



Risk evaluation of rainfall-triggered landslides on multiple scales of Japan

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$$\text{Landslide risk (R)} = \text{Hazard (H)} \times \text{Exposure (E)} \times \text{Vulnerability (V)}$$

Theory

$$N_F = N_L \times \frac{N_F/N_L}{N_H/N_L} \times \frac{N_H/N_L}{N_L}$$

Most fatalities occurred indoor

$$N_F/N_H \times N_H/N_L$$

N_F : Number of fatalities, N_L : Number of landslides,
 N_H : Number of collapsed houses

Features of N_F

N_L

Factors underlying N_F

Rainfall

Forest development

Hard measures

N_H/N_L

Households in landslide-prone areas

Household members

N_F/N_H

Structure of residential buildings

Soft measures (e.g., Early warning system)

Comparison of trends in N_F , features of N_F , and factors underlying N_F

Factors reducing landslide fatalities change with time

Kure City, Hiroshima Prefecture:

Features of N_F Three heavy rainfall events in 1945, 1967, and 2018

Year	Landslide type	N_F	N_L	N_H	N_F/N_L	N_F/N_H
1945	Debris flows	949	842	1.127		
	Steep-slope failures	46	44	1.045		
	Total	995	315	886	3.159	1.283
1967	Debris flows	12	14	0.857		
	Steep-slope failures	69	50	1.38		
	Total	81	1186	64	0.068	1.266
2018	Debris flows	14	14	0.08		
	Steep-slope failures	0	0	0.00		
	Total	14	517	176	0.027	0.08

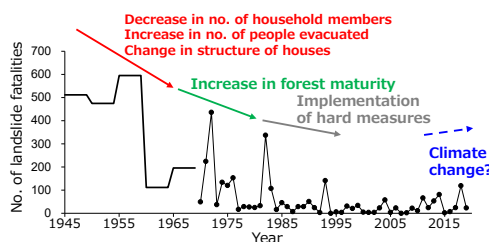
Factors underlying N_F

Factors	1945	1967	2018
Forest growing stocks (10^6 m ³)	38.6	31.9	110.3
Number of check dams	3	131	187
Number of household members	4.21	3.47	2.29
Percent of residential buildings built with non-woody materials (%)	0.3	4.7	32.9

Arrows: Large contributions on reducing fatalities

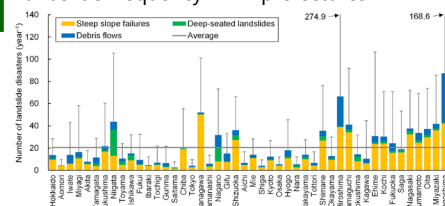
Shinohara and Shimomura (2025) Natural Hazards
<http://dx.doi.org/10.1007/s11069-024-06816-6>

Japan overall:



Shinohara and Kume (2022) Science of The Total Environment
<http://dx.doi.org/10.1016/j.scitotenv.2022.154392>

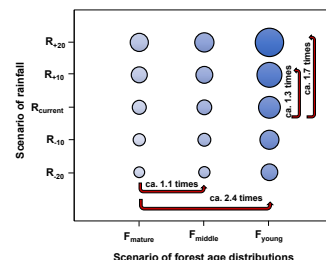
Landslide frequency in 47 prefectures



Factors affecting landslide frequency differ depending on landslide types

Steep slope failures: Rainfall, Geology, Land use
Deep-seated landslides: Rainfall, Geology
Debris flows: Rainfall, Geology

Shinohara and Watanabe (2023) Natural Hazards
<http://dx.doi.org/10.1007/s11069-024-06816-6>



Estimated number of landslides in Japan based on 15 scenarios with different rainfall and forest age structure

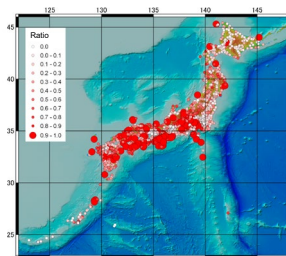
Scenarios

$R_{current}$: Current rainfall; $R_{+10\%}$: Increased by 10% or 20%; $R_{-10\%}$: Decreased by 10% or 20%
 F_{mature} : > 40 years; F_{middle} : 21–40 years; F_{young} : < 20 years forests dominated

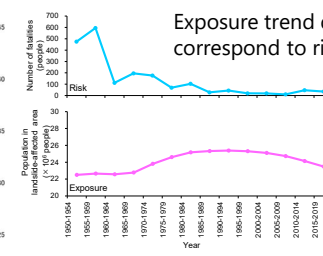
Maturity of forests have potentially larger impacts on landslide frequency than changing rainfall

Lusiana et al (2024) Natural Hazards
<https://doi.org/10.1007/s11069-024-06537-w>

Exposure



Exposure population ratio for all municipalities of Japan



Exposure trend does not correspond to risk trend

Effects of exposure on risk may be not significant at the national scale

Shinohara, submitted to Natural Hazards

Exposure population ratio:
Population exposed to landslides / Total population

Vulnerability

Floor and gender affect the possibility of death in collapsed houses by landslides

Database for landslide fatalities in collapsed houses
Floor, gender, age, landslide type, trigger, time
Period: July 2010–July 2024

All factors are available: 275 people
All factors except floor are available: 621 people

Possibility of death

First floor: 131/183 (72%)
Second floor: 18/92 (20%)

Female: 250/321 (78%)
Male: 201/300 (67%)