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Cascading Effects of Major Natural Hazards in Greece †

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Abstract: 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 induces changes in some trigger factors and thereby 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. The purpose of this research is to identify, through a review process, the cascading effects of major natural hazards that occurred in Greece and had a significant impact on society.

Keywords: natural hazards; cascade effects; Greece

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1. Introduction

Hazards can be generated by natural processes, human activities or a combination of them and the interaction of these hazardous events with the exposure of people, infrastructure and assets, their vulnerability to the expected consequences and their capacity to manage and reduce disaster risks will lead to negative impacts [9], which will be worsen due to the interaction relationships of natural hazards. 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 [5]. Lightning is one of the trigger factors of wildfires when considering the natural causes of unplanned or uncontrolled landscape fires [6]. 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 [3] and thus these cascading effects can be turned into "cascading disasters" [5]. The research aims to present the framework of natural hazard interrelations [3] associated with the major disasters occurred in Greece during the time period 2014–2021 [8], in order to bring out the significance of multi-hazard risk.

2. Methods

2.1. 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. More specifically, the State of Civil Protection Emergency is activated in case of the occurrence of large-scale natural, technological 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 and thus emergency rehabilitation measures of a certain time duration must be taken into account. Among the disastrous events for which the State of Civil Protection Emergency was activated from 2014 until

2021 [8], the major natural hazards were heavy rainfall-floods, forest fires, snowfall-frost, earthquake, landslide and hailstorm.

2.2. Classification of Hazards

The United Nations Office for Disaster Risk Reduction (UNDRR), the International Science Council (ISC) and the Sendai Framework for Disaster Risk Reduction 2015–2030 provide the hazard information profiles for the hazards' definition and classification [6]. More precisely, 302 hazards are classified into 47 cluster types which in turn are classified into 8 hazard types: the Meteorological and Hydrological hazards (60 hazards), the Extraterrestrial hazards (9 hazards), the Geohazards (35 hazards) the Environmental hazards (24 hazards), the Chemical hazards (25 hazards), the Biological hazards (88 hazards), the Technological hazards (53 hazards) and the Societal hazards (8 hazards). 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 [6], 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: Thunderstorm	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

2.3. Hazard Interactions and Types of Hazard Interrelations

2.3.1. Hazard Interactions

Hazard interactions mean the unidirectional and bidirectional effect(s) between one hazard/process and another hazard/process [2] and thus the terms "multi-hazard" and "multi-hazard risk" emerge, where the first one reflect the occurrence and the interactions of all possible hazards in a given spatial region and/or temporal period [3] and the second one integrates the evaluation of risk when the effects of multiple hazards are considered [1]. Moreover, according to the technical report of the United Nations Office for Disaster Risk Reduction (UNDRR), the International Science Council (ISC) and the Sendai Framework for Disaster Risk Reduction 2015–2030 on the hazard definition and classification [9], 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 simultaneously, cascadingly or cumulatively over time, and taking into account the potential interrelated effects. Multi-hazards can be depicted in the Figure 1, where Gill and Malamud [3] illustrated the spatial and temporal scales of 16 specific natural hazards, having defined the spatial scale as the area that the hazard impacts and the temporal scale as the timescale that the single hazard acts upon the natural environment.

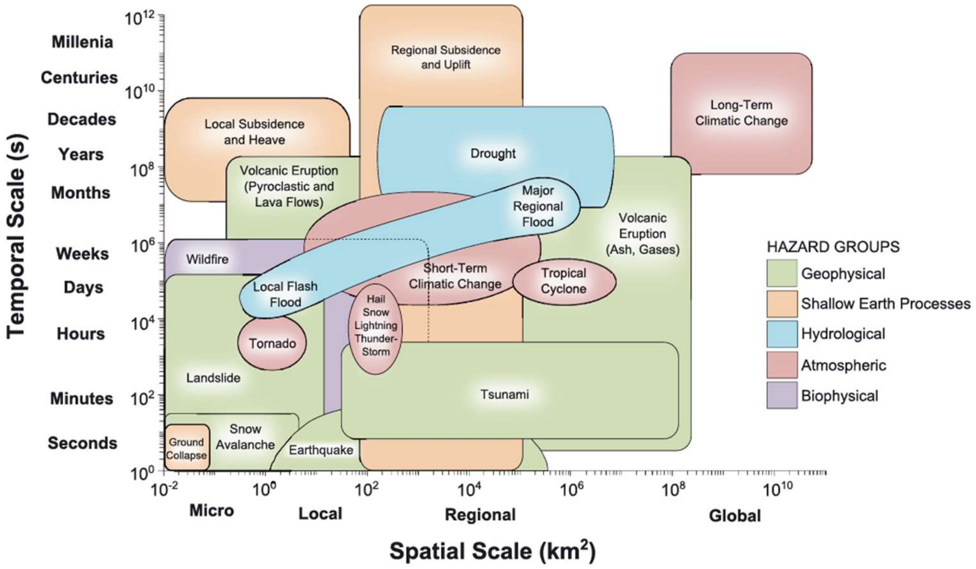

Figure 1. The spatial and temporal scales of 16 natural hazards, classified into 6 hazard groups, according to Gill and Malamud [3] (p. 681).

Regarding the interactions between the natural hazards, Gill and Malamud [3] considered the physical process by which each primary hazard triggers or increases the probability of a secondary hazard. The occurrence of a primary hazard induces changes in environmental parameters within one or more components of the geosystem (i.e., the atmosphere, biosphere, lithosphere, and hydrosphere), which in turn can increase the probability of a particular secondary hazard or trigger it if the threshold of environmental change is exceeded. Hence, Gill and Malamud [3] identified 90 natural hazard interactions between 21 hazards, which refer both to relationships of increasing probability and triggered relationships. According to Figure 2, a primary hazard such as a volcanic eruption can trigger the occurrence of 9 secondary hazards, such as earthquake events, a tsunami, landslides, snow avalanches, a flood, a lightning and both hot and cold extreme temperature. On the other hand, a secondary hazard such as ground collapse can be triggered by earthquake events, a tsunami, a flood, a drought, a storm, a hailstorm and a snowstorm. These hazard relationships can be characterized by the potential of a small or large number of primary or secondary hazard events.

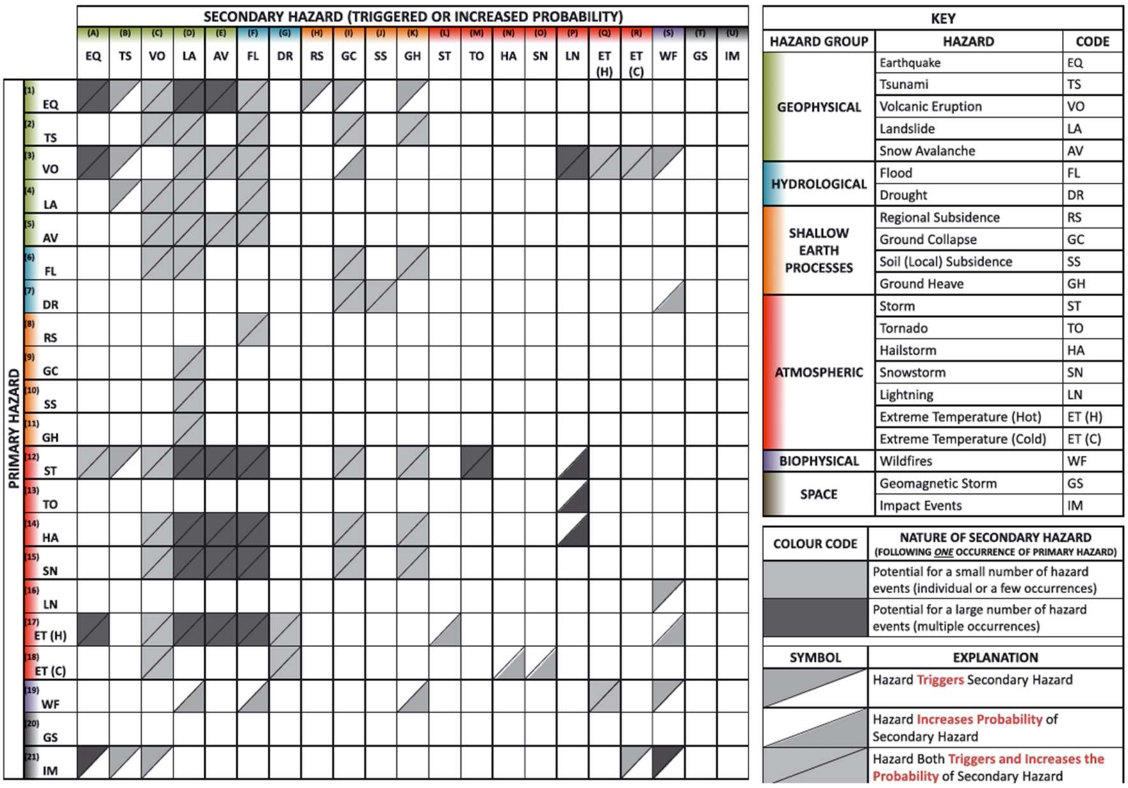

Figure 2. The interaction of 21 natural hazards, through a wide-ranging review of grey- and peer-review literature, resulting into 90 interactions, according to Gill and Malamud [3] (p. 693).

2.3.2. Types of Hazard Interrelations

There are several types of hazard interrelations [2–4,7], 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, as illustrated in the Figure 3, 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. According to Liu et al. [4], 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.

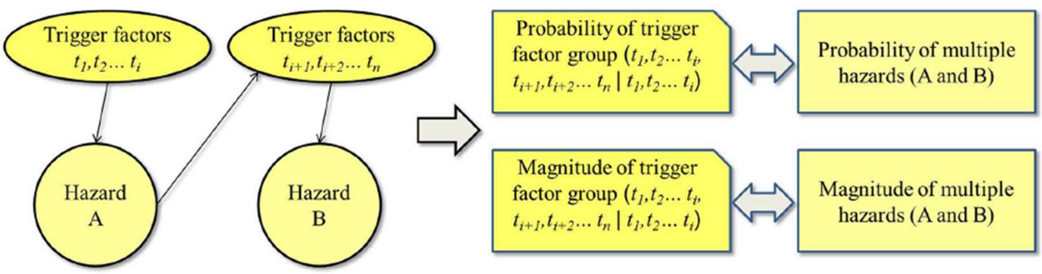

Figure 3. The triggering relations (cascade or domino effect) or series relationship, according to Liu *et al.* [4] (p. 634).

3. Results

When considering the interactions between natural hazards as illustrated in Figure 2, where the type of interaction refers to the cascade or domino effect as illustrated in Figure 3, it is observed that there are a lot of cascade effects for each of the 6 disasters mentioned in the context of the State of Civil Protection Emergency. Among the 6 major disastrous events that occurred in Greece during the time period 2014–2021, the event "Heavy Rainfall-Floods" can be divided into two hazards, the "Thunderstorm" and the "Flash Flood", according to the hazard information profiles provided by the UNDRR, ISC and the Sendai Framework [6]. Although "Flash Flood" is generally characterized by raging torrents generated by heavy rainfall, "Thunderstorms" are accompanied by precipitation and can cause flash flooding [6]. Thus, in the context of hazard interrelations as presented in Figure 2, "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 ("Hail" to "Hailstorm", "Landslide or Debris Flow (Earthquake Trigger)" to "Landslide", etc.). Regarding the cascade effects of the major natural hazards occurred in Greece, as presented in the table 1, according to the hazard interactions illustrated in Figure 2:

- 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;
- 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 [3]);
- 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)).

4. Discussion

There are a lot of triggering relations between natural hazards, where it is worth pointing out that storm, snowstorm and hailstorm events both trigger and increase the probability of occurrence for the most of secondary hazards, while landslides and floods can be both triggered and have an increased probability of occurrence as a secondary hazard by the most of primary hazards.

Regarding the interaction relationship between storm events, floods, snowstorm, hailstorm, landslides, earthquakes and wildfires [3]:

- 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, floods;
- Hailstorm both trigger and increase the probability of landslides, flood;
- 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.

5. 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, multi-hazard approaches should be incorporated into the mitigation plans.

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