Tomorrow's CITIES
Urban Risk in Transition

Multi-hazard interactions to inform disaster risk reduction in Istanbul

EGU General Assembly 2021

Ekbal Hussain[1*], Eser Cakti[2], Bruce Malamud[3], Aslihan Yolcu[2], Joel Gill[1], Robert Trogrlic[3]

1. British Geological Survey, UK
2. Kandilli Observatory, Turkey
3. Kings College London, UK
* ekhuss@bgs.ac.uk

TomorrowsIstanbul.org @UrbanRiskHub

BGS British Geological Survey

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GCRF Global Challenges Research Fund

Overview

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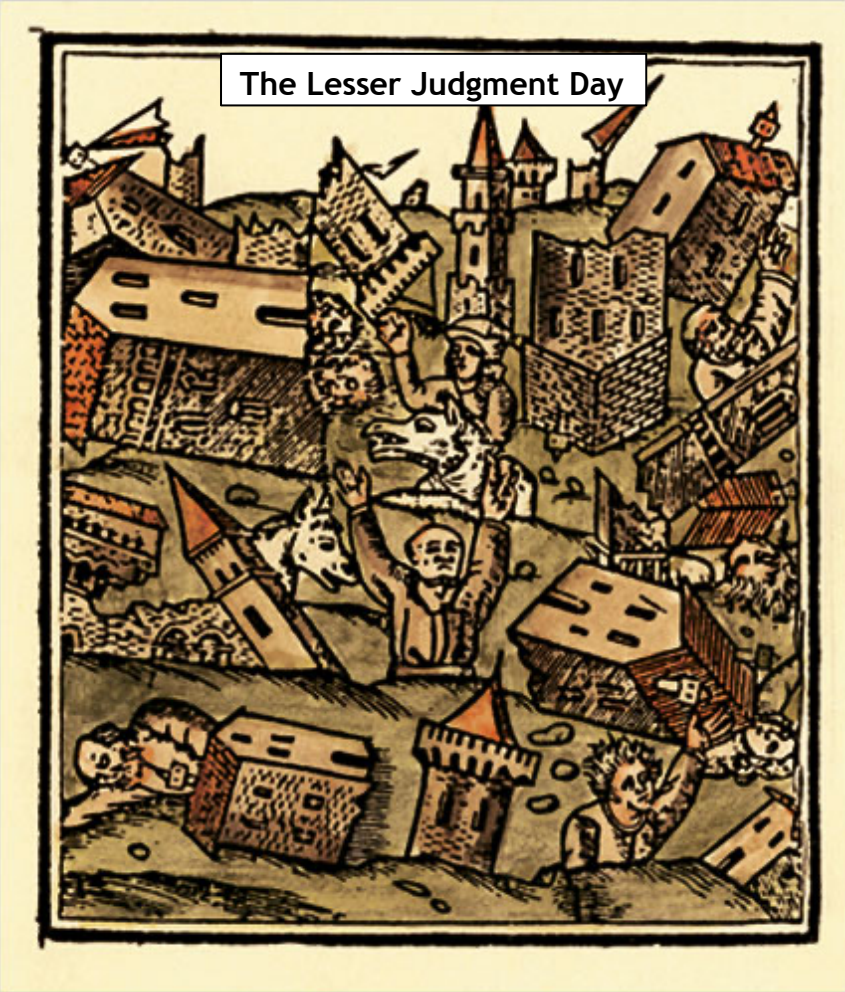


Ambraseys and Finkel. 'The Marmara Sea Earthquake of 1509'

A. Aims and Objectives

Main aim: To better understand the **natural hazard landscape** of Istanbul and the **interrelationships** between these hazards.

- **Objective 1.** To produce a **coarse overview** of the natural hazards that have occurred or have the potential to occur in or near Istanbul. Collecting evidence from peer reviewed and grey literature as well as social media.
- **Objective 2.** To collect evidence of **hazard interrelationships** and build a **hazard interaction matrix.**
- **Objective 3.** Develop multi-hazard **scenarios** to explore **dynamic risk.**

B. Data Sources

The overview of single natural hazards and hazard interactions are based on evidence collected from:

- **Peer-reviewed** literature (where possible we used review papers)
- **Grey** literature (Government/NGO reports, research grant reports)
- National/International hazard **databases** (AFAD, EM-DAT)
- **Media/news** reports
- **Social media** (YouTube)

AFAD MINISTRY OF INTERIOR DISASTER AND EMERGENCY MANAGEMENT PRESIDENCY

4th International Conference on Earthquake Geotechnical Engineering
June 25-28, 2007
Paper No. 1354

Reviews of Geophysics
REVIEW ARTICLE
10.1002/2013RG000445
Reviewing and visualizing the interactions of natural hazards

IPC-MERCATOR POLICY BRIEF
DROUGHT IN TURKEY
Levent Kurnaz

Hürriyet DAILY NEWS
LEADING NEWS SOURCE FOR TURKEY AND THE REGION

Centre for Research on the Epidemiology of Disasters CRED

STORMS AND METEOROLOGICAL PARAMETERS AFFECTING THE AVIATION
Ph.D. THESIS
Emrah Tuncay ÖZDEMİR

Analysis of Secular Ground Motions in Istanbul from a Long-Term InSAR Time-Series (1992–2017)
by Gokhan Aslan [1,2,*], Ziyadin Cakır [3], Semih Ergintav [4], Cécile Lasserre [1,5] and François Renard [1,6]

Examples of data sources used to collect evidence for natural hazard occurrence and their interactions

C. Coarse overview of single natural hazards in Istanbul

Natural hazard classification:

- **5** main hazard groups
- **23** natural hazards
- Some natural hazards consist of numerous **component hazards**

For example: **Earthquake** includes **Ground shaking** and **Liquefaction**

(Click on each Hazard Group to see the definition of the Hazards)

Adapted from Gill and Malamud (2014) *Rev. of Geophys.*

HAZARD GROUP	HAZARD	COMPONENT HAZARDS
GEOPHYSICAL	Earthquake	Ground Shaking and Rupture; Liquefaction; Co-Seismic Subsidence; Co-Seismic Uplift
	Tsunami	Marine Tsunami; Freshwater Tsunami
	Volcanic Activity or Eruption	Volcanic Explosions; Volcanic Ash or Tephra Ejection; Volcanic Gas or Aerosol Emission; Pyroclastic Density Current; Lava flow; (for Lahar - see Landslide)
	Landslide	Submarine Landslide; Subaerial Rockfall; Subaerial Rotational/Translational Landslide; Subaerial Debris Flow; Lahar
	Snow Avalanche	
HYDROLOGICAL	Flood	Pluvial Flood (incl. flash floods, urban ponding); Fluvial Flood; Groundwater Flood; Coastal Flood (incl. storm surge)
	Seiche	
	Drought	Meteorological Drought; Agricultural Drought; Hydrological Drought
SHALLOW EARTH PROCESSES	Regional Subsidence	Tectonic Subsidence
	Ground Collapse	Karst/Evaporite Collapse (sinkhole); Piping Collapse; Metastable Soils
	Soil (Local) Subsidence	Soil Shrinkage; Consolidation or Settlement
	Ground Heave	Tectonic Uplift; Soil Expansion (Swelling)
ATMOSPHERIC	Storm	Heavy rain; strong winds; Tropical Cyclone, Hurricane; Typhoon; Mid-Latitude Storm; Windstorms; Dust storms
	Fog	
	Tornado	
	Hail	
	Snow	Snowstorm; Blizzard
	Lightning	
	Extreme Temperature (Hot)	Heat Wave; Climatic Change
	Extreme Temperature (Cold)	Cold Wave; Frost; Climatic Change
BIOPHYSICAL	Wildfire	
SPACE	Space Weather	Geomagnetic Storm
	Impact Event	Asteroid; Meteorite

HAZARD GROUP	HAZARD	CODE	ISTANBUL?
GEOPHYSICAL	Earthquake	EQ	Y
	Tsunami	TS	Y
	Volcanic Activity or Eruption	VO	Y
	Landslide	LA	Y
	Snow Avalanche	AV	N
HYDROLOGICAL	Flood	FL	Y
	Seiche	SE	Y
	Drought	DR	Y
SHALLOW EARTH PROCESSES	Regional Subsidence	RS	Y
	Ground Collapse	GC	Y
	Soil (Local) Subsidence	SS	Y
	Ground Heave	GH	Y
ATMOSPHERIC	Storm	ST	Y
	Fog	FO	Y
	Tornado	TO	Y
	Hail	HA	Y
	Snow	SN	Y
	Lightning	LN	Y
	Extreme Temperature (Hot)	ET (H)	Y
	Extreme Temperature (Cold)	ET (C)	Y
BIOPHYSICAL	Wildfire	WF	Y
SPACE	Space Weather	SW	Y
	Impact Event	IM	Y

Y Potential for hazard to occur in Istanbul

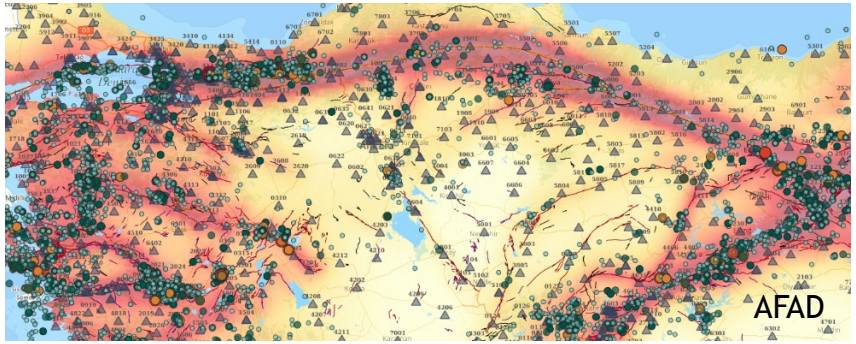
N No evidence for hazard occurrence in Istanbul

C. Overview of single natural hazards in Istanbul

Of the 23 natural hazards in our hazard classification, we found **evidence for 22** of these to have the potential to occur in Istanbul.

Examples of evidence:

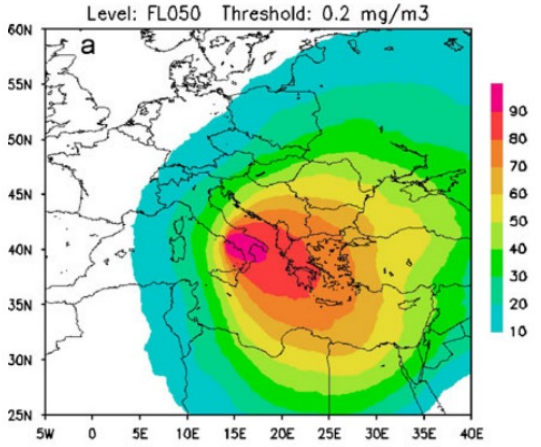
Geophysical Hazards



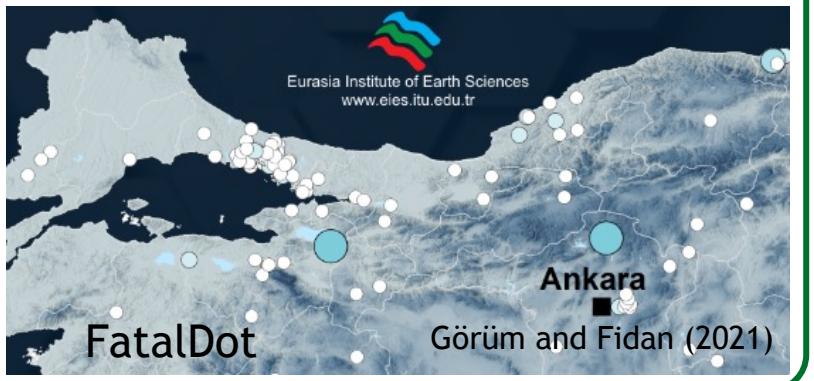
Seismic hazard map of Turkey showing high hazard near Istanbul.

Large volcanic eruptions in the Mediterranean (e.g. Vesuvius) can result in **ash dispersal** as far as Istanbul.

Sulpizio *et al.* (2012)



Database of **fatal landslides** in Turkey Shows a cluster of fatalities in Istanbul.



HAZARD GROUP	HAZARD	CODE	ISTANBUL?
GEOPHYSICAL	Earthquake	EQ	Y
	Tsunami	TS	Y
	Volcanic Activity or Eruption	VO	Y
	Landslide	LA	Y
	Snow Avalanche	AV	N
HYDROLOGICAL	Flood	FL	Y
	Seiche	SE	Y
	Drought	DR	Y
SHALLOW EARTH PROCESSES	Regional Subsidence	RS	Y
	Ground Collapse	GC	Y
	Soil (Local) Subsidence	SS	Y
	Ground Heave	GH	Y
ATMOSPHERIC	Storm	ST	Y
	Fog	FO	Y
	Tornado	TO	Y
	Hail	HA	Y
	Snow	SN	Y
	Lightning	LN	Y
	Extreme Temperature (Hot)	ET (H)	Y
	Extreme Temperature (Cold)	ET (C)	Y
BIOPHYSICAL	Wildfire	WF	Y
SPACE	Space Weather	SW	Y
	Impact Event	IM	Y

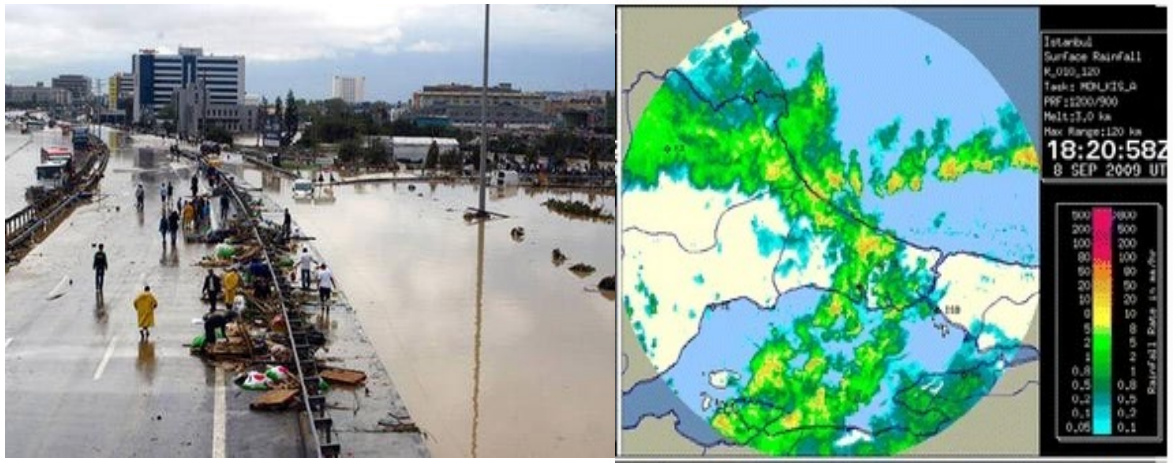
Y Potential for hazard to occur in Istanbul

N No evidence for hazard occurrence in Istanbul

C. Overview of single natural hazards in Istanbul

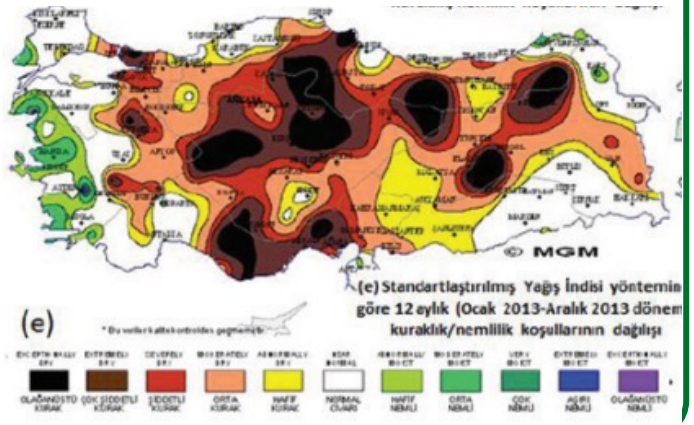
Examples of evidence:

Hydrological Hazards



Floods are a common hazard in Turkey. Record rainfall across the Marmara region in 2009 resulted in **flash floods** causing 32 deaths in Istanbul.

Kömüşacü *et al.* (2013)



Detailed review of **droughts** in Turkey and impacts on water supply to Istanbul in a policy brief by Kurnaz (2014).

"2007-2008 **meteorological drought** led to **agricultural**, **hydrological**, and **socioeconomic droughts**."

HAZARD GROUP	HAZARD	CODE	ISTANBUL?
GEOPHYSICAL	Earthquake	EQ	Y
	Tsunami	TS	Y
	Volcanic Activity or Eruption	VO	Y
	Landslide	LA	Y
	Snow Avalanche	AV	N
HYDROLOGICAL	Flood	FL	Y
	Seiche	SE	Y
	Drought	DR	Y
SHALLOW EARTH PROCESSES	Regional Subsidence	RS	Y
	Ground Collapse	GC	Y
	Soil (Local) Subsidence	SS	Y
	Ground Heave	GH	Y
ATMOSPHERIC	Storm	ST	Y
	Fog	FO	Y
	Tornado	TO	Y
	Hail	HA	Y
	Snow	SN	Y
	Lightning	LN	Y
	Extreme Temperature (Hot)	ET (H)	Y
	Extreme Temperature (Cold)	ET (C)	Y
BIOPHYSICAL	Wildfire	WF	Y
SPACE	Space Weather	SW	Y
	Impact Event	IM	Y

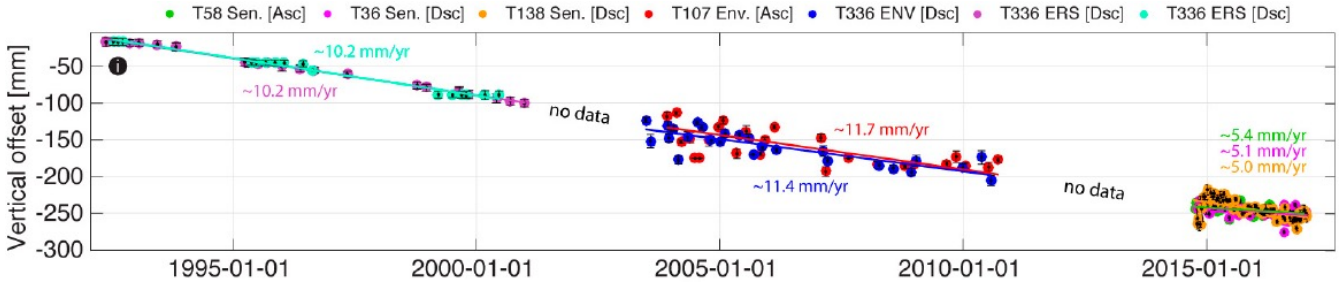
Y Potential for hazard to occur in Istanbul

N No evidence for hazard occurrence in Istanbul

C. Overview of single natural hazards in Istanbul

Examples of evidence:

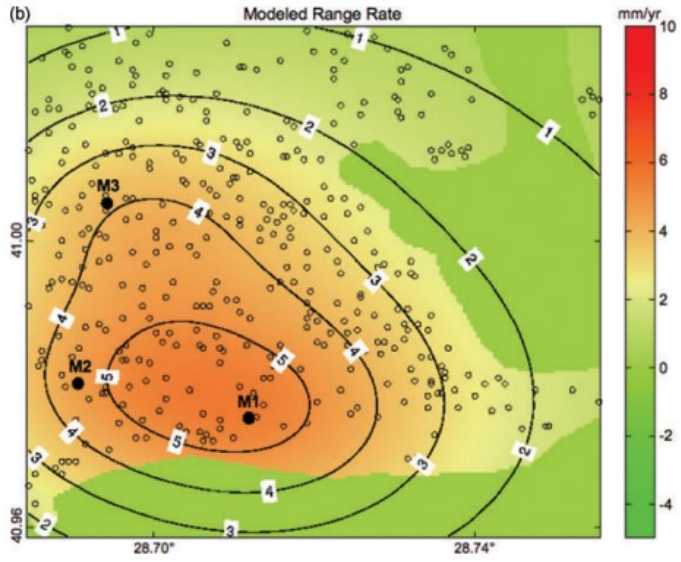
Shallow Earth Processes



Aslan *et al.* (2018)

Reclaimed lands along the coast of Istanbul underwent **subsidence** of up to **8±1.3 mm/year** between 1992-2017.

Maximum **subsidence** rate of 6 mm/year in Avcilar district measured between 1992-1999 with satellite observations. This area was **damaged** by the 1999 **earthquake**.



Akarvardar *et al.* (2009)

HAZARD GROUP	HAZARD	CODE	ISTANBUL?
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	Volcanic Activity or Eruption	VO	Y
	Landslide	LA	Y
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HYDROLOGICAL	Flood	FL	Y
	Seiche	SE	Y
	Drought	DR	Y
SHALLOW EARTH PROCESSES	Regional Subsidence	RS	Y
	Ground Collapse	GC	Y
	Soil (Local) Subsidence	SS	Y
	Ground Heave	GH	Y
ATMOSPHERIC	Storm	ST	Y
	Fog	FO	Y
	Tornado	TO	Y
	Hail	HA	Y
	Snow	SN	Y
	Lightning	LN	Y
	Extreme Temperature (Hot)	ET (H)	Y
	Extreme Temperature (Cold)	ET (C)	Y
BIOPHYSICAL	Wildfire	WF	Y
SPACE	Space Weather	SW	Y
	Impact Event	IM	Y

Y Potential for hazard to occur in Istanbul

N No evidence for hazard occurrence in Istanbul

C. Overview of single natural hazards in Istanbul

Examples of evidence:

A **hailstorm** in 2017 produced 'golf ball' size hail. (NBC News, YouTube)

Atmospheric Hazards

A review of **shipping accidents** in the Istanbul Straits between 2001-2008 found that most of the 170 recorded events occurred due to **reduced visibility** due **to fog, snow** or **heavy rain**.

Bayar *et al.* (2017)

D. Hazard interrelationships in Istanbul

Hazard interrelationship: **Primary** hazard directly **triggers** or **changes the probability of occurrence** of a **secondary** hazard.

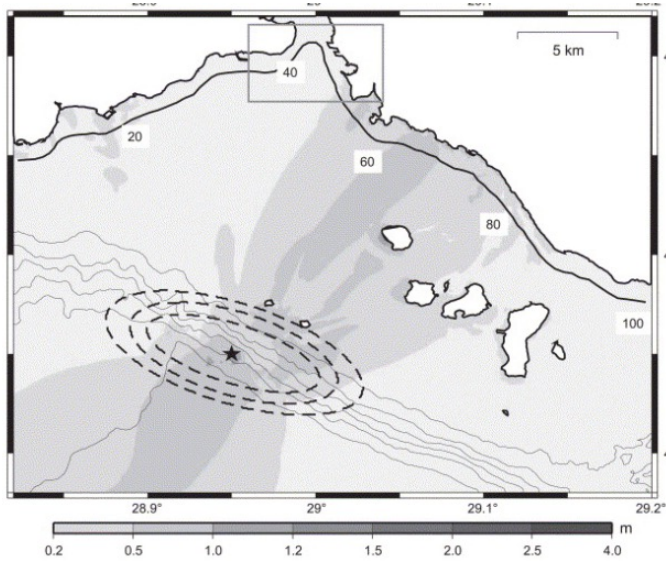
For example: An earthquake can directly ***trigger*** landslides

We also know that after a big earthquake the ***probability*** of a landslide happening in the near future **increases**, e.g. Marc et al., 2015.

We collected evidence of these relationships for the hazards identified for Istanbul.

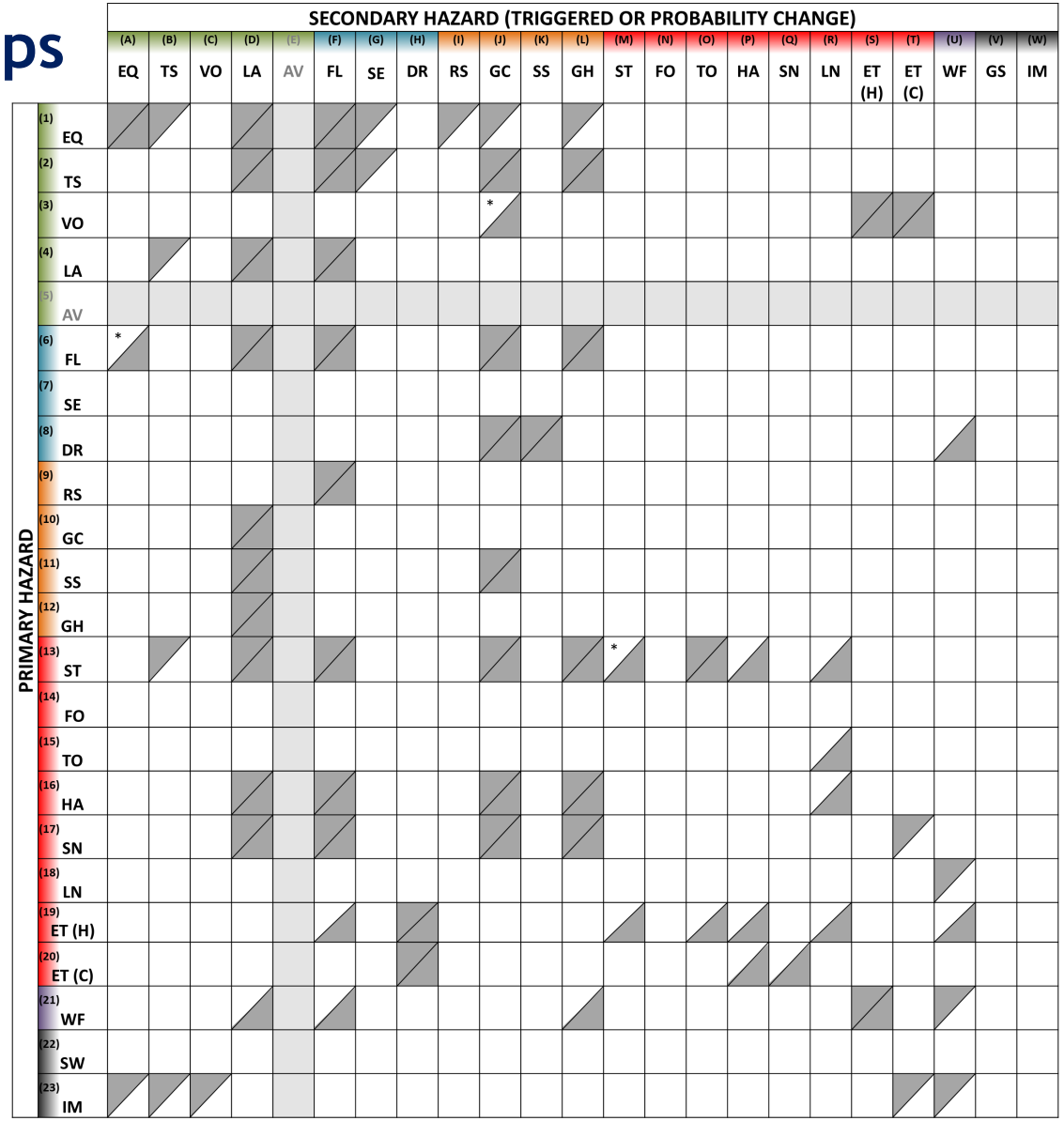
E.g. A modelling study of the tsunami hazard in Istanbul showed that landslide triggered tsunamis have the potential to cause more damage to the city than those produced by an earthquake.

Hébert *et al.* (2005)



D. Hazard interrelationships in Istanbul

- **25 examples of hazard interactions** found in Istanbul
- Supplement with the global hazard interactions of Gill and Malamud (2014)
- In total **73 potential hazard interactions** relevant to Istanbul



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BIOPHYSICAL	Wildfire	WF
SPACE	Space Weather	SW
	Impact Event	IM

SYMBOL	EXPLANATION
	Hazard Triggers Secondary Hazard
	Hazard Changes the Probability of Secondary Hazard occurrence
	Hazard Both Triggers and Changes the Probability of Secondary Hazard occurrence
	No evidence of hazard occurrence in Istanbul

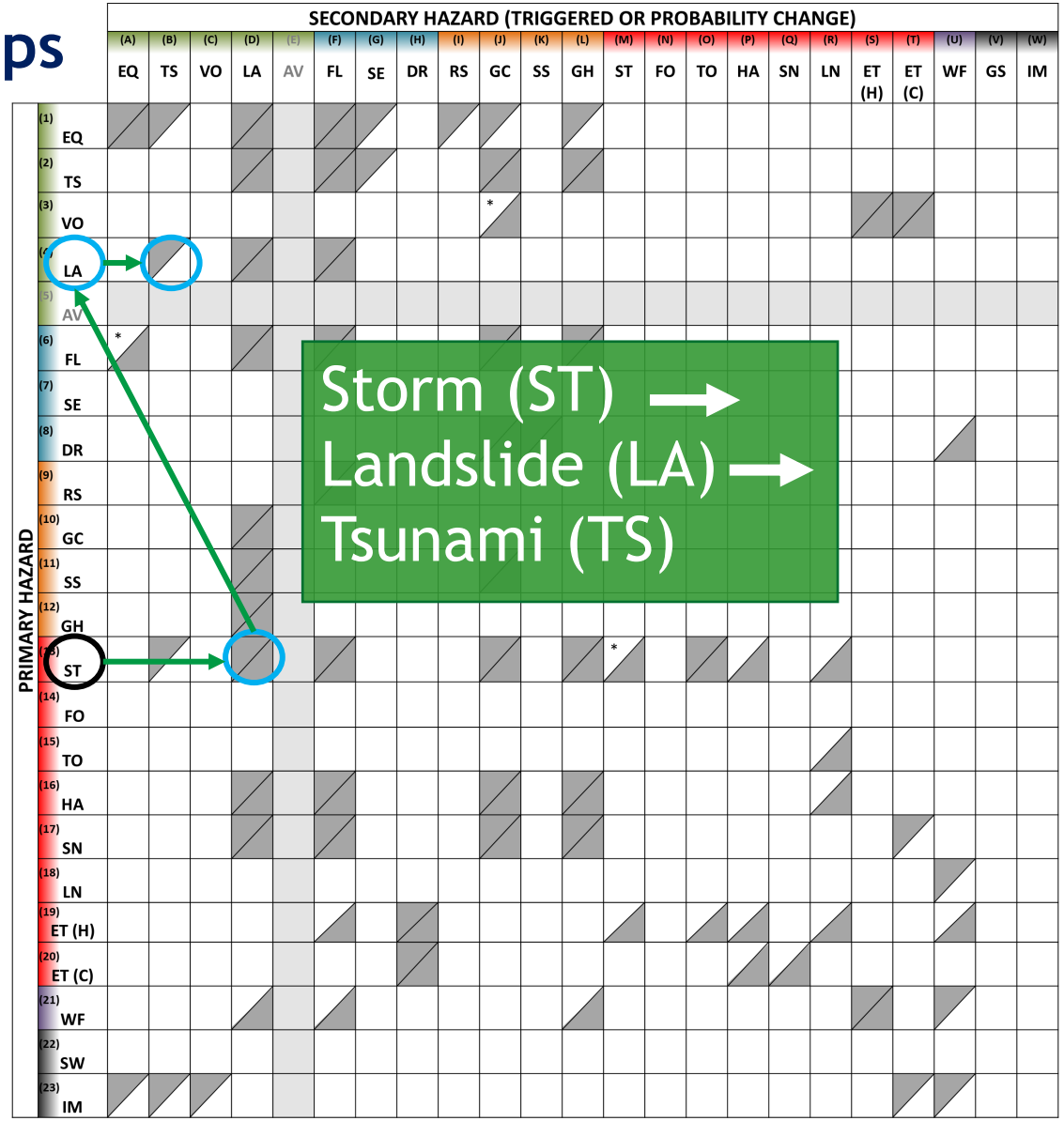
Adapted from Gill and Malamud (2014)

D. Hazard interrelationships in Istanbul

Example interactions:

Storms can **trigger** or **change the probability** of occurrence of landslides

Landslides can **trigger** tsunamis



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	Tornado	TO
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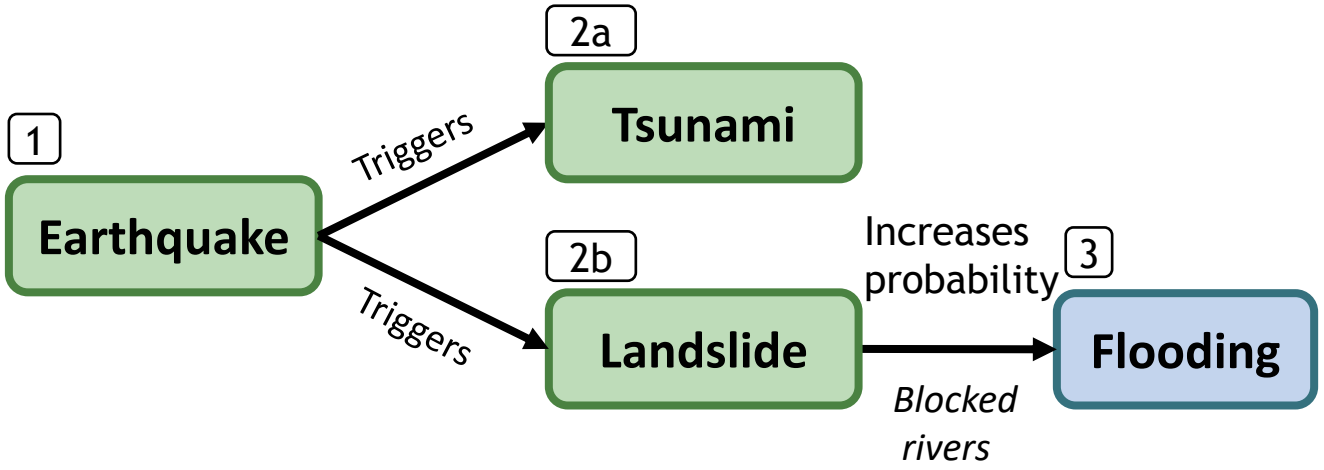
	Hazard Both Triggers and Changes the Probability of Secondary Hazard occurrence
	No evidence of hazard occurrence in Istanbul

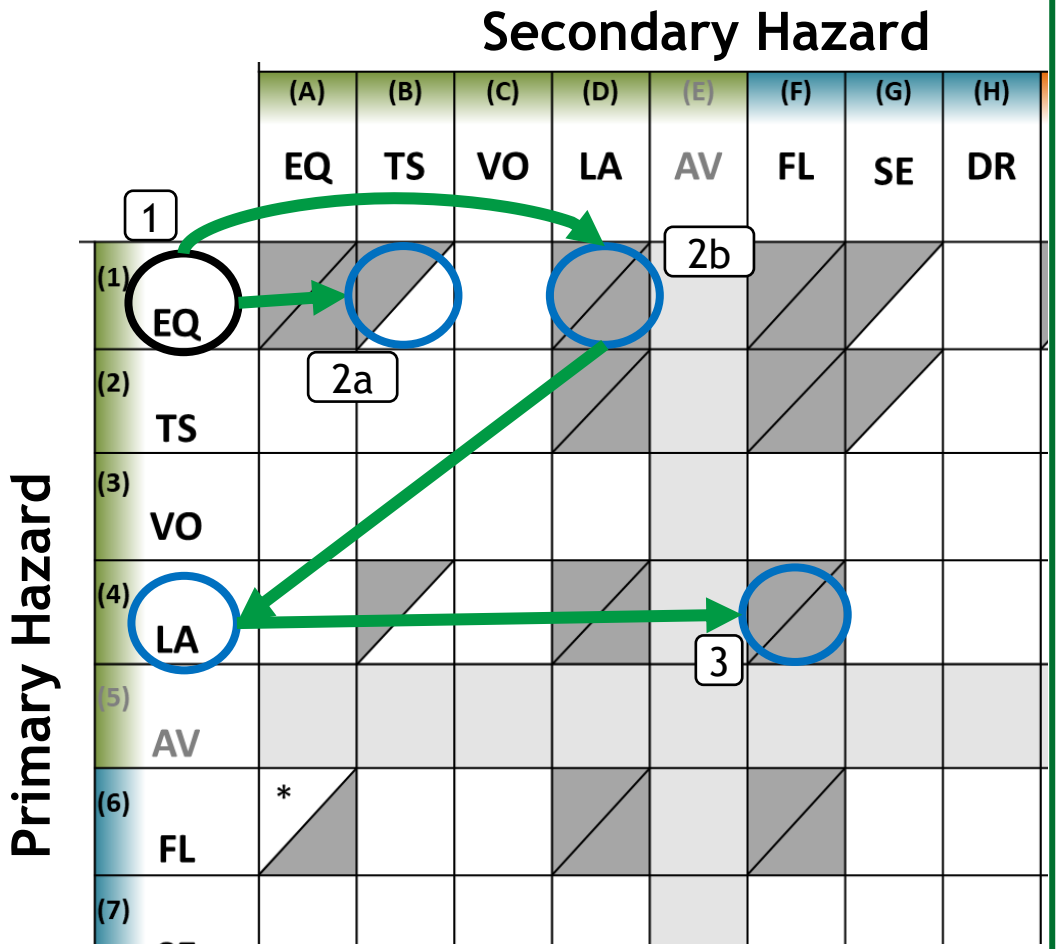
Adapted from Gill and Malamud (2014)

E. Multi-hazard scenarios for Istanbul

Using this hazard interaction matrix we can now develop plausible **multi-hazard scenarios** that could impact Istanbul.

For example:



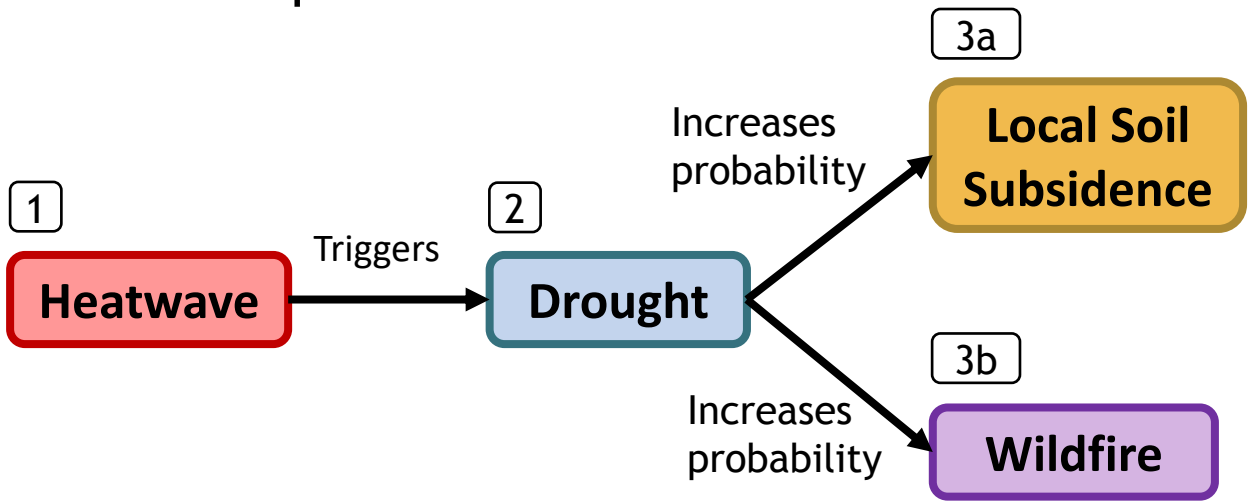


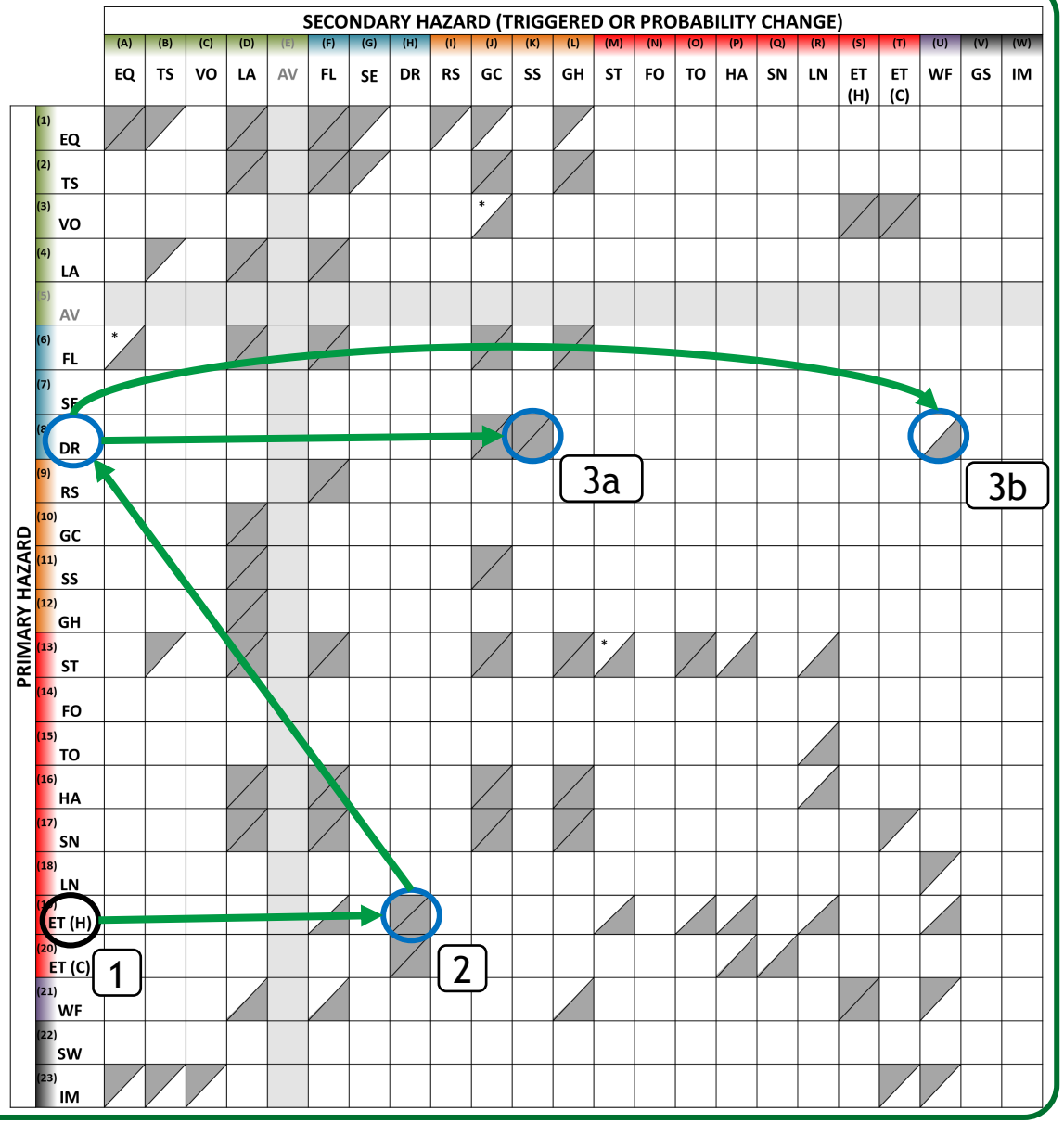
Extract from multi-hazard matrix.
Clipped for clarity

E. Multi-hazard scenarios for Istanbul

Using this hazard interaction matrix we can now develop plausible **multi-hazard scenarios** that could impact Istanbul.

For example:





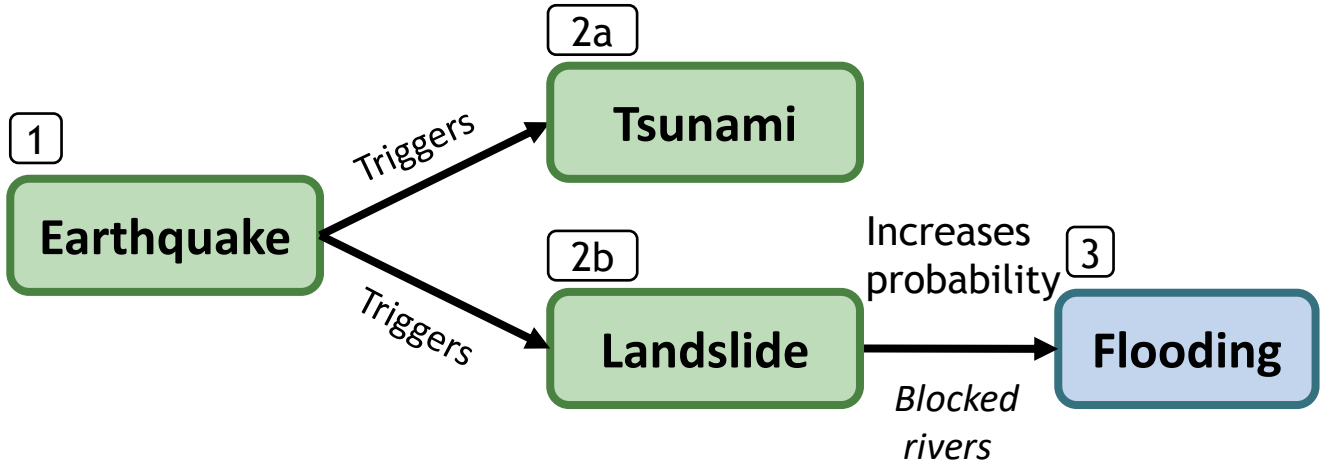
E. Multi-hazard scenarios for Istanbul - Anthropogenic Processes

Multi-hazard scenarios allow us to explore how *anthropogenic processes* might influence **hazard interactions**.

For example, some anthropogenic processes that might influence landslide occurrence after an earthquake ([1] -> [2b]) are:

- Deforestation
- Aggressive farming practices on hillslopes
- Roads undercut into hillsides

Each of these **increase the chance** of an **earthquake triggered landslide.**



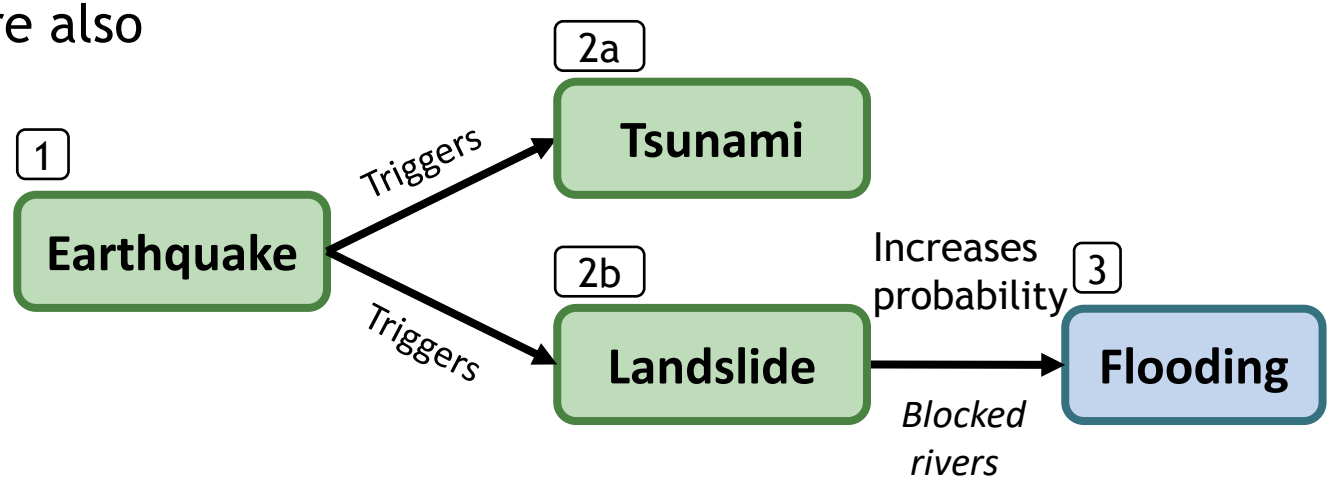
In this example, the development of preventative measures to **reduce the susceptibility** of earthquake triggered landslides also **reduces the potential for flooding** due to blocked rivers.

E. Multi-hazard scenarios for Istanbul - Exposure and Vulnerability

Additionally these scenarios allow us to explore how **exposure** and **vulnerability** might change during the scenario.

For example:

- After an **earthquake** people relocate outside, which ***increases their exposure*** to a **tsunami.**
- People with disabilities who are outside are also more ***vulnerable*** to a tsunami.
- People camping on hillslopes in temporary structures (e.g. tents) are ***more exposed*** and ***more vulnerable*** to landslides that often occur after earthquakes.



We need to ensure that **disaster response strategies** and planning encompass the **dynamic** nature of **exposure** and **vulnerability**. Response to one hazard **should not increase** the risk to the next.

F. Summary

- Istanbul is exposed to 22 of the 23 major natural hazards identified in this study.
- There are 73 potential hazard interactions relevant to Istanbul in terms of one natural hazard **triggering** another natural hazard or a hazard **changing the probability** of occurrence of a second hazard.
- Our hazard interaction matrix enables the production of **multi-hazard scenarios**.
- These scenarios can be used to explore how **anthropogenic processes** influence hazard interactions.
- Multi-hazard scenarios can also be used to understand **dynamic risk** by exploring how **exposure** and **vulnerability** changes during a scenario.

Appendix. Hazard Definitions

HAZARD GROUP	HAZARD	CODE	DEFINITION
GEOPHYSICAL	Earthquake	**EQ**	The sudden release of stored elastic energy in the Earth's lithosphere, caused by its abrupt movement or fracturing along zones of pre-existing geological weakness, and resulting in the generation of seismic waves [Smith and Petley, 2009].
	Tsunami	**TS**	The displacement of a significant volume of water, generating a series of waves with large wavelengths and low amplitudes [Alexander, 1993]. As the waves approach shallow water, their amplitude increases through wave shoaling.
	Volcanic Activity or Eruption	**VO**	The subterranean movement of magma and its eruption and ejection from volcanic systems under the influence of its confining pressure and superheated steam and gases [Alexander, 1993], together with associated tephra, ash and gas.
	Landslide	**LA**	The down-slope displacement of surface materials (predominantly rock and soil) under gravitational forces [Smith and Petley, 2009].
	Snow Avalanche	**AV**	The down-slope displacement of surface materials (predominantly ice and snow) under gravitational forces [Smith and Petley, 2009].

Appendix. Hazard Definitions

HAZARD GROUP	HAZARD	CODE	DEFINITION
HYDROLOGICAL	Flood	FL	The inundation of typically dry land with water.
	Seiche	SE	A standing wave in an enclosed or partially enclosed body of water.
	Drought	DR	A prolonged period with lower than expected precipitation [Smith and Petley, 2009] resulting in a serious hydrological imbalance [Alexander, 1993], or the removal of once existent and persistent water through poor agricultural practice or water diversion.
SHALLOW EARTH PROCESSES	Regional Subsidence	RS	The sudden or gradual, downward vertical movement of the ground surface over a regional spatial extent.
	Ground Collapse	GC	The rapid, downward vertical movement of the ground surface into a void.
	Soil (Local) Subsidence	SS	The gradual, downward vertical movement of the ground surface over a localized spatial extent.
	Ground Heave	GH	The sudden or gradual, upward vertical movement of the ground surface.

Appendix. Hazard Definitions

HAZARD GROUP	HAZARD	CODE	DEFINITION
ATMOSPHERIC	Storm	**ST**	A significant perturbation of the atmospheric system, often involving heavy precipitation and violent winds.
	Fog	**FO**	A cloud on the ground that has formed through a cooling or modification process [Croft et al, 1997]. It occurs when water droplets form or are suspended in air that is within 10% of saturation [Houghton, 1985].
	Tornado	**TO**	A violently rotating column of air pendant (normally) from a cumulonimbus cloud and in contact with the surface of the Earth [Alexander, 1993].
	Hail	**HA**	A significant perturbation of the atmospheric system, in which strong up-draughts occur within convective storms where there is an ample supply of supercooled water droplets. This results in heavy precipitation of hailstones when they have sufficient mass to leave the atmospheric system [Alexander, 1993].
	Snow	**SN**	A significant perturbation of the atmospheric system, with heavy precipitation of snow.
	Lightning	**LN**	The atmospheric discharge of static electricity, caused when the resistance of the intervening air between areas of positive and negative charge is overcome [Alexander, 1993].
	Extreme Temperature (Hot)	**ET (H)**	A prolonged period of temperatures above the normal average for that period of time (either short or long term, local, regional or global).
	Extreme Temperature (Cold)	**ET (C)**	A prolonged period of temperatures below the normal average for that period of time (either short or long term, local, regional or global).

Appendix. Hazard Definitions

HAZARD GROUP	HAZARD	CODE	DEFINITION
BIOPHYSICAL	Wildfire	**WF**	An uncontrolled fire fuelled by natural vegetation [Smith and Petley, 2009].
SPACE	Space Weather	**SW**	A perturbation of the Earth's magnetosphere, because of changes in space weather, i.e., the intensity of solar wind.
	Impact Event	**IM**	The impact of a celestial body with the Earth's surface.