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METHODOLOGICAL CHALLENGES OF MULTI-RISK AND MULTI-HAZARD APPROACHES

DESAFIOS METODOLÓGICOS DAS ABORDAGENS MULTIRRISCOS E MULTIPERIGOS/MULTIAMEAÇAS

Thomas Glade[1]

Abstract:

Multi-hazards and risks are getting more and more important all over the world. Hereby, many different institutions and scientific disciplines are involved. A variety of multi-hazard and risk approaches are available. Following a brief review of the key terms in that field of disaster risk reduction, the main multi-hazard risk approach is presented. Hereby, the importance of interactions in terms of compound and cascading events is explored. The demand to move from classical risk management to disaster-based risk management is explored. Finally, challenging issues such as extreme events, emerging risks, communication in social media and artificial intelligence are put into perspective of multi-hazard risks.
Keywords: Multi-hazard, multi-risk, compound and cascading events, terminology, extreme events, emerging risks, social media, artificial intelligence.

Resumo:
Os multirriscos e multiperigos/multiameaças estão se tornando cada vez mais importantes em todo o mundo. Nesse contexto, diversas instituições e disciplinas científicas estão envolvidas. Existem várias abordagens para multirriscos e múltiplos perigos/ameaças. Após uma breve revisão dos termos-chave nesse campo de redução de riscos de desastres, é apresentada a principal abordagem de multirrisco. A importância das interações em termos de eventos compostos e em cascata é explorada. Além disso, a necessidade de uma transição da gestão de riscos clássica para a gestão de riscos baseada em desastres é discutida. Por fim, questões desafiadoras, como eventos extremos, riscos emergentes, comunicação nas redes sociais e inteligência artificial, são colocadas em perspectiva em relação aos multirriscos e multiperigos/multiameaças.

Palavras-chave: Multirriscos; multiperigos; multiameaças; eventos compostos e em cascata; terminologia; eventos extremos; riscos emergentes; redes sociais; inteligência artificial.

1. Introduction

Multi-hazards and following multi-risks are getting more and more important all over the world. Many disasters are occurring constantly – wildfires on Maui, Hawaii, an earthquake in Morocco, a flood in Dena, Libya or floods and landslides in Austria and Slovenia, to name a few examples from 2023 only. Each event caused significant consequences, including huge damages, many affected people, and in some cases even fatalities (Fig. 1). In most of these examples also multi-hazards and risks occurred, being

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compound events (i.e. different hazards occurring at the same time and region) or cascading events (i.e. one event leads to the next to the next etc.) (Alexander & Pescaroli 2019).

As all these examples show, the consequences for nature, but also for society are significant – and manifold (UNDRR 2022). Often, these consequences exceed the capacity of the locals to cope with the respective effects – and external help is required. The term "Locals" can refer to single persons, to families, to municipalities, to institutions ranging from major to city and regional councils, or even states, and might also include private enterprises. Therefore, the society as a whole is challenged.

In order to support sustainable development and to strengthen both the adaptation and coping capacities, concepts of multi-hazard risks have been developed. These concepts help to identify the process and impact chains, but can also be used to design preventive measures. These might include engineering structures, but also raising awareness and land use planning.

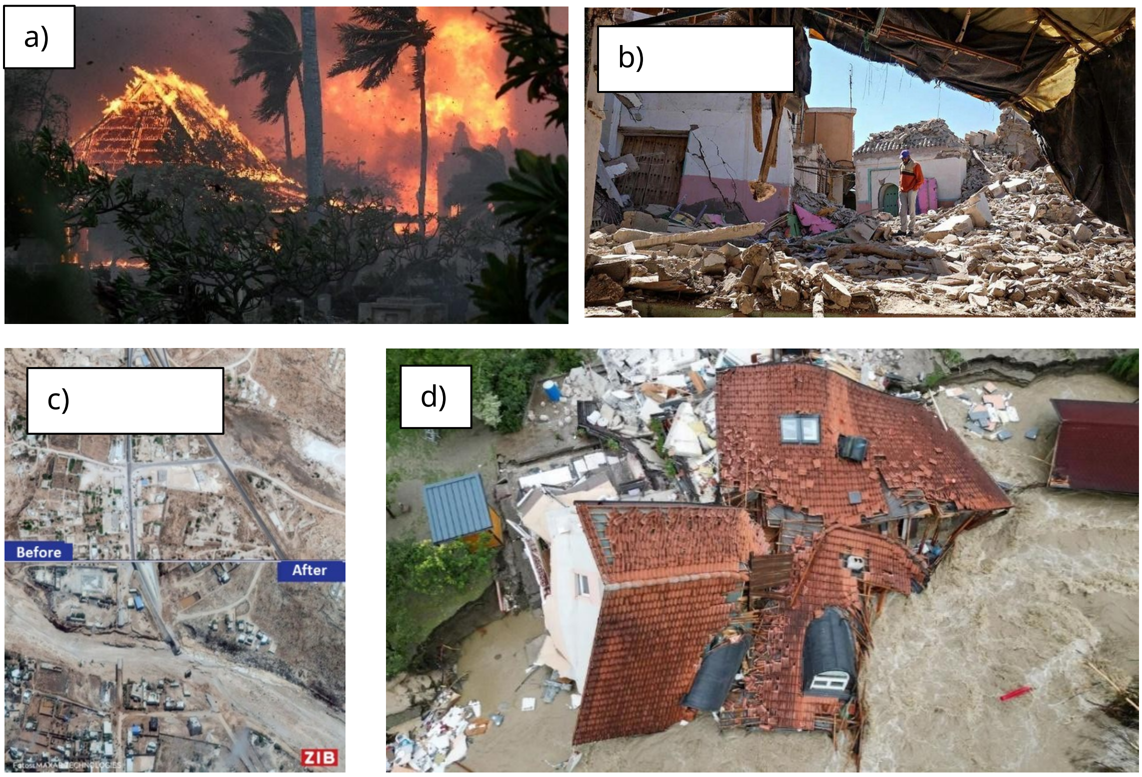

Fig. 1: Examples of hazards and devasting consequences of a) wildfires on Maui, Hawaii (Aug. 2023 – CNN 2023), b) earthquake in Morocco (Sep. 2023 – UNICEF 2023), c) flood in Derna, Libya (Sep. 2023 – ORF 2023), and d) floods and landslides in Austria and Slovenia (Aug. 2023 – ZEIT 2023).

To get into the multiple risk perspective within the previously mentioned examples, the extreme weather event in Slovenia, Croatia and Austria caused flooding and landslides

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and multiple consequences. Similarly in Haiti, where homes were and are subject to landslides and earthquakes, which makes these situations even more complex, challenging and – from a scientific point of view - interesting.

It is evident, though, that many different actors are working together in order to handle such events and the consequences. Many different scientific disciplines are involved too, ranging from engineers to natural and social scientist, but also lawyers, insurances, etc. are included. All involved parties have their tradition in using the most important terms, but it became evident with IDNDR and ISDRR, that a common definition of terms is missing. Therefore, the UN started an initiative to propose an international terminology, which is now being followed in international strategies – and literature. This terminology is reviewed in the following by explaining some basic terms in order to avoid any misunderstanding.

2. Basic terminology

Many various disciplines address multi-hazard and risk and related topics, and therefore, the definitions of similar words differ. In addition, also in different countries, same words can have another meaning in the respective cultural setting, and respective language. Therefore, it is appropriate, to reflect the relevant international literature to avoid any misunderstanding, or even confusion (UNISDR 2009, 2017).

Whether it is a flood, a landslide or a storm, this is defined as a **natural event**. The society is not necessarily affected. But once society is affected, that natural event is potentially damaging, turning into a **natural hazard**, which includes the probability of occurrence in a given area, with a known magnitude and within a predefined time (e.g. a day, week, month, years).

And then when we refer to a **specific hazard** for a given zone and a given reference period, you start with the risk, and with the risk, you also have the expected loss included, and the loss can be of different forms, such as lives, people injured, material damage and so on.

If we are also interested to investigate the consequences, we have to analyze the **risk**. If one combines a single or various hazards and the vulnerability of the elements at risk in relation to these hazards, we refer to a **specific risk** or a **multi-risk**. And that brings us to the **function of risk**, in which we have the hazard, the elements at risk and their vulnerability as follows:

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$$Risk = f(Hazard, ElementsatRisk, Vulnerability)$$

Herein, the Elements at Risk and their Vulnerability constitute the **consequences**. Commonly, these consequences are negative, e.g. monetary damage, number of fatalities or people displaced.

In the scheme of the risk equation, all **elements at risk** have some potential for harm, whether they are fixed points such as houses or bridges, fixed lines such as roads, or areas such as an airport. But they can also be mobile elements, such as commuting people, moving cars or other means of transportation, and live lines (e.g. energy lines, water supply, gas and oil pipelines, etc.).

These elements can be exposed to a hazard in a given susceptibility zone. This is not yet risk, but rather **exposure**. In order to move on to risk, a quantification of risk is essential.

Different types of processes as well as different intensities of one hazard might affect the same element at risk. However, the element at risk might be characterized by different vulnerabilities. In this context, we also have to consider the **paradox of vulnerability**. This paradox refers to a situation, that the more structured the country, the less susceptible the services are to interruption. But if they are interrupted, the consequences can be even greater. In other words: the more you invest, the safer you are, but if you fail, the consequences are even greater.

Within any type of risk assessment, we will always have the **residual risk**, which is the risk that remains unmanaged, even when risk reduction measures are taken. The residual risk expresses the consequences, no matter what proportion of measures and actions are taken, the remaining risk will always be there.

The question under debate is often how effective the taken measures must be in order to reach a **tolerable risk**. Here, tolerable should be understood as the measures that must be taken so that the existing risk can be reduced to a level where society agrees on the remaining risk. In contrast, **acceptable risks** refer to a risk level, which is generally accepted by the society, and no countermeasures have to be installed.

Also, resilience, adaptation and coping are some key terms used in disaster risk. **Resilience** is defined as the amount of disturbance that a system can absorb and still remain in a degree of self-organization. **Adaptation** is the increase in the learning capacity of this

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system in the face of a disturbance. If a society is affected by a single or multi-hazard, it is essential how the different actors can **cope** with the impact.

Risk management as such refers to a systematic report on managing uncertainty to minimize potential damage and losses. This differs from **disaster management**, which is the total interruption of the functioning of a society. Disaster – or catastrophe – refers to a situation, where the impact exceeds the capacity of the affected community to cope with its own resources, which can be on a municipal, state or regional scale. External support is required to deal with this situation.

Risk-based disaster management must include the consequences – therefore "risk-based". This concept must consider the hazards and the elements of risk, such as exposure, coping capacity and respective vulnerability. It is a systematic process to be applied in administration, in particular. These institutions are directive organizations and have operational skills to implement strategies in order to reduce the adverse impacts of the hazard (e.g. Glade & Crozier 2005)and the possibility of a disaster occurring. At the same time, they should increase the capacity of the potentially affected system or community to deal with the consequences.

Another term that emerged in the last decades is the term **risk governance**, which can be defined as a process by which risk information is collected, analyzed, and management decisions are made and communicated (Greiving & Glade 2013). This risk governance is carried out by different stakeholders and different actors in the social group, i.e. risk management is often carried out by experts and specialists in the field only, whereas governance goes beyond (IRGC 2017). Within a risk governance process, all different types of parties are involved, such as landowners, insurance companies and municipalities, who have a specific perception of the "problem" as such and who have different ideas how to solve it (Greiving et al. 2014). In this setting, the experts may participate if they get involved as agreed by all parties. This whole process has to be embedded in the different resources, being them human resources and social capital, financial and technical resources or institutional means (Fig. 2). To make up this core of risk governance, it takes a lot of time and energy to bring all the stakeholders together and moderate the necessary discussions. But since the final agreement on actions has been negotiated together, by involving all parties, the result(s) are commonly accepted, refer to local demands, requests and needs and also are implemented much quicker.

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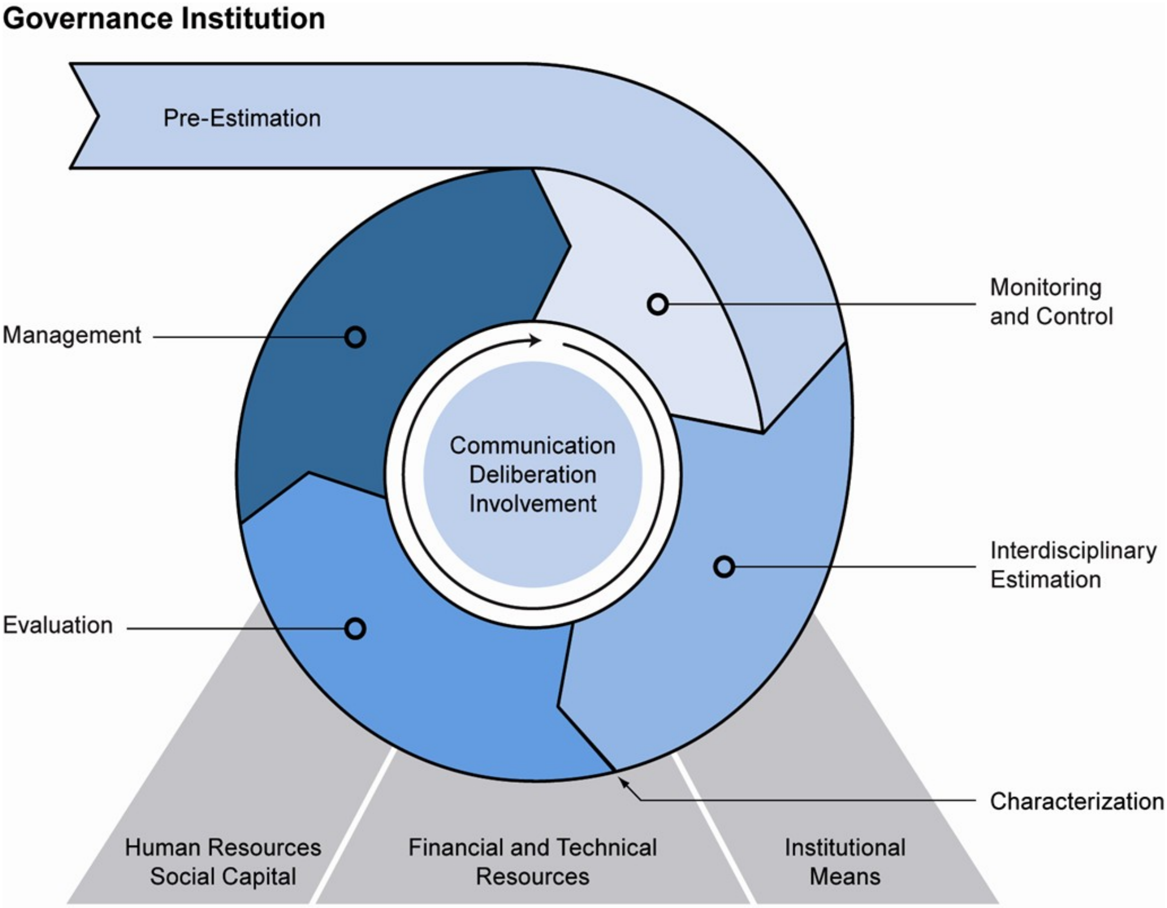

Fig. 2: The principle of risk governance (IRGC 2017).

As a major consequence there is a need for **transdisciplinary collaboration**, including also scientists working together with stakeholders such as public bodies. And the scientists can immensely benefit from these collaborations, thus this cooperation between science and practice is really essential and beneficial for all parties (Bell & Klinke 2015).

3. From hazard to risk

In order to move from hazard to risk analysis, a lot of data on the different elements at risk and vulnerability in relation to a given hazard is required. But once hazard and risk is calculated, respective results can be compared with other hazards and risks, and respective adaptation strategies can be developed – and ultimately implemented.

Within data acquisition, the first step is to set up a database or hazard inventory based on your knowledge of environmental factors, triggering conditions, elements at risk and the potential damage. This data acquisition can be done using topographical maps, images from satellites or drones (e.g. Erdelj et al. 2017), different types of open-source online data and

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historical data. By complementing all these information with the reported damage of past events, an overview of vulnerability can be established for the different elements at risk in relation to the different hazards.

With regard to the elements at risk, different types include critical infrastructure (e.g. schools, transport facilities, hospitals, energy supplies), lifelines (e.g. roads, water and energy network including power grid, oil and gas pipelines), the population, the economy, but also environmental elements indeed (e.g. vegetation, soil, hydrology). For the same element at risk, there might be different types of risk. In the category of "buildings", for example, there are different specific elements such as number of floors, type of building materials, number and age structure of residents. Furthermore, these different risks can be categorized for different types of elements, and by combing all available information, a database can be developed which provides for instance information on elements at risk and individual vulnerabilities to a particular hazard.

In the next step, the assessment of the different hazards and their individual characteristics needs to be assessed. Hereby, natural hazards are often differentiated in meteorological, hydrological, geophysical including geomorphological and geological hazards, biological and ecological hazards, extraterrestrial hazards. These natural hazards are often accompanied with man-made and technological hazards. In any case, it has to be known where the hazards occur, how often, how strong the magnitude is (e.g. Crozier 1999), when and for how long they will last. All these information will finally allow us to develop a hazard model. In addition, it is most important to get the best possible information on the different factors influencing the occurrence of hazards, namely the disposition factors (e.g. the slope gradient, underlying lithology, etc.), the triggering factor (e.g. rainstorm events, earthquakes, but also man-made explosions or slope modifications), and the controlling factors of the movement (e.g. vegetation cover, topographic conditions).

Once summarized, one is able to determine the spatial probability, temporal occurrence and intensity for an individual hazard or to conduct an overall multi-hazard assessment. Such a detailed study has to be carried out for each hazard, such as floods, landslides, storms, blizzards, snow avalanches, tsunamis, earthquakes, soil erosion, drought, to name a few hazards only. It is evident, that within any hazard analysis, the assessment of magnitude and frequency is very crucial.

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Within any hazard assessment, the mapping of the extent, the magnitude and the timing should be based on historical events and involve the affected communities and experts. In addition, the hazard modeling should not be static, thus for a given condition only. It should rather be dynamic and involve potential changes in the future, considering not only climate change, for example, but also urban development and land use change (e.g. Hufschmidt et al. 2005), which would be very useful when considering alternative prevention measures.

After achieving information on the events, the hazards, the elements at risk and the respective vulnerabilities, all this data must be combined within a risk analysis. Here, all the different aspects have to be quantified in order to get a *quantitative risk assessment* (e.g. Bell & Glade 2004). If such quantitative data for the hazard, the elements and the vulnerability is not available, or only partially available, a *qualitative risk assessment* has to be performed. Indeed, the quantitative and the qualitative assessment differ, but it has to be stressed, that both assessments have their pros and cons. Uncertainty is inherent on all assessments and consequently both assessments fulfill their strength to support decision makers in the implementation of the best possible preventive measure, being it a direct intervention by a structural measure (e.g. a dam, snow avalanche fences, rockfall nets) or indirect measures (e.g. raising awareness, land use plans). In both cases, especially if these are combined, there is comprehensive information available for further analysis. The final risk maps show not only the hazards, but in particular the expected consequences. All information of different kind should be presented in a variety of means: printed documents, but also digital, e.g. in animations or visualization within a GIS and/or web-based interface.

4. From single hazards to mult-hazards – and interactions

After having moved from events to hazards and finally risk, there is a recent urgency to address the multi-faceted nature of both hazards and risks (van Westen et al. 2011, 2020). When examining most recent events, one realizes, that in most cases, the hazards do not occur as single processes, but they are somehow interconnected (Gill & Malamud 2016) – and similarly risks. There are different types of connections, also in terms of one-way or two-way interactions (Fig 3).

Within **compound events**, different processes occur in a given time interval in the same area. For example, there is a storm event on a given day, and the next day, there is an

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earthquake. **Coupled events** are characterized by the same trigger for different processes in the same area. For example, a major storm event occurs which cause overland flow on the slopes and then causing floods. Another type of interaction are **domino or cascading events**. This type is defined as one process leading to the next and to the next and so on – for example, a storm event that causes a landslide on a slope which blocks the valley (Alexander 2018). This causes a rise in the level of the blocked river that floods a nearby house. Once the lake overtops the landslide deposition, it erodes it very quickly and causes a devasting flood, which might impact significantly the river course and settlements far away from the landslide deposition – and possibly also in far distance to the triggering rainfall event (e.g. Pescaroli & Alexander 2016). Besides the distance issue, another major challenge herein is the time window, during which these cascading events might occur (Pöppl & Sass 2020). The cascading events might follow up immediately, or within a few hours, or days, or weeks or sometimes even years. This is a challenge for the potentially affected society.

In this context, these interactions and sometimes coincidences of these hazards and the different vulnerabilities for the various elements at risk have to identified. All of these dynamics have to be addressed within multi-risk studies. This comprehensive concept requires knowledge of the different hazards and their interactions, of the various triggers, of the various elements at risk and their vulnerabilities in order to determine the different effects. The investigation of these interrelationships is dynamic and becomes increasingly complex as one process influences another, which leads to a huge cause-effect matrix of different types of hazard combinations (Fig. 3).

A major challenge for any disaster risk assessment is the manageability of these complex conditions. If there are interconnections between different atmospheric, biophysical and geophysical environments, we have to identify our complex system as a human society in different variables. On this path, experts have begun to engage in impact-based forecasting, focusing on impact chains (Cocuccioni & Pittore 2023) to get information about what might happen in the future. Since the occurrence of events will affect people, affect families, municipalities and the economy in the future, such assessments are one of the key strategic management decisions our whole society is facing.

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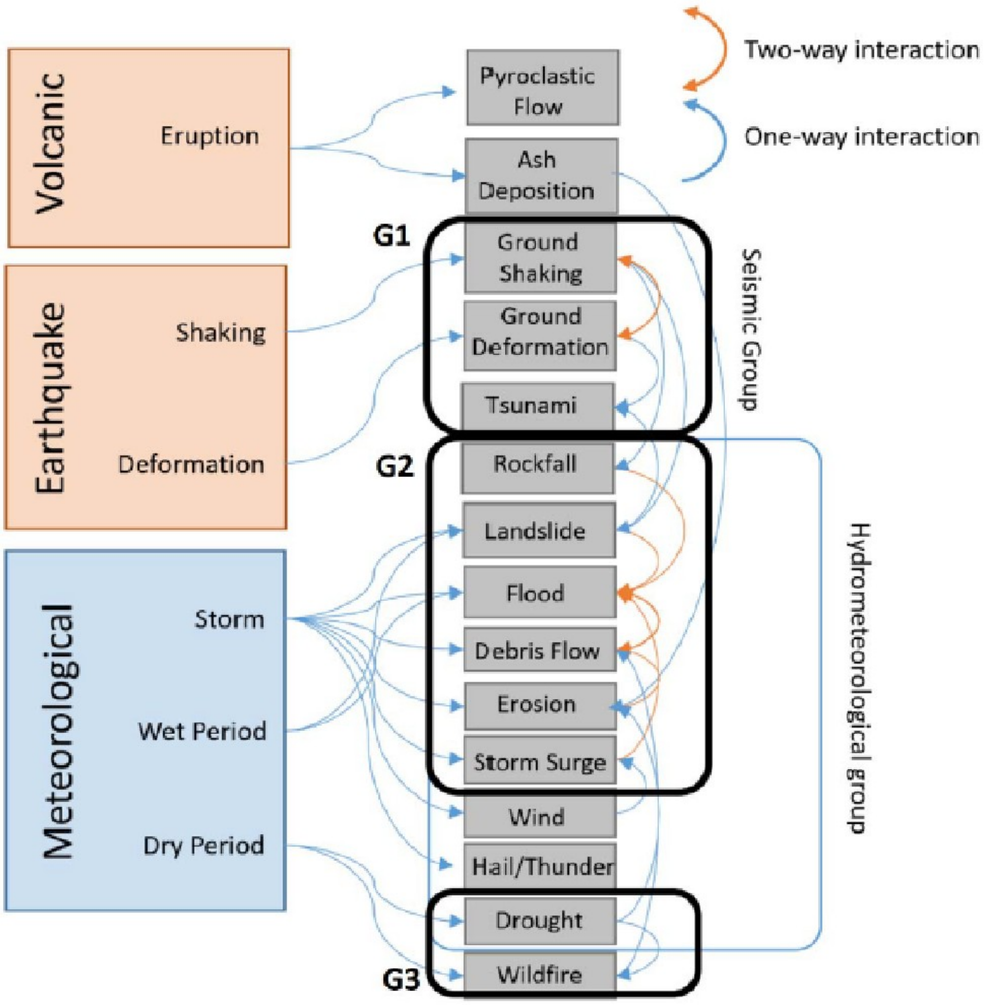

Fig. 3: Single hazards and various potential interactions (Gill & Malamud 2016)

5. Multi-hazard risk assessments

Unfortunately, there aren't many tools available to identify multi-risk, particularly on a local scale. This is due to the fact, that the processes themselves are often so complex, broad and general and consequently, a lot of data are required – data specific to the individual location, region or country. Therefore, it is most important to have models for processing this data within software tools. Ultimately, these tools should be able to include future scenarios, potential losses and allow for the availability of multi-risk interaction information.

Within climate change, the focus should not only be on studying these changes but also has to include how the society can adapt to these changes. Hereby the discussion is not if these changes happen or not, the only question is when they will occur, and where in which magnitude and with which consequences. And these changes do not relate to climate change

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only but refer also to socio-economic change. Population density, age and income changes, all this alters exposure and vulnerability. For example, the same person who experienced a flood 50 years ago and managed to escape, might not be able to rescue themself due to a limited physical condition today. Thus, not only the hazards, the interactions change, but also the socio-economy changes within all its facets.

In order to address these observations, **impact chains** are currently under development. This demand raises from a current risk situation and the knowledge, that this will change in the future. Consequently, these potential future climatic and socio-economic changes have to be addressed for the potentially affected community. Based on such information, the capacity of affected groups to cope and adopt to these changes will ultimately strengthen community resilience.

And this might open new options for reactions: For example, it might not be wise to invest millions and millions of e.g. US $ to improve and maintain technical structure, it might be more sustainable to relocate people to a new area that isn't exposed to the same hazard. Such process can only be run together with all stakeholders, such as the municipal government, small businesses, landowners and so on. Hereby, the hazards, the elements at risk and the vulnerabilities need to be identified, the types of linkages between them need to be determined in order to support the community in developing their own, individual adaption and coping strategy. And this whole process should be governed by the risk governance concept.

6. Challenges in multi-hazard risk analysis

Although the required efforts for the previously described procedures are evident, there are additional challenges which we need to address carefully in the near future. Although these challenges seem not to be appropriate in many regions, it is important to carefully consider them.

One of the largest challenges is the increased occurrence of extreme events (Glade et al. 2020; Huppert et al. 2006). Extreme events can be characterized by extreme process, by extreme consequences, or by a combination of both (Tab. 1). Examples of *extraordinary processes* include devasting floods, huge landslides or intensive droughts. This is often associated by the change in the process, e.g. different periods are getting hotter or colder in

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their extreme values, or generally hot periods are getting colder and cold periods are getting hotter (e.g. IPCC 2012). *Extreme consequences* might refer to the number of fatalities or the infrastructure affected. Therefore, a similar rainstorm event with a given return period might have caused minor damage in the past. But since the region developed heavily and much more assets are exposed and highly vulnerable, the same event might now cause a catastrophe, thus is extreme with regard to its consequences. And indeed, in many cases it can be observed, that both – the changes in the process and the changes in the exposed elements at risk and their vulnerabilities – occur simultaneously. Consequently, measuring the occurrence of these extreme processes is a major demand.

Tab. 1: Two different definitions of extremes, which can also occur jointly (Mergili et al. 2018).

Extreme Processes	Extreme Consequences
Extraordinary physical events that deviate from a means of observational observation	Extraordinary in terms of consequences
Charakteristics: Mass, volume, velocity, precipitation, energy released	Deaths, injuries, damage to buildings, critical infrastructure
Not necessarily a disaster	**Disaster**

The second challenge are newly emerging risks (Mazri 2017), referring to changes in their components, such as exposure and vulnerability. There might be new hazard types in areas that never experienced these before (e.g. flash floods in small side valleys). In addition, known processes might occur with magnitudes, which have never been experienced or (at least) reported beforehand. Due to the lack of knowledge, the society's ability to cope is very limited, and this circumstance would ultimately increase the damage. Since these emerging risks are difficult to forecast, it is most demanding for the society to prepare themselves for these unexperienced events. Nevertheless, prevention needs to be carried out, making public authorities and stakeholders aware of such potentially emerging risks and the consequent risk condition in order to be better prepared in the future.

The third challenge are social media and networks (Keim & Noji 2011). Hereby, fast and direct communication is of major importance, and also needs to be addressed in a comprehensive risk management (Alexander 2014). From an interaction perspective, there is a fast and quick exchange of content between individuals, institutions and social organizations

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on different types of platforms (Domalewska 2020). In disaster management, digital communication is sometimes much faster than traditional approaches, allowing responsible institutions to integrate this information into emergencies, planning and crisis management (Civelek et al. 2016; Zhang et al. 2019). Social media will get increasingly important also in the risk cycle within response, recovery, prevention and preparedness (Dufty 2015) (Fig. 4). But there is also the inherent danger of the spread of false and misleading information and this can lead to the failure of this type of action.

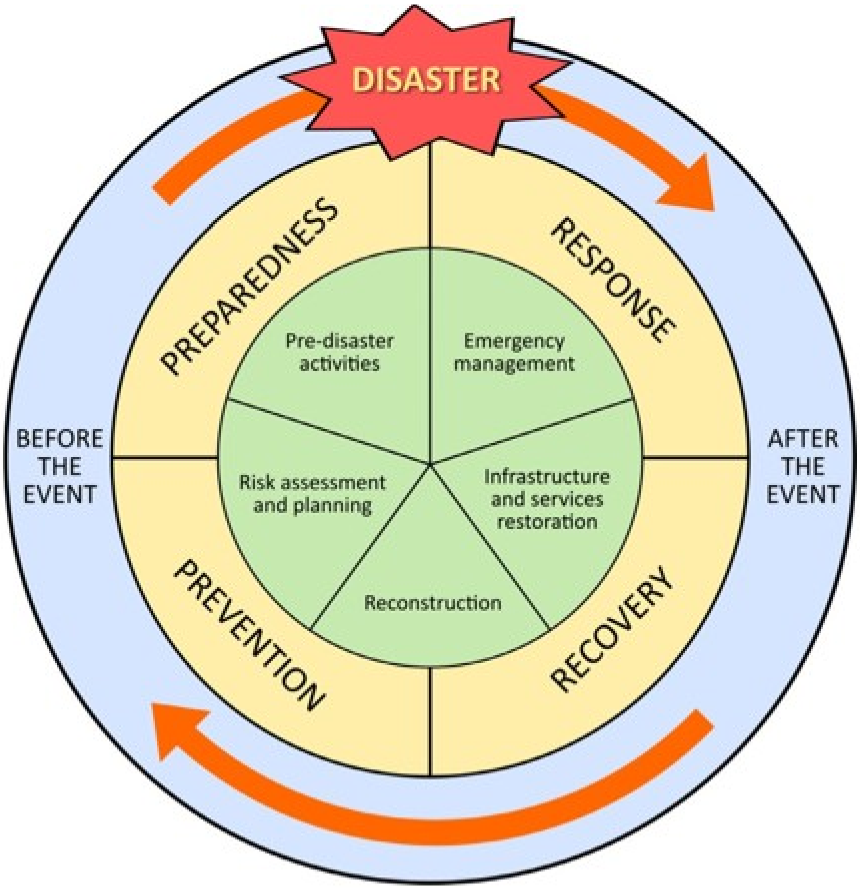

Fig. 4: One disaster management cycle (Erdeli et al. (2017).

Finally, a last challenge is cyber technology (e.g. Rossi et al. 2019) and machine learning, herein particularly artificial intelligence AI (Guikema 2020; Sun et al. 2020). There are computer programs capable of processing new data without the help of humans. These results can be achieved in seconds, such as analyzing from an image where the road is, what kind of damage has happened here and what the house numbers are along this road. Such a data gathering could never be done at this speed with traditional approaches. And there are

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many, many more examples. The main disadvantage is that the routines and criteria used to identify items and characteristics by AI is unknown. Such AI systems often develop patterns of analysis which are not reproducible. On the other side, there are major advances and changes possible (Abid et al. 2021; Velev & Zlateva 2023) – in particular with reference to the utilization of big data (Yu et al. 2018). The disaster risk community has to further explore the usability of AI in the different steps of disaster risk cycle (Thekdi et al. 2023).

7. Closing remark

Our society has to face these different challenges - and many others. The whole society has to recognize and understand that we are living in a dynamic environment and world that is constantly changing. The key question is how to address these different challenges and how to prepare ourselves better and sustainable for the future. These challenges are becoming increasingly complex in all their dimensions and the society should not ignore them just because it is difficult.

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