CASCADE MULTIRISK EVENTS – CAUSES, ORIGIN, INTERACTIONS

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Abstract: *Cascade disastrous events are in the focus of the scientific community because they produce heavy consequences to the society and are very difficult to be modeled and the risks they produced to be assessed and managed. The multirisks are caused by consecutive hazard events which triggered each other. What is important to mention is the fact that the damages they produced are not a simple sum of the damages produced by the separate hazards. This means that the strong nonlinearity is in fact and are dominant modes regarding these events. There are two separated groups of multirisk events: the first one – consecutive events triggered by each other. The second groups are occasional cases of coincidence of events which neither are nor interrelated but occasionally happening in the (approximately) same time. We deal with the risk assessment qualitatively by convolution of hazard, vulnerability, exposure and coping capacity and illustrate this by several heavy powerful events worldwide observed multihazard and multiurisk case studies. This work is part of the COST- SPARC Project.*

КАСКАДНИ МУЛТИРИСКОВИ СЪБИТИЯ – ПРИЧИНИ, ПРОИЗХОД, ВЗАИМОДЕЙСТВИЯ

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Ключови думи: *Каскада, Мултириск, Катастрофални събития, Произход, Примери*

Резюме: *Каскадните катастрофални събития са във фокуса на вниманието на научната общност, тъй като водят до тежки последици за обществото, а моделирането им, както и оценката и управлението на свързаните с тях рискове, са изключително трудни. Мултирисковите сценарии възникват в резултат на поредица от опасни събития, които се провокират последователно. Важно е да се отбележи, че щетите от тях не представляват просто сбор от щетите, причинени от отделните опасности поотделно; това означава, че при тези събития доминираща роля играе силната нелинейност. Разграничават се две групи мултирискови събития: първата обхваща последователни събития, които се задействат едно друго, а втората включва случаи на съвпадение на събития, които не са взаимно свързани, но се случват приблизително по едно и също време. В настоящата работа оценката на риска се извършва качествено чрез комбиниране (конволюция) на компонентите опасност, уязвимост, изложеност и капацитет за справяне, като подходът е илюстриран чрез примери за мащабни събития от цял свят, свързани с множествени опасности и рискове. Тази разработка е част от проекта COST-SPARC.*

Introduction

Public interest in cascading risk processes is growing in parallel with urbanization. Until a few decades ago (less than a century), population density (especially outside highly urbanized areas) was negligible in the risk-prone regions of the world. In past historical times and in antiquity, major natural cataclysms were recorded in historical annals, but they never had such a destructive effect as in recent decades [1]. As population density increases, an increasing number of disaster events of lesser magnitude affect society and trigger increasingly severe consequences. While well-established risk assessment models exist for all individual disaster events (e.g., earthquakes, tsunamis, floods, fires,

landslides, frosts and ice storms, avalanches, hurricanes, and many more [2]), multi-risk cascading disasters prove quite difficult to model and, despite the rapid development of technology, cannot yet be evaluated with sufficient accuracy. This also poses a challenge for early warning systems, which are becoming increasingly sophisticated and effective. Assessing risk in multi-risk cascading disasters presents a particular difficulty due to their extremely low predictability. This necessitates a modern approach for the quantitative assessment of multi-risk cascading events (especially the most powerful ones). Despite the rapid development of artificial intelligence, there is still no unified algorithm for multi-risk assessment in cascading disasters and its integration into early warning systems.

Definitions and Methodology

Cascading risk events (or cascading effects) are a series of events in which an initial hazard or incident triggers a chain of subsequent events, where each succeeding event is a direct consequence of the preceding one. This phenomenon is often described as a "domino effect" or a "butterfly effect" and is a key concept in risk management, systems engineering, and ecology [3].

It is important to note that risk, according to the UN definition, represents a convolution between hazard, vulnerability, exposure, and societal resistance. It is this last factor that most frequently determines the capabilities for counteracting risk phenomena and processes [4].

Hazards can be natural or anthropogenic. A hazard is a phenomenon or process that threatens the life and health of the population, infrastructure, and human-made material assets.

Vulnerability indicates how severely a given system can be disrupted by a hazard.

Exposure is a parameter that quantitatively demonstrates how vulnerable a given system is.

Societal resistance (called Coping capacity) describes society's readiness to cope with the consequences of a hazard's impact combined with vulnerability and exposure.

Mathematically, this is expressed as the convolution * of the described parameters, or:

(1) $R = H * V * E * C$

*(Note: Using the acronyms: Risk = Hazard * Vulnerability * Exposure * Coping capacity)*

- Convolution is an operation in which all possible combinations of the considered parameters are calculated and the inverse probability is derived, insofar as the entire mathematical formulation is based on a probabilistic approach.

Implied, and the interactions between sequences of negative events are defined.

Sometimes, multi-risk events are defined not only as sequences of triggering each subsequent type of disaster phenomenon, but also as situations where events of different genesis occur in parallel, compounding negative effects as they unfold concurrently or close in time. This frequently leads to troubles in the Early Warning Systems regarding their effectiveness [5].

In practice, almost every natural disaster has a platform developed for risk assessment and Often, the first three parameters carry the negative component and are usually summed with a positive sign (+), while Coping capacity (C) reduces the overall risk and is subtracted from the resulting sum.

Normally, in determining multi-risk, cascading hazard effects (natural and/or anthropogenic) are calculation.

This is not the case with cascading disasters. Insofar as the problem is ill-defined, depends on many factors and nonlinearities, and is difficult to formalize, existing simulation models are usually limited to two consecutive, mutually conditioned hazardous events [5].

Multi-risk represents the overall risk from natural and anthropogenic hazards characteristic of a given area of observation or study. It is also often called complex risk.

The concept of multi-risk is based on the fact that most hazards are not isolated hazards in themselves, but are interconnected, with this connection often being very strong. Consequently, the total negative effect is much greater than the sum of the effects of individual hazards. This has been proven both theoretically and through numerous case observations and statistical analysis [4].

It is important to note that negative effects are often subdivided into primary (generated by the processes of hazard inception themselves) and secondary—impacts resulting from the disruption of societal systems relative to their normal functioning under non-critical situations, rather than under disaster conditions.

Usually, more powerful disasters are accompanied by more severe secondary effects, although this rule often has exceptions [4].

The main characteristics of cascading multi-risks are:

- **Scale multiplication:** The consequences of a cascade are often much larger and more destructive than the initial single incident.
- **Systems complexity:** They manifest in highly interconnected systems (critical infrastructure, ecosystems, financial markets) where elements depend on one another.

- **Difficulty in forecasting:** Due to the non-linear nature of connections, accurately predicting the final outcome is extremely difficult, making developed models for multi-risk assessment and management largely ineffective.

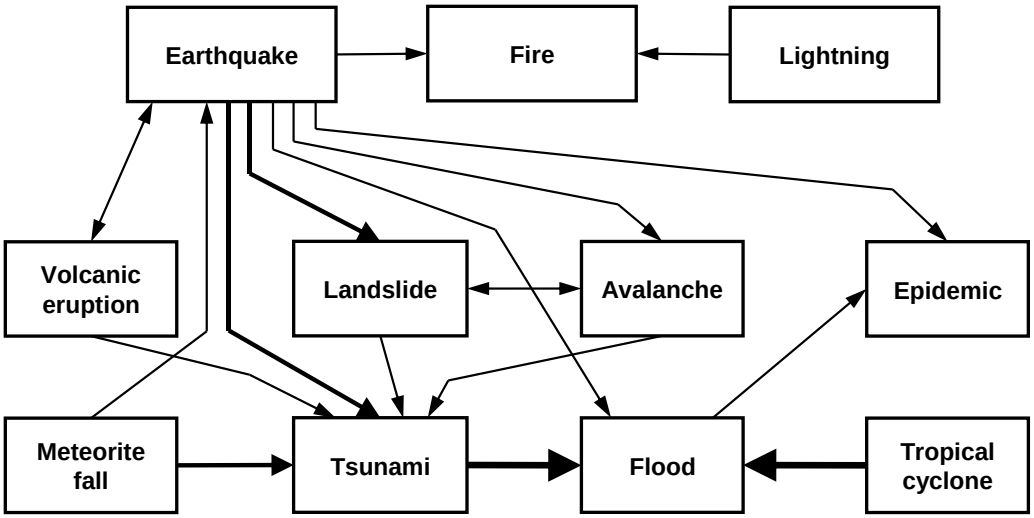


Fig. 1. Connections between different natural disasters.
The thickness of the arrows indicates the strength of the connection.

Interconnections and interactions exist between individual natural disasters and eco-catastrophes. A number of catastrophic processes can either directly generate other types of eco-catastrophes or create preconditions for them.

Chains of cascading events (illustrative examples: EARTHQUAKE, VOLCANO, etc.)

- **PAIRS:** Earthquake – landslide (onshore and/or submarine), earthquake – aftershocks, earthquake – tsunami, earthquake – volcanic eruption, earthquake – rockfall, earthquake – surface deformations and ruptures, earthquake – soil liquefaction, earthquake – avalanche (icefall), etc.
- **TRIPLETS:** Earthquake – landslide – tsunami, earthquake – volcanic eruption – tsunami, earthquake – deformations – tsunami, earthquake – icefall – tsunami, earthquake – soil liquefaction – landslide, etc.
- **QUADRUPLETS:** Earthquake – volcanic eruption – landslide – tsunami, etc.

This type of cascading risk phenomena cannot be unified by a single formula, despite the mathematical formalization of the phenomenon, because the problem is multi-parametric with many unknown parameters.

Some global examples

Table 1

Chain of disasters	**Location and initial source**	***Negative effects***	***Preceding events***	***Future expectations and Potential Early warnings***
Earthquake – tsunami	Lisbon, 1755. (Source in Atlantic Ocean)	Widespread destruction and flooding in many areas along European coasts	Earthquake felt several hours earlier	Yes, Early Warning System deployed.
Earthquake – volcano	Hawaii, 1975. Earthquakes preceded volcanic eruption of Mauna Loa	Powerful volcanic eruption	Earthquake swarm activated several months earlier	Yes, Early Warning System deployed.

Chain of disasters	**Location and initial source**	***Negative effects***	***Preceding events***	***Future expectations and Potential Early warnings***
Earthquake – tsunami	Indonesia, 2004. Extreme tsunami generated by powerful earthquake (M9.0)	Four continents, 12 countries affected, about 300,000 deaths and 1 million homeless people	No preliminary signals detected	Yes, Early Warning System deployed.
Volcano – tsunami	Krakatoa, 1883. Extreme tsunami generated by explosive volcanic eruption	20-meter tsunami struck Batavia (Jakarta) and surrounding coasts	Earlier seismic activity	Yes, Early Warning System deployed.
Volcano – landslide – tsunami	Anak Krakatau, 2018, Sunda Strait. Collapse of volcano flank built up by earlier eruption generated local tsunami	Severe Destruction and more than 3,000 deaths	Preliminary models predicted the consequences	Yes, Early Warning System deployed.
Earthquake – icefall – landslide – tsunami	Lituya Bay, 1958, Alaska. Megatsunami generated by earthquake-triggered rock/icefall	Glacier fall and landslide produced a huge tsunami (525 meters)—the highest in recorded history	Witnesses observed the collapse	No
Earthquake – flood	Mississippi, 1811	Missouri, flooded 500 km^2	Flooding started hours later	No
Glacier fall – mud flow – flooding	Nepal, 2026, Himalayas. Melted ice produced mud flow (~20 meters) and extensive flooding in lowlands	About 3,000 deaths. Secondary lake formed due to debris, preventing extensive rescue operations for some time	No preliminary signals detected	Yes, EWS intended
Hurricane – storm surge – flood – rip currents – tornadoes	New Orleans, Louisiana. Hurricane Ida generated storm surges, flood intrusion, strong rip currents, and tornadoes	112 deaths, over several hundred injured, many houses destroyed, tornadoes generated	Satellite tracking several days earlier showed possible path. Evacuation performed	Yes, Early Warning System works.
Earthquake – avalanche – mud flows – flood	Huascarán, Peru, 1970. Produced avalanche transformed into mud flows and flooding in lower areas	About 30,000 deaths, 1 town and 30 villages completely destroyed	No preliminary signals detected	No
Meteorological disturbance – meteotsunami – rip currents	Odesa, 2014	Beaches flooded, panic and rumors	No preliminary signals detected	No

Undoubtedly, the most typical example of such a chain event is an earthquake. It can generate a tsunami, trigger landslide processes, induce a volcanic eruption, serve as a release mechanism for snow avalanches, cause flooding due to dam failure, and so on [6]. Figure 1 schematically illustrates the connections between different natural eco-catastrophes.

As seen from the figure, earthquakes generate the most severe cascading multi-risks. One of the most serious cascading hazards is a tsunami, for which there are numerous historical examples with terrible consequences [7].

Analysis of Results

Just as with natural hazards and eco-catastrophes, secondary effects often have a comparable and sometimes even greater negative impact than the triggering phenomenon itself, and the primary hazard often leads to multiple secondary hazards with much higher destructive potential than that of the original hazard alone. Characteristic examples of this include the Lisbon earthquake of November 1755 and the Great Kantō fire in Japan. In Lisbon, the number of people drowned by the tsunami was comparable to those killed under the rubble numbering in the thousands. The number of victims burned in the Kantō fire of 1923 was many times greater than those who died as a direct result of the earthquake itself. Same was observed in Philippines [9].

Lightning is also one of the most common causes of wildfires, fires in barns and storage rooms with flammable materials, and, less frequently, in residential buildings. Globally, lightning accounts for about 5% of these fires. Statistics show that every year in the US, about 10,000 forest and field fires are caused by lightning. Fires also frequently occur in urban agglomerations, for example following an earthquake. A typical example is the seismic event in Kobe, Japan, where damage from fires exceeded that from ground shaking.

A landslide also triggered the major ecological disaster at the Vajont Dam on the river of the same name, a tributary of the Piave River in Italy. On October 9, 1963, a landslide of approximately 250 million/m^3 detached from the southern side of the valley and collapsed into the reservoir basin. As a result, a massive water wave was generated, exceeding the height of the dam crest by about 100 m. The surge swept down the valley, destroying five settlements and killing nearly 3,000 people.

There is also an interesting question that does not seem to receive sufficiently serious attention: whether the cumulative negative consequences of several smaller disasters equal the impacts of a single severe (catastrophic) disaster event. If this question were to be answered immediately, the answer is a definitive NO. There are many examples supporting this statement. For instance, it is impossible for several minor earthquakes to trigger the entire spectrum of negative effects associated with a single major earthquake. The effects of the latter are highly diverse crustal ruptures, landslide generation, tsunamis, ground liquefaction, etc. None of these effects can be produced as the cumulative result of a series of weak earthquakes [8]. Similarly, a series of small tsunamis occurring along the coasts of the Indian Ocean cannot reproduce the impact of a single giant wave, such as the one in December 2004, because low-magnitude tsunamis cannot propagate across an entire ocean and instead concentrate their energy only on nearby shores. It is likewise obvious that the destruction and damage caused by a single powerful hurricane are never the same as those from several smaller ones.

As with any rule, there are some exceptions here as well. For example, several small avalanches can displace as much snow in total as one larger avalanche. Several small wildfires can collectively destroy an area equivalent to that destroyed by a single large-scale fire. A series of droughts can ruin crops just as a larger one would… However, if all these series of small-scale disasters are spaced sufficiently far apart in time, the cumulative negative effect would be significantly mitigated.

Conclusion

Definitions of risk and cascading multirisks are presented with examples of generating disastrous events and observed negative consequences. The analysis shows clear nonlinear behavior of cascading multirisks which means difficulties in modeling and management. Troubles are expected in the early warning systems alerting the society about threats. All these difficulties need new complex algorithm to solve problems. This could be achieved by using AI and modern space technologies.

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