Strategies for exposure, vulnerability and resilience assessment: State-of-the-art and challenges

Day 1, Pillar 1: Disaster Risk Knowledge

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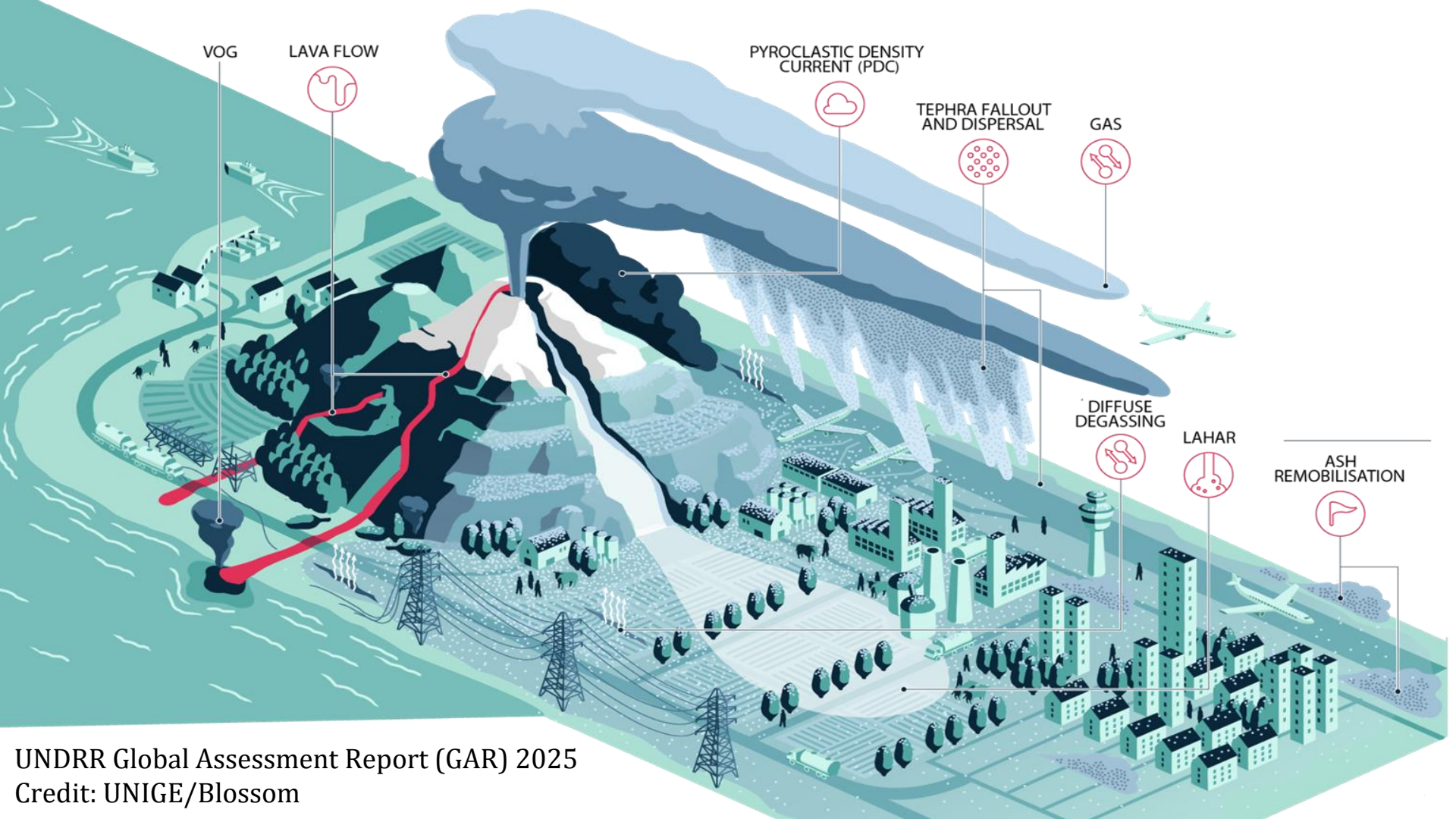
Merapi 2010 eruption, Indonesia. Buildings destroyed in Balerante, 5 km from the vent
Photo taken by village chief, surveying the damage to his village.



UNDRR Global Assessment Report (GAR) 2025
Credit: UNIGE/Blossom

Outline

- What are state-of-the-art methods to characterise **exposure**, **vulnerability** and **resilience** in volcanic contexts?

- Review associated needs, gaps, challenges and opportunities

- Overarching conclusions and future perspectives

Exposure

- **Exposure**: The spatiotemporal situation of people, man-made and natural elements potentially affected - directly or indirectly - by the occurrence of hazardous phenomena.

population characteristics

housing type

land use

critical infrastructure & essential services

Courtesy of Evelyn Mühlhofer / IDMC

Collecting exposure data

Collected data

- Census → full *enumeration* vs *sampling*
- UAVs + high res images + computer vision
- *Volunteered Geographic Information Systems*

Courtesy of PHIVOLCS/REDAS

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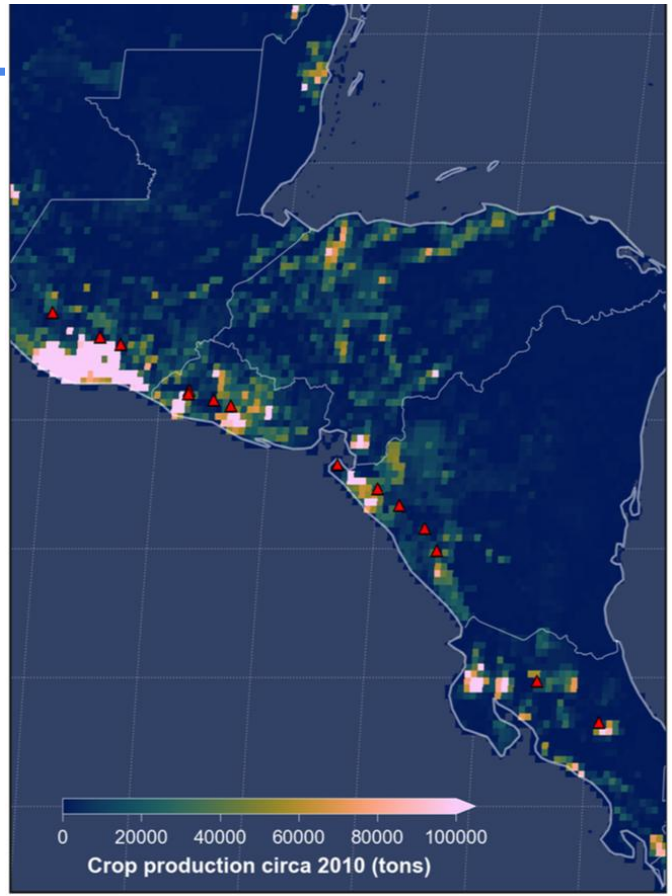
Modelled data

- Spatial disaggregation based on proxies
- Importance of geostats + ML + data availability

Crop exposure around Central America



Yu et al (2020); Lu et al (2020)

Collecting exposure data

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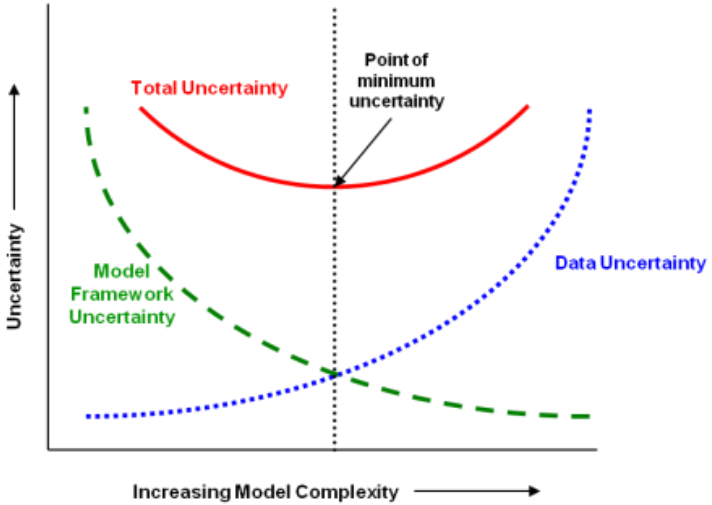
Uncertainties

- Hard to constrain (type of data, temporality)
- Stem from various sources

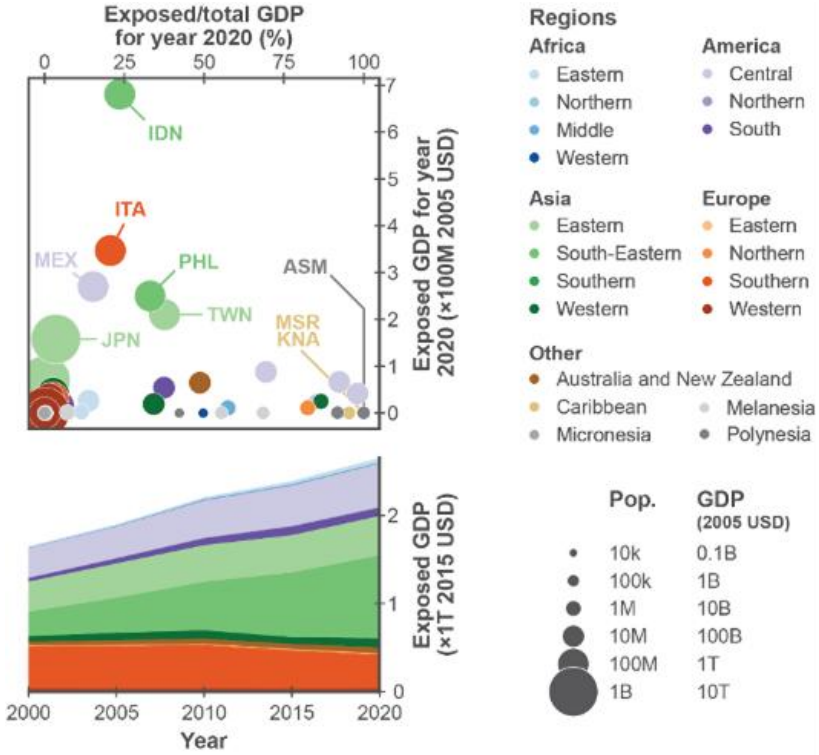


From EPA (2009)

Exposure analyses

Global/international

- Modelled data
- Help identifying global trends



Country/region GDP exposure within 100 km of a Holocene volcano

Exposure analyses

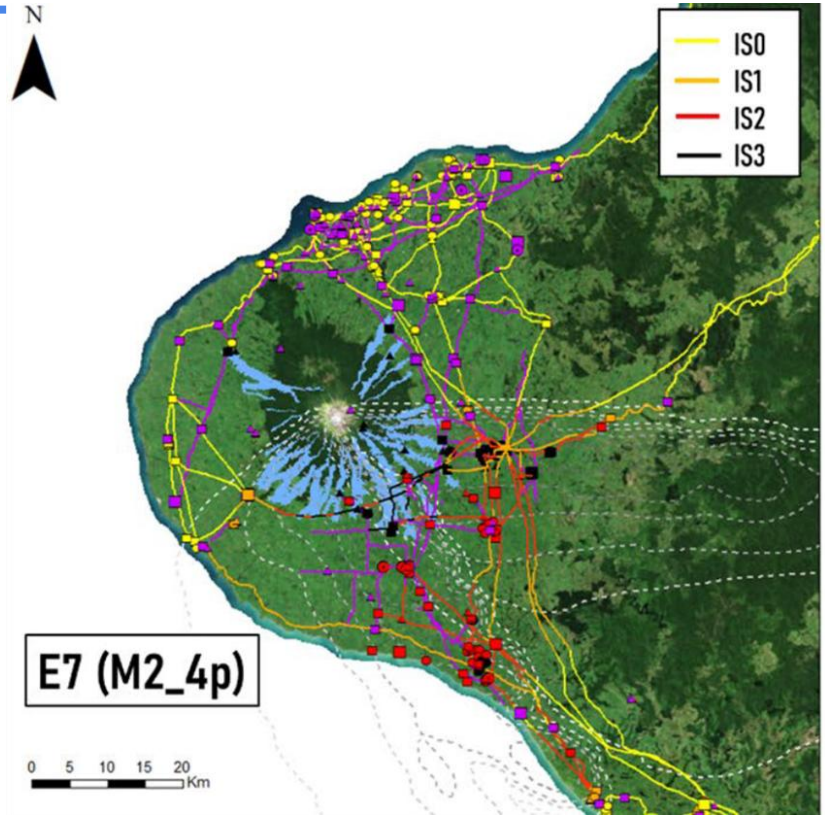
Global/international

- Modelled data
- Help identifying global trends

(Sub) National

- Modelled / collected → Philippines
- Trust with data providers → New Zealand

Direct and indirect impacts on infrastructures around Taranaki, New Zealand



Weir et al. (2024)

Exposure analyses

Global/international

- Modelled data
- Help identifying global trends

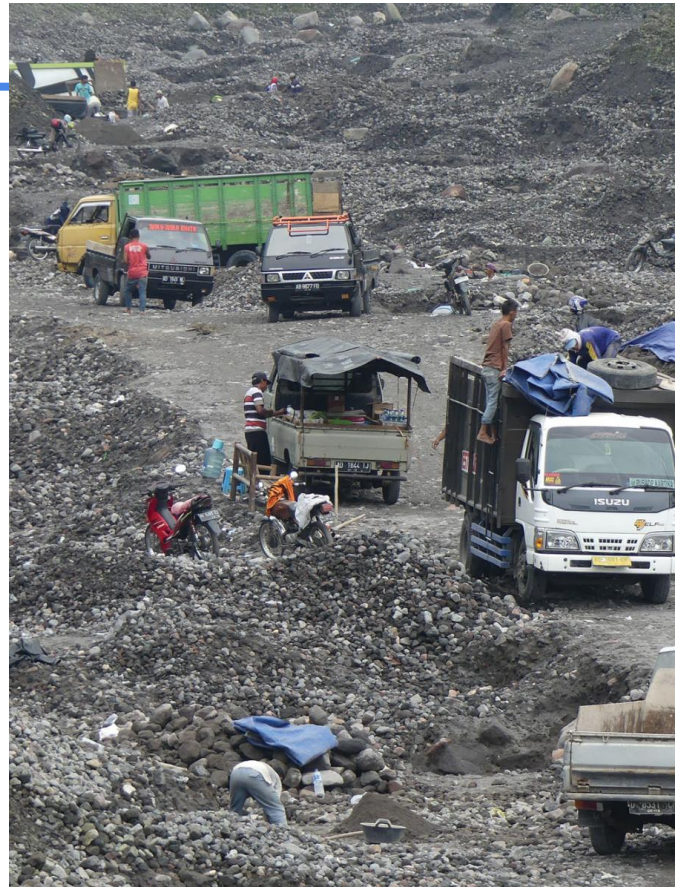
(Sub) National

- Modelled / collected → Philippines
- Trust with data providers → New Zealand

Local

- Ideally collected, often complemented with global modelled data
- Often qualitative indicators → drivers

Mining following the 2010 Merapi eruption



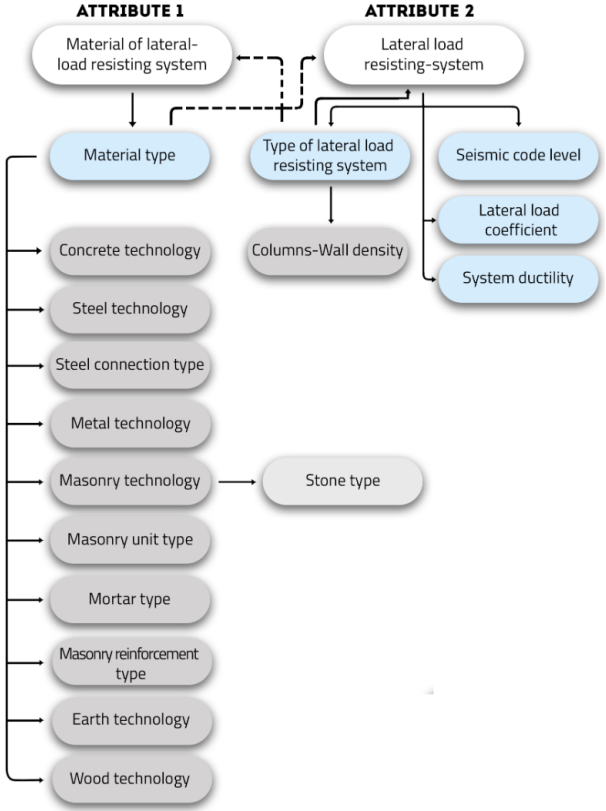
From Miller (2022)

Needs & gaps

2 out of 13 attributes of the GEM building taxonomy

Taxonomies

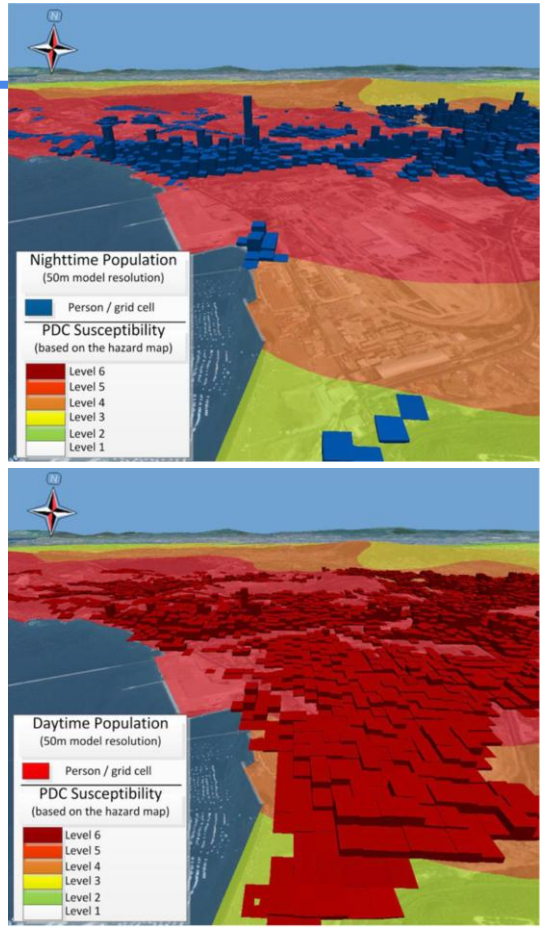
- Designs for volcanic (multi)hazards
- Alignment with vulnerability models → GEM



Yepes-Estrada et al. (2023)

Needs & gaps

Daytime vs nighttime population exposure around Vesuvius



Taxonomies

- Designs for volcanic (multi)hazards
- Alignment with vulnerability models → GEM

Temporality

- Capture dynamics of exposure
- Short and long-term displacements → IDMC

Freire et al. (2015)

Needs & gaps

Taxonomies

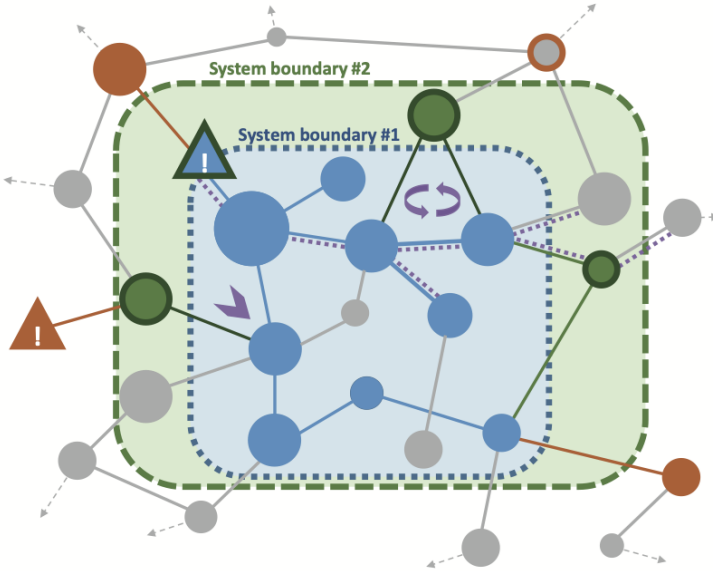
- Designs for volcanic (multi)hazards
- Alignment with vulnerability models → GEM

Temporality

- Capture dynamics of exposure
- Short and long-term displacements → IDMC

Systems (of systems) & indirect exposure

- Hard to define domains and metrics
- Largely lacking transdisciplinary expertise



GAR (2022)

Challenges & opportunities


La Palma, 2021

Challenges

- Dynamics of exposure and associated drivers
- Global data often inform data-poor environments
- Systemic / indirect / intangible

Opportunities

- Data acquisition & analysis
- Collaboration with data providers (e.g., local, big tech)

We have loads to learn from other communities!

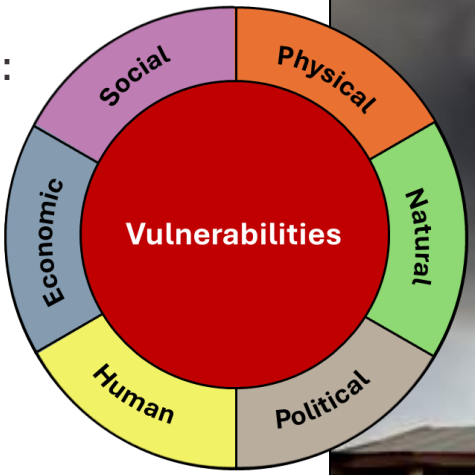
Vulnerability: Approaches

Vulnerability describes how an exposed element (e.g. person, building, crop) is impacted by a hazard.

Disasters occur when hazards affect vulnerable people.

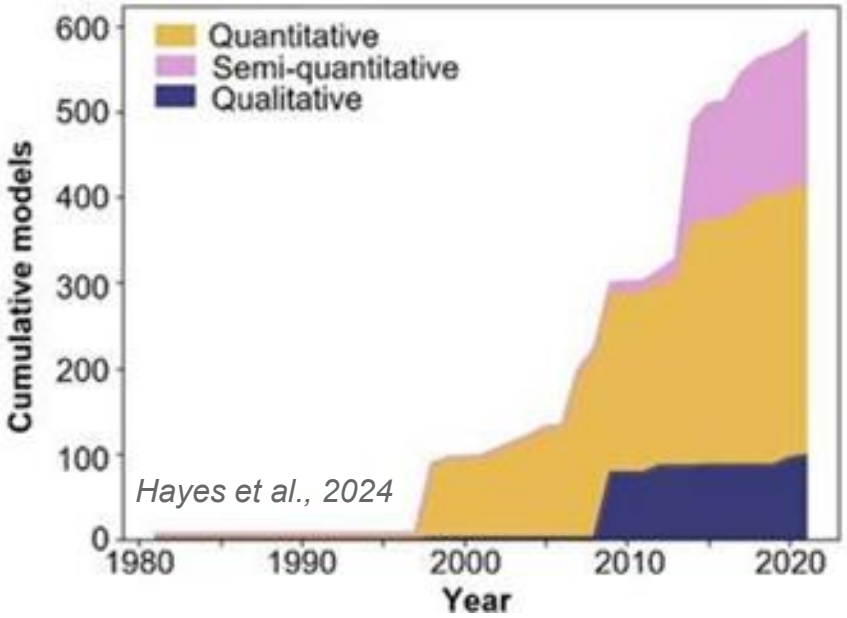
It takes **many forms**:

- Physical
- Social
- Economic
- Institutional
- Functional
- Systemic
- Environmental
- …

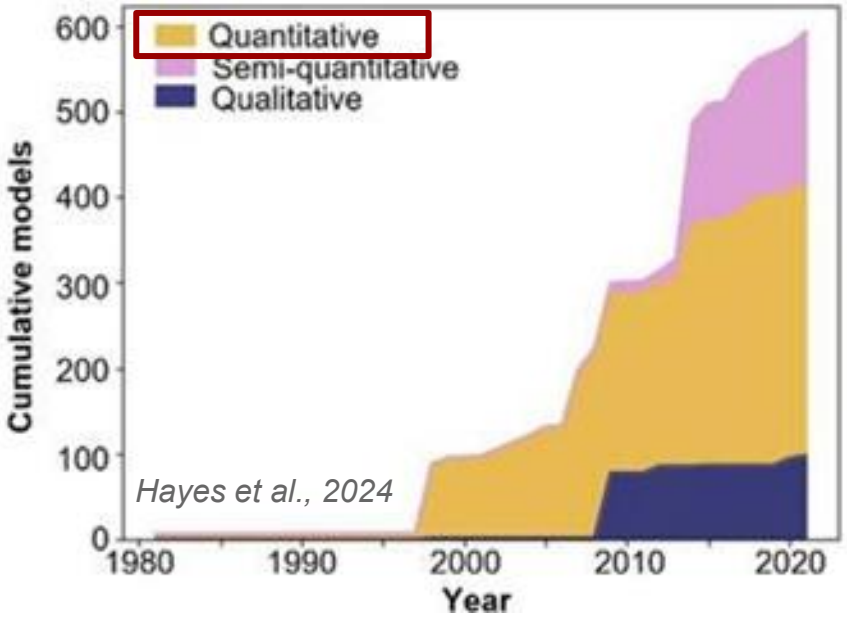


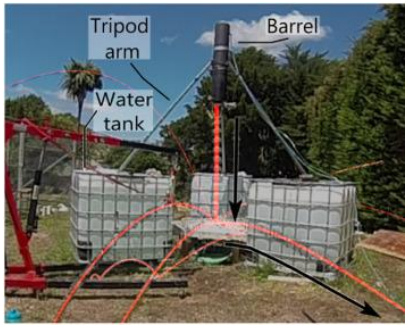
Karo district, North Sumatra during the Sinabung eruption, 2013 © Reuters

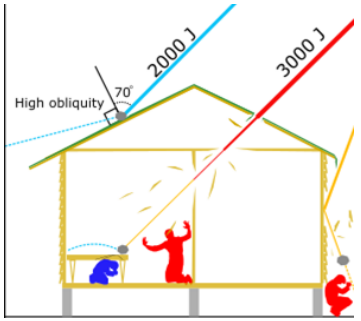
Vulnerability: Approaches

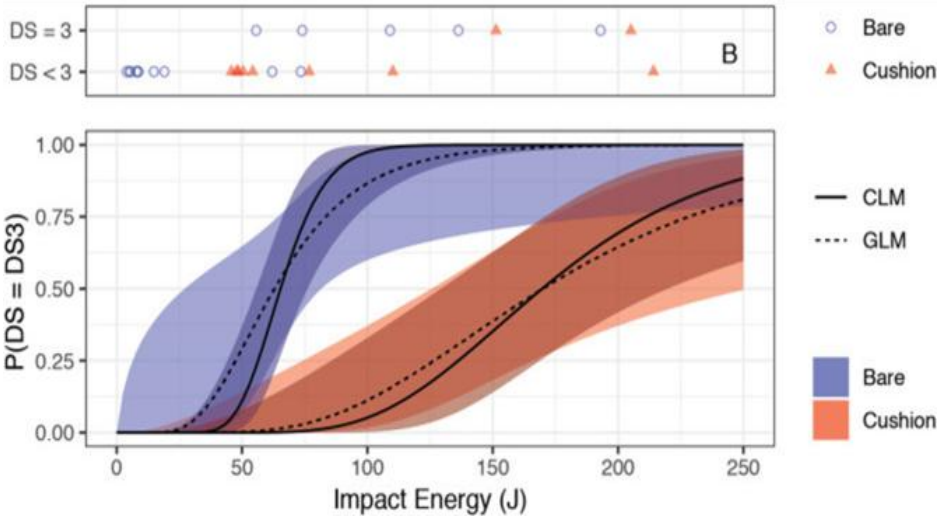


Vulnerability: Approaches





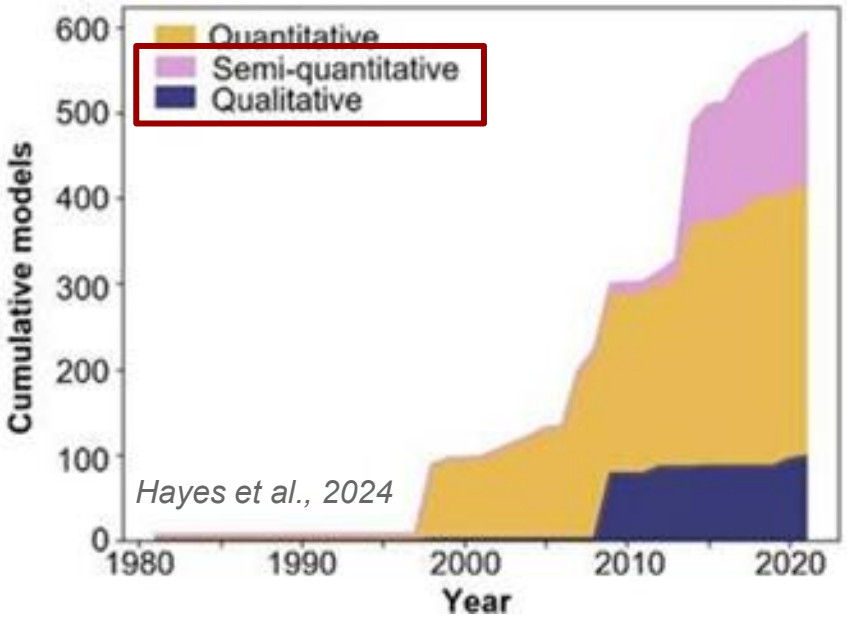


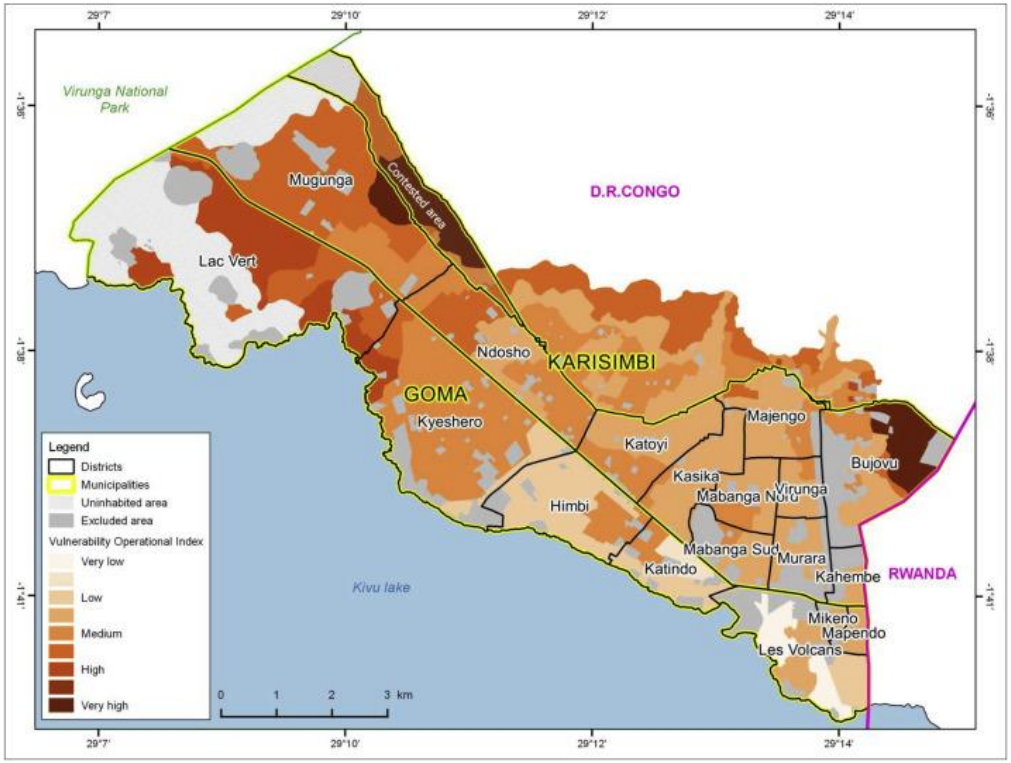


Fragility functions for ballistic projectiles to damage clay tiles (with or without tephra), based on experimental data.

Williams et al. 2019.

Vulnerability: Approaches





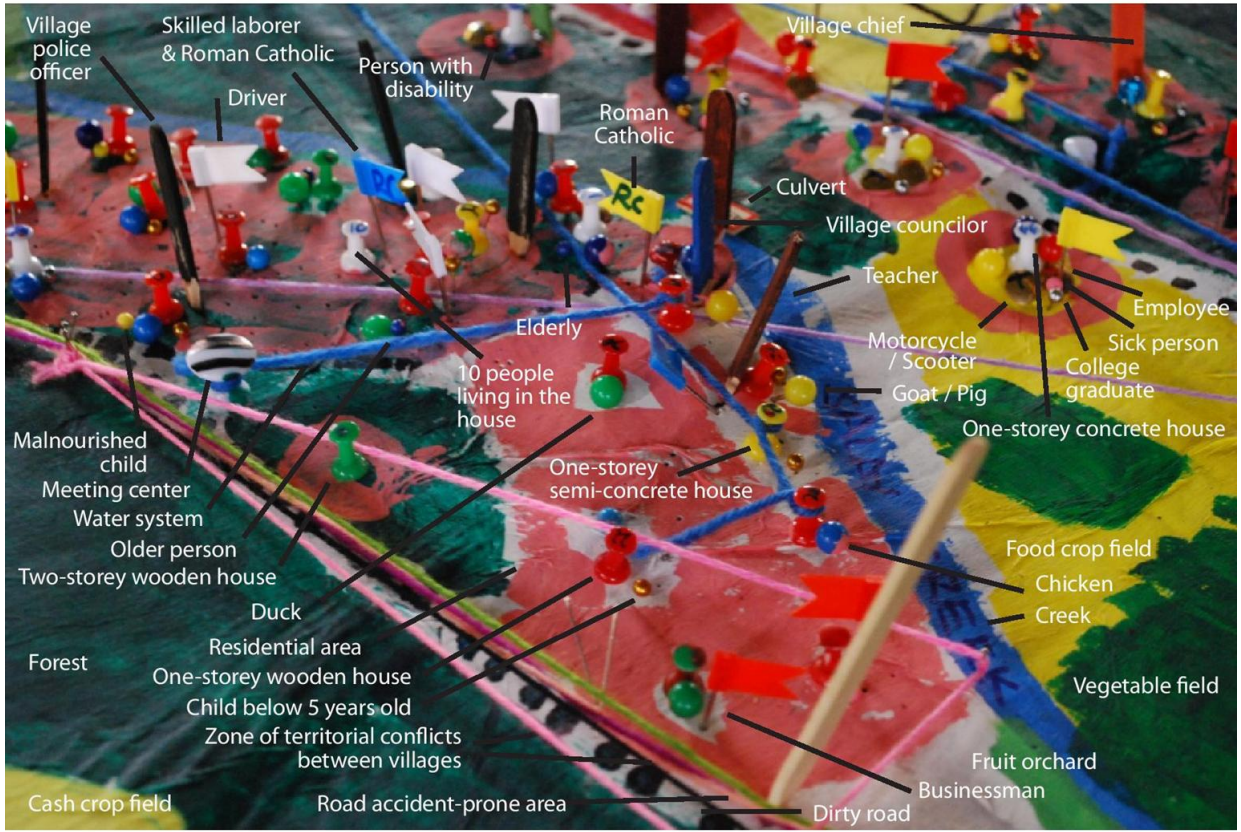
Operational Vulnerability Index for Goma, DRC. Based on economic factors, education, household resources, risk perception, and household structure.

Michellier et al., 2020

Vulnerability: Data

Three main sources:

- **Empirical**

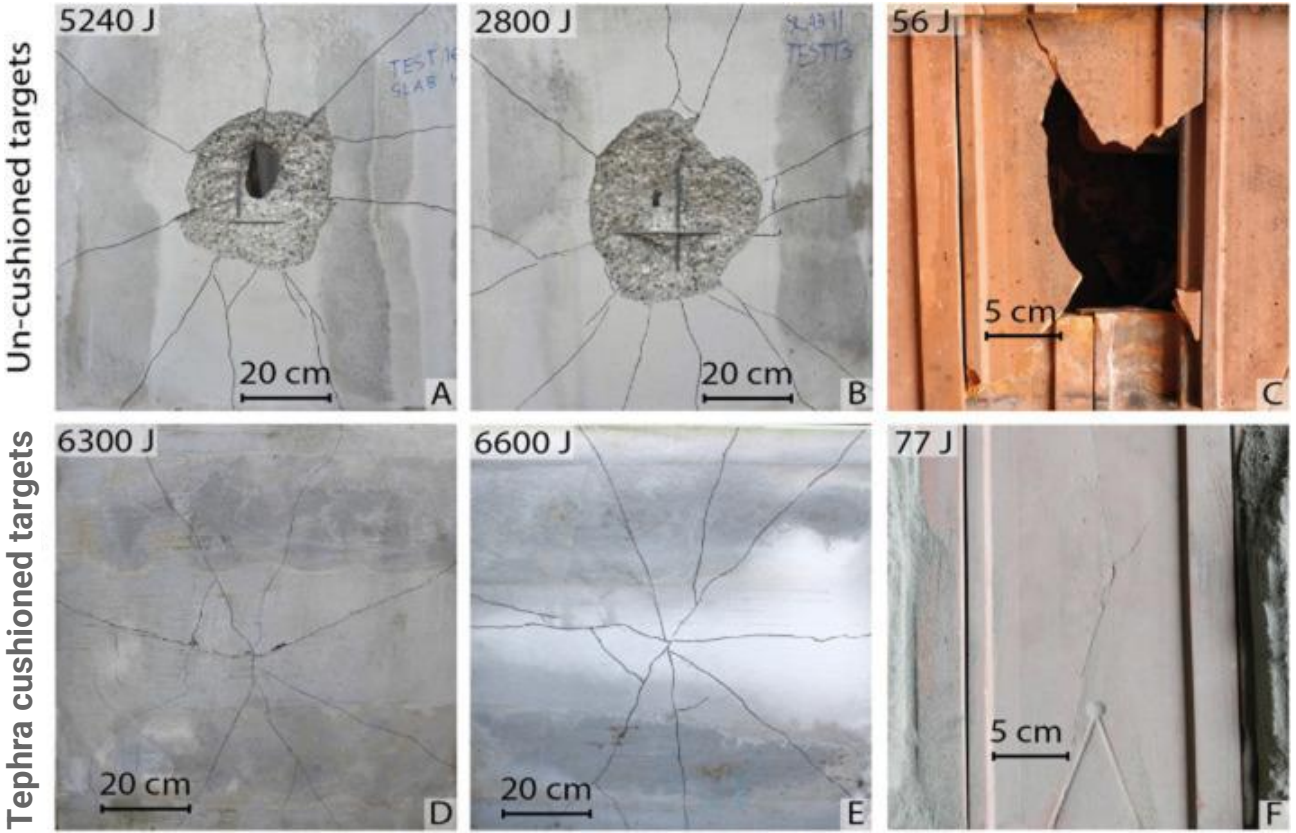


Participatory 3D mapping (Gaillard, 2010)

Vulnerability: Data

Three main sources:

- Empirical
- **Experimental**

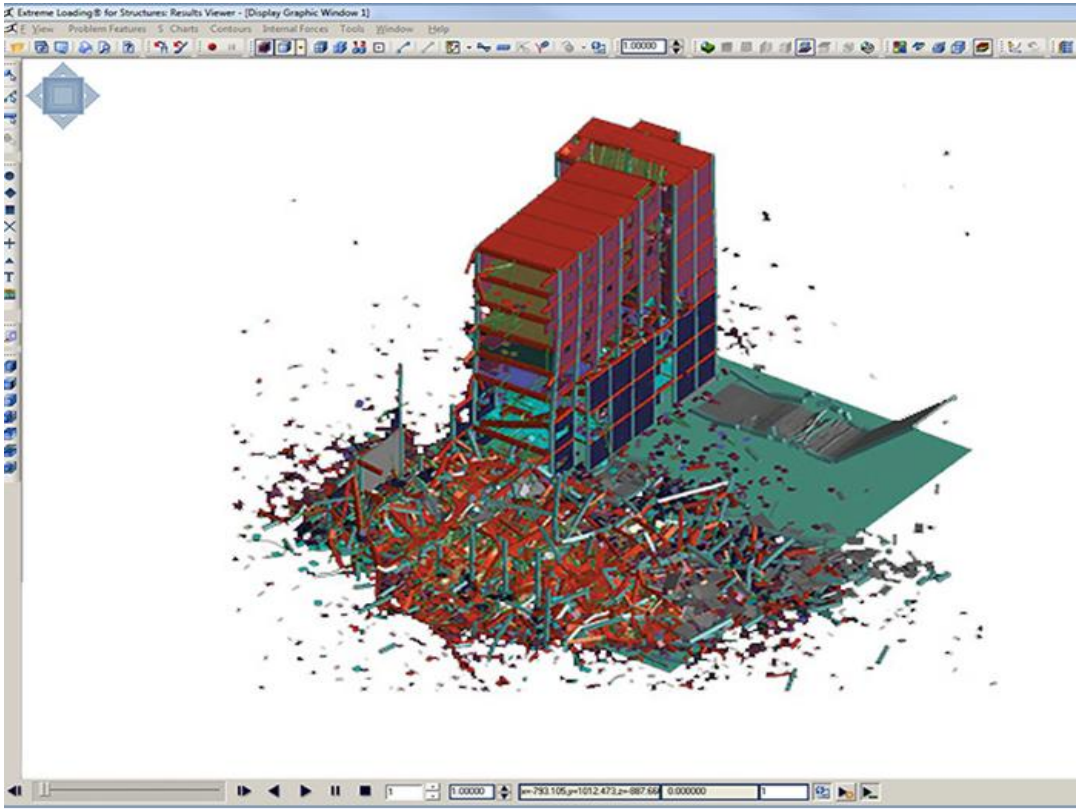


Williams et al. 2019.

Vulnerability: Data

Three main sources:

- Empirical
- Experimental
- **Theoretical**



Simulation © Extreme loading for structures

Vulnerability: Data

- Data are (sometimes) available locally.
- Globally applicable data are not.
- Extrapolation is common (to different scales, locations, exposure types).

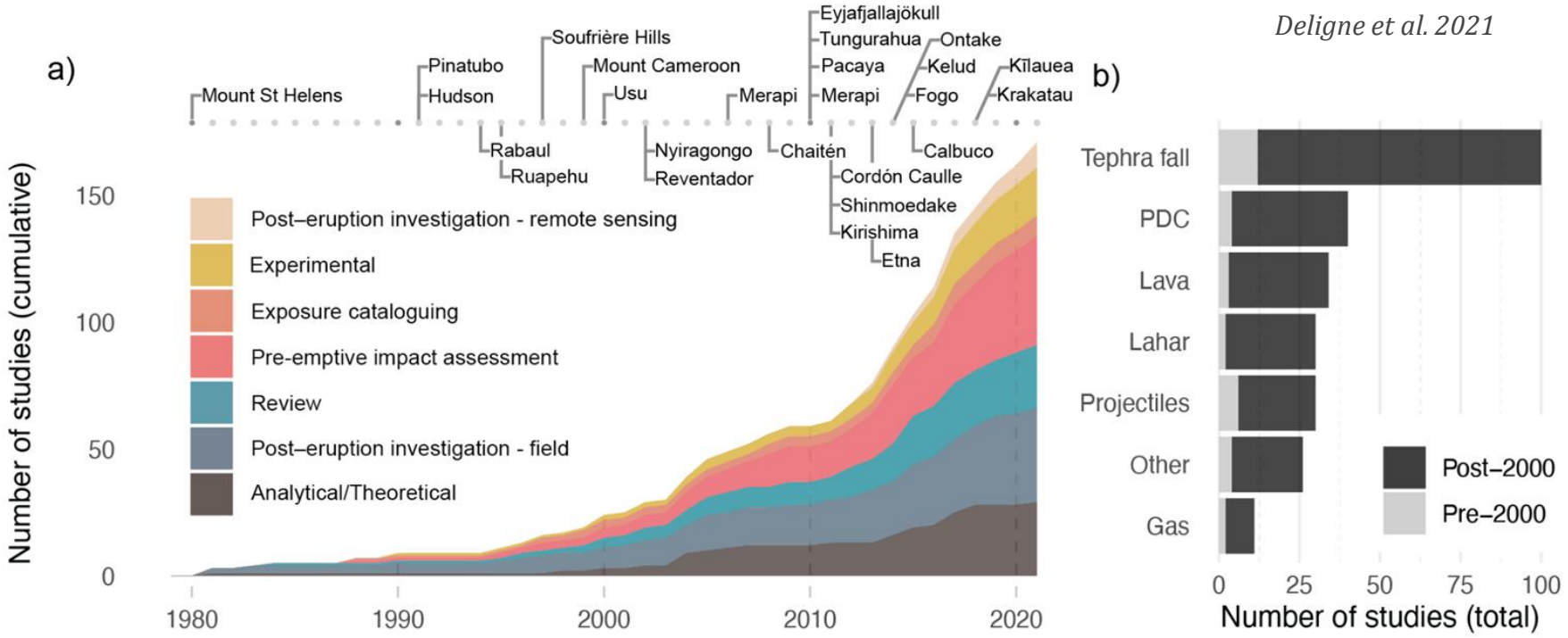
Vulnerability: Needs, gaps

Vulnerability: Needs, gaps

DATA

- Data collection requires funding, collaboration, expertise, and more eruptions.
- Systematic guidelines for collection are needed to promote data transferability.

Vulnerability: Needs, gaps

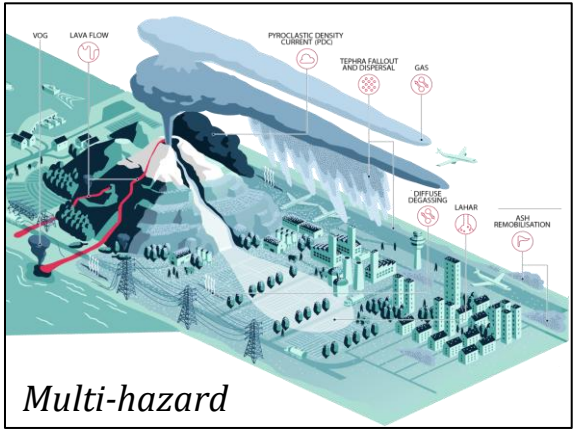


Deligne et al. 2021

Vulnerability assessments are currently based on very few data.
Volcanic impact assessment is in its infancy compared to other natural hazards.

Vulnerability: Challenges, opportunities

Challenges



Multi-hazard


Dangerous and unpredictable

1 NO POVERTY


Driven by root causes

Opportunities

Transdisciplinary collaboration

Exposure and advocacy

Early Warnings for All

Data collection opportunities

Resilience

The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management. UNDRR definition

Close relationship with capacity/coping capacity and often viewed as the inverse of vulnerability

Nature and scale of the hazard are key here- e.g.:

Getty/Fabrizio Villa

ARLAN NAEG/AFP/Getty

…and many that have not erupted in living memory, where there is little social or political awareness…

Resilience

…What does resilience to a volcanic eruption look like in practice?

Returning and rebuilding?

Relocation?

AP/Kyodo News

Clean-ups and incremental management?

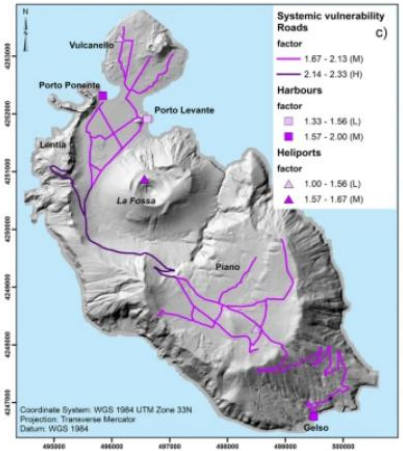
Resilience: Approaches

To date, largely qualitative or semi-quantitative and focus on identifying coping capacities, adaptive capacities, mitigation measures

- Interviews and surveys with residents, officials, scientists
- Focus groups, participatory methods
- GIS mapping to show critical links, identify redundancies (or lack thereof)
- Expert judgement

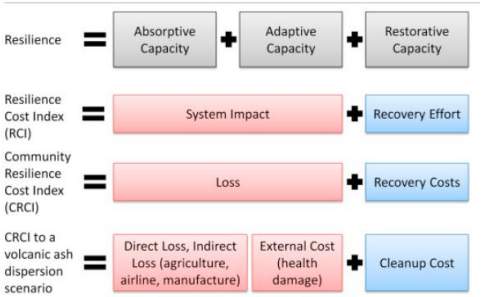
Resilience assessment in volcanology very much in its infancy with a few exceptions

Most studies focus on a single volcano/local area



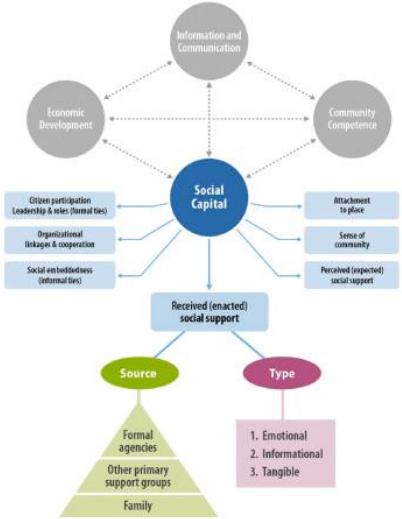
Bonadonna et al, 2021

Resilience: Approaches

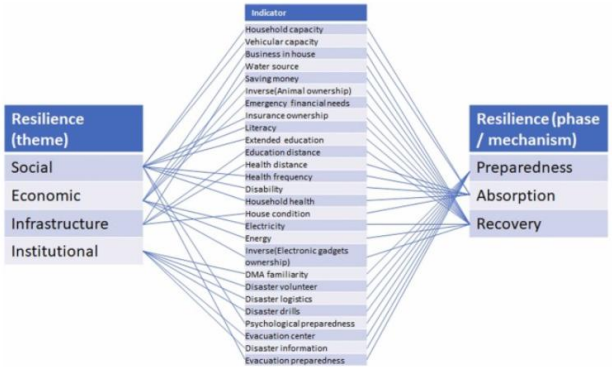


Yu, et al, 2016, Paektu/Changbaishan for RoK, scenario-based, economic resilience

Ómarsdóttir et al, 2022, Eyjafjallajökull, interview-based, community resilience



Wardekker et al, 2023, Agung, mixed methods, cultural/heritage resilience



Resilience: Data

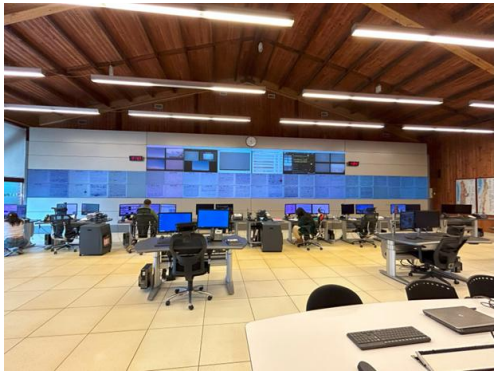
Similar to vulnerability. Useful information includes:

- Institutional capacities (esp observatories)
- Institutional connections/flows of information and trust (link to pillars 3 and 4)
- Infrastructural capacities and connections (transport links, hospitals/healthcare, construction, communications)
- Indicators of social cohesion (social network analysis, strong grassroots groups, religious groups, schools)
- Existence (or not) of evacuation plans
- Public awareness of risk and planning
- Land-use planning (e.g. zonation and development limitations) and risk-sensitive development

Resilience: Needs, gaps

Strong, well-resourced and trusted institutions

- Studies show scientists often highly trusted
- Institutions need capacity to assess resilience

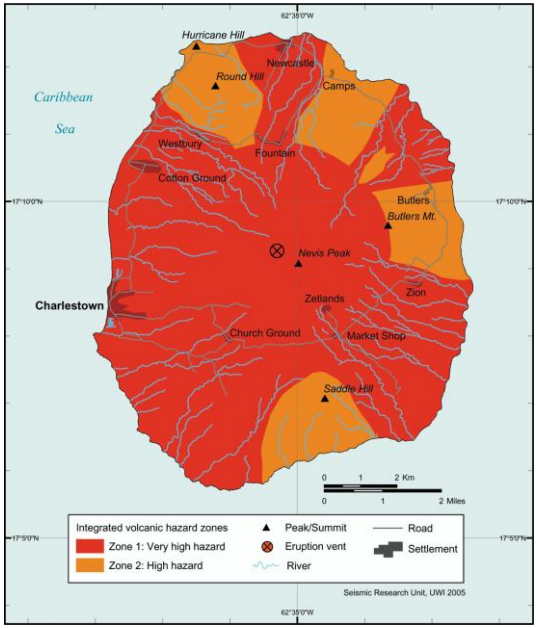


Best practices for assessments, planning, communication/dialogue with communities at risk

Data and funding to assess and build resilience, especially in developing contexts

Resilience: Challenges, opportunities

- As with other hazards, **SIDS face particular challenges** because they cannot easily absorb the cost
- Huge variation in resourcing between nations
- Very many unmonitored or poorly monitored volcanoes especially in sub-saharan Africa
- … need data to understand these gaps better and funding to plug them!
- …volcanoes need to be part of a multi-hazard, multi-risk approach



UWI, 2005

Links to pillars 3 and 4: understanding community and institutional/governmental capacities to disseminate warnings and respond

Resilience: Challenges, opportunities

- Awareness of volcanic risk is typically poor in areas without historical eruptions and among marginalised groups - but place-specific
- Many unstudied/unreached communities are living at risk - **opportunities to add volcanic resilience assessment to multi-hazard/risk assessment efforts in these areas**
- … need data to understand these gaps better and funding to plug them!
- …volcanoes need to be part of a multi-hazard, multi-risk approach

Links to pillars 3 and 4: understanding community and institutional/governmental capacities to disseminate warnings and

What do we need?

As a minimum for exposure, vulnerability, resilience assessment?

DATA (and funding)

That is as high spatial and temporal resolution as possible.

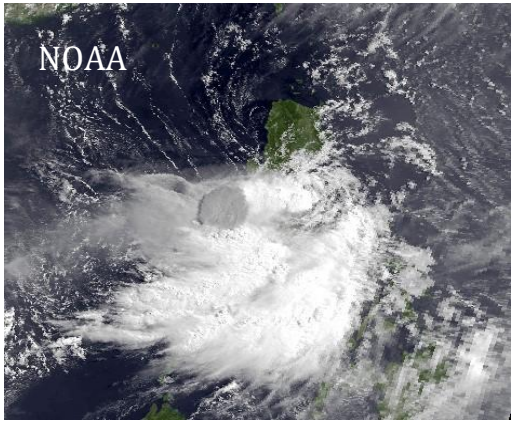
We are getting close to a minimum capabilities for direct ± physical impacts, but these remain associated with important modelling assumptions and large uncertainties due to limited data..

Methods for social/systemic assessments are in their infancy, and their final form remains unclear.

What next?

Where are the opportunities?

- Synergies within IAVCEI to advance interdisciplinary academic research and operational links
- Opportunity to link with institutions (UN, NGOs)
- Integrate the broader multi-hazard perspective (specificities of eruptions → we have a lot to learn from other hazards, but some things we can contribute too)
- Resourcing for community engagement
- Bottom line:
    - We need eruptions to improve DRR
    - We need DRR to reduce eruption impacts



Take aways

1. **DATA** - we need it! Our uncertainties are LARGE.

2. Need to **promote volcanic hazard within wider multi-hazard community**
3. **Collaboration** is required to access data and for **equitable capacity building.**
4. **Volcano observatories need to be adequately resourced** for monitoring and engagement, both through funding and collaboration.

Strategies for exposure, vulnerability and resilience assessment: State-of-the-art and challenges

Day 1, Pillar 1: Disaster Risk Knowledge

Thank you

Merapi 2010 eruption, Indonesia. Buildings destroyed in Balerante, 5 km from the vent
Photo taken by village chief, surveying the damage to his village.