IECG 2022

The 4th International Electronic Conference on Geosciences

01–15 DECEMBER 2022 | ONLINE

Chaired by PROF. JESÚS MARTÍNEZ FRÍAS

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Cascading Effects of Major Natural Hazards in Greece

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- When a disaster occurs, the society in risk is not only threatened by the consequences of this event.

- Stable and trigger factors generate a natural hazard, which in turn

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  induces changes in some trigger factors and thereby

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  these changes can induce another natural hazard.

- Furthermore, natural hazards are characterized by interactions, which consist of various types, such as the triggering (cascading) interrelations, which

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  can aggravate the negative impact of a disaster.

- For example, a relationship between drought, wildfires and landslides exists and it is possible to be occurred. More specifically,
  - ➢ the **lack of rainfall** constitutes the trigger factor
  - ➢ for a **drought** event (Lawrence, *et. al*., 2020).
  - ➢ **Lightning** is one of the trigger factors
  - ➢ of **wildfires** when considering the natural causes of unplanned or uncontrolled landscape fires (Murray, *et al*., 2021).

  If an area is characterized by **drought** then the occurrence of **lightning** could result in

  - ✔ the triggering of **wildfires** which increases the probability
  - ✔ of **landslides** through **removing vegetation** (Gill and Malamud, 2014)
  - ✔ and thus these **cascading effects** can be turned into **"cascading disasters"** (Lawrence, *et. al*., 2020).

- The research aims to present the framework of natural hazard interrelations associated with the major disasters that occurred in Greece and had a significant impact on society, in order to bring out the significance of multi-hazard risk.

Selection of Major Natural Hazards

- The selection of major natural hazards that have occurred in Greece is based on the **declarations of the affected areas in a State of Civil Protection Emergency**.

- The State of Civil Protection Emergency is activated in case of the occurrence of large-scale:

1) natural

2) technological

3) and other disasters

On the population and the infrastructures

for the handling of which the **immediate available resources**, **means** and **materials** of the management bodies **are not sufficient.**

Thus, emergency rehabilitation measures of a certain time duration must be taken into account.

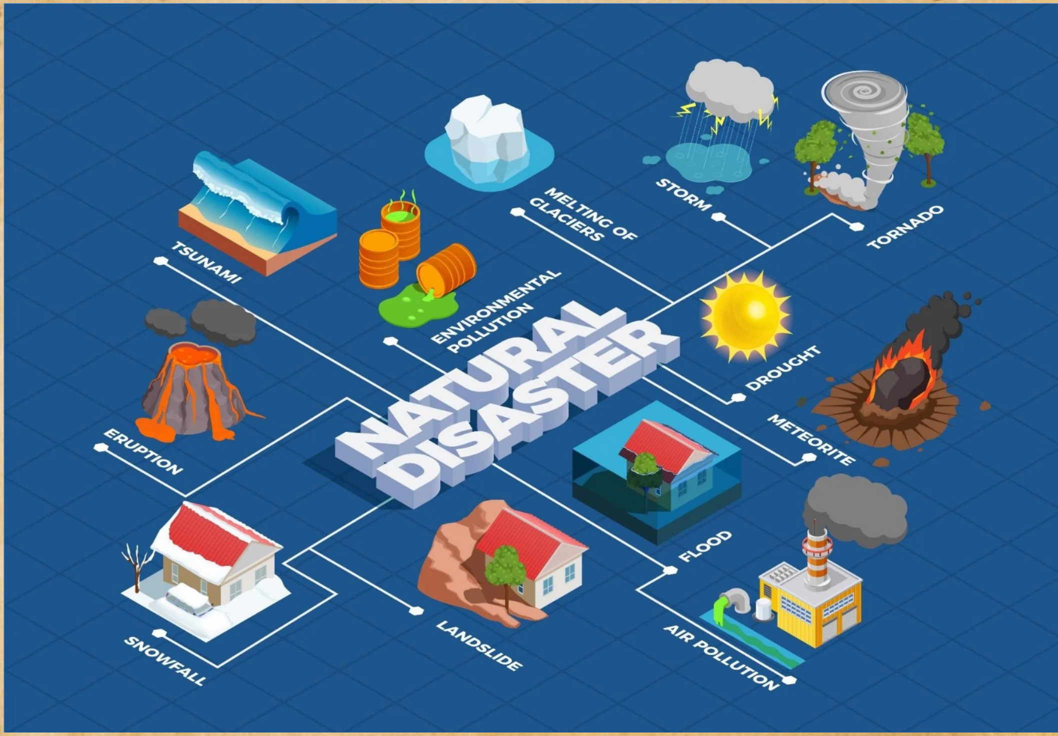


Figure 1:
Indicative types of hazards that can be turned into a disaster

According to the Secretary General for Civil Protection of the Ministry for Climate Crisis and Civil Protection (2021), among the disastrous events for which the State of Civil Protection Emergency was activated from 2014 until 2021, the major natural hazards were:

- **Earthquake**, such as in the case of Vrisa, (Lesvos, North Aegean) on June 12, 2017

Figure 2

Figure 3

- **Flood**, such as in the case of Mandra (West Attica) on November 15, 2017

Figure 4

Figure 5

Figure 6

- **Forest Fire**, such as in the case of Mati (East Attica) on July 23, 2018


Figure 7


Figure 8

- **Heavy Rainfall & Thunderstorm**, such as in the case of Chalkidiki (Central Macedonia) on July 10, 2019


Figure 9


Figure 10

- **Frost**, such as in the case of Vilia, Erythres & Oinoi (Mandra-Eidyllia, West Attica) on December 29, 2019
- **Snowfall**, such as in the case of Dionysos (East Attica) on February 15, 2021


Figure 11

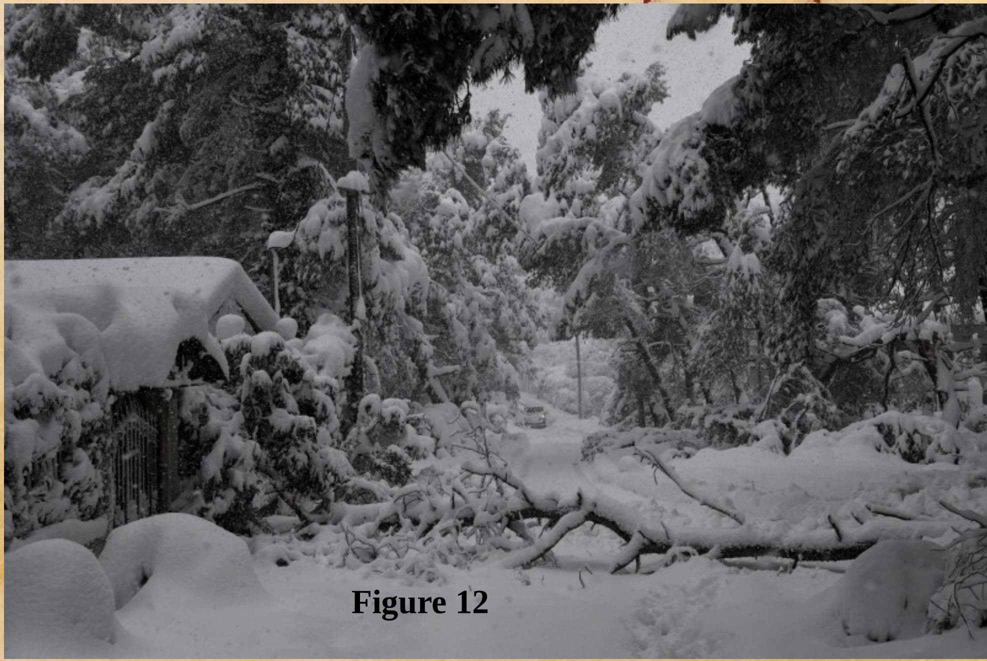


Figure 12

- **Hailstorm**, such as in the case of Skopelos (Sporades) on October 04, 2019


Figure 13


Figure 14

• **Landslide**, such as in the case of Skopelos (Sporades) on January 12, 2019

Figure 15

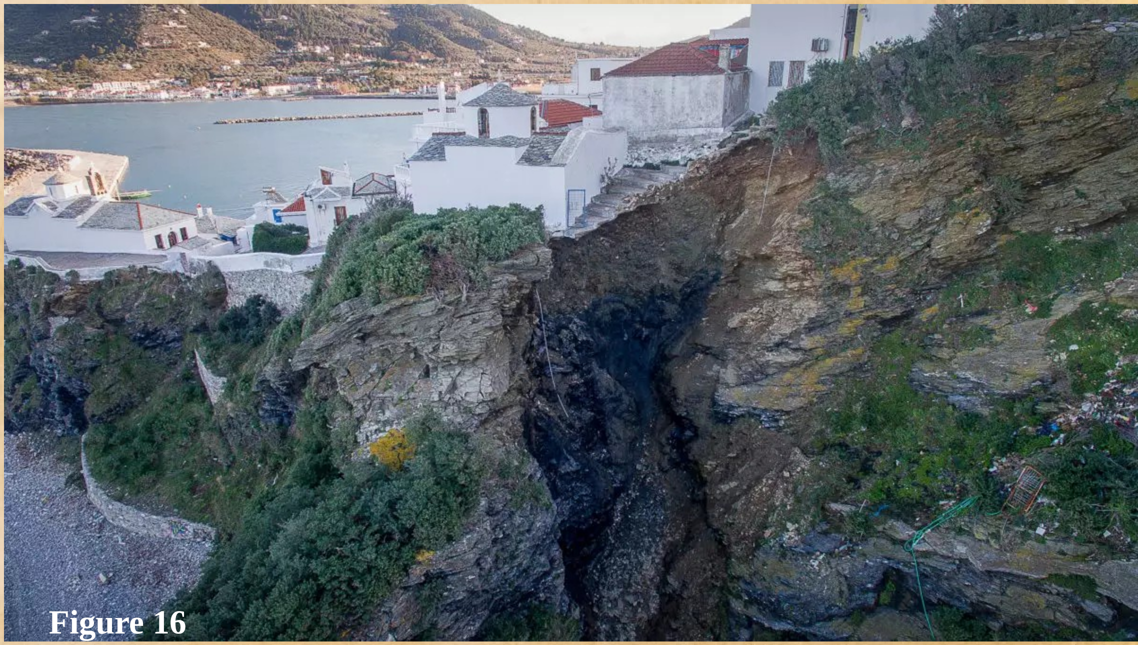


Figure 16

Figure 17

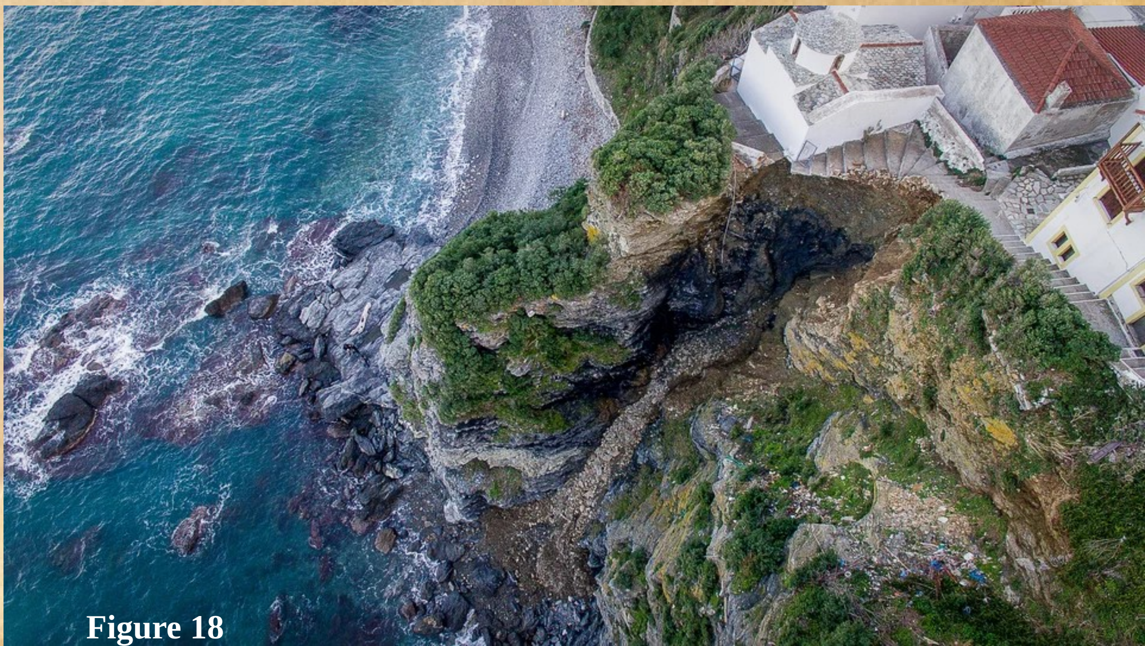


Figure 18

Classification of Hazards

- The definitions and classifications of hazards are based on the report (Murray, *et al.*, 2021) conducted by:
  - ✔ The United Nations Office for Disaster Risk Reduction (UNDRR)
  - ✔ the International Science Council (ISC)
  - ✔ and the Sendai Framework for Disaster Risk Reduction 2015–2030

- **302 hazards** are classified into → **47 cluster types** which in turn → are classified into **8 hazard types**:

  1) the Biological hazards (88 hazards)
  2) the Meteorological and Hydrological hazards (60 hazards)
  3) the Technological hazards (53 hazards)
  4) the Geohazards (35 hazards)
  5) the Chemical hazards (25 hazards)
  6) the Environmental hazards (24 hazards),
  7) the Extraterrestrial hazards (9 hazards)
  8) and the Societal hazards (8 hazards)

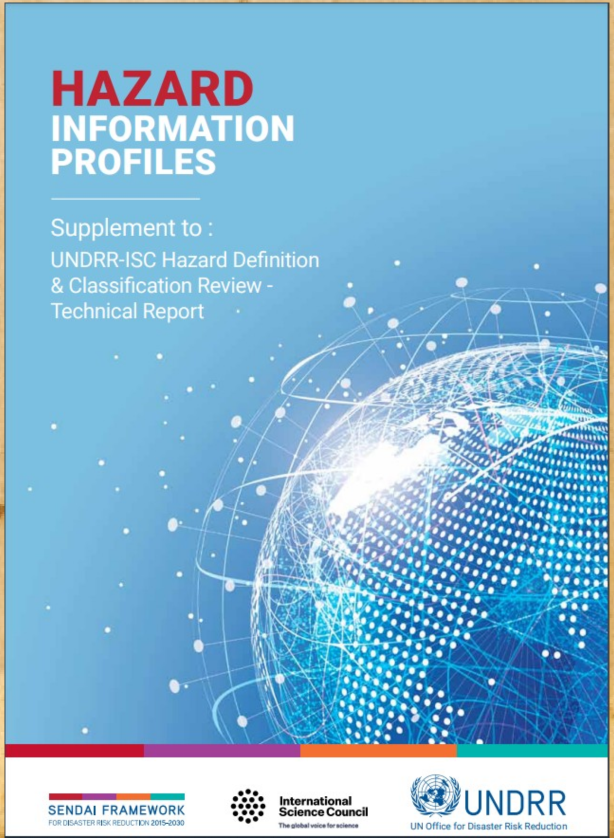


Figure 19: *The Hazard Information Profiles report*

- In order to define and classify the disastrous events whose affected area was declared in a State of Civil Protection Emergency,

each of these disasters was corresponded with the relevant hazards contained in the hazard information profiles provided by the UNDRR, ISC and the Sendai Framework (Murray, *et al.*, 2021), as illustrated in the table 1.

Table 1*. Correspondence of the disastrous events in Greece for which the State of Civil Protection Emergency was activated with the Specific Hazards (and their identifier), Cluster Types and Hazard Types according to the hazard information profiles provided by the UNDRR, ISC and the Sendai Framework*

Type of disasters as mentioned in the context of the State of Civil Protection Emergency	Specific Hazards (and their identifier)	Cluster types	Hazard types
Heavy Rainfall-Floods	MH0003: Thunder-storm	Convective-Related	Meteorological and Hydrological hazards
	MH0006: Flash Flood	Flood	
Snowfall-Frost	MH0039: Snowstorm	Precipitation-Related	
Hailstorm	MH0036: Hail		
Landslide	GH0007: Landslide or Debris Flow (Earthquake Trigger)	Seismogenic (Earthquake)	Geohazards
Earthquake	GH0001: Earthquake		
Forest Fires	EN0013: Wildfires	Environmental Degradation (Forestry)	Environmental

- Consequently, during the period 2014-2021, Greece has been mainly affected by:
  - 4 types of meteorological and hydrological hazards
  - 2 types of geohazards
  - and 1 environmental hazard

Hazard Interactions and Types of Hazard Interrelations

Hazard Interactions

refer to the unidirectional and bidirectional effect(s) between one hazard/process and another hazard/process (Gill and Malamud, 2016). When considering the physical processes, each primary hazard triggers or increases the probability of a secondary hazard (Gill and Malamud, 2014).

- **"Multi-hazard"**
  - ✔ reflects the occurrence and the interactions of all possible hazards in a given spatial region and/or temporal period (Gill and Malamud, 2014)

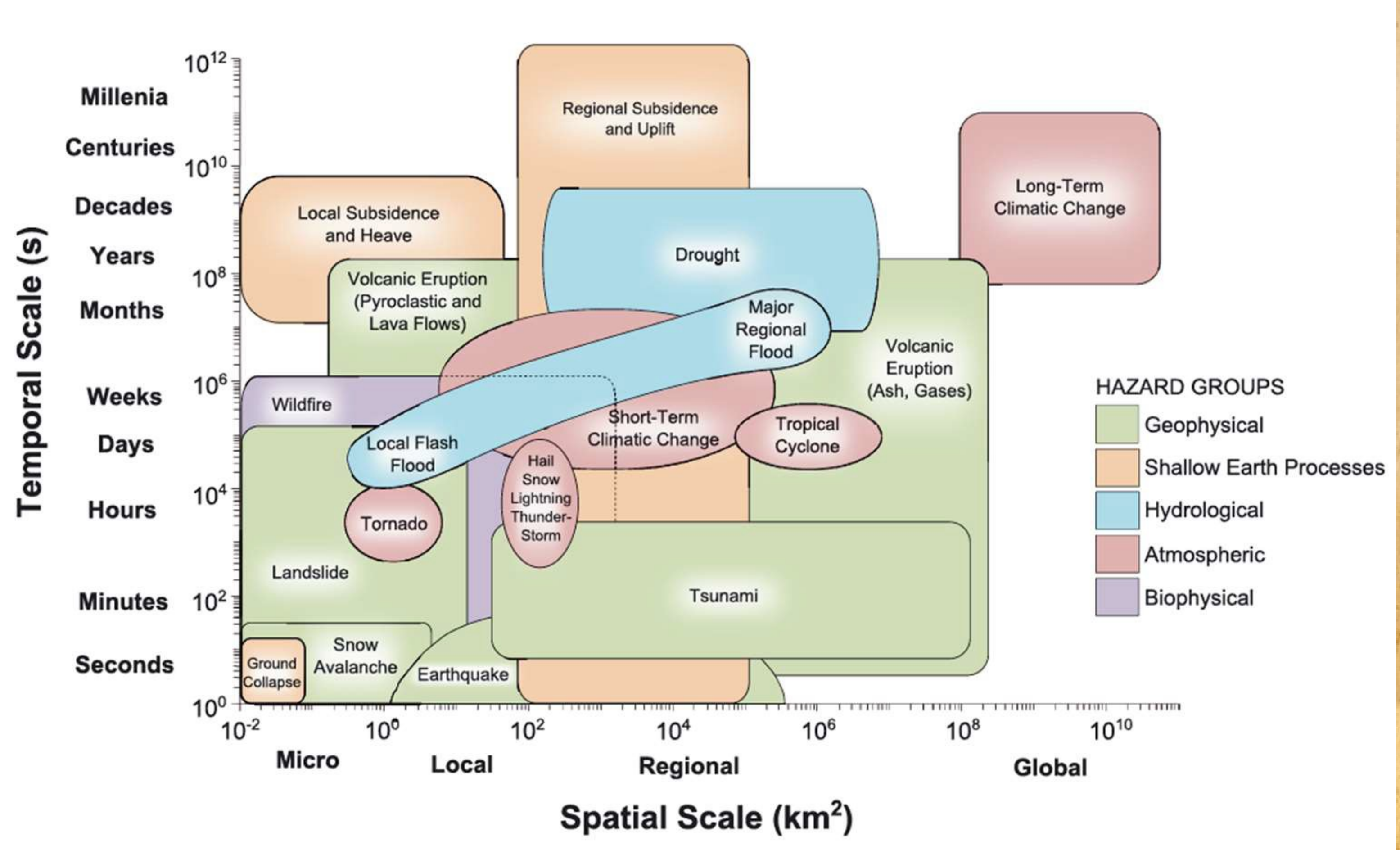


***Figure 20**. The spatial and temporal scales of 16 natural hazards, classified into 6 hazard groups, according to Gill and Malamud (2014, p. 681).*

- **“Multi-hazard”**
  - ✔ denotes both the selection of multiple major hazards that the country faces, as well as the specific contexts where hazardous events may occur (Murray, *et al.*, 2021):
    - ➢ **simultaneously,**
    - ➢ **cascadingly** or
    - ➢ **cumulatively**

  over time, and taking into account the **potential interrelated effects**.

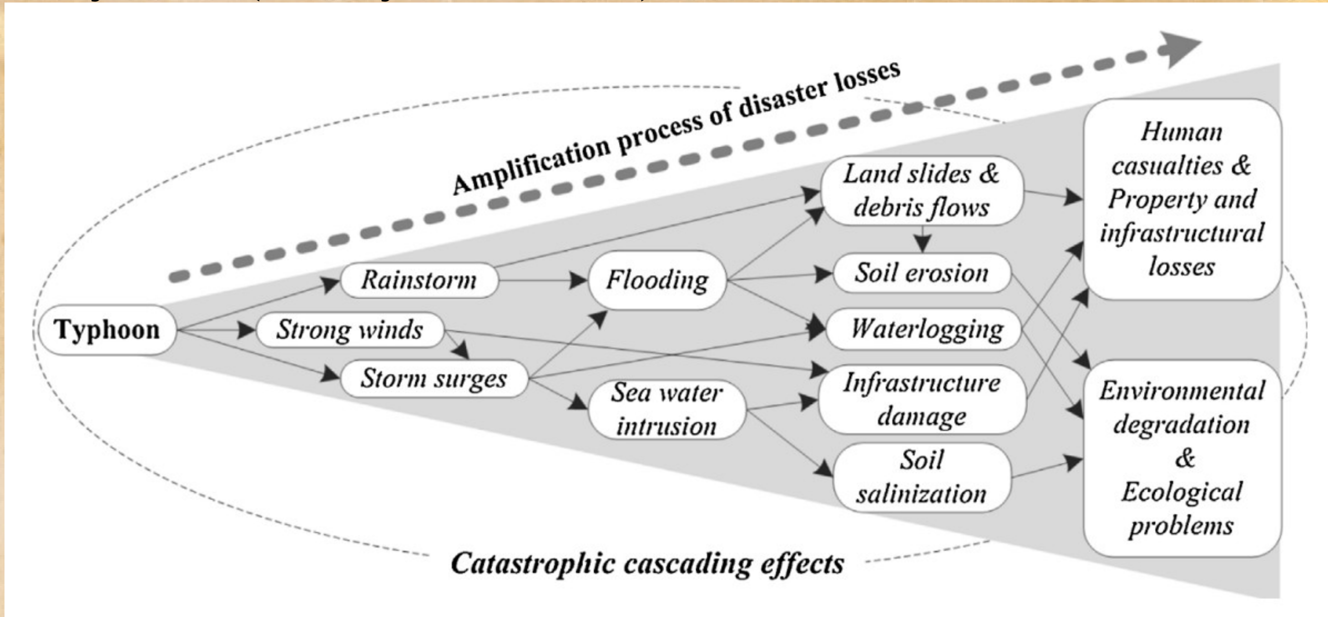


***Figure 21**. Cascading effects of typhoon disasters, according to Lei, at al., 2015 (p. 284).*

- **“Multi-hazard risk”**
  - ✔ integrates the evaluation of risk when the effects of multiple hazards are considered (Angeli, *et al.*, 2022)

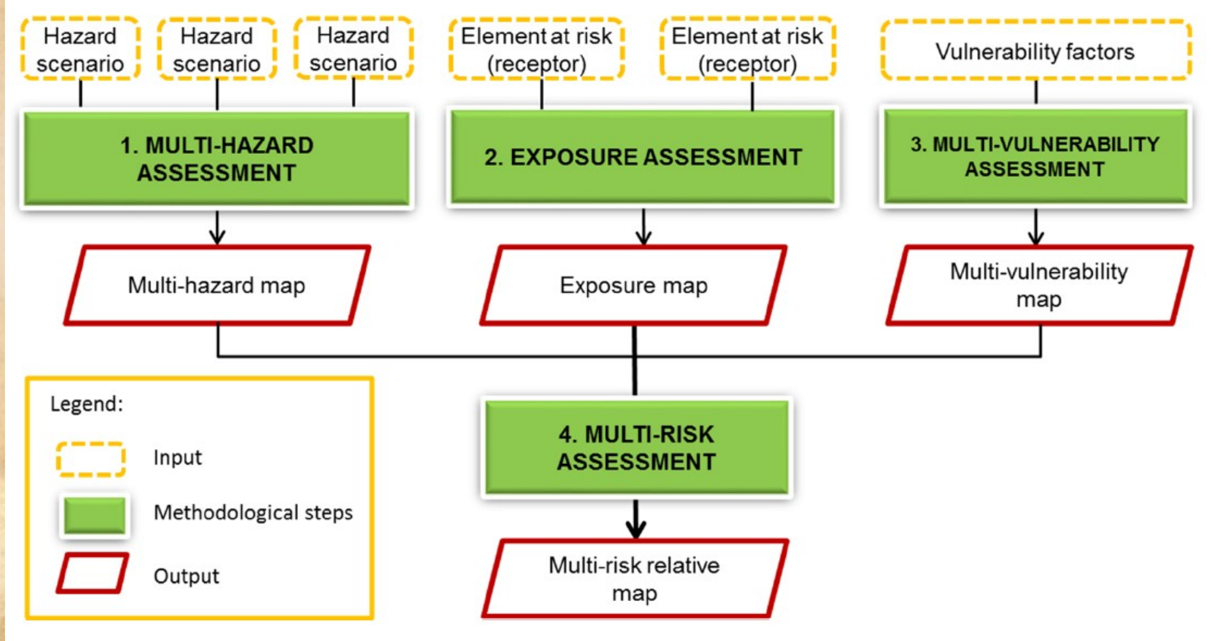


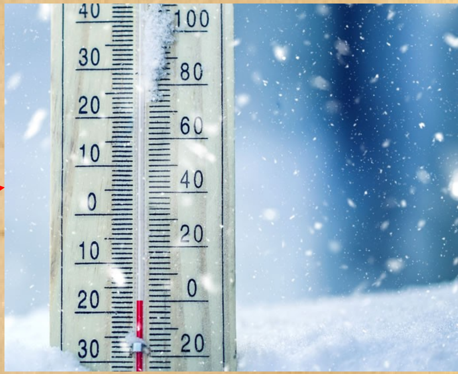
***Figure 22**. The multi-risk methodology, according to Gallina, et al., 2020 (p. 7)*

Gill and Malamud (2014) identified 90 natural hazard interactions between 21 hazards, which refer both to **relationships of increasing probability** and **triggered relationships.** According to Figure 38:

Figure 31. *Lightning*

- ***Figure 23***. *Earthquake*

- ***Figure 30***. *Cold extreme temperature*



- a primary hazard, such as a volcanic eruption

Figure 32. *Volcano*

can trigger the occurrence of 9 secondary hazards, such as:

- ***Figure 24***. *Tsunami*

- ***Figure 29***. *Hot extreme temperature*

- ***Figure 25***. *Landslide*

- ***Figure 26***. *Flood*

- ***Figure 27***. *Snow avalanche*

- ***Figure 28***. *Wildfires*

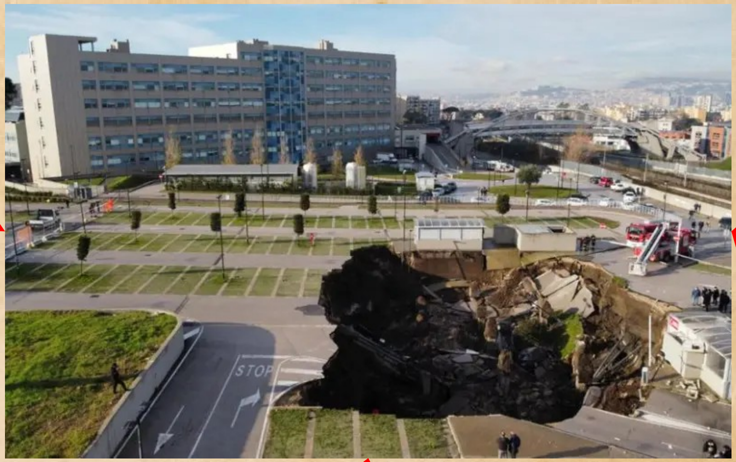
- On the other hand, a secondary hazard such as ground collapse can be triggered by 7 primary hazards, such as:

➢ ***Figure 23***. *Earthquake*

➢ ***Figure 24***. *Tsunami*

➢ ***Figure 26***. *Flood*

Figure 37. *Ground Collapse*



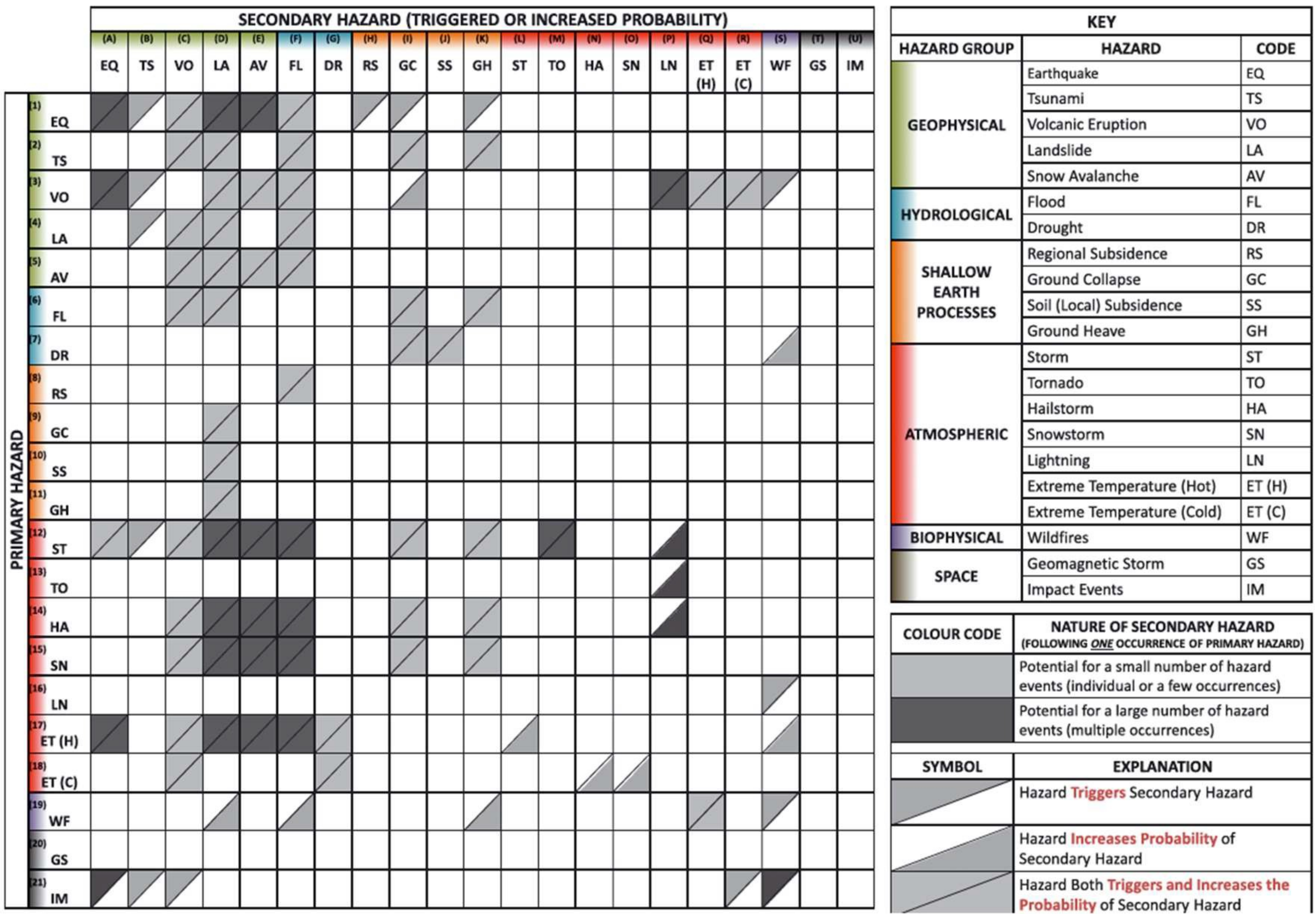
➢ ***Figure 33***. *Drought*

➢ ***Figure 36***. *Storm*

➢ ***Figure 35***. *Hailstorm*

➢ ***Figure 34***. *Snowstorm*

Figure 38. *The interaction of 21 natural hazards, through a wide-ranging review of grey- and peerreview literature, resulting into 90 interactions, according to Gill and Malamud (2014, p. 693).*

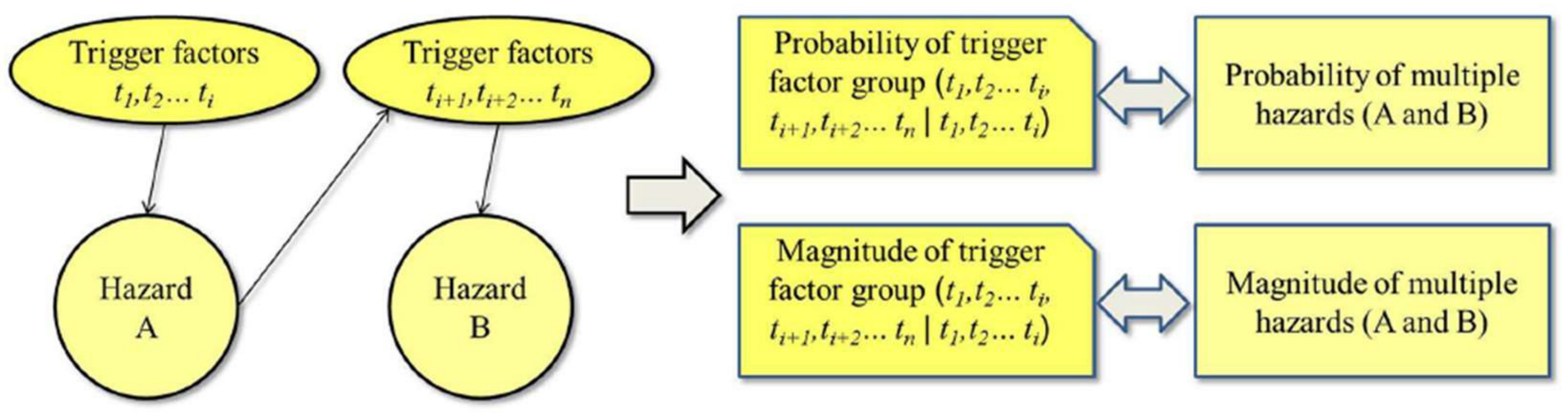


Types of Hazard Interrelations

- There are several types of hazard interrelations (Tilloy, *et al.*, 2019; Liu, *et al.*, 2016; Gill and Malamud 2016; Gill and Malamud 2014), such as:
  - ✔ the independence
  - ✔ the triggering relations (cascade or domino effect) or series relationship
  - ✔ the parallel relationship where a common primary event triggers the co-occurrence of multiple hazards simultaneously resulting in a compound hazard
  - ✔ the change of environmental conditions which results in the increase of the probability of occurrence of secondary hazard
  - ✔ the mutual exclusion
  - ✔ and the catalysis or impedance of cascading relations.

- In this research, the series relationship will be taken into consideration regarding the cascading effects of the major disasters occurred in Greece in the context of the State of Civil Protection Emergency.

Figure 39. *The triggering relations (cascade or domino effect) or series relationship (Liu, et al., 2016, p. 634).*



According to Liu, *et al. (*2016), stable factors identify the type of natural hazards that influence a given area, while trigger factors determine the frequency and magnitude of multiple interacting hazards occurring together.

Results

- Among the 6 major disastrous events that occurred in Greece during the time period 2014–2021

"Heavy Rainfall-Floods" can be divided into:

"Flash Flood" is generally characterized by raging torrents generated by heavy rainfall;

"Thunderstorms" are accompanied by precipitation and can cause flash flooding (Murray, *et al.*, 2021).

MH0003: Thunderstorm → Storm-ST

MH0006: Flash Flood → Flood-FL

In the context of hazard interrelations, as presented in Figure 38, "Thunderstorm" will be correlated to "Storm" and "Flash Flood" will be correlated to "Flood".

The rest of the hazards will be correlated with the similar denominations (MH0036: Hail to Hailstorm-HA, GH0007: Landslide or Debris Flow (Earthquake Trigger) to Landslide-LA, etc.).

- When considering the interactions between natural hazards as illustrated in Figure 38,

where the type of interaction refers to the cascade or domino effect as illustrated in Figure 39, in which an emphasis has been placed in the increased probability of occurence of secondary hazards in the context of severity of disasters,

  - ✔ it is observed that there are a lot of **cascade effects for each of the disasters** mentioned in the context of the State of Civil Protection Emergency.

Results

- Storm events both trigger and increase the probability of 8 secondary hazards (earthquake, volcanic eruption, landslide, snow avalanche, flood, ground collapse, ground heave and tornado), while it triggers a small number of tsunami events and it increases the probability for a large number of lightning events. On the other hand, storm cannot be triggered as a secondary event, but extreme temperature (hot) can increase the probability of its occurrence;

- Flood events both trigger and increase the probability of 4 secondary hazards (volcanic eruption, landslide, ground collapse and ground heave). However, floods can be both triggered and have an increased probability of occurrence as a secondary hazard by 10 primary hazards (earthquake, tsunami, volcanic eruption, landslide, snow avalanche, regional subsidence, storm, hailstorm, snowstorm, extreme temperature (hot)), where wildfires increase the probability of occurrence of a flood event;

- Snowstorm both trigger and increase the probability of 6 secondary hazards (volcanic eruption, landslides, snow avalanche, flood, ground collapse and ground heave), while extreme temperature (cold) increases the probability of occurrence of a snowstorm event;

- Hailstorm both trigger and increase the probability of 6 secondary hazards (volcanic eruption, landslides, snow avalanche, flood, ground collapse and ground heave), while it increases the probability for a large number of lightning events. On the other hand, extreme temperature (cold) increases the probability of occurrence of a small number of hailstorm events;

Results

- Landslides both trigger and increase the probability of 3 secondary hazards (volcanic eruption, landslides and flood), while it triggers a tsunami event. On the contrary, landslides can be triggered by 13 secondary hazards (earthquake, tsunami, volcanic eruption, landslides, snow avalanche, floods, ground collapse, soil (local) subsidence, ground heave, storm, hailstorm, snowstorm and extreme temperature (hot)), while wildfires increase the probability of occurrence of a small number of landslide events;

- Earthquake both trigger and increase the probability of 5 secondary hazards (earthquake, volcanic eruption, landslide, snow avalanche, flood), while it triggers the occurrence of tsunami, regional subsidence, ground collapse and ground heave. However, earthquake events can be both triggered and have an increased probability of occurrence as a secondary hazard by 4 primary hazards (earthquake events, volcanic eruption, storm, extreme temperature (hot), as well as, impacts events, namely, when a celestial body impacts the Earth's surface (Gill and Malamud, 2014);

- Wildfires both trigger and increase the probability of extreme temperature (hot) and triggers the occurrence of more wildfire events. However, wildfires increase the probability of occurrence of landslides, floods and ground heave. Additionally, wildfires can be triggered as a secondary hazard by 4 primary hazards (volcanic eruption, lightning, wildfires and impact events) and have an increased probability of occurrence as a secondary hazard by 2 primary hazards (drought and extreme temperature (hot)).

Discussion

- It is worth pointing out that:
  - ✔ storm, snowstorm and hailstorm events both trigger and increase the probability of occurrence **for most of the secondary hazards**,
  - ✔ while landslides and floods can be both triggered and have an increased probability of occurrence as a secondary hazard **by most of the primary hazards.**

- Regarding the interaction relationships **between the major natural hazards** that occurred in Greece during 2014-2021 (Gill and Malamud, 2014):
  - ✔ Storm events both trigger and increase the probability of earthquake events, landslides, floods;
  - ✔ Flood events both trigger and increase the probability of landslides,
    - ➢ While floods can be both triggered and have an increased probability of occurrence as a secondary hazard by earthquake events, landslides, storm, hailstorm and snowstorm.
    - ➢ Furthermore, wildfires increase the probability of occurrence of a flood event;
  - ✔ Snowstorm both trigger and increase the probability of landslides and floods;
  - ✔ Hailstorm both trigger and increase the probability of landslides and floods;

Discussion

- Landslides both trigger and increase the probability of landslides and floods.
  - However, landslides can be triggered by earthquake, landslides, floods, storm, hailstorm and snowstorm,
  - while wildfires increase the probability of occurrence of landslides;
- Earthquake events both trigger and increase the probability of more earthquake events, landslides and floods.
  - However, earthquake events can be both triggered and have an increased probability of occurrence as a secondary hazard by a primary earthquake event and storm;
- Wildfires triggers the occurrence of more wildfire events and increase the probability of occurrence of landslides and floods. Moreover, wildfires can be triggered as a secondary hazard by a primary wildfire event.

Conclusions

- The disasters for which a State of Civil Protection Emergency was activated consist of:
  - ✔ 4 meteorological and hydrological hazards
  - ✔ 2 geohazards and
  - ✔ 1 environmental hazard

according to the hazard information profiles provided by the UNDRR, ISC and the Sendai Framework, **thus highlighting the broad spectrum of types of natural hazards.**

- The declaration of the affected areas in a State of Civil Protection Emergency due to the occurrence of a natural hazard reflects the frequency and the significant impact of this hazard on society, as the natural hazard turned into a disastrous event.
- Taking into consideration:
  - ➢ the seriousness of the cascade effects of each of the disasters occurred in Greece,
  - ➢ as well as their high number of interaction relationships and
  - ➢ the fact that all of the disastrous events increase the probability of occurrence of secondary hazards,

multihazard approaches should be incorporated into the mitigation plans.

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- Figure 22: Gallina, V.; Torresan, S.; Zabeo, A.; Critto, A.; Glade, T.; Marcomini, A. A Multi-Risk Methodology for the Assessment of Climate Change Impacts in Coastal Zones, *Sustainability* **2020**, 12, 3697, 1-28.
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Should you have any questions, please contact me at:
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