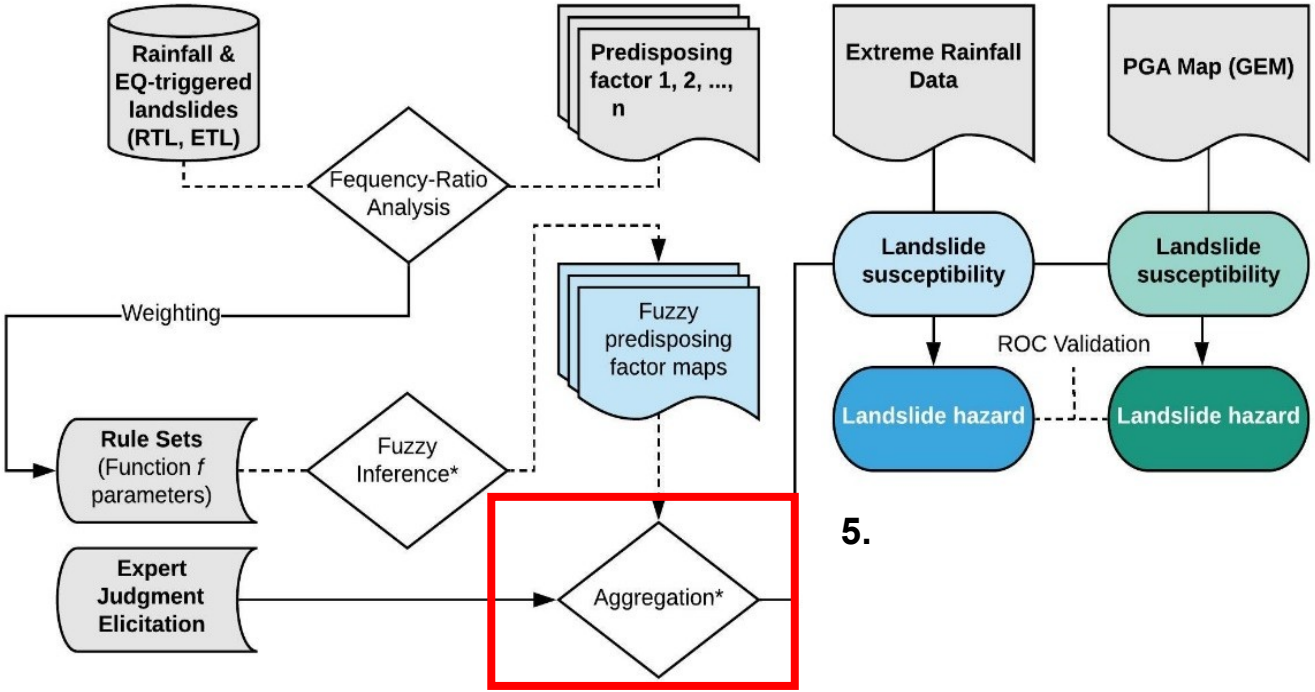
Step 3. Weighting (combining Experts' Judgments)

- Statistical accuracy and information scores are multiplied to create an expert's combined score. Combined scores serve as the mechanism for producing performance-based weights for combining the experts' assessments

- A combination of expert assessments is called a **decision maker (DM)**.

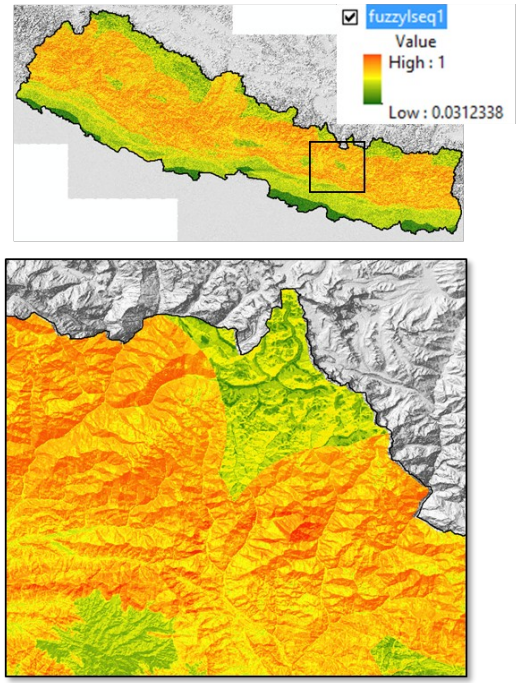
- The calibration (statistical accuracy) score varies more than then information score ☾ *it drives the differences in weightings much more than the information score*

5. Aggregation

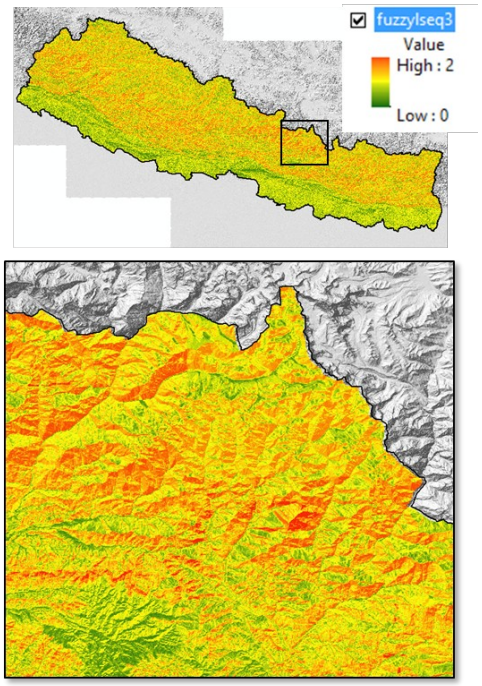


5. Aggregation

1. ***Arithmetic mean - All factors equal weight***



3. ***(Slope x Geol) + Aspect***



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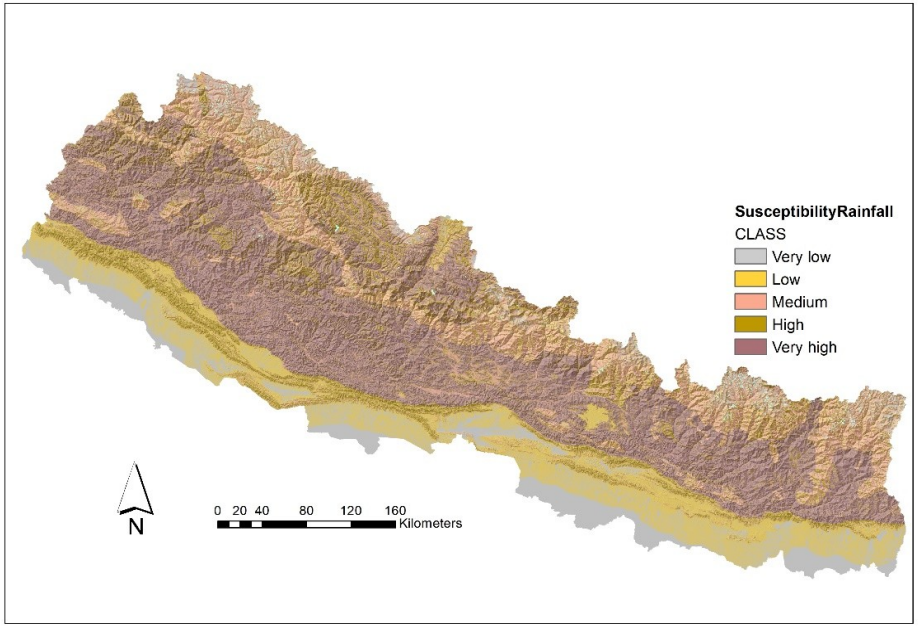
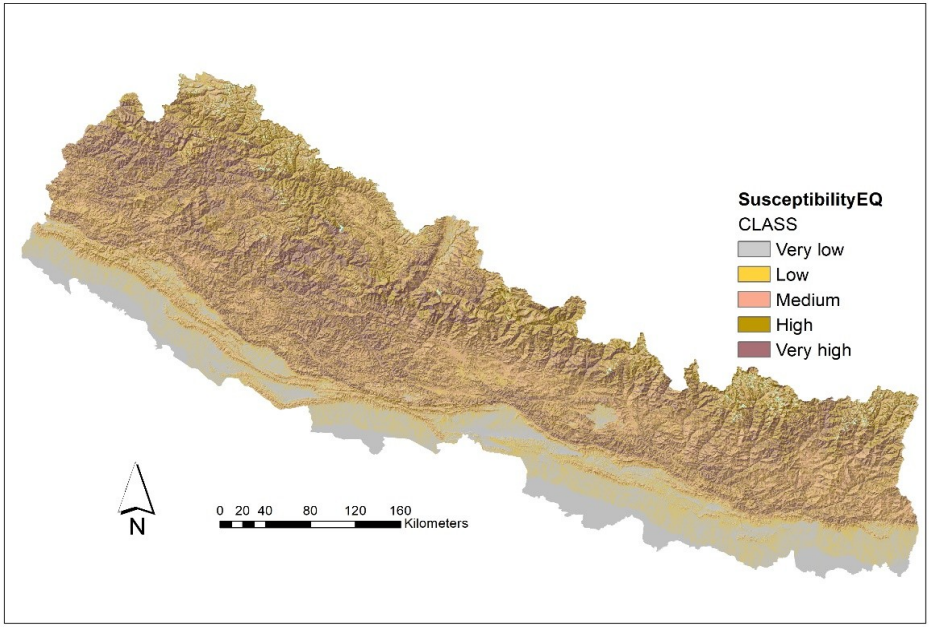
5. Aggregation

Factor	Class fuzzy weight (W1)	Group	Factor Weight (W2)	Group Weight (W3)
Slope		Morphology	0.8	0.4
Aspect			0.2	
Lithology		Geology	0.8	0.4
Distance to faults			0.2	
Drainage density		Environmental	0.5	0.2
Land cover			0.1	
Annual mean rainfall			0.4	

- $\mathbf{W_{factor} = W1 \times W2 \times W3}$
- Susceptibility = $W_{slope} + W_{aspect} + W_{lithology} + \ldots + W_{distance\_faults}$





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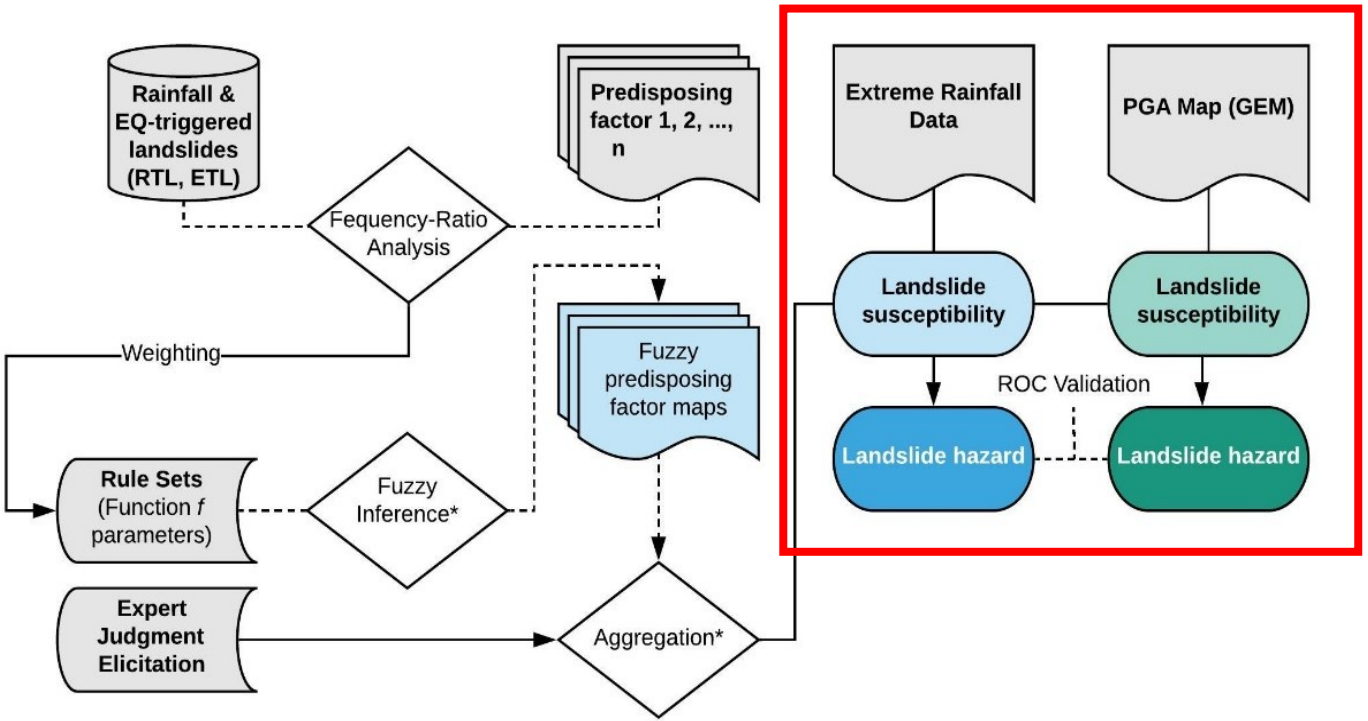
6. Landslide Hazard Maps



6.

6. Landslide Hazard Map

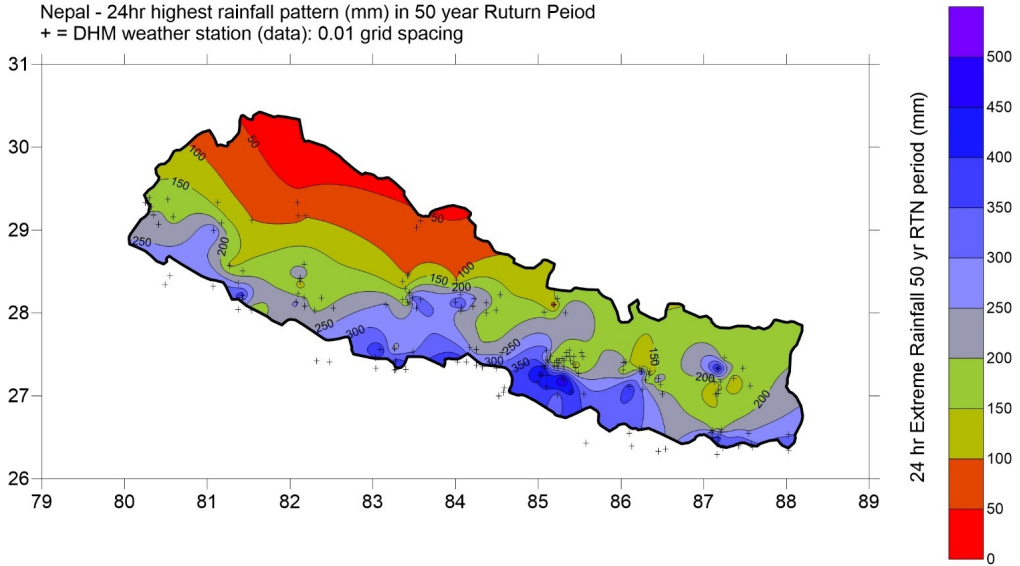
Reichenbach *et al.,* (2018) define hazard as **"*the probability that a landslide of a given magnitude will occur in a given period and in a given area*".**

Susceptibility x Trigger = Hazard

Hazard in this study is expressed through the combination of susceptibility and a trigger value following Varnes (1984) and is similar in approach to assessments carried out by Jaedicke *et al.*, (2014) and Nadim *et al.*, (2006).

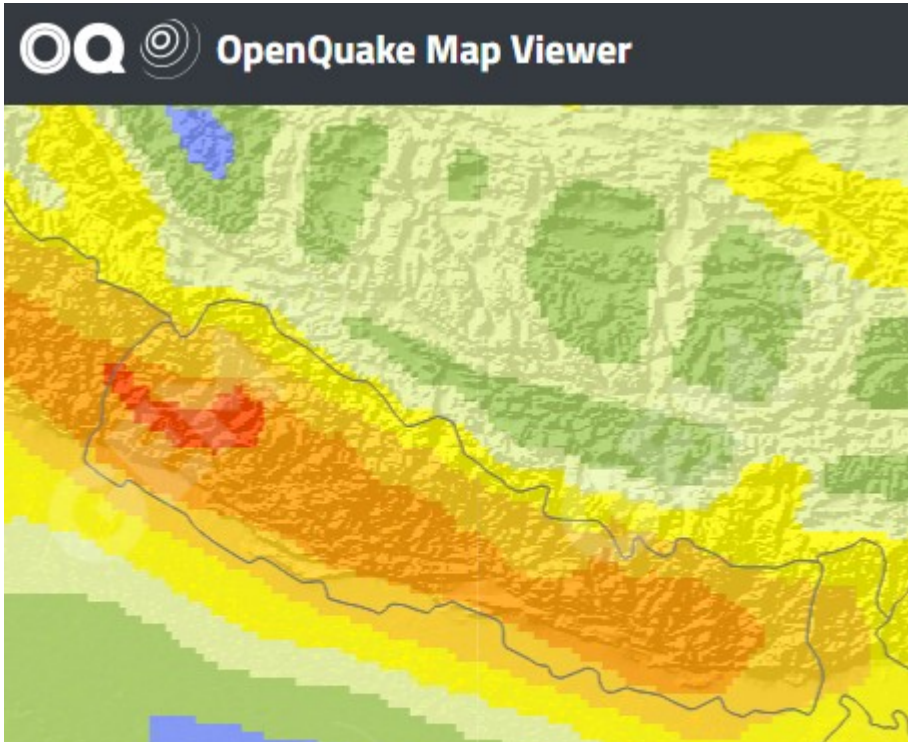
Rainfall Trigger

- Extreme rainfall values (mm/day) recorded monthly at 166 weather stations across Nepal between 1976 and 2005.
- Extreme rainfall with a 50yr return period was chosen as the trigger value.

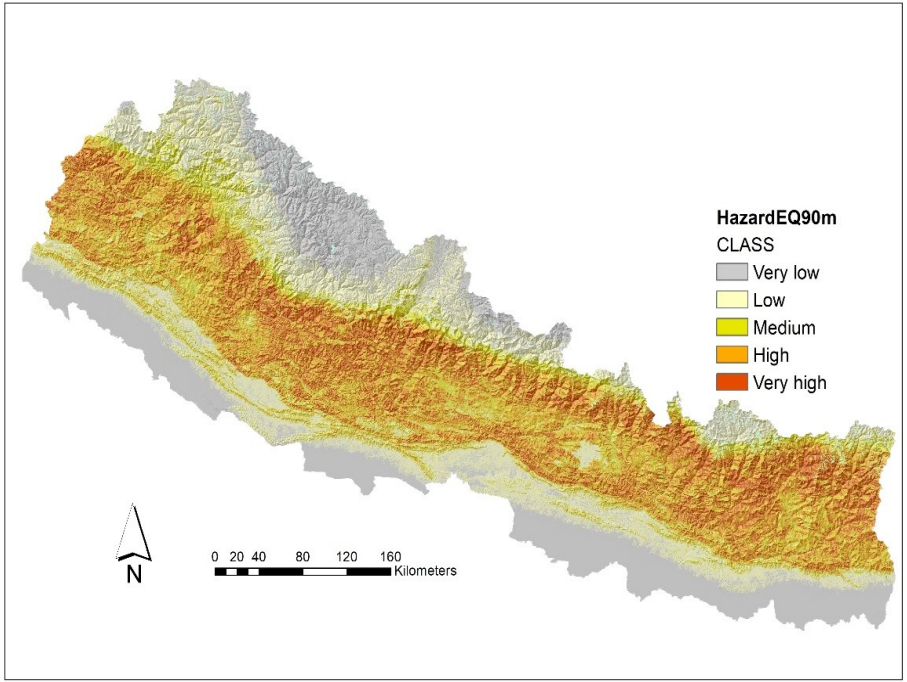


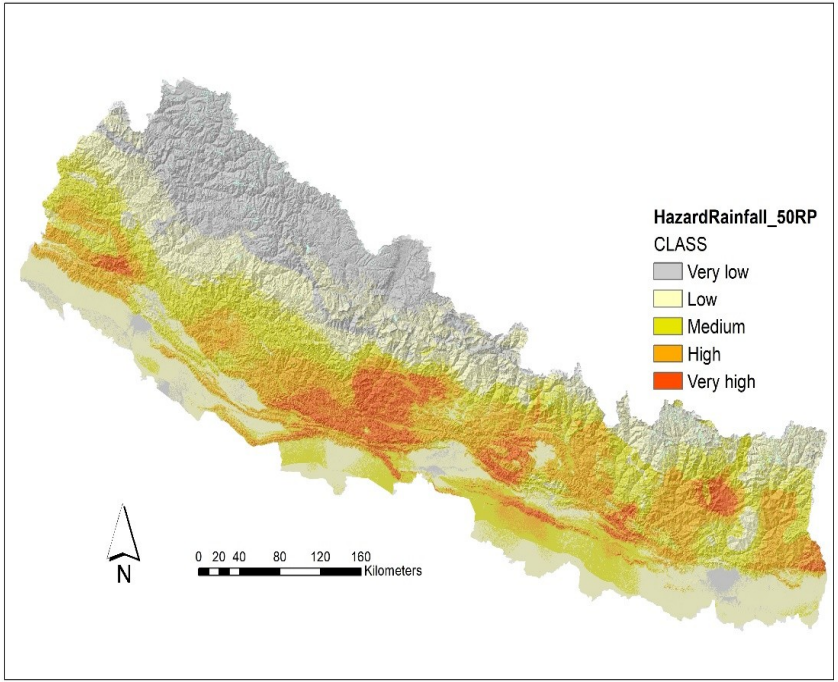
Earthquake Trigger

- Trigger: Peak Ground Acceleration (PGA) with a 10% probability of being exceeded in 50 years (return period of 475 year).
- The PGA values were categorised into 12 classes based on an expanded Jaedicke *et al.,* scale.



https://www.globalquakemodel.org/gem





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