Government of Nepal
Ministry of Home Affairs
National Disaster Risk Reduction & Management Authority

ICIMOD

CONSULTATIVE MEETING ON

Development of multi-hazard risk and loss and damage assessment framework for HKH

8–9 December 2022

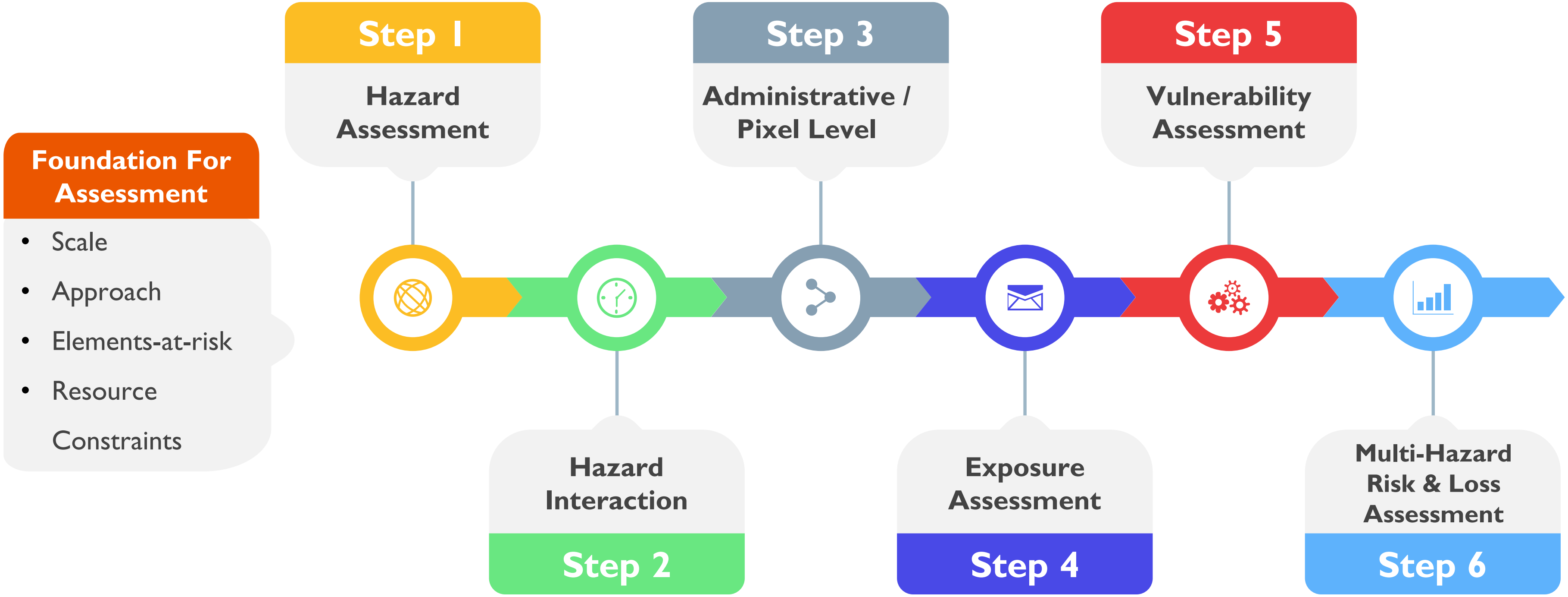
#HKHmultihazardL&D

Methodological Framework for the Hazard Risk Assessment in the HKH Region

Basanta Raj Adhikari
Suraj Gautam

Presentation on Hazard, Exposure, Vulnerability and Risk assessment methodology

Steps for Multi-hazard risk Assessment



Foundation For Assessment

- Scale
- Approach
- Elements-at-risk
- Resource Constraints

Step 1

Hazard Assessment

Step 2

Hazard Interaction

Step 3

Administrative / Pixel Level

Step 4

Exposure Assessment

Step 5

Vulnerability Assessment

Step 6

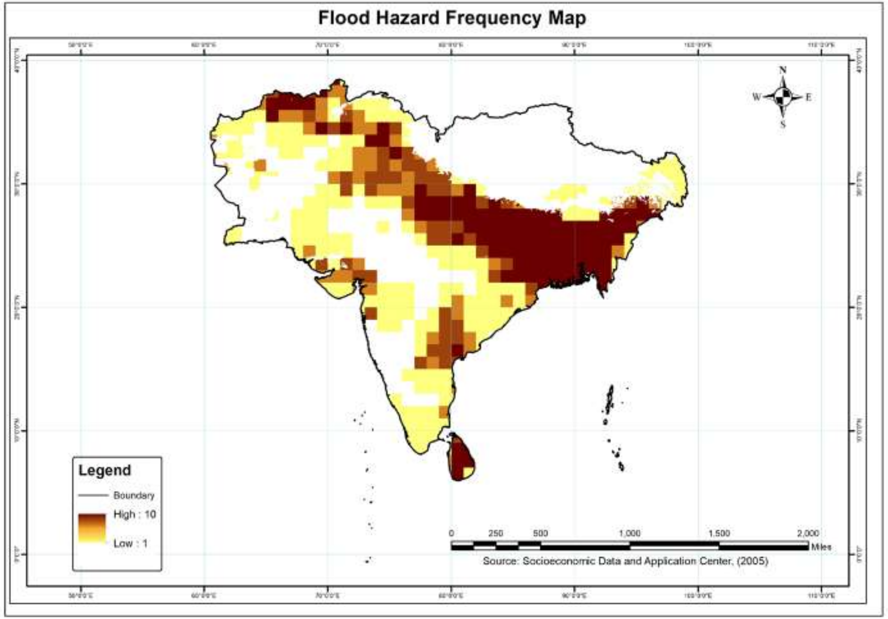
Multi-Hazard Risk & Loss Assessment

Hydro-Meteorological Hazards

- Flood
- Glacial Lake outburst floods (GLOF)
- Landslide
- Forest fire

Flood-hazard Assessment

- The intense rainstorm (540 mm in 24 hours) in July 1993 in the central Nepal destroying more than 52 houses and 62 death tolls (Dhital, 2003; Upreti & Dhital, 1996)
- The 2010 flooding incident in Pakistan with more than 2000 death tolls (FFC, 2010);
- 2013 flooding in Uttarakhand with more than 5000 death tolls (Champati Ray et al., 2016b);
- Pakistan 2022 flooding

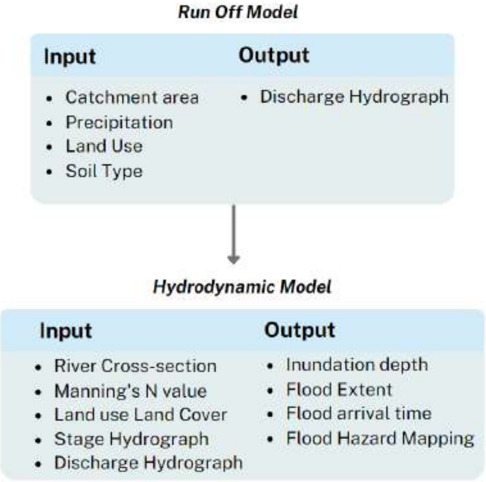


Source: Socioeconomic Data and Application Center, (2005)

Flood-hazard Assessment

Particulars	Derivatives	Source
Elevation	Local drainage direction (LDD), accumulation flux, channel properties, and watershed delineation Channel Depth, **Cross-section** Channel Width	Digital Elevation Model (DEM)
Channel network	Drainage network from DEM	DEM
Land Surface	☐ Land Use Map ☐ Land Cover classes ☐ Vegetation Density, Normalized Difference Vegetation Index (NDVI)	Satellite images, Open Street Maps
Random Roughness	☐ Mannings ‘n’	Landcover
Soil-Material	☐ Conductivity (k)/permeability ☐ Cohesion (c), angle of internal friction ☐ Porosity and suction derived from literature values ☐ Density	Soilgrids (https://soilgrids.org/)
Precipitation	Design Rain Storm (Half an hour rainfall record in a grid of 10X10 km)	Integrated Multi-satellite Retrievals for GPM (IMERG) data for different periods

Flood-hazard Assessment



Run Off Model

Input
- Catchment area
- Precipitation
- Land Use
- Soil Type

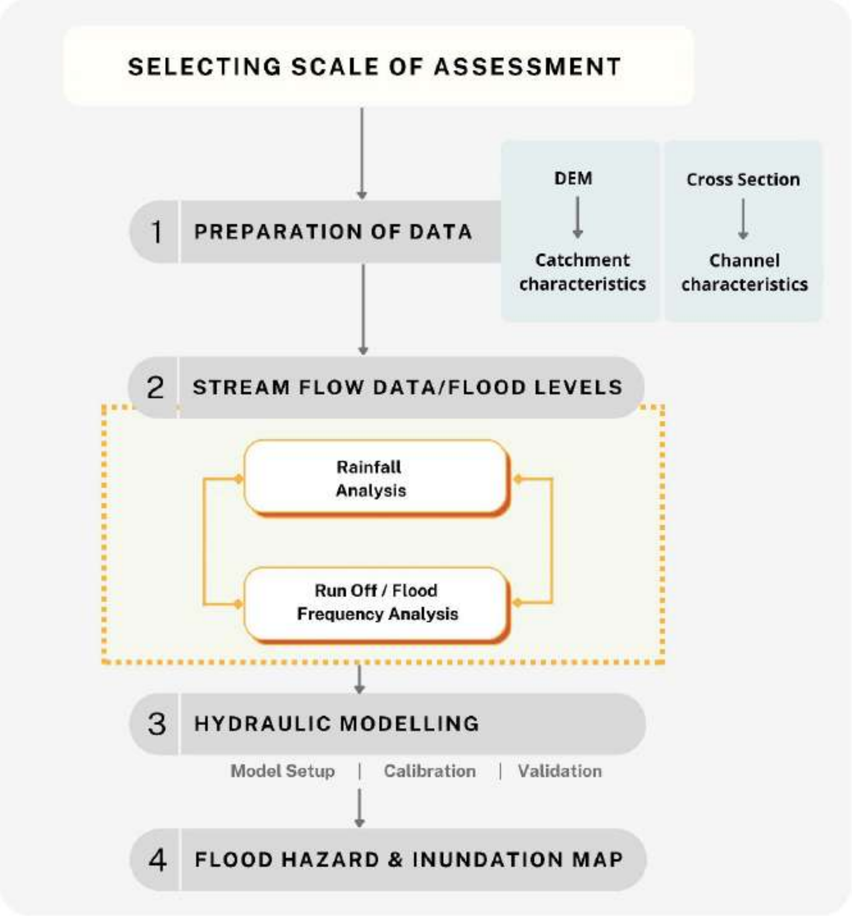
Output
- Discharge Hydrograph

Hydrodynamic Model

Input
- River Cross-section
- Manning's N value
- Land use Land Cover
- Stage Hydrograph
- Discharge Hydrograph

Output
- Inundation depth
- Flood Extent
- Flood arrival time
- Flood Hazard Mapping

Model/Tools Selection	
HEC-RAS (Hydrologic Engineering Center- River Analysis System)	HEC- HMS (Hydrologic Engineering Center-Hydrologic Modeling System)
Open-LISEM	ISIS Free
Premium: Flood Modeler, TUFLOW, SOBEK, MIKE SHE, MIKE Urban	



SELECTING SCALE OF ASSESSMENT

1 PREPARATION OF DATA

DEM → Catchment characteristics

Cross Section → Channel characteristics

2 STREAM FLOW DATA/FLOOD LEVELS

Rainfall Analysis

Run Off / Flood Frequency Analysis

3 HYDRAULIC MODELLING

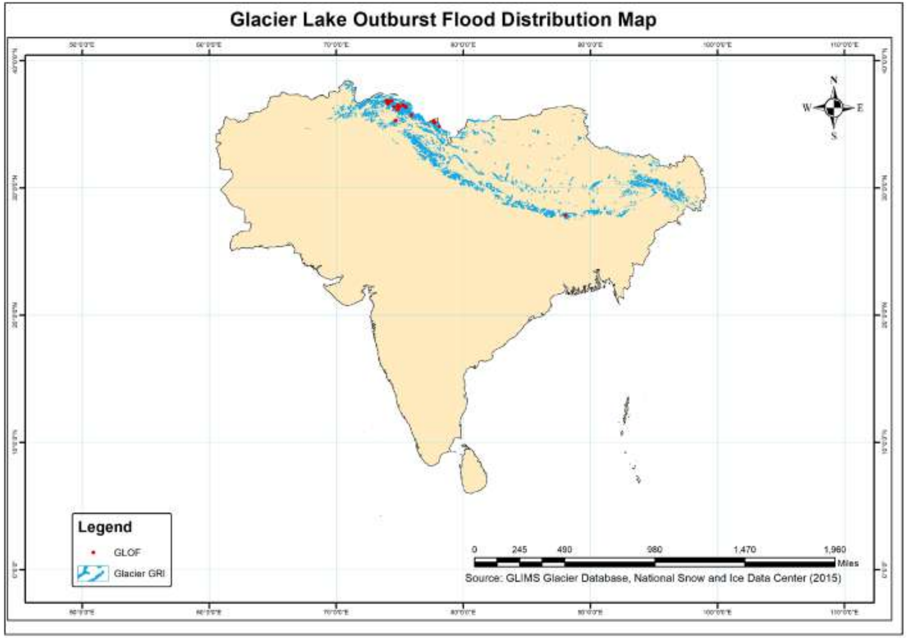
Model Setup | Calibration | Validation

4 FLOOD HAZARD & INUNDATION MAP

GLOF Susceptibility Assessment

- 25,614 glacial lakes covering an area of 1,444 km^2 within the five major river basins — Amu Darya, Indus, Ganges, Brahmaputra, and Irrawaddy, including Mansarovar Interior Basin — in the HKH (Maharjan, 2018)

- 2013 GLOF event, suffered catastrophic losses on infrastructures like hydropower dams and resulted in affecting more than 100,000 people in the region (Champati Ray et al., 2016a; Schwanghart et al., 2016).

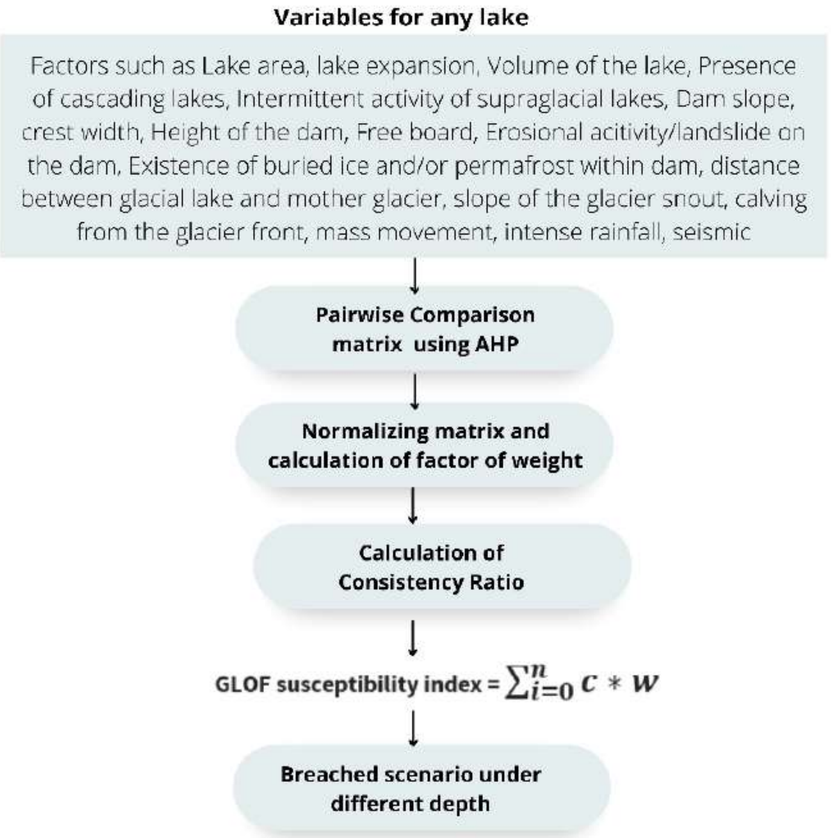


Source: GLIMS Glacier Database, National Snow and Ice Data Center (2015)

GLOF Susceptibility Assessment

Wang.et.al. (2011)

Susceptibility index	Hazard class	Rank	Assigned scores
≤0.5	Low	4	0.25
0.5 – 0.7	Medium	3	0.50
0.7– 0.8	High	2	0.75
>0.8 - 1	Very high	1	1.00



Variables for any lake

Factors such as Lake area, lake expansion, Volume of the lake, Presence of cascading lakes, Intermittent activity of supraglacial lakes, Dam slope, crest width, Height of the dam, Free board, Erosional acitivity/landslide on the dam, Existence of buried ice and/or permafrost within dam, distance between glacial lake and mother glacier, slope of the glacier snout, calving from the glacier front, mass movement, intense rainfall, seismic

Pairwise Comparison matrix using AHP

Normalizing matrix and calculation of factor of weight

Calculation of Consistency Ratio

GLOF susceptibility index = $\sum_{i=0}^{n} C * W$

Breached scenario under different depth

Methodology for GLOF susceptibility

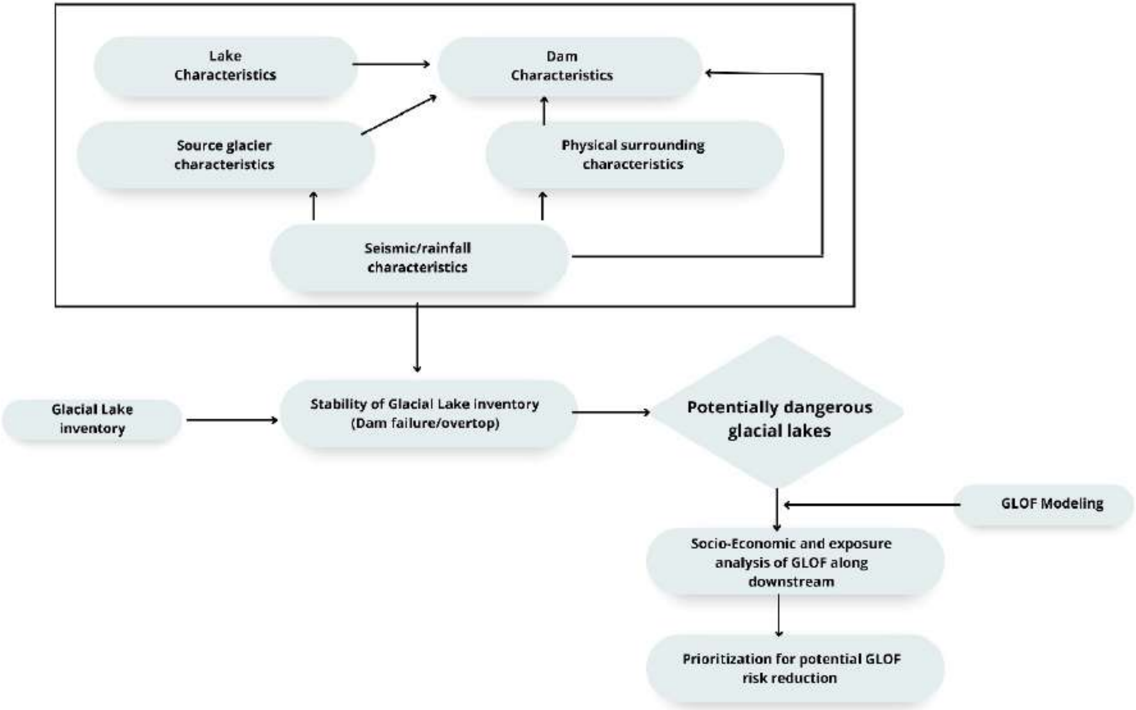
GLOF Susceptibility Assessment

Methodology for the identification of Potentially Dangerous Glacial Lakes (PDGL)

S. N	Factors	Critical values	Outburst probability	Assigned scores
1	Lake area	≥0.1 sq. km	High	1
		0.05–0.1 sq. km	Medium	0.5
		≥0.02 – <0.05 sq. km	Low	0.25
2	Lake expansion	>100%	High	1
		50–100%	Medium	0.5
		<50%	Low	0.25
3	Volume of the lake	1	High	1
		0	Low	0.5
4	Presence of cascading lakes	1	High	1
		0	Low	0.5
5	Intermittent activity of supraglacial lakes	1	High	1
		0	Low	0.5
6	Dam slope	>20°	High	1
		10°–20°	Medium	0. 5
		<10°	Low	0.25
7	Crest width	<60 m	High	1
		>60 m	Low	0.25
8	Height of the dam	1	High	1
		0	Low	0.25

S. N	Factors	Critical values	Outburst probability	Assigned scores
9	Freeboard	<1 m	High	1
		<10 m	Medium	0.5
		>20 m	Low	0.25
10	Erosional activity/landslide on the dam	1	High	1
		0	Low	0.25
11	Existence of buried ice and/or permafrost within dam	1	High	1
		0	Low	0.25
12	Distance between glacial lake and mother glacier	< 500 m	High	1
		500–1000 m	Medium	0.5
		>1000 m	Low	0.25
13	Slope of the glacier snout	>16°	High	1
		8°–16°	Medium	0.5
		<8°	Low	0.25
14	Calving from the glacier front	1	High	1
		0	Low	0.25
15	Mass movement	>30°	High	1
		<30°	Low	0.25
16	Intense rainfall	1	High	1
		0	Low	0.25
17	Seismic	1	High	1
		0	Low	0.25

GLOF Susceptibility Assessment

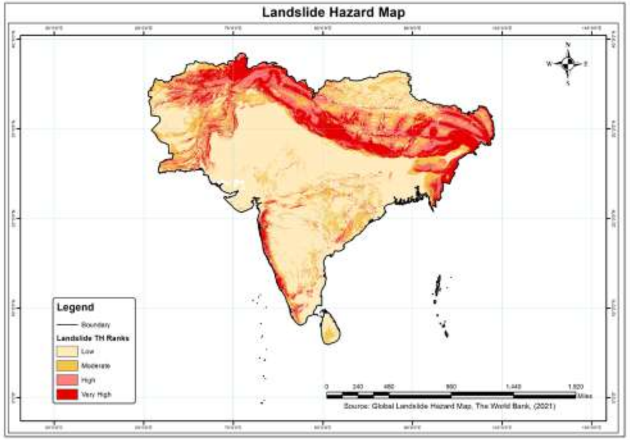


Methodology to identify Potentially Dangerous Glacial Lakes (PDGL) and prioritization for potential GLOF risk reduction

Landslide-Susceptibility Assessment

Data Preparation for Susceptibility

Particulars	Conditioning Factors	Source
Inventory		Historical data, Earth observation data
Topography	Slope Aspect Curvature Topographic Wetness Index Stream Power Index Flat areas	Digital Elevation Model (DEM)
Lithology	Geology	Geological Map
Seismology	Peak Ground Acceleration (PGA)	PGA Maps
	Fault distance	
Meteorology	Average Annual Rainfall	Station Data and Integrated Multi-satellite Retrievals for GPM (IMERG)
Proximity	Drainage	DEM
	Road Network	Road Map
	Distance to existing landslides	
Land Surface	Land Use Land Cover (LULC) Map Normalized Difference Vegetation Index (NDVI)	Satellite images, Open Street Maps


Landslide Hazard Map

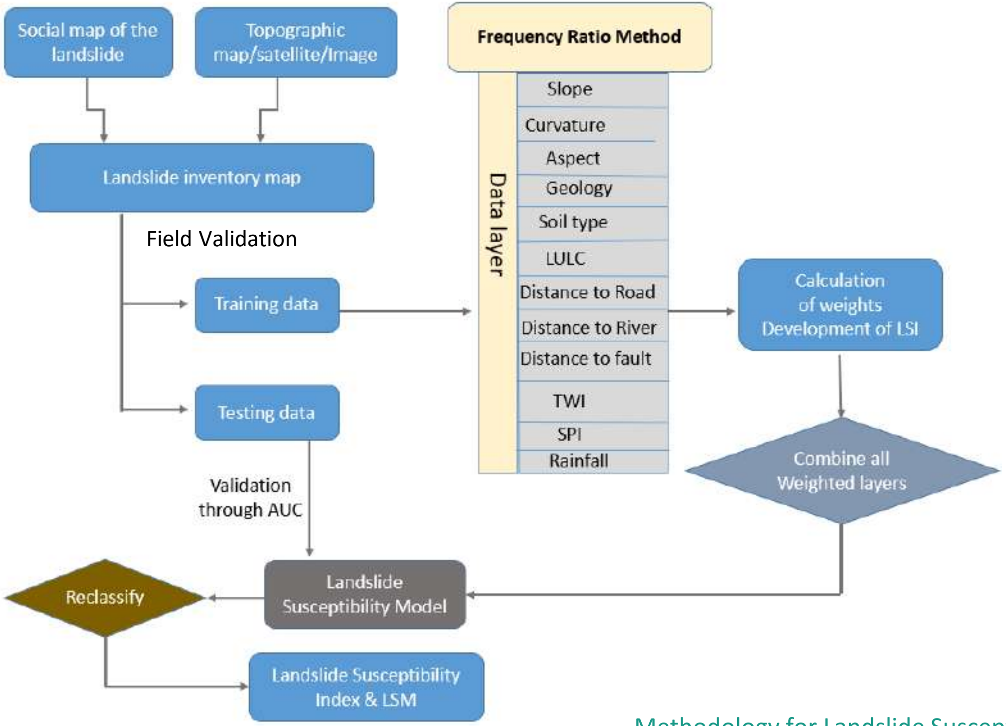
Source: Global Landslide Hazard Map, The World Bank, (2021)

Landslide-Susceptibility Assessment

Methods for Landslide Susceptibility Assessment

Models	Methods	Source
Bivariate Models	Frequency Ratio (FR)	(Avinash & Ashamanjari, 2010; S. Lee & Pradhan, 2007; Poudyal et al., 2010; Pradhan, 2010; Solaimani et al., 2013; Yilmaz, 2009)
	Information Value Model (IVM)	(Luo et al., 2019; Sarkar et al., 2013)
	Weight of Evidence Model (WoE)	(Dahal et al., 2008; Kayastha et al., 2012; S. Lee & Choi, 2004; Vahidnia et al., 2009; Vakhshoori & Zare, 2016)
	Weighted Overlay Model	(Basharat et al., 2016; Khatun et al., 2022; Sarkar et al., 1995; Shit et al., 2016)
	Index of Entropy (IoE)	(Devkota et al., 2013; Jaafari et al., 2014; Mondal & Maiti, 2013)
	Certainty Factors	(Devkota et al., 2013; Hong et al., 2017; Sujatha et al., 2012)
	Fuzzy Logic	(Bibi et al., 2016; Kayastha et al., 2013; Pradhan, 2010)
Multi Variate Models	Logistic Regression	(Ahmed & Dewan, 2017; S. Lee, 2005; S. Lee & Pradhan, 2007; Pradhan, 2010; Raja et al., 2017; Rasyid et al., 2016; Solaimani et al., 2013; Yilmaz, 2009)
	Discriminant Analysis	(Eiras et al., 2021; Murillo-García & Alcántara-Ayala, 2015; G. Wang et al., 2020)
Machine Learning Models	Artificial Neural Network (ANN)	(Poudyal et al., 2010; Pradhan & Lee, 2009; Vahidnia et al., 2009; Yilmaz, 2009)
	neuro-fuzzy	(Oh & Pradhan, 2011; Vahidnia et al., 2010)
	Support Vector Machine	(Huang & Zhao, 2018; Luo et al., 2019; Shahzad et al., 2022)
	Decision Tree	(Pal & Mather, 2003; Poudyal, 2013)

Landslide-Susceptibility Assessment



Methodology for Landslide Susceptibility Assessment

$$F_r = \frac{N_{pix(1)}/N_{pix(2)}}{\sum N_{pix(3)}/\sum N_{pix(4)}}$$

Where,

- N pix (1) = The number of pixels containing landslide in a class
- N pix (2) = Total number of pixels of each class in the whole area
- P N pix (3) = Total number of pixels containing landslide
- P N pix (4) = Total number of pixels in the study area

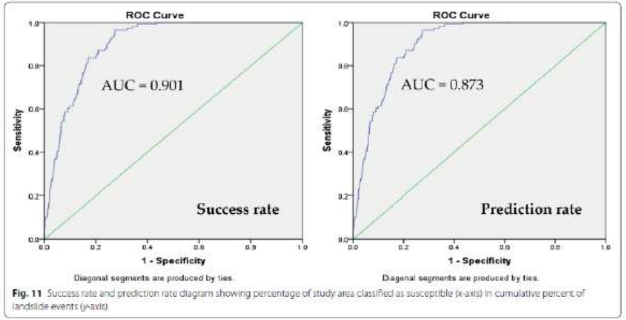


Fig. 11 Success rate and prediction rate diagram showing percentage of study area classified as susceptible (x-axis) in cumulative percent of landslide events (y-axis)

Sample Diagram for AUC (Silalahi et al., 2019)

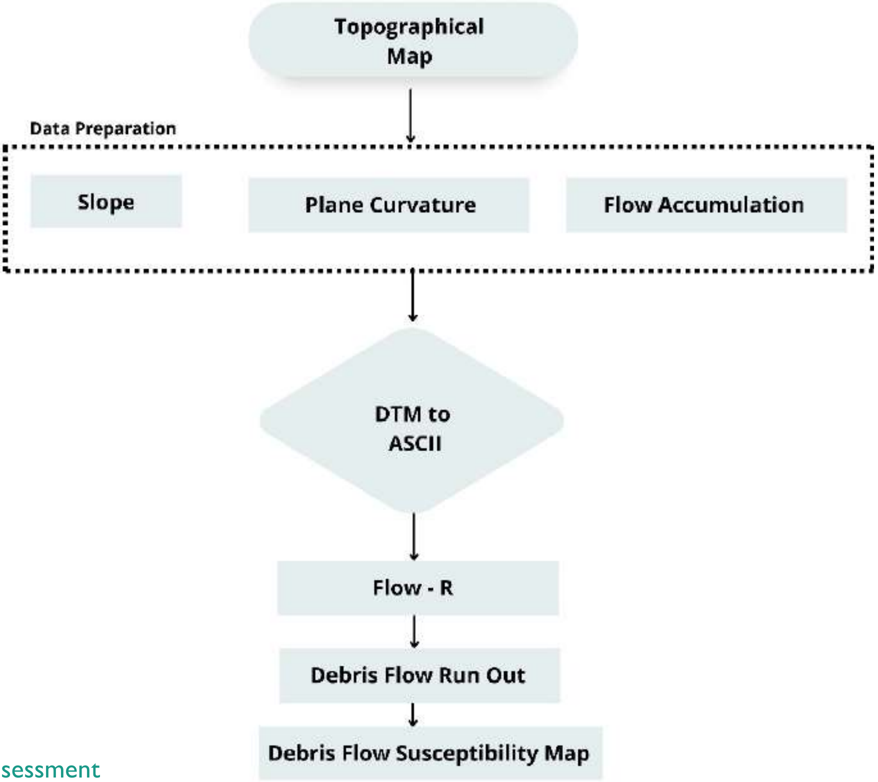
Debris Flow Susceptibility Assessment

Data Preparation for Susceptibility

Data	Source
Digital Terrain Model **ASCII based DTM**	Digital Elevation Model (DEM)
Flow Accumulation	
Slope Slope terrains in degrees Angle of Slope >15 degree is considered suitable for modeling	
Plan Curvature Relief of the terrain: driving force in the model of debris flow.	
Land Use sensitivity of irrigated lands is higher than the bedrock	Sentinel 2 Image, ESRI Land use Classification

Debris Flow Susceptibility Assessment

Tools for Debris Flow Susceptibility
Flow R Model
AvaFlow
Flo2D
Open LISEM



Topographical Map

Data Preparation

Slope

Plane Curvature

Flow Accumulation

DTM to ASCII

Flow - R

Debris Flow Run Out

Debris Flow Susceptibility Map

Methodology for Debris Flow Susceptibility Assessment

Forest Fire Susceptibility Assessment

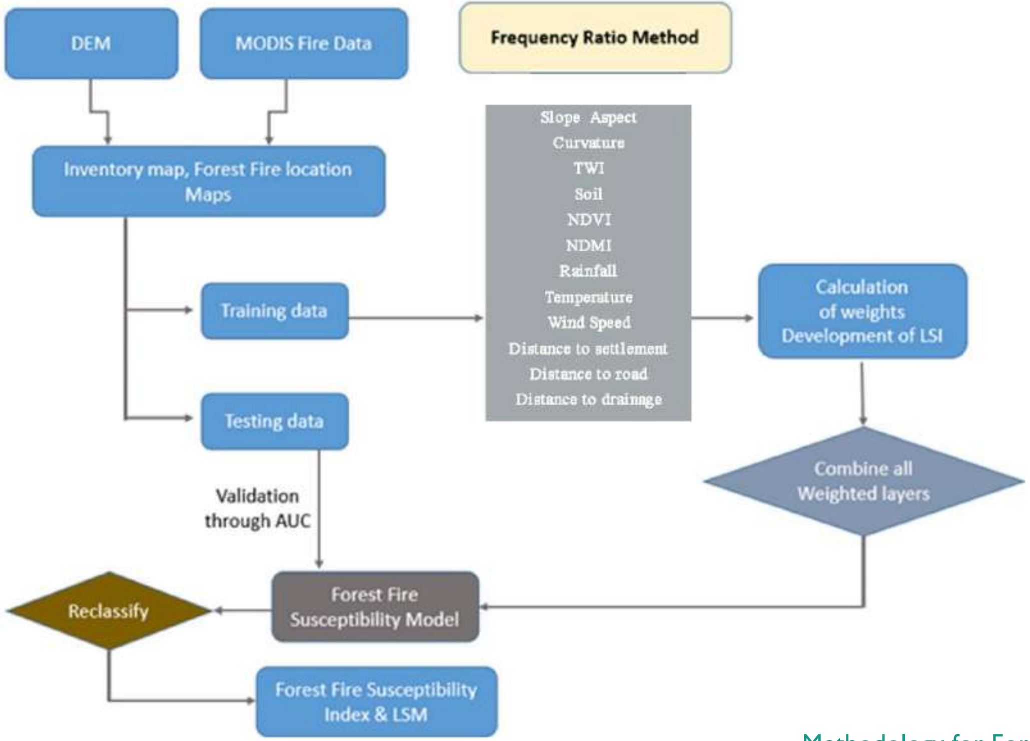
Data Preparation for Susceptibility

Datasets	Details	Source
MODIS Fire Data Near Real time within three hours of a satellite observation from NASA's MODIS and VIIRS	X, Y, Burn Date, Burnt area confidence (1 km)	NASA/MODIS/FIRMS/ ESDOS Data
ASTER DEM	Elevation, Slope, Aspect	Vertex/Alaska Satellite Facility
Land Cover	Land Cover Classes of Nepal	ICIMOD
TWI = ln (As/ TanB)	Topographic wetness index (TWI)	DEM
NDVI $= \frac{NIR - R}{NIR + R}$	Normalized Diference Vegetation Index	Landsat-8 OLI (USGS)
NDMI $= \frac{SWIR - NIR}{SWIR + NIR}$	(Normalized Difference Moisture Index)	Landsat-8 OLI (USGS)

Datasets	Details	Source
Rainfall	Rainfall	IMERG, Station Data
Land Surface Temperature	Monthly temperatures of day and night time (1 km)	NASA/MODIS/MOD11C3
Roads	Highway and associated roads	ICIMOD / OSM layers
Drainage	Rivers	DEM
Settlements	Cluster of Settlements	OCHA Nepal

Forest Fire	http://nepal.spatialapps.net/nepalforestfire	Forest Fire Monitoring System

Forest Fire Susceptibility Assessment



DEM

MODIS Fire Data

Frequency Ratio Method

Inventory map, Forest Fire location Maps

Training data

Testing data

Slope Aspect
Curvature
TWI
Soil
NDVI
NDMI
Rainfall
Temperature
Wind Speed
Distance to settlement
Distance to road
Distance to drainage

Calculation of weights Development of LSI

Combine all Weighted layers

Validation through AUC

Forest Fire Susceptibility Model

Reclassify

Forest Fire Susceptibility Index & LSM

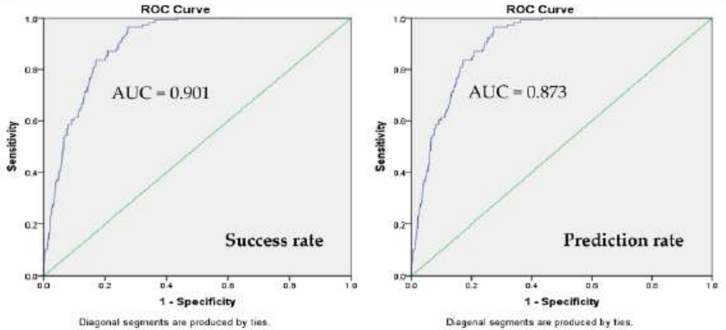


Fig. 11 Success rate and prediction rate diagram showing percentage of study area classified as susceptible (x-axis) in cumulative percent of landslide events (y-axis)

Sample Diagram for AUC (Silalahi et al., 2019)

Methodology for Forest Fire Susceptibility Assessment

Multi Hazard Maps

A For each Hazards

The Units, Resolution and extent of the map shall be made consistent

B Normalization of Indices

By $xn_i = \frac{x_i - x_l}{x_h - x_l}$

C Calculation of Weights

	Hazard A	Hazard B	Hazard C	……….
Hazard A	▨			
Hazard B	▨	▨		
Hazard C	▨	▨	▨	
…………	▨	▨	▨	▨

D Overlay Analysis

In this GIS Environment, using Raster Calculator, this process can be carried out.

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Methodological Framework for the Exposure, Vulnerability & Risk Assessment in the HKH Region

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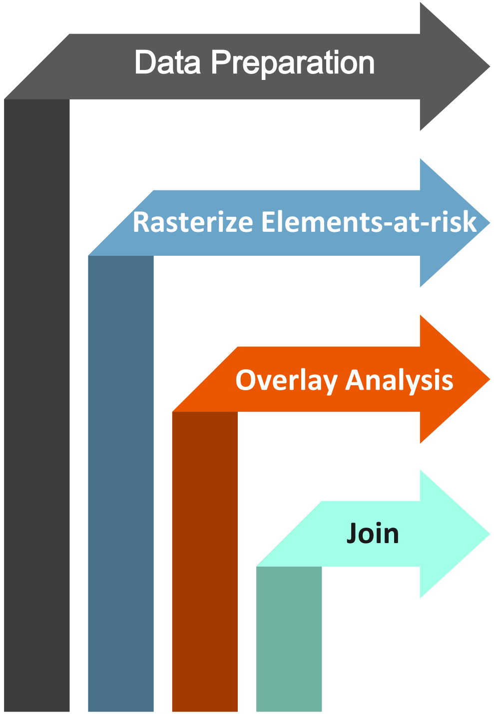
Exposure Assessment

Exposure Assessment



Data Preparation

Rasterize Elements-at-risk

Overlay Analysis

Join

The scale of the assessment (national or local) needs to be identified and thus the attributes for the elements-at-risk needs to be finalized.

The spatial vector data of elements-at-risk shall be rasterized taking in due considerations to the georeferencing and Coordinate Reference System

The prepared raster maps of hazard of certain return periods & intensity maps (High, Moderate & Low) is imported in the GIS environment

The combined Exposure map values are then joined with the administrative units to calculate exposed fraction per unit

Exposure Assessment

Exposure of Flood to Element-at-risk (For Administrative Unit A)

Building Count	Flood		
	10 years	50 years	100 years
Low	A	D	G
Moderate	B	E	H
High	C	F	I

Summary of Exposure of Flood to Element-at-risk

Administrative Unit Level	Flood								
	10 years			50 years			100 years		
	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Unit 1									
Unit 2									
…..									

Vulnerability Assessment

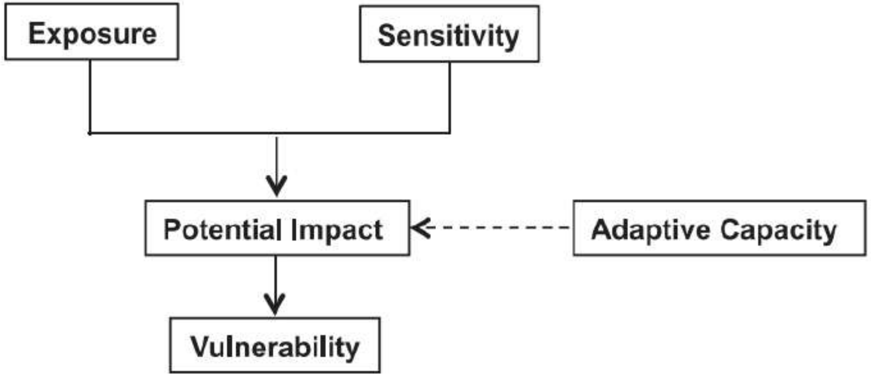
Vulnerability

United Nations (2004) has distinguished four groups of vulnerability factors that are relevant in the context of disaster reduction:

- ❑ **Physical factors,**
- ❑ **Economic factors**
- ❑ **Social factors,**
- ❑ **Environmental factors,**

Vulnerability

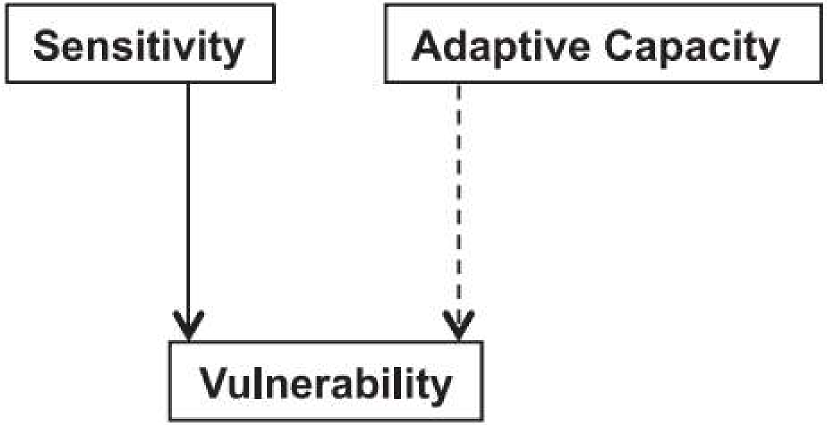
- ❑ Vulnerability to climate change is ‘the degree, to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes.
- ❑ Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.



IPCC 2007 Paradigm

Vulnerability

- ❑ Vulnerability is defined by the Sensitivity and Adaptive Capacity as the ‘new paradigm’.



IPCC 2014 Paradigm

Vulnerability Assessment

Vulnerability Curves / Damage Functions

- Relation between the hazard intensities and damage data.
- Damage ratio vs given Level of hazard intensity.
- Different for different types of elements-at-risk

.

Vulnerability Indices:

- Indicators of vulnerability;
- May not have direct relation with the different hazard intensities.
- Expressing social, economic and environmental vulnerability.

Vulnerability table:

- Relation between hazard intensity and degree of damage

Physical Vulnerability Assessment

Physical Vulnerability Assessment

Physical Vulnerability to Floods

Step 1: Intensity Classification:

The intensity of floods is classified into four classes: no flooding, Low, Moderate and High

Step 2: Threshold for Damages due to flooding:

The threshold for the depth of water in inundation is considered.

Buildings

- Typology
- Number of floors
- Construction Class

Crops

- Type of Crops
- Area

Population

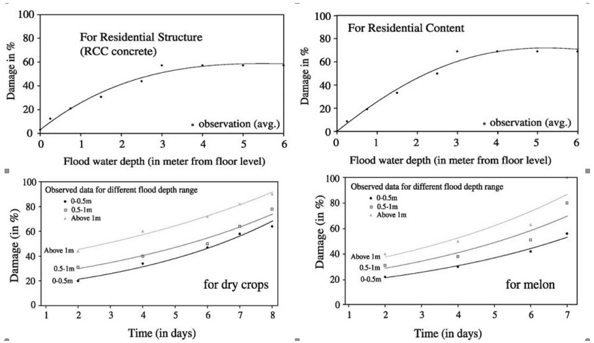
- Injured
- Death

Physical Vulnerability Assessment

Physical Vulnerability to Flooding

Step 3: Damage Function

Buildings, Crops and Roads



Flood Intensity	Water Depth	Effect on Buildings	Effect on Crops	Effect on Roads
No Flood	< 0.2 cm	0% damage	0% destroyed	0% length disturbed
Low	0.2 to 1m	A % of building sever damage B % people killed or injured	G % destroyed	K % of length unpassable
Moderate	1 – 2m	C % of building sever damage D % people killed or injured	H % destroyed	L % of length unpassable
High	> 2 m	E % of building sever damage F % people killed or injured	I % destroyed	M % of length unpassable

For each element-at-risk, considering the effects summarized above a plot of Depth- Damage curve is developed

Source: https://www.cdema.org/virtuallibrary/index.php/charim-hbook/use-case-book/7-exposure-and-vulnerability/7-2-generating-physical-vulnerability-curves

Physical Vulnerability Assessment

Physical Vulnerability to Flooding

Step 3: Damage Function

Population

Flood Intensity	Water Depth	Population					
		Mud Masonry Houses		Temporary House		RCC Frame House	
		Injured	Death	Injured	Death	Injured	Death
Low	0.2 to 1m						
Moderate	1 – 2m						
High	> 2 m						

For each element-at-risk, considering the effects summarized above a plot of Depth- Damage curve is developed

Physical Vulnerability Assessment

Physical Vulnerability to Landslides

Step 1: Intensity Classification:

The Landslide susceptibility is classified into three classes: Low, Moderate and High.

Step 2: Threshold for Damages for Landslide:

The threshold for the damage due to the landslide is based on the % of exposed elements in a given area.

House Typology

- Adobe
- Brick-Cement Masonry
- RCC Frame
- Temporary

Rural Settings

- No. of people killed R_D
- No. of people injured R_I

Urban Settings

- No. of people killed U_k
- No. of people injured U_I

Susceptibility in Rural Settings

- Low R_L
- Moderate R_M
- High R_H

Susceptibility in Urban Settings

- Low U_L
- Moderate U_M
- High U_H

Physical Vulnerability Assessment

Physical Vulnerability to Landslides

Step 3: Damage Function

Population: The Damage function for population is then estimated by multiplication of factors. (nep= number of exposed population) **Roads**

Landslide Susceptibility	Effect on Population Number of Exposed Population (nep) killed (d) or injured (i)		Effect on Roads
	Rural Settings	Urban Settings	
Low	$R_L * nep * R_d$ $R_L * nep * R_i$	$U_L * nep * U_d$ $U_L * nep * U_i$	A % of length of road destroyed
Moderate	$R_M * nep * R_d$ $R_M * nep * R_i$	$U_M * nep * U_d$ $U_L * nep * U_i$	B % length of road destroyed
High	$R_H * nep * R_d$ $R_M * nep * R_i$	$U_H * nep * U_d$ $U_L * nep * U_i$	C % length of road destroyed

For each element-at-risk, considering the effects summarized above a plot of Damage curve is developed

Physical Vulnerability Assessment

Physical Vulnerability to Landslides

Step 3: Damage Function

For Buildings and Crops

Landslide Susceptibility	Effect on Buildings		Effect on Crops
	Rural Settings	Urban Settings	
Low	A % of exposed building destroyed	D % of exposed building destroyed	G % destroyed
Moderate	B % of exposed building destroyed	E % of exposed building destroyed	H % destroyed
High	C % of exposed building destroyed	F % of exposed building destroyed	I % destroyed

Comprehensive Vulnerability Assessment

- Vulnerability is multi-dimensional

  Physical, Social, Economic, Environmental, institutional

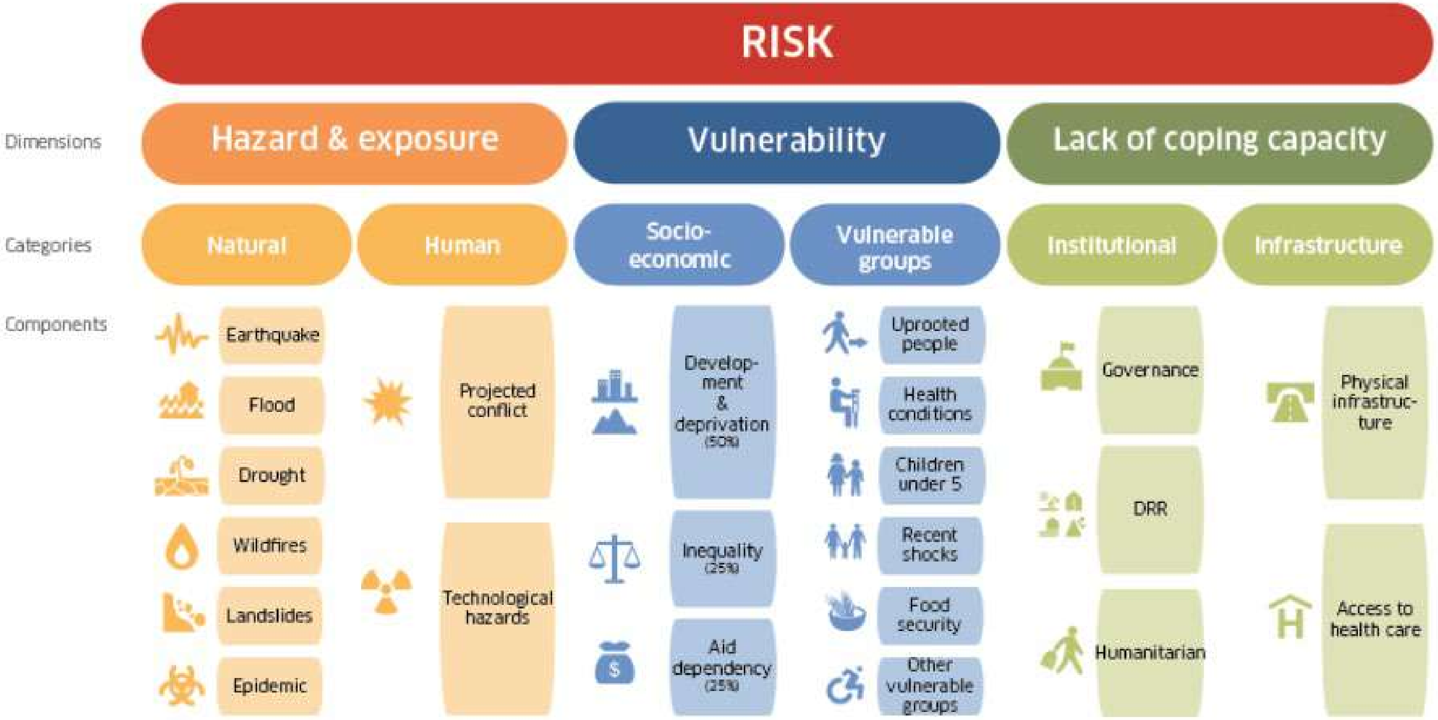
- Vulnerability is dynamic
- Scale to be defined: National/Regional level, Community level, Household level

Tools

- Social Vulnerability Index (SVI)
- Poverty and Vulnerability Assessment (PVA)
- Climate Disaster Risk Index (CDRI)
- INFORM
- Multidimensional Vulnerability Index

Comprehensive Vulnerability Assessment

Comprehensive Vulnerability Assessment



RISK

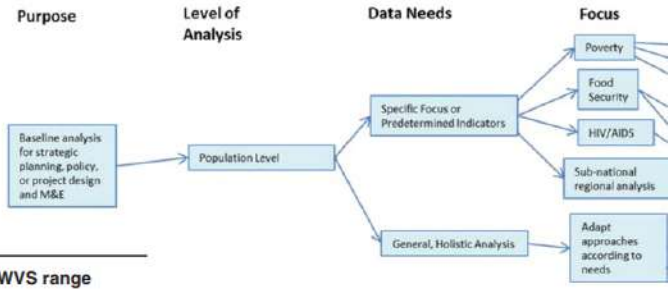
Dimensions

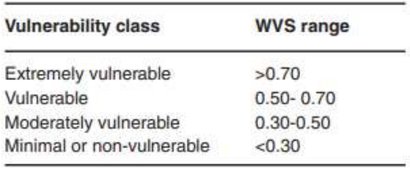
Categories

Components

- Hazard & exposure
  - Natural
    - Earthquake
    - Flood
    - Drought
    - Wildfires
    - Landslides
    - Epidemic
  - Human
    - Projected conflict
    - Technological hazards
- Vulnerability
  - Socio-economic
    - Development & deprivation (50%)
    - Inequality (25%)
    - Aid dependency (25%)
  - Vulnerable groups
    - Uprooted people
    - Health conditions
    - Children under 5
    - Recent shocks
    - Food security
    - Other vulnerable groups
- Lack of coping capacity
  - Institutional
    - Governance
    - DRR
    - Humanitarian
  - Infrastructure
    - Physical infrastructure
    - Access to health care

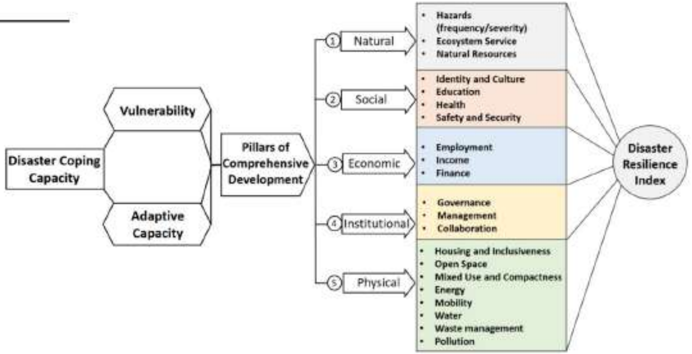
Comprehensive Vulnerability Assessment





Vulnerability class	WVS range
Extremely vulnerable	>0.70
Vulnerable	0.50- 0.70
Moderately vulnerable	0.30-0.50
Minimal or non-vulnerable	<0.30

Moret (2014)



Karmkar et. al. (2019)

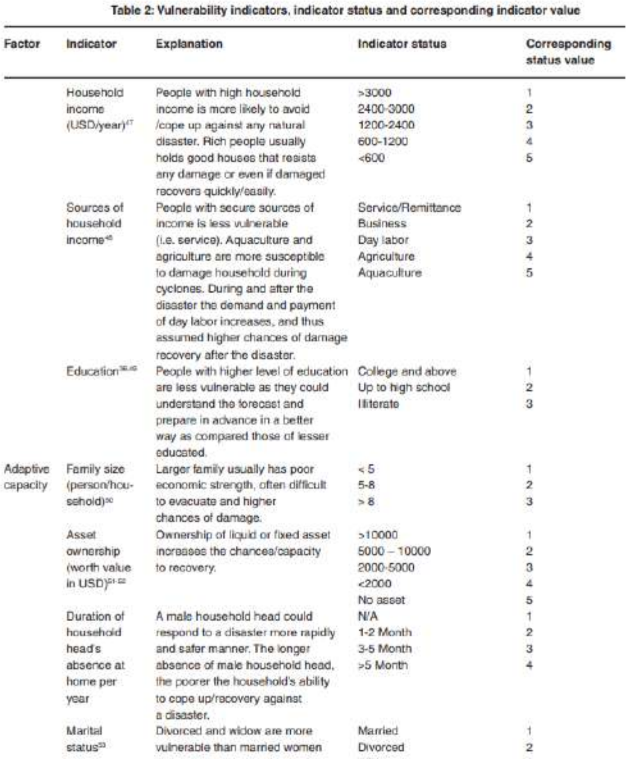
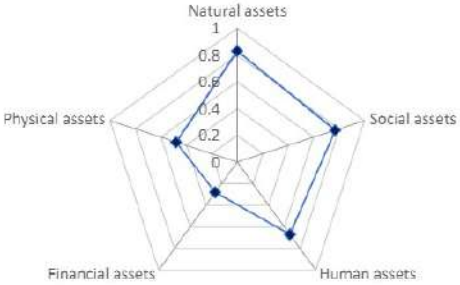


Table 2: Vulnerability indicators, indicator status and corresponding indicator value

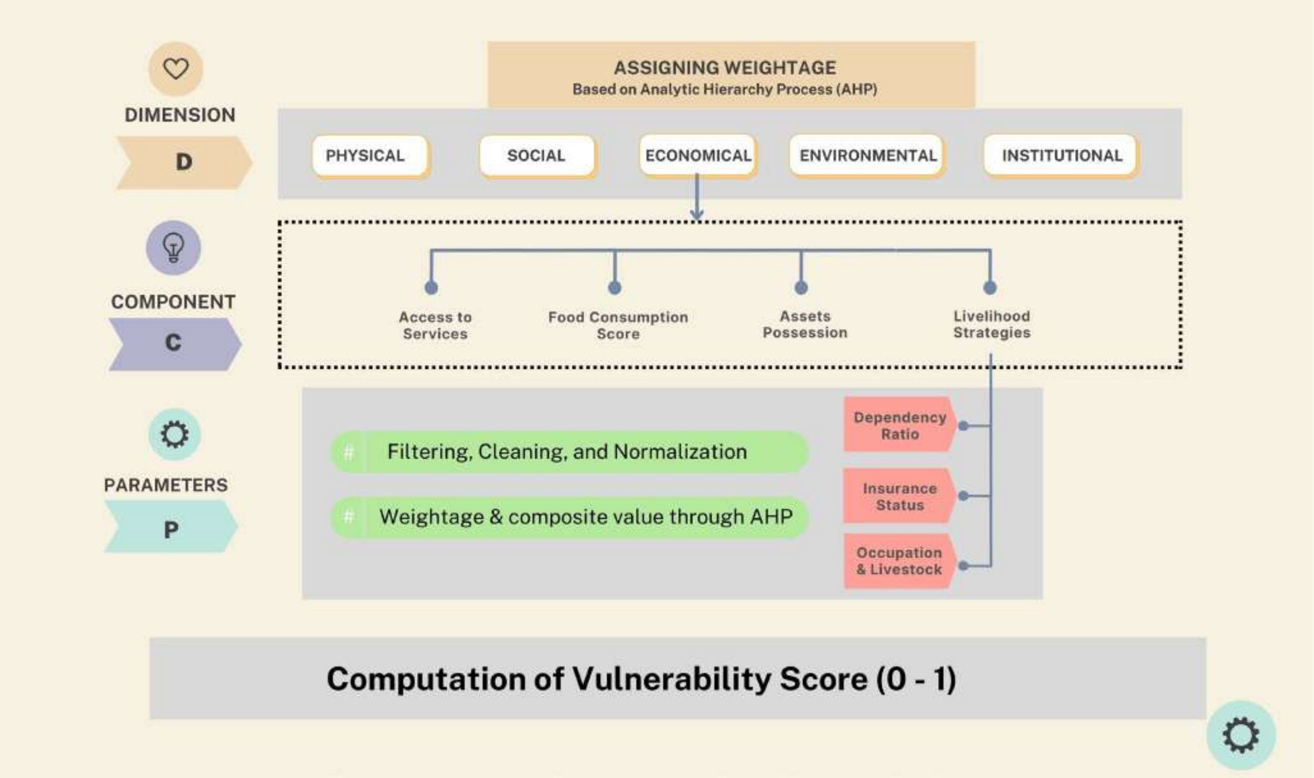
Factor	Indicator	Explanation	Indicator status	Corresponding status value
	Household income (USD/year)[47]	People with high household income is more likely to avoid /cope up against any natural disaster. Rich people usually holds good houses that resists any damage or even if damaged recovers quickly/easily.	>3000 2400-3000 1200-2400 600-1200 <600	1 2 3 4 5
	Sources of household income[48]	People with secure sources of income is less vulnerable (i.e. service). Aquaculture and agriculture are more susceptible to damage household during cyclones. During and after the disaster the demand and payment of day labor increases, and thus assumed higher chances of damage recovery after the disaster.	Service/Remittance Business Day labor Agriculture Aquaculture	1 2 3 4 5
	Education[38,49]	People with higher level of education are less vulnerable as they could understand the forecast and prepare in advance in a better way as compared those of lesser educated.	College and above Up to high school Illiterate	1 2 3
Adaptive capacity	Family size (person/household)[50]	Larger family usually has poor economic strength, often difficult to evacuate and higher chances of damage.	< 5 5-8 > 8	1 2 3
	Asset ownership (worth value in USD)[51-52]	Ownership of liquid or fixed asset increases the chances/capacity to recovery.	>10000 5000 – 10000 2000-5000 <2000 No asset	1 2 3 4 5
	Duration of household head's absence at home per year	A male household head could respond to a disaster more rapidly and safer manner. The longer absence of male household head, the poorer the household's ability to cope up/recovery against a disaster.	N/A 1-2 Month 3-5 Month >5 Month	1 2 3 4
	Marital status[53]	Divorced and widow are more vulnerable than married women	Married Divorced	1 2

Comprehensive Vulnerability Assessment

	THEME	Thematic weight	Category
HVRI	Physical		**Building Details**
			Access to Services
	Economic		**Livelihood Status**
			Wealth/ Assets Possession
			Livelihood Components
			Food Consumption Score
	Social		**Socio-Characteristics**
			Social Safety nets
	Environmental		**Hazard and Exposure**
			Knowledge & Skills
			Pre-Disaster
			During Disaster
			Post-Disaster

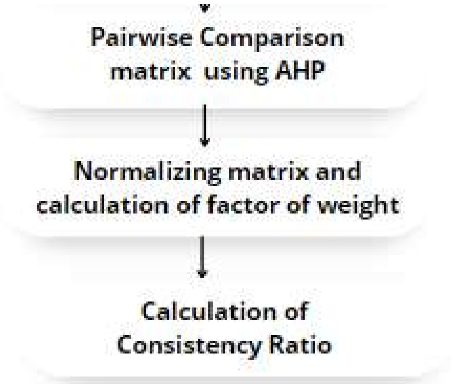


Comprehensive Vulnerability Assessment



Comprehensive Vulnerability Assessment

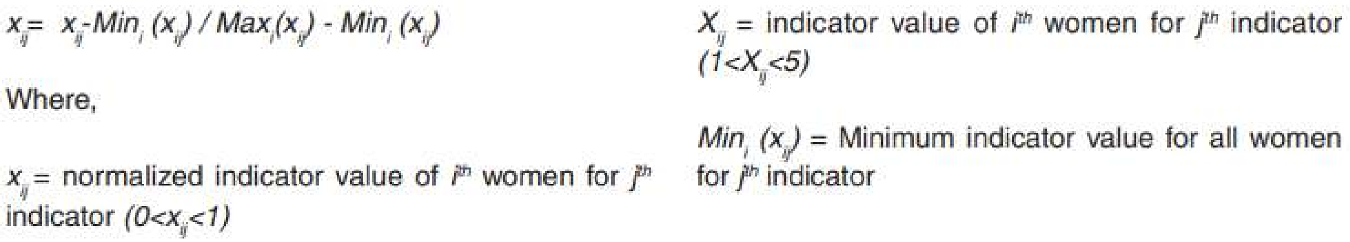
- Vulnerability indicators can have varying status (different units and scales) and corresponding values, hence it is necessary to normalize the values
- The normalized indicator values for all the indicators will lie between 0 and 1.
- The value 1 corresponds to that maximum vulnerability potential and 0 corresponds to minimum vulnerability potential



Pairwise Comparison matrix using AHP

Normalizing matrix and calculation of factor of weight

Calculation of Consistency Ratio



$x_{ij} = x_{ij} - Min_i\ (x_{ij})\ /\ Max_i(x_{ij}) - Min_i\ (x_{ij})$

Where,

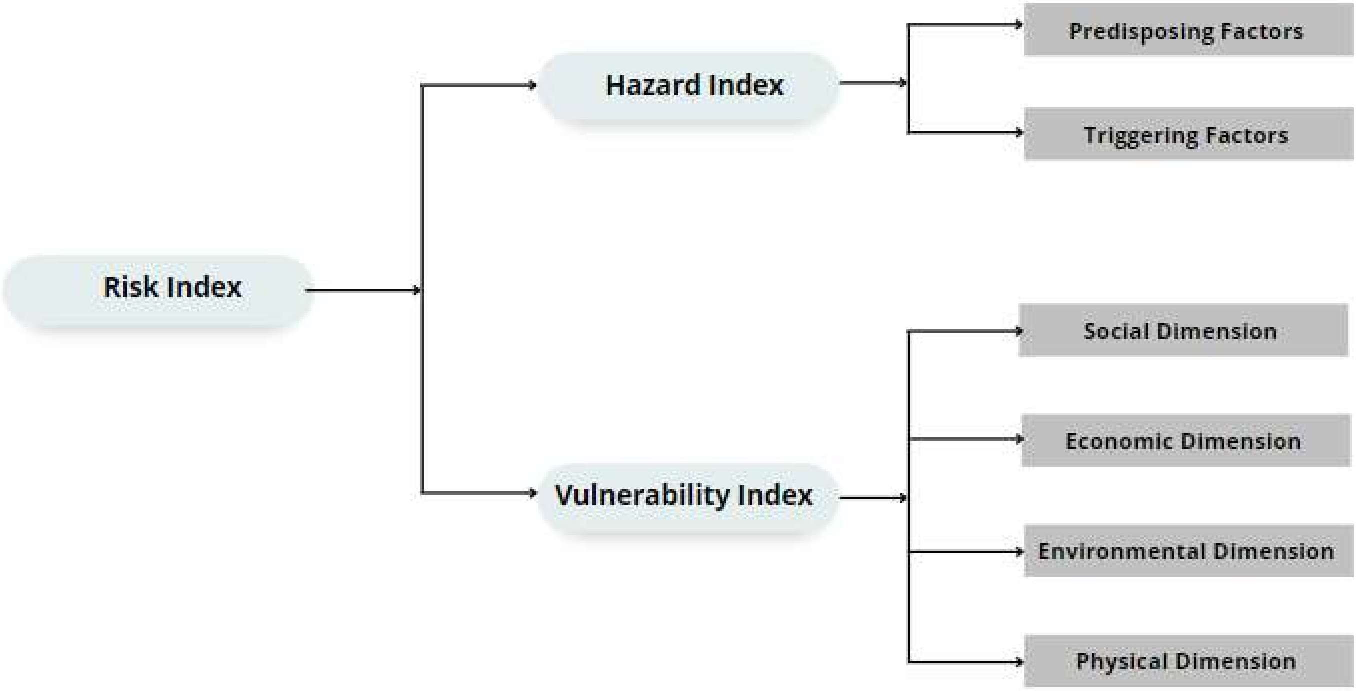
x_{ij} = normalized indicator value of i^{th} women for j^{th} indicator $(0<x_{ij}<1)$

X_{ij} = indicator value of i^{th} women for j^{th} indicator $(1<X_{ij}<5)$

$Min_i\ (x_{ij})$ = Minimum indicator value for all women for j^{th} indicator

Multi-Hazard Risk Assessment

Qualitative Multi-Hazard Risk Assessment



Qualitative Multi-Hazard Risk Assessment

Step 1: Development of Multi-Hazard Map

A For each Hazards

The Units, Resolution and extent of the map shall be made consistent

B Normalization of Indices

By $xn_i = \frac{x_i - x_l}{x_h - x_l}$

C Calculation of Weights

	Hazard A	Hazard B	Hazard C	....
Hazard A	▨			
Hazard B	▨	▨		
Hazard C	▨	▨	▨	
....	▨	▨	▨	▨

D Overlay Analysis

In this GIS Environment, using Raster Calculator, this process can be carried out.

Qualitative Multi-Hazard Risk Assessment

Step 2: Assigning of Value to Hazards (on the scale 1-5) for each Administrative Unit

Multi Hazard Class	Low	Medium	High	Assigned Value
Unit 1				
Unit 2				
Unit 3				
....				

By making a visual inspection of the total percentage of low, medium and high, through the expert judgement, the multi-hazard value of 1,2,3 corresponding to Low, Medium and High classes of Multi-Hazard respectively can be assigned.

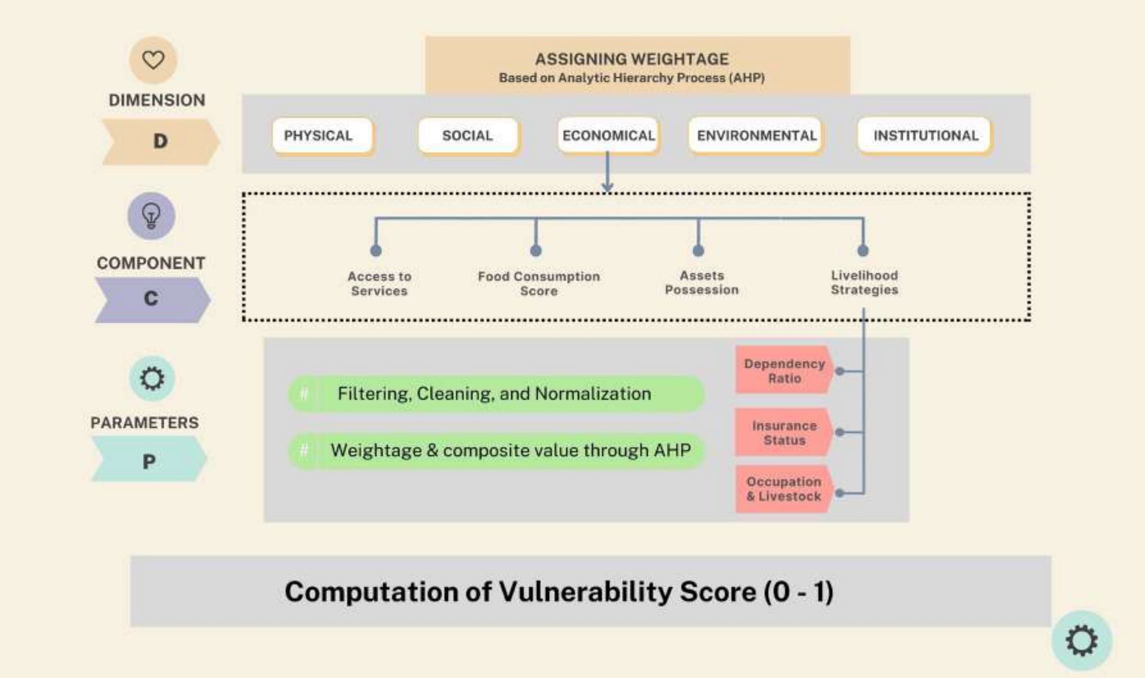
Qualitative Multi-Hazard Risk Assessment

Step 3: Exposure Assessment

Element at risk		Hazard classes				
Elements	Unit	Very Low	Low	Moderate	High	Very high
Population	Number					
Roads	Length in km					
Buildings	Number					
Agriculture land	Area in km^2					

Qualitative Multi-Hazard Risk Assessment

Step 4: Comprehensive Vulnerability Assessment



Qualitative Multi-Hazard Risk Assessment

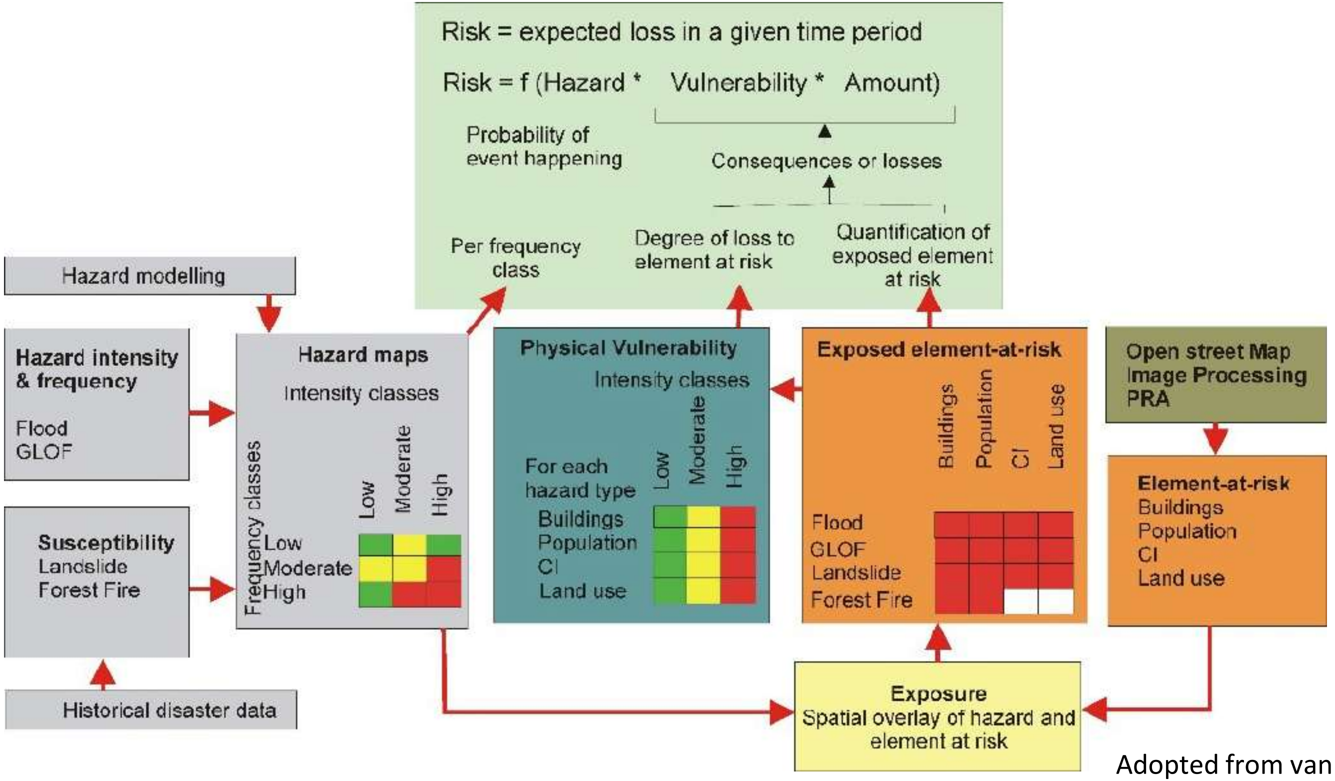
Step 5: Quantification of Multi-Hazard Risk

The risk assessment can be carried out by combining the combination of hazard Index (H) and vulnerability Index (V) of the exposure elements as

Multi Hazard Risk = Multi-Hazard (MH) * Comprehensive Vulnerability Index (V)

Can be done for household level, community level, ward level, regional/ national level

Quantitative Multi-Hazard Risk Assessment



Risk = expected loss in a given time period

Risk = f (Hazard * Vulnerability * Amount)

Probability of event happening

Consequences or losses

Per frequency class

Degree of loss to element at risk

Quantification of exposed element at risk

Hazard modelling

Hazard intensity & frequency
Flood
GLOF

Susceptibility
Landslide
Forest Fire

Historical disaster data

Hazard maps
Intensity classes

Frequency classes	Low	Moderate	High
Low	🟩	🟨	🟩
Moderate	🟨	🟨	🟥
High	🟩	🟥	🟥

Physical Vulnerability
Intensity classes

For each hazard type	Low	Moderate	High
Buildings	🟩	🟨	🟥
Population	🟩	🟨	🟥
CI	🟩	🟨	🟥
Land use	🟩	🟨	🟥

Exposed element-at-risk

	Buildings	Population	CI	Land use
Flood	🟥	🟥	🟥	🟥
GLOF	🟥	🟥	🟥	🟥
Landslide	🟥	🟥	🟥	🟥
Forest Fire	🟥	🟥	☐	☐

Open street Map
Image Processing
PRA

Element-at-risk
Buildings
Population
CI
Land use

Exposure
Spatial overlay of hazard and element at risk

Adopted from van Westen, 2019

Quantitative Multi-Hazard Risk Assessment

The quantitative multi-hazard risk assessment is based on the following combination of following components (van Westen et al., 2011; van Westen & Abella, 2007):

$$R = P_T * P_L * V * A$$

P_T is the temporal (e.g. annual) probability of occurrence of a specific hazard scenario within a given return period in an area;

P_L is the Spatial probability of occurrence of a specific hazard scenario with a given return period in an area impacting the elements-at-risk. ;

V is the physical vulnerability, specified as the degree of damage to a specific element-at risk

A is the Quantification of the specific type of element at risk evaluated.

Quantitative Multi-Hazard Risk Assessment

Step 1: Development of Hazard Map

For flooding

- The hazard intensity, i.e. water depth can be estimated through the established modelling tools
- Frequency can be obtained from historical records of precipitation

For GLOF, Landslide and Forest Fire,

- intensity/frequency map is difficult due to its nature or data scarcity, hence **Susceptibility Mapping.**

Quantitative Multi-Hazard Risk Assessment

Step 2: Spatial Probability

- Indicates the chance that a particular location, within one of the three susceptibility classes (high, moderate or low) might be impacted by a hazardous phenomenon (e.g., landslide) within a particular time period (e.g., 10 or 50 years).

- Density of hazardous phenomena within a given time period and susceptibility zone.

Hazard	Type of Modelling	Frequency Classes	Intensity Classes	Intensity Type
Flood	Probabilistic	10, 50, 100 years	3 classes	Water Depth
GLOF	Statistical	3 susceptible classes		Relative Class
Landslide / Debris Flow	Statistical	3 susceptible classes		Relative Class
Forest Fire	Statistical	3 susceptible classes		Relative Class

Quantitative Multi-Hazard Risk Assessment

Step 2: Spatial Probability to Floods

- A flood with larger return period is expected to affect a larger area.
- While for any kind of extreme events like that occurs once in every fifty or hundred years,

Hazard Type	Return Period	Spatial Probability	Remarks
Flood	10 years	X	X % of the modelled area is expected to experience flooding with every 10-year return period flooding.
	50 years	Y	Y% of the modelled area will be affected by moderate event of 50 years.
	100 years	Z	For such extreme event, that occurs once every hundred years, Z% of the modelled area will be affected

Z > Y > X

Quantitative Multi-Hazard Risk Assessment

Step 2: Spatial Probability to Landslides

Assumptions

- **Spatial probability** that a particular area would be impacted
  = f (expected area of future events, and the area of the susceptibility classes)
- Expected area of future events is based on limited historical records and expert estimation.
- Spatial Probability is zero in low Susceptibility classes
- No. of events that happen in high class is greater than the moderate class.
- No. of events that happen in 100 years return period is more than the event with 50 years return period.

Quantitative Multi-Hazard Risk Assessment

Step 2: Spatial Probability to Landslides

Assumptions

- **X m^2** of area of Landslide event is estimated in 1 km^2 of area
- Estimation of spatial probability for three return periods: 10, 50 and 100 years.
- Multiplication factor to account missing information.
- Eg: Data available for 50 years, to make calculation of 10 years, we do 10/100.

Quantitative Multi-Hazard Risk Assessment

Step 2: Spatial Probability to Landslides

- X m^2 of area of Landslide event is estimated in 1 km^2 of area
- $Spatial\ Probability = \frac{Size\ of\ Single\ Event\ X\ (m^2)}{Per\ Number\ of\ (km^2)} x\ No\ of\ Events$

For Eg: For a major event with 100 years Return period, there would be f number of landslides with an area X in each 1 Km^2 of High Susceptibility zone,

- Thus, Spatial probability = $\frac{X\ (m^2)}{1\ km^2} x\ f$

Quantitative Multi-Hazard Risk Assessment

Step 2: Spatial Probability to Landslides

$f > e$, $d > c$, and $b > a$

Hazard	Return Period	Susceptibility Class	Size of Single Event (m^2)	No of Events	Per Number of Km^2	Spatial Probability
Landslides	10	Low	X	0	1	0.0000
		Moderate	X	a	1	$\frac{X\ (m^2)}{1\ km^2} x\ a$
		High	X	b	1	$\frac{X\ (m^2)}{1\ km^2} x\ b$
	50	Low	X	0	1	0.0000
		Moderate	X	c	1	$\frac{X\ (m^2)}{1\ km^2} x\ c$
		High	X	d	1	$\frac{X\ (m^2)}{1\ km^2} x\ d$
	100	Low	X	0	1	0.0000
		Moderate	X	e	1	$\frac{X\ (m^2)}{1\ km^2} x\ e$
		High	X	f	1	$\frac{X\ (m^2)}{1\ km^2} x\ f$

Quantitative Multi-Hazard Risk Assessment

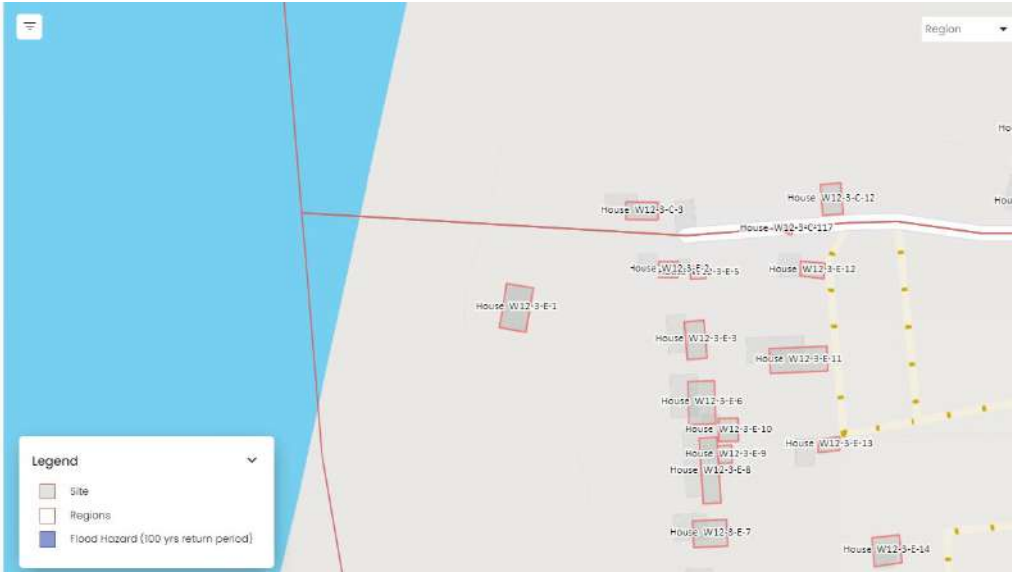
Step 3: Calculation of Losses

- Losses can be calculated for each hazard type, frequency classes and elements-at-risk combination
- Definition of administrative unit.
- Loss = Exposure x Physical Vulnerability x Spatial probability

Quantitative Multi-Hazard Risk Assessment

Step 3: Calculation of Losses

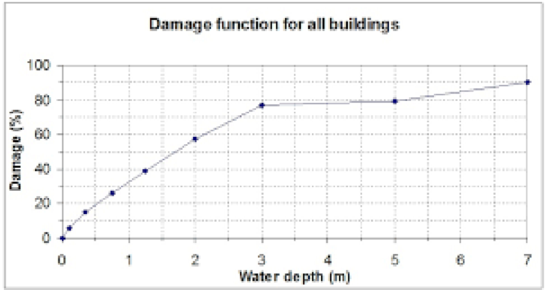
- Loss = Exposure x Physical Vulnerability x Spatial probability

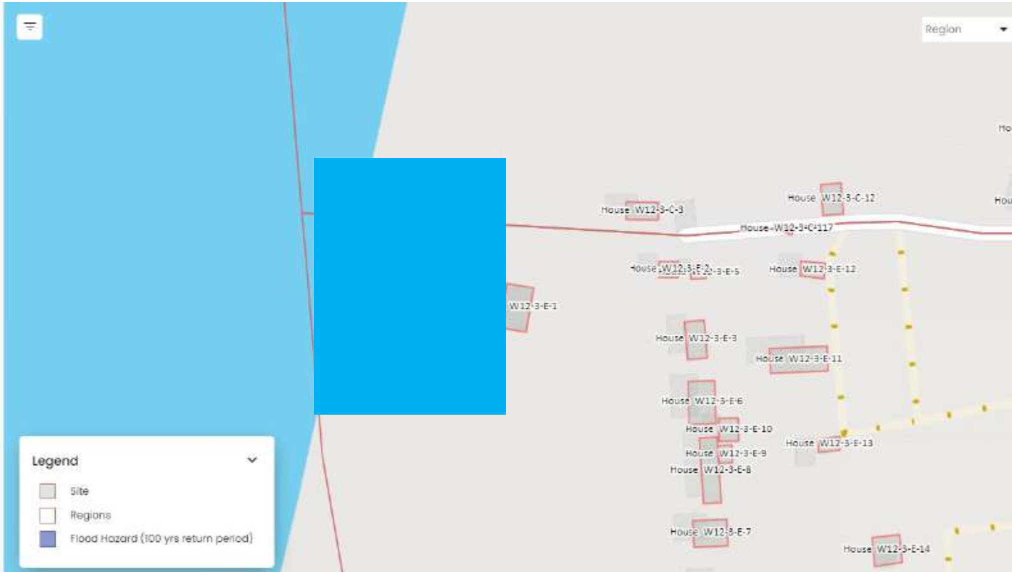


Quantitative Multi-Hazard Risk Assessment

Step 3: Calculation of Losses

- Loss = Exposure x Physical Vulnerability x Spatial probability





- By the flood depth of 3m, 75% of the building is exposed.
- Remaining 20% of building has 0% exposure,

- Depth Damage Curve for 3m, Damage % is 0.78

- So, the loss of the building W12-3-E-1 is

Loss = NPR 500000 [(75% * 0.78) + (25%*0)]
Loss = NPR 292,500

Quantitative Multi-Hazard Risk Assessment

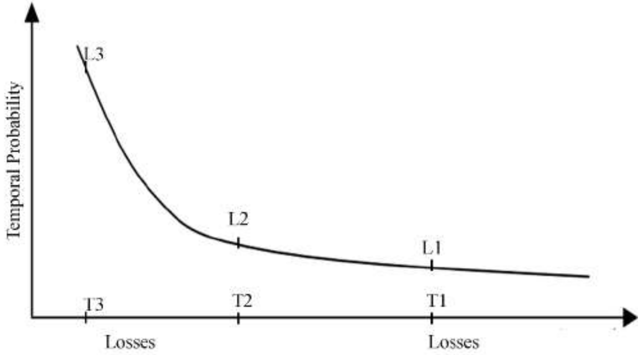
Step 4: Calculation of Losses in Administrative Units

Hazard, EAR, Administrative Units		Unit 1	Unit 2	…….
Landslide	No. of buildings damaged			
	No of people injured/killed			
	Agri. Crops destroyed (hectares)			
	Roads damaged (km)			
Forest Fire	No. of buildings damaged			
	No of people injured/killed			
	Agri. Crops destroyed (hectares)			
	Roads damaged (km)			
GLOF	No. of buildings damaged			
	No of people injured/killed			
	Agri. Crops destroyed (hectares)			
	Roads damaged (km)			
Flood	No. of buildings damaged			
	No of people injured/killed			
	Agri. Crops destroyed (hectares)			
	Roads damaged (km)			

Quantitative Multi-Hazard Risk Assessment

Step 5: Calculation of Average Annual losses in Administrative Units

Return Period (T)	Annual Probability	Losses (L)
T3 = 10 years	0.1	L3
T2 = 50 years	0.02	L2
T1 = 100 years	0.01	L1



Average Annual Losses **(AAL):** The area under the risk curve can be calculated using following formula

$$\frac{1}{T1}.L1+\left(\frac{1}{T2}-\frac{1}{T1}\right).\frac{L1+L2}{2}+\left(\frac{1}{T3}-\frac{1}{T2}\right).\frac{L2+L3}{2}+\left(\frac{1}{T4}-\frac{1}{T3}\right).\frac{L3+L4}{2}$$

Quantitative Multi-Hazard Risk Assessment

Step 6: Identifying Hazard Interaction for Multi-Hazard

Hazard Interaction	Hazard X	Hazard Y	Total Loss	Remarks
Independent Events	Loss X	Loss Y	Loss X + Loss Y	Can be summed up
Compounding Events	Loss X	Loss Y	Min (Total value, Loss X + Loss Y)	Calculation of Loss Y when A has occurred.
Coupled Events	Loss X	Loss Y	Max (Loss X, Lossy)	Calculated together
Conditional Events	Loss X	Loss Y	A* Loss X + B* Loss Y	Calculation of Y is done after A occurs

Adopted from Risk Changes & Van Westen, 2019

Thank you

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