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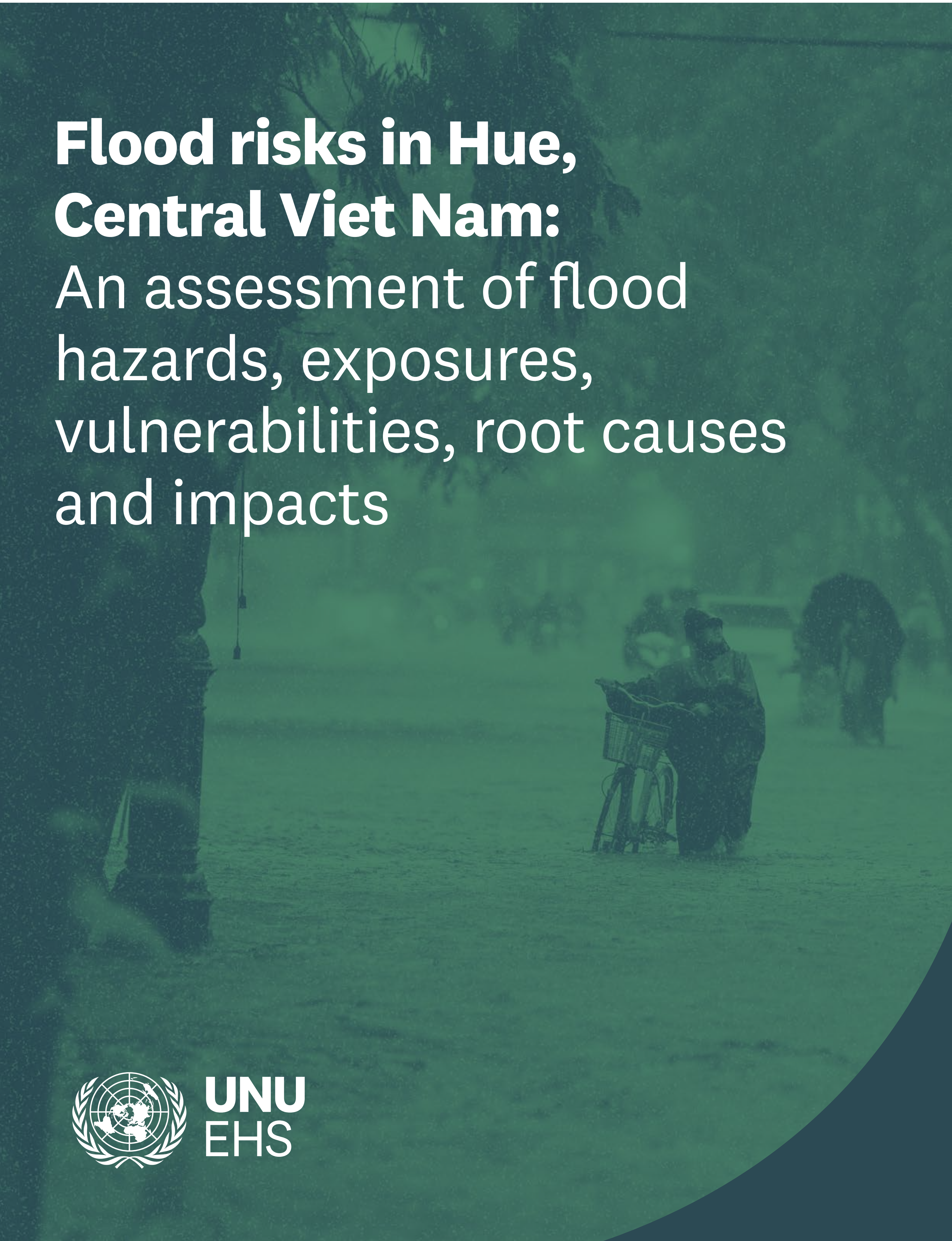

Flood risks in Hue, Central Viet Nam: An assessment of flood hazards, exposures, vulnerabilities, root causes and impacts

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FLOOD ADAPT VN

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Tóm tắt

Với đường bờ biển dài và dân số đông tập trung dọc theo các sông và vùng ven biển, Việt Nam là một trong những quốc gia chịu ảnh hưởng nặng nề nhất bởi lũ lụt trên thế giới. Tỉnh Thừa Thiên Huế nằm ở miền Trung Việt Nam là một trong những khu vực đặc biệt dễ bị lũ lụt. Hằng năm, khu vực này phải chịu khoảng 2–3 trận lũ với mức độ khác nhau, gây thiệt hại đáng kể về người, cơ sở hạ tầng và môi trường. Trong tương lai, để giảm thiểu tác động của lũ lụt và tăng cường khả năng chống chịu, việc hiểu rõ các yếu tố gây ra lũ lụt và cách chúng dẫn đến những tác động bất lợi là rất quan trọng. Điều này bao gồm việc xác định các khu vực dễ bị lũ lụt, các đối tượng bị ảnh hưởng và đánh giá mức độ dễ tổn thương trước các nguy cơ từ lũ lụt. Tuy nhiên, hiện nay những thông tin này vẫn chưa đầy đủ, gây khó khăn trong việc quản lý rủi ro lũ lụt.

Để giải quyết các vấn đề trên, báo cáo này sẽ cung cấp những hiểu biết sâu sắc về bản chất phức tạp của rủi ro lũ lụt tại khu vực đô thị của tỉnh Thừa Thiên Huế. Báo cáo cũng sẽ đưa ra các khuyến nghị về quản lý rủi ro lũ lụt toàn diện và bền vững, cũng như các chiến lược thích ứng, bao gồm quy hoạch phát triển không gian dựa trên thông tin rủi ro.

Cụ thể, báo cáo sẽ trình bày: Tổng quan về các sự kiện lũ lụt trong quá khứ và tác động của chúng (xem chương 2); Phân tích tác động của lũ lụt đối với con người, sinh kế, giao thông và chất lượng nước (xem chương 3); Dự báo về rủi ro lũ lụt trong tương lai (xem chương 4); Các điểm khởi đầu cho quản lý rủi ro lũ lụt và thích ứng (xem chương 5); Kết luận và khuyến nghị chính sách (xem chương 6)

Các điểm chính:

- **Lũ lụt gây ra cả tác động trực tiếp và lan tỏa nghiêm trọng:** Thừa Thiên Huế bị ảnh hưởng nặng nề bởi lũ lụt, đặc biệt là những tác động tiêu cực đến sức khỏe, sinh kế của người dân trồng lúa, giao thông và chất lượng nước. Các tác động này có sự liên kết chặt chẽ với nhau, ví dụ gián đoạn giao thông có thể làm ảnh hưởng đến sinh kế, hoặc ô nhiễm nước có thể tác động trực tiếp đến sức khỏe của người dân.

- **Phần lớn diện tích Thừa Thiên Huế dễ bị lũ lụt nghiêm trọng:** Gần một nửa diện tích (46%) của Thừa Thiên Huế có nguy cơ bị ảnh hưởng bởi các trận lũ lớn, như sự kiện lũ lụt năm 2020. Trong khi các khu vực thượng nguồn ít bị ảnh hưởng hơn, gần 90% khu vực đô thị mới và các khu vực hạ lưu dễ bị ngập sâu, với độ sâu có thể vượt quá 2 m ở một số nơi.

- **Mức độ phơi nhiễm lan rộng:** Lũ lụt gây ảnh hưởng nghiêm trọng đến các khu dân cư, sinh kế và cơ sở hạ tầng ở Thừa Thiên Huế, đặc biệt là đối với những hộ gia đình sống ở khu vực dễ bị ngập. Hơn nữa, hầu hết các hộ gia đình đều bị ảnh hưởng gián tiếp, do tỷ lệ cao các cơ sở y tế, đường giao thông và đất nông nghiệp nằm trong khu vực có nguy cơ lũ lụt.

- **Mức độ dễ tổn thương là động lực chính gây rủi ro lũ lụt:** Tính dễ bị tổn thương là yếu tố chính gây ra rủi ro lũ lụt và có sự khác biệt rõ rệt giữa các khu vực. Ví dụ, vùng thượng nguồn có mức độ dễ bị gián đoạn giao thông cao nhất, trong khi vùng hạ lưu dễ bị ô nhiễm nguồn nước. Các yếu tố chính ảnh hưởng đến tính dễ tổn thương bao gồm khả năng ứng phó hạn chế, chất lượng xây dựng thấp, thiếu bảo hiểm và sự suy giảm sức khỏe của hệ sinh thái.

- **Các nguyên nhân gốc rễ gây ra rủi ro lũ lụt cần được giải quyết để đảm bảo quản lý rủi ro bền vững:** Các yếu tố dẫn đến rủi ro lũ lụt đều xuất phát từ các nguyên nhân chung. Ví dụ việc chuyển đổi hệ sinh thái thành các khu đô thị đã làm gia tăng mức độ phơi nhiễm và tính dễ tổn thương, dẫn đến những tác động tiêu cực lên sức khỏe, sinh kế, giao thông và chất lượng nước.

- **Các kịch bản tương lai dự báo rủi ro lũ lụt sẽ gia tăng nếu các xu hướng kinh tế - xã hội hiện tại tiếp diễn, nhưng đồng thời cũng tạo ra cơ hội để tăng cường khả năng chống chịu:** Nếu chính sách ưu tiên tăng trưởng xanh và phát triển bền vững, rủi ro lũ lụt có thể được giảm đáng kể. Ngược lại, nền kinh tế trì trệ và gia tăng phân hóa xã hội có thể làm rủi ro trở nên nghiêm trọng hơn.

- **Thích ứng dựa vào hệ sinh thái (EbA) mang lại những giải pháp quan trọng để giải quyết các rủi ro lũ lụt:** Các giải pháp EbA không chỉ giải quyết các nguyên nhân gốc rễ gây ra rủi ro lũ lụt mà còn giúp giảm thiểu bền vững những rủi ro hiện tại và trong tương lai.

Phẩm của dự án FloodAdaptVN, "*Phương pháp tiếp cận dựa vào hệ sinh thái để quản lý rủi ro lũ lụt nhằm phát triển đô thị theo hướng thích ứng và bền vững ở miền Trung Việt Nam*". Mục tiêu chung của dự án FloodAdaptVN nhằm giảm nhẹ rủi ro lũ lụt hiện tại và tương lai thông qua việc triển khai các chiến lược thích ứng và giảm thiểu rủi ro dựa trên hệ sinh thái vào khung quản lý rủi ro lũ lụt ở miền Trung Việt Nam. Thông tin chi tiết có thể truy cập tại: https://floodadapt.eoc.dlr.de/

Executive summary

With its long coastline and dense populations along rivers and coastal zones, Viet Nam is one of the world's countries most affected by floods. Thua Thien Hue province in Central Viet Nam is one region that is particularly prone to flooding as it has two to three floods of varying severity each year, which cause significant damage to people, infrastructure and nature. To effectively reduce future flood impacts and enhance the region's resilience to floods, it is crucial to understand flood risk drivers and how they progress to the adverse impacts. These include identifying flood-prone areas, understanding who and what is in these areas, that is, exposed to floods (e.g. people or infrastructure), and determining how exposed people and elements are vulnerable to harm from floods. However, this information is currently unavailable in the region, hindering effective risk management. This report addresses this need with insights into the complex nature of flood risks for the urban region of Hue, and recommendations for comprehensive and sustainable flood risk management and adaptation strategies at the catchment level, including risk-informed spatial development planning.

More specifically, this report provides an overview of past flood events and their impacts on the region (see chapter 2), an in-depth analysis of key flood impacts on people, livelihoods, transport and water quality, including risk drivers, root causes and interconnections (see chapter 3), an outlook on future flood risks in Hue (see chapter 4), and entry points for comprehensive flood risk management and adaptation (see chapter 5). The report concludes with a summary and an outlook (see chapter 6).

Key points:

- **Floods lead to severe direct and cascading impacts:** Hue has been severely affected by floods, particularly through adverse health impacts, rice livelihood disruptions, individual transportation disruptions and water contamination. A strong interaction is observed between these and other impacts, such as cascading effects on livelihood disruptions induced by transport disruptions or water contamination-related health impacts.

- **Large parts of Hue are prone to severe floods:** almost half (46 per cent) of Hue's total area is prone to exceptional floods, such as the 2020 event. While upstream areas are less affected, almost 90 per cent of the new urban development and downstream regions are prone to inundation, which has exceeded 2 m depth in several parts.

- **Flood exposure is widespread:** Hue's population, livelihoods and infrastructure are widely exposed to floods, especially households living in flood-prone areas. In addition, virtually every household is indirectly exposed because of the high percentage of health facilities, roads and agricultural land in flood hazard zones.

- **Vulnerabilities are a central flood risk driver, with varying patterns:** vulnerability patterns differ across Hue, due to the city's diverse urban regions. For example, the upstream region is characterized by the highest vulnerability to transport disruption, while the downstream region is particularly vulnerable to water contamination. Key vulnerability drivers include poor response behaviour, poor building conditions, lack of insurance and poor ecosystem health.

- **Underlying root causes fuel flood risks and should be addressed for sustainable flood risk management:** risk drivers across key flood impacts share underlying root causes. For example, the transformation of ecosystems into highly sealed, densely populated urban areas, as observed in particular in the new development region in Hue, fuels hazards, exposures and vulnerabilities that drive impacts on health, livelihoods, transport and water quality.

- **Future scenarios predict increasing risks if socioeconomic trends continue but also offer entry points for cascading resilience** as several future scenarios for Hue indicate a wide range of potential future risks. While a policy focus on green growth and sustainability would significantly reduce flood risks, economic stagnation and social fragmentation could further exacerbate risks.

- **Ecosystem-based adaptation offers strong leverage points for addressing interconnected flood risks:** several entry points for comprehensive disaster risk management were identified, based on the outlined risks. First and foremost, ecosystem-based adaptation solutions are promising as they help address central root causes, thereby sustainably reducing current and future risks.

This report is part of the FloodAdaptVN project, Integrating Ecosystem-based Approaches into Flood Risk Management for Adaptive and Sustainable Urban Development in Central Viet Nam. The project aims to reduce flood risks in Central Viet Nam by incorporating ecosystem-based adaptation strategies into flood risk management frameworks. More information can be accessed through the project website: https://floodadapt.eoc.dlr.de/

Lời tựa

Tỉnh Thừa Thiên Huế đối mặt với nhiều rủi ro lũ lụt do đặc điểm địa lý và khí hậu của khu vực. Trung bình hàng năm, Thừa Thiên Huế trải qua 2 đến 3 đợt lũ lụt với các mức độ khác nhau, gây nhiều thiệt hại về người và tài sản. Các trận lũ lớn vào các năm 1999, 2020 và 2023 đã ghi nhận mực nước đỉnh tại sông Hương (Trạm Kim Long) lần lượt là 5,18 m; 4,17 m; 4,34 m. Những năm gần đây, dưới tác động của biến đổi khí hậu, hiện tượng lũ lụt tại tỉnh Thừa Thiên Huế có nhiều biến động bất thường cả về tần suất và cường độ, gây ra nhiều khó khăn cho đời sống của người dân cũng như quá trình phát triển kinh tế xã hội của địa phương. Do đó, nghiên cứu về lũ lụt nói chung và đặc biệt là xác định nguy cơ lũ lụt, nguyên nhân, mức độ phơi nhiễm, mức độ dễ bị tổn thương có ý nghĩa quan trọng. Kết quả nghiên cứu cung cấp các thông tin hữu ích để các cơ quan quản lý nhà nước và cơ quan chuyên môn xây dựng các chiến lược và kế hoạch thích ứng với lũ lụt một cách chính xác, kịp thời và có hiệu quả.

Báo cáo này được thực hiện bởi nhiều nhà khoa học có uy tín trong lĩnh vực nghiên cứu về lũ lụt, kết hợp với các đợt đi thực địa, khảo sát trên địa bàn do đó các số liệu bảo đảm độ tin cậy. Nghiên cứu này cũng áp dụng các phương pháp tiên tiến và phù hợp, kết hợp cả yếu tố định tính và định lượng, phản ánh được ý kiến của các bên liên quan. Cấu trúc của báo cáo đi từ tổng thể đến chi tiết từng nội dung, bao gồm:

- Đặc điểm điểm thuỷ văn của tỉnh Thừa Thiên Huế;
- Các đợt lũ lịch sử trên địa bàn;
- Xác định bốn rủi ro liên quan đến sức khỏe cộng đồng, nông nghiệp, giao thông và ô nhiễm nước;
- Mức độ tác động của các kịch bản phát triển kinh tế xã hội đến quản lý rủi ro lũ lụt;
- Các khuyến nghị để quản lý rủi ro lũ lụt toàn diện.

Báo cáo này bảo đảm các thông tin được xem xét toàn diện và khách quan.

Văn phòng ban chỉ huy phòng chống thiên tai và tìm kiếm cứu nạn tỉnh Thừa Thiên Huế là cơ quan chuyên môn, giúp việc cho Ủy ban nhân dân tỉnh Thừa Thiên Huế trong việc phân tích, đánh giá và đưa ra các quyết định về ứng phó với thiên tai, đặc biệt là trong việc quản lý các rủi ro lũ lụt. Báo cáo này là một tài liệu hỗ trợ các cơ quan chuyên môn và chính quyền địa phương trong việc triển khai hiệu quả các kế hoạch ứng phó với rủi ro lũ lụt trên địa bàn tỉnh một cách hiệu quả.

Đặng Văn Hòa
Chánh văn phòng Ban chỉ huy phòng chống thiên tai và tìm kiếm cứu nạn tỉnh Thừa Thiên Huế, Việt Nam

Foreword

The Thua Thien Hue province faces many flood risks due to its geographical and climatic characteristics. On average, Thua Thien Hue experiences two to three annual floods of varying severity, which cause significant damage to people and property. The major floods of 1999, 2020 and 2023 resulted in peak water levels at the Huong River (Kim Long Station) of 5.18 m, 4.17 m and 4.34 m, respectively. In recent years, climate change has impacted flooding in the region, with unusual fluctuations in frequency and intensity. These events create numerous difficulties in the lives of residents and the local socioeconomic development process. Therefore, research on flooding, particularly identifying flood risks, causes, exposure levels and vulnerability, is very important. The results provide useful information for state management agencies and specialized agencies to develop accurate, timely and effective flood adaptation strategies and plans.

Many reputable scientists in flood research were involved in the study, which included field trips and surveys in the area, ensuring data reliability. This research applies advanced and appropriate methods, including qualitative and quantitative factors, reflecting stakeholders' opinions. The report is structured to range from a general overview to detailed content, including the following:

- hydrological characteristics of Thua Thien Hue province
- historic floods in the area
- identification of four risks related to public health, agriculture, transportation and water pollution
- the impact levels of socioeconomic development scenarios on flood risk management
- recommendations for comprehensive flood risk management.

The resulting report ensures comprehensive and objective consideration of the information.

The Office of the Provincial Steering Committee for Disaster Prevention and Search and Rescue of Thua Thien Hue is a specialized agency that assists the People's Committee of Thua Thien Hue province in analysing and evaluating information on flood risks and making decisions on disaster response, especially in flood risk management. This report is a document that will support specialized agencies and local authorities in effectively implementing flood risk response plans in the province.

Đặng Văn Hòa
Chief of Office of the Provincial Steering Committee for Disaster Prevention and Search and Rescue, Thua Thien Hue, Viet Nam

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1. Introduction

With its long coastline and dense populations along rivers and coastal zones, Viet Nam is one of the world's countries most affected by floods. These floods account for about 97 per cent of the average annual losses from hazard-induced disasters (Dinh et al., 2021) and include coastal floods, pluvial floods (i.e. caused by heavy rainfall) and fluvial floods (i.e. caused by increased water levels in rivers, canals and other waterbodies) (Nguyen et al., 2021). Floods in Viet Nam have led to severe economic losses, infrastructure damage, ecosystem harm and loss of life. Over the past 20 years (2004–2023), floods affected more than 9.7 million people, caused 1,843 fatalities, and resulted in direct damages totalling US$4.1 billion (CRED, 2023). Almost half the country's population is exposed to high flood risk, particularly in deltas, coastal zones and low-lying areas (Rentschler et al., 2022). Rapid urbanization since the Doi Moi reforms has increased flood risks in many cities (Huong and Pathirana, 2013). Climate change, population growth, economic development and the expansion of buildings and infrastructure into flood-prone areas have worsened this trend (Sudmeier-Rieux et al., 2015).

Central Viet Nam, especially Thua Thien Hue province, the city of Hue and its increasingly urbanized surroundings, are particularly prone to floods (Luu et al., 2019). Over the past few decades, numerous devastating floods have struck this region (see chapter 2 for an overview).

Local authorities have implemented structural measures to manage flood risks, such as large reservoirs upstream, canal and drainage systems in urban areas and flood gates downstream. Despite these efforts, floods continue to occur regularly in Hue, affecting large parts of the city and hindering climate-resilient sustainable development, as seen in the significant flood of late 2020 (Ortiz-Vargas and Sebesvari, 2021).

Understanding the different types of flood risks and their underlying causes is crucial to effectively reduce the risks and enhance the region's resilience. This work includes identifying flood-prone areas, understanding what is exposed (e.g. buildings and infrastructure), and why they are vulnerable. Such insights can inform comprehensive and sustainable flood risk management and adaptation strategies at the catchment level, including risk-informed spatial development planning.

This report aims to provide an understanding of flood risks in Hue and potential strategies for flood risk management and adaptation. Specifically, it includes the following:

- an overview of past floods and their key impacts on the region (see chapter 2)
- an analysis of flood risks, namely the root causes, underlying drivers and spatial patterns of flood risks affecting people, livelihoods, transport and water contamination and their interconnections (see chapter 3)
- an outlook on future flood risks in Hue (see chapter 4)
- entry points for comprehensive flood risk management (see chapter 5).

The report concludes with a summary and an outlook (see chapter 6).

2. Catchment characteristics and past floods in Thua Thien Hue

This chapter describes the hydrological and hydraulic characteristics of Thua Thien Hue (see chapter 2.1) and Hue, the provincial capital (see chapter 2.2), and offers insights into past flood events in the province and their associated key impacts (see chapter 2.3).

2.1. Hydrological and hydraulic characteristics of Thua Thien Hue

Floods in Thua Thien Hue province are significantly influenced by the Huong River, which plays a crucial role in the region's water dynamics. The Huong River system includes three tributaries: the Huu Trach and Ta Trach Rivers, which merge into the Huong River, and the Bo River. This river system covers a catchment area of 2,830 km², encompassing nearly 60 per cent of the province (see figure 1) (Dau and Kuntiyawichai, 2020). In addition, the Ô Lâu River, which originates in Quang Tri province, significantly contributes to discharge into the northern part of Tam Giang Lagoon during flooding season.

The Huong River originates from the mountainous region with elevations of up to 1800 m above sea level and a steep riverbed (Le et al., 2014). As it flows into the coastal plain and through Hue city, the provincial capital of Thua Thien Hue province, the river becomes a gentle, meandering waterway influenced by tides and salinity. After travelling a total length of 104 km, it flows into the Tam Giang Lagoon. During the flood season, the river's upper sections in the hills and mountains experience strong currents, velocities and water levels. In contrast, the water levels drop significantly during the dry season, revealing a riverbed with many pebbles and boulders. In addition to natural tributaries, the Huong River has artificial channel connections to both the Tam Giang Lagoon and the Cau Hai Lagoon. The Bo River also has a natural connection to the Huong River and an artificial channel to the Tam Giang Lagoon. Furthermore, there are three main reservoirs (Ta Trach, Huong Dien and Binh Dien) in the Huong River catchment, near the tributaries of the Ta Trach, Bo and Huu Trach Rivers, respectively (Dau and Kuntiyawichai, 2020).

As described above, the Huong catchment has various hydrological and hydraulic characteristics along its course from the mountainous areas down to the lagoon, along with various built-up structures and human activities across the catchment. These structures and activities significantly alter the hydrological and hydraulic characteristics, with important implications for flood risks, as further described in chapter 3.

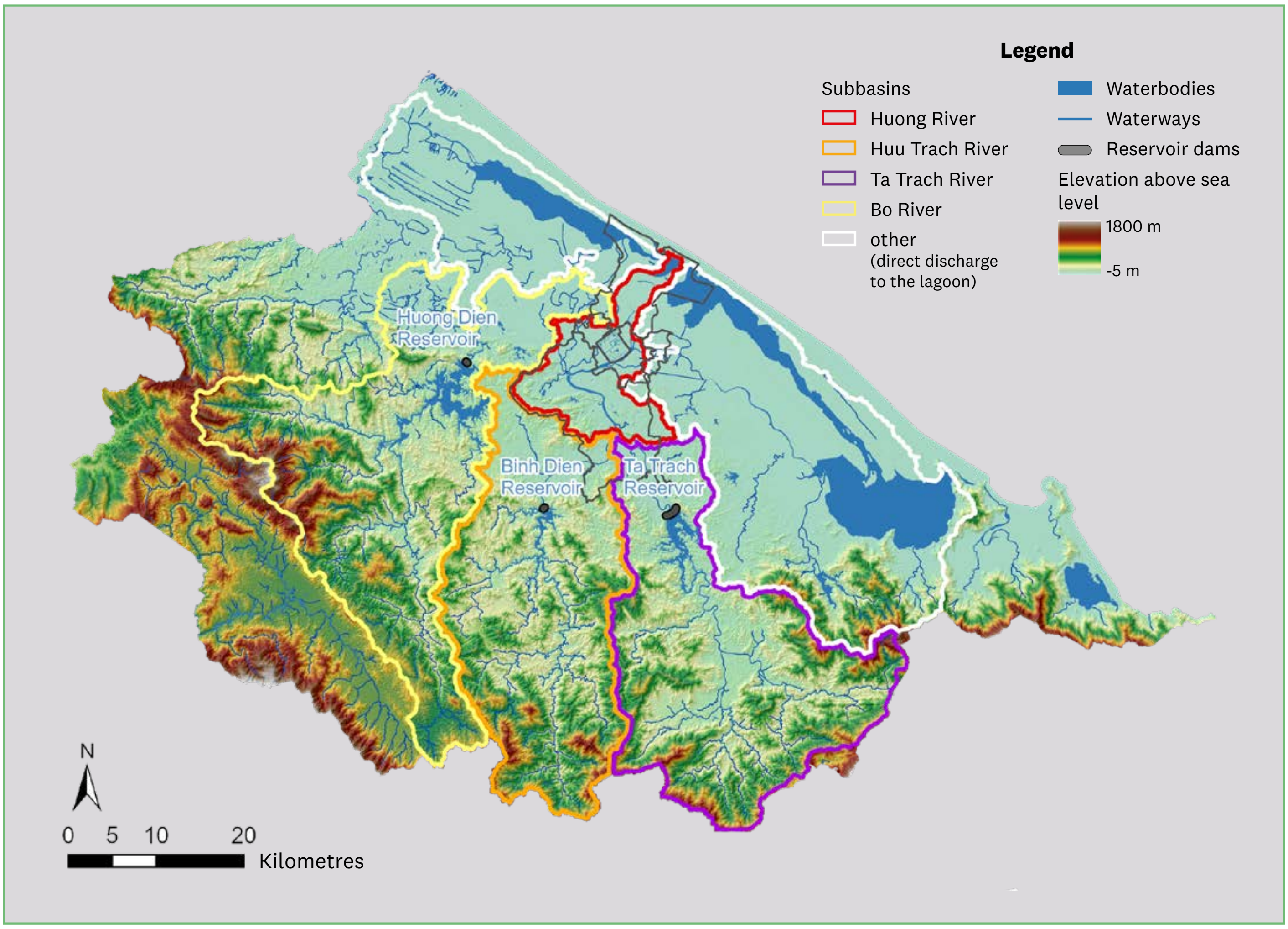


Figure 1: Huong River basin and its subbasins Huu Trach, Ta Trach and Bo in Thua Thien Hue province.

To better grasp the diversity and specific contribution of conditions, structures and activities to flood risks in Thua Thien Hue, the catchment has three main subsets: a mountainous upstream region, a flat, highly urbanized mid-stream region and a coastal downstream region.

Upstream region

This area includes the upstream forest and reservoirs. The management and conditions of upstream regions play a crucial role in influencing floods downstream (Rackelmann et al., 2023; Pattison, 2010). Thua Thien Hue province's forest cover was 57.38 per cent of the country's total in 2020 (MARD, 2021) and is characteristic of the Huong River catchment's upstream area. This upstream forest is integrated with the Bach Ma National Park, special use, protection and production forests (Cochard et al., 2023). However, land use changes, illegal logging, monocultural systems, urban expansion and the creation of reservoir areas (Phuong and Thien, 2024) are creating forest degradation and deforestation of natural forests.

Midstream area

This area includes riparian buffers, urban areas and peri-urban areas in Hue. Midstream areas and riparian buffers are critical for storing excess water and supporting the reduction of downstream flooding (Dixon et al., 2016). Hue is in the catchment's mid-stream area with various urban settlements on the coastal plain's low elevation. Dense populations and many impervious surfaces characterize urban areas, while peri-urban areas serve as transitional zones towards rural regions with more agricultural and aquacultural activities. The Huong River goes through the city, and the riparian buffers are key protective boundaries between the river and the settlements. Hue is known as the green city of Viet Nam with awards from the World Wide Fund For Nature (WWF, 2016) and the Association of Southeast Asian Nations (ASEAN) for its environmental efforts (Huong, 2024). The local government is committed to maintaining this status by ensuring green and sustainable development (ADB, 2014). This subset of the catchment is the most impacted by floods.

Downstream area

This area includes the Tam Giang Lagoon and coastal areas, offering a unique ecosystem and habitat for many species. The Tam Giang Lagoon spans 70 km and has a total area of 216 km^2, making it the largest lagoon system in South-East Asia. This subset is also characterized by peri-urban settlements that generally depend on agricultural and aquacultural activities, which are often impacted by floods. Additional concerns and challenges in this subset are coastal floods, storms and rising sea levels.

Understanding the challenges and opportunities in the Huong River catchment's different subsets allows for the development of holistic strategies with clear intervention areas for implementing solutions to flood risks.

2.2. Urban regions in Hue

Hue, the provincial capital, is characterized by a huge diversity between its various neighbourhoods, namely wards and communes. The city was Viet Nam's capital from 1802 to 1945 and has a central imperial city, the 'citadel', with many historical buildings. The citadel is designated a UNESCO World Heritage site and includes residential buildings, with the area enclosed by a walled complex. In contrast, the 'core urban area' on the opposite side of the Huong River, is dense with modern, large, high-rise commercial and residential building complexes (figure 2). Following the city's recent population growth and economic and political rise, two 'new urban development regions' were established west of the citadel and east of the core urban area. These new areas are characterized by a mix of small, old neighbourhoods and large building complexes and extensive construction sites, including infrastructure extension. Lastly, two peri-urban regions, characterized by low population density, stretch along the Huong River and its tributaries, 'upstream' and 'downstream' of Hue's urban core.

Apart from the building and population densities, Hue's urban regions differ significantly in other sociodemographic and economic characteristics. For example, income levels and respective purchasing power are significantly higher in the citadel and the core urban area than in the peri-urban upstream and downstream areas, where agricultural and forestry livelihoods dominate (Hue Statistics Office, 2022). Sociodemographic and economic factors play a crucial role as drivers of flood risks (see chapter 3), and it is important to consider these differences among urban areas when assessing flood risks.

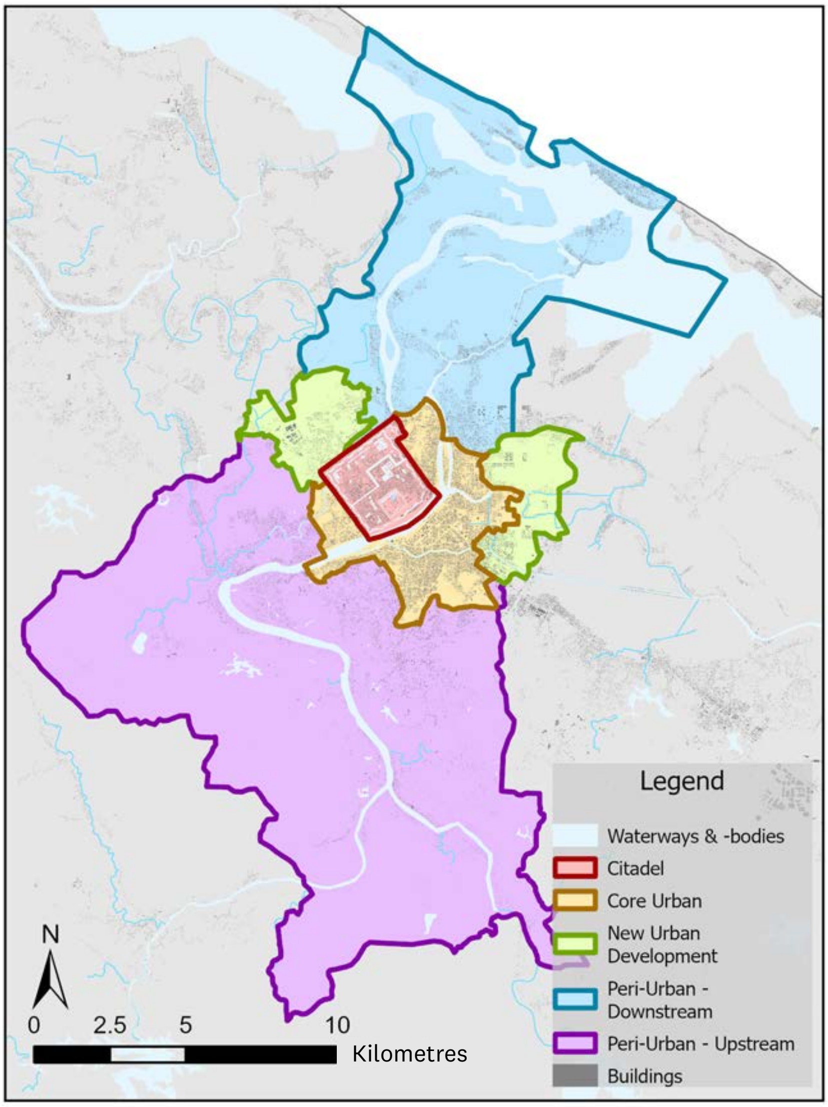


Figure 2: Location and building density across urban regions in Hue (source: authors).

2.3. Past flood events and impacts in Thua Thien Hue

Flood events in Viet Nam are categorized into five levels, based on their peak height compared to historical data for a given period and averaged across many years, referred to as the trung bình nhiều năm (TBNN) reference period (MONRE, 2014):

1. **Small floods (Category 1)** with peak heights lower than the average or TBNN flood level

2. **Moderate floods (Category 2)** reach average or TBNN flood peak level

3. **Major floods (Category 3)** exceed the average or TBNN peak level

4. **Exceptional floods (Category 4)** have unusually high peak levels rarely recorded in the observation period

5. **Historic floods (Category 5)** mark the highest peak levels recorded during the observation period.

In recent decades, Thua Thien Hue province has faced several devastating floods. While the region has annual small to moderate floods with minor impacts, the occasional major to historic floods have severe consequences for people, the economy, infrastructure and the environment. However, even small flood events can erode development achievements and opportunities and should be addressed by flood risk management interventions (UNDRR, 2019). Local stakeholders and households identified the floods of 1999, 2020, and 2023 as particularly severe. Furthermore, an increased frequency of severe flood events leading to adverse impacts was observed over the past two decades.

1999 historic floods
The most severe flood in recent history struck Central Viet Nam in November 1999, affecting Thua Thien Hue particularly hard. Between 6 and 16 November, Hue experienced record rainfall of 3,063 mm in the city centre (Villegas, 2004). The excessive rainfall led to widespread flooding, with water depths in Hue reaching up to 5 metres in the most affected regions according to a household survey conducted within the FloodAdaptVN project. The flood resulted in 793 deaths and damage to over 870,000 houses, and severely impacted households in Hue (IFRC, 1999). In addition, the flooding severely damaged infrastructure, including schools, hospitals and health centres, with long-lasting impacts on basic service provision and stark challenges for recovery (IFRC, 1999).

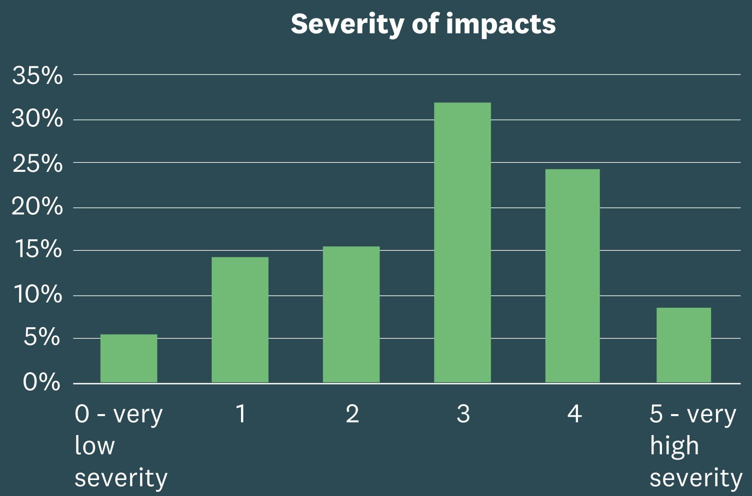
2020 exceptional floods
From early October to mid-November 2020, nine consecutive major storms and typhoons hit Central Viet Nam (DMPTC, 2021). The storms brought heavy precipitation, with 2,747 mm recorded in Hue and up to 5,226 mm in the mountainous upstream areas (VRAIN, 2024), which progressed to riverine and flash floods, and triggered landslides in some areas (IFRC, 2020). The floods resulted in 291 deaths and 66 people missing, and affected around 7.7 million people, many of whom suffered injuries or waterborne diseases (Ortiz-Vargas and Sebesvari, 2021). Additionally, the floods caused significant losses of crops and livestock, directly and indirectly impacting farmers' livelihoods and food availability in the market (FAO, 2020). Other key economic sectors, including tourism, aquaculture and industry, also suffered, affecting the incomes of most of Hue's population (EOC, 2020).

2023 exceptional floods
In October and November 2023, another exceptional flood occurred in Central Viet Nam. Heavy rainfalls of up to 2,858 mm were recorded in the city centre and more than 4,135 mm in the mountainous upstream regions (VRAIN, 2024). The excessive rainfall triggered very high river water levels, almost reaching the historic levels of the 1999 floods. Therefore, the 2023 floods were also categorized as the 'worst in a decade' (Thanh, 2023). Local authorities' evacuation of the population at risk meant that while the flood affected more than 104,000 people in the Central region, there were only seven deaths and two people missing (ADINet, 2023). However, crops were significantly affected and livestock fatalities, such as cattle and poultry, could not be avoided (Thanh, 2023).

Box 1: Flood impacts in Hue: results from the 2023 FloodAdaptVN household survey

A household survey conducted within the FloodAdaptVN project in early 2023 revealed that floods have severely affected many households in Hue. About 65 per cent of the surveyed households rated their past affectedness by floods as high (4 or higher on a scale from 1 (low severity) to 6 (high severity), with 8.5 per cent rating the highest severity (see figure 3).

Livelihoods and basic services were reportedly the most affected. Almost all (95 per cent) respondents reported impacts on non-agricultural jobs, 87 per cent on agricultural jobs, and 88 per cent on basic service interruption. Health impacts were reported by 36 per cent, indicating that more than a third of respondents were affected.



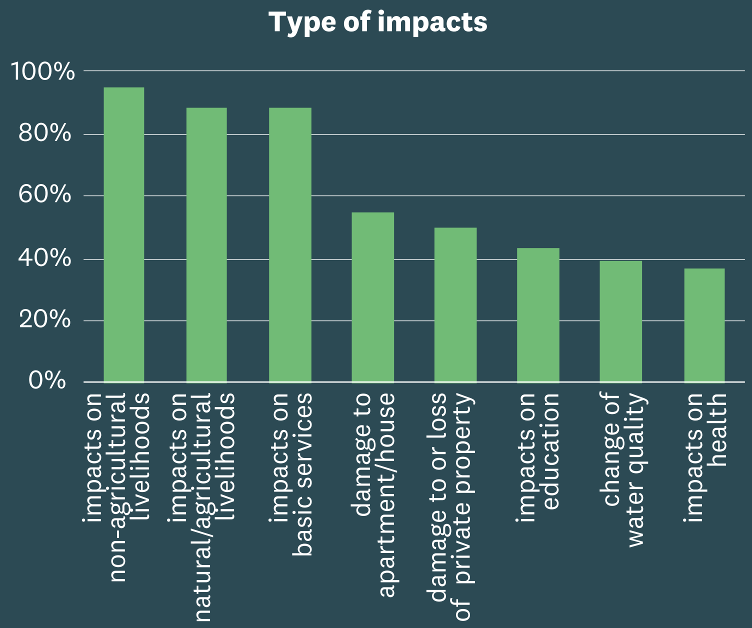


Figure 3: Findings from the household survey on flood impacts in Thua Thien Hue.

Note:

The survey included an equal number of households (n=55) from 10 different wards and communes in Hue (total: 550 households). While the results do not fully represent all households in Hue, they highlight critical impacts across a broad range of citizens and reflect the variety of effects observed in the city. For more details on the sampled areas, see chapter 3.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3. Flood risks in Hue

This chapter briefly introduces the conceptual risk framework and overall workflow for the flood risk assessment presented in this report (see chapter 3.1). Further, it provides in-depth insights into:

- **Flood hazards:** assessment of flood hazards, including pluvial, fluvial and coastal flooding in the study area and simulation of various flood hazard scenarios under current climate conditions (see chapter 3.2)
- **Key flood impacts, their risk drivers and root causes:** assessment of root causes, risk drivers and spatial risk patterns for key flood impacts on people, livelihoods, transport and water quality (see chapter 3.3)
- **Interactions across key flood impacts, their risk drivers and root causes:** analysis of how the four key flood impacts and their risk drivers and root causes interact (see chapter 3.4).

3.1. Conceptual risk framework and methods applied

Conceptual framework

The flood risk assessment presented in this report is guided by the risk definition and conceptual framework provided by the Intergovernmental Panel on Climate Change (IPCC) in its 6th Assessment Report (IPCC, 2022). As outlined in Figure 4, flood impacts, such as injuries or damaged buildings, result from the complex, dynamic interactions of three risk drivers that create flood hazards: inundation, exposure of people or livelihoods in flood-prone areas, and vulnerabilities such as lack of people's capacity to cope with and adapt to flood impacts or ineffective government responses. Assessing these risk drivers is vital to understanding past and future impacts, including understanding the underlying root causes that can significantly increase hazards, exposures and vulnerabilities, and indirectly exacerbate impacts. Root causes often stem from socioeconomic and political structures, processes, choices and values (Wisner et al., 2003).

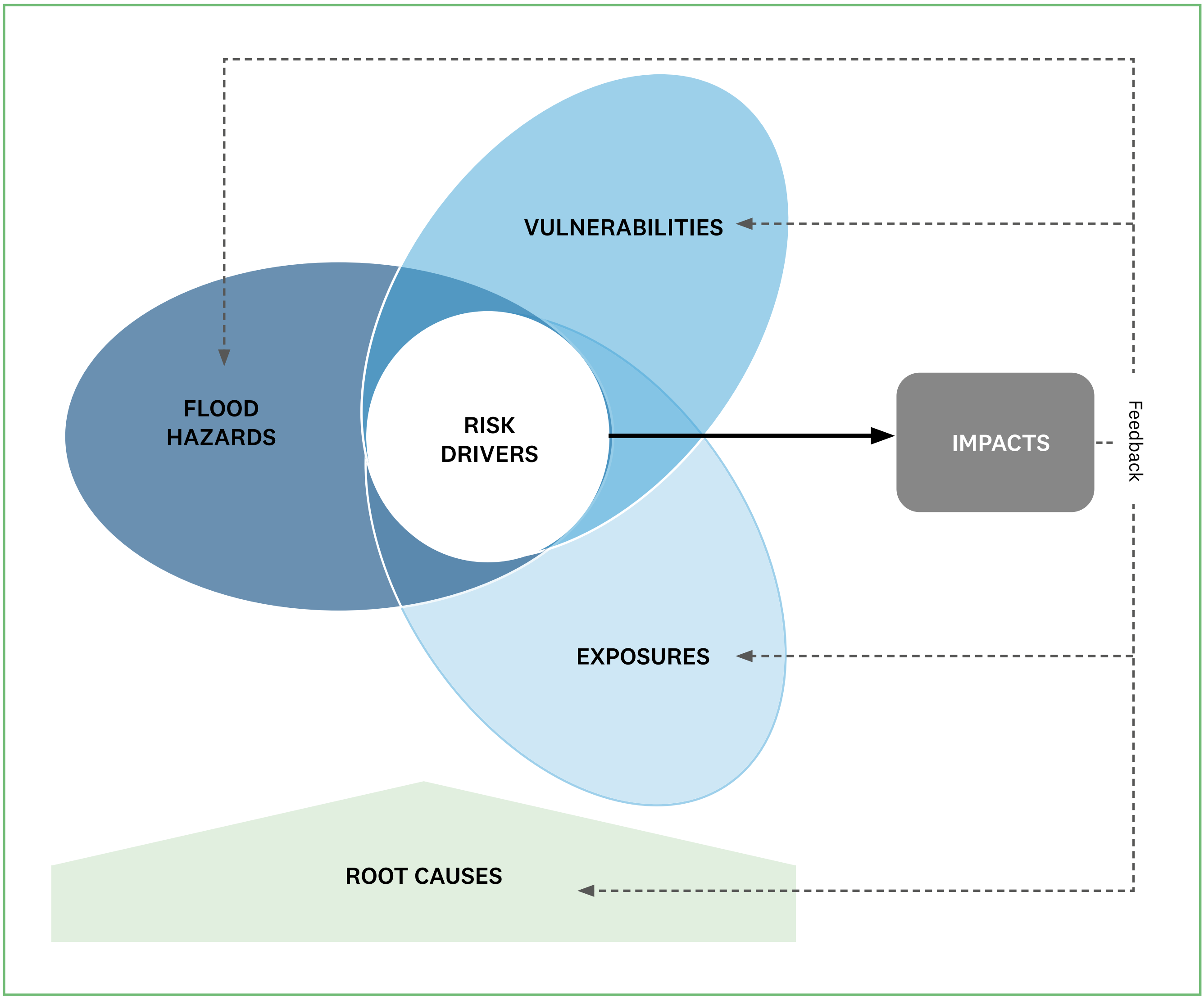

Figure 4: Conceptual risk framework guiding the analysis (source: adapted from IPCC, 2022).

Workflow for the flood risk assessment
This report's assessment of flood impacts and their risk drivers was guided by a mixed-method approach, combining various knowledge sources, data collection and analysis methods. It was conducted in three subsequent phases: including (i) scoping to identify key flood impacts of particular concern for stakeholders in Hue, (ii) a qualitative risk assessment to advance the understanding of these key impacts and their risk drivers, and (iii) a quantitative assessment to identify spatial patterns of risk drivers across Hue (see figure 5). Each of these three phases is described in more detail below.

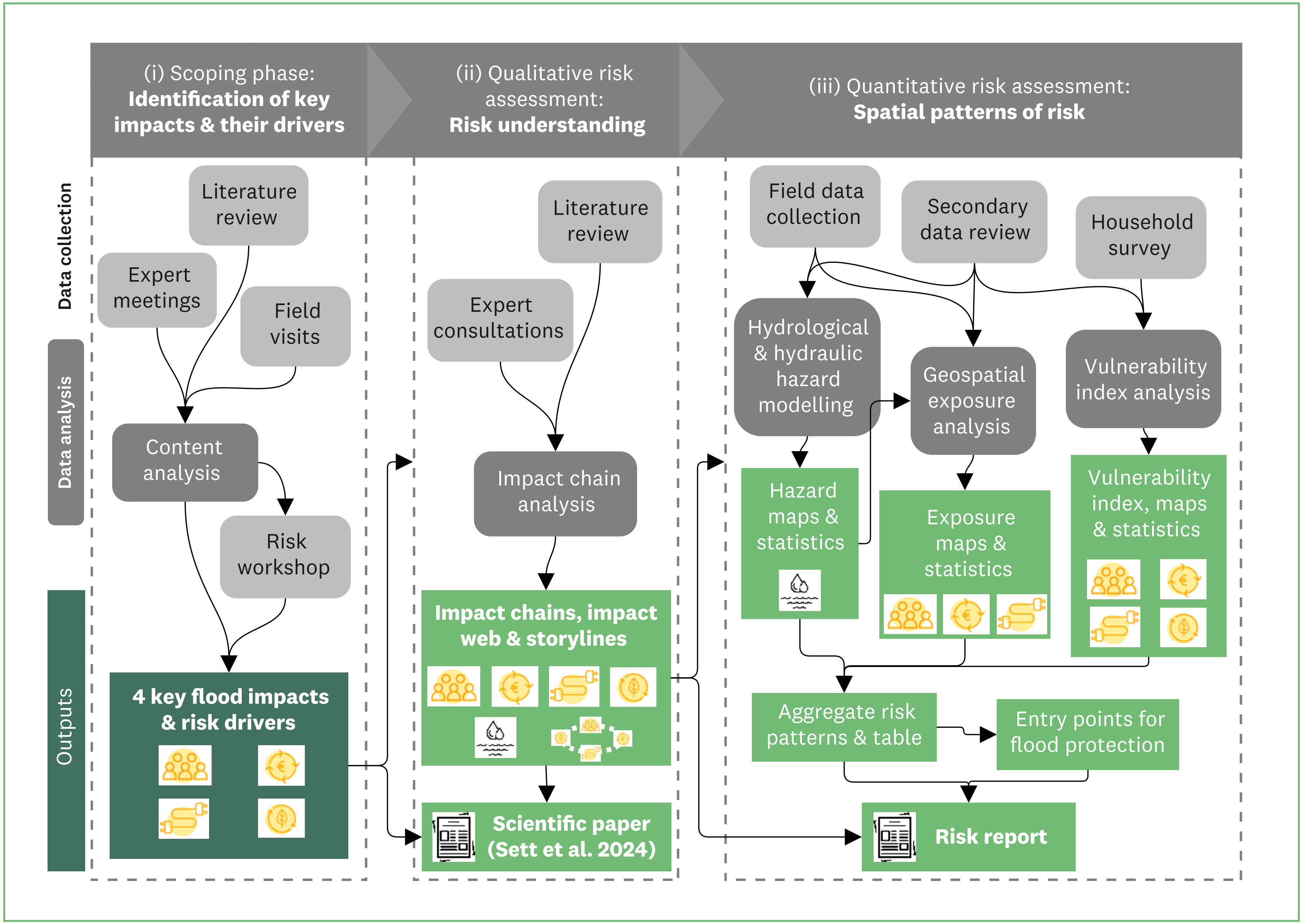

Figure 5: Workflow of the flood risk assessment (adapted from Sett et al., 2024).

Step 1:
Scoping to identify key flood impacts and their risk drivers

The flood risk assessment started with an initial scoping phase to identify the province's key flood impacts and their risk drivers and root causes. The scoping comprised a qualitative content analysis of data from the national disaster impact database and a review of English and Vietnamese literature, including policy and research reports, journal papers and news articles identified through an unstructured search on Google and the Web of Science.

The findings from the respective content analysis were used to prepare an expert workshop on flood risks in Hue in July 2022. It brought together 18 local flood risk management and adaptation experts from various authorities, including the Department of Natural Resources and Environment (DONRE), the Committee for Flood and Storm Control (CCFSC), academia and civil society in Thua Thien Hue.

During the workshop, local stakeholders identified four key flood impacts (KFIs) that are particularly relevant for the region and that require further flood risk management efforts:

1. **Key flood impact 1 (KFI1): severe health impacts**, particularly injuries and fatalities
2. **Key flood impact 2 (KFI2): disruption of agricultural livelihoods**, particularly disruption of rice production livelihoods
3. **Key flood impact 3 (KFI3): disruption of transportation**, particularly disrupted individual mobility
4. **Key flood impact 4 (KFI4): water contamination** and associated cascading impacts on people and nature.

In addition, the participants stressed the importance of flood hazards as a key driver for all selected key impacts, which was included in subsequent analysis steps (see chapter 3.2).

Photo of the flood risks workshop in Hue, 2022.

Step 2:
Qualitative risk assessment to advance the understanding of key flood impacts

In a second step, findings on key flood impacts and their risk drivers derived from the scoping were complemented by an additional systematic literature review to develop so-called 'conceptual risk models' for each of the four key flood impacts, with a further risk model for flood hazards (see chapter 3.2) using the impact chain approach (Zebisch et al., 2023). Understanding flood-impact drivers is critical for sustainable flood risk management. The conceptual risk models and impact chains aim to provide an in-depth understanding of the root causes, risk drivers, impacts and their interactions, for each of the four key impacts (see chapter 3.3). Local experts validated the resulting impact chains (see figures 9, 12, 15, 18) in a series of in-person consultations in Hue in March and April 2023.

Additionally, an overarching conceptual risk model shows the interlinkages of the four key flood impacts and their risk drivers from a systems perspective (see chapter 3.4, figure 20). The resulting conceptual risk models were used to create narrative storylines that provide relevant contextual information.

Step 3:
Quantitative risk assessment to identify spatial patterns

Building on the findings from the previous steps, a quantitative, data-driven assessment of flood hazards, exposures and vulnerabilities was conducted for each of the four key impacts to identify risk hotspots and possible spatial differences in the study area. More specifically, this assessment included:

- **Hazard models:** hydrological and hydraulic model calculation based on our own data collection on river profiles and past inundation levels, and available data on rainfall and past inundation levels (see chapter 3.2)
- **Geospatial exposure analysis:** spatial analysis to identify 'who and what' is in flood-prone areas, along with maps and descriptive statistics to visualize results on spatial patterns for each of the four key flood impacts (see chapter 3.3)
- **Vulnerability maps and profiles:** vulnerability maps and profiles were developed to show spatial hotspots and differences in patterns across Hue, based on available data from the General Statistics Office (GSO) and the FloodAdaptVN household survey (see chapter 3.3)
- **Aggregate risk information:** aggregation of flood hazards, exposures, vulnerabilities and patterns, in a risk matrix for each key flood impact (see chapter 3.3) and across all key flood impacts (see chapter 3.4).

3.2. Flood hazards in Hue

This chapter provides insights into the factors leading to flood hazards in the catchment, the modelling approach and the results of simulating flood hazards under current conditions.

Flood hazard progression

Floods in Hue typically occur during the rainy season in October and November, when tropical cyclones and storms bring heavy precipitation and trigger storm surges (see figure 6). These storm surges primarily cause coastal flooding, which raises water levels in the Tam Giang Lagoon. This event can create backwater effects, reducing the discharge of rivers and canals to the lagoon or even causing water to flow upstream from the lagoon into smaller creeks and canals (Triet et al., 2018). These backwater effects increase water levels and cause water bodies to overflow, leading to fluvial floods.

Heavy rainfall can directly raise water levels or cause flooding through run-off that exceeds the land's absorption and infiltration capacity (pluvial floods). The interconnected water canals in the lowlands mean that floods can quickly spread across floodplains and affect large areas. Additionally, fluvial flooding is often exacerbated by the release of water from reservoirs, whether as part of reservoir management or due to failure. Reservoir management strategies are crucial to aim for power generation or respond to high flood levels.

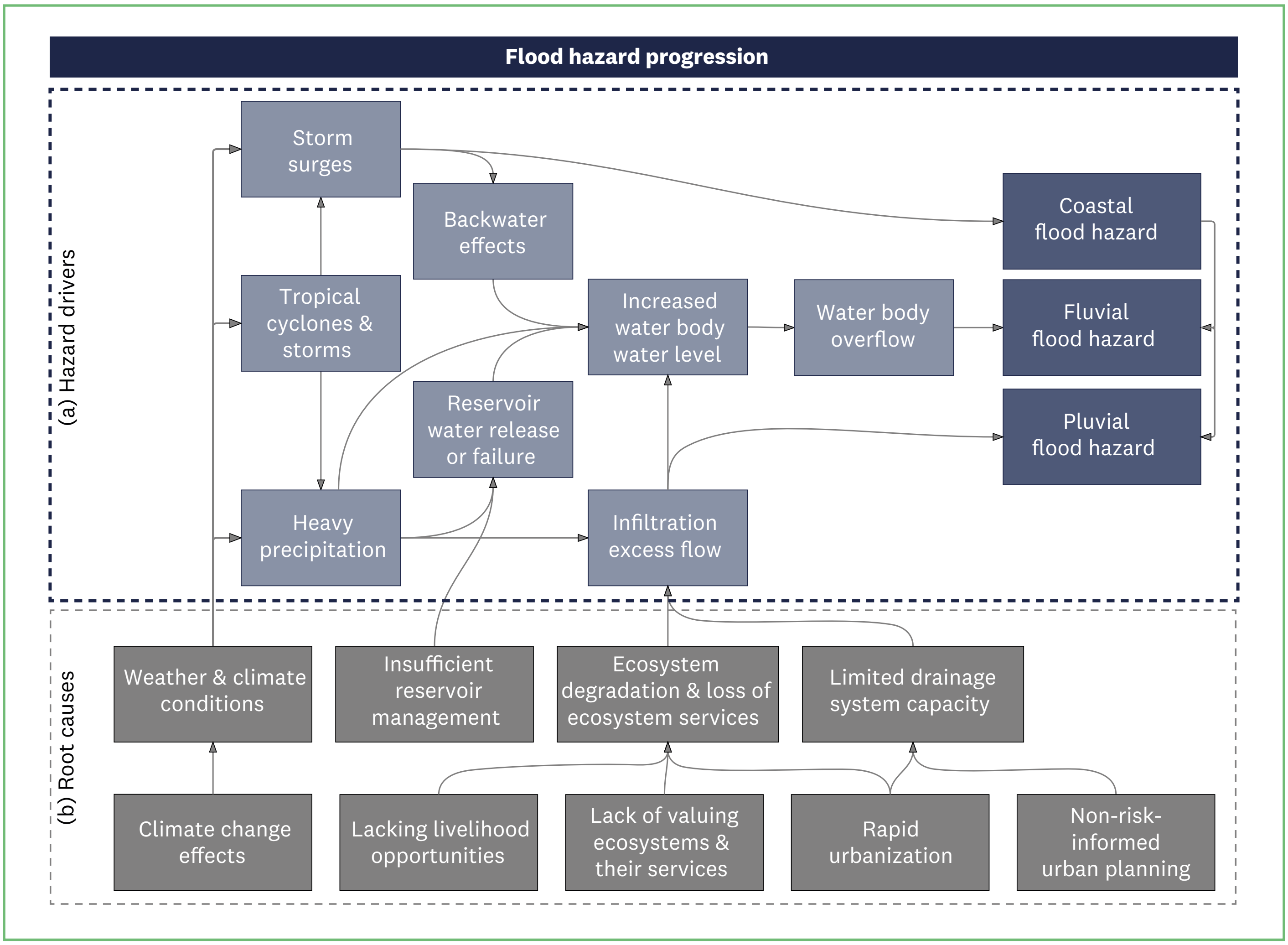

Figure 6: Flood hazard progression chain displaying the interaction of hazard drivers and root causes (adapted from Sett et al., 2024).

Four main root causes accelerate flood progression:

1. **Climate change** increases heavy rainfall and tropical cyclones' intensity across Central Viet Nam, making floods more likely and severe

2. **Ecosystem degradation** reduces natural infiltration and protection against floods (this cause is closely related to the third root cause)

3. **Urban growth and lack of risk-informed planning** lead to more surface sealing, reduced infiltration (see root cause 2), and overwhelmed drainage systems due to non-risk-informed planning

4. **Limits of reservoir management** lead to intentional or accidental water release from dams (also linked to technical failure), which can raise downstream river levels.

Flood risks in Hue are influenced by local, national and even global processes, such as climate change and activities in the upstream region of the Huong River catchment, as illustrated by these root causes.

Flood model development

A hydrologic–hydraulic model chain was developed to assess flood hazards in Thua Thien Hue province. A detailed description of the modelling methodology is presented in Annex A to this report.

Hydrological modelling simulates processes like rainfall, evapotranspiration (canopy loss), depression storage loss, infiltration and soil storage, and hydrograph transformation. In a first step, the catchment model was built to display the complex river network by dividing the whole catchment into smaller sub-catchments, which can be parameterized individually to represent local conditions. Numerous processes were parameterized to simulate hydrologic processes from rainfall to discharge. Those values were derived from literature and by calibrating the model with past events. HEC-HMS 4.9 (Army Corps of Engineers, Hydrologic Engineering Center) was used for hydrologic modelling.

The subsequent **hydraulic model** focuses on Thua Thien Hue province lowlands, downstream of the reservoirs, as these regions experience the most severe floods. The 2D model accounts for complex flow patterns: the area's low slope, the impact of gates and openings on flow behaviour, lagoon water levels causing backwater effects, stream divisions, interconnected canals, sea level, tides and flow direction changes. While the model can capture several of these conditions, some assumptions must be made regarding gate and channel management strategies during flood events. The model, set up in HEC-RAS 6.5 (also by the Army Corps of Engineers, Hydrologic Engineering Center), uses discharge hydrographs from the hydrologic model as input (see figure 7).

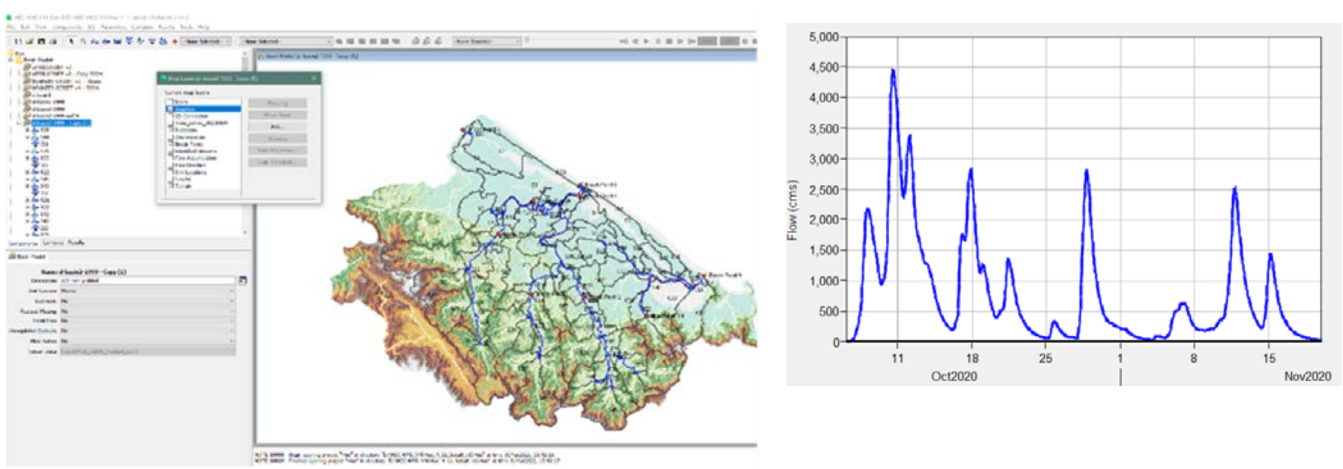

Figure 7: Hydrologic model of Thua Thien Hue province (left) and hydrograph showing the discharge of a Huong River tributary (right).

For the flood event simulation and to capture different flood magnitudes (see chapter 2.3), three flood events were modelled. They represent three different flood categories (historic floods in 1999, exceptional floods in 2020 and major floods in 2022), displaying the inundation depth and flood extent. The results were discussed and validated with Vietnamese stakeholders, making improvements to achieve the best possible accuracy. Based on local expert recommendations, the model for exceptional floods, such as the 2020 event, will serve as the baseline for further analysis and reference.

Spatial flood hazard patterns across Hue
The model results confirm severe flood hazards across Thua Thien Hue, particularly in the low-lying areas around Hue's urban centre (see figure 8).

Nearly half (46 per cent) of Hue's surface area is prone to exceptional floods (category 4 floods), and this increases to 55 per cent for historic floods (category 5 floods). Significant variation exists within different urban regions in Hue (see table 1). The peri-urban upstream region is the least prone to flooding, with only 16 per cent of its area at risk. In contrast, the new urban and peri-urban downstream regions face the highest flood hazards at 88 per cent. In the downstream region, 70 per cent of the area is prone to critical flood levels of at least one metre.

For historic floods (category 5 floods), the extent and depth of inundation increase significantly. For example, while 36 per cent of the core urban area is affected by critical inundation during an exceptional flood event (category 4 flood), this rises to over 84 per cent during historic floods (category 5 flood). These figures highlight Hue's severe flood hazard threat, especially during extreme events.

Table 1 Hazard levels across Hue's urban regions for different flood events (Percentage)

Flood hazard prone areas	Overall hazard level	Exceptional flood (2020)		Major flood (2022)		Historic flood (1999)	
		Total share	Critical share (>1m)	Total share	Critical share	Total share	Critical share
Core Urban	high	64	36	52	32	97	84
Citadel	high	59	23	51	21	75	57
New urban	very high	88	43	78	27	99	77
Peri-urban downstream	very high	88	70	83	60	93	87
Peri-urban upstream	moderate	16	8	13	7	25	23
Average Hue		**46**	**31**	**42**	**26**	**55**	**49**

Note: Numbers indicate the share of flood-prone areas on the total surface of the respective regions.

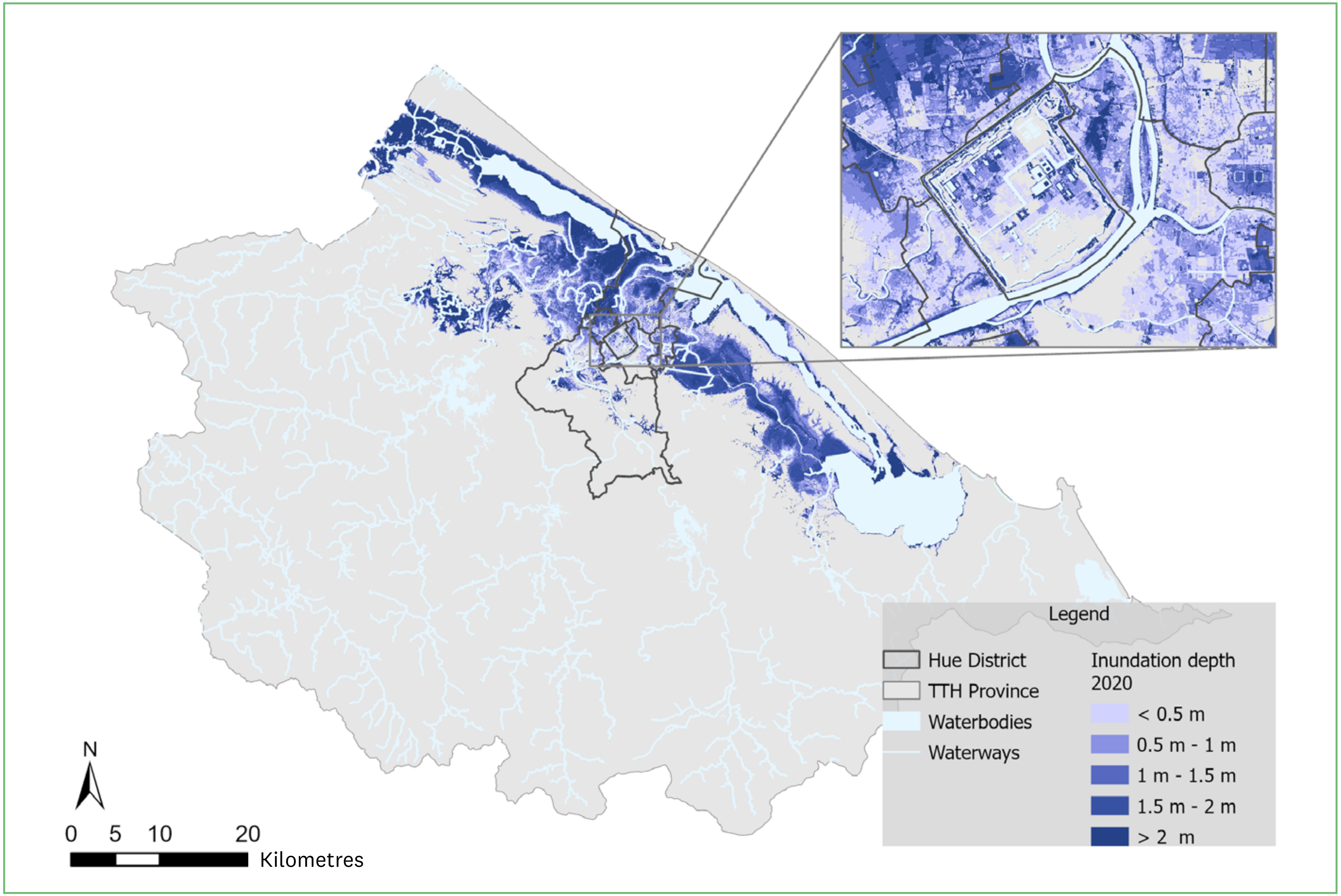

Figure 8: Flood hazard model map of the 2020 event.

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3.3. Key flood impacts and their risk drivers in Hue

This chapter presents the findings of the four key flood impacts assessments identified as critical by local stakeholders (see chapter 3.1). A conceptual risk model is introduced for each, deciphering the complex interplay of different root causes, risk drivers and impacts. Additionally, an overall risk matrix compiles the results of the quantitative, data-driven assessment of exposure and vulnerabilities.

3.3.1. Key flood impact 1: severe health impacts

Impacts, risk drivers and root causes

Severe flood impacts on people's health can occur directly through drowning or indirectly from damaged buildings and diseases from contaminated water (see also key flood impact 4 of this report). Injuries and diseases can lead to fatalities, especially with disrupted health services that, in turn, can cause mental health issues (figure 9).

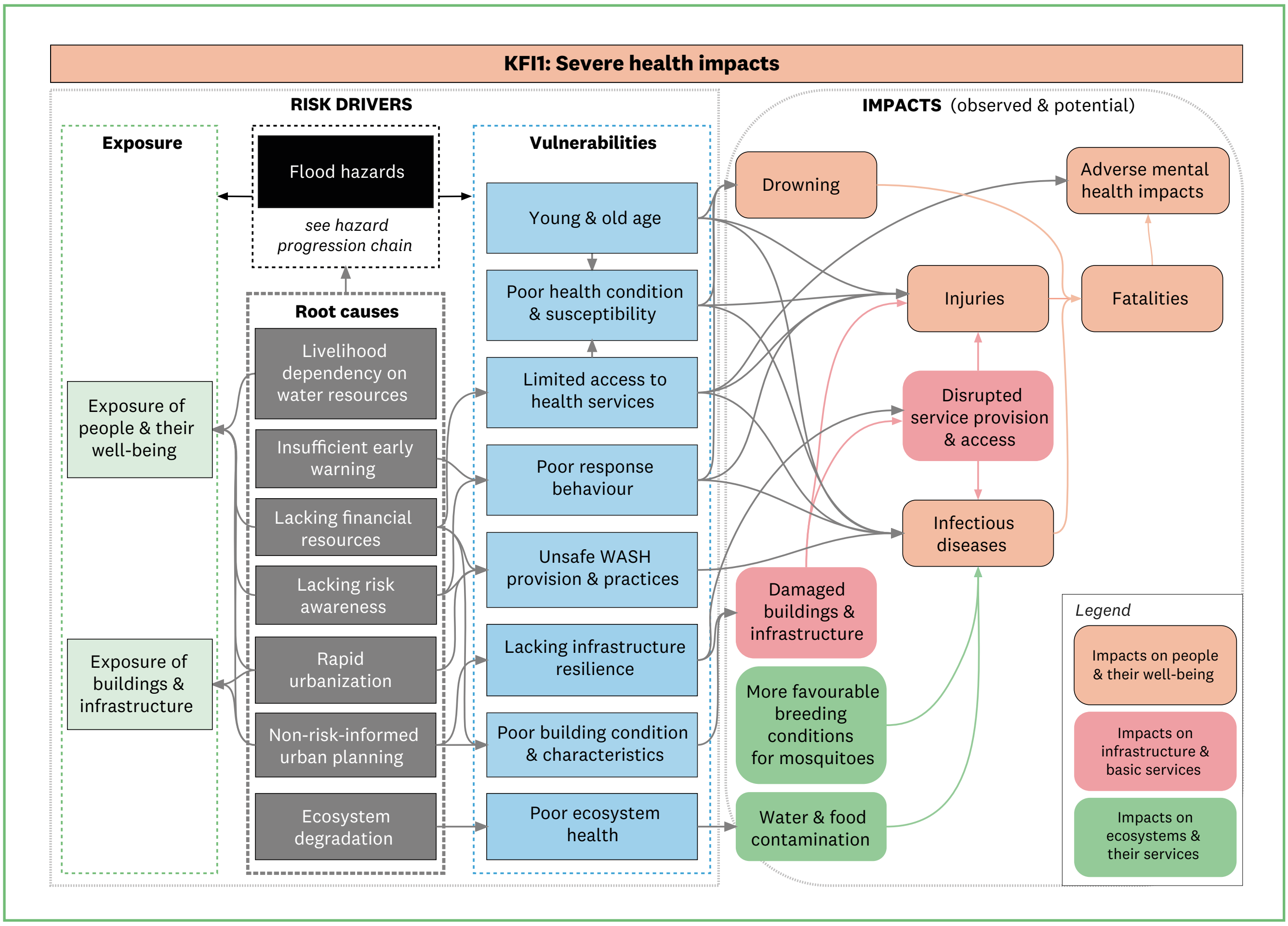

Figure 9: Conceptual risk model for KFI1: severe health impacts (adapted from Sett et al., 2024).

Note: WASH, water, sanitation and hygiene.

People's characteristics, such as age and health, can drive flood impacts on human health, increasing their susceptibility to adverse effects. These risks are exacerbated by a lack of coping capacities, such as poor response behaviour (e.g. walking or driving through floodwater) and unsafe water use and sanitation practices. These deficiencies often stem from underlying root causes such as limited financial resources and a lack of risk awareness.

Infrastructure and physical vulnerability drivers also contribute to health impacts. Poorly constructed buildings and infrastructure are more likely to be damaged, causing injuries. Poor ecosystem health can lead to water contamination (see also key flood impact 4 in this report), increasing the risk of water-borne diseases. Rapid urbanization without considering flood risks in urban planning is a major root cause driving both infrastructure and ecosystem vulnerabilities.

Spatial exposure patterns

A geospatial analysis quantified exposures that drive severe health impacts in Hue. It overlaid the exceptional flood event model (see chapter 3.2) with population and infrastructure location data (see figure 10). Population data for 2020 was obtained from the population grid dataset of the Joint Research Centre (JRC) of the European Commission at a 100-metre resolution (Carioli et al., 2023). Health facility infrastructure data was from the Open Street Map via the Geofabrik database (Geofabrik, 2024), supplemented with data provided by the Information Department of Thua Thien Hue (Thua Thien Hue Government, 2024).

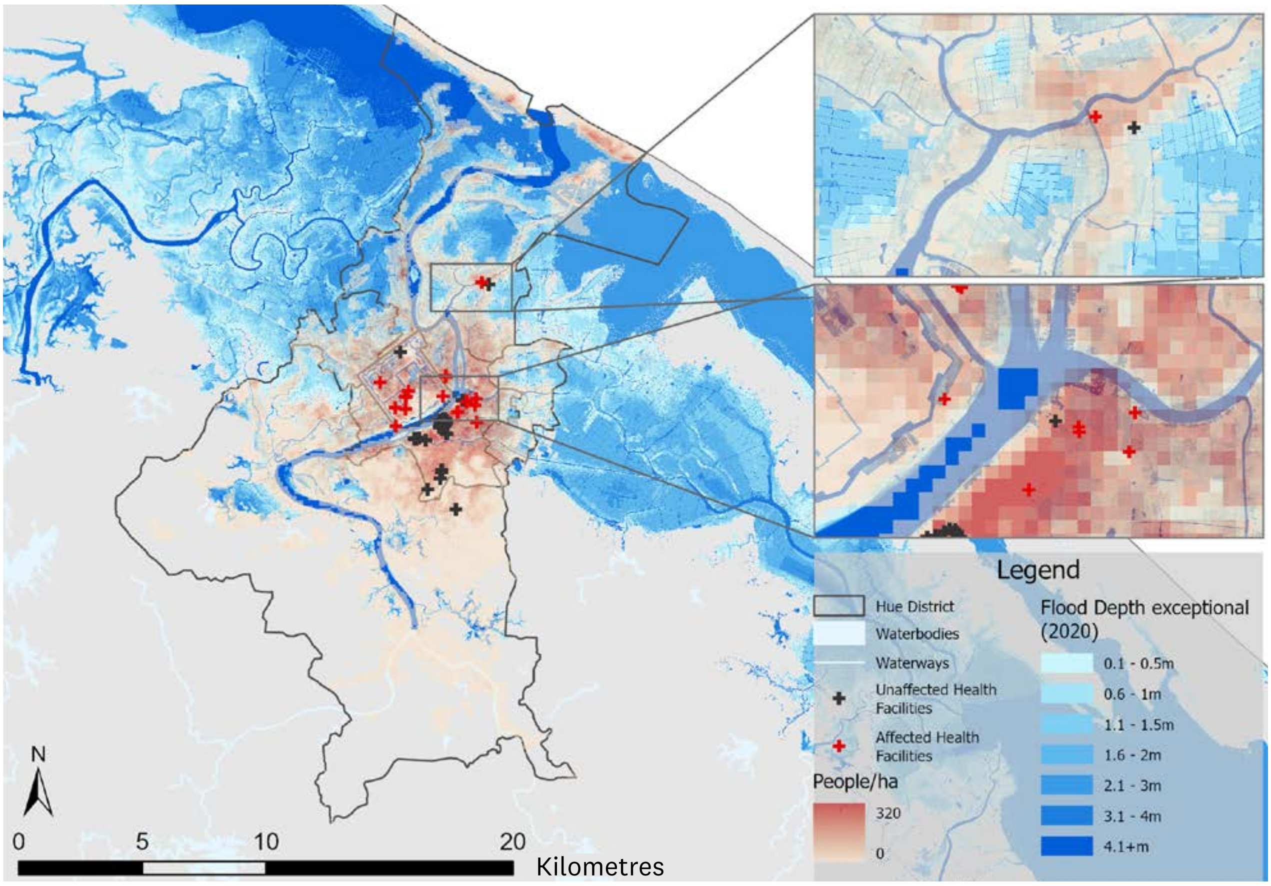

Figure 10: Map of exposed population in Hue, based on population density (yellow-red shades), exposed health facilities (crosses) and exceptional flood events (blue shades).

The 2020 flood scenario shows that a third (31 of 93) of all health facilities in Hue are exposed to floods. Most of these facilities are in the citadel (18 facilities, 17 exposed) and the core urban area (72 facilities, 13 exposed). The facility located in the upstream area is not exposed, although one of the two facilities downstream is exposed. There are no health facilities in the new urban area.

The population's exposure to floods is more widespread. Nearly all citadel and the new urban area populations are exposed, at 96 per cent and 99 per cent, respectively (table 2). In the core urban and downstream areas, 73 per cent and 86 per cent of the population, respectively, are exposed. The upstream area has a lower share (45 per cent) of exposed population. In this scenario, an estimated 335,601 people (76 per cent of the population) are exposed to floods. Despite having the second lowest percentage of exposed population, the core urban area, being the most populated, has the highest absolute number of people exposed, estimated at 126,000.

Table 2: Exposures of people and health facilities to floods (Absolute numbers; percentage)

Exposures driving health impacts	Overall exposure level	Exposed population		Exposed health facilities	
		Absolute	Share	Absolute	Share
Core Urban	high	125,604	73	13	18
Citadel	very high	56,512	96	17	94
New urban	very high	43,627	99	n/a	n/a
Peri-urban downstream	high	73,717	86	1	50
Peri-urban upstream	moderate	36,141	45	0	0
Average Hue		**335,601**	**76**	**31**	**33**

Spatial vulnerability patterns

A spatial vulnerability index was developed to assess and compare vulnerability levels across Hue's urban regions. For health impacts, this index includes six underlying risk drivers based on the results of the impact chain analysis (see figure 9). The six drivers are: (i) age-related susceptibility (young or old age); (ii) poor health condition and susceptibility; (iii) inadequate provision of and access to health services; (iv) poor response behaviour before, during and after flood events; (v) unsafe water, sanitation and hygiene (WASH) practices; and (vi) poor building conditions and characteristics.

High flood-vulnerability levels that drive human health impacts are observed in all of Hue's urban regions, except for the citadel, which shows a slightly lower moderate vulnerability (see figure 11b). However, the drivers of vulnerability differ across regions (see figure 11a). In the new urban development areas, vulnerability is driven by the high proportion of young and older people: 17 per cent of households in this region consist of older-only households, and the overall dependent population ratio is 45 per cent. This percentage indicates a significant need for support before, during and after floods, as many households

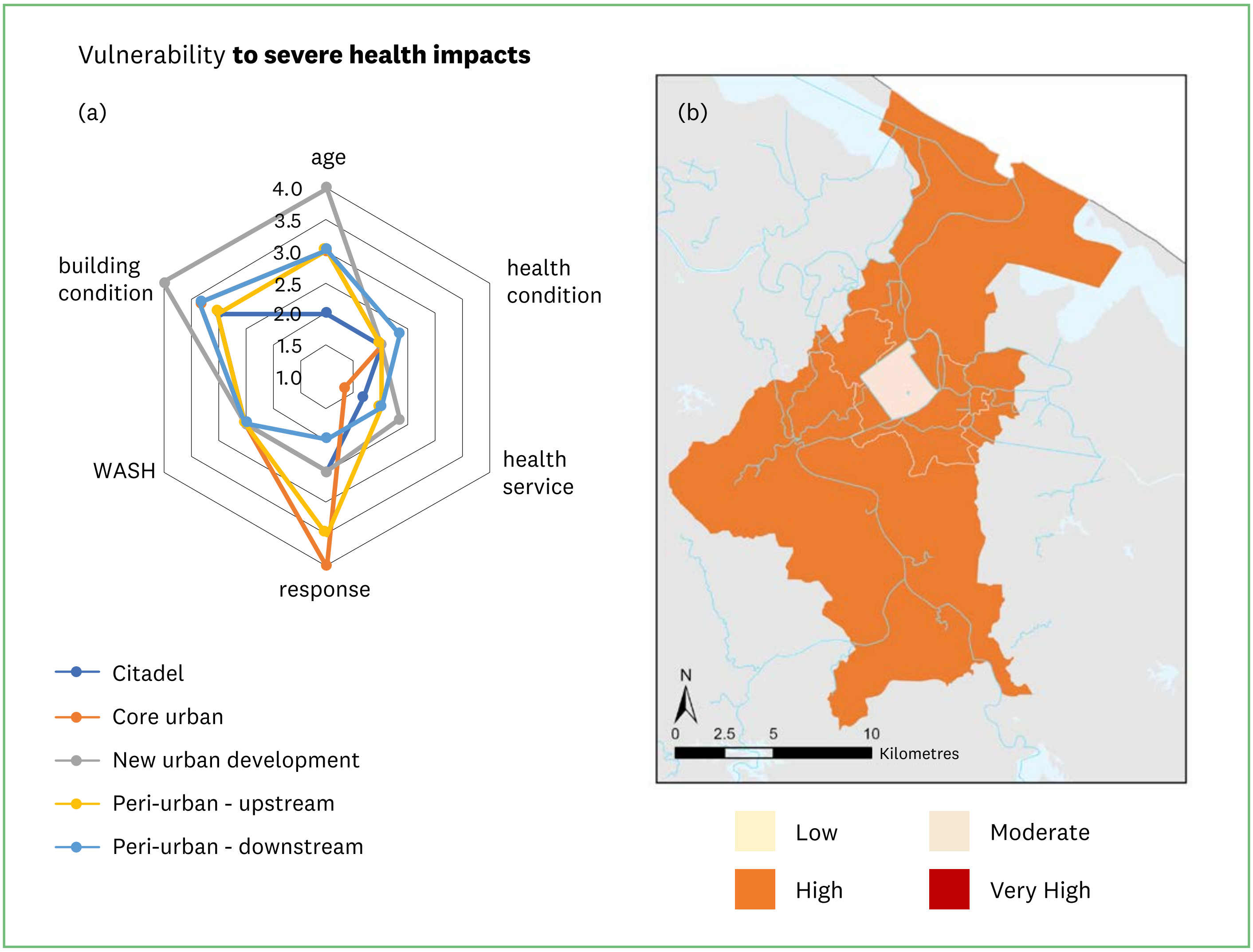

Figure 11: Map and composition of the vulnerability of people, infrastructure and services to floods.

cannot act independently due to age and dependency. Additionally, the new urban development areas have poor building conditions and high physical susceptibility: 85 per cent of houses lack a second floor for shelter, nearly half of the residential houses are rated as having low robustness (49 per cent) and 47 per cent are elevated less than 50 cm above street level. These factors make them vulnerable to flood impacts on health, such as injuries and diseases. Poor building characteristics are also found in the peri-urban downstream areas. For instance, in Huong Phong, 96 per cent of houses lack a second floor.

In contrast, poor response and adaptation behaviour drives vulnerability in the core urban and peri-urban upstream regions. Only 7 per cent of households in the upstream region have implemented adaptive measures. Additionally, 64 per cent of households in the core urban area reported not receiving help before, during or after floods, compared to only 11 per cent in the downstream region, where 22 per cent have implemented adaptive measures. Public provision of clean water by centralized water supply systems is very good across all urban regions, contributing to lower vulnerabilities (see table 3). However, less than 5 per cent of households across Hue adjust their water use behaviour during floods, increasing their risk of infectious water-borne diseases.

Table 3: Vulnerability to floods driving health impacts, including key drivers and overall vulnerability levels, on a scale from 1 (lowest vulnerability) to 4 (highest vulnerability) across Hue's urban regions

<table>
<tr><th>Urban areas</th><th>Overall vulnerability</th><th>Specific vulnerability drivers across urban regions</th><th>General vulnerability drivers in Hue</th></tr>
<tr><td>Core urban</td><td>high
[2.7/4]</td><td>– poor response: 64% of households did not receive support; 86% are without adaptive measures
(–) poor building condition: 50% of houses have elevation less than 50 cm above street level
(+) health services provision: highest share of health facilities per population</td><td rowspan="5">(+) health services: good coverage of hospital beds and medical staff per population
(+) WASH: 99% of the population in Thua Thien Hue is provided with clean water by a centralized water supply system
(–) WASH: on average, 95–100% of households do not adjust their water use behaviour during floods</td></tr>
<tr><td>Citadel</td><td>moderate
[2.3/4]</td><td>below average values for all vulnerability drivers</td></tr>
<tr><td>New urban</td><td>high
[2.9/4]</td><td>(–) young & old age: 45% average share of dependent people (children, older people) in the household; 17% older-only households
(–) poor building condition: 49% of residential houses are characterized by low building robustness; 47% of houses with an elevation less than 50 cm above street level; 85% without a second floor</td></tr>
<tr><td>Peri-urban downstream</td><td>high
[2.5/4]</td><td>(–) poor building condition: 89% of residential houses are without a second floor</td></tr>
<tr><td>Peri-urban upstream</td><td>high
[2.7/4]</td><td>(–) poor response: 93% of households have not yet implemented any adaptive measures</td></tr>
</table>

Aggregate risk of flood impacts for KFI1

Table 4 provides a summary of the findings for key flood impact 1 and its risk drivers.

Table 4: Aggregate results for key flood impact 1 and its risk drivers

Key flood impact 1: Severe health impacts in Hue				
	Hazards	**Exposures**	**Vulnerabilities**	**Aggregated risk of health impacts**
Core urban	High flood extents (64%), with more than one third of the area (36%) prone to critical water depths of at least 1 m; excessive increase in coverage (97%) and water levels for historic flood events	High exposure of 73% of the population – although based on the high population density of the core urban area, it still presents a very high absolute number of more than 126,000 people exposed; in addition, 18% of all health facilities exposed	High vulnerability, driven by poor response behaviour, such as the lack of adaptive measures and low level of help received, and poor building conditions, such as low housing elevation levels	High aggregate risk of flood-induced health impacts, composed of high hazard, exposure and vulnerability levels
Citadel	Widespread flood extents, covering almost two thirds (62%) of the region, while critical flood depths of at least 1 m cover around one third (31%) of the citadel	Extremely high exposure, with 96% of the population exposed to exceptional floods and 94% of all health facilities	Moderate vulnerability, with below-average levels for all vulnerability drivers; however, still high prevalence of poor building conditions	High aggregate risk of flood-induced health impacts, resulting from moderate vulnerability levels interacting with extremely high exposure levels and high hazard levels
New urban development	Highest flood extents (89%) of all urban regions in Hue, with more than half of the area (57%) prone to critical water depths of at least 1 m	Extremely high exposure, with 99% of the population exposed to exceptional floods	High absolute and highest relative vulnerability compared to the other urban regions, driven by age susceptibility and poor building conditions	Highest aggregate risk of flood-induced health impacts, resulting from extremely high hazard and exposure levels coupled with high vulnerability
Peri-urban downstream	Very high flood extents (84%), with the highest coverage of areas (61%) with a critical water depth of at least 1 m	High exposure, with 86% of the population and one of two (50%) health facilities exposed	High vulnerability, particularly driven by poor building conditions, that is, lacking second floors that significantly reduces coping capacities of residents	Very high aggregate risk of flood-induced health impacts, mainly composed of very high hazard levels, coupled with high exposure and vulnerability
Peri-urban upstream	Moderate extent (20%) with several flood-prone areas along the Huong River system and the northern plains; high relative share of critical flooding: 78% of the flood-prone area exceed a critical water depth of at least 1 m (15% absolute)	Moderate exposure of 45% of the population and the only hospital in the region being outside a flood-prone area	High vulnerability, particularly driven by poor response behaviour, that is, lacking adaptive measures	Moderate absolute and lowest relative aggregate risk of flood-induced health impacts compared to the other urban regions, characterized by moderate hazard and exposure, and high vulnerability levels, indicating high risks for extreme events

3.3.2. Key flood impact 2: agricultural livelihood disruptions

Impacts, risk drivers and root causes

Floods can significantly impact rice farming in Hue through a chain of effects on people, infrastructure and the environment. Health issues like injuries or diseases can prevent rice farmers from working. Damage to infrastructure, such as irrigation systems, and direct crop damage can disrupt rice production, leading to reduced income and potentially driving farmers into poverty (see figure 12).

Rice farming in Hue is vulnerable due to multiple interconnected factors. The heavy reliance on rice as the primary source of income is a key issue, exacerbated by a lack of other livelihood opportunities and insufficient insurance coverage to mitigate the financial impact of crop losses. Poor building and infrastructure resilience also increases the risk of damage during floods. Environmental factors also play a significant role. Ecosystem degradation leads to poor soil and water health, increasing crop susceptibility. High-yield crops, which are often more vulnerable to flooding, further aggravate the situation and reflect unsustainable agricultural practices.

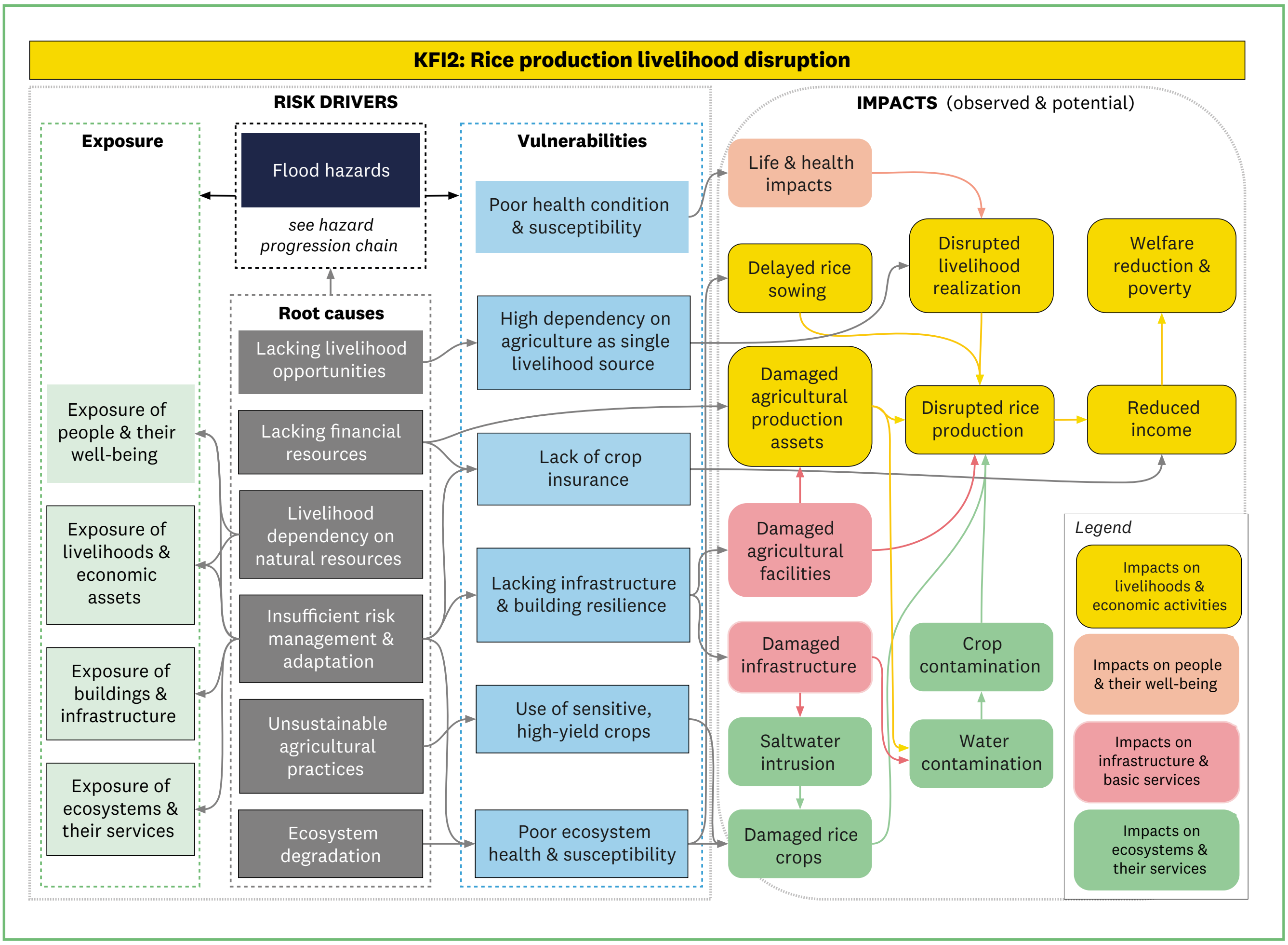

Figure 12: Conceptual risk model for KFI2: agricultural livelihood disruption (adapted from Sett et al., 2024).

Overall, the disruption of rice livelihoods in Hue highlights the complex interplay of human, economic, infrastructural and environmental vulnerability drivers. Addressing these issues requires a holistic approach that diversifies income sources, improves infrastructure resilience and adopts sustainable agricultural practices.

Spatial exposure patterns

Four types of agricultural land cover were identified in the research area (figure 13). The most common are tree plantations, covering approximately 5,840 hectares, primarily in the upstream region. Rice paddies occupy about 4,680 ha, mostly found downstream of the city. Woody crops and other croplands account for about 1,850 ha and 2,150 ha, respectively, with the majority also located upstream. The core urban area and the citadel have the smallest agricultural areas, with 370 ha and 200 ha, respectively. Larger agricultural areas are found in the new urban area (1,170 ha), the downstream peri-urban area (3,220 ha) and the upstream peri-urban area (9,550 ha). This land cover data is based on Japan Aerospace Exploration Agency (JAXA) data at a 30-metre grid resolution (EORC, 2021).

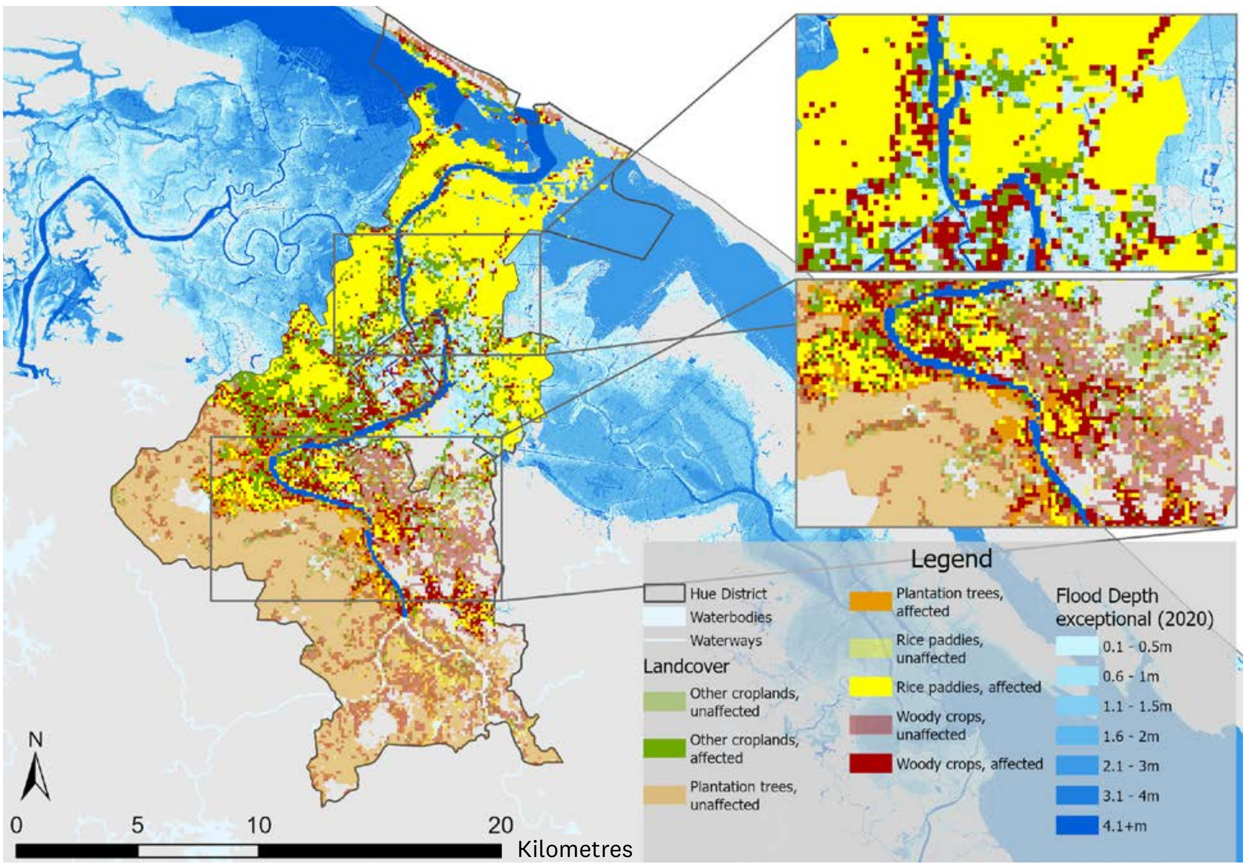

Figure 13: Map of agricultural land in Hue exposed to exceptional flood events (blue shades), including rice paddies (yellow shades), plantation trees (orange shades), woody crops (red shades) and other croplands (green shades). Lighter shades indicate areas that are not exposed to flooding (source: authors).

Rice paddies' exposure to the 2020 flood scenario is highest in the new urban areas, the citadel and the peri-urban downstream regions, with almost the entire rice paddy area exposed (table 5). While this exposure amounts to only 24 ha in the citadel, the peri-urban downstream area is characterized by more than 2,660 ha exposure. Exposure of other crops is equally high for the new urban area and the citadel (all above 98 per cent). In addition, even the peri-urban upstream region, which has the lowest relative exposure, is still highly exposed, with almost 800 ha of rice paddies in flood-prone areas.

Table 5: Exposure of rice paddies to floods (Hectares; percentage)

Exposures driving rice livelihood disruptions	Overall exposure level	Exposed rice paddies	
		Absolute	Share
Core urban	high	79	86
Citadel	very high	24	99
New urban	very high	880	100
Peri-urban downstream	very high	2,664	99
Peri-urban upstream	high	795	79
Average Hue		**4,442**	**95**

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Spatial vulnerability patterns

A spatial vulnerability index was developed to assess and compare vulnerability levels across urban regions in Hue, which is a key flood impact. The index for disruptions to rice livelihoods includes five drivers based on the results of the impact chain analysis (see figure 12). These factors are: (i) poor health conditions and susceptibility (see also chapter 3.3.1); (ii) high dependency on agriculture as the sole livelihood source; (iii) lack of crop and unemployment insurance; (iv) poor ecosystem health and susceptibility; and (v) use of sensitive high-yield crops.

High vulnerability levels to rice livelihood disruptions are evident in the core urban area and the peri-urban upstream and downstream areas (see figure 14b). However, vulnerability factors vary across regions (see figure 14a). In the peri-urban downstream areas, vulnerabilities are highest due to high agricultural dependency and poor ecosystem health. On average, 28 per cent of households in this region rely solely on agriculture for their income, rising to 39 per cent in Huong Phong. In contrast, no surveyed households in the citadel area depend solely on agriculture. Additionally, the downstream area has the lowest vegetation health index in Hue.

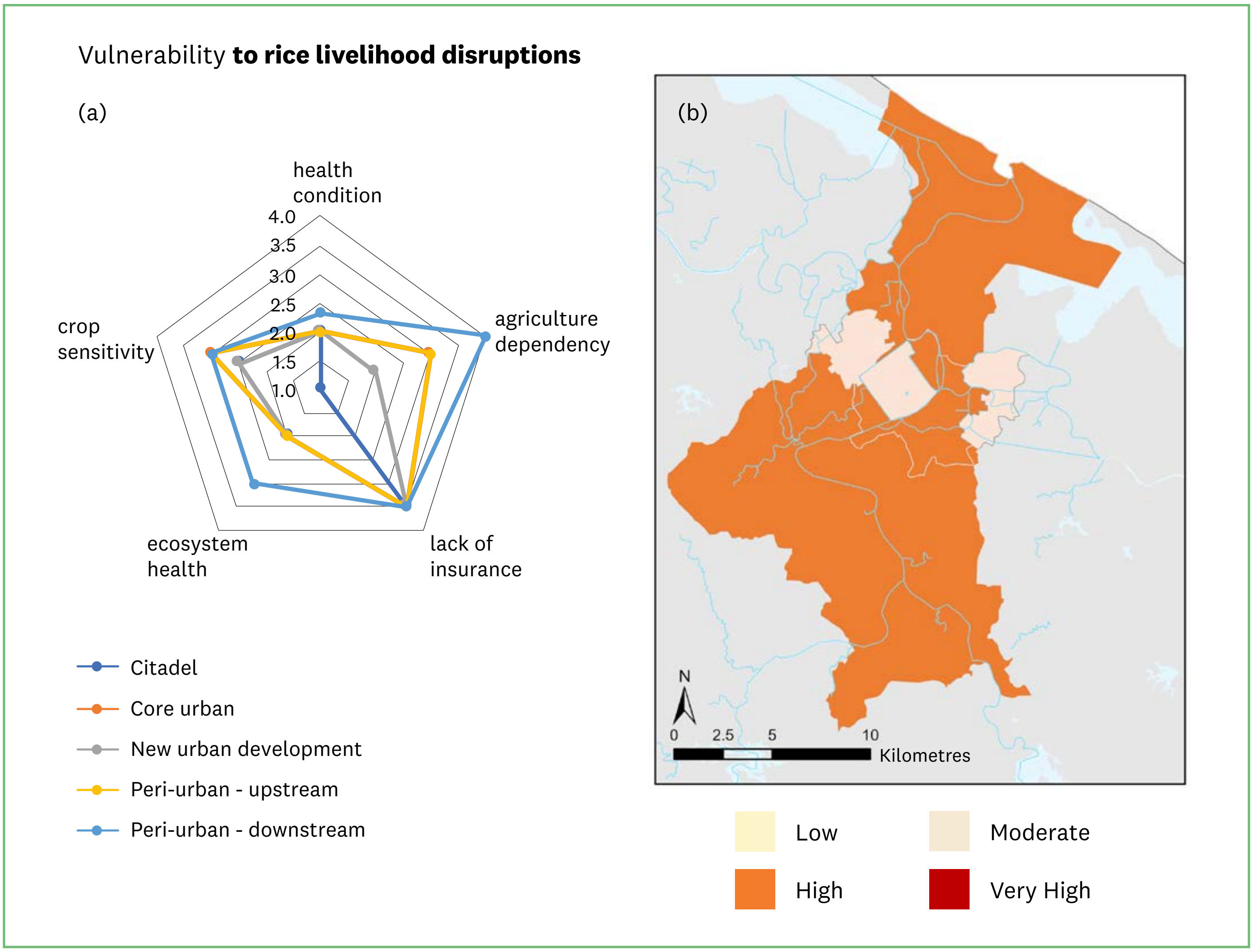

Figure 14: Map and composition of the vulnerability of people, livelihoods and ecosystems to floods.

Surprisingly, the core urban area also faces high vulnerability levels, primarily due to the use of high-yield crops (see table 6). Limited space in the core urban area means that the scarce agricultural land is used for crops that produce higher yields but are more susceptible to disturbances like floods or heat stress, posing a significant risk to rice production in this area.

Table 6: Vulnerability to floods driving rice livelihood disruptions, including key drivers and overall vulnerability levels, on a scale from 1 (lowest vulnerability) to 4 (highest vulnerability) across urban regions in Hue

<table>
<tr><th>Urban areas</th><th>Overall vulnerability</th><th>Specific vulnerability drivers across urban regions</th><th>General vulnerability drivers across Hue</th></tr>
<tr><td>Core urban</td><td>high
[2.7/4]</td><td>slightly above average vulnerability levels leading to an overall high vulnerability degree to rice livelihood disruptions</td><td rowspan="5">(–) lack of insurance: No single surveyed household had any crop insurance, indicating a low level of coping and adaptive capacities of agricultural households across Hue if affected</td></tr>
<tr><td>Citadel</td><td>moderate
[2.2/4]</td><td>(+) agricultural dependency: no single household is solely relying on agricultural income only</td></tr>
<tr><td>New urban</td><td>moderate
[2.4/4]</td><td>slightly below average vulnerability levels, including for agricultural dependency and crop sensitivity</td></tr>
<tr><td>Peri-urban downstream</td><td>high
[3.2/4]</td><td>Highest vulnerability to rice livelihood disruptions across Hue's urban regions:
(–) agricultural dependency: 28% of households solely rely on agricultural incomes, even 39% in Huong Phong
(–) ecosystem health: lowest Vegetation Health Index levels for Hue</td></tr>
<tr><td>Peri-urban upstream</td><td>high
[2.7/4]</td><td>slightly above average vulnerability levels leading to an overall high degree of vulnerability to rice livelihood disruptions</td></tr>
</table>

Another key factor is the lack of crop insurance. None of the surveyed households reported having any type of agricultural insurance, and only about 14 per cent of households in Viet Nam have unemployment insurance. This lack of risk-transfer options leaves rice farmers vulnerable to potential crop damage and its consequent financial impacts.

Aggregate risk of flood impacts for KFI2

A summary of the findings for key flood impact 2 and its risk drivers is provided in Table 7.

Table 7: Aggregate results for key flood impact 2 and its risk drivers

Key flood impact 2: Rice livelihood disruptions in Hue				
	Hazard	**Exposure**	**Vulnerability**	**Aggregate risk of livelihood impacts**
Core urban	High flood extents (64%), with more than one third of the area (36%) prone to critical water depths of at least 1 m; excess increase in coverage (97%) and water levels for historic flood events	High exposure, with almost four fifths (79%) of the rice paddy area exposed (Total exposed area: 131 ha)	High vulnerability resulting from slightly above average vulnerability levels across drivers	High aggregate risk of flood-induced rice livelihood disruptions, composed of high hazard, exposure and vulnerability levels
Citadel	Widespread flood extents, covering almost two thirds (62%) of the region, while critical flood depths of at least 1 m cover around a third (31%) of the citadel	Highest relative exposure, with the entire rice paddy area exposed (Total exposed area: 75 ha)	Moderate vulnerability, with comparatively lower levels than other urban regions due to diversification of livelihoods and resulting low agricultural dependency	High absolute aggregate risk of flood-induced rice livelihood disruptions, composed of high hazard levels, very high exposure and moderate vulnerability
New urban development	Highest flood extents (89%) of all urban regions in Hue, with more than half of the area (57%) prone to critical water depths of at least 1m	Highest relative exposure, with the entire rice paddy area exposed, which amounts to more than 215 ha	Moderate vulnerability resulting from slightly below average vulnerability levels across drivers	Very high aggregate risk of flood-induced rice livelihood disruptions, mainly resulting from very high hazard and exposure levels coupled with moderate vulnerability
Peri-urban downstream	Very high flood extents (84%), with the highest coverage of areas (61%) with critical water depths of at least 1 m	Very high exposure, with almost the entire rice paddy area exposed (94%), amounting to more than 316 ha	Highest vulnerability, particularly driven by high agricultural dependency and low ecosystem health	Highest aggregate risk of flood-induced rice livelihood disruptions, composed of very high hazard and exposure levels and high vulnerability
Peri-urban upstream	Moderate extent (20%) with several flood-prone areas along the Huong River system and the northern plains; high relative share of critical flooding: 78% of the flood-prone area exceed a critical water depth of at least 1 m (15% absolute)	High exposure, with two thirds (66%) of the rice paddy area exposed; due to the very high total growing area, the absolute exposure is very high, as more than 888 ha are affected	High vulnerability resulting from slightly above average vulnerability levels across drivers	High absolute aggregate risk of flood-induced rice livelihood disruptions and lowest relative risks level compared to other urban regions, mainly due to moderate hazard levels, with high exposure and vulnerability

3.3.3. Key flood impact 3: transport interruption

Impacts, risk drivers and root causes
Flood-induced impacts on transportation and mobility primarily stem from three direct effects: vehicle damage, damage to transport facilities such as fuel stations, and damaged or blocked roads (figure 15). These issues disrupt mobility, leading to severe indirect and cascading impact risks such as restricted access to services, livelihoods and markets.

Infrastructure exposure and vulnerability largely drive the disruption of individual transportation. Roads and bridges constructed in flood-prone areas, due to rapid urbanization, make them inaccessible during floods. This problem is exacerbated by urban planning that does not consider flood risks and the lack of adaptation in transport infrastructure.

Limited transportation options, both individual and public, further compound mobility disruptions. Without reliable public transport, people often engage in risky behaviour, such as driving through floodwaters, especially if their livelihoods depend on being mobile, which increases the likelihood of vehicle damage and poses significant personal health risks. This risky behaviour can be attributed to a lack of risk awareness and inadequate early warning systems that fail to effectively communicate flood dangers and their potential impacts.

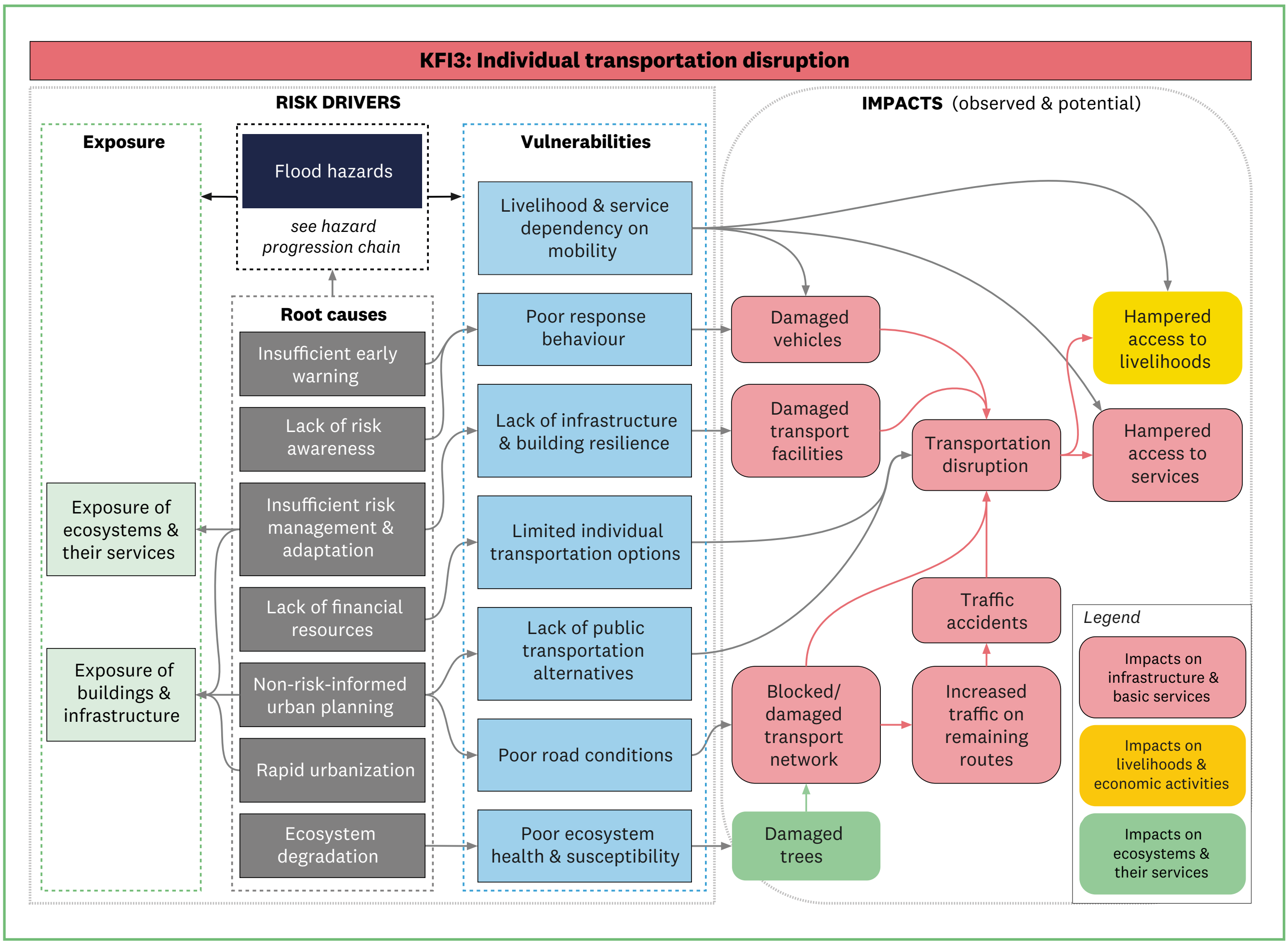

Figure 15: Conceptual risk model for KFI3: individual transportation disruption (adapted from Sett et al., 2024).

Spatial exposure patterns

Transportation is crucial for accessing daily facilities and supporting the local economy. In the research area, different road types and the national railway system are essential for spatial exposure assessments of floods. About half of the train tracks pass through the core urban area. The new urban area and the citadel cover nearly the remaining half, with only a small portion in the upstream area. In the 2020 flood scenario, about 41 per cent of the train tracks are exposed to flooding. The new urban area and the upstream peri-urban area have higher shares of flooded train tracks (88 per cent and 67 per cent, respectively), while the citadel and the core urban area show lower exposure, with 21 per cent and 28 per cent of tracks exposed to flooding, respectively. Table 8 and Figure 16 provide more details on the exposure. The data used for this analysis are open street map data provided by Geofabrik (Geofabrik, 2024).

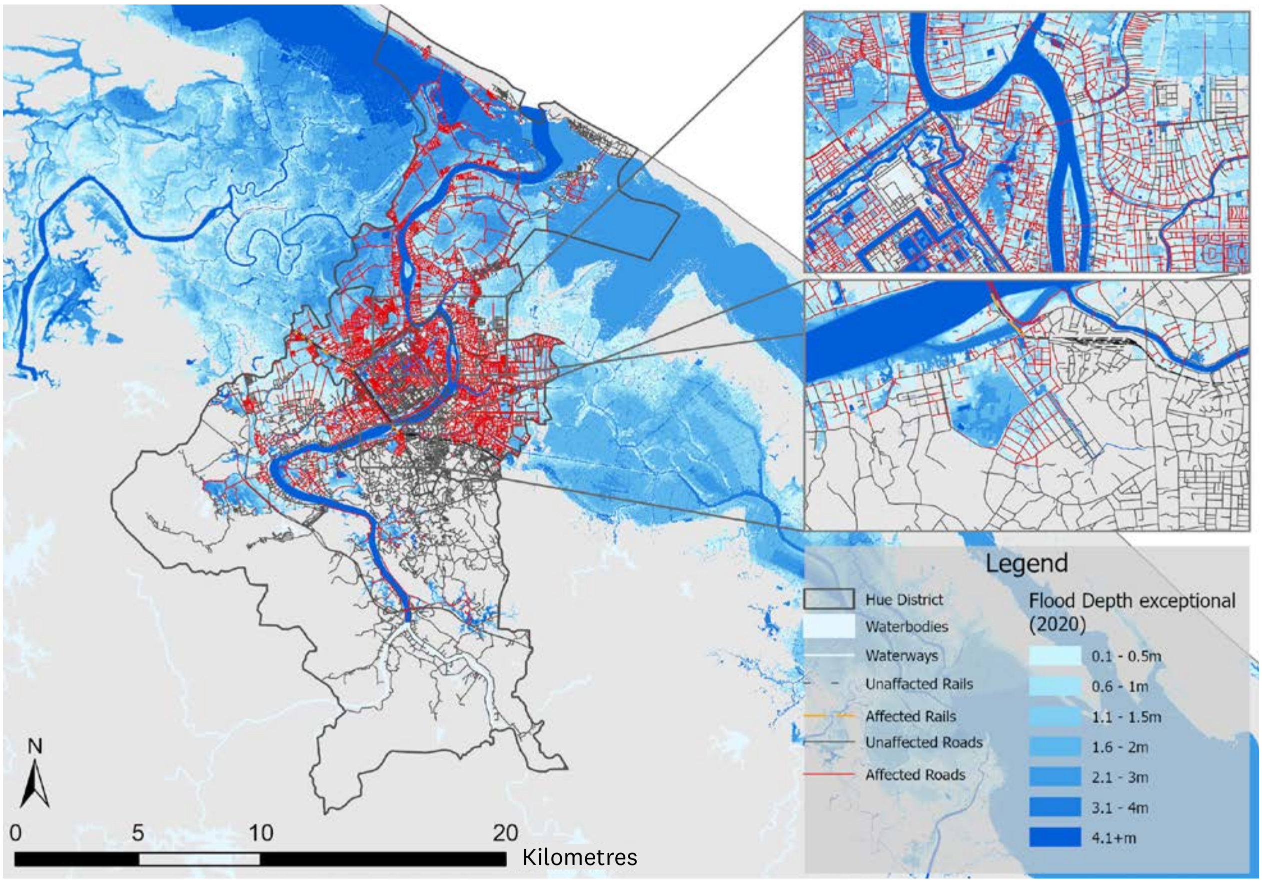

Figure 16: Map of exposed transportation infrastructure.

Red lines denote exposed roads, grey lines show unaffected roads, the yellow line indicates the affected train tracks while the grey dashes indicate the unaffected train tracks.

In terms of roads, during the 2020 flood event about half (51 per cent, 861 km) the road network in the research area was exposed. The citadel, core urban and new urban areas have the highest road density. The road network in the new urban area is the most exposed (80 per cent, 194 km), followed by the peri-urban downstream area, which has the highest absolute exposure (280 km, 72 per cent). The peri-urban upstream area is least exposed, with 21 per cent of its road network exposed, which still accounts for more than 117 km.

Table 8: Exposure of road network to floods (Kilometres; percentage)

Exposures driving transport disruptions	Overall exposure level	Exposed roads	
		Absolute	Share
Core Urban	high	189	56
Citadel	moderate	81	47
New urban	very high	194	80
Peri-urban downstream	high	280	72
Peri-urban upstream	moderate	117	21
Average Hue		**861**	**51**

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Spatial vulnerability patterns
The spatial vulnerability index for transport disruptions comprises five drivers, based on the results of the impact chain analysis (see above). Those are (i) poor response behaviour (see also chapter 3.3.1); (ii) transport dependency; (iii) limited individual transportation options; (iv) lack of public transportation alternatives; and (v) poor road conditions.

The transport system's very high vulnerability levels can be observed in the upstream region, while high vulnerability levels persist in Hue's other regions (see figure 17b). The composition of vulnerability to transport disruptions varies significantly across regions (see figure 17a). Poor road conditions and a lack of individual transport options characterize the peri-urban downstream and upstream regions. More than 98 per cent of households in these regions do not possess a car, a vulnerability factor also high in the new urban development region (99 per cent without a car). In contrast, vulnerability in the citadel is mainly driven by high transport dependency, with 82 per cent of households relying on mobility for their livelihoods (table 9).

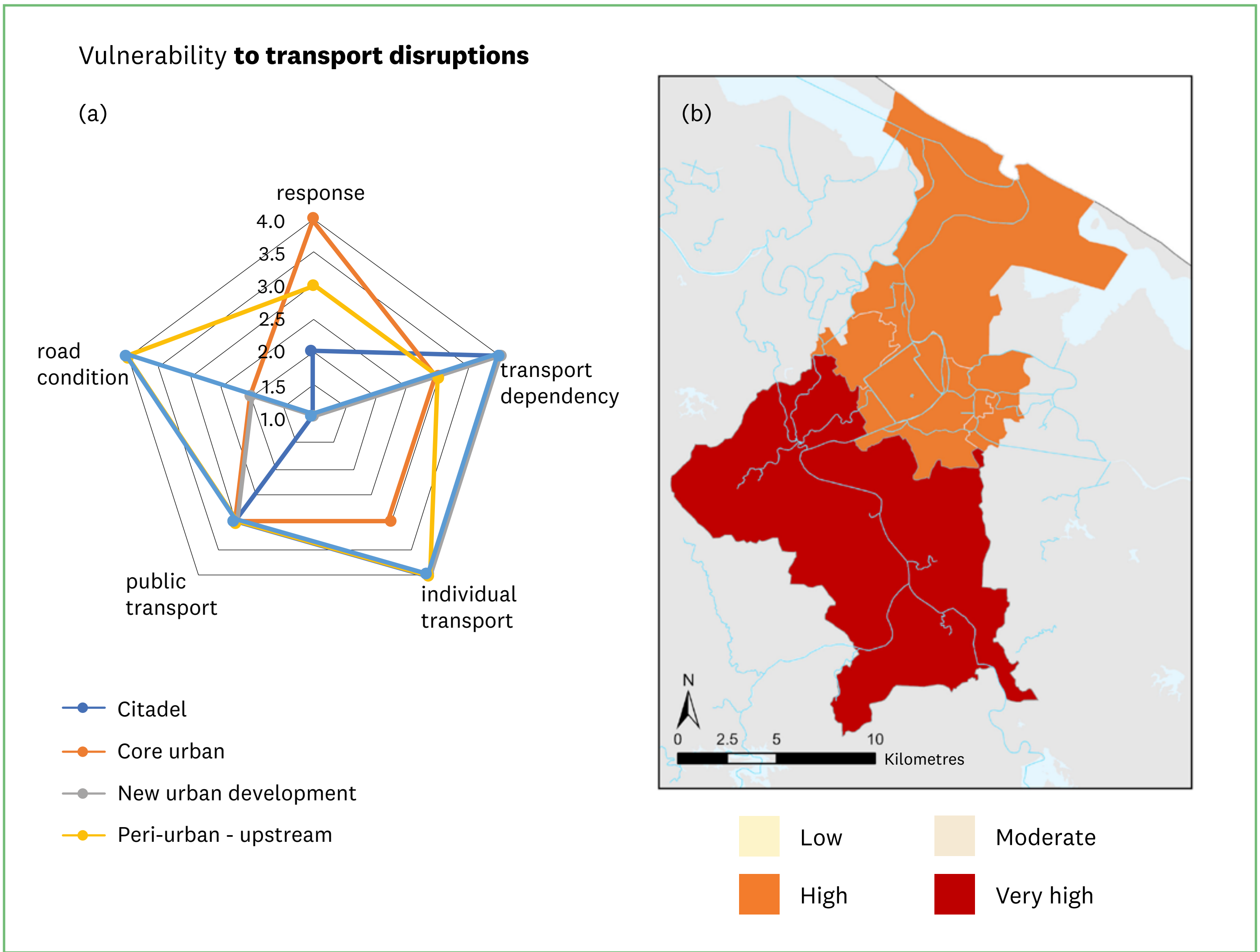

Figure 17: Map and composition of people, infrastructure and services vulnerability to floods.

Table 9: Vulnerability to floods driving transport disruptions, including key drivers and overall vulnerability levels, on a scale from 1 (lowest vulnerability) to 4 (highest vulnerability) across urban regions in Hue

Urban areas	Overall vulnerability	Specific vulnerability drivers across urban regions	General vulnerability drivers across Hue
Core urban	**high** [2.8/4]	(–) **poor response**: 64% of households did not receive support; 86% of houses are without adaptive measures	(–) **lack of public transport alternatives**: number of public transport passengers significantly below the national average
Citadel	**high** [3.0/4]	(+) **road conditions**: highest road density (–) **transport dependency**: 82% of households are dependent on mobility to fulfil their livelihoods (-) **individual transport**: 93% of households do not possess a car	
New urban	**high** [2.8/4]	(+) **response behaviour**: high share of households that received help during floods (–) **transport dependency**: 81% of households are dependent on mobility to fulfil their livelihoods (–) **individual transport**: 99% of households do not possess a car	
Peri-urban downstream	**high** [3.2/4]	(+) **response behaviour**: high share of households that received help during floods (–) **transport dependency**: 90% of households are dependent on mobility to fulfil their livelihoods (–) **individual transport**: 98% of households do not possess a car (–) **poor road conditions**: low road density and high dependency on specific routes	
Peri-urban upstream	**very high** [3.4/4]	(–) **individual transport**: no single surveyed household possess a car (–) **poor road conditions**: lowest road density and high dependency on specific routes	

Another key vulnerability factor across all regions in Hue is the lack of public transportation alternatives. The average passenger numbers for the Thua Thien Hue province are significantly below national averages due to the inadequate provision and use of public buses or trains.

Aggregate risk of flood impacts for KFI3

Table 10 provides a summary of the findings for key flood impact 3 and its risk drivers.

Table 10: Aggregate results for key flood impact 3 and its risk drivers

Key flood impact 3: Transport disruptions in Hue				
	Hazard	**Exposure**	**Vulnerability**	**Aggregate risk of transport impacts**
Core urban	High flood extents (64%), with more than one third of the area (36%) prone to critical water depths of at least 1 m; excessive increase in coverage (97%) and water levels for historic flood events	High exposure, with more than half (59%) of all roads exposed (total exposed length: 201 km)	High vulnerability, mainly driven by poor response behaviour	Very high aggregate risks of flood-induced transport disruptions, composed of high hazard, exposure and vulnerability levels
Citadel	Widespread flood extents, covering almost two thirds (62%) of the region, while critical flood depths of at least 1 m cover around a third (31%) of the citadel	Moderate exposure, less than half (47%) of all roads exposed, and 21% of train tracks	High vulnerability, resulting from high transport dependency and lacking individual transport options, and lowered by good road conditions	High aggregate risks of flood-induced transport disruptions, mainly driven by high hazard and vulnerability levels, and moderate exposure levels
New urban development	Highest flood extents (89%) of all urban regions in Hue, with more than half of the area (57%) prone to critical water depths of at least 1 m	Highest exposure, with 87% of all roads exposed, amounting to a total length of 212 km of exposed roads	High vulnerability, resulting from high transport dependency and lack of individual transport options, and lowered by good response behaviour	Highest aggregate risks of flood-induced transport disruptions, composed of very high hazard and exposure levels and high vulnerability
Peri-urban downstream	Very high flood extents (84%), with the highest coverage of areas (61%) with a critical water depth of at least 1 m	High exposure, with about three quarters of all roads exposed; due to high overall road network, a total of 288 km is exposed	High vulnerability, resulting from high transport dependency, lack of individual transport options, and poor road conditions, and lowered by good response behaviour	Very high aggregate risks of flood-induced transport disruptions, mainly driven by very high hazard levels and high vulnerability and exposure
Peri-urban upstream	Moderate extent (20%) with several flood-prone areas along the Huong River system and the northern plains; high relative share of critical flooding: 78% of the flood-prone area exceed a critical water depth of at least 1 m (15% absolute)	Moderate exposure with less than a third of all roads being exposed, which however still amounts to a total length of exposed roads of 177 km	Highest vulnerability, mainly driven by lack of individual transport options and poor road conditions	High aggregate risks of flood-induced transport disruptions, mainly driven by very high vulnerability levels and moderate hazard and exposure levels

3.3.4. Key flood impact 4: risks for water contamination

Impacts, risk drivers and root causes
Flood-induced water contamination can result from various direct impacts, leading to different types of contamination, such as solid waste, chemical, microbial and saltwater, typically caused by infrastructure damage and service disruptions. For example, saltwater can intrude if protective dikes and flood gates are damaged, while microbial contamination can occur from the destruction and overflow of sewer systems. Solid-waste contamination of water can result from transport disruptions that hinder waste collection or safe disposal.

Water contamination can lead to severe consequences for people and ecosystems. It can harm health, linking it to key flood impact 1, and can negatively impact ecosystems and crops, linking it to key flood impact 2. These connections highlight the importance of considering the interrelationships between key impacts and their risk drivers.

The primary cause of water contamination is infrastructure damage and service disruption. The resilience of infrastructure systems is a crucial factor in preventing contamination. Poor and non-risk-informed urban planning often results in expanding urban areas without corresponding infrastructure development, such as sewer and stormwater systems. Additionally, chemical contamination in floodwater is often due to the high use of fertilizers and pesticides to maximize agricultural yields. Unsafe disposal of livestock waste can also cause contamination, leading to cascading impacts on people, animals and nature.

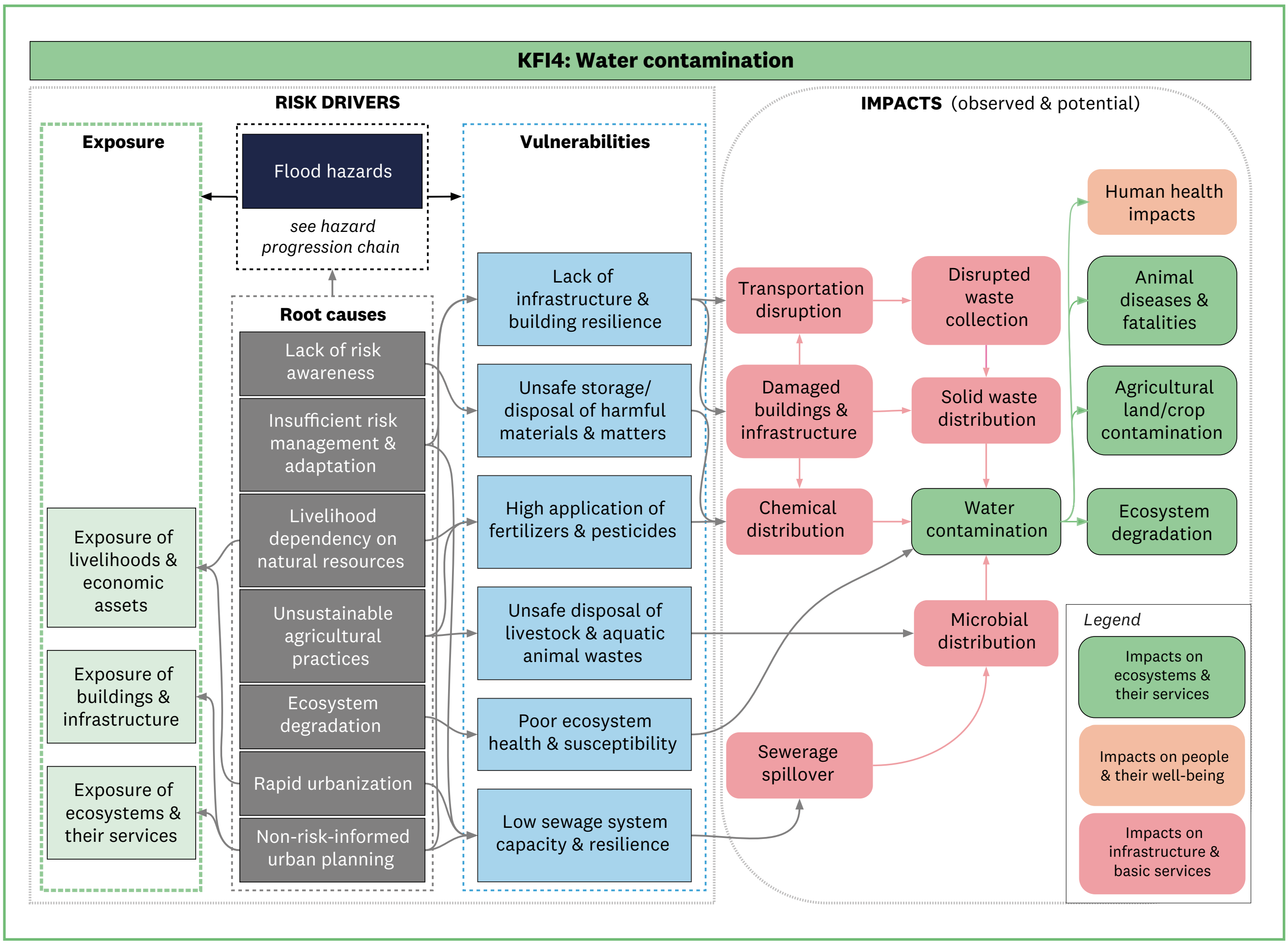

Figure 18: Conceptual risk model for KFI4: water contamination (adapted from Sett et al., 2024).

Spatial exposure patterns
Water contamination is widely distributed across the entire flood-hazard zone (see flood-hazard maps in chapter 3.2). Even if the contamination source is localized, its effects will be felt across all of Hue's regions due to the strong distribution effect, making it challenging to assess exposure to water contamination in a spatially explicit way. Hence, a spatial exposure map is not provided for this key flood impact.

Spatial vulnerability patterns
The spatial vulnerability index for water contamination includes five drivers, based on the results of the impact chain analysis (see figure 18). These are (i) low waste treatment capacity and resilience; (ii) high application of fertilizers and pesticides; (iii) unsafe disposal of livestock and aquatic animal waste; (iv) unsafe storage and disposal of harmful materials; and (v) poor ecosystem health.

Hue's downstream region exhibits very high vulnerability of its water bodies to adverse impacts on water quality, while the other four regions also show high vulnerability levels (see figure 19b). The peri-urban downstream region has the highest values across all vulnerability components, particularly for fertilizer use, disposal of harmful materials and poor ecosystem health (see figure 19a). Over half of the surveyed households in this region use fertilizers, and the aquaculture area covers more than 721 ha, making it especially susceptible to chemical and microbial water contamination. The citadel, with the lowest vulnerability levels, still faces significant risks of water contamination.

Vulnerability **to water contamination**

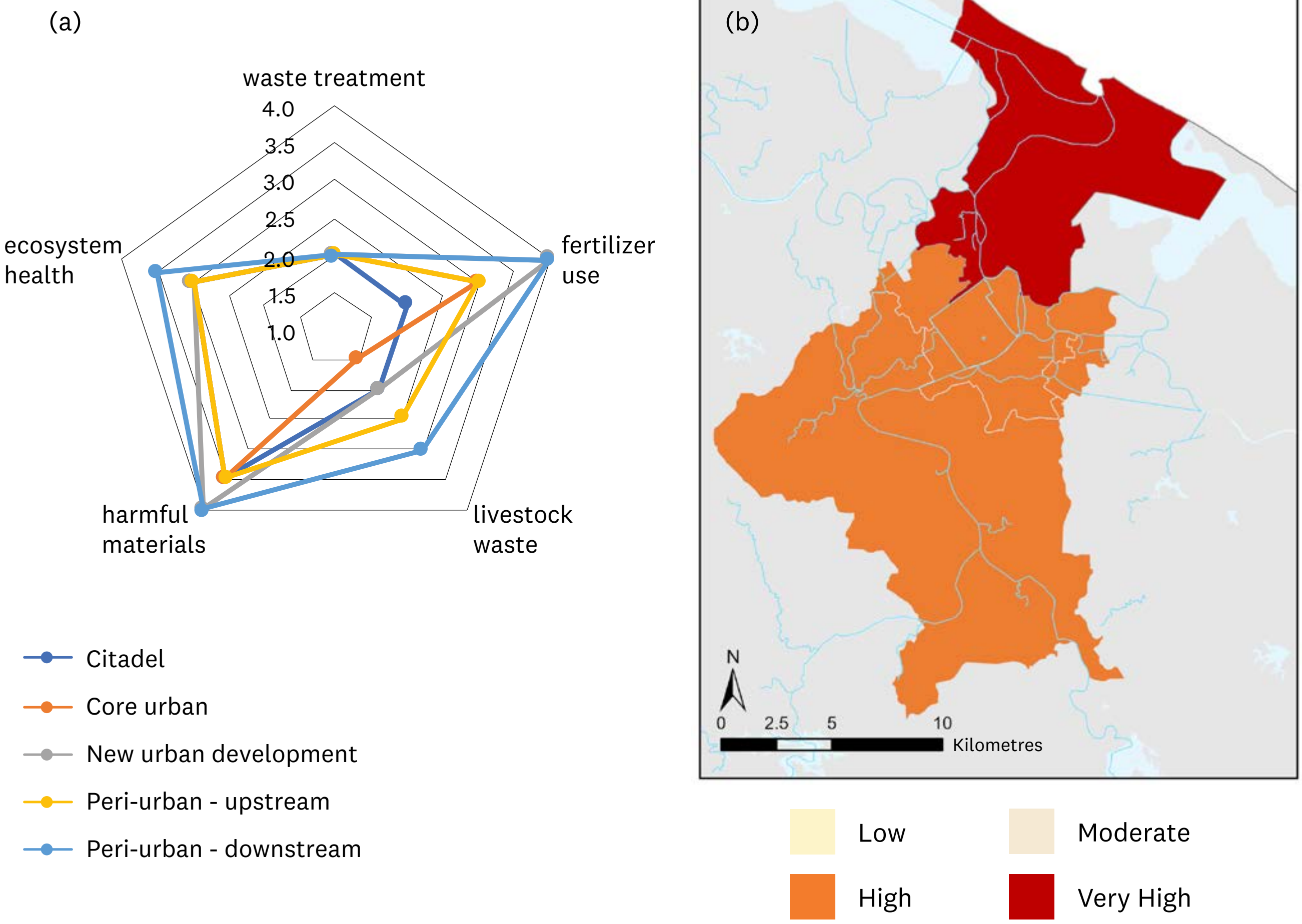

Figure 19: Map and composition of the vulnerability of livelihoods, services and nature to floods.

A critical vulnerability factor across all regions in Hue is the unsafe storage and disposal of harmful materials. In Thua Thien Hue province, more than 83 per cent of industrial parks lack centralized wastewater treatment plants that meet environmental standards, compared to the national average of 9 per cent, highlighting a pressing need for improvement (table 11).

Table 11: Vulnerability to floods driving water contamination, including key drivers and overall vulnerability levels, on a scale from 1 (lowest vulnerability) to 4 (highest vulnerability) across urban regions in Hue

Urban regions	Overall vulnerability	Specific vulnerability drivers across urban regions	General vulnerability drivers across Hue
Core urban	**high** [2.5/4]	(+) **livestock waste disposal**: lowest aquacultural area and livestock count, hence low livestock waste	(–) **unsafe storage/ disposal of harmful materials**: 83% of industrial parks do not treat their wastewater according to environmental standards
Citadel	**high** [2.6/4]	slightly below average vulnerability levels across categories	
New urban	**high** [3.0/4]	(–) **high fertilizer use**: almost half (48%) of all surveyed households apply fertilizers	
Peri-urban downstream	**very high** [3.3/4]	(–) **high fertilizer use**: more than half (53%) of all surveyed households apply fertilizers (–) **highest aquaculture area** (< 700 ha) (–) **poor ecosystem health**: lowest Mean Vegetation Health Index	
Peri-urban upstream	**high** [2.8/4]	average vulnerability levels across categories	

Aggregate risk of flood impacts for KFI4

Table 12 provides a summary of the findings for key flood impact 4 and its risk drivers.

Table 12: Aggregate results for key flood impact 4 and its risk drivers

Key flood impact 4: Water contamination in Hue				
	Hazard	**Exposure**	**Vulnerability**	**Aggregate risk of water quality impacts**
Core urban	High flood extents (64%), with more than one third of the area (36%) prone to critical water depths of at least 1 m; excessive increase in coverage (97%) and water levels for historic flood events	*No geospatial assessment possible due to the strong distribution nature of water contamination*	High vulnerability, particularly driven by unsafe disposal of harmful materials, but lowered by low livestock waste disposal	Very high aggregate risk of flood-induced water contamination, driven mainly by very high hazard levels and high vulnerability
Citadel	Widespread flood extent, covering almost two thirds (62%) of the region, while critical flood depths of at least 1 m cover around a third (31%) of the citadel		High vulnerability, particularly driven by unsafe disposal of harmful materials	High aggregate risk of flood-induced water contamination based on high hazard and vulnerability levels
New urban development	Highest flood extent (89%) of all urban regions in Hue, with more than half of the area (57%) prone to critical water depths of at least 1 m		High vulnerability, driven by high application of fertilizers and unsafe disposal of harmful materials	Very high aggregate risk of flood-induced water contamination, mostly driven by very high hazard levels and high vulnerability
Peri-urban downstream	Very high flood extent (84%), with the highest coverage of areas (61%) with critical water depths of at least 1 m		Highest vulnerability driven by the high application of fertilizers, unsafe disposal of harmful materials, and poor ecosystem health	Highest aggregate risk of flood-induced water contamination due to the interaction of very high hazard and vulnerability levels
Peri-urban upstream	Moderate extent (20%) with several flood-prone areas along the Huong River system and the northern plains; high relative share of critical flooding: 78% of the flood-prone area exceeds critical water depth of at least 1 m (15% absolute)		High vulnerability, particularly driven by unsafe disposal of harmful materials	High aggregate risk of flood-induced water contamination, mainly driven by high vulnerability coupled with moderate hazard levels

3.4. Aggregate flood risks

Spatial risk patterns
As outlined in the previous key flood impact chapter (3.3), the flood-induced risk for impacts on people, agricultural livelihoods, transportation and water quality is high across Hue (see table 13). However, the new urban and peri-urban downstream areas are most at risk, with very high aggregate risk levels across all four key flood impacts. In contrast, the core urban area, the citadel and the peri-urban upstream areas are characterized by mostly high aggregate risk levels. Although these findings align well with the hazard patterns (see chapter 3.2), they also highlight the crucial influence of vulnerability and exposure in shaping overall risks. Therefore, all regions in Hue need to be addressed by enhanced flood risk management and climate change adaptation actions to comprehensively manage observed risks.

Table 13: Aggregate results across all key flood impacts

Aggregated risk across key flood impacts in Hue				
	Health impacts	**Rice livelihood disruptions**	**Transport disruptions**	**Water contamination**
Core urban	high	high	high	very high
Citadel	high	high	high	high
New urban	very high	very high	very high	very high
Peri-urban downstream	very high	very high	very high	very high
Peri-urban upstream	moderate	high	high	high

Interconnections across key flood impacts
This chapter explores the interconnected nature of flood risks, impacts and their drivers in Hue, by building on the integration of the four key flood impacts, thus revealing their complexity (see figure 20). As shown, all four key flood impact risks are interlinked, either directly or indirectly, through cascading effects. For example, livelihoods in Hue have been directly disrupted by severe health impacts leading to an inability to work, or by transport disruptions resulting in an inability to reach workplaces. Additionally, water contamination can cascade into livelihood disruptions, either by contaminating crops and causing animal diseases that severely impact agricultural livelihoods or by causing waterborne diseases that lead to severe health impacts. These cascading risks can also result in severe mid- to long-term impacts. For instance, livelihood disruptions can lead to poverty, exacerbating risk drivers and root causes, such as a lack of financial resources. In turn, this can lead to a lack of insurance, transport options and health service coverage, reinforcing potential future risks.

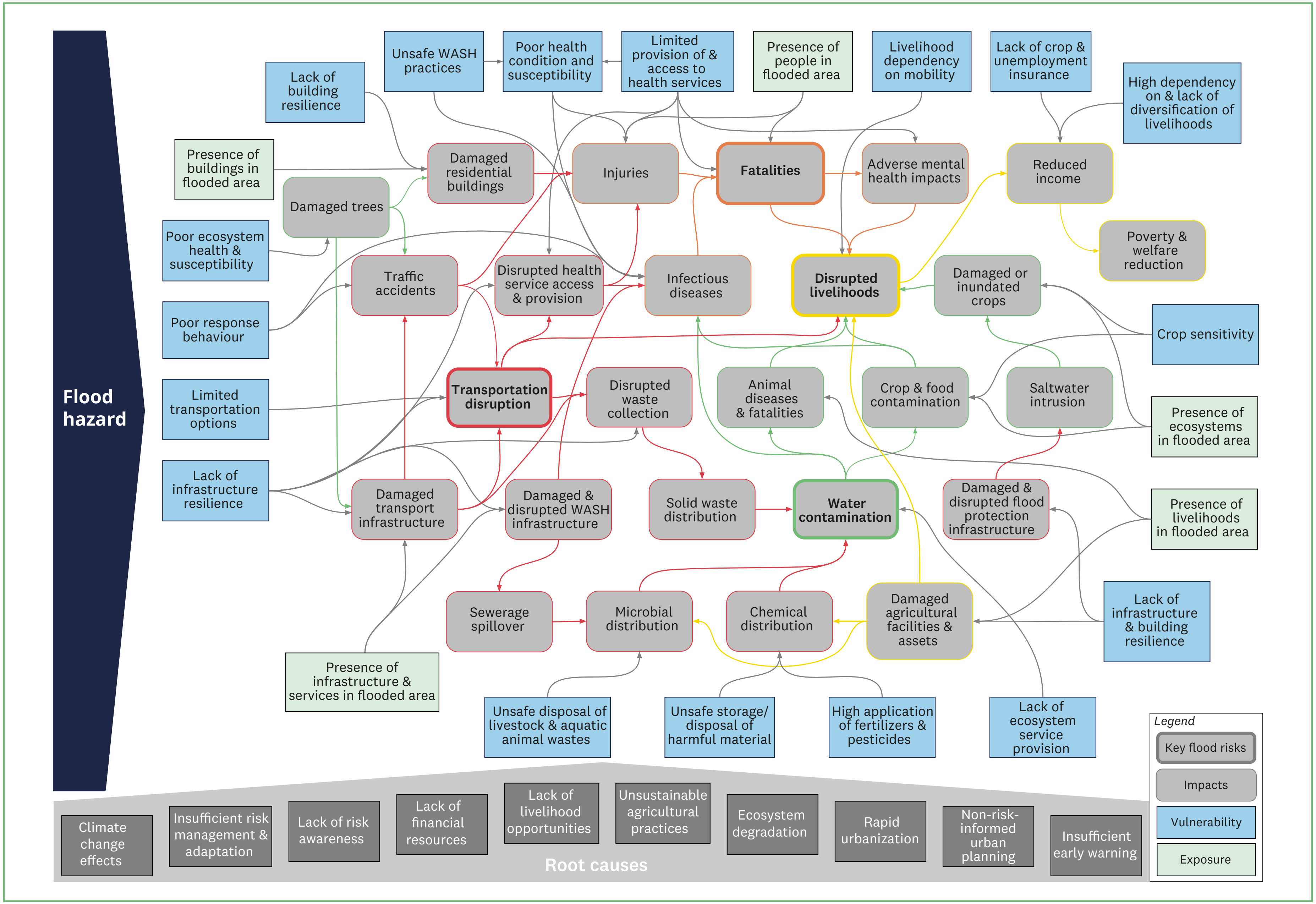

Figure 20: Compounding and cascading flood-induced impacts and their risk drivers and root causes (source: Sett et al., 2024).

Note: WASH, water, sanitation and hygiene.

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From Figure 20, four central patterns emerge:

1. Interlinkages across all four key flood impacts

2. Cascading effects of impacts

3. Feedback loops of impacts on risk drivers and root causes

4. Shared risk drivers and root causes across diverse risks.

The figure shows that the same underlying risk drivers and root causes induce various risks and impacts. For example, the exposure and vulnerability of buildings and infrastructure significantly drive transport disruption, severe health impacts, disrupted livelihoods, and water contamination. Similarly, poor preparedness and response behaviour drive all key flood impacts and are a key determinant for cascading impacts. For example, unsafe water, sanitation, and hygiene (WASH) practices are crucial for the cascade of water contamination into waterborne diseases and human health impacts.

Both Figure 20 and the conceptual risk models for each key flood impact reveal shared root causes across key flood impacts and flood hazards. As discussed earlier in this report, one of the main root causes of flood hazards in Hue is the interaction of rapid urbanization with non-risk-informed urban planning and ecosystem degradation. This interlinkage of root causes also plays a vital role in the exposure and vulnerability of people, infrastructure and livelihoods, affecting all four key flood impacts (see table 14). Similarly, insufficient flood risk management and adaptation directly affect all key flood impacts and the flood hazard components. Although all key flood impacts and root causes are at least indirectly interlinked, table 14 summarizes the key linkages identified by our expert consultations.

Table 14: Shared root causes across the four key flood impacts and the hazard progression model

Root causes	**KFI1:** Severe health impacts	**KFI2:** Agricultural livelihood disruption	**KFI3:** Individual transport disruption	**KFI4:** Water contamination	**Hazard:** Flood hazard progression
Ecosystem degradation	x	x	x	x	x
Insufficient risk management and adaptation	x	x	x	x	x
Rapid urbanization	x		x	x	x
Non-risk-informed urban planning	x		x	x	x
Limited financial resources	x	x	x	x	
Livelihood dependency on natural resources	x	x		x	
Lacking risk awareness	x		x	x	
Unsustainable agricultural practices		x		x	

4. Outlook on future flood risks

This report focuses on present-day flood risks in Hue, considering current climate and socioeconomic conditions and how these currently influence flood hazards, exposures and vulnerabilities. Next to assessing flood risks as described above, the FloodAdaptVN project also aims to simulate future trends and scenarios of flood risks for the region, including future flood hazard, exposure and vulnerability dynamics. This chapter provides information about ongoing work on future flood risks, notably how various climate-change scenarios will affect future flood hazard characteristics, and how different socioeconomic development scenarios might influence future exposure, vulnerabilities and the ability to manage flood risks. A detailed description of the scenario development methodology and supplementary results on future risks is presented in Annex B to this report.

4.1. Quantitative Representative Concentration Pathways (RCP) to model future flood hazards

Assessing projected changes in key climate parameters and effects such as air temperature, rainfall and sea level rise is essential in determining future flood hazard levels. The projection of greenhouse gas emissions, the main drivers of anthropogenic climate change (IPCC, 2023), can identify future climate characteristics. In other words, higher global greenhouse gas emissions result in greater changes in climate parameters. It is vital to project future levels of greenhouse gas emissions to predict climate change.

Quantitative Representative Concentration Pathways (RCPs) are standardized greenhouse gas emission scenarios that describe different trajectories for emissions and respective climate effects, and can be used as input for future hazard modelling (IPCC, 2023). Four main scenarios are used by the international community, ranging from RCP2.6, which describes a significant reduction of greenhouse gas emissions and respective minor climate change alterations, to RCP4.5 and RCP 6.0, describing a minor reduction or continuation of current greenhouse gas emission levels (‘business as usual’), leading to moderate and severe climate changes, and finally RCP8.5, projecting increased emissions leading to exacerbating and irreversible climate change effects ('worst-case scenario') (see figure 21) (Met Éireann, 2020). RCPs significantly impact the modelling of future flood hazards by providing essential data for predicting changes in rainfall and sea level rise. As shown in chapter 3.2, these two climate change effects are key drivers of flood hazards.

Within the FloodAdaptVN project, the scenarios RCP4.5 and RCP8.5 are used to develop future hazard models, based on discussions with local stakeholders. These models are developed for the years 2030, 2050 and 2100. In addition, urban growth models (see chapter 4.2) are included as additional model input, as urbanization was identified as an additional key hazard driver (see chapter 3.2).

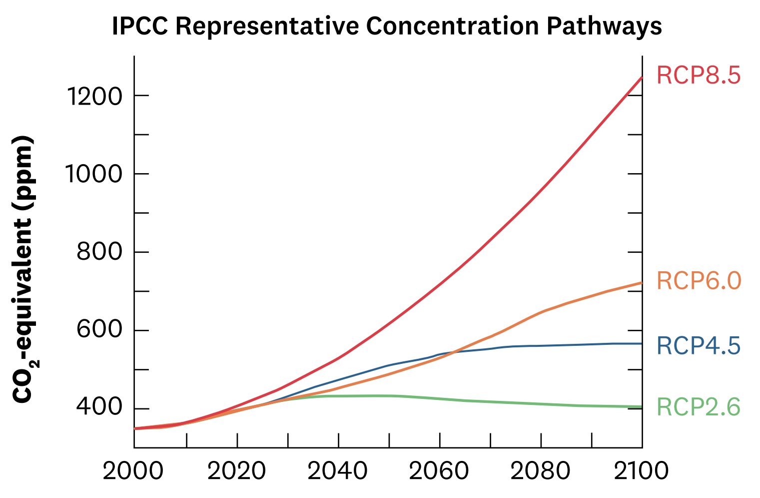

Figure 21: Greenhouse gas concentration in the earth's atmosphere for various RCP scenarios (Met Éireann, 2020).

4.2. Qualitative Shared Socioeconomic Pathways (SSPs) to model future risks

As outlined throughout chapter 3, multiple additional factors – other than climate change – drive flood risks. A main driver is insufficient risk management and adaptation (see chapter 3.4), which exacerbates future hazards, exposures and vulnerabilities. Therefore, to project changes in future risks, it is important to consider changes in future flood risk management and adaptation.

The Shared Socioeconomic Pathways (SSPs) are used by the international community, and describe five alternative socioeconomic development scenarios that highlight possible challenges linked to the mitigation of greenhouse gases and adaptation to climate hazards, including floods (IPCC, 2023).

The FloodAdaptVN project focuses on three of these five scenarios, namely SSP1, SSP2 and SSP3, as local stakeholder consultations revealed that these three SSPs are considered most relevant for future flood risk management in Hue. The three selected SSPs were downscaled to the provincial level of Thua Thien Hue province and presented unique trajectories for future development, which can impact the management of future flood risks in the region. Below is a summary of the narratives and how they may affect future flood risk.

SSP1: Strong and sustainable growth

There is a strong emphasis in SSP1 on green growth and sustainability, driving substantial economic growth supported by policy changes, education and the development of green industries. Major investments in infrastructure and tourism enhance the city's capacity for flood management, with robust infrastructure development and digitization fostering more effective flood management strategies. Additionally, significant investments in education and healthcare and the response to the COVID-19 pandemic contribute to social stability and resilience, facilitating community engagement in floo -management efforts. Sustainable urban planning integrates flood management considerations, potentially reducing vulnerability in urban areas.

SSP2: Current trends continue

SSP2 continues the trend of green growth initiatives but may need more productivity gains to realize its full potential. Despite ongoing infrastructure improvements, funding and human capacity constraints limit the effectiveness of flood management measures. While there are improvements in education and healthcare, the lasting effects of the COVID-19 pandemic strain resources for flood management. Urbanization continues without adequate planning, potentially increasing flood risks in densely populated areas.

SSP3: Partially controlled growth and fragmentation

Economic stagnation or decline characterizes SSP3, leading to limited resources for flood management. Increased migration to cities strains the urban infrastructure, exacerbating flood risks. Environmental degradation due to economic pressures further compounds flood vulnerabilities. Social welfare systems face challenges that hinder effective flood management and response. Uncontrolled urban growth and limited planning increase vulnerability to flooding, particularly in informal settlements.

Comparison of scenarios for future flood management

Trends in economic development: Strong emphasis on green growth in SSP1 drives substantial economic growth and enhances flood management capacity. Green growth initiatives continue in SSP2 but may not realize their full potential, potentially limiting resources for flood management. There is economic stagnation in SSP3, posing challenges for flood management efforts.

Welfare and social change: Significant investments in education and healthcare in SSP1 enhance community resilience to flood events. There are improvements in education and healthcare in SSP2 but also challenges due to the COVID-19 pandemic. There are struggles with social welfare systems in SSP3, impacting flood management capacity.

Infrastructure: Robust infrastructure development in SSP1 supports flood management efforts, while SSP2 and SSP3 face challenges due to funding constraints and uncontrolled urban growth.

Environment and ecological factors: The emphasis on ecological sustainability and climate change awareness in SSP1 contributes to resilience against flood events. Environmental conservation efforts continue in SSP2, while SSP3 faces environmental degradation, exacerbating flood risks.

Population density and urbanization: Sustainable urban planning in SSP1 reduces vulnerability by integrating flood management considerations. However, SSP2 experiences increased urbanization without adequate planning, while SSP3 faces uncontrolled urban growth, leading to heightened flood vulnerability.


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5. Entry points for comprehensive flood risk management

Effective flood risk management and adaptation should be based on a deep understanding of the underlying drivers and root causes of hazard, exposure and vulnerabilities, their spatial patterns, dynamics (including future trends) and interconnections. This chapter draws on the findings of the flood risk assessment presented in this report, and points at possible entry points for comprehensive flood risk management and adaptation in the catchment, including potential enablers and barriers provided by future risk and development scenarios.

Structural/physical options:

- **Structural housing measures:** Scale-up existing programmes to support housing elevation and the construction of a second floor can provide essential shelter in high-exposure areas. For example, in downstream regions where more than 80 per cent of houses have only one floor, such measures can significantly enhance safety during floods. However, this proposal depends on additional financial commitments from authorities and other actors and will become increasingly difficult under economic stagnation scenarios, such as SSP3.
- **Early warning systems:** Improving the effectiveness of early warning systems is crucial, as many people often find the information provided is not useful. Effective early warning systems should offer actionable and timely information on upcoming hazards and possible impacts to help communities and authorities prepare for future floods. Integrating risk knowledge, such as the information provided in this report, into hazard-based warning systems can facilitate early action by offering insights into 'what the weather will be' and 'what the weather will do'. In addition, community training on how best to act given different warning scenarios can further increase the effectiveness of warnings.

Institutional options:

- **Risk-informed planning and development:** It is vital to integrate flood risk information, and adaptation and flood risk reduction strategies, into spatial information systems and spatial and socioeconomic development planning. This integration includes mainstreaming risk information into urban extension planning, and incorporating knowledge of ecosystem service values into flood risk management plans. Risk-informed planning is often competing against economic interests. Therefore, prioritizing risk reduction and ecosystem value information over economic interests in planning will be at significant risk under strong economic growth scenarios, such as SSP2.
- **Multi-level and cross-sector flood risk governance:** As flood risks and impacts in the catchment are interconnected and linked to processes at national, regional and local levels, enhanced disaster risk management efforts across provincial administrative boundaries, commanding committees and working groups are vital.
- **Crop insurance:** Crop insurance can be crucial in covering agricultural losses and residual risks for agricultural livelihoods. It can help mitigate the economic impacts of floods on farmers and promote resilience in agricultural communities. It is important to increase the readiness for risk insurance solutions, including through insurance literacy training to support peoples' understanding of the benefits and limitations of risk insurance, and enable an increase in insurance uptake.

Social options:

- **Risk awareness:** Targeted information must be created and shared to provide actionable knowledge. A key priority in the provincial government's 2020–2025 disaster-prevention plan is strengthening public risk awareness. Understanding citizens' disaster preparedness and prevention behaviour and its drivers is essential to best target available government support to increase awareness. Investment in education, such as predicted under SSP1, will be a vital enabler for accelerated awareness raising and risk education.
- **Adaptation knowledge sharing and learning:** In addition to risk awareness, adaptation awareness is crucial to enable households to better protect themselves against flood risks and impacts. Knowledge and skills training, and platforms to share best practices and flood protection experiences among households, are crucial tools in supporting enhanced understanding and self-perceived efficacy in implementing required actions.

Ecosystem-based options:

- **Vegetated riparian buffers:** Ecosystem degradation is a key root cause of increased flood hazard, exposure and vulnerability levels across all key flood impacts in this report. Implementation, conservation and restoration of ecosystems, such as vegetated riparian buffers, are vital to sustainably reduce flood risks. More specifically, vegetated riparian buffers serve as crucial regulators against flood impacts as they can convey and store water, allowing infiltration and water filtration to tackle water contamination. They also provide important additional co-benefits, such as increased biodiversity and recreational opportunities, to enhance community well-being.
- **Sustainable forest management:** As outlined in this report, flood risks to Hue city and downstream regions are significantly influenced by upstream processes. For example, the degradation of natural ecosystems is linked to reduced water infiltration and storage capacities, leading to accelerated flood levels downstream. Therefore, a shift to sustainable ecosystem management, such as sustainable forest management schemes, would reduce flood hazard levels by providing important water-retention functions upstream. Green growth and investment strategies, such as foreseen in SSP1, can significantly enable such a management shift.

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6. Conclusions and outlook

This report comprehensively assesses the root causes, drivers, spatial patterns and trends of flood risks for people, agricultural livelihoods, transport and water contamination in Thua Thien Hue province. Flood risks in Hue are complex, characterized by shared root causes across sectors, cascading and interconnected impacts, and strong dynamics over time. Despite their common complex nature, risks are spatially different. This fact highlights the importance of conducting integrated risk assessments and sharing generated knowledge with all relevant stakeholders, particularly at-risk households.

Based on the identified risks, this report provides specific entry points for comprehensive flood risk management in Hue, including measures to address particular risks and more generic interventions with risk management potentials across key flood impacts. It is important to stress that several measures need to be combined for successful comprehensive risk management, as focusing on only one type of action will not achieve the desired risk-reduction outcomes. In addition, it is vital to place households at the centre of risk management interventions. This report has shown that human behaviour and respective values, beliefs and norms can be an important enabler for successful risk management. They can act as a key root cause of risk if not considered.

Moving forward, it is crucial to further specify and evaluate suggested and additional risk management options. This evaluation should be based on cost-benefit analyses, plus other criteria such as social acceptance of measures or non-flood-related co-benefits for community well-being.

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Annexes
Two Annexes are available comprising a detailed description of the methodology and supplementary results on the hazard modelling (Annex A, https://collections.unu.edu/view/UNU:10108) and future risk scenarios (Annex B, https://collections.unu.edu/view/UNU:10111).

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