Assessing cascading effects from multiple hazards

An example from Sweden

SEI project brief
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"Multiple hazards" are hazardous events that occur "simultaneously, cascadingly, or cumulatively over time" (UNDRR, 2020). Vital societal services are assets essential for the maintenance of societal functions (European Commission, 2019), whereas critical infrastructure can be defined as the physical structures that maintain these functions (MSB, 2014).

The HydroHazards project explores locations, sectors, and vital societal functions exposed to multiple hydrometeorological events. The project devises methods and tools to assess the cascading effects that multiple events may have upon critical infrastructures and social groups. This brief provides an overview of these methods and tools and a summary of their application in a Swedish case study (see Figure 1 for a timeline of activities).

The stable welfare society in Sweden and in Nordic countries in general makes them among the least vulnerable societies in the world. However, exposures to multiple hazards are on the rise, not least due to climate change impacts (Hieronymus et al., 2022).

Much of the existing assessments of climate change impacts are large-scale simulations. Small- and local-scale assessments are necessary for nuanced understanding of possible impacts of multiple hazards on society. This view is needed for supporting local adaptation strategy and planning. At the same time, societies' dependency on critical infrastructure and vital societal services is increasing, due to growing system complexity and interconnectedness. Together, these shifts are likely to increase societal vulnerability and impact adaptive capacity.

In response to this need, HydroHazards zooms into the municipality of Halmstad to explore the likelihood of multiple hydrometeorological (i.e., water and weather) events occurring sequentially or in the same location. Furthermore, we investigate the effects that climate change may have on the intensity and frequency of multiple hazards by focusing on extreme – low likelihood but high impact – events. Lastly, we look at the cascading or so-called domino effects on critical infrastructures and vital societal services and how these effects may cause new social vulnerabilities.

Multiple hazards in Sweden

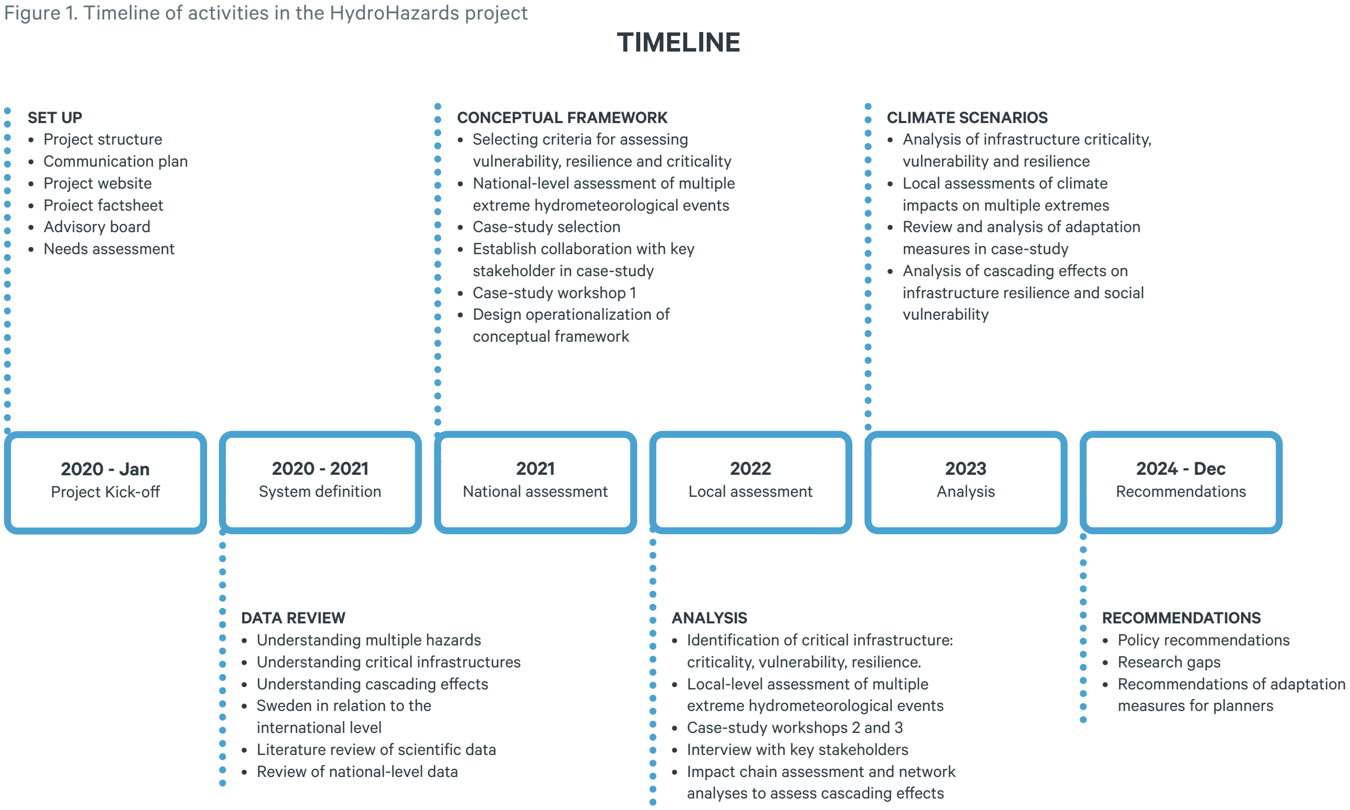
Climate change already has increased exposure to multiple hazards: HydroHazards' nation-wide analysis showed that multiple extremes of at least 10-year return levels of precipitation and streamflow tend to cluster around the summer months for most of the

IMAGE (ABOVE): Flooding in Lysekil during Storm Ciara © W.CARTER / WIKIMEDIA country (Hieronymus et al., 2022). Extreme sea levels were found to occur simultaneously over large areas and may thus contribute to “multiple extremes”, where impacts are amplified because many neighbouring locations are affected at the same time.

The analysis also shows that extreme precipitation, extreme river stream flows and extreme sea levels are unlikely to occur at the same time in the same location: extreme sea levels tend to occur in winter months; extreme river streamflow in spring; and extreme precipitation most often in summer. However, parts of Sweden’s south and west coast are the exception, where the hydrological extremes are more strongly connected to winter storms or earlier spring flooding than the more northern parts of the country; therefore, the likelihood is higher in these places that floods and extreme sea levels will occur at the same time. Furthermore, the southeast coast was found to typically have both high precipitation and high river streamflow during July.

Thus, the potential for multiple extremes is present in most of Sweden for some months of the year. This national-level analysis needs to be combined with detailed local assessments to properly quantify the hazard, its potential impacts and cascading effects.

Figure 1. Timeline of activities in the HydroHazards project



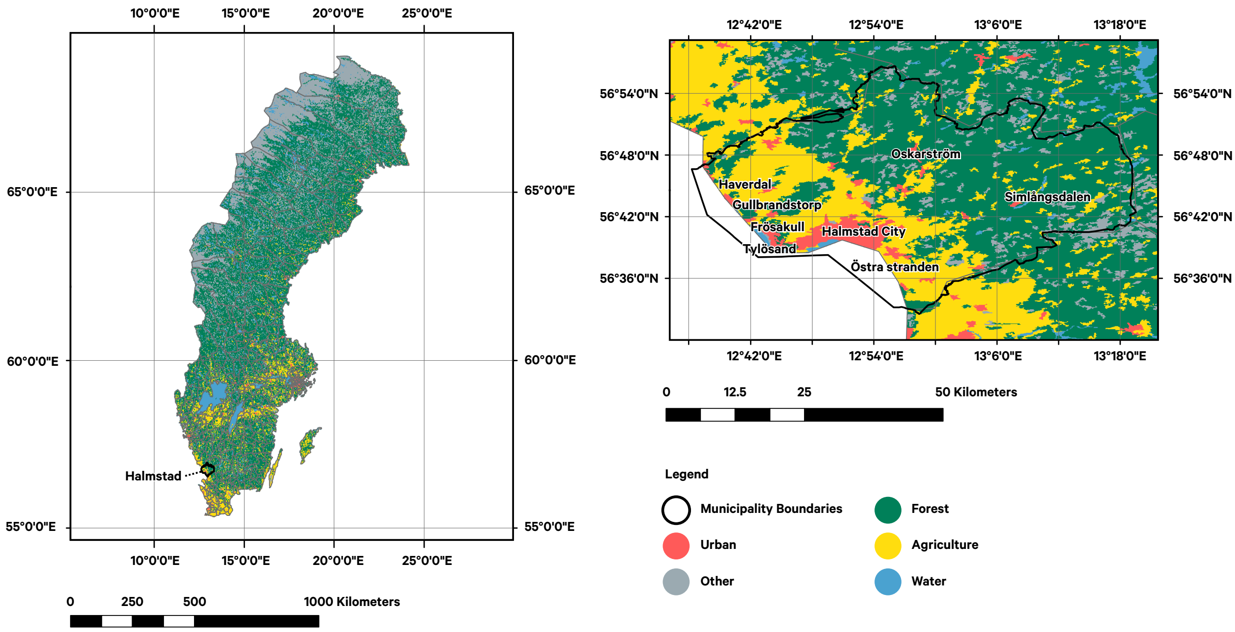
Multiple hazards in Halmstad Municipality

Preliminary results of the HydroHazards project’s hotspot mapping of multiple hydrometeorological extremes in Sweden showed that Halmstad was among the areas exposed to multiple water hazards (Hieronymus et al., 2022).

Halmstad is a coastal town located in Laholmsbukten, in southwest Sweden, with a population of around 70 000 (SCB, 2022). The river Nissan runs through Halmstad, dividing the city into two areas with clear socioeconomic differences. Citizens residing in the eastern neighbourhoods have less education, less income and fewer employment opportunities in comparison to those living in the western parts of Halmstad (Delmos, 2020).

Halmstad's geographical location makes it particularly vulnerable to water-related risks (Figure 2). The city is exposed to flooding and storm surges from a local effect due to the right combination of the direction and strength of wind and waves. That confluence triggers extreme local sea level rise, resulting in 50- to 100-cm higher sea level in Halmstad compared to nearby coastal towns (Johansson, 2018). As climate change unfolds, Halmstad is expected to have increased risk of rising sea levels, high fluvial flows, and intense precipitation. Droughts and heatwaves have also been shown to lead to reduced groundwater levels and shortages of drinking water in the region (Halmstad Municipality, 2022).

Figure 2. Halmstad Municipality



Source: Copernicus Land Monitoring Service (2018)

Halmstad Municipality is actively working on climate adaptation, with the aim of reducing the municipality's vulnerability and seizing opportunities to build a resilient and robust society for the long term (Halmstad Municipality, 2021). In November 2021, Halmstad adopted a climate adaptation plan that is divided into three parts: the baseline analysis, the municipal council's plan for climate adaptation, and the municipal board's plan for climate adaptation. Five priority areas are considered particularly exposed to the effects of climate change:

- health and well-being,
- buildings, construction and urban planning,
- critical infrastructure and technical provisioning,
- cultural and natural environment, and
- recreation

Moving forward, Halmstad Municipality seeks to analyse what hazards can cause disruptions in vital societal services and critical infrastructures within each priority area. Thereafter, a plan will be drafted outlining prioritized adaptation measures, accompanied with a time plan for implementation.

Criticality, vulnerability and resilience

Based on the area exposed to multiple hazards, we identify critical infrastructures and their services at risk and evaluate nine criteria (see Figure 3):

BOX 1

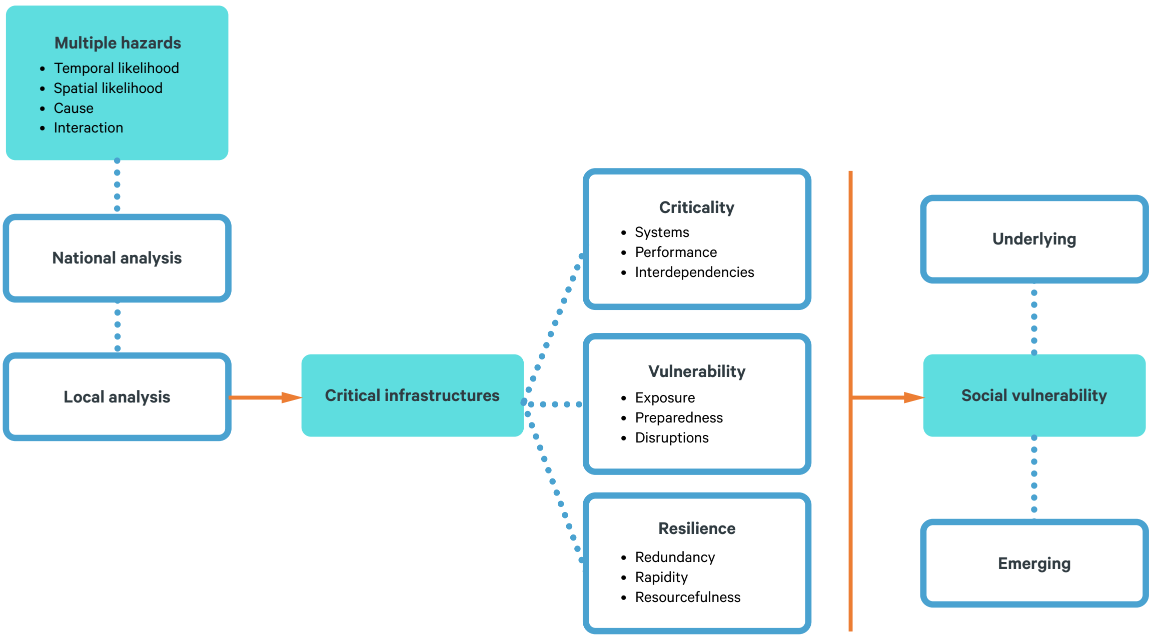
Criticality is a relative measure of the importance of a piece of infrastructure in relation to the consequences of a disruption or failure, for the security of a supply of important goods and services to society (Kruse et al., 2021).

Vulnerability refers to the conditions determined by physical, social, economic and environmental factors or processes that increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards (UNDRR, 2020).

Resilience in hazards research means the ability to survive and cope with a disaster with minimum impact and damage. It incorporates the capacity to reduce or avoid losses, contain the effects of disasters, and recover with minimal social disruptions (Cutter et al., 2008).

- Criticality:
  - **risk of systems** is a function of the hazard likelihood, the asset's vulnerability, the resilience of the asset, and the magnitude of the consequences resulting (Petit et al., 2015);
  - **performance** is the operation of a system under normal circumstances (i.e., before a hazard; Fu et al., 2018);
  - **system interdependencies** are bidirectional relationships between two infrastructural systems, through which the state of each infrastructure influences or is correlated to the state of the other (Guidotti et al., 2016).
- Vulnerability:
  - **exposure** to hazard zones that make people or infrastructure subject to potential losses (UNDRR, 2020);
  - **preparedness** for disruptions includes activities undertaken by an entity in anticipation of the hazards, and the possible consequences, to which the entity may be subject (Petit et al., 2015);
  - **disruptions** are short- or long-term interruptions of normal operations, which may cause a service or infrastructure to be temporarily unavailable or to operate at significantly lower capacity (DRI International, 2021; Pant et al., 2018).
- Resilience:
  - infrastructure **redundancy** is the degree to which a system is substitutable and can continue satisfying functional requirements in the event of disruption (Bruneau et al., 2003);
  - **rapidity** or time of recovery is the capacity to recognize problems and contain and avoid further losses (Bruneau et al., 2003);
  - **resourcefulness** is the ability of a system to mobilize resources to manage disruptions (Bruneau et al., 2003).

Figure 3. HydroHazards seeks to assess the impacts of multiple hazards on critical infrastructures and the cascading effects on vital societal services and social vulnerability



Social vulnerability is explored considering two types of vulnerability: underlying vulnerabilities, which capture intersectional indicators, for example income or age, and emerging vulnerabilities, following infrastructure disruptions or due to adaptation or mitigation actions. Emerging vulnerabilities may not be linked to underlying social vulnerabilities; for example, neighbourhoods that are not socially vulnerable still may lack access to pharmacies or grocery stores during shorter or longer periods of time during a disaster, or coastal neighbourhoods at risk of erosion usually are home to less socially vulnerable populations, with higher levels of wealth and education.

Network analyses and impact chains

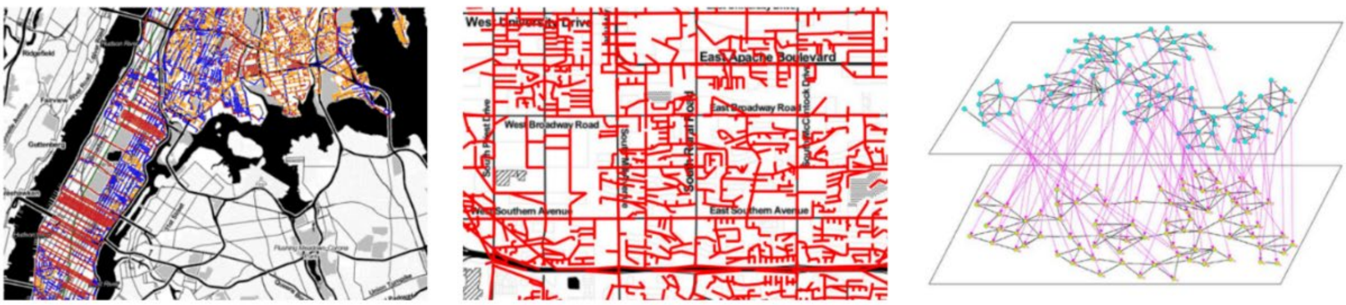
Infrastructure is inherently connected, dependent or interdependent (Holden et al., 2013; Rinaldi et al., 2002). Studying these interdependencies is complex because of the interplay of societal factors, but also because infrastructures are complex adaptive systems.

HydroHazards highlights physical interdependencies, which include material commodities, or inputs and outputs, such as water, foodstuffs or electricity. This is done through a flow-based method applying network analysis. Wherever location data for critical infrastructure and its network are lacking, we use a methodology called synthetic distribution networks (Ahmad et al., 2020; Saha et al., 2019). Figure 4 shows a synthetic network.

Data collection is structured according to the Impact Chain model (Fritzsche et al., 2014), that was developed by Eurac Research (Schneiderbauer et al., 2013) and has been aligned with the IPCC AR5 terminology (Zebisch et al., 2017). The Impact Chain model is an analytical tool to “better understand, systemize and prioritise the factors that drive risk in the system of concern” (Zebisch et al., 2017, p. 27). The approach proposes eight modules and subsequent steps to *inter alia* (1) identify potential climate impacts and risks, (2) determine hazards and intermediate impacts, (3) determine the vulnerability of the system, and (4) determine exposed elements (Fritzsche et al., 2014; GIZ et al., 2018).

In HydroHazards, impact chains are applied to identify cascading effects on the population. This is done through a mixed methods approach combining results from the network analysis with participatory mapping and expert-based validations.

Figure 4. Example of synthetic distribution networks



Water distribution | Power distribution | Interdependencies

Sources: Ahmad et al. (2020); Saha et al. (2019)

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