Swedish Civil Contingencies Agency

Research

HydroHazards

Popular Science Report

HydroHazards Popular Science Report

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Lead researcher/author: Karina Barquet

HydroHazards investigated multiple water hazards in Sweden, focusing on cascading and compound risks affecting critical infrastructure and vulnerable populations. Using a case study in Halmstad, the project developed a decision-support tool to aid climate adaptation, combining hazard mapping, social vulnerability indices, and stakeholder insights. Findings indicate the need to go beyond the primary impact area to better understand cascading effects on vital societal functions, which in some cases can result in more severe consequences for infrastructure and social vulnerability than the initial shock.

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Preface

This popular science report presents the key findings from the HydroHazards project, funded by the Swedish Civil Contingencies Agency (MSB) and the government research council for sustainable development (FORMAS) and carried out between 2020 and 2024. As extreme hydrometeorological events become more frequent and complex, understanding their potential impacts on society is critical to improving planning, preparedness, and the protection of both people and essential services.

HydroHazards provided new insights and practical tools for managing disaster risk, with a particular focus on multiple, compound water-related hazards in the Swedish context. The project addressed risks at both regional and local levels, combining environmental and societal perspectives. It identified trends and hotspots for floods, droughts, and heatwaves, while also examining how social vulnerabilities and interdependencies between critical infrastructure systems can amplify the consequences of extreme events.

A central innovation of the project was its systems approach to understanding cascading effects—how the failure of one critical service can affect many others. While the project used natural hazards as the primary trigger, the methods and tools developed are transferrable to a wide range of disruptions, including cyber threats, pandemics, and geopolitical shocks. This makes the project relevant not only for climate adaptation, but also for strengthening broader civil preparedness.

This report is intended for professionals working with disaster risk management, climate adaptation, and civil protection, as well as interested non-experts. It aims to support a deeper understanding of how environmental hazards intersect with social and infrastructural systems—and how we can collectively strengthen resilience in the face of growing uncertainty.

Stockholm, 30/05/2025

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Contents

Introduction

1. Introduction

Societies are highly dependent on multiple infrastructure systems for the delivery of essential functions and goods. Simultaneously, natural hazards such as floods are intensifying in many regions, disrupting key water, electricity, and communication systems. This dependence, combined with rising hydroclimatic risks, is expected to exacerbate existing vulnerabilities or create new ones through cascading effects across interconnected infrastructures and services.

Although significant progress has been made in predicting and mapping hydrometeorological hazards, substantial knowledge gaps remain regarding their potential adverse impacts on people and critical infrastructure. The Hydro-Hazards project investigated multiple water-related hazards at both regional and local scales to support planners in mitigating these risks.

At the regional level, the project assessed the likelihood of compound hydrometeorological events occurring simultaneously in the same area, identifying the West Coast as particularly exposed. To examine social vulnerability to such events, an indicator-based vulnerability framework was developed at the municipal level, using Halmstad municipality as a case study. Spatial analyses were conducted to evaluate potential impacts on Halmstad's critical infrastructures— emergency services, communication, transportation, wastewater, electricity and water supply. Network analyses were also applied to assess cascading effects of infrastructure failures on vital societal functions.

The methodology and tool draw on open-source data and the participation of local stakeholders from various sectors. Findings were compiled into a decision-support tool designed to help planners prioritize adaptation and preparedness measures. Future research aims to enhance the tool by integrating features such as goods flow, real-time risk detection, and additional hazard types to strengthen urban resilience.

This final project report is structured as follows: Section 2 outlines the theoretical framework for assessing multiple water hazards; Section 3 presents national-level findings; Section 4 presents results from the case study in Halmstad; and Section 5 offers concluding remarks.

Exposures of social systems to multiple water hazards

2. Exposures of social systems to multiple water hazards

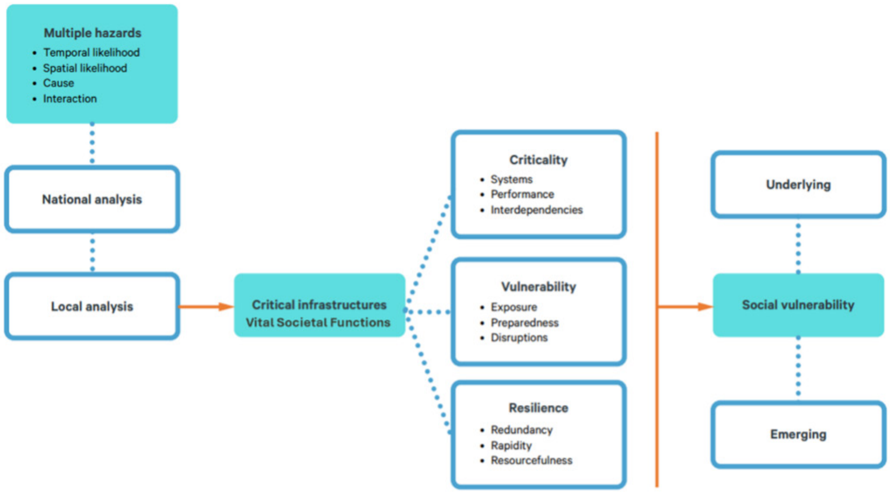
Climate change is expected to lead to a range of hydrometeorological risks in Sweden, including extreme rainfall, high river and lake levels, storm surges, snowstorms, droughts, and water shortages. Traditional risk and vulnerability assessments often focus on individual risks, potentially overlooking connections between different events. However, multiple natural events can occur simultaneously or trigger cascading effects (domino effects) and lead to cumulative impacts over time. As climate change progresses, the effects of such events are expected to increase, which, combined with society's growing reliance on critical services, could affect societal vulnerability and adaptive capacity.

This study analysed areas, sectors, and essential services particularly exposed to multiple hydrometeorological events at national, regional, and local levels in Sweden. A special focus was placed on identifying social groups at the local level that rely on critical services and may be negatively impacted if these services are disrupted. The overall goal of the HydroHazards project was to provide insights for planning and decision-making on strategies and adaptation measures that can reduce vulnerability and increase resilience.

A framework was introduced for assessing the impact of multiple hydrometeorological hazards, such as floods and storms, on Critical Infrastructures (CIs) and Vital Societal Functions (VSFs), like emergency services, communication, transportation, wastewater, electricity and water supply. With the increasing complexity of infrastructure and urbanization, societies, including Sweden, are becoming more vulnerable to such hazards. While traditionally focusing on single hazards, this approach highlights the importance of understanding how multiple hazards interact and their cascading effects on essential services.

The proposed framework combines key concepts such as criticality, vulnerability, and resilience (Figure 1). It uses a mixed-methods approach that is both accessible and flexible, designed to be applied to various case studies and adaptable to different conditions. A crucial aspect is differentiating between physical infrastructures (CIs) and the services or entities that constitute VSFs, allowing for a better analysis of both pre-existing and emerging social vulnerabilities. Disruptions to critical services can have ripple effects, potentially worsening societal vulnerabilities, particularly for more fragile social groups, or creating new vulnerabilities.

Figure 1. Framework used in HydroHazards to assess impacts from multiple hazards. The flowchart illustrates how the analysis of multiple hazards begins at the national level and continues at the local level, where impacts on critical infrastructures and vital societal functions are assessed. The assessment focuses on three dimensions: criticality (systems, performance, interdependencies), vulnerability (exposure, preparedness, disruptions), and resilience (redundancy, rapidity, resourcefulness). Finally, it shows how these dimensions together influence social vulnerability, shaped by both underlying and emerging factors.



The core of the project is a case study of Halmstad municipality, which is vulnerable to water-related risks such as flooding from high sea levels, extreme river flows, pluvial flooding, as well as drought-induced drinking water shortages. Climate change is expected to exacerbate these issues. Halmstad is actively working on climate adaptation with a focus on building long-term resilience, guided by a climate adaptation plan divided into three parts: a current situation analysis, a climate adaptation plan from the municipal council, and one from the municipal executive board.

The case study involved stakeholders from public administration, businesses, and civil society, along with researchers, through workshops, interviews, and surveys. SMHI contributed with climate and hydrometeorological models to support Halmstad's planning. Capacity-building activities took place, and a decision-support dashboard was developed to enhance the municipality's understanding of how to apply these models in practical planning.

Multiple-extremes in Sweden, physical characteristics across the country

3. Multiple-extremes in Sweden, physical characteristics across the country

3.1 A nationwide analysis of multiple water related hazards in Sweden

Coastal flood risk was evaluated together with precipitation and river streamflow in a nationwide analysis to highlight areas that might be exposed to an elevated risk of water hazards. The analysis emphasized the seasonality of the different extremes by looking at return levels for different months. A secondary analysis also related sea level extremes to different weather patterns (Hieronymus & Kalén, 2022).

The main finding was that in most parts of Sweden, the most extreme river streamflows —typically the spring floods— occur later in the season than the highest sea levels. However, along parts of the western and southeastern coasts, these two water hazards tend to coincide within the same season. This overlap was one of the key reasons for selecting Halmstad as the case study. In contrast, the most extreme precipitation events occur across the country during the summer, when higher temperatures increase the atmosphere's capacity to hold moisture.

The weather pattern analysis for sea level extremes revealed that large areas of the coast experienced the most extreme sea level under one specific atmospheric pattern, and that different patterns dominated along the western, southern and northern coastlines. This analysis strongly suggested a large spatial homogeneity in coastal flooding. That is, large areas of the coast tend to experience sea level extremes at the same time, which may complicate efforts to bring in help from neighboring municipalities during extreme events.

3.2 Regional hotspots of floods, droughts, heatwaves and their co-occurrences

This study assessed how well different climate indices can detect natural hazards like heatwaves, droughts, and floods across Sweden (Vieira Passos et al., 2024). The findings offer insights into hazard detection and trends over the past century, revealing some interesting patterns.

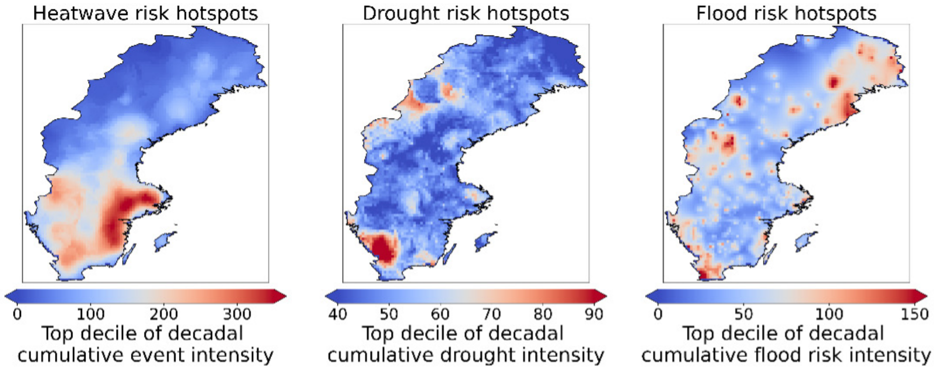
Indicators for heatwave detection, particularly based on temperature data, can accurately detect heatwaves in Sweden, previously documented by SMHI. The study found that heatwaves are becoming more frequent and intense, especially in southern Sweden. The most extreme heatwave occurred in July 2018 in Kalmar County, lasting 31 days. Heatwaves typically happen between June and August but can also occur in May and September, especially in the south.

Drought indicators such as the Standardized Precipitation and Evapotranspiration Index (SPEI) also performed well to detect dry periods, though slightly less effectively than heatwave indicators. Severe droughts in Sweden have been recorded during periods like 1933–1934, 1976, and 2016–2019. Historically, southern Sweden has experienced the longest droughts, with the longest lasting over seven years in Halland County during the 1930s. Droughts have occurred more often in the past, particularly since the 1960s, due to a long-term wetting trend. In 2018 a severe drought event impacted Sweden, causing extensive damage to agriculture, water supply, and energy sectors (Bakke et al., 2020).

Flood detection proved to be the most challenging, with mixed results depending on the indicators used. However, the Daily Flood Index (DFI) showed reasonable accuracy, and trends indicate an increase in flood events over time, particularly in southern and northern Sweden. In these areas, periods with elevated flood risk – as indicated by consecutive days with a positive DFI value – can extend for over 100 days, with such prolonged high-risk periods becoming more frequent over time.

The hazard hotspots map revealed areas in southern Sweden that are particularly vulnerable to heatwaves and droughts, while both southern and northern regions face significant flood risks (Figure 2). Climate change seems to be driving these trends, with heatwaves and floods expected to become more frequent and intense over the coming decades.

Figure 2. Identified hotspots of hydroclimatic hazards in Sweden (Vieira Passos et al., 2024). The figure shows three maps of Sweden highlighting hotspots of hydro-climatic hazards: heatwaves, drought, and floods. The left map shows heatwave risk hotspots, with the highest cumulative event intensities concentrated in southern Sweden and along parts of the western and eastern coast (red areas), while northern regions show lower risk (blue areas). The middle map displays drought risk hotspots, with the highest intensities in southern Sweden, especially around Skåne and Gotland. There are also a few smaller orange hotspots along the southeastern coast, in some inland areas, and in the northwest near the Norwegian border. The right map illustrates flood risk hotspots, with scattered high-risk areas across central and southern Sweden and several notable hotspots in the northeast. Color scales range from blue (low risk) to red (high risk) for each hazard type.



The study also explored how these hazards– heatwaves, droughts, and floods – might overlap. For example, heatwaves and droughts frequently co-occur, particularly in northern Sweden during the summer months, while floods are more likely to follow droughts in certain regions. The study highlights that as these hazards become more frequent, their combined impacts could be more severe, especially as the interdependencies between them evolve due to climate change.

A continuation of the study on hazard hotspots was undertaken in collaboration with another project to estimate the impacts from these hazards on water, energy, food supply, and property damage (Vieira Passos, Kan, et al., 2025). Results indicate that droughts contributed to 2.9 billion euros in losses in Sweden from 2005 to 2022. Crop yields, surface water availability, and hydropower production have been significantly reduced due to droughts in 2013, the period from 2016 to 2018, and 2022. Heatwaves in 2018 exacerbated agricultural losses and storm Gudrun led to extensive property damage in 2005. Flood damage on infrastructure is associated with 4.7 billion euros in losses during the study period, affecting mostly the insurance sector and propagating to other sectors such as real state and electricity production.

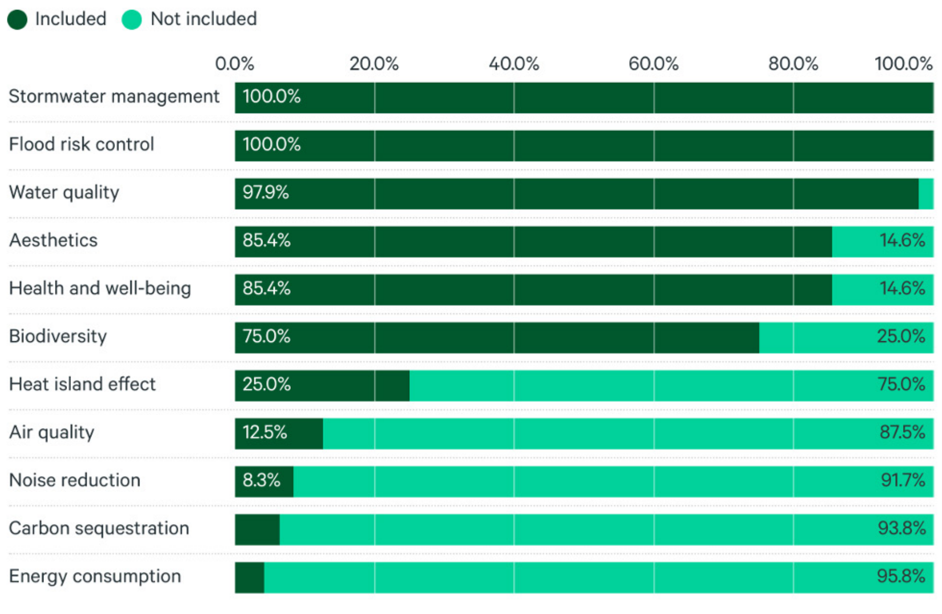
3.3 Nature-Based Solutions in Swedish Stormwater Management

The project also examined the planning and policy context for implementing nature-based solutions (NbS) in municipal stormwater management in Sweden (Gunnarsson & Barquet, 2025). Through an analysis of 48 municipal steering documents, we assessed their alignment with national, EU, and international policy frameworks and cost data availability. The findings reveal that while NbS are widely recognized – though often not explicitly named as such – the availability of cost estimates, especially for operation and maintenance, remains limited.

Municipal documents increasingly highlight the multifunctionality of NbS and their potential co-benefits, such as flood risk reduction, improved water quality, biodiversity, aesthetics, and public health. However, other benefits, including heat regulation, carbon sequestration, and energy savings, are less frequently addressed. The analysis also identifies challenges in clarifying roles and responsibilities across stakeholders, particularly for shared or privately owned land, and underscores gaps between regulatory support and practical implementation.

Overall, the report highlights both opportunities and barriers for scaling up NbS in Swedish municipalities, emphasizing the need for standardized cost data, stronger integration of co-benefits into planning, clearer allocation of responsibilities, and better alignment with policy frameworks to fully realize their potential in sustainable stormwater management.

Figure 3. Coverage of different co-benefits in the analysed municipal stormwater documents. Figure 3 shows the share of municipal stormwater documents that mention different co-benefits of nature-based solutions. All documents (100%) include co-benefits related to stormwater management and flood risk control, and nearly all (98%) reference water quality improvements. Aesthetics, health and wellbeing and biodiversity are addressed in about 75–85% of documents. In contrast, fewer documents mention heat island reduction (25%), improvements to air quality (13%), noise reduction (8%), carbon sequestration (6%), and energy consumption (4%). The figure highlights that while multifunctionality is widely acknowledged, several potential co-benefits remain underrepresented.

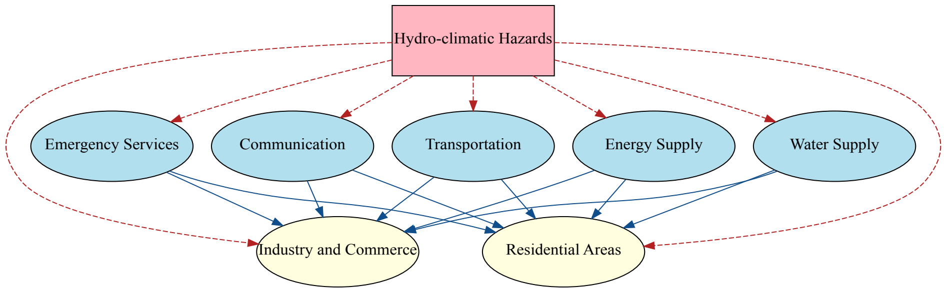


Case study in Halmstad

3.4 Cascading effects on multi-sectoral critical infrastructures

Based on the HydroHazards' framework (Figure 1), a model was developed to estimate cascading risks on interdependent infrastructures (Barquet et al., 2022; Vieira Passos, Barquet, et al., 2025). The model connects vital societal functions of physical type between multiple sectors, such as the delivery of electricity from power substations to hospitals. The generated infrastructure interdependency network comprises five layers: emergency services, communication, transportation, electricity supply, and water supply (Figure 4). By considering the spatial connections between critical infrastructures and vital societal functions, some aspects related to criticality, vulnerability, and redundancy can be measured at local and systemic levels. The model was tested in Halmstad's municipality, in collaboration with stakeholders, which provided data and inputs regarding the relative importance of different sectors delivering vital societal functions.

Figure 4. Cascading hydrometeorological hazard risks in infrastructure systems. The diagram illustrates how hydro-climatic hazards affect critical societal functions and, ultimately, people and businesses. At the top, hydro-climatic hazards influence five key sectors: emergency services, communication, transportation, energy supply, and water supply. These sectors are shown in blue ovals. Arrows from these sectors lead to two main impact areas shown in yellow ovals: industry and commerce and residential areas. The diagram also shows interconnections among sectors, where disruptions in one (e.g., energy supply or transportation) can cascade into others and affect both economic activities and households. Dashed red arrows illustrate the overall feedback loop, where impacts on industry, commerce, and residential areas can, in turn, increase vulnerability to hydro-climatic hazards.



The results for Halmstad showed that communication towers, power plants and substations, and water treatment services were the most critical nodes in the infrastructure network due to their high number of outgoing connections. Some road intersections could be identified as key transmission points for emergency and transport services. To enhance systemic redundancy and emergency preparedness, planners can consider alternative routes to improve efficiency in service delivery. Infrastructures related to residential, industrial and educational sectors were the most vulnerable, primarily due to their reliance on basic services like transport, water, energy, and telecommunications.

A detailed disruption analysis with existing inundation maps showed which nodes were at risk from coastal, river, and heavy rainfall flooding. The disruption of a power plant located near a flood prone area would result in the most extensive cascading failures, affecting many nodes from multiple sectors. Other significant potential disruptions included wastewater treatment plants and communication towers, causing major connectivity losses and overall network performance reduction.

This study highlights the importance of understanding vital societal functions' interdependencies to improve resilience to flooding hazards, particularly in urban planning and climate adaptation. The findings emphasize the need for protecting highly provisioning infrastructure nodes to prevent or mitigate widespread cascading effects. The developed model provides a quantitative tool for local planners to assess systemic vulnerabilities and prioritize climate adaptation investments. The tool provided detailed maps showing infrastructure networks and high-risk areas, enabling planners to simulate potential failures in specific sectors and assess the resulting chain reactions. Results can guide future decisions on which essential infrastructure and services to prioritize for reducing systemic risks. The tool shifted users' understanding from focusing solely on the primary or direct impacts of hazards to recognizing the significance of network effects, which can lead to more severe disruptions than the initial event. By using the tool, local planners identified critical public utilities and neighbourhoods that had been previously overlooked, informing the municipality's climate adaptation strategy. Future directions include validating assumptions with open-source data against official utility data and the addition of aspects related to supply and demand of goods in the network. The infrastructure interdependence model developed in Halmstad is a prominent example of advances in complex climate change risk assessment for adaptation in coastal areas (Simpson et al., 2025).

3.5 Social vulnerability index for flooding

As part of the case study in Halmstad, a Social Vulnerability Index (SVI) for flood risks was proposed and tested at the municipality level using data for demographic areas or neighborhoods (DeSO), and combining bottom-up and top-down approaches with focus on socially-just flood protection (André et al., 2022; Englund et al., 2022, 2023; Petutschnig et al., 2023).

The study identified ten key variables for assessing social vulnerability to flooding in Halmstad Municipality. These variables derived from stakeholder dialogues and cover aspects related to human and social capital, access to resources, and exposure to risks. Some variables contribute to increased vulnerability (sensitivity), while others enhance resilience (adaptive capacity). Age was one such variable, with both the very young and the elderly highlighted as vulnerable groups. Young children and older adults may struggle with mobility and accessing critical information during a flood, making them more dependent on others for evacuation. The percentage of people under 15 and those over 75 were used as indicators of these age-related vulnerabilities.

Language proficiency was another important variable, particularly for foreign-born residents. Stakeholders pointed out that language barriers can hinder access to emergency information, a challenge that was observed during the COVID-19 pandemic. While no direct data on language proficiency exists in Sweden, the percentage of foreign-born individuals serves as a proxy for this variable. Foreign-born residents, depending on their time in Sweden, income, education, and housing situation, may face additional challenges in understanding the crisis management system.

Health conditions and disabilities were also identified as factors increasing vulnerability. People with serious mobility impairments, intellectual disabilities, or those dependent on healthcare services may require assistance to ensure their safety. The number of sick leave days, a proxy for illness and disability, was used to assess the number of people with reduced functional capacity due to long-term illness or disability. Educational attainment also emerged as a critical factor. Adults with lower education levels often have less access to information and financial resources, making them more vulnerable. Two indicators were used to measure education: percentage of people who completed only primary education and those with at least two years of post-secondary education.

Single-parent households were noted as a potentially vulnerable group, as they face greater demands during extreme weather events. Unlike co-habiting parents, single parents are less likely to share responsibilities with another adult, increasing their dependency on external childcare services. Vehicle ownership was identified as a factor that can reduce vulnerability, as access to a car facilitates evacuation. Housing type also played a role, with house owners bearing more responsibility for protecting their property against flood risks compared to apartment dwellers, who can rely on housing associations. Income, unsurprisingly, was a key determinant of vulnerability, with lower-income households having fewer financial resources to cope with flooding. Four indicators were used to assess income, including the proportion of households with income below 60% of the national median and those with income above 200% of the median.

Unemployment, particularly long-term unemployment, was also associated with higher vulnerability. Long-term unemployed individuals are less likely to have the financial means to recover from a flood. Finally, human exposure to flood risk was assessed using the average distance to areas exposed to river and coastal flooding.

One notable exclusion was gender. Although some stakeholders identified it as a relevant factor, our analysis found that gender had minimal influence on social vulnerability to flooding in Sweden. A possible explanation is that in Nordic contexts, gender-based differences in vulnerability are often outweighed by other intersecting factors—such as socioeconomic status, ethnicity, and psychological capacity to adapt to climate-related hazards.

Factor analysis was implemented to aggregate the ten input variables into three main factors contributing to flooding vulnerability. The first factor, ”House-owners with children”, showed high scores in rural areas and smaller towns, which are home to 30% of Halmstad’s population. These areas are characterized by agricultural or forestry land use, with many residents living in single-family houses and owning vehicles, due to the distance from municipal services and employment centers. The second factor, ”People outside the labour force”, had the highest levels of vulnerability. Eastern Halmstad, which was developed during Sweden’s 1965–1975 housing boom, scored particularly high. These areas consist mainly of rental apartments, have high unemployment rates, and are home to many low-income and foreign-born residents. Östra Stranden, a coastal area with a high flood risk, also scored high due to its exposure to both coastal and fluvial floods and its transient population, which includes tourists and residents in sublet housing. Oskarström, the second-largest locality in Halmstad, also exhibited high vulnerability due to a significant portion of its population having low incomes and lower levels of education. The third factor, ”Elderly with accumulated wealth”, indicated low vulnerability in coastal neighbourhoods dominated by affluent, older residents. These areas, especially popular during the summer season, attract wealthier individuals living in single-family homes. A fourth factor, “Exposure”, was included to reflect the average distance between a locality and potentially inundated areas during extreme events near the coast and the Nissan River.

The overall social vulnerability index for Halmstad Municipality revealed a clear spatial divide in socioeconomic conditions. The Nissan River, which runs through the city, separates eastern neighbourhoods with lower education, income, and employment levels from more affluent western areas. The vulnerability index ranged from −1.7 to +2.1 standard deviations, with eleven neighbourhoods identified as the most vulnerable, scoring above +1 standard deviation. These vulnerable neighbourhoods are home to 21,910 people, representing 22% of Halmstad's total population. The findings underscore the strong disparities in vulnerability across the municipality, driven primarily by factors related to income, education, and employment, and the role of geographical exposure to flood risks.

3.6 Compound flooding risks: causes and the effects of climate change

Compound flooding from sea level extremes, river streamflow and precipitation was evaluated in Halmstad using a large ensemble of downscaled climate projection from the model intercomparison project (CMIP5) (Hieronymus et al., 2024).

River streamflow and sea level extremes were found to co-vary on interannual timescales, primarily due to their shared sensitivity to the North Atlantic Oscillation (NAO). In years with a strong positive NAO phase, more low-pressure systems reach the Swedish coast, bringing increased precipitation and strong winds. This results in amplified variability in both sea levels and river streamflows.

Climate projections were also analysed to assess whether the covariance between these hazards is influenced by climate change. However, the natural variability in both hazards was too large for any climate-driven signal to be clearly detected within the ensemble available, indicating the need for more comprehensive data to draw firm conclusions. Nonetheless, both hazards exhibited strong warming-related trends. The assessment concluded that future increases in compound flooding risk are very likely to be driven primarily by mean sea level rise, with secondary contributions from increases in mean river discharge.

An interesting local phenomenon was observed: during certain sea level extremes, Halmstad experiences significantly higher sea levels than neighbouring areas. While this pattern is confirmed by observations, it is not captured by our models. The exact cause of this localized effect remains unknown. However, our analysis revealed strong correlations between sea level extremes and both wave height and direction, suggesting that wave setup may be a contributing factor. Wave setup is a localized process that elevates mean sea level in areas where wind-driven surface waves break, while slightly lowering it outside the breaking zone. This effect can persist for several hours—long enough to be recorded by tide gauges or leave a detectable imprint. To conclusively determine the cause and spatial extent of this phenomenon, additional high-resolution measurements are needed.

Conclusions

4. Conclusions

The HydroHazards project successfully integrated emerging concepts in disaster risk reduction into practical planning tools and management strategies. By combining regional and local analyses, the project shed light on the growing risks posed by both single and compound water-related hazards in Sweden, as well as the social and infrastructural vulnerabilities that amplify their impacts.

Key findings reveal that climate change is intensifying multiple hydroclimatic hazards—including floods, droughts, and heatwaves—and increasing the likelihood of their co-occurrence. These risks are further compounded by society's reliance on interconnected infrastructure systems. Our analysis of cascading impacts across sectors identified critical nodes—such as power substations, communication towers, and water treatment facilities—that, if disrupted, can trigger widespread systemic failures.

At the same time, social vulnerability is unevenly distributed. Demographic factors such as age, income, education, employment status, and migration background influence how different groups are affected by disruptions to vital societal functions. The social vulnerability index developed for Halmstad revealed stark inequalities between neighbourhoods, with clear spatial divides and clusters of high vulnerability linked to both socioeconomic conditions and geographical exposure.

The project's innovative framework, tested through a case study in Halmstad, offers a flexible tool for assessing both physical and social vulnerabilities to multiple water hazards. It enables local planners to visualize infrastructure interdependencies and simulate cascading risks, thereby supporting more informed and targeted adaptation planning.

Importantly, while natural hazards were the primary trigger examined in this project, the approach and tools developed are transferrable to other types of disruptions—such as cyberattacks, pandemics, or geopolitical shocks. The propagation of cascading effects through critical infrastructure systems follows similar patterns, regardless of the initial cause. As such, the methodology can contribute to broader civil preparedness efforts, enhancing overall societal resilience by helping decision-makers anticipate and manage systemic vulnerabilities across a range of scenarios.

The results highlight the need to move beyond traditional, hazard-specific assessments toward systemic, cross-sectoral approaches that incorporate indirect, interconnected, and compound risks. As climate and other global threats grow more complex, risk management must become more inclusive, integrated, and data-driven. Continued collaboration between researchers, policymakers, local authorities, and communities is essential for designing adaptive and cost-effective strategies that strengthen resilience in the face of future uncertainties.

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