Quick overview

Extensive overview

EGU General Assembly 2021
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27 April 2021

Structuring a Bayesian Belief Network using Expert Knowledge for Landslide Hazard Assessment

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Structuring a Bayesian Belief Network using Expert Knowledge for Landslide Hazard Assessment

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Structuring a Bayesian Belief Network using Expert Knowledge for Landslide Hazard Assessment: Quick overview

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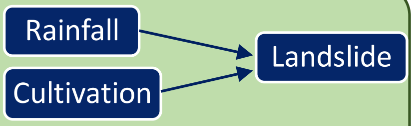
1. Motivation

Challenges of Landslide Hazard Assessment in India:
1. Lack of recording of anthropogenic influences on landsliding
2. Difficulty of obtaining systematic landslide occurrence data

Use expert knowledge for Bayesian Belief Networks (BBN)
1. Allows using expert knowledge for quantifying anthropogenic influences or in the absence of inventory data

2. Introduction

- Bayesian approach "uses **probability** to express **belief** in a statement about **unknown quantities**".
- Represented as a **directed acyclic graph** with a **conditional probability distribution** for each set of variables called '**nodes**' connected with a set of directed links called '**arcs'.**



A dummy BBN

3. Methodology

12/2018
- **29 literature sources** reviewed
- **16 landslide-related** variables (LV) selected

01-02/2019
- **11 experts interviewed**
- **35** LV identified (22 added, 2 merged, 2 branched)

04-09/2020
- **16 experts rated 35 LV**
- **46** LV identified (9 added, 4 merged)

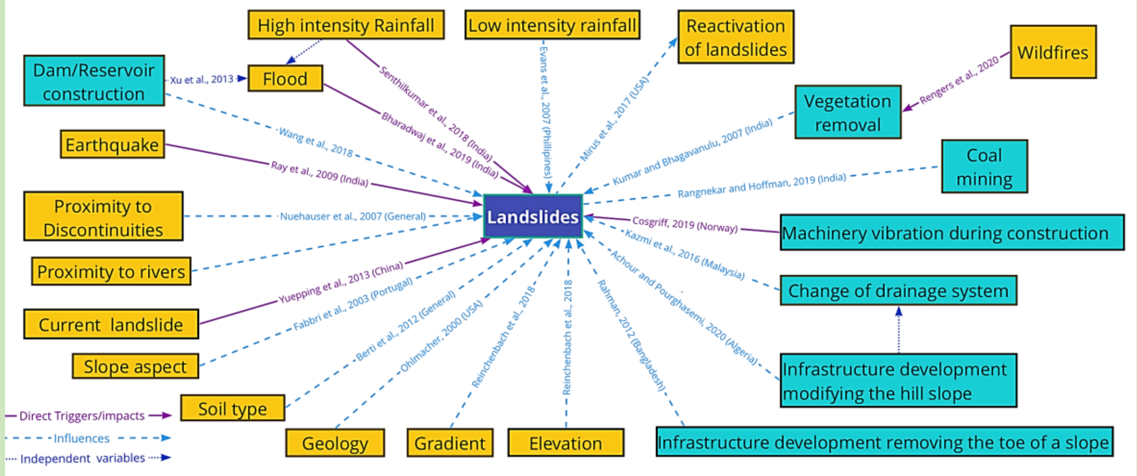
01-03/2021
- **Spatial-temporal** scales of variables
- **21 LV** selected for two BBN structures

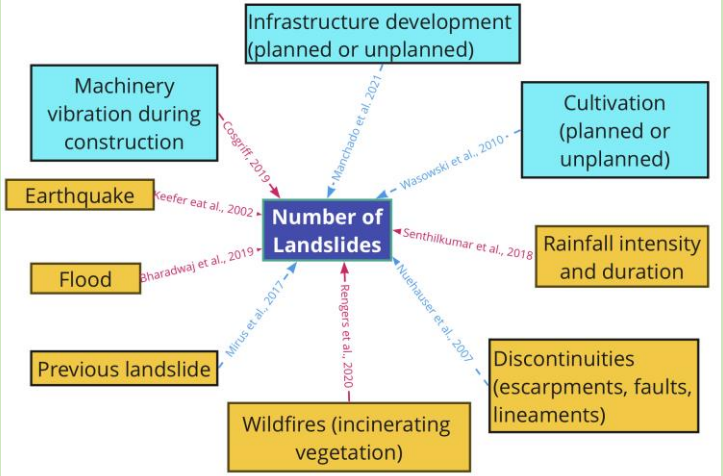
4. Results

Two BBN structures for landslides in Darjeeling District:

(1) For **forecasting landslide occurrence probability** (Fig. on the left)

(2) For **forecasting number of landslides** (Fig. on the right)





Left: **5 triggering** and **4 influencing** LV; regional scale; Right: **5 triggering** and **17 influencing** LV; local to regional spatial scale;
Lines: Primary variable that may **trigger** (**purple solid line**) or **influence** (**blue dashed line**) a secondary variable;
Nodes: Anthropogenic (**blue box**) or **geomorphic** (**yellow box**) variables.

1.0 Introduction to Bayesian Belief Network (BBN)

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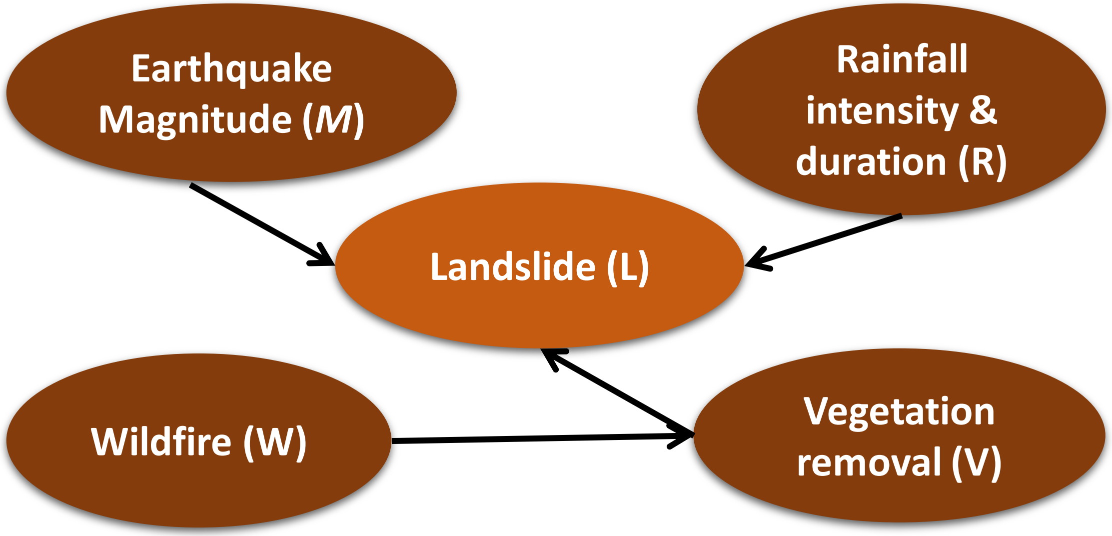
- This research uses expert knowledge to inform Bayesian Belief Networks (BBN) to aid our understanding of landslide probabilities in India.
- BBN approach: uses **probability** to express **belief** about **unknown quantities**.
- BBN are **directed acyclic graphs** with a **conditional probability distribution** for each set of variables called ‘**nodes**’ connected with a set of directed links called ‘**arcs**’
- **Arcs** represent the **direction of causality** or influence between the nodes.
- **Variables** may be either **continuous** or **discrete**.



$$P\left(L = L_1\right) = \sum_{i=1}^{2}\sum_{j=1}^{2}\sum_{k=1}^{2} P\left(M = M_i, R = R_j, V = V_k, L = L_1\right)$$

L_1= Probability of landslide occurring; $[i,j,k]_1$= low; $[i,j,k]_1$= high

A simple Bayesian Network for occurrence of landslide. *The prior probability of Landslide (L) in **Fig. 1**, P (L=L_1) is calculated using the **equation above.***

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1.1 Rationale for using BBN for Landslide Hazard Assessment in India

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#	Challenges for landslide hazard assessment in India	How does BBN help?
1	**Low/no/unobtainable landslide occurrence data** in India	Can be developed using a culmination of **data, expert elicitation, or previous models**
2	**Data gaps** in landslide occurrence attributed to **under-representation** of **small-scale landslides**	Using **local people's knowledge** to structure the BBN can **help identify** small-scale landslides
3	**Lack of recording** of the **physical or anthropogenic influences** on landsliding in India	**Expert knowledge** can be used to **quantify the influences**, otherwise absent in the data
4	Landslides are influenced by **numerous variables** with **different spatial & temporal** patterns of occurrence, thus the **forecasting landslide occurrence** becomes **complex**	Aims to better **represent complex systems** (e.g., those that include multi-hazards) and **allow** the **inclusion** of **different spatial & temporal** scales of data sets
5	**Inability** to **quantify uncertainty** present in such **complex and low data**, poor knowledge situations.	Every event has **uncertainty quantified** by event's **probability distribution**

Expert knowledge has been used in this study to structure the BBN and add **conditional probabilities** to the arcs.

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2.0 Methodology: Structuring a BBN for landslides in Darjeeling District

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CLICK THE ICONS BELOW TO SEE THE LIST OF VARIABLES

STEP 1 — Dec 2018

- **29 peer- and grey literature sources critically** reviewed
- **16 landslide-related variables** identified (Click here)

STEP 2 — Jan-Feb 2019

- 30 experts* invited
- **11 experts* responded**
- Experts interviewed on importance of 16 variables (Step 1)
- **19 additional potential variables** identified
- **Total = 35 variables (Click Here)**

STEP 3 — Apr-Sep 2020

- 80 experts* invited
- **16 experts* responded**
- Experts rated 35 variables (from Step 2) on a scale of 1-10
- **13 additional potential variables** identified
- **4 variables merged** into 2 variables
- **Total = 46 variables (Click Here)**

STEP 4 — Jan-Mar 2021

- **31 variables** used to structure **initial BBN** based on Step 2 & 3
- **21 variables** used to structure **final BBN** based on spatial and temporal scales of variables (See next slide)

*Experts in this research study include **local people** (or indigenous people), **academics** and **employees** of different **private** and **public sector** institutions

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2.1 Methodology: Spatial-temporal scales for landslide-related variables

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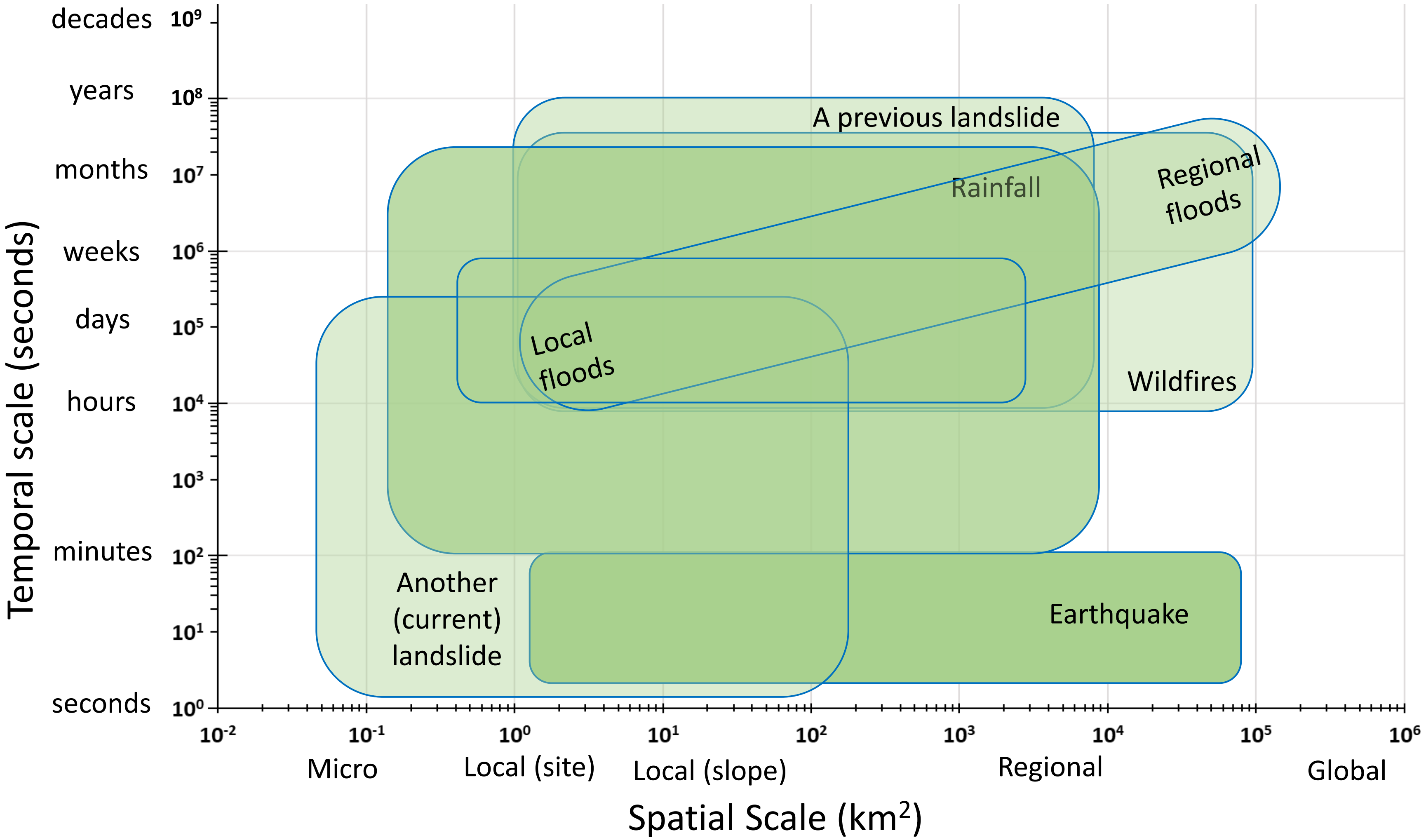
Jan-Mar 2021

Following from **Step 4 in previous slide**:

The graph shows the spatial-temporal scales of **6 out of 21 variables** that were used to structure the **final BBN,** as shown in **Slide 9** and **Slide 10**.



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2.1 Spatial-temporal scales for landslide-related variables (contd.)

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Jan-Mar 2021

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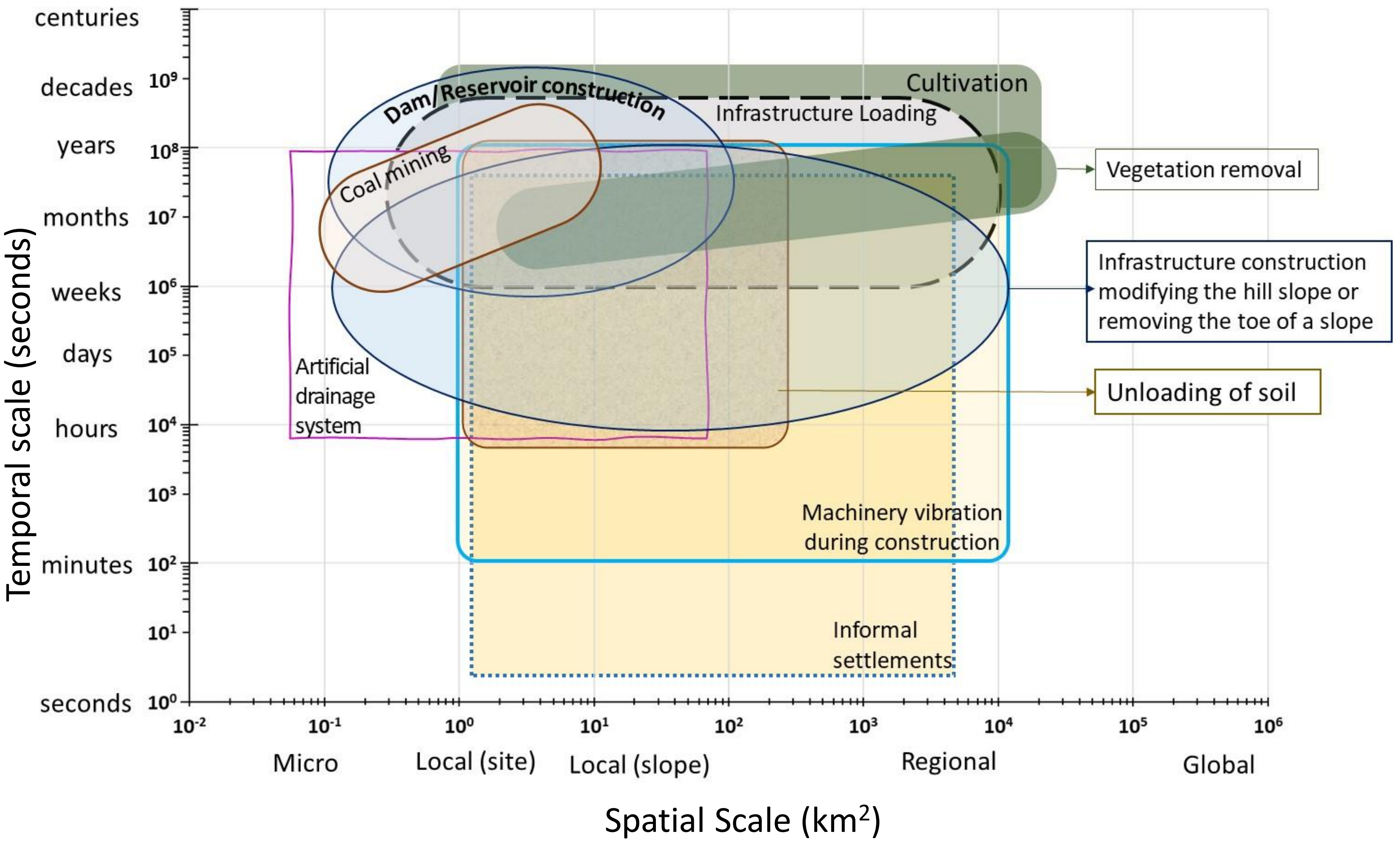

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3.0 Summary of Results

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- Based on 11 expert interviews, 18 expert ratings, and authors' personal experiences, an **initial Bayesian Belief network** (BBN) with **31 variables** (triggering and influencing, anthropogenic and geomorphic) was developed (See Slide 8)
- To **simplify and develop** a BBN for regional scale landslide hazard assessment,
  - **6 micro-scale variables** were **removed**
  - **7 micro-scale variables** were **merged** with **3 other** local or regional scale **variables**.
- Example:

  (1) *Dumping of garbage* (a **micro-scale** variable) and *change in artificial drainage due to construction* were **merged** into "*Influence on Landslide due to Artificial Drainage System*" OR

  (2) Change in slope angle due to railway construction, change in slope angle due to villages at the toe of slope, change in slope angle due to road construction merged into "*Planned/unplanned Infrastructure Construction changing Slope Angle*"
- Following the simplification process, **21 variables** were used to develop **2 final BBNs**:
  1. BBN for **forecasting landslide occurrence probability** in Darjeeling Himalayas using **5 triggering** and **17 influencing** variables (See Slide 9)
  2. BBN for **forecasting number of landslides** in Darjeeling Himalayas using **5 triggering** and **4 influencing** variables (See Slide 10)

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3.1 Results: Initial linkages between 31 variables for landslide occurrences

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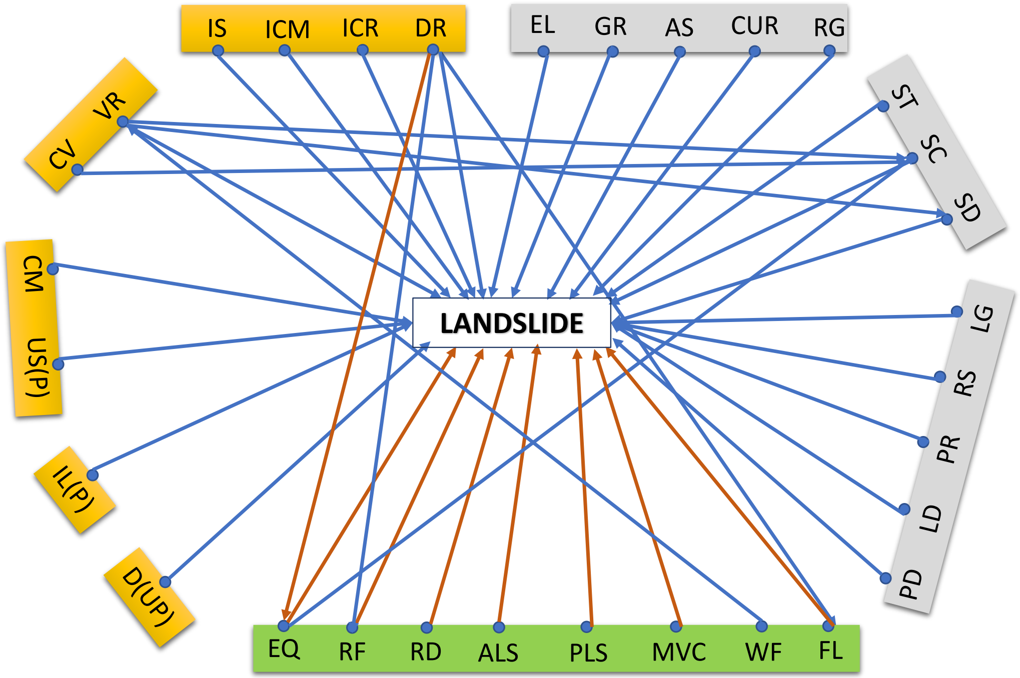

Triggering factors

Contributing factors: Geomorphic variables

Contributing factors: Anthropogenic variables

Origin	Code	Primary variables
Events triggering landslides	EQ	Earthquake
	RF	Rainfall intensity
	RD	Rainfall duration
	ALS	Another (current) landslide
	PLS	A previous landslide
	MVC	Machinery vibration during construction
	WF	Wildfire
	FL	Flood
Terrain morphology	EL	Elevation
	GR	Slope (gradient)
	AS	Aspect
	CUR	Curvature
	RG	Roughness
Soil variables	ST	Soil type
	SC	Soil cohesion
	SD	Soil depth
Geological variables	PD	Proximity to discontinuities
	LD	Lineament density
	PR	Proximity to rivers
	RS	Rock strength
	LG	Lithology

Origin	Code	Primary variables
Hydrologic variables	D(UP)	Drainage system (unplanned)
Material extraction	CM	Coal mining (planned/unplanned)
	US(P)	Unloading of soil (planned)
Material addition	IL(P)	Infrastructure loading (planned)
Land use	CV	Cultivation (planned or
	VR	Vegetation removal (planned or unplanned)
Population	IS	Informal settlements
Infrastructure variables	ICM	Infrastructure construction modifying the hill slope (planned)
	ICR	Infrastructure construction removing the toe of a slope (planned or unplanned)
	DR	Dam and reservoir construction

- **Network linkage diagram** showing **interactions between 31** coded variables (codes noted in the key)
- Diagram based on **expert interviews** (Steps 2 and 3 in Methodology) and **literature reviews** (Step 1 in Methodology)
- **Lines**: Primary variable that may **trigger** (orange lines) or **influence** (blue lines) a secondary variable.

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3.2 Results: Final Structure of BBN for landslides in Darjeeling district (1 of 2)

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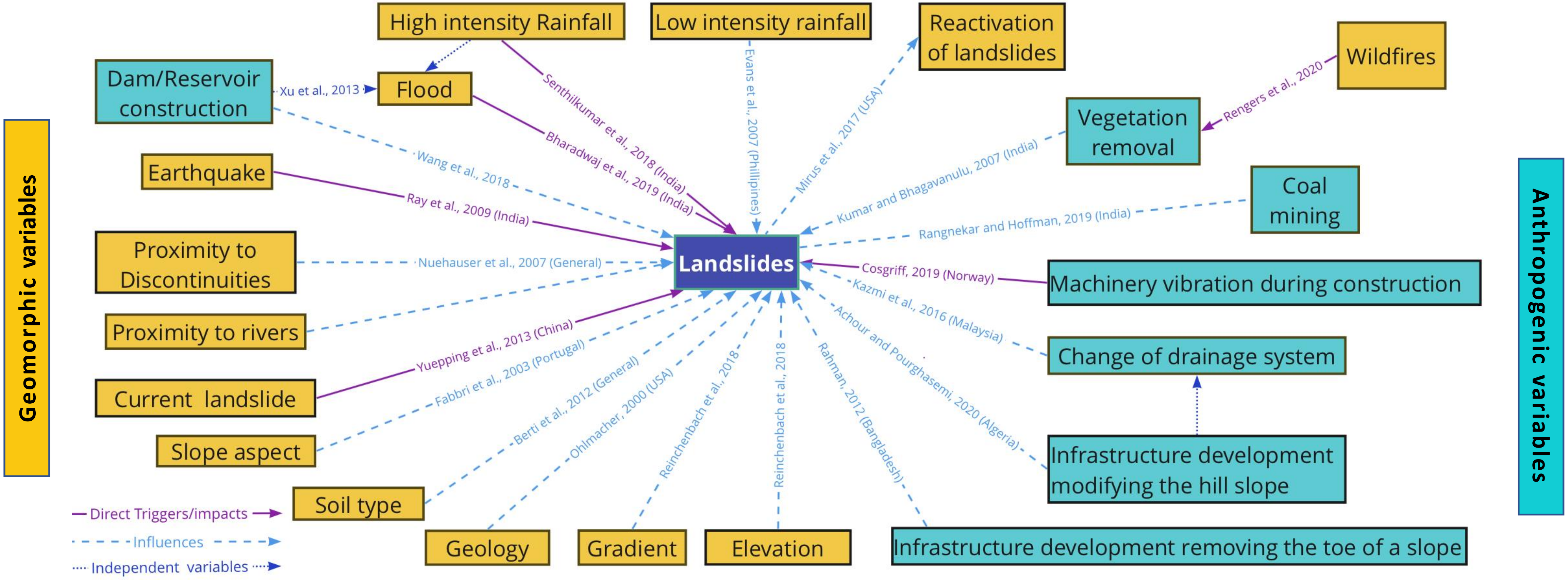

- BBN structure for probability of occurrence of landslides (local to regional spatial scale; months to years temporal scale).
- Lines **(w. references):** Primary variable that may **trigger** (**purple solid line**) or **influence** (**blue dashed line**) a secondary variable.
- **Nodes: Anthropogenic** (**blue box**) or **geomorphic** (**yellow box**) variables.
- **References** and list of variables can be found here.

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3.2 Results: Final Structure of BBN for number of landslides in Darjeeling (2 of 2)

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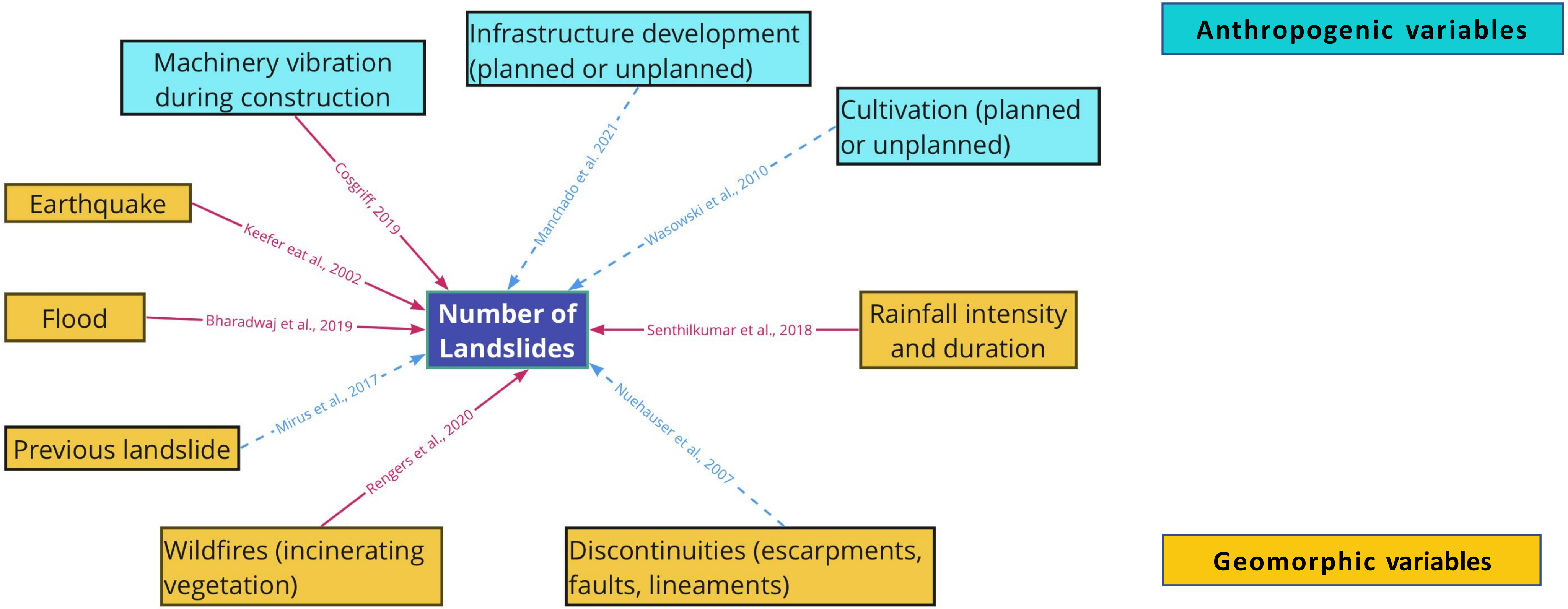

- **BBN structure between 9 variables for identifying the number of landslides (regional spatial scale; seconds to decades temporal scale.**
- Lines **(w. references):** Primary variable that may **trigger** (**purple solid line**) or **influence** (**blue dashed line**) a secondary variable.
- **Nodes: Anthropogenic** (**blue box**) or **geomorphic** (**yellow box**) variables.
- **References** and list of variables can be found here.

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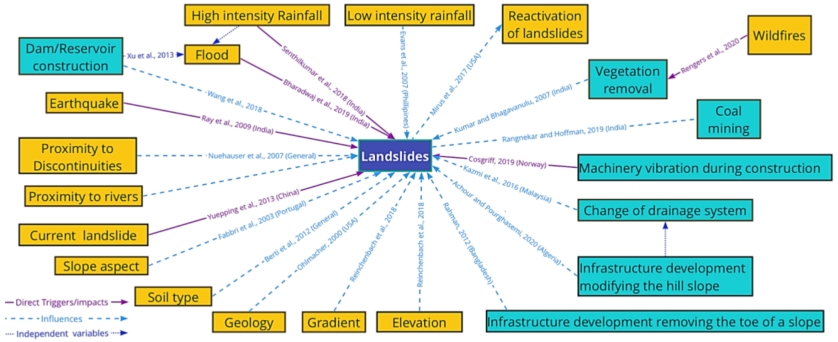
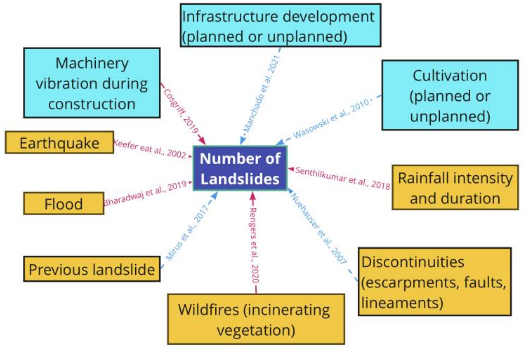
4. Conclusion

- Bayesian approach: uses **probability** to express **belief** about **unknown quantities**.
- A **Bayesian Belief Network (BBN)** can be developed using **data, expert elicitation, and/or previous models.**
- Given the data challenges/gaps for landslide occurrence in India, this study uses **experts** to inform **BBNs** for landslide hazard assessment in Darjeeling, India.
- Based on 11 expert interviews, 18 expert ratings, authors' personal experiences, and spatial-temporal scales of anthropogenic and geomorphic variables: **21 variables** were used to develop **two BBNs**:
  - BBN for **forecasting landslide occurrence probability** in Darjeeling Himalayas using **5 triggering** and **17 influencing** variables (See Slide 9)
  - BBN for **forecasting number of landslides** in Darjeeling Himalayas using **5 triggering** and **4 influencing** variables (See Slide 10)





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